Nest success of Black-winged Stilt *Himantopus himantopus* and Kentish Plover *Charadrius alexandrinus* in rice fields, southwest Spain

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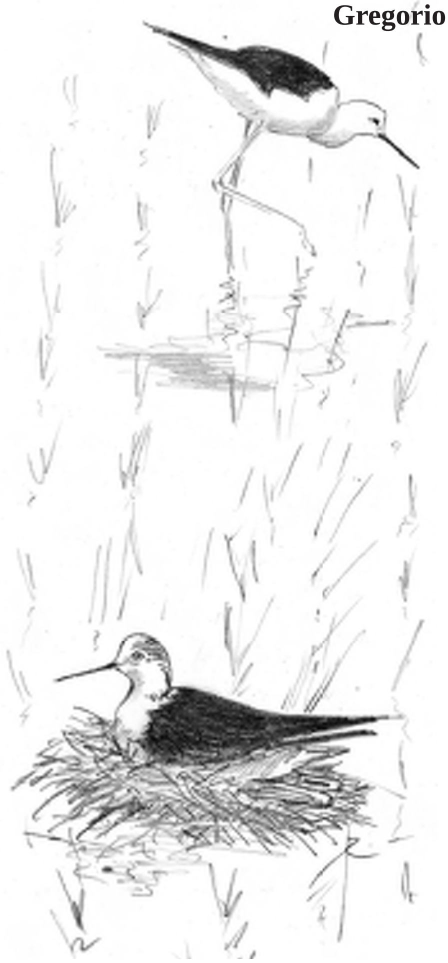

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We monitored nests of Kentish Plover *Charadrius alexandrinus* and Black-winged Stilt *Himantopus himantopus* breeding in rice fields near the Doñana National Park (southwest Spain) during the breeding seasons 2005–2007. We used a logistic-exposure method to calculate nest success and examined daily nest survival as a function of year, locality, nest age, and date. Nest success was also calculated using a model assuming constant nest survival through time (equivalent to the Mayfield method). Daily nest survival increased during incubation in Black-winged Stilt, probably due to a higher predation risk during the first days of incubation. Daily nest survival in Kentish Plover showed little variation in relation to nest age, suggesting a constant but lower predation rate. Nest survival also varied with date in Kentish Plover and showed higher values in the middle of the nesting season. The nest success of Black-winged Stilt and Kentish Plover breeding in rice fields (50% and 45%, respectively, based on the Mayfield method) was within the range of nest success reported in stable populations breeding in natural habitats. The observations suggest that rice fields adjacent to the marshes of the Doñana National Park are an important additional breeding habitat for the two wader species studied.

Key words: Mayfield, reproduction, avian eggs, Doñana, logistic-exposure method

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Several studies have reported a decline of farmland bird populations across Europe over the last three decades related to a general process of agricultural intensification (e.g. Donald *et al.* 2001, 2006, Wretenberg *et al.* 2007). However, waterbirds may use man-made and agricultural habitats located near remaining natural wetlands, such as fish-ponds, salt pans and rice fields. Although man-made habitats may be important alternative habitats for waterbirds (Czech & Parsons 2002), little attention has been paid to their value during the breeding season. For appropriate species conservation, knowledge is required on the distribution of breeding individuals, and on breeding success and productivity in each habitat. These aspects of breeding biology need to be investigated in tandem since – theoretically – apparently preferred habitats could be functioning as ecological traps when reproductive output is lower than in non-preferred habitats (Donovan & Thompson 2001).

Due to the high availability of water and invertebrates, rice fields are used by a variety of waterbirds as breeding sites (Fasola & Ruiz 1996). Although information on breeding densities and nesting success is generally scarce, birds commonly nesting in rice fields include ducks, bitterns, rails, shorebirds, terns, and passerines (Pierluissi 2010). In southern Europe large areas of wetlands have been transformed into rice fields and these paddy fields now cover 581,978 ha (Ferrero & Nguyen 2004). An example is the Guadalquivir marshes in Doñana, where between 1926 and 1997 36,000 ha of an original area of 180,000 ha of fresh and brackish marshes were transformed into rice

