The impact of livestock on Lapwing *Vanellus vanellus* breeding densities and performance on coastal grazing marsh

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The impact of livestock on Lapwing *Vanellus vanellus* breeding densities and performance on coastal grazing marsh

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Capsule Even at very low stocking densities, livestock reduce breeding densities of adult Lapwings and increase the risk of nest loss due to predation.

Aims To assess the effects of livestock on Lapwings breeding on coastal grazing marshes.

Methods Densities of breeding adults, clutch sizes, laying dates, incubation schedules, clutch and chick survival were compared between marshes grazed at low stocking densities (0.2–0.51 livestock units/ha) and marshes where livestock had been excluded. Repeated measurements of sward heights were also made.

Results. Breeding densities in 1995 and 1997, but not 1996, were negatively correlated with the presence of livestock. Though few nests were trampled, livestock disrupted incubation schedules and increased the risk of nest predation. Clutches were smaller on grazed marshes than on ungrazed marshes, while more clutches were also laid later on grazed marshes. Grazed swards remained shorter, and more suitable for nesting, longer than ungrazed swards but clutches laid later in the season were more likely to be predated.

Conclusion The exclusion of livestock from selected areas to increase the nesting success of lapwings is a desirable option on coastal grazing marshes where the rate of grass growth is slow in spring. Grazing regimes are suggested that would maintain relatively short swards, provide refuge to Lapwings from livestock during the peak nesting period, and allow grazers to exploit all of their marshes.

Coastal grazing marshes are wet grasslands that support nationally important breeding populations of Lapwings *Vanellus vanellus* and other waders (Davidson *et al.* 1991, Smith 1983) and are the subject of a Biodiversity Action Plan (Anon. 1995). The Environmentally Sensitive Area (ESA) scheme, which is administered by the Department for Environment Food and Rural Affairs (DEFRA), has an important role to play in the conservation management of coastal grazing marshes because four major areas of this habitat (Broads, Suffolk River Valleys, Essex Coast and North Kent Marshes) lie within ESAs (Coates 1997, Tallowin & Mountford 1997). In these ESAs, farmers receive financial incentives to manage grazing marsh and follow conservation management prescriptions.

The North Kent Marshes ESA contains the largest tract of coastal grazing marsh remaining in England (*c.* 6500 ha) (ADAS 1997) and one of the largest breeding populations of Lapwing on lowland wet grassland (Burston *et al.* 1999). The importance of this population has increased as Lapwing numbers have declined markedly elsewhere in Britain (Hudson *et al.* 1994, Siriwardena *et al.* 1998, Wilson 1999). In 1995 and 1996, Lapwings were counted on *c.* 3000 ha of grazing marsh in the ESA (Milsom *et al.* 2000). These counts showed respectively that 76% and 66% of Lapwings were on land-holdings managed exclusively or primarily for nature conservation, even though these land-holdings constituted only *c.* 35% of the survey area. The ESA scheme presents an opportunity to maintain or increase the numbers of Lapwings nesting on grazing marsh managed primarily for agriculture.

Management of livestock is a key issue in the main-

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tenance of viable breeding populations of Lapwings on coastal grazing marshes. However, the relationship between the demography of Lapwings breeding on grassland and livestock is not well understood. Grazing is a major determinant of the location and extent of suitable breeding habitat on grassland because Lapwings are very sensitive to the height and structure of swards (Milsom *et al.* 2000). Lapwings prefer to nest in short swards (<5cm) with many tussocks. Grazing regimes and the sward structure that they produce may be critical because nests are more visible and vulnerable to predation on uniformly short swards than on heterogeneous swards (Baines 1990). Grazing animals may also depress the breeding success of birds that settle on grazed marshes by trampling eggs or young (Beintema & Muskens 1987) or possibly by disturbing incubating adults thereby increasing the risk of egg loss by either predation or desertion (Shrubb 1990). It is also possible that the presence of livestock deters Lapwings from settling in grazed marshes and, as nesting success tends to be positively correlated with the size of nesting groups (Berg *et al.* 1992, Elliot 1985), this effect might also result in a reduction in breeding success of those pairs that do nest in grazed marshes. Consequently, the management of livestock for Lapwing conservation on grassland becomes a problem of optimizing stocking densities and grazing regimes not only to create grass swards suitable for nesting but also to minimize adverse effects on breeding success.

Limits to stocking rates are prescribed during the breeding season in some lowland wet grassland ESAs, to minimize the risk of nest trampling. The limits set were based on Beintema & Muskens' (1987) trampling models. In the North Kent Marshes ESA, the stocking limit is 0.75 livestock units (LU) per hectare between 1 April and 31 May (MAFF 1993), where 1.0 LU = 0.15 sheep, 0.6 bovine (six months to two years) or 1.0 bovine (less than two years old), and is applied uniformly across all land in ESA agreement. However, trampling risk may be difficult to estimate if livestock are not confined to individual marshes for specified periods and also because the confidence limits of the hatching success estimates in the trampling models of Beintema & Muskens tend to be widest at the lowest stocking rates. Moreover the nesting success estimates may be too high for a given stocking density because of the effects of disturbance by livestock proposed above. One possible solution to these problems is to exclude stock during the nesting period from selected marshes within farms. However, the potential benefits of this approach may have to be balanced against possible adverse effects on the suitability of marshes for nesting due to changes to the height and structure of the sward, especially on grassland where the rate of grass growth is rapid in spring.

Here we assess the effects of livestock on the settling densities of Lapwings on coastal grazing marsh in the North Kent Marshes ESA and explore the relative importance of trampling and disturbance by livestock to nest and chick survival. We compare the effects of a low stocking rate and a no-grazing option on breeding success and also on sward growth during the nesting period.

