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Managing water levels on wet grasslands to improve foraging conditions for breeding northern lapwing *Vanellus vanellus*

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Summary

1. The widespread drainage of wetlands and grazing marshes has been one of the main drivers of severe reductions in the number and range of breeding waders across Europe. Wader chicks require wet, invertebrate-rich foraging habitats and most agricultural land is now too dry to support sustainable breeding populations. Recent efforts to re-create wet grasslands and improve wader breeding success have focussed on reinstating wet features, in order to provide foraging habitats for chicks. The success of wet feature installation will therefore depend on whether they provide sufficient invertebrate prey for chicks throughout the pre-fledging period.

2. Techniques for re-creating lowland wet grasslands from arable and pastoral farmland are becoming increasingly well-established, and support from agri-environment initiatives is now available for wet feature installation on grasslands. Here we explore the effect of wet feature provision on invertebrate abundance and the growth rates and body condition of northern lapwing *Vanellus vanellus* chicks, on grazing marshes in eastern England.

3. Wet features supported more than double the biomass of surface-active invertebrates and a greater abundance of aerial invertebrates than the vegetated grazing marsh. Chick foraging rates were also two to three times higher in wet features than in the grazing marsh, as was the estimated biomass intake per food item.

4. At the start of the breeding season, chick condition was unrelated to wet feature provision but late in the season, when water levels were low, chick body condition was significantly higher in fields with footdrain densities of more than 150 m ha\(^{-1}\). Chick condition declined with increasing rainfall, and low growth rates and longer pre-fledging periods in 2007 are likely to have resulted from unusually intense and prolonged summer rainfall.

5. **Synthesis and applications.** The installation of wet features on grasslands provides valuable foraging locations for chicks, particularly later in the season when these features are likely to be the main source of water available. Predicted changes to the seasonality of precipitation at temperate latitudes means that provision of wet features is likely to be increasingly important for maintaining breeding wader populations.

**Key-words:** chick body condition, environmental stewardship, foraging rates, grazing marsh, habitat creation, managed wet features, northern lapwing

Introduction

An increase in the intensity of management of agricultural land over the last 50 years has been linked to the declines of many farmland birds (Chamberlain & Fuller 2000; Donald,
Green & Heath 2001; Robinson & Sutherland 2002). For breeding waders on wet grasslands, drainage has been the main driver of the reduction in both their number and range (Williams & Bowers 1987; Wilson, Vickery & Browne 2001; Newton 2004). Drainage allows reseeding with faster growing grass species, increased use of fertilizers, more intense grazing, and easier use of machinery for cutting of silage or hay, all of which tends towards the production of a drier habitat with a more uniform sward structure and more frequent cutting regime, and a reduction in the amount and quality of food available to birds (Benton et al. 2002). Changes in food supply have been important in the declines of many farmland bird species (Benton et al. 2002; Robinson & Sutherland 2002; Newton 2004). On wet grasslands, reductions in soil wetness are thought to be of particular importance in influencing invertebrate abundance, with drier habitats tending to support fewer invertebrates (Green & Cadbury 1987; McKeever 2003).

Actions aimed at improving breeding wader numbers on grazing marshes are generally undertaken through control of water levels and restrictions to stocking and cutting rates. One of the key processes in the management, restoration and re-creation of wet grassland is the re-introduction of water into the habitat (Smart et al. 2006). This can be achieved through the use of shallow wet features, sometimes known as footdrains, which can be used to move water into the middle of marshes and retain it through the season. Footdrains are shallow channels, approximately 2–3 m wide and 50 cm deep, which were often originally installed to facilitate in-field drainage or are relic parts of an old marsh creek system. By connecting footdrains to ditches and raising water levels, water can be re-introduced to the centre of grazing marshes, and these features are usually able to maintain water longer than isolated areas of surface flooding (Eglington et al. 2008). This process creates areas of flooding and damp habitat that can potentially provide a mosaic of nesting habitat and profitable feeding areas (Ausden & Treweek 1995; Ausden et al. 2003). Installation of these wet features has been carried out extensively on nature reserves and their use within commercial farmland is also increasing, with support from agri-environment initiatives.

Wader chick distribution is often strongly associated with wet features (Joiner 2002; Milsom et al. 2002; Eglington et al. 2008), but the success of wet feature installation as a technique for improving wader breeding success will depend on whether they provide the resources necessary for chick growth and survival and do not lead to a proportionately increased predation risk. Here we explore how wet features influence invertebrate abundance and the foraging rates and condition of northern lapwing chicks in an area of wet grassland in which managed wet features have been extensively installed. Specifically, we address whether (i) invertebrates are more abundant around wet features than within the surrounding grazing marsh; (ii) wet features provide areas where chick foraging rates are higher and (iii) chick body condition increases in areas of high wet feature density.