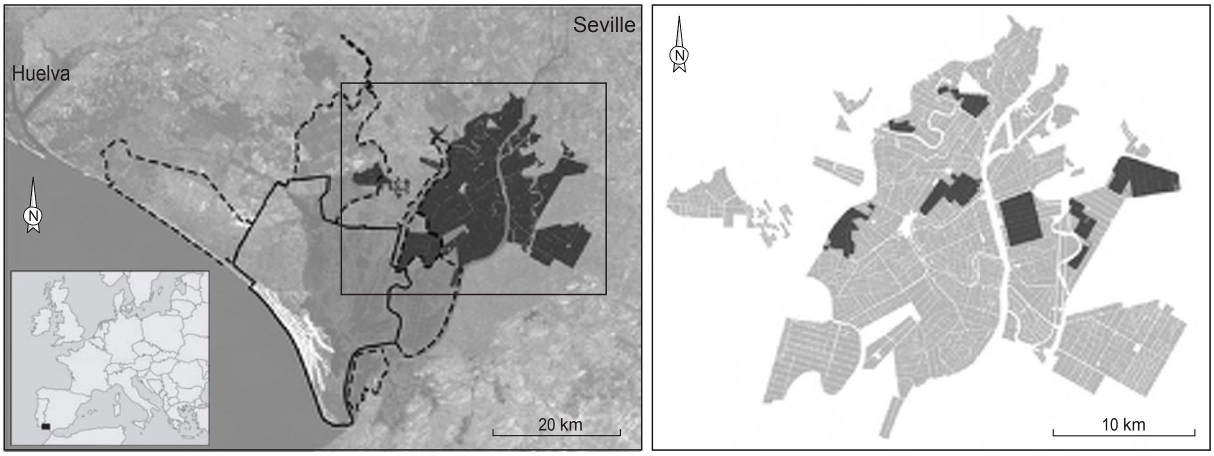

Figure 1. Left. Location of the study area with rice fields (black), Doñana National Park (within solid line) and Doñana Natural Park (within broken line). Right. Distribution of Doñana rice fields with the location of the seven study plots.

fields (García-Novo & Martín-Cabrera 2005, Rendón *et al.* 2008). Additionally, for other purposes the area of natural marshes has been reduced to just 30,000 ha at present (Enggass 1968, García-Novo & Martín-Cabrera 2005).

Kentish Plovers *Charadrius alexandrinus* and Black-winged Stilts *Himantopus himantopus* are the two commonest breeding waterbirds in the Doñana rice fields. Black-winged Stilts build their nests inside flooded rice fields, and nests of stilts and Kentish Plover can also be found on the paths and banks running between rice paddies. The reproductive biology of Kentish Plover and Black-winged Stilt has been studied extensively (e.g. Tinarelli 1992, Fraga & Amat 1996, Amat & Masero 2004, Norte & Ramos 2004, Cuervo 2005, Kosztolanyi *et al.* 2009). However, we are not aware of studies regarding the nesting success of these species in rice fields (although see Tinarelli 1992 for the apparent success of Black-winged Stilts breeding in rice fields).

Our objectives in this study were (1) to document the breeding population of Kentish Plovers and Black-winged Stilts in rice fields in relation to the populations in the natural marshes, and (2) to examine nesting success in comparison to the success reported in the literature for natural areas.

METHODS

Study area

Field work was carried out during the breeding season (April–July) in 2005–2007 in the largest area of rice fields in Spain (36,000 ha) situated in reclaimed marshland near the Doñana National Park. This 50,000 ha wildlife reserve lying north of the Guadalquivir estuary (Andalusia, SW Spain) also contains 30,000 ha of natural marshland (Figure 1).

Data collection

Kentish Plover and Black-winged Stilt nests were located by car surveys, regularly conducted along banks running between rice paddies in seven areas (Figure 1). Nest location was recorded using a GPS, and contents were checked every 2–10 days during incubation until their fates were known. Nest visits lasted no more than five minutes and periods with extreme temperatures (dawn and noon) were avoided. No predators were observed to take advantage of researcher-induced disturbance to the nests. Eggs were individually marked and their length and width were measured with a digital caliper to the nearest 0.01 mm and weighed with a portable digital balance (accuracy 0.1 g).