METHODS

Study area

The study was undertaken at Elmley Marshes on the Isle of Sheppey (Ordnance Survey grid ref. TQ9468) in North Kent. Elmley Marshes comprise 674 ha of grazing marsh and are managed by the Elmley Conservation Trust (ECT) as a demonstration farm where grazing marsh management for livestock production and wildlife conservation have been integrated. During our study Elmley Marshes were grazed at low stocking densities (0.2–0.51 LU/ha) by cattle and sheep, although livestock were excluded from a proportion of marshes each spring to prevent nest trampling. High water levels were maintained over much of the estate to encourage breeding waders and wildfowl. Elmley Marshes support large breeding populations of Lapwings: in 1995, 1996 and 1997, 215, 136 and 165 pairs of Lapwing, respectively, were counted.

Bird counts and nest data

Lapwings were counted on Elmley Marshes in 1995, 1996 and 1997 as part of a larger survey of ground-nesting birds on the North Kent Marshes (see Milsom *et al.* 2000). In each year, three counts were made on 79 marshes at monthly intervals between April and June, using a modified version of the field-by-field method (Bibby *et al.* 1992). To minimize counting biases due to disturbance, observers used available cover (e.g. buildings, gates, banks and ditches) or a four-wheel drive vehicle as a hide when assessing numbers, distribution and breeding behaviour of Lapwings, before they walked over a particular marsh. Adults were sexed using plumage patterns on the head and breast (Cramp & Simmons 1982). All sightings of individuals were plotted onto *c.* 1:7000 scale marsh maps. Estimates of

the maximum number of breeding pairs per marsh were derived from registrations of incubating adults and of pairs showing breeding behaviour (e.g. display, mating, alarm calling and caring for young).

In 1997, between 15 April and 14 June we collected data from 102 Lapwing nests on 18 marshes. Six of these marshes were left ungrazed by agreement with the ECT. Sheep, beef or suckler cattle were introduced to the remaining 12 marshes between 6 and 21 April, and low stocking densities (0.2–0.51 LU/ha) were maintained when possible thereafter. All the marshes had been grazed the previous year (1996). The marshes were broadly similar in their sward characteristics, surface topography and wetness (see Habitat measurements section). Mean sward height, when it was first measured (1–3 April), prior to the introduction of livestock, and mean rill density were not significantly different between the marshes from which nest data were compared (sward height, $t = 1.45$, df $= 4$, P ns, and rill density, $t = 1.94$, df $= 5$, P ns).

Nests were located by scanning marshes for incubating adults or by watching adults return to their nests. Nest positions were marked inconspicuously with short bamboo canes placed at a distance of several metres and the following data were recorded. (1) Clutch size, egg volume and weight; egg volume was calculated from length $\times$ breadth$^2 \times 0.457$ (after Galbraith 1988a). (2) Estimated first egg laying date, see text below. (3) Clutch size at hatching, hatching date and the number of young hatched. (4) Chick condition at hatching; chick condition was calculated from weight/head-bill length (after Galbraith 1988b).

Nests were visited on their estimated date of hatching to ring, mark and measure the chicks. Some nests where eggs were due to hatch were empty when visited. The presence or absence of fine eggshell fragments in the nest lining was taken as evidence of successful hatching; this feature was seen in all the successfully hatched nests observed and has also been employed in other studies (Beintema & Muskens 1987, Galbraith 1988a, Higgens & Kirsch 1975). Nest losses were attributed to predation, trampling or desertion. Evidence of trampling was obvious and eggs found cold and unguarded after clutch completion and the start of incubation were assumed deserted. Empty nests containing yolk stains and large eggshell fragments, indented eggshells in the nest vicinity or no eggshell fragments were assumed to have been predated. Chicks were ringed on the day they hatched using conventional metal BTO rings. Coloured duct tape was then wrapped around the ring so that the combination of colour, ring position (above/below tarsus) and ringed leg (left/right) identified each chick individually and from which brood it hatched.

Incubation schedules

Between 24 April and 29 May, we conducted timed observations of incubation schedules from portable hides to assess any disruption by livestock. For each nest, the sex of the incubating bird, the frequency of nest departures, the time spent incubating and the cause of the cessation in incubation were recorded during each observation period which lasted on average 148.6 minutes. Using a subset of the observations where disturbance was determined as the cause of nest departure, we compared the frequency and duration of nest absenteeism between grazing regimes.

To determine whether nest absenteeism also varied according to the stage of incubation we separated the mean observations per nest into two time periods (days 1–15 and 16–31 after first-egg date) and compared the proportion of time and the frequency that Lapwings were observed off their nests between these two periods. This analysis was only possible for nests on the ungrazed marshes because we obtained observations from too few nests on the grazed marshes during the later stage of incubation. We compared observations from nine and seven nests on the ungrazed marshes during the early and late stages of incubation, respectively.

Habitat measurements

In 1995 and 1996, each marsh was visited in April and again in June, to record sward height, frequency and size of tussocks, and surface features, comprising rills (relict saltmarsh creeks), ridges and furrows (see Milsom *et al.* 2000). In 1997, the frequency of visits was increased to track changes in sward height during the nesting period: four measurements were made between March and June. The undisturbed sward surface height was measured in each marsh along representative transects using the HFRO swardstick and recorded in a portable microcomputer (Hodgson *et al.* 1986). Sufficient readings were taken to obtain a mean value with an accuracy of ±1.0 cm based on 95% confidence limits; this usually required between 20 and 40 measurements. The frequency and size of tussocks, and the frequency of rills, ridges and furrows in each marsh were estimated using the methods outlined in Milsom *et al.* (2000). All of the sward measurements were made

by the same observer. The lengths of rills in each marsh were also estimated to the nearest five metres from aerial photographs taken in April 1996, and were converted to rill densities per hectare. The wetness of the substrate at the bottom of rills and other hollows was recorded in June. The area of individual marshes was taken from farm maps. Full details of all the habitat measurements are given in Milsom *et al.* (2000).

