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Livestock grazing and trampling of birds' nests: an experiment using artificial nests

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Abstract The purpose of this study is to experimentally determine the differences between four grazing treatments on the trampling of nests. Additionally, we examine to what extent the trampling probability of nests is higher close to a source of fresh water. We compare the trampling of artificial nests in five different grazing treatments in an experimental design. We use buried clay pigeon targets as artificial mimics of bird nests to obtain reliable estimates of trampling risk and compare these with real nests. We find that horses trample significantly more artificial nests than cattle resulting in lower survival rates of artificial nests under horse grazing than under cattle grazing. For both horses and cattle, we find a clear trend, approaching significance, towards more trampling at higher numbers of livestock. We found that more artificial nests are trampled closer to a freshwater tank. The survival probability of artificial nests in cattle grazed treatments in this study is found to be in the same range as real nests in the study area and very close to the survival probability of Northern Lapwing (*Vanellus vanellus*) nests under cattle grazing in a different system. We recommend that horses should not be used as grazers for management purposes in areas with high densities of birds' nests in order to minimize the risk of nests being trampled.

Additionally, we confirm that the location of freshwater tanks has an important effect on the distribution of livestock and hence on trampling of nests.

Keywords Cattle · Grazing treatments · Ground breeding · Horse · Salt marsh · Wader

Introduction

Livestock grazing is commonly used as a nature management tool (Bakker 1989; Ebrahimi et al. 2010). However, a standing question in nature management is what type of livestock to use and in which densities. Trampling by livestock may result in the destruction of nests of ground-nesting birds (Fuller and Gough 1999). The risk of nests being trampled depends on the bird species as well as the type and density of livestock and time of nesting (Beintema and Müskens 1987; Green 1988; Fuller and Gough 1999). Effects of the type of livestock on trampling of birds' nests have been thoroughly studied for cattle and sheep (Beintema and Müskens 1987; Fuller and Gough 1999; Hart et al. 2002; Ottvall 2005; Pakanen et al. 2011). Studies on trampling by horses, however, are largely absent. The digestive system of horses is different from that of cattle (Duncan et al. 1990). To obtain sufficient nutrition, horses have higher rates of food intake and consume larger quantities of food on a daily basis than cattle with similar body mass (Arnold 1984; Duncan et al. 1990; Menard et al. 2002). This leads to horses having been observed to have longer daily grazing times than cattle (Arnold 1984; Duncan et al. 1990; Janis et al. 2010). Therefore they are likely to be more active, presumably increasing the probability of trampling a nest. Additionally, horses trample with greater pressure than cattle, an effect that is strengthened by running (Liddle 1997). A possible positive effect of horse grazing is their creation

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of 'latrines', especially in low stocking densities. The rejection of herbage contaminated by dung (Frame and Laidlaw 2011) may lead to a higher canopy height, which is a major descriptor of canopy structure (Frame and Laidlaw 2011). Canopy structure, in turn, is important for ground nesting waders, such as Redshanks and Lapwing (Norris et al. 1997; Whittingham and Evans 2004).

Another potentially important factor on the trampling probability of nests is water availability. Water availability affects the distribution of livestock in areas where fresh water is scarce (Vallentine 1971; Holechek 1988; Ganskopp 2001). An uneven distribution of livestock can lead to several problems associated with grazing, such as damage caused by trampling (Lange 1985). We expect that the relative density of livestock is higher close to a freshwater tank, thereby increasing the trampling probability of nests near freshwater tanks. The purpose of the present study is to experimentally determine the differences between four grazing treatments (1 horse/ha, 0.5 horse/ha, 1 cattle/ha and 0.5 cattle/ha) on the trampling of nests and to assess to what extent the trampling probability of nests is affected by the proximity of a freshwater tank.

The study was carried out in a salt marsh system. Fresh water is only available at the freshwater tanks provided in the experiment. As the density of birds' nests was too low for direct comparisons of trampling risk between grazing treatments of real nests, we used artificial nests to compare treatments. Artificial nests have been used in a number of studies to assess predation of birds' nests (e.g. Martin, 1987; Picman 1987; Major 1991; Bayne and Hobson 1997; Maier and Degraaf 2001; Boulton and Cassey 2006). They have also been used successfully for studies on trampling (Koerth et al. 1983; Jensen et al. 1990; Paine et al. 1996; Pavel 2004). In this study, we use artificial nests to assess the relative trampling risk between different grazing treatments.