A nest was considered successful when at least one egg hatched. Hatching was determined if (1) a recently hatched chick was found in the nest or nearby, (2) at least one egg showed evidence of imminent hatching (cracked or drilled eggshell), or (3) the date of egg disappearance matched the expected hatching date and no sign of predation was found. A nest was considered to have failed if (1) remains of the eggs were found, (2) the nest had been deserted (cold eggs), or (3) egg disappearance was prior to the expected hatching date. The fate of all other nests was considered unknown. Only nests whose fate was known were used to assess nest success.

We compared nest counts conducted during 2005, 2006, and 2007 in the Doñana National Park that are part of the long-term monitoring program run in the area (http://www-rbd.ebd.csic.es/seguimiento/ seguimiento.htm) with nest counts in the rice fields. Data were transformed into densities (nest/ha). The Black-winged Stilt nests situated inside rice paddies were used to calculate nest density, but since they could not be monitored from the banks without entering the paddies they were not used to calculate nest success.

Calculations

To estimate nest age we used the formula developed by Fraga & Amat (1996) with parameters estimated from our own data. Egg volumes were estimated by means of Douglas' formula (1990): $Ve = Kv \times L \times W^2$, where $Kv = 0.5236–(0.5236 \times 2 \times (L/W)/100)$, L = egg length (cm) and W = egg width (cm).

A total of 142 nests of Black-winged Stilt were located. Eggs lost on average 0.1315 ± 0.0342 g per day during incubation ($n = 40$ eggs). To calculate the relationship between volume and the mass of a fresh egg, we used the measurements and mass of one egg from each incomplete clutch of the corresponding species. The relationship between the mass of fresh eggs (MFE) and Ve was described by the regression equation $MFE = 5.4627+0.7578 \times Ve$ ($r^2 = 0.78$, $n = 20$ eggs, each egg from a different clutch, $P < 0.0001$). For clutches found during incubation, we estimated the laying date using the equation: Days since laying = (MFE–OM)/0.1315, where OM = observed mass. The laying date was estimated as an average for all the eggs in the clutch. We checked the accuracy of these estimates in 2006 and 2007 using 12 eggs (one from each clutch) for which we knew their laying dates. On average, laying dates were underestimated by 0.41 ± 2.61 days (range –3.28 to 3.89).

A total of 301 nests of Kentish Plover were found. Following the methodology described above, we found that eggs lost on average 0.0512 ± 0.0157 g per day during incubation ($n = 122$ eggs). The relationship between MFE and Ve was $MFE = –0.244 + 1.031 \times Ve$ ($r^2 = 0.92$, $n = 34$ eggs, $P < 0.0001$). For clutches found during incubation the laying date was estimated as: Days since laying = (MFE–OM)/0.0512. We checked the accuracy of these estimates using 10 eggs from 2006 (one from each clutch) for which we knew their laying dates. On average, laying dates were underestimated by 0.27 ± 2.45 days (range –4.68 to 3.14).

Statistical analysis

Regression analyses were carried out using R software (R Development Core Team 2008). We modelled daily nest survival as a function of nest age, date of laying, year, and location (seven different sampled areas, see Figure 1) using the logistic-exposure method following Shaffer (2004), in which date and age were treated as continuous explanatory variables. The logistic-exposure method is a generalized linear model with a binomial response distribution (where the interval nest fate is 1 if successful and 0 if failed) and a modification of the logit link function used to account for variation in the length of observation intervals. This modification converts survival probabilities for observation intervals into daily nest survival probabilities.

We used information-theoretic methods (Burnham & Anderson 2002) to evaluate 23 candidate models explaining variation in daily nest survival. In addition to a model that assumed constant daily nest survival, we considered models that included (1) either a linear or quadratic effect of nest age; (2) either a linear or a quadratic effect of date; (3) a categorical year effect; (4) a categorical location effect; and (5) all combinations of nest age, date, location, and year effects. Our global model included year, location, quadratic effects of nest age and date. We use the term 'quadratic effect' to refer to polynomial models that included both linear and quadratic terms. We employed the quadratic effect of date and nest age because some studies have reported nest survival to be higher in mid-season than at the start or end of the breeding season (e.g. Zimmerman 1984, Burhans *et al.* 2002).