Materials and methods

STUDY AREA

The study was carried out on managed wet grasslands within the Broads Environmentally Sensitive Area (ESA) in eastern England (52°35’N 01°35’E, National Grid reference TG40) from March to July in 2005 to 2007. The Broads ESA is one of the few remaining large areas of wet grassland in Britain, extending over 43 000 ha of river valley, grazing marsh and fen. Whilst the Broads themselves (a series of man-made shallow lakes) are a unique feature of eastern England, their associated grasslands are typical of those found throughout lowland Europe. Nine study sites were selected within this area, comprising five sites managed by conservation organisations and four managed by commercial landowners. The study area consists predominantly of clay soils, with some small areas of peat soil. All sites were grazed with livestock (beef cattle or sheep) and had some level of water control. Grazing intensity (livestock units, LU ha⁻¹) varied across the study sites from 0.25 to 1.5 LU ha⁻¹, and towards the end of the breeding wader season many fields were mechanically cut. In this part of the breeding range, northern lapwing typically begin nesting at the end of March, and most first clutches are laid during April.

INVERTEBRATE SURVEYS

Six focal fields from each of six study sites (36 fields in total, mean ± SE area = 4.70 ha ± 0.3) were used to estimate the abundance of both ground-active and aerial invertebrates between 5 and 20 June 2006. The selected fields all contained examples of all types of wet features, and included both commercially managed sites (three) and sites managed for nature conservation (three).

As the primary aim of the invertebrate surveys was to compare abundance among different habitat features, sampling stations within each field consisted of one pitfall and one sticky trap located in one of each of five different habitat types (two types of wet features and three dry habitats): wet footdrain, dry footdrain, wet pool, dry pool and within the vegetated grazing marsh. Footdrain floods are areas where water overtops footdrains. Pools are unconnected areas of surface flooding. Pitfall and sticky traps were located on the wet mud at the edge of the water within wet footdrains and wet pools. Within dry pools and dry footdrains, traps were located on dry mud in the middle of the feature. The grazing marsh sample was located within the grazing marsh at least 10 m from any wet feature.

Ground-active invertebrates were sampled using plastic pitfall traps (depth 10 cm, diameter 7 cm) filled to a depth of ca. 4 cm with ethylene glycol and placed in the ground and covered with a metal grid (150 mm × 150 mm) to prevent capture of vertebrates. Each field was sampled once and traps were set in early morning and removed after 48 h, and the contents were counted and identified to the level of Order.

The biomass (ash-free dry mass, AFDM) of invertebrates on each habitat type was calculated by dividing each Order into four size classes (<2, 2–3, 3–5, 5–10 and >10 mm maximum body length) and the AFDM of 10 randomly selected individuals from each size class in each Order was measured and multiplied by the number of individuals in that size class. These figures were summed to give the total AFDM for each Order. The only exception to this was earthworms, for which so few were trapped that each was weighed individually. Individuals were dried in a ventilated oven at 55–60 °C to constant mass, then incinerated at 550 °C for 2 h, and the mass of the...
incinerated samples was subtracted from the dry mass to yield a measure of organic content.

Aerial invertebrates were sampled using sticky traps (20 cm × 10 cm, supplied by Oecos Limited, Kimpton, Hertfordshire, UK), which were secured on small canes at a height of approximately 10 cm above the ground. Sticky traps were set up at the same time as pitfall traps. After 48 h the traps were removed and the number of invertebrates on each trap was counted.

**CHICK FORAGING RATES**

Between May and July 2006, the foraging behaviour of northern lapwing chicks (aged between 2 and 35 days) was explored on 18 fields across four of the study sites (three managed for conservation and one commercially managed site). For each observation of an individual chick, the time taken to make 20 paces was recorded, along with the number of pecks made in the same period. This was repeated up to 10 times, or for as long as the chick remained in view, to obtain a mean peck and step rate per chick. When multiple individuals in a brood were present, one chick per brood was randomly selected for foraging observations. Individuals were observed only once per day and only five chicks were observed on two separate days. For each foraging observation, the habitat in which the chick was observed (grazing marsh or wet or dry footdrain or pool) was recorded.

