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

3
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21 **Running head:** Pernollet et al.: Ricefield flooding for wintering ducks

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

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

45
46

47 **1. Introduction**

48 Historically, conservation biology was largely oriented to preserving wilderness in
49 remaining natural environments (e.g. Leopold, 1949). Since the 1980s, however, there has
50 been growing interest in the improvement of anthropized landscape matrices, such as
51 agricultural lands, as these represent a growing proportion of the environment in areas with
52 intensive agriculture (Balmford et al., 2012). The two approaches have now been shown to be
53 complementary in mitigating erosion of biodiversity and biotic interactions, and many studies
54 have commented on the respective roles of natural and artificial wetlands for waterbird
55 conservation (e.g. Fasola and Ruiz, 1996; Elphick, 2000; Toral and Figuerola, 2010 versus
56 Tourenq et al., 2001a; Bellio et al., 2009; Taylor and Schultz, 2010; Guadagnin et al. 2012).
57 Such questions have been recurrently raised around the Mediterranean region, one of the first
58 25 Global Biodiversity Hotspots (Myers et al., 2000) but also one of the regions where natural
59 habitats have been transformed by human activities for the longest period. In the
60 Mediterranean region an estimated 80-90% of former natural wetlands have disappeared
61 (Finlayson et al., 1992), and ca. 23% of the remaining wetlands are artificial (e.g. ricefields,
62 salt pans, irrigation reservoirs; Perennou et al., 2012).

63 Ricefields are one of the most important of these artificial habitats, and currently represent
64 15% of the world's wetlands (Lawler, 2001). Around the Mediterranean, in the European
65 Union, rice is cultivated on a total of ca. 460,000 ha, the top producers being Italy (53%),
66 Spain (24%), Portugal (7%), Greece (6%) and France (4%) (FAOSTAT, 2012).

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

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

82 Whether ricefields are attractive and provide abundant food resources to waterbirds may
83 greatly depend on agricultural practices during the crop growing season (e.g. seeding
84 practices, agro-chemical use and harvest method, Ibáñez et al., 2010) as well as during the
85 post-harvest period (e.g. straw management such as crushing or burning, soil mechanical
86 work such as mowing or disking, winter flooding and their combinations, Elphick et al.,
87 2010b). In Europe, environment-friendly practices are supported by Agri-Environment
88 Schemes (AES hereafter) contracted by farmers and implemented through the Common
89 Agricultural Policy (CAP) (EC Directorate General for Agriculture and Rural Development,
90 2005). However, recommended practices can vary from one region to another as the final
91 decision of which AES to implement is taken at the regional scale. Moreover, the European
92 Community often lacks the data necessary to implement these recommendations, and
93 scientific assessment of the efficiency of current schemes is also needed (e.g. Tourenq et al.,
94 2001b; Ernoul et al., 2013).

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

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

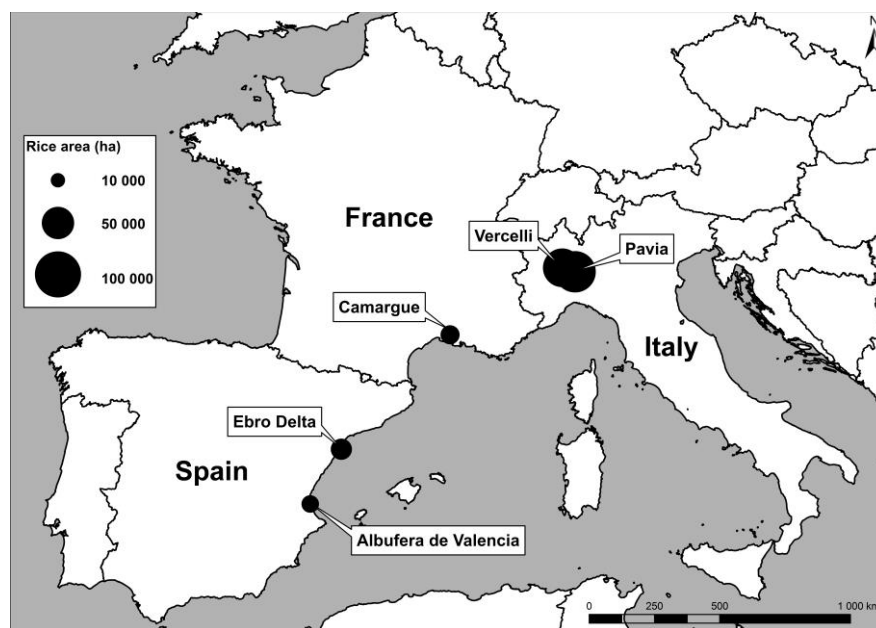
108 Local nocturnal surveys in the Camargue, southern France, have highlighted the great
109 potential of flooded harvested ricefields to act as duck foraging grounds, since an average of 5
110 to 33 ducks/ha was recorded in flooded fields vs. 0.14 ducks/ha in dry paddies (C.A. Pernellet
111 et al.,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