Analyses

The relative influence of livestock on marsh selection by breeding Lapwing was assessed by comparing the breeding density of Lapwing pairs, counted on 79 marshes during 1995, 1996 and 1997, with habitat features known to affect Lapwing distribution (see Milsom *et al.* 2000) and livestock presence. Of the 79 marshes surveyed during 1995, 1996 and 1997, livestock were present in 71, 59 and 48 marshes, respectively. For each year we attempted to fit the data to multiple regression models in GENSTAT 5 (Genstat 5 Commitee 1993) using the habitat features and livestock data as predictor variables of Lapwing settling density.[a]

We compared nest and chick survival between grazing regimes (grazed and ungrazed marshes) by using data from marshes with five or more nesting attempts recorded in 1997. Data from 86 nests were analysed from eight marshes. Fifty nests were examined from four ungrazed marshes, 36 nests from four grazed marshes (with stocking rates between 0.2 and 0.51 LU/ha). Except where stated otherwise, the data were analysed in Minitab 12.1 and SPSS 9.0 statistical software packages (Minitab 1995, SPSS 1999). Daily nest and chick survival were estimated using Mayfield's (1975) method of analysis and confidence limits were calculated by Johnson's (1979) method. Egg laying and incubation of a four-egg clutch were assumed to take 31 days (after Galbraith 1988a) such that nest survival was calculated as p^{31} where p = daily survival rate. Nine nests within three of the grazed marshes were laid before livestock were introduced. Although none of these nine nests was lost or hatched before livestock were present, overall nest survival for grazed marshes was calculated using the total number of days survived by all nests minus the number of days any nest was exposed before livestock were introduced.

Chick survival was estimated and compared between grazing regimes by observing leg-flagged chicks. Thorough searches were conducted at no more than

three day intervals to assess survival and movement. The searches on each marsh were conducted until all the breeding Lapwing known to be resident and all marked broods were accounted for. These searches were difficult to standardize as the ease with which broods could be observed was very variable. In the ungrazed marshes the sward eventually grew to a height that made observation more difficult and time consuming. Also, older chicks were often more difficult to observe as they ventured further from their parents and, as some of these chicks foraged in both grazed and ungrazed marshes, the effect of grazing regime on chick survival was difficult to quantify. Nonetheless, we observed no chicks less than ten days old in marshes other than where they were hatched. We were therefore able to estimate and compare chick survival up to ten days old between grazing regimes.

The number of nesting Lapwing and the distribution of nest laying through the breeding season were compared between grazing regimes. Egg density was used to estimate laying or hatching dates when neither were known. Hatching date was calculated from a formula established by Galbraith (1988c); days until hatching = $150.84 \times$ density $- 140.68$ ($r = 0.905$, $P < 0.001$) with a mean error of 2.3 days, where density = mean egg weight/mean egg volume. Nests were checked at three- to four-day intervals and more frequently immediately prior to hatching. We assumed that our nest visits did not affect the probability of nest loss due to predation (Galbraith 1987). As no nest found during the laying stage was seen to hatch successfully, the mean incubation period for all nests was assumed to be no different to Galbraith's (1988a) estimate of 25 days after the last egg was laid. First-egg date was then estimated by subtracting from the hatching date 25 days and a mean two-day laying interval for each egg. We assessed the relative effects of laying date and grazing regime on nest survival by fitting a multiple regression model to the data.[b] Only data from nests initiated after the 21 April, the latest date livestock were introduced, were included in the analysis. We compared egg and clutch sizes between grazed and ungrazed marshes and assessed the effect of mean egg volume per nest on chick survival.

Clutch sizes were of either three or four eggs (except for one incidence of a five-egg clutch in an ungrazed marsh). We assessed the combined effect of grazing regime and laying date on the relative frequency of three- and four-egg clutches using a binary logistic regression method in GLIM4 (Francis *et al.* 1993).[c]

We compared nest predation between grazing

regimes and examined the variation in predation with the number of nests present through the breeding season. We decided that it was important to take into account any variation in predation levels in relation to time and the number of nests present rather than to simply compare the total number of nests predated in each marsh. We calculated the nesting densities of Lapwing and their nest survival rates due to predation for 12 consecutive periods of five days, between 15 April and 14 June. The survival rates per period were calculated using Mayfield's (1975) method, discounting nest losses other than to predation.

RESULTS

The effect of livestock presence on the settling densities of Lapwing pairs

We were able to fit habitat and livestock data that had a significant influence on Lapwing settling densities to multiple regression models for 1995 (R^2 = 17.3%, F_{2-62} = 7.47, P < 0.001), 1996 (R^2 = 6.2%, F_{2-62} = 5.13, P < 0.05) and 1997 (R^2 = 28.5%, F_{2-72} = 15.33, P < 0.001). However, in all three years the percentage variance in the settling density of Lapwings explained by the models was low and much of the variation in the data remained unexplained by the habitat and livestock variables. In the models derived for 1995 and 1997, the variation in the density of Lapwing pairs per marsh was best explained by rill density and livestock presence (Table 1). For 1996, the variation in the density of Lapwing pairs was best explained by rill density only (Table 1).

The effect of livestock presence on nest and chick survival

Mean nest survival, estimated using Mayfield's (1975) method, on ungrazed marshes (63.6 ± 19.6%, n = 4) was higher than on grazed marshes (33.8 ± 9.4%, n =

4), but this difference only approached significance (at the 5% level), t = 2.66, df = 4, P < 0.057. Just 4% of Lapwing chicks in our sample (n = 73) survived to fledging. The survival rate for chicks up to ten days old, hatched on ungrazed marshes (33.3 ± 3.3%, n = 59) tended to be higher than those hatched on grazed marshes (15.1 ± 11.0%, n = 14), although the difference was not significant (t = 0.5, df = 3, ns).