In order to validate the use of artificial nests, we compare artificial nests with real wader nests by calculating trampling probabilities (Beintema and Müskens 1987) for our artificial nests and comparing them to trampling probabilities found for the small sample of real wader nests in our study area. We also compare trampling probabilities of artificial nests with trampling probabilities of real wader nests found by Beintema and Müskens (1987) in an inland grassland system.

Methods

Study site

This study was carried out on a site along the Dutch Wadden Sea coast in a mainland salt marsh (53° 20'N 5° 43'E), which is part of the UNESCO Wadden Sea World Heritage

Site. It is a man-made marsh with high clay content in the soil, created with the aid of sedimentation fields. These are maintained to avoid erosion of the salt marsh. Approximately half of the study area can be considered high marsh, close to the summer dike, (Fig. 1) and half low marsh, close to the sea. Higher parts of the marsh are inundated less frequently with sea water than lower parts. The study site is an important breeding area for several wader species.

Experimental design

Within the study area, a grazing experiment was set up with three replicate blocks. Each replicate area of 55 ha consisted of five equally sized paddocks with different grazing treatments. We studied four grazing treatments: 5 cattle, 5 horses, 10 cattle and 10 horses per 11 ha (Fig. 1). A fifth treatment (rotational grazing with 10 cattle at yearly intervals) was not studied because it also contained 10 cattle at the time of this study, providing little extra information. The different grazing treatments were allocated randomly to the paddocks in each replicate with the restriction that no two horse grazed treatments were placed next to each other, as horses were expected to influence one another if placed in adjacent paddocks. Each paddock contained a freshwater tank close to the summer dike (Fig. 1).

Clay pigeon targets used as artificial nests

To estimate and compare the trampling intensity between different grazing treatments, we used clay pigeon targets (fragile round discs used for shooting sports) as artificial nests.

Fig. 1 Distribution of five grazing regimes over five 11 ha paddocks within one of the 55 ha replicate blocks. Fifty artificial nests were randomly placed in all treatments, except for the rotational treatment. Black dots indicate the position of freshwater tanks. The grey line indicates the position of the summer dike

Clay pigeon targets have been used extensively to estimate the effects of trampling by livestock (Koerth et al. 1983; Jensen et al. 1990; Paine et al. 1997; Gregory and Gamett 2009). Paine et al. (1997) found that trampling levels were similar for clay pigeon targets and simulated nests with pheasant eggs. Pavel (2004) found that artificial nests with plasticine clay in jam jar lids had similar trampling rates as natural nests of Meadow Pipit (*Anthus pratensis*) and Water Pipit (*Anthus spinoletta*). However, during a pilot study, we found that the plasticine clay was eaten by the cattle in our study area, making this an unsuitable method. Instead we chose to use clay pigeon targets. The high visibility of clay pigeon targets may, however, attract livestock (Pavel 2004). Therefore, we covered the clay pigeon targets with soil to counterbalance the high visibility. For this, a soil core of 10 cm diameter and 10 cm depth was taken, a clay pigeon (diameter=10 cm) was placed in the hole and the intact soil core was placed on top of the clay pigeon. The clay pigeon breaks when these soil cores are stepped on by cattle and horses. The study area was not open to the public and was fenced off with electric fence. Therefore it was not possible for large grazers other than the livestock to enter the field and breaking of artificial nests could be fully attributed to the livestock used for the experiment.

Random coordinates to place the artificial nests were generated in ArcGIS (ArcGIS Desktop 2010). Pavel (2004) did not find a difference in nest trampling of artificial nests placed in 'nest like locations' and artificial nests placed in a grid. This suggests that random placing of nests should provide proper estimates of trampling by livestock. In this manner, 50 clay pigeon targets were placed randomly in each of the four grazing treatments within each replicate block (total number=600). Although 50 nests per 11 ha is a higher density than generally expected with natural nests of non-colonial bird species, Koerth et al. (1983) and Beintema and Müskens (1987) showed that relative trampling loss does not increase at higher nest densities.

The artificial nests were placed on 26, 27 and 30 May 2011 respectively in each replicate and were left in the field for 21 days, which is similar to the incubation time of a number of breeding waders (von Blotzheim, 2004). Artificial nests were checked after 7 and 21 days and recorded to be intact or trampled. A metal pin was placed in the ground next to each artificial nest and the coordinates were recorded in order to be able to find the artificial nests again with a GPS and metal detector. If artificial nests could not be found after 21 days, they were left out of the analysis. Artificial nests trampled after 7 days were removed from the field.