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

125 2. Material and methods

126 2.1. Study regions

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



132
133 **Fig. 1.** Map of the five study regions in western Europe (the size of dots represents the area
134 cultivated in rice, expressed in ha).
135

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

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

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

154 The last two study regions are located in Spain along the Mediterranean coast: the Ebro
155 Delta (40°42'N 0°43'E), where 21 000 ha of the total 32 000 ha of the area are covered with
156 ricefields (details in Curcó and Bigas, 2012), and Albufera de Valencia (39°27'N, 0°13'E)
157 where ricefields represent ca. 15,000 ha of the total 21,000 ha (details in Oltra et al., 2001).
158 Rice cultivation was introduced at a large scale to both areas around 1860 (Mañosa i Rifé,
159 1997). The climate and soil conditions make rice the only crop in the lowlands of the Ebro
160 Delta and Albufera de Valencia. Ricefields there remain flooded for a longer period, i.e.
161 harvest is conducted in water and fields are only dried by the end of January as part of the
162 AES, even sometimes later in hunted ricefields. The AES “ricefield winter flooding” consists
163 of maintaining the ricefield surface under flooding for at least 3.5 months in Albufera de
164 Valencia (Law: RD 4/2001 and RD 708/2002) and at least 4 months in the Ebro Delta

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

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

187 *2.2. Databases*

188 *2.2.1. Duck numbers*

189 Our study focused on the six most common European dabbling ducks, i.e. gadwall (*Anas*
190 *stepera*), northern pintail (*A. acuta*, hereafter pintail), mallard (*A. platyrhynchos*), common
191 teal (*A. crecca*, hereafter teal), Eurasian wigeon (*A. penelope*, hereafter wigeon) and northern
192 shoveler (*A. clypeata*, hereafter shoveler). These species are known to use ricefields during
193 winter whenever these are available within their range (Mateo et al., 2000; Elphick et al.,
194 2010a).

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

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

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

220

221 2.2.2. *Habitat data*

222 The surface areas of wetlands other than ricefields, of the total ricefields of the previous
223 summer and of winter-flooded paddies were obtained or computed for each winter of the
224 2002-2012 period directly for each of the five study regions.

225 To extract the natural or semi-natural wetland area of Pavia (Lombardy) and Vercelli
226 (Piedmont) provinces, two land cover maps were used, one for Lombardy (DUSAF2008,
227 database cartografia.regione.lombardia.it/geoportale) and one for the Piedmont region
228 (LCP2008, Land Cover Piemonte, Classificazione uso del suolo 2008). Both were produced
229 from digital color orthophoto maps (2005-2007 for Lombardy and 2000-2005 and 2007 for
230 Piedmont, respectively). Corine Land Cover codes corresponding to wetland habitats were
231 selected and a calculation of their total area was done with ArcGis software. Natural and
232 semi-natural wetlands are considered to have been stable in these regions over recent decades
233 (G. Bogliani personal communication), therefore the value of the surface area obtained for
234 these wetlands in each of these regions with the above method was applied to all years of the
235 2002-2012 period.

236 In the Camargue, natural and semi-natural wetland area was available for the years 2001,
237 2006 and 2010 (Observatoire des Zones Humides Méditerranéennes, 2014). From these data,
238 missing annual values were extrapolated using linear regression, which was assumed

239 appropriate because of the gradual change of the Camargue wetland habitats over the last
240 decades (Parc Naturel Regional de Camargue, 2013, annual rate of decline for period 1991-
241 2001: 0.08%, Tour du Valat, 2009).