We used the GENMOD procedure of SAS 9.2. (SAS Institute 2009) to estimate the regression coefficients in our logistic-exposure models (Shaffer 2004). We then estimated daily nest survival rates from the resulting logistic function (see Shaffer 2004 for details). Each interval between visits to a nest was treated as one observation in the analysis. Nest age and date for each observation were calculated at the interval midpoint. Nest success was calculated as the product of daily nest survival rates throughout the incubation period. Incubation length was established as 27 days for Kentish Plover and 22 days for Black-winged Stilt (Fraga & Amat 1996, Cuervo 2005). We used the Hosmer & Lemeshow goodness-of-fit test to assess the fit of the global model (Hosmer & Lemeshow 2000) and used the 'effective sample size' as defined by Rotella *et al.* (2004) to compute Akaike's Information Criterion (AICc). We ranked candidate models by ascending AICc values, and identified a preferred model for each species by choosing the model with the smallest AICc value (Burnham & Anderson 2002). We employed model averaging for models with ΔAICc<2 to avoid the potential effects of model-selection uncertainty (Burnham & Anderson 2002). Since previous studies often used the Mayfield method, we compared nest success estimates from the preferred model with estimates derived from a logistic-exposure model that assumed constant survival during incubation. The latter nest success estimates are equivalent to Mayfield (1961) estimates.

RESULTS

Nest densities

The average nest densities of Black-winged Stilts were similar in natural marshes and in rice-fields (mean±SE: 0.043 ± 0.039 *versus* 0.025 ± 0.013, $Z = -0.60$, $P = 0.55$) (see Figure 2). The nest density of Kentish Plovers was lower in natural marshes than in rice fields (0.002 ± 0.002 *versus* 0.035 ± 0.002, $Z = 20.27$, $P < 0.001$). Densities in rice fields remained similar throughout the whole study period. In contrast, in the natural marshes large differences in densities occurred among years, with densities varying by one order of magnitude. Huge differences in rainfall occurred in the three seasons, with as a consequence great differences in the surface area of the flooded marshes (194 ha in May 2005; 7,073 ha in 2006 and 18,560 ha in 2007).

Nest success

In all, we used 214 nests for estimating nest success in the Kentish Plover and 75 nests in the Black-winged Stilt, giving effective sample sizes of 3,324 and 893, respectively. Estimates of nest success based on a constant survival per year (similar to Mayfield 1961) are summarized in Table 1. Daily nest survival (based on Mayfield) of Kentish plovers in 2005 was significantly higher than in 2006 (0.981 ± 0.005 *versus* 0.966 ± 0.004, $Z = 66.96$, $P < 0.001$) and 2007 (0.970 ± 0.005, $Z = 45.09$, $P < 0.001$). Daily nest survival of Black-winged Stilts in 2005 was also significantly higher than in 2006 (0.987 ± 0.008 *versus* 0.968 ± 0.008, $Z = 29.37$, $P < 0.001$) and 2007 (0.966 ± 0.008, $Z = 33.92$, $P < 0.001$). The mean interval between nest visits was seven days for Kentish Plovers and eight days for Black-winged Stilts. The global model of nest survival provided an adequate fit for both Kentish Plover ($\chi^2 = 12.4$, $df = 8$, $P = 0.14$) and Black-winged Stilt ($\chi^2 = 9.84$, $df = 8$, $P = 0.28$).

Based on the variables in the preferred model, the daily nest survival of Kentish Plovers differed between years and locations (each of the seven sampled areas), and was influenced by date, nest age, and quadratic terms (see Table 2). The daily nest survival decreased during the middle of incubation and increased towards hatching (Figure 3). Nest survival also varied with date, with higher values in the middle of the nesting season