Trampling probability in different grazing treatments

As all the artificial nests in a paddock (field within a replicate, Fig. 1) were pseudo-replicates, we used a linear mixed-

effects model approach to analyse this data (Zuur et al. 2009). We assessed the effect of livestock species, grazing intensity and distance from the fresh water supply on trampling risk of our artificial nests. The artificial nests we could find after 21 days were used to model trampling as a binary input variable (trampled or intact), as explained by the distance of each artificial nest to the freshwater tank, the type of livestock, the density of livestock, an interaction between distance to the freshwater tank and livestock type, an interaction between distance and livestock density and a three way interaction between distance, livestock type and livestock density. Replicate and paddock were used as random factors in the model. Models were fitted using the lme4 package (Bates et al., 2011) in R, version 2.14.1 (R Development Core Team 2011) and model selection was conducted using backward elimination, using AIC values to compare models. Using the parameters from the statistical model, pairwise comparisons between livestock types and densities were made with the multcomp package (Hothorn et al. 2008). The results for the effect of density and livestock were confirmed using an ANOVA approach on the fractions of nests trampled at different livestock types and densities. The distance from artificial nests to the fresh water supply in a paddock was calculated with ArcMap version 10.0 (ArcGIS Desktop 2010).

Comparison with real nests

We calculated *V*-values (survival rates of artificial nests per grazing animal per hectare per day) for the artificial nests in each grazing treatment as described by Beintema and Müskens (1987), using the observations after 7 and 21 days. A *V*-value of 1 indicates a nest survived 1 day with one grazer per hectare, while a value of 0 indicates a nest has been trampled after 1 day with one grazer per hectare. These *V*-values are directly comparable to *V*-values found for real nests. We calculated *V*-values for Common Redshank (*Tringa totanus*) (*N*=16) and Eurasian Oystercatcher (*Haematopus ostralegus*) (*N*=24) nests (two of the most common ground breeding waders in the study area). These nests were found and monitored in 2010 and 2011. Each trampling event was recorded. Additionally, Beintema and Müskens (1987) calculated *V*-values for several wader species under different grazing treatments in an inland grassland system. We compared *V*-values between cattle and horses with a Z-test as described by Johnson (1979) and applied by McGowan et al. (2005).

Results

Out of 600 artificial nests placed, 524 could be found after 21 days and of those 118 had been trampled, a fraction of

0.225 (Table 1). There is no reason to assume differences in the probability of finding back trampled or non-trampled artificial nests. Those nests not found back were generally located in large patches of tall vegetation, or were submerged under sea water, due to a flood of the study area just prior to the final check of the artificial nests. One paddock which combined a relatively tall canopy with a large amount of standing water due to the flood had a particularly low recovery rate (Table 1).

The trampling probability of artificial nests differed with grazer type. Horses trampled significantly more artificial nests than cattle as shown by pairwise comparisons of grazing treatments (Fig. 2) and regression analysis (Fig. 3). Pairwise comparison showed that 10 horses trampled significantly more than 10 and five cattle and that five horses trampled significantly more than five cattle (Fig. 2). Within each species of grazer, we found a clear, although non-significant ($p=0.076$, Table 2), trend towards more grazers leading to more trampling of artificial nests. We did not find an interaction between grazing treatment and distance to a freshwater tank. This suggests that both for cattle and for horses, the distance to water has a similar effect.

With the linear mixed model used in this study, we found that the variance between paddocks within blocks is zero. To confirm the outcome of the model relating to differences in trampling between horses and cattle and between 5 and 10 animals, we did an additional analysis (ANOVA) on the fractions of nests trampled per paddock (Table 1). In this reduced form, the data still showed a significant difference between horses and cattle and a significant difference between 10 and 5 animals was found as well (F -values of 90.58 and 26.78 and p -values of <0.001 and <0.001

Table 1 Numbers of artificial nests placed and the fraction trampled after 21 days