As it was not possible to differentiate between successful and unsuccessful pecks, peck rate was used as an index of intake rate (total peck rates of northern lapwing chicks have previously been shown to be positively related to intake rates; McKeever 2003). The mean rate of biomass intake on each of the five habitat types was then estimated by multiplying the mean chick peck rate and the mean prey biomass within each of the different habitats. Mean prey biomass for each habitat was calculated by dividing the total AFDM by the total number of individual invertebrates for each pitfall sample (wet pools = 0.0032 g ± 0.0003 SE, wet footdrains = 0.0032 g ± 0.0002, grazing marsh = 0.0028 g ± 0.0002). This method assumes no active prey selection by chicks and is therefore only an estimate of the likely profitability of foraging in the different habitats.

**CHICK GROWTH AND CONDITION**

In each of the 3 years, the majority of chicks were ringed and marked with a numbered metal ring and leg flag in the nest, shortly after hatching. The body mass of chicks less than 100 g was recorded to the nearest 0.1 g using an electronic balance while heavier birds were weighed to the nearest 0.5 g using a pesola balance. Bill length (bill tip to feathering) was measured to the nearest 0.1 mm, using the formula from Galbraith (1988a); 

\[
V = 0.457LB^2
\]

Rainfall data were obtained from the archive of the British Atmospheric Data Centre (BADC) and were extracted from the climate station closest to the study site (Lingwood, 52°61'N 1°48'W, mean distance from all sites = 7 km ± 1 SE). Cumulative rainfall in the 7 days up to and including the day of chick measurement was calculated to explore the effect of environmental conditions on chick growth.

**WET FEATURE DENSITIES**

Wet features within each field from all study sites were digitised on MapInfo GIS maps produced from aerial photos using the Millennium Map 2000 (a full-colour aerial survey of the UK displayed as a raster image at 1:2 500 resolution). The digitised maps were checked in the field at the start of each season and any inaccuracies were corrected. Three types of wet feature were identified: (i) ‘footdrains’; (ii) ‘footdrain floods;’ and (iii) ‘isolated pools’. Densities of the three types of wet feature were calculated using field area data generated from MapInfo. These data were used in the analyses of chick condition.

**STATISTICAL ANALYSIS**

Variation in invertebrate densities and chick foraging rates among the five habitat types were analysed using analysis of variance with
post-hoc tests. All data were log-transformed to help normalise the distribution.

An index of chick body condition was calculated by fitting a logistic growth curve to the relationship between chick age and mass, where mass = \( a/(1 + T \times \exp(-k \times t)) \); \( a \) = asymptotic mass, \( T \) = age at inflection, \( k \) = growth coefficient and \( t \) = age. The difference between each actual mass and that predicted by the logistic growth model was calculated and these residuals were divided by the predicted mass to produce a standardized residual which formed the condition index. The condition index was calculated for chicks up to 40 days old, the age at which chicks would normally fledge (Cramp & Simmons 1983). The growth curve was fitted separately for each year, allowing us to compare growth rates across the 3 years of the study.

The effects of footdrain density, pool density, footdrain flood density, rainfall, hatch date, egg volume and year on the condition index of chicks were modelled using a Generalized Linear Mixed Model (GLMM) implemented using PROC GLIMMIX in SAS (SAS V9-1).

Two-way interactions between footdrain density and hatch date and footdrain flood density and hatch date were included in these models to explore the effect of seasonal reductions in the amount of water within each of these wet features. Chick identity nested within brood identity was included as a random term to account for non-independence of chicks within a brood and multiple measures of the same chick. Site was also fitted as a random term. A full-model approach was taken with all explanatory variables being entered into the model. We specified a normal distribution with an identity link function.

Results

INVERTEBRATE ABUNDANCE IN DIFFERENT GRAZING MARSH HABITATS

The biomass of surface-active invertebrates and the abundance of aerial invertebrates varied significantly across the five habitat types (Fig. 2). Wet footdrains and wet pools supported higher biomasses of surface-active invertebrates and more aerial invertebrates than the grazing marsh. There was a tendency for the abundance of surface-active invertebrates to show the same differences across habitat types (Fig. 2a), but this was not statistically significant (\( F_{4,181} = 0.83, P = 0.57 \)).

CHICK FORAGING RATES IN DIFFERENT HABITATS

Northern lapwing chicks were observed foraging in sufficient numbers for statistical analysis on only three of the habitat types. Only two chicks were observed feeding in dry pools and none were observed foraging in dry footdrains. Foraging rates were significantly higher in wet footdrains and wet pools than within the grazing marsh (Fig. 3a). The estimated biomass intake per food item also varied significantly across the three habitat types (Fig. 3b); wet pools had higher estimated biomass intake rates than wet footdrains and both were higher than grazing marsh estimated biomass intake rates.