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

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

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

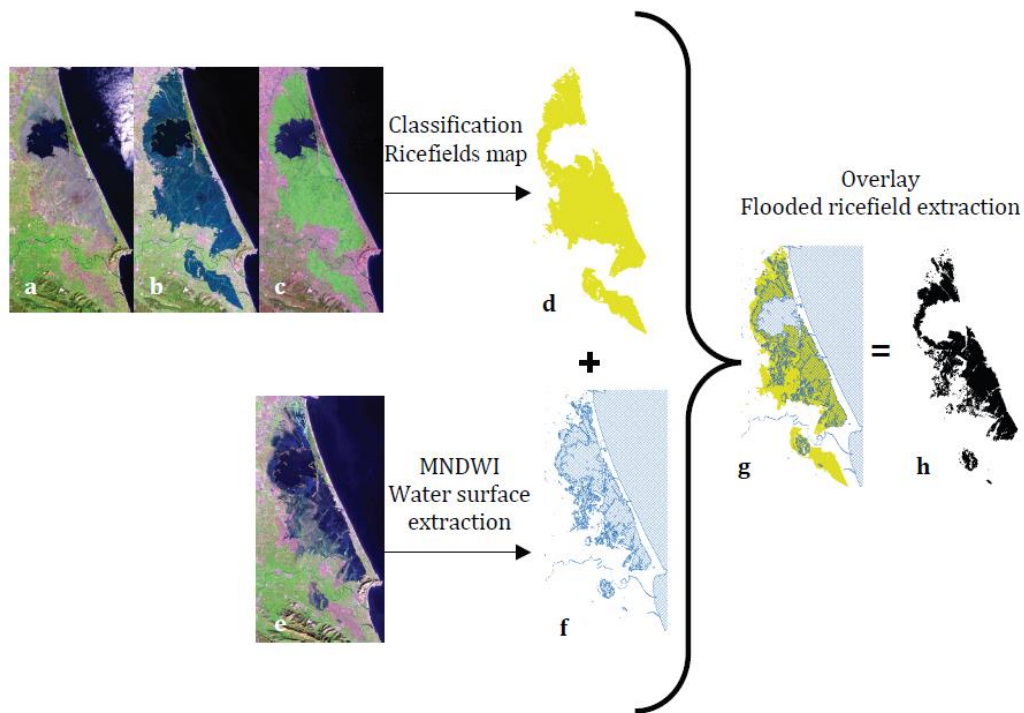
264 This multi-temporal approach enabled us firstly to avoid confusion between ricefields and
265 other aquatic habitats (e.g. marshes, lagoons, sea, etc.), and secondly to separate rice from
266 other crops. We used two functions of the Spatial Analyst Tool of Arcgis. The function
267 Reclass/Reclassify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

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

$$275 \quad \quad \quad MNDWI = 1 - (SWIR / G) / 1 + (SWIR / G)$$

276 The resulting water area map was then overlaid with the ricefield map produced
277 during the previous step, and the GIS intersection between the two shapefiles was calculated
278 (Fig. 2g and h). This figure represented the flooded area within all ricefields at a given site for
279 a given date. The proportion of winter flooded ricefields was computed for each site each
280 November, December and January whenever satellite images were available. The mean of
281 these values (one to three, depending on available satellite images) was then used in the
282 analyses. In practice, an area of flooded ricefields was available for 2 years of the 2002-2012
283 period in Albufera de Valencia (2002, 2003), 3 years in the Camargue (2002, 2003, 2006),
284 Vercelli (2002, 2003, 2012), and Pavia (2002, 2003, 2012), and 5 years in the Ebro Delta
285 (2002, 2003, 2007, 2010, 2011). Due to the limited number of satellite images available in
286 Albufera de Valencia, missing annual data were complemented by information on winter
287 flooded ricefields provided by the Dirección General de Innovación Agraria de la Consejería
288 de Agricultura, Pesca y Alimentación of the Valencian community