Replicate	Density	Species	Nests placed	Nests found (after 21 days)	Nests trampled (21 days)	Fraction
1	5	cattle	50	46	6	0.13
1	10	cattle	50	50	8	0.16
1	5	horses	50	49	14	0.286
1	10	horses	50	44	17	0.386
2	5	cattle	50	50	3	0.06
2	10	cattle	50	49	9	0.184
2	5	horses	50	48	12	0.25
2	10	horses	50	47	17	0.362
3	5	cattle	50	31	4	0.129
3	10	cattle	50	41	7	0.171
3	5	horses	50	28	6	0.214
3	10	horses	50	41	15	0.366

Fig. 2 In horse-grazed treatments, more artificial nests were trampled after 21 days than in cattle-grazed treatments. Error bars represent standard errors of the mean, calculated over three replicates. Letters denote significant differences at 0.05 % between grazing treatments in the trampling intensity of nests as found with a logistic regression model

respectively). The ANOVA therefore confirms the results of the more appropriate, linear mixed model.

The distance to a freshwater tank had a strong effect on the trampling probability of artificial nests. Logistic regression showed that the probability an artificial nest was trampled decreased with the distance to a freshwater tank (Fig. 3).

To compare artificial nests to real nests, daily survival rates of artificial nests per grazing animal per hectare (V -values, (Beintema and Müskens 1987)) were calculated. The survival rates we found for horse treatments were

Fig. 3 The probability of an artificial nest being trampled was greater closer to a freshwater tank. Letters denote significant differences between grazing treatments (shown in inset legend). Horses were more likely to trample nests than cattle. Nests were left in the study area for a maximum of 21 days

Table 2 Results of a linear mixed model with distance to fresh water as a continuous explanatory variable and livestock species and livestock density as factors. Replicate and paddock were included as nested random factors in the model. The results of this model are followed by the results of a multiple comparison of all factor levels based on the model. Due to an adjustment to the p -values, because of the multiple comparisons, the difference in trampling between 10 and 5 animals is just not significant at the 5 % level. However, there is a clear trend (Fig. 2)

	Z-value	p -value
Intercept	-3.654	<0.001
Distance to fresh water	-5.881	<0.001
Livestock species	4.647	<0.001
Livestock density	2.067	<0.05
Results of multiple comparison of factors in the model		
Horses-cattle	4.647	<0.001
10 animals-5 animals	2.067	0.076

significantly lower than those for cattle treatments (Table 3). This result complies with the earlier findings on the trampling probability of artificial nests.

The V -values can be used to compare artificial nests to real nests of different bird species. With limited Eurasian Oystercatcher and Common Redshank nests exposed to

Table 3 V -values (survival rate of artificial nests per grazing animal per hectare per day) $\pm$ standard deviations as calculated according to Beintema and Müskens (1987). A value of 1 indicates a nest definitely survives a day with one grazer per ha, a value of 0 indicates a nest is definitely trampled after 1 day with one grazer per ha. Survival rates over several days (t) can be calculated by V^t . Using the average V -value for horses, we expect 29 out of 50 nests to survive a 21 day period with one horse per ha ($50 \times 0.975^{21} = 29$ nests). V -values were calculated using data collected after 7 days and after 21 days

Treatment	Replicate	V
10 cattle	1	0.991 $\pm$ 0.003
10 cattle	2	0.990 $\pm$ 0.003
10 cattle	3	0.991 $\pm$ 0.003
5 cattle	1	0.994 $\pm$ 0.004
5 cattle	2	0.986 $\pm$ 0.006
5 cattle	3	0.987 $\pm$ 0.006
Average cattle		0.990 $\pm$ 0.004*
10 horses	1	0.978 $\pm$ 0.006
10 horses	2	0.978 $\pm$ 0.006
10 horses	3	0.978 $\pm$ 0.005
5 horses	1	0.979 $\pm$ 0.008
5 horses	2	0.966 $\pm$ 0.009
5 horses	3	0.970 $\pm$ 0.008
Average horse		0.975 $\pm$ 0.007*