The effect of grazing on laying date and nest survival

Clutches on ungrazed marshes were laid between 22 March and 22 May, and on grazed marshes between 20 March and 3 June. We inferred from the model presented above that livestock presence had an adverse effect on the settling densities of Lapwing and therefore predicted that proportionately more of the clutches in ungrazed marshes would be laid earlier than those on the grazed marshes. This proved to be the case (one-tailed Kolmogorov–Smirnov test: z = 1.296, P < 0.05) (Fig. 1). Nine nests in the grazed marshes were laid before livestock were introduced between 6 and 21 April. Prior to 21 April there was no significant difference in the density of nests in grazed and ungrazed marshes (Mann–Whitney U-test: W = 24.5, ns).

On ungrazed marshes the number of active nests was highest in late March and early April and did not decline much until mid-May (Fig. 2). The decline of nesting effort in ungrazed marshes coincided with a rapid increase of sward height (Fig. 3). Mean sward height on ungrazed marshes was significantly longer than on grazed marshes when measured after mid-May (Table 2). In contrast, in grazed marshes, where sward height changed little, nesting effort peaked later (in early May), and continued into June.

Earlier nesting attempts did better. The multiple regression analysis we used to determine whether the relationship between laying date and nest survival differed between grazing regimes was highly significant

Table 1. The multiple regression models derived to predict Lapwing settling densities for 1995, 1996 and 1997 from habitat and livestock presence data.

Predictors	1995 (n = 62)		1996 (n = 62)		1997 (n = 72)	
	Coefficient (se)	t-value	Coefficient (se)	t-value	Coefficient (se)	t-value
Constant	0.44 (0.12)	3.58***	0.15 (0.05)	3.31**	0.26 (0.06)	4.19***
Rill density	0.001 (0.00)	2.69**	0.001 (0.00)	2.26*	0.001 (0.00)	3.68***
Stock presence	–0.024 (0.11)	–2.28*	–	–	–0.23 (0.06)	–3.95***

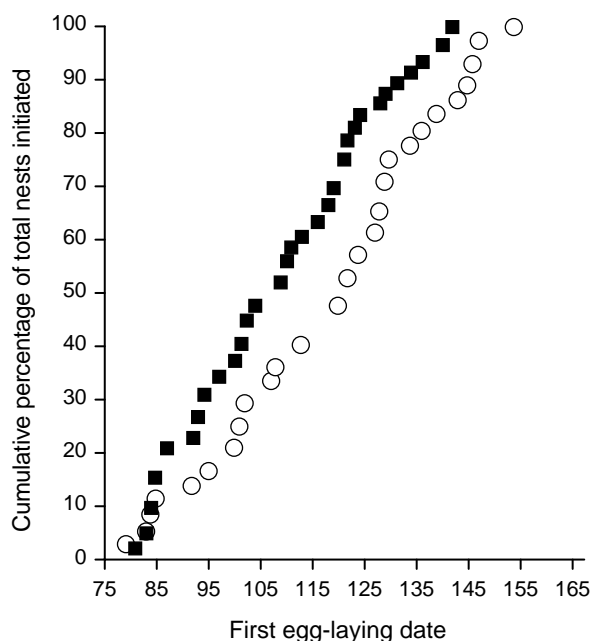*P < 0.05, **P < 0.01, ***P < 0.001.

Figure 1. The cumulative proportions of clutches laid on ungrazed (■) and grazed (○) marshes between 16 March and 14 June. Day 75 = 16 March.

(R^2 = 38.8%, $F_{3,36}$ = 9.24, $P < 0.001$). The significant *t*-values indicated an effect on survival of laying date and of the grazing regime interaction term (Table 3). However, the significant effect of the interaction term between laying date and grazing regime also indicated that the slope of the relationship between laying date and nest survival differed between grazing regimes. The effect of laying date on nest survival in ungrazed marsh-
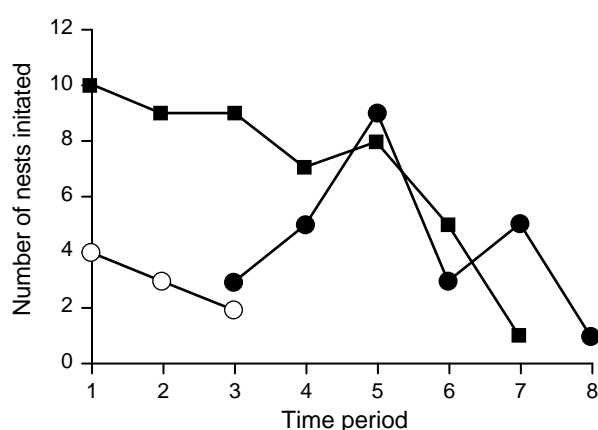

Figure 2. Changes in the frequency of nesting attempts (first egg laying dates) between 21 March and 9 June in ungrazed and grazed marshes. Each time period is ten days; period 1 runs from 21 March. Livestock were introduced to the grazed marshes between 6 and 21 April. ■, Nests in ungrazed fields; ●, nests in grazed fields after livestock introduced; ○, nests in grazed fields before livestock introduced.
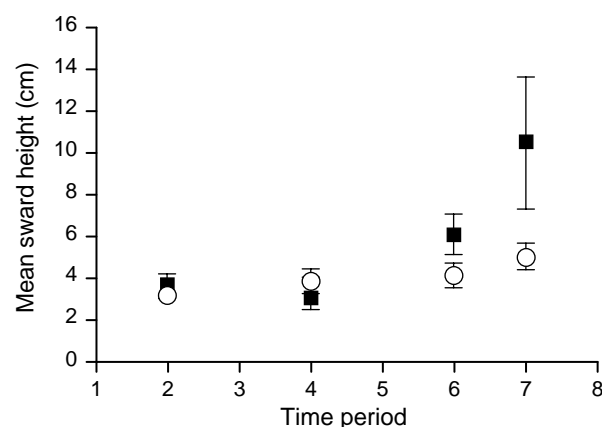
Figure 3. Changes in mean sward height (cm) between 1 April and 30 May in grazed (○) and ungrazed (■) marshes. Each time period is ten days; period 1 runs from 21 March.

es was very marked, but it was much weaker in grazed marshes (Fig. 4).