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



295
 296
 297 **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
 298 May 2003), c) Mature fields before harvest (9 August 2003), d) Ricefield delineation map
 299 derived from the 3 acquisition dates using an automatic remote sensing classification, e) and
 300 f) Extraction of water surface areas using the MNDWI (29 December 2002), g) and h)
 301 Extraction of the flooded ricefields for one acquisition date during the winter season (here,
 302 December) of the 2003 time period. The mapping technique is illustrated here with images of
 303 Albufera de Valencia.
 304

305
 306 *2.3. Statistical analyses*

307 *2.3.1. Habitat features and duck abundance*

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

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

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

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

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

333

334

335 2.3.2 *Effect of flooding regime on the number of ducks*

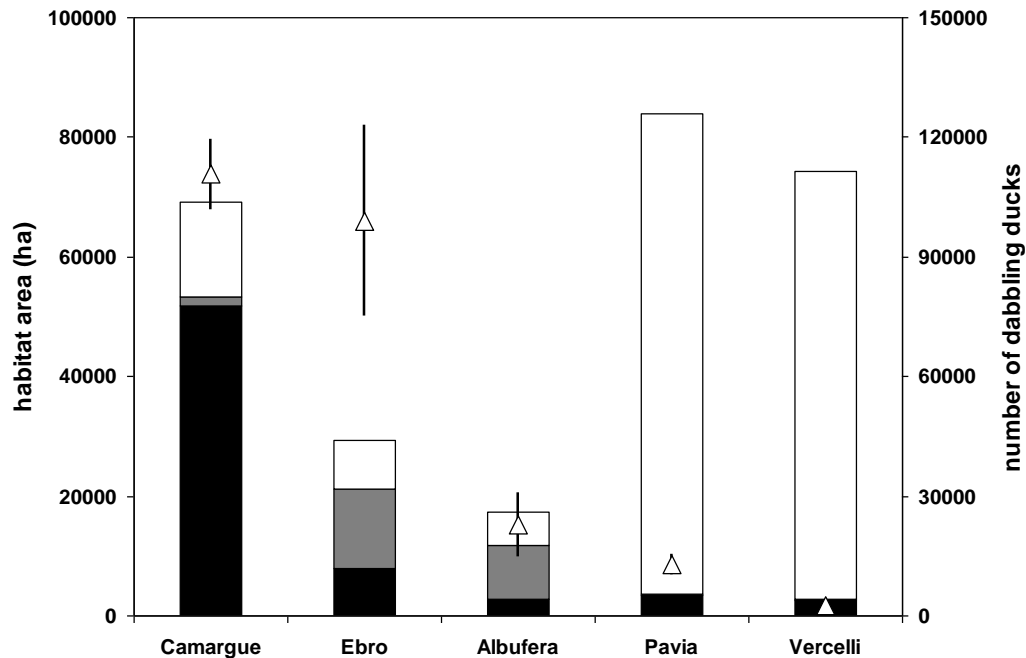
336 To test whether regional duck population trends were related to the AES “Winter
337 Flooding” application, we compared the trends in the numbers of ducks at the Ebro Delta and
338 Albufera de Valencia before and after winter flooding was introduced. The spatial images
339 were insufficient to compare the proportion of rice actually flooded before and after the
340 implementation of the measure. Hence, two periods of similar duration (with the date of AES
341 application chosen as the change point) were considered at each site: 1989-1999 (Ebro) and
342 1989-2001 (Albufera) were the periods before the AES, and 1999-2010 (Ebro) and 2001-2010
343 (Albufera) were the post-AES implementation periods. The most recent data (i.e. 2011-2012)
344 were removed from the analysis as flooding politics changed again in the Ebro Delta after
345 winter 2010, with parts of the ricefields currently kept dry as a measure against the spread of
346 the exotic Apple Snail *Pomacea insularum* (Curcó and Bigas, 2014). Duck population trends
347 were calculated using TRIM, a freeware widely used in Europe to implement Poisson
348 regressions to analyze time-series of counts, especially for waterbirds (Pannekoek and van
349 Strien, 2001). The time effects model with imputed indices was used, considering serial
350 correlation and overdispersion (e.g. Wretenberg et al., 2007) to estimate the overall trends and
351 their 95% confidence intervals over the whole study period (1989-2010) for each of the two
352 regions. This procedure was then used with years 1999 (Ebro) and 2001 (Albufera) as change
353 points in linear trend models. Finally, to test if any increase in duck numbers was explained
354 by a global trend at the flyway scale, the analysis was performed for the Camargue, which
355 was considered a control site, using 2000 (the mid-point between AES implementation at
356 Ebro and Albufera) as the change point, i.e. pre-AES years: 1989-2000, post-AES years:
357 2000-2010.