*The average V -values for cattle and for horses are significantly different, $p < 0.05$ (Z test (Johnson 1979; McGowan et al. 2005))

livestock (14 Eurasian Oystercatcher nests and 12 Common Redshank nests exposed to cattle and 10 Eurasian Oystercatcher nests and 4 Common Redshank nests exposed to horses) and few nests trampled (0, 2, 1 and 0 respectively) in this study, we could only calculate biologically relevant V -values for Common Redshanks exposed to cattle and Eurasian Oystercatchers exposed to horses. When no nests were found trampled, the calculated survival probabilities would be 1. It is highly unlikely that this would be true in any grazed system, so a larger sample size is required in these cases. We found a V -value of 0.962 ± 0.026 for Common Redshanks under cattle grazing and a V -value of 0.971 ± 0.028 Eurasian Oystercatchers under horse grazing. We also compared V -values of artificial nests with V -values found by Beintema and Müskens (1987) in a grassland system. We found that our V -values for artificial nests under cattle grazing were very similar to V -values of Northern Lapwing nests under cattle grazing as found by Beintema and Müskens (1987) (Table 4). As Beintema and Müskens (1987) did not study horse grazed treatments, we could not directly compare artificial nests under horse grazing with real nests under horse grazing. However, for three of the four wader species studied by Beintema and Müskens (1987), the survival rates of nests under cattle-grazed treatments were higher than the survival rates we found for artificial nests under horse-grazed treatments (Tables 3 and 4). This again suggests a higher risk of nest trampling with horses than with cattle.

Table 4 V -values $\pm$ standard deviations from Beintema and Müskens (1987). Grazing systems: 1, dairy cattle during the day only; 2, dairy cattle day and night; 3, yearlings day and night; 4, sheep day and night

Species	Grazing system	V
Northern Lapwing	1	0.995 $\pm$ 0.0013
	2	0.990 $\pm$ 0.0017
	3	0.984 $\pm$ 0.0024
	4	0.996 $\pm$ 0.0015
Black-tailed Godwit	1	0.988 $\pm$ 0.0027
	2	0.982 $\pm$ 0.0031
	3	0.960 $\pm$ 0.0050
	4	0.993 $\pm$ 0.0026
Common Redshank	1	0.972 $\pm$ 0.0097
	2	0.973 $\pm$ 0.0045
	3	0.964 $\pm$ 0.0045
	4	0.993 $\pm$ 0.0034
Eurasian Oystercatcher	1	0.996 $\pm$ 0.0015
	2	0.986 $\pm$ 0.0017
	3	0.991 $\pm$ 0.0011
	4	0.999 $\pm$ 0.0004

Discussion

Survival probabilities of artificial nests were significantly higher for cattle than for horses and significantly more nests were trampled by horses than by cattle in similar densities in this study. Additionally, we found a non-significant, but clear trend towards an increased trampling probability with higher grazer densities. The probability of an artificial nest being trampled was significantly greater close to a freshwater tank. The analysis did not show an interaction effect between distance to water and grazing treatment, suggesting a similar effect of distance to water for all grazing treatments.

Effect of different grazing treatments on artificial nests

The differences we found between species of livestock are likely to be explained by differences in behaviour of horses and cattle. Horses are more active than cattle (Arnold 1984; Duncan et al. 1990; Janis et al. 2010) and use longer parts of the day to graze because of their different digestive systems (Duncan et al. 1990). Studies on the behaviour of horses and cattle in our study area suggest that both livestock species prefer to graze close to the summer dike (Nolte, unpublished data). Nonetheless, horses spent more time on the low marsh, further away from the summer dike, than cattle. Cattle also spent less time per day grazing than horses. This means that horses move more than cattle, increasing the risk of trampling a nest (Nolte unpublished data).

Increasing the number of grazers per paddock is likely to increase the risk of a grazer trampling a nest (Beintema and Müskens 1987). We found such a trend, bordering significance. We did, however, not find as strong an effect as expected. One could argue that, when doubling the number of grazers, the number of nests trampled should double as well. This was clearly not the case in this study. Unpublished data showed that horses as well as cattle show a positive selection for specific plant communities (Nolte, unpublished). The positive selection for certain vegetation types would suggest that livestock are not randomly distributed over a salt marsh. Since the artificial nests in our study were randomly placed in each paddock, some artificial nests are more likely to be trampled than others. Additionally, with an increasing time interval, the chance of a nest being trampled more than once increases. We cannot distinguish this double trampling in our design. The non-random distribution of livestock over the paddocks and the relatively long time of 21 days of exposure would therefore explain why we do not find a stronger effect of livestock density, with a doubling of the number of livestock.