The relationship between livestock presence and egg and clutch size

Clutches comprised either three or four eggs (except for one five-egg clutch). After livestock were introduced, three-egg clutches were more frequent in grazed marshes than in ungrazed marshes (χ^2 = 10.458, df = 1, $P < 0.001$). Three-egg clutches also became more

Table 2. Mean sward height (cm) of the ungrazed (n = 4) and grazed marshes (n = 4) from which nest data were compared and the *t*-statistic of the difference between grazing regimes.

Measurement date	Mean sward height		
	Ungrazed (sd)	Grazed (sd)	*t*-value
1–3 April	3.59 (0.46)	3.22 (0.22)	1.45 ns
21–23 April	3.78 (0.48)	3.02 (0.51)	2.19 ns
12–14 May	6.13 (1.04)	4.16 (0.48)	3.45*
27–30 May	10.49 (3.13)	5.03 (0.52)	3.43*

ns, Not significant,*P < 0.05.

Table 3. Results of a multiple regression model using laying date, grazing regime and their interaction as predictors of nest survival (n = 41).

Predictor	Coefficient (sd)	*t*-value
Laying date	–0.846 (0.22)	–3.83***
Grazing regime	–89.811 (33.82)	–2.66*
Interaction	0.669 (0.27)	2.50*

Grazing regime was entered as a 0,1 dummy variable. F_{3-36} = 9.24, $P < 0.001$. *$P < 0.05$, ***$P < 0.001$.
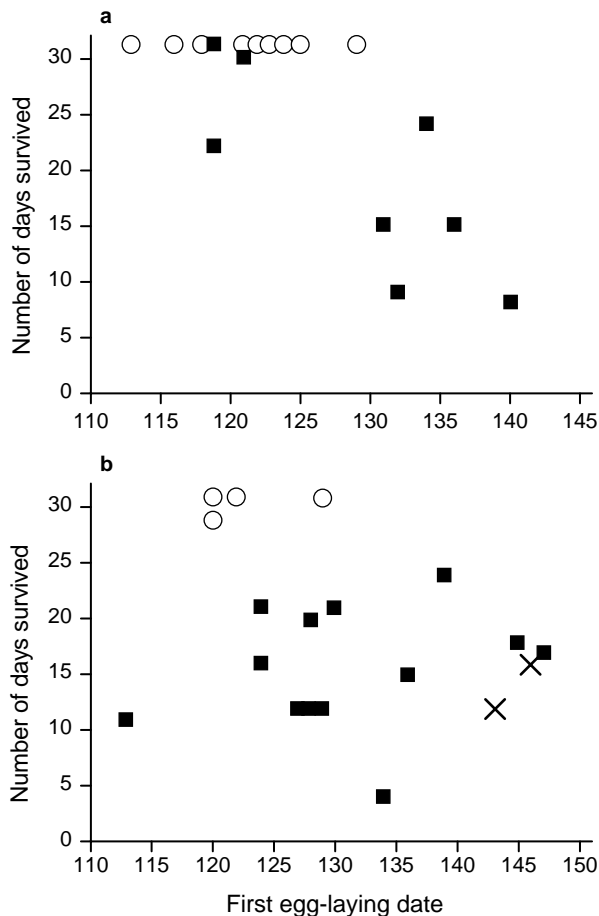
Figure 4. The relationship between survival and laying date in (a) ungrazed and (b) grazed marshes. Day 110 = 20 April. ○, Hatched nests; ■, predated nests; ×, trampled nests.

prevalent as the breeding season progressed (Kendall's tau-c = –2.439, $P < 0.05$). Nest survival of three-egg clutches ($21 \pm 1.3\%$, $n = 18$) was significantly less than four-egg clutches ($57 \pm 0.8\%$, $n = 43$, $t = 2.975$, $P < 0.01$).

The binary logistic regression model to assess the combined effect of grazing regime and first-egg date on the relative frequency of three- and four-egg clutches suggested the relative frequency of each clutch size was influenced more by grazing regime than by laying date (Table 4).

Although mean egg volume per nest varied by 30%, it was not significantly correlated with date ($r = -0.087$, $n = 78$, ns); on average, later clutches did not contain smaller eggs than earlier clutches. Also, mean egg volume for three-egg (mean = 23.1 ml, $n = 18$) and four-egg clutches (mean = 23.3 ml, $n = 43$) did not differ ($t = 0.5$, ns), although the mean egg volume for the single occurrence of a five-egg clutch was considerably smaller (20.6 ml).

Mean egg volume per nest also did not differ between grazed and ungrazed marshes ($t = 0.63$, $df = 5$, P ns) and although egg size affected mean chick condition per brood at hatching ($R^2 = 51.1\%$, $F_{1,18} = 20.88$, $P < 0.001$), it did not correlate with per brood chick survival up to ten days old ($r = -0.116$, $n = 35$, P ns).

The impact of livestock presence on incubation schedules

A total of 95 hours of observations was recorded from 14 nests in two ungrazed marshes (mean = 146.8 minutes per nest, sd = 29.5) and 70 hours from nine nests in two sheep-grazed marshes (mean = 138.5 minutes per nest, sd = 30.3). The nests observed in the grazed marshes were occupied after the introduction of livestock.