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363 3. Results

364 3.1 Habitat features and duck abundance



365

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

371

372 Mean wetland percentage cover differed greatly among the five regions (ANOVA: $F_{4,49} =$

373 12648, $P < 0.001$), with the proportion of natural and semi-natural wetlands versus ricefields

374 highest in the Camargue, intermediate in the Ebro Delta, and lowest in the Albufera and Italy

375 (Fig. 3). The two Italian provinces were almost completely covered with ricefields (only 3%

376 of natural and semi-natural wetlands in Vercelli). The mean proportion of ricefields that were

377 flooded during winter was 62% on average in the Ebro Delta and Albufera de Valencia. The

378 figure was 9% on average in Camargue. The other extremes were the two Po Valley provinces

379 in Italy with only 0.17% (Vercelli) and 0.28% (Pavia) of the ricefields being flooded during

380 winter.

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

387 **Table 1**

388 Abundance of six dabbling duck species \pm SE (January censuses) in five major European rice
 389 production regions, and mean relative percentage of each species in the duck community of
 390 each region (\pm SE, in parentheses). Average values over the 2002-2012 period.
 391

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)

392

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

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402 **Table 2**
 403 Set of all candidate GLMMs testing the relationship between the environmental variables
 404 (NatWet: natural & semi-natural wetlands, FloodRice: flooded rice, DryRice: dry rice and
 405 TotWet: natural & semi-natural wetland + flooded rice, TotRice: dry rice + flooded rice) and
 406 the mean annual numbers of dabbling ducks in five major European rice production regions
 407 over the 2002-2012 period. Significance of the predictor variables is represented by * as
 408 followed: °: Tendency, * : $P < 0.05$, ** : $P < 0.01$, *** $P < 0.001$.
 409

		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

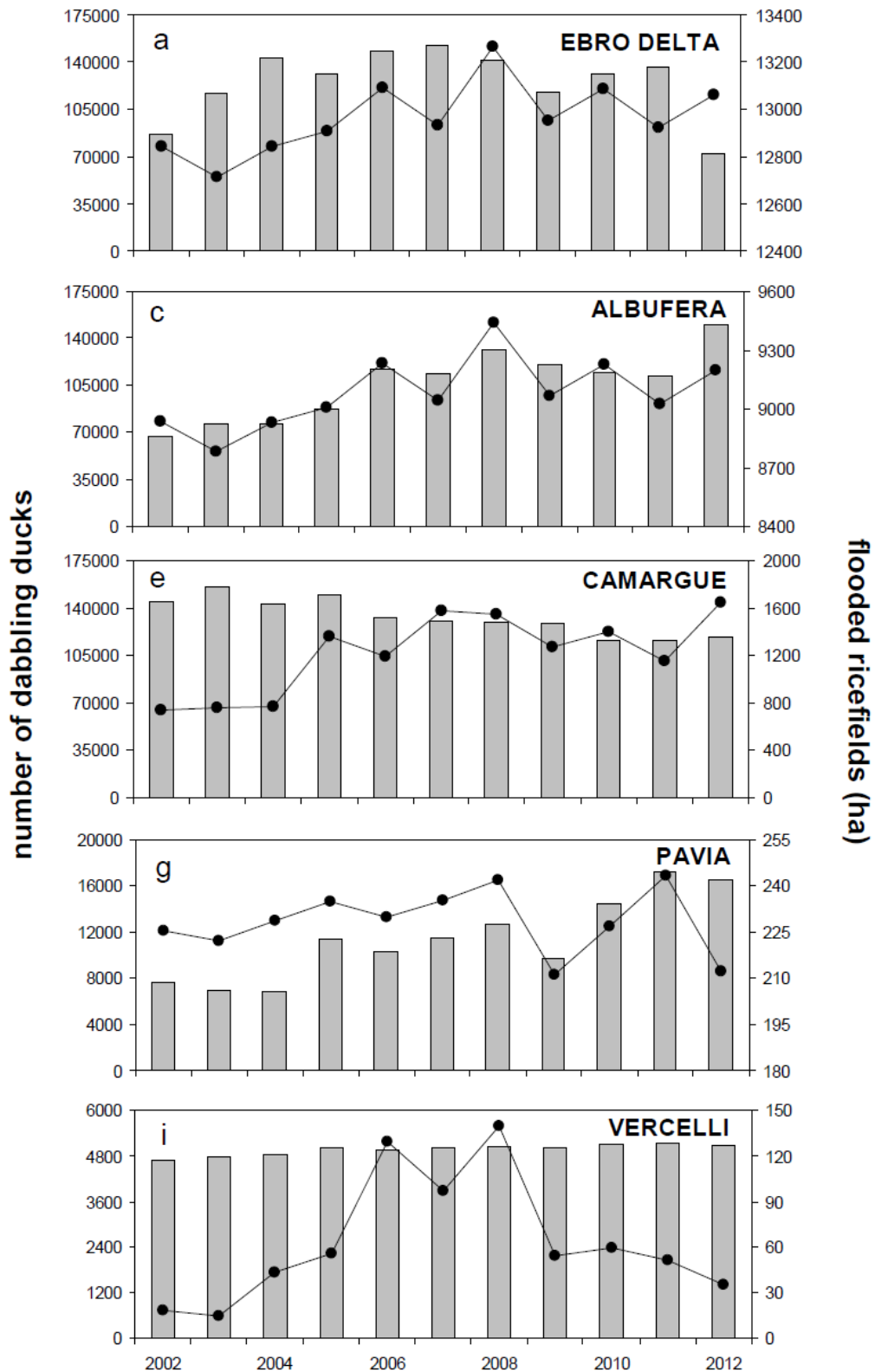
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411 **Table 3**
 412 Model-averaged parameter estimates, standard-errors, z values and P values of the predictor
 413 variables of the best GLMM (i.e. lowest AIC) testing the relationship between environmental
 414 variables (areas of natural & semi-natural wetlands, winter flooded ricefields) and the mean
 415 annual numbers of dabbling ducks in five major European rice production regions over the
 416 2002-2012 period.