Although this study found an effect of distance to a freshwater tank on the number of artificial nests trampled, it should be noted that on a salt marsh, other gradients may

influence the behaviour of livestock as well. Most food for livestock is available close to the summer dike and salt water inundates higher parts of the marsh (closer to the summer dike) less frequently than the lower parts. Nonetheless, although this study was conducted in a salt-marsh area, fresh water was an important and limiting resource for livestock. The only available fresh water was at the freshwater tanks supplied in each experimental paddock. Under comparable circumstances, livestock was shown to concentrate around freshwater tanks (Arnold 1984). This could be a partial explanation for the increased trampling with decreasing distance from a fresh water source.

Artificial nests compared to real nests

An obvious difference between real birds' nests and artificial nests is that no birds breed on and protect an artificial nest and, therefore, artificial nests will never have the same properties as real nests (Major and Kendal 1996; Wilson et al. 1998; Moore and Robinson 2004). We suggest, however, that the relative differences we found between horses and cattle and between grazers of the same type in different densities are comparable to effects on real wader nests. To study the absolute effect of livestock on ground-breeding birds using artificial nests, a correction of the V -values of artificial nests would be necessary, depending on the bird species. The behaviour of breeding birds will influence the probability of a nest getting trampled. Three factors are of particular importance: active nest defence, the effectiveness of active nest defence and the nest site choice in relation to the position of artificial nests. Using the few real nests in this study, we calculated V -values for Eurasian Oystercatcher nests under horse grazing, which were close to V -values of artificial nests under horse grazing. Eurasian Oystercatchers show active nest defence (Beintema et al. 1995), but our results suggest that the effectiveness of this defence against horses is low. For Common Redshank nests under cattle grazing, the V -values were still in the same range but clearly lower than V -values for artificial nests. Common Redshanks do not actively defend their nest (Beintema et al. 1995), so they may choose nest sites with a relatively low trampling risk, compared to the random position of our artificial nests. When comparing our artificial nests to real nests in a much greater sample (Beintema and Müskens, 1987), we found that V -values for artificial nests were very similar to V -values found for Northern Lapwing nests in a cattle-grazed treatment. Northern Lapwings are an aggressive species which actively defend nests but active nest defence was found to have little effect on nest survival of waders in coastal meadows (Ottvall et al. 2005). This would explain why artificial nests without a defending adult have similar survival probabilities to real Northern Lapwing nests.

Apart from the described and tested direct effects of trampling by livestock on nest survival, there may also be a number of associated indirect effects. MacDonald and Bolton (2008), for example, show that Lapwings suffer from lower predation rates when nesting at high densities, possibly through a mobbing effect, deterring predators. Therefore, nest loss due to trampling may lead to lower nest densities and higher predation rates. Trampling may also lead to the destruction and loss of vegetation or to changes in the botanical composition of grasslands (Frame and Laidlaw 2011). Since waders tend to select habitat with greater concealment than generally available (MacDonald and Bolton 2008), loss of vegetation may lead to loss of breeding habitat for waders. Changes in botanical composition may lead to changes in food availability for birds. Horses have been found to apply greater pressure to vegetation than cattle (Liddle 1997) and destruction of soils through trampling is greater with high stocking densities (Frame and Laidlaw 2011). Therefore it seems likely that the indirect, as well as the direct effects of trampling on ground breeding birds are greatest in high density horse grazed sites.

On salt marshes and many other grassland systems, sheep are another important livestock species. Sheep were not included in this study. However, a pilot study using 15 artificial nests and two breeds of sheep (Ouessant and Texelaar) was conducted to test the suitability of our method to assess the impact of trampling by sheep. With our set-up, the clay pigeon targets did not consistently break when stepped on by sheep, most likely because of the lower body weight of sheep compared to cattle and horses. Therefore, our method in its present form would not be suitable for studies on sheep grazing.

Implications for management

We suggest that the use of horses as grazers in areas with high densities of birds' nests should be avoided to minimize the risk of nests being trampled. To further assess the impact of grazers on trampling of nests, we conclude that artificial nests, as described in this study, are a useful tool for studies on cattle and horses.

In regions with limited availability of important resources such as drinking water, livestock show distribution patterns (Valentine 1947; Bailey et al. 1996; Bailey and Brown 2011). This may create a gradient of grazing intensity by livestock. The negative impact of livestock on ground-breeding birds may be minimized by providing that resource far away from breeding colonies or areas with high densities of breeding birds. In this way, the use of fences can be largely avoided, as these might have a negative effect by acting as perches for predators (Ottvall et al. 2005; Wallander et al. 2006). Additionally, fences are largely viewed in a negative light

by the general public due to the aesthetics of using fencing in natural areas (Huijser and Kociolek 2008).