Incubating birds on grazed marshes left their eggs more frequently than those on ungrazed marshes (Mann–Whitney U-test: $U = 26$, $P < 0.05$) but, on average, the length of their absences did not differ between grazing regimes (Mann–Whitney: $U = 42$, P ns) or individual marshes (Kruskal–Wallis: $H = 2.38$, P ns). Nest departures caused by predators, livestock and farm work were more frequent in grazed marshes (Mann–Whitney: $U = 35$, $P < 0.05$). However, despite observed interference by stock, no significant differences between either grazing regimes (Mann–Whitney: $U = 41$, P ns) or individual marshes (Kruskal–Wallis: $H = 2.55$, P ns) were detected in the mean proportion of time Lapwing pairs were observed not incubating due to disturbance.

There was a negative relationship between disturbance frequency and nest survival. In ungrazed marshes, where predation was the only cause of nest loss, nest survival decreased with increasing disturbance frequency ($r = 0.580$, $n = 12$, $P < 0.05$) (Fig. 5).

We observed no significant differences between the early (days 1–15) and late (days 16–32) stages of incubation in the proportion of time (Mann–Whitney: $U = 31$, P ns) or frequency (Mann–Whitney: $U = 25$, P ns) that Lapwings were absent from their nests.

Table 4. Results of a binary logistic regression model assessing the relative effects of laying date and grazing regime on the prevalence of 3-egg ($n = 22$) and 4-egg ($n = 59$) clutches.

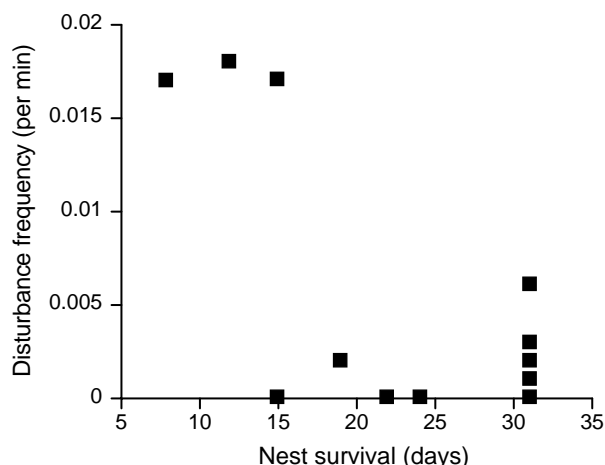| Predictor	Slope coefficient (se)	Deviance test statistic χ^2
Constant	3.785 (2.627)	–
First egg date	–0.017 (0.02)	3.32 ns
Grazing regime	–1.617 (0.656)	–6.55*

ns, Not significant, *$P < 0.05$.

Figure 5. The frequency of disturbance to nests in ungrazed marshes (n = 14) and the number of days they survived.

The distribution and effect of predation

Predation had a large effect on nesting success, accounting for 90% of Lapwing nest losses (n = 43). The observed proportion of nests predated on grazed marshes (0.58, n = 36) was higher than on ungrazed marshes (0.36, n = 50). However, the probability of nest loss due to predation was not significantly different between ungrazed marshes (63.6 ± 20.3%, n = 4) and grazed marshes (37.6 ± 12.4%, n = 4) (t = 2.19, df = 4, P = 0.09). Clearly the amount of predation varied more between the individual marshes than between grazing regimes although there was some indication that the risk of predation was higher on the grazed marshes.
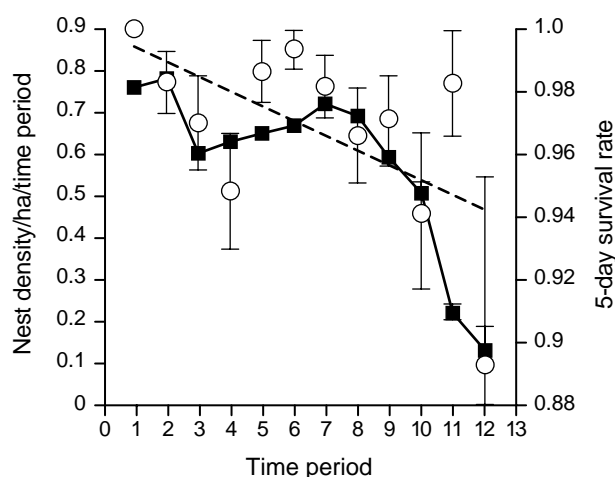

Figure 6. Changes in the nest densities of Lapwing between 15 April and 14 June and the projected linear decline in survival due to predation. Each time period is five days; period 1 runs from 15 April. ■, Lapwing nest density; ○, five-day survival rate; – – –, projected linear decline of survival.

There was a positive correlation between the number of nesting Lapwing and their nest survival between 15 April and 14 June when data from all compared marshes were pooled (r = 0.666, n = 12, P < 0.05). Thus, during this period, nests survived longest when nests were most abundant. There was also a significant linear decline in nest survival between these dates (R^2 = 38.8%, $F_{1,10}$ = 7.96, P < 0.05), although the trend appeared clearest before mid-May (Fig. 6).

Of those Lapwing nests in grazed marshes that were not predated (n = 15), only three were trampled.

DISCUSSION

The effect of livestock on marsh selection by breeding Lapwing

The presence of livestock may influence the selection of individual marshes by breeding Lapwing. Our multiple regression models indicated that Lapwing breeding densities tended to be lower on grazed marshes than on ungrazed marshes in 1995 and 1997, after allowance had been made for the effects of other habitat variables. In 1995, 1996 and 1997, rill density was also important and the implications of this habitat feature are discussed in Milsom *et al.* (2000). However, as the overall R^2 values were low in all three models, there was still much unexplained variation in the settling densities, and the variables that were included in the models were not powerful predictors of the density of Lapwing pairs per marsh. The simplicity of the livestock variable may have contributed to the poor fit of the models because it did not reflect the variation in livestock turnout dates and stocking densities between those marshes that had been grazed. However, it was not practicable to estimate stocking densities in many marshes because particular groups of livestock had unrestricted access to several marshes at one time and their movements were complex. The performance of the regression models may also have been poor because there was relatively little variation in the breeding density of Lapwings between the marshes. This was particularly true during 1996 when the number of breeding pairs was lowest. The variables may also have been particularly poor predictors for 1995 and 1996 because there were fewer ungrazed marshes available in these years.