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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***

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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.

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

433

434 *3.2 Effect of winter ricefield flooding on the number of ducks*

435 Over the 1989-2010 period, the numbers of wintering dabbling ducks in the Ebro Delta,
436 Albufera de Valencia and the Camargue all increased significantly, at approximately similar
437 rates, although profound changes occurred in the Spanish regions over the period considered
438 (Table 4, Fig. 5). However, while such a positive trend was already apparent before the years
439 2000 in the Camargue, the numbers of wintering ducks in the two Spanish regions were
440 declining. Only after the implementation of AES did the Spanish trends increase, especially
441 so at Albufera, then becoming positive as in the Camargue (Table 4, Fig. 5).

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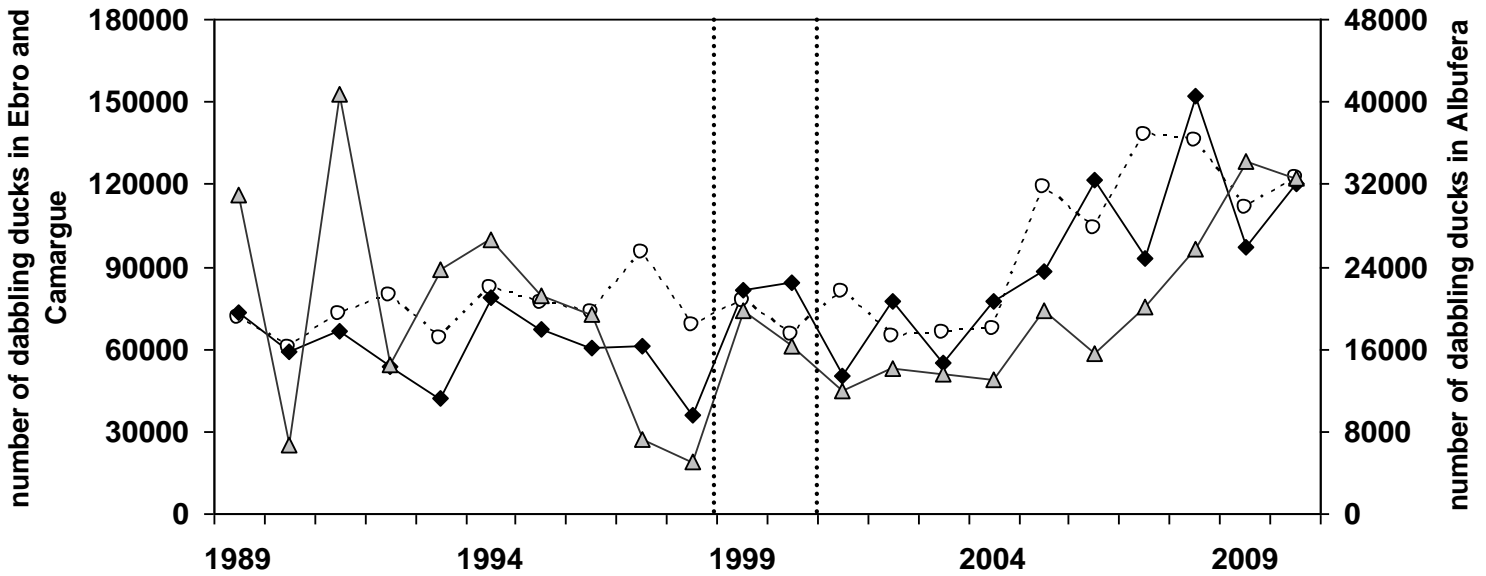
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Table 4

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

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

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

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

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

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

508 Conversely, the number of wintering ducks increased with the area of flooded ricefields.
509 Harvested ricefields have abundant waste grains, weed seeds and invertebrates (Stafford et al.,
510 2010), which are made accessible to ducks by the addition or the retention of water in the
511 fields after the rice crop season, hence likely explaining the above relationship. Earlier studies
512 in Japan and the US have demonstrated increases in local duck numbers with increased local
513 winter rice flooded areas (e.g. Day and Colwell, 1998; Shimada et al. 2000; Tajiri and
514 Ohkawara, 2013), or recorded larger numbers of non-breeding ducks in flooded than