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References

- ArcGIS Desktop (2010) Version 10. ESRI Inc.
- Arnold GW (1984) Comparison of the time budgets and circadian patterns of maintenance activities in sheep, cattle and horses grouped together. *Appl Anim Behav Sci* 13:19–30
- Bailey DW, Brown JR (2011) Rotational grazing systems and livestock grazing behaviour in shrub-dominated semi-arid and arid rangelands. *Rangel Ecol Manag* 64:1–9
- Bailey DW, Gross JE, Laca EA, Rittenhouse LR, Coughenour MB, Swift DM, Sims PL (1996) Mechanisms that result in large herbivore grazing distribution patterns. *J Range Manag* 49:386–400
- Bakker JP (1989) Nature management by grazing and cutting. Kluwer Academic Publishers, Dordrecht
- Bates D, Maechler M, Bolker B (2011) lme4: Linear mixed-effects models using Eigen and Eigen. R package version 0.999375-42. <http://CRAN.R-project.org/package=lme4>
- Bayne EM, Hobson KA (1997) Comparing the effects of landscape fragmentation by forestry and agriculture on predation of artificial nests. *Cons Biol* 11:1418–1429
- Beintema AJ, Moedt O, Ellinger D (1995) Ecologische atlas van de Nederlandse weidevogels. Schuyt & Co Uitgevers en Importeurs, Haarlem
- Beintema AJ, Müskens GJDM (1987) Nesting success of birds breeding in Dutch agricultural grasslands. *J Appl Ecol* 24:743–758
- Boulton RL, Cassey P (2006) An inexpensive method for identifying predators of passerine nests using tethered artificial eggs. *N Z J Ecol* 30:377–358
- Duncan P, Foote TJ, Gordon IJ, Gakahu CG, Lloyd M (1990) Comparative nutrient extraction from forages by grazing bovids and equids: a test of the nutritional model of equid/bovid competition and coexistence. *Oecologia* 84:411–418
- Ebrahimi A, Milotić T, Hoffmann M (2010) A herbivore specific grazing capacity model accounting for spatio-temporal environmental variation: A tool for a more sustainable nature conservation and rangeland management. *Ecol Model* 221:900–910
- Frame J, Laidlaw AS (2011) Improved grassland management. The Crowood Press Ltd., Ramsbury
- Fuller RJ, Gough SJ (1999) Changes in sheep numbers in Britain—Implications for bird populations. *Biol Cons* 91:73–89
- Ganskopp D (2001) Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. *Appl Anim Behav Sci* 73:251–262
- Green RE (1988) Effects of environmental factors on the timing and success of breeding of common snipe *Gallinago gallinago* (Aves: Scolopacidae). *J Appl Ecol* 25:79–93
- Gregory JS, Gamett BL (2009) Cattle trampling of simulated bull trout redds. *N Am J Fish Manag* 29:361–366