CHICK GROWTH AND CONDITION

Chick mass increased with age following a typical logistic growth curve (Fig. 4) and this relationship was used to provide an index of chick body condition. Chick condition varied significantly across the 3 years of the study, with chicks in 2007 being in much poorer condition than the other 2 years (Fig. 5a; Table 1). Chick body condition was also negatively related to the amount of rainfall in the preceding week.
(Fig. 5b; Table 1) and positively related to mean egg volume (Fig. 5d; Table 1). There was a significant interaction between footdrain density and hatch date (Fig. 5c; Table 1) indicating that, at the start of the season, footdrain density had little influence on chick condition, but that later in the season condition was significantly higher in fields with a higher footdrain density. There was no significant effect of pool density or footdrain flood density on chick condition (Table 1).

Chick growth rates varied between years and the lack of overlap in the confidence intervals indicates that the growth coefficients were significantly lower in 2007 than in either 2005 or 2006 (Table 2). In 2007, two chicks had not fledged at 50 days. This is considerably outside the normal fledging period of 35–40 days (Cramp & Simmons 1983) and suggests that slow growth lengthened the pre-fledging period in this year. The high asymptotic mass in 2007 also suggests that few low-mass chicks survived in this year.

### Discussion

Wet pools and footdrains supported a greater biomass of terrestrial invertebrates and a greater abundance of aerial invertebrates (Fig. 2); chick foraging rates and estimated biomass intake rates were also higher in wet features than within the grazing marsh (Fig. 3). Chick condition varied little at the start of the season but, for chicks hatched after mid-May, body condition was significantly higher when chicks inhabited fields

<table>
<thead>
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<th>Variable</th>
<th>d.f.</th>
<th>F</th>
<th>P</th>
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<tr>
<td>Rainfall</td>
<td>1,1090</td>
<td>52.06</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Footdrain density</td>
<td>1,698</td>
<td>13.42</td>
<td>0.0003</td>
</tr>
<tr>
<td>Pool density</td>
<td>1,902</td>
<td>1.02</td>
<td>0.31</td>
</tr>
<tr>
<td>Footdrain flood density</td>
<td>1,803</td>
<td>1.31</td>
<td>0.25</td>
</tr>
<tr>
<td>Hatch date</td>
<td>1,772</td>
<td>13.97</td>
<td>0.0002</td>
</tr>
<tr>
<td>Hatch date × footdrain density</td>
<td>1,781</td>
<td>22.88</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Hatch date × footdrain flood density</td>
<td>1,776</td>
<td>0.35</td>
<td>0.55</td>
</tr>
<tr>
<td>Clutch volume</td>
<td>1,561</td>
<td>33.60</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Year</td>
<td>2,201</td>
<td>19.88</td>
<td>&lt; 0.0001</td>
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Significant factors are shown in bold.

Fig. 4. The relationship between chick age (days since hatching) and mass from 1754 measures of 901 individual northern lapwing chicks up to 40 days old from grazing marshes within the Broads between 2005 and 2007 (Mass = 157.6/(1 + 8.21 × exp(-0.11 × age))).

Fig. 5. Variation in the mean body condition index of northern lapwing chicks on grazing marshes in the Broads in relation to (a) year, (b) rainfall, (c) footdrain density (low footdrain density = <149 m ha\(^{-1}\); closed circles, high footdrain density = >150 m ha\(^{-1}\); open circles) and hatch date (early = hatched before mid-May, late = hatched after mid-May) and (d) mean clutch volume. For b and d, filled circles = 2005, open circles = 2006, filled triangles = 2007.
with high densities of wet features (Fig. 5). The installation of wet features thus appears to be highly effective at providing the resources necessary for foraging chicks, particularly in the latter half of the season. At temperate latitudes, winter rainfall typically results in high water levels on wet grasslands at the start of the breeding season, but water levels lower and wet features dry out as the season progresses (Eglington et al. 2008). Providing sources of water throughout the breeding season can clearly enhance conditions for chick growth and re-instating wet features in grasslands is therefore likely to improve wader breeding success.