515 unflooded fields of the same area (Elphick and Oring 1998; 2003). Studies at a broader
516 geographic scale are however far less numerous: in Europe only Toral and Figuerola (2010)
517 demonstrated a positive relationship between European waterbird population trends and an
518 index of rice field use during the autumn in Spain, highlighting how the provision of ricefields
519 at key migration sites can enhance whole populations. To our knowledge, the present study is
520 the first to consider how the post-harvest management of such fields, through their flooding,
521 can promote duck numbers among scattered winter quarters within the ducks non-breeding
522 range in Europe.

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

529 each variable (natural & semi-natural wetland area and flooded rice area) considered
530 separately (Table 2). Thus, a certain area of flooded ricefields was not strictly equivalent to
531 the same area of natural wetland. Both present almost equivalent effect size, indicating that
532 they are both important and complementary. Indeed, it is possible that these two habitat types
533 do not play the same role: in Camargue, for instance, natural wetlands typically provide
534 nocturnal foraging areas and day roosts to wintering ducks (Tamisier and Dehorter, 1999),
535 while flooded ricefields are mostly used as nocturnal feeding grounds (Pirot et al., 1981;
536 Mesléard et al., 1995), but are probably too frequently disturbed by humans or predators to
537 represent valuable day-roosts. Some earlier studies have found lower bird numbers, species
538 richness and species evenness in rice fields than in neighbouring wetlands, but these were
539 based on diurnal censuses (Tourenq et al., 2001a; Bellio et al., 2009; Taylor and Schultz,
540 2010; Guadagnin et al., 2012). Such surveys hence completely overlooked the use of rice
541 fields by ducks foraging at night (McNeil et al., 1992). Actually, the present results suggest
542 that the number of ducks at day-roosts (mostly large lakes or marshes, where they were
543 censused during IWC or aerial surveys) also depends on the availability of suitable nocturnal
544 foraging grounds, which includes flooded ricefields.