- Hart JD, Milsom TP, Baxter A, Kelly PF, Parkin WK (2002) The impact of livestock on lapwing *Vanellus vanellus* breeding densities and performance on coastal grazing marsh. *Bird Study* 49:67–78
- Holecchek JL (1988) An approach for setting the stocking rate. *Rangel* 10:10–14
- Hothorn T, Bretz F, Westfall P (2008) Simultaneous inference in general parametric models. *Biom J* 50:346–363
- Huijser MP, Kociolek AV (2008) Wildlife-vehicle collision and crossing mitigating measures: A literature review for Blaine county Idaho. Western Transportation Institute, Montana State University, Bozeman
- Janis CM, Constable EC, Houpt KA, Streich WJ, Clauss M (2010) Comparative ingestive mastication in domestic horses and cattle: a pilot investigation. *J Anim Phys Anim Nutr* 94:e402–e409
- Jensen HP, Rollins D, Gillen RL (1990) Effects of cattle stock density on trampling loss of simulated ground nests. *Wildl Soc Bull* 18:71–74
- Johnson DH (1979) Estimating nesting success: the Mayfield method and an alternative. *Auk* 96:651–661
- Koerth BH, Webb WM, Bryant FC, Guthery FS (1983) Cattle trampling of simulated ground nests under short duration and continuous grazing. *J Range Manag* 36:385–386
- Lange RT (1985) Spatial distributions of stocking intensity produced by sheep-flocks grazing Australian chenopod shrublands. *Trans R Soc S Aust* 109:167–174
- Liddle M (1997) Recreation ecology: the ecological impact of outdoor recreation and ecotourism. Chapman & Hall, London
- MacDonald MA, Bolton M (2008) Predation of Lapwing *Vanellus vanellus* nests on lowland wet grassland in England and Wales: effects of nest density, habitat and predator abundance. *J Ornithol* 149:555–563
- Maier TJ, Degraaf RM (2001) Difference in depredation by small predators limit the use of plasticine and Zebra Finch eggs in artificial- nest studies. *Condor* 103:180–183
- Major RE (1991) Identification of nest predators by photography, dummy eggs and adhesive tape. *Auk* 108:190–196
- Major RE, Kendal CE (1996) The contribution of artificial nest experiments to understanding avian reproductive success—a review of methods and conclusions. *Ibis* 138:298–307
- Martin TE (1987) Artificial nest experiments – effects of nest appearance and type of predator. *Condor* 89:925–928
- McGowan CP, Simons TR, Golder W, Cordes J (2005) A comparison of American Oystercatcher reproductive success on barrier beach and island habitats in coastal North Carolina. *Waterbirds* 28:150–155
- Menard C, Duncan P, Fleurance G, Georges JY, Lila M (2002) Comparative foraging and nutrition of horses and cattle in European wetlands. *J Appl Ecol* 39:120–133
- Moore RP, Robinson WD (2004) Artificial bird nests, external validity and bias in ecological field studies. *Ecol* 85:1562–1567
- Norris K, Cook T, O'Dowd B, Durdin C (1997) The density of Redshank *Tringa totanus* breeding on the salt marshes of the Wash in relation to habitat and its grazing management. *J Appl Ecol* 34:999–1013
- Ottvall R (2005) Nest survival among waders breeding on coastal meadows: the relative importance of predation and trampling damages by livestock. *Ornis Svecica* 15:89–96
- Ottvall R, Larsson K, Smith HG (2005) Nesting success in Redshanks *Tringa totanus* breeding on coastal meadows and the importance of habitat features used as perches by avian predators. *Bird Study* 52:289–296
- Paine L, Undersander DJ, Sample DW, Bartelt GA, Schatteman TA (1996) Cattle trampling of simulated ground nests in rotationally grazed pastures. *J Range Manag* 49:294–300
- Paine L, Undersander DJ, Sample DW, Bartelt GA, Schatteman TA (1997) Technical note: comparison of simulated ground nest types for grazing/trampling research. *J Range Manag* 50:231–233
- Pakanen V-M, Luukkonen A, Koivula K (2011) Nest predation and trampling as management risks in grazed coastal meadows. *Biodivers Conserv* 20:2057–2073
- Pavel V (2004) The impact of grazing animals on nesting success of grassland passerines in farmland and natural habitats—a field experiment. *Folia Zool* 53:171–178
- Picman J (1987) An inexpensive camera setup for the study of egg predation at artificial nests. *J Field Ornith* 58:372–382
- Development Core Team R (2011) R: A language and environment for statistical computing. R Foundation for statistical computing, Vienna
- Valentine KA (1947) Distance from water as a factor in grazing capacity of rangeland. *J Forestry* 45:749–754
- Vallentine J (1971) Range Development and Improvements. Young University Press, Provo
- Von Blotzheim UNG (2004) Handbuch der Vögel Mitteleuropas. Mit einem Lexikon ornithologischer Fachbegriffe von Ralf Wassmass. Vogelzug-Verlag, Wiebelsheim
- Wallander J, Isaksson D, Lenberg T (2006) Wader nest distribution and predation in relation to man-made structures on coastal pastures. *Biol Cons* 132:343–350
- Whittingham MJ, Evans KL (2004) The effect of habitat structure on predation risk of birds in agricultural landscapes. *Ibis* 146(Suppl 2):210–220
- Wilson GR, Brittingham MC, Goodrich LJ (1998) How well do artificial nests estimate success of real nests? *Condor* 100:357–364
- Zuur AF, Ieno EN, Walker NJ, Saveliev AA, Smith GM (2009) Mixed effects models and extensions in ecology with R. Springer Science + Business Media, New York