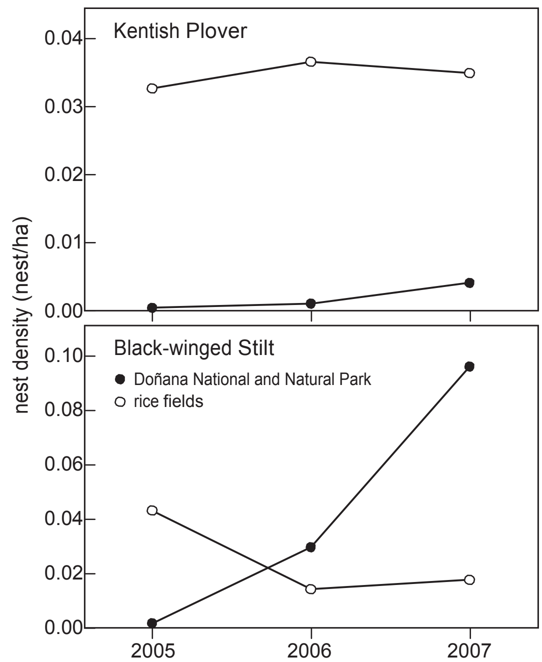

Figure 2. Nest density of the species studied in rice fields *versus* the natural areas of Doñana during the breeding seasons of 2005–2007. The area sampled in rice fields covered 1,641 ha in 2005, 3,692 ha in 2006 and 3,150 ha in 2007. The sampled area in Doñana covered 29,735 ha.

Table 1. Nest success of Kentish Plover and Black-winged Stilt in rice fields of Doñana during the breeding seasons of 2005–2007. Nest success is expressed as the proportion of nests that hatched at least one egg. Estimates are based on models assuming a constant nest survival in each of the years (the Mayfield method), and on the preferred models listed in Table 2.

Year	Constant survival		Preferred models	
	Kentish Plover	Black-winged Stilt	Kentish Plover	Black-winged Stilt
2005	0.59	0.71	0.66	0.31
2006	0.40	0.44	0.49	0.31
2007	0.44	0.47	0.58	0.31
All years	0.45	0.50	0.58	0.31

(Figure 4). In Black-winged Stilts, the four preferred models included a linear nest age effect, with daily nest survival increasing during incubation (Figure 3).

The preferred models were superior to the models that assumed constant survival (Kentish Plover: ΔAICc = 40.9; Black-winged Stilt: ΔAICc = 20.6). The estimated nest success of the preferred model for Kentish Plover was 0.58, which was higher than the value predicted by the constant model (0.45). The estimated nest success for Black-winged Stilt, obtained by model averaging (three best models), was 0.31, which was considerably lower than the value estimated by the constant model (0.50).

To compare nest success in rice fields to nest success in the natural marshes, we extrapolated our observations to the whole rice field area (Table 3). The estimated number of successful nests of Kentish Plover was higher in rice fields than in natural marshes (Table 3). In Black-winged Stilts, the number of successful nests was higher in the marshes.

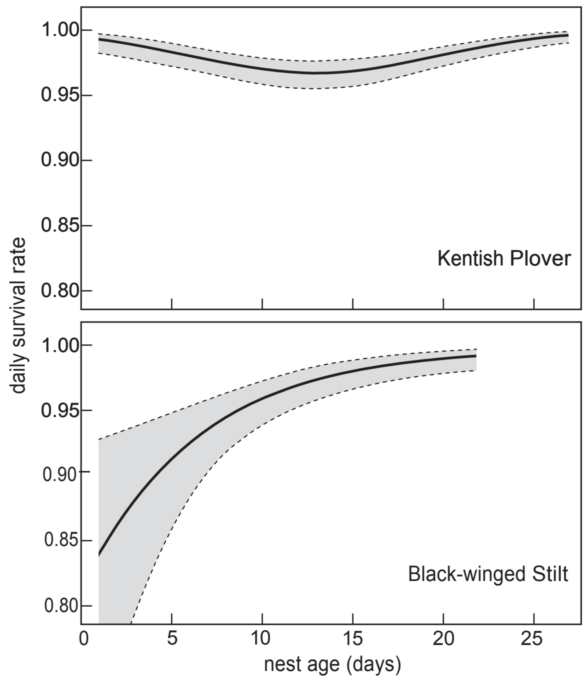

Figure 3. Daily survival rates in Kentish Plover and Black-winged Stilt nests in relation to nest age (days since laying) in rice fields in southwest Spain in 2005, 2006, and 2007. The dashed lines represent the 95% confidence limits for the logistic-exposure model.