545

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

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

562 In the Camargue, most ducks concentrating at large roosts during daylight hours disperse
563 at dusk into a variety of shallow wetlands, 78% of which are private properties (Brochet et al.,
564 2009). While the large day-roosts have long been identified and protected in one way or
565 another, the provision of more nocturnal foraging grounds and the protection of some of these
566 have now been identified as priorities for conservation (Brochet et al., 2009). The present
567 study suggests that the simple flooding of harvested ricefields may be a valuable technique to
568 provide such nocturnal habitats, likely translating into more abundant and varied wintering
569 duck communities. If some flooded ricefields become completely free from human
570 disturbance, these may even potentially turn into suitable day-roosts as observed in North
571 America (Rave and Cordes, 1993).

572

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

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

590

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

604 flooded ricefields may function as a buffer during critical drought periods (Fasola and Ruiz,
605 1996; Tourenq et al., 2001a; Kloskowski et al., 2009), thus providing a more predictable
606 habitat to waterbirds than some temporary natural wetlands (Márquez-Ferrando et al., 2014).

607

608 Besides the expected benefits of winter flooding of ricefields in terms of bird habitat
609 provisioning, this practice could also bring agronomic benefits to farmers. Unlike stubble
610 from other crops, the silica content of rice straw confers unsuitable characteristics for several
611 uses, and rice straw disposal is a problematic issue. Burning is a common practice, e.g. in the
612 Camargue, but causes problems of air pollution (Monier et al., 2009). Flooding of rice
613 stubbles was introduced to California after the implementation of the California Rice Straw
614 Burning Act (AB 1378) of 1991 which imposed a strong reduction in burning. Flooding in
615 itself helps rice straw decomposition, which is further promoted by the trampling of
616 waterbirds using the fields (Bird et al., 2000; van Groenigen et al., 2003). The agronomic
617 benefits of flooding ricefields have been studied at length in North America (Manley et al.,
618 2005), and are also being revealed in Europe (e.g. in the Camargue, Brogi et al., unpublished
619 data).

620

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

629 Tinarelli personal communication). There are however hurdles to the general introduction of
630 winter flooding in European ricefields. This would for example be easier in Italy where fields
631 are flooded by gravity than in France, where water has to be pumped from the Rhône river
632 and energetic costs are currently too high to encourage flooding without financial
633 compensation. Some opposition has arisen in Italy, which was in part due to the fact that some
634 of the irrigation channels are dried for maintenance during the winter and, therefore, only a
635 fraction of rice growers could benefit from the contribution. Invasive alien species in such
636 artificially-created wetlands may also become an issue, and in the Ebro Delta many ricefields
637 have actually been kept dry or flooded with sea water since 2010 as a measure against the
638 spread of the exotic Apple Snail *Pomacea insularum* (Curcó and Bigas, 2014), although
639 ducks can help to control this pest (Green and Elmberg, 2014). The proposed new rural
640 development Act of the region (Pla de desenvolupament rural de Catalunya (PDR) (2014-
641 2020) PDR 2014-2020, 2015) proposes drying harvested ricefields during winter in areas
642 highly invaded by the Apple Snail and keeping flooding the non-affected fields.

643

644 In any case, economics are the main driving factor of these and other agricultural
645 practices; in Spain, the financial crisis and associated political decisions likely induced the
646 end of the financial AES winter flooding help to rice farmers in Albufera de Valencia since
647 2012. The proposed new rural development Act of the region (Programa de Desarrollo Rural
648 de la Comunitat Valenciana PDR CV 2014-2020, 2015), only considers to keep flooded the
649 lowlands ricefield until mid-January. In France as well as in Spain, it is the rice industry in
650 general that could be affected by economic changes, especially since the CAP 2015 plans
651 some changes to the financial support to the cultivation of this crop. As a matter of fact,
652 changes in the agricultural landscape have already been observed (reduction of ca. 25 % of
653 the rice in the Camargue in 2013 and replacement by dry crops such as wheat or vegetables,

654 C.A. Pernollet, unpub. data). In the early 1980s, the rice area in France already declined to
655 only 4,000 because of reduced financial incentives (Mañosa i Rifé, 1997). The decoupling of
656 the direct payments applied in the 2003 CAP have proven that they could have negative
657 consequences on biodiversity but could be offset by strengthening AES (Brady et al., 2009).
658

659 *4.1 Conservation and policy implications*

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

671

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682

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