It is also possible that factors other than the physical structure of the habitat and the presence of livestock, such as individual fitness of the birds, may have had a significant effect on settling densities. For example,

Hegyi and Sasvari (1998b) found that male quality affected territory size, the incidence of polygyny and the density of nesting females. Gronstol (1996) also found that male song-flight performance was correlated with the density of food within a territory. We did not compare the density of food between the marshes under study, therefore we do not know whether livestock presence affected food density or availability in the marshes. Variation in predation pressure between marshes may also have affected the density of nesting Lapwings. These factors may account for some of the unexplained variation in the data fitted to our models derived to predict Lapwing breeding densities.

Some of the habitat variables may have had greater influence on Lapwing breeding densities if the fitted data had been recorded at a different time during the breeding season. For example, we fitted sward height, measured during April, as a predictor variable but found it had no effect on Lapwing settling densities. This was probably because the sward heights on Emley Marshes during April were uniformly low over most of the farm. However, during 1997 we were able to show that sward height in May was more variable between marshes due to differences in grazing pressure and the rapid rise of grass growth rates. At this time of year sward height probably had greater influence on Lapwing breeding densities.

The pattern of settling densities suggested there was a preference for nesting on ungrazed fields. However, in 1997, this preference was possibly reversed later in the breeding season when sward height became a more important determinant of nest-site selection than livestock avoidance. Sward height influenced the distribution of breeding Lapwings across individual marshes.

Milsom *et al.* (2000) showed that the probability of a marsh being occupied by breeding Lapwing decreased as mean sward height increased. The optimum sward height at the time of initial territorial establishment in early April was 3–4 cm. Between late April and late May, the mean sward height in our ungrazed marshes increased from 3.8 cm to 10.8 cm and the number of nesting attempts on these marshes declined (see Fig. 3 & Table 2). In contrast, despite the presence of livestock, the number of nesting attempts on grazed marshes increased and peaked in early May. The increase in mean sward height in ungrazed marshes probably stimulated late arrivals, and pairs attempting to re-nest, to settle on grazed marshes where the mean sward height was maintained at around the optimum for breeding Lapwing until June.

The effect of livestock on Lapwing breeding performance

Productivity on grazed marshes was potentially lower than on ungrazed marshes because three-egg clutches survived less well than four-egg clutches and were more prevalent on grazed marshes. Clutches of three eggs also became relatively more frequent in both grazing regimes later in the breeding season. We were unable to determine why clutches were smaller on grazed marshes. There was no difference in mean egg volume per nest between three- and four-egg clutches and so we could not infer any difference in parental quality between clutch sizes or grazing regimes (Hegyi & Sasvari 1998a, Blomqvist *et al.* 1997, Galbraith 1988a).

Nests laid later in the year may have been replacement clutches and the lower clutch size under grazing might simply reflect a decline in clutch size with time and a greater frequency of renesting on grazed marshes. However, as individuals were not marked, we had no evidence to suggest that three-egg clutches were more prevalent in replacement nests. We found Lapwings settled to breed on some marshes later than others, e.g. the laying dates of the first clutches laid on the eight marshes we compared varied between 20 March and 9 May. The birds that commenced breeding on the marshes in early May may have bred earlier elsewhere or they may have been first-attempt breeders, perhaps young birds breeding for the first time or birds that had travelled further from wintering quarters. Our model of the relationship between the prevalence of three- and four-egg clutches from grazing regime and laying date suggested that the relative frequency of either clutch size was more closely linked to grazing regime rather than to laying date. Our results suggested that egg size and, to a lesser extent, clutch size were relatively stable through the breeding season. These results agree with Klomp's (1970) observations of Lapwing and Yogev *et al.* (1996) clutch removal experiments with Spur-winged Plover *Vanellus spinosa*.

There was evidence that nest survival was lower on grazed marshes than on ungrazed marshes although few nests were trampled. On all the marshes, predation was the main cause of nest loss. Predation levels varied between marshes. This may have been due partly to differences in the ranging behaviour of the predators and partly to variation in Lapwing nesting densities and their collective nest defence (Berg *et al.* 1992, Elliot 1985). Carrion Crows *Corvus corone* were the only predators observed taking eggs, but Fox *Vulpes vulpes* and Stoat *Mustela erminea* were also frequently

seen hunting over the marshes. Nonetheless, nesting success on grazed marshes was lower than on ungrazed marshes, probably because the birds tended to nest later and possibly because of an effect of nest disturbance by livestock on the risk of predation. Most nesting in grazed marshes occurred later in the breeding season when nest loss due to predation was higher. The risk of predation in the grazed marshes may also have been enhanced by more frequent nest absenteeism due to disturbance.

Our results suggested that the risk of nest predation was correlated with the frequency with which incubating adults were disturbed from their nests rather than the amount of time the nests were left unattended. Although the average length of time Lapwings were absent from their nests due to disturbance did not differ between grazing regimes, the frequency of absenteeism was greater on the grazed marshes. Therefore, each disturbance event must have lasted longer on the ungrazed marshes. On the ungrazed marshes predator activity was the main disturbance whereas on the grazed marshes, livestock and associated farming activities also occurred. The movement of the adults to and from their nests on the grazed marshes possibly assisted predators by providing clues to the whereabouts of nests.