Table 2. The top six (out of 23 examined) logistic-exposure models of daily survival rates for Kentish Plover and Black-winged Stilt nests in rice fields in southwest Spain in 2005, 2006, and 2007. K is the number of parameters in the model, AICc is Akaike's Information Criterion for small samples, ΔAICc is the scaled value of AICc, and W is the Akaike weight. N = linear effect of nest age, N^2 = quadratic effect of nest age, D = linear date effect, D^2 = quadratic effect of date, Y = categorical year effect, L = categorical location effect.

Model	Deviance	K	AICc	ΔAICc	W
Kentish Plover					
D+Y+N+L+D^2+N^2	518.6	7	538.6	0.0	0.66
N+L+N^2	525.1	4	541.1	2.5	0.19
D+Y+N+L+N^2	523.7	6	541.8	3.1	0.14
D+Y+N+D^2+N^2	533.3	6	547.4	8.7	0.01
N+N^2	545.6	3	551.6	13.0	0.00
D+Y+N+N^2	542.1	5	554.2	15.5	0.00
Black-winged Stilt					
N	133.1	2	137.1	0.0	0.29
N+N^2	132.2	3	138.2	1.1	0.17
N+D	132.9	3	139.0	1.9	0.11
N+Y+L[a]	126.9	4	139.0	1.9	0.11
Y+N	132.5	3	140.5	3.4	0.05
Y+N+L+N^2	126.5	5	140.6	3.5	0.05

[a]Model not included in model averaging as not all parameters could be estimated.

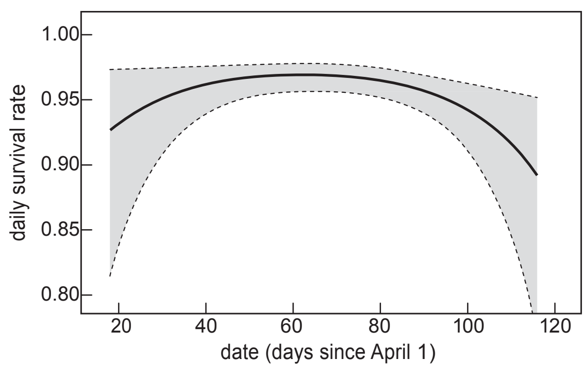

Figure 4. Daily survival rate of Kentish Plover nests in relation to date of laying of the average egg in rice fields in southwest Spain in 2005, 2006, and 2007. The dashed lines represent the 95% confidence limits for the logistic-exposure model.

DISCUSSION

The high density of Kentish Plovers breeding in the Doñana rice fields observed in this study highlights the potential importance of this habitat. Both the density and abundance of Black-winged Stilt nests in natural marshes was positively correlated with the surface area

Table 3. Breeding numbers and nest success of Kentish Plover and Black-winged Stilt in natural marshes and rice fields in southwest Spain. Area sampled is the average for three years (2005–2007). Total number of hatched nests (nest that hatched at least one egg) was calculated by extrapolating data from the sampled area to the total area. For purpose of comparison, nest success is based on models assuming constant nest survival (Mayfield method).

Species	Habitat	Sampled area				Total area	
		Area (ha)	Breeding pairs/ha	Nest success	Hatched nests/ha	Area (ha)	Hatched nests
Kentish Plover	Natural[a]	29735	0.002	0.29	0.0006	29735	17
	Rice	2828	0.035	0.45	0.0158	36000	567
Black Winged Stilt	Natural[a]	29735	0.043	0.60	0.0258	29735	767
	Rice	2828	0.025	0.50	0.0125	36000	450

[a]Source: Equipo de Seguimiento de Procesos Naturales belonging to the Estación Biológica de Doñana (C.S.I.C.)(unpubl. data).

of flooded marshes in 2005–2007. This pattern shows the importance of rice fields as a refuge for breeding Black-winged Stilts during droughts, which are common in the area. Furthermore, the density of Black-winged Stilt nests in rice fields may have been under-estimated in our study since nests situated inside rice paddies are difficult to detect. We suppose that these nests are less accessible to land predators and, consequently that their success rate is on average higher than the nests that we monitored. Our results are in line with other studies demonstrating the high quality of rice fields as breeding habitat. For example, Purple Gallinule *Porphyrio martinica* and Common Moorhen *Gallinula chloropus* find adequate breeding sites in rice crops in Louisiana (Helm *et al.* 1987, Hohman *et al.* 1994, Pierluissi 2006), with larger clutch sizes and higher nest success in rice fields than in marshes (Helm *et al.* 1987).

Tinarelli (1990, 1992) found in Italy that artificial habitats (salt pans, rice fields and settling ponds in sugar factories) were better for breeding Black-winged Stilts than natural habitats. Although Tinarelli did not examine nest success, the author did report that the total number of fledged young was higher in rice fields than in natural habitats.

The nest success of Kentish Plover based on the logistic-exposure method (0.58) and on Mayfield (0.45) was higher than the nest success based on Mayfield reported from natural habitats in southern Spain (values between 0.16 and 0.29; Fraga & Amat 1996) and the United Arab Emirates (0.22; Kosztolanyi *et al.* 2009). The nest success estimated in our study is similar to values needed to maintain a stable population reported for the Llobregat Delta, where hatching success ranged from 0.22 to 0.84 (Figuerola *et al.*, unpubl. data).

Daily nest survival increased during incubation in Black-winged Stilt, probably due to a higher predation risk during the first days of incubation. Daily nest survival in Kentish Plover showed little variation in relation to nest age, suggesting a constant but lower predation rate. Nest survival also varied with date in Kentish Plover and showed higher values in the middle of the nesting season, a pattern that has been found in other bird species (e.g. Zimmerman 1984, Burhans *et al.* 2002).

Although studies of reproduction in these species in the marshes of Doñana National Park are necessary, the rice fields near Doñana seem to be an important breeding habitat for Black-winged Stilts and, above all, for Kentish Plovers. When we translate our results to the population level (see Table 3), rice fields seem to produce a similar or even higher number of hatchlings than in natural marshes. Assuming that mortality for both groups of chicks is similar, our results indicate that Doñana rice fields could play an important role in the conservation of Black-winged Stilt and Kentish Plover.

We showed that Black-winged Stilts and Kentish Plovers in rice fields had a nest success that is comparable to, or is even better than, the success in natural habitats. Nevertheless, human disturbance could have a negative effect on the birds during other stages of reproduction. More studies of the species' breeding biology in rice fields are needed to examine the impact of agricultural practices and chemical products on breeding waterbirds.

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SAMENVATTING

Strandplevier *Charadrius alexandrinus* en Steltkluut *Himantopus himantopus* zijn veel voorkomende broedvogels in het Nationaal Park Doñana in het zuidwesten van Spanje. Tegenwoordig broeden beide soorten niet alleen in het moerasgebied, maar ook in de aangrenzende rijstvelden. In 2005–2007 is met behulp van de statistische methode van Shaffer onderzocht wat de overlevingskans van de nesten in de rijstvelden was in relatie tot het jaar van onderzoek, plaats, leeftijd van het nest en dag van het jaar. Ter vergelijking met ander onderzoek werd de nestoverleving ook berekend onder de aanname dat er geen variatie in de

tijd was (vergelijkbaar met de traditionele Mayfield methode). Bij de Steltkluut nam de overlevingskans toe naarmate het nest ouder was. Dit wijst erop dat de predatie van de eieren vooral hoog was tijdens de eerste dagen van het broeden. Bij de Strandplevier bestond veel minder variatie met de leeftijd in overlevingskans van het nest. Dit wijst op een betrekkelijk constante kans op predatie. De overlevingskans van nesten van de Strandplevier varieerde wel in de loop van het broedseizoen. Die kans was het grootst halverwege het broedseizoen. Het nestsucces van Steltkluut (berekend volgens Mayfield) was gemiddeld 50%, dat van Strandplevier 45%. Daarmee was het succes van beide soorten vergelijkbaar met het broedresultaat in natuurlijke gebieden met een florerende populatie. Dit wijst erop dat de rijstvelden grenzend aan het moerasgebied van het Nationaal Park Doñana een belangrijk aanvullend broedhabitat vormen voor beide soorten. (DH)

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