Due to very high levels of predation, the differences in nesting success between grazed and ungrazed marshes at our study site did not match the predictions from Beintema & Muskens' (1987) model of hatching success in relation to cattle and sheep stocking densities. Though we were not able to distinguish between the effects of cattle and sheep, the nest survival rate on grazed marshes at Elmley in 1997 lay beneath the lower end of the confidence limits placed on the nest survival rates predicted by Beintema & Muskens (1987) for either sheep or cattle at comparable stocking densities. We suggest the presence of livestock had an additional rather than a compensatory effect (as defined by Newton 1993) on the risk of nest predation. Where predation risk is high, the detrimental effect of a given stocking rate may be greater. Further research to investigate how variation in sward height and other topographical features affect predation may help to elucidate any relationships between livestock presence and predation.

Chick survival up to ten days did not differ between grazed and ungrazed marshes. The factors affecting survival of chicks up to ten days old were not known, although observations indicated cold weather soon after hatching, and predation were the main causes of chick loss.

To summarize, grazing by livestock at low stocking densities (0.2–0.51 LU/ha) in the North Kent ESA appeared to maintain swards that were suitable for Lapwing throughout the breeding season and result in few nest losses by trampling. Nevertheless, we found some evidence that the stocked marshes had lower breeding densities and that livestock presence adversely affected Lapwing nesting success. Livestock presence increased the risk of nest predation by disrupting incubation schedules and providing habitat for late nesting when predation risk was higher. The amount of predation may also have masked the true risk of trampling and more trampling effects may have been detected at higher stocking rates within the ESA limit. Clutch sizes were also smaller on the stocked marshes, although no direct link between clutch size, livestock presence or grazing effects was identified.

Management strategies to improve Lapwing breeding performance on ESAs

As breeding Lapwing are very sensitive to the height and structure of grass swards (Milsom *et al.* 2000), the suitability of grazing marshes to the species is dependent upon grazing. However, as this study has shown, the presence of livestock, even at low stocking densities, may also have several adverse effects on breeding productivity. Mitigation of these effects may be possible by restricting the density of livestock during critical periods when nests and broods are vulnerable. In the North Kent Marshes ESAs, stocking rates are limited to 0.75 LU/ha in April and May. According to the model of Beintema and Muskens (1987), this stocking rate should permit *c.* 70–90% of the hatching success per pair that would have been achieved had no trampling occurred.

However, it is often difficult to estimate trampling risk in a particular marsh when livestock have unrestricted access to several interconnected marshes. This practice may be widespread, as in 1996, when the availability of grass in spring on the North Kent Marshes was very poor. Moreover, animal husbandry considerations preclude the rigid application of stocking rate restrictions throughout the Lapwing breeding season. It is often necessary to round up livestock and to move them through marshes to holding pens either for veterinary procedures, or for shearing in the case of sheep, and the potential for nest destruction may be very great during these operations. Given these problems, the exclusion of stock from marshes holding high densities of breeding Lapwings, or indeed other waders,

may be a preferable alternative. The practicability of this approach will depend largely upon whether grazing outside the Lapwing breeding season is sufficient to generate swards that are attractive to Lapwing in spring, and upon the rate of grass growth during the species' breeding season. At Elmley, in 1997, the grass growth was slow in April and early May, and ungrazed marshes remained attractive to Lapwing until mid-May, after the main hatching period, but this may not be the case for all areas of coastal grazing marsh. Experienced graziers should be able to assess what is practicable on their marshes.

Clearly, only a proportion of marshes on a given land holding managed as a livestock enterprise could be left ungrazed during the Lapwing breeding season. These marshes could be selected prior to the breeding season according to the presence of habitat features that determine their suitability for nesting Lapwings (Milsom *et al.* 2000) or, at some well-observed sites, by their traditional preferential use by Lapwings. The length of period over which livestock are excluded may well be determined not only by the interests of the birds but also by the grass growth and the grazing abilities of livestock. Though exclusion for the entire breeding season would be the ideal, a shorter period of livestock exclusion, between late March and late May (when nesting success was greatest), would still be beneficial. By the end of May the detrimental effects of introducing livestock into the preselected marshes should be reduced as most successful nests should have hatched and nest densities declined. Although late clutches would be vulnerable to trampling and at greater risk of predation after the introduction of livestock, the presence of livestock would help to maintain suitable habitat for late nesting and relaying birds. This strategy would maintain relatively low swards in all marshes (particularly in the North Kent Marshes where spring sward growth is slow), provide some refuge from livestock for Lapwings during their peak nesting time, and allow the grazier to exploit all the marshes. The exact date that livestock were introduced to the ungrazed marshes should be determined ideally by the time of peak hatching and the increase in sward height.

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ENDNOTES

a. The following variables were fitted as predictors of Lapwing settling density; rill density and wetness (assessed during May), tussock size and frequency (assessed during May), sward height (measured during April), marsh area and livestock presence/absence. Marsh area, rill density, sward height and tussock size were fitted as continuous variables, rill wetness and tussock frequency were fitted as factors and livestock presence/absence was fitted as a 0,1 dummy variable. To establish a model for each year that best explained the variation in Lapwing settling density, we initially fitted all the available data to derive a 'maximal model'. We then progressively simplified the 'maximal model' by discarding one variable at a time and refitting the new set of data. The discarded variables were selected as those that contributed least to the variability in Lapwing settling density. These variables were identified from the significance (at the 5% level) of the t-values of each parameter estimate or, for the variables fitted as factors, from the amount of change in the F statistic. After discarding each variable we then compared the R^2 values of the 'maximal model' with the simplified models to determine which explained most of the variation in Lapwing settling density.

b. Grazing regime (entered as a 0,1 dummy variable), laying date and the interaction between these two variables were tested as predictors of nest survival (number of days eggs survived).

c. In the regression model, clutch size (either three or four eggs) was the response variable and grazing regime (fitted as a 0,1 dummy variable) and first egg date were the predictor variables. We excluded all nests laid before 6 April (the earliest date livestock were introduced) from the model and, as livestock were introduced into some of the grazed marshes later than 6 April, we also pooled into the ungrazed category any nests laid in these marshes before the date livestock were introduced.

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