THE IMPORTANCE OF WET FEATURES FOR CHICK GROWTH AND CONDITION

Previous studies have shown that northern lapwings and other waders exhibit a preference for nesting on habitats with wet features (Milsom et al. 2002; Gunnarsson et al. 2005; Eglington et al. 2008) and that these areas can provide benefits in terms of food abundance and foraging efficiency (Milsom et al. 2002; McKeever 2003). As the declines in many wader populations have been linked to reductions in productivity (Scheuckerman, Teunissen & Oosterveld 2009), the effectiveness of wet features depends on whether they are likely to enhance chick growth and survival. The higher invertebrate abundances and chick foraging rates found on wet features in comparison to the marsh and dry habitats in this study (Figs 2 and 3) suggests that prey are probably both more abundant and more accessible around wet features. The difference in peck rates between wet features and marsh habitats could reflect differences in prey encounter rates, for example prey may be present but harder to locate in vegetation, or the vegetation structure on the marsh may directly limit foraging efficiency (e.g. Whittingham & Markland 2002; Butler & Gillings 2004; Devereux et al. 2004). The edges of wet features provide substantial areas of wet mud and short vegetation, particularly as water levels recede, and so are likely to be ideal foraging areas for chicks. The high water levels associated with wet features can also impede vegetation growth (Ausden, Sutherland & James 2001), which may increase invertebrate accessibility further.

The length of time for which wet features retain water throughout the season also appears to influence chick growth and condition. At the start of the breeding season, surface water is often present in grasslands throughout the Broads, but effective drainage and warming temperatures mean that water levels rapidly drop and many areas of isolated surface flooding dry up, leaving footdrains as the main source of water (Eglington et al. 2008). The significantly better condition of chicks on fields with high footdrain densities late in the season suggests that these habitats provide key foraging resources for chicks that are not available elsewhere at this time of year. As a high proportion of northern lapwings on these sites re-nest following the loss of a first clutch, maintaining high footdrain densities may contribute substantially to the overall productivity of northern lapwings. This effect may be particularly apparent on the compacted clay soils that are common in this region, as limited lateral movement of water through these soils means that footdrains and high water levels in surrounding ditches are the primary means of maintaining water in field centres (Eglington et al. 2009a).

Interestingly, chicks in fields with high footdrain densities were in poorer body condition early in the season than later (Fig. 5c). This may be related to seasonal variation in temperature and invertebrate abundance (e.g. Beintema et al. 1991; Pearece-Higgins & Yalden 2002, 2004). Hence, there may be a trade-off between the increased survival rates often associated with early hatching (Galbraith 1988b) and reduced food availability and cooler temperatures early in the season.

Predation is a major source of wader chick mortality and chicks in poor condition may be more susceptible to predation (Evans 2004). Neither mammalian predator distribution nor the probability of nest or chick predation is influenced by wet feature distribution (Eglington et al. 2009b), however, predation risk for waders is highest during the pre-fledging period, thus the lower body condition of chicks in fields with low footdrain densities in the latter half of the season (Fig. 5c) may have increased their susceptibility to predation. Previous studies have shown that lapwing chicks in better body condition tend to have higher survival rates (Sharpe et al. 2009), and the lower growth rates of chicks in 2007 are also likely to have resulted in an increased length of pre-fledging period, which lengthens the time for which chicks are vulnerable to predation (Scheukerman et al. 2009).

EFFECT OF CHANGING WEATHER CONDITIONS

One of the main climatic changes predicted for temperate latitudes is an increase in the seasonality and intensity of rainfall (IPCC 2007). The significantly higher body condition of chicks in areas with high footdrain densities late in the season indicates the importance of providing water sources at a time when grasslands are generally drying out. However, high levels of rainfall can significantly reduce chick body condition (Fig. 5b), and the unusually high rainfall in May and June 2007 (when rainfall was approximately twice that recorded at the same time in the previous 2 years) is the likely cause of the greatly reduced chick condition in this year (Fig. 5a). Although this rainfall meant that water was retained within wet features later

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<th>2005</th>
<th>2006</th>
<th>2007</th>
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<tr>
<td>Growth coefficient</td>
<td>0.12 (0.115–0.125)</td>
<td>0.12 (0.113–0.126)</td>
<td>0.08 (0.077–0.089)</td>
</tr>
<tr>
<td>Age at inflection (days)</td>
<td>9.84 (9.22–10.46)</td>
<td>7.44 (7.01–7.87)</td>
<td>10.74 (9.53–11.95)</td>
</tr>
<tr>
<td>Asymptotic mass (g)</td>
<td>182.5 (171–193.8)</td>
<td>148.2 (141.8–154.6)</td>
<td>201.3 (176.9–225.6)</td>
</tr>
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</table>

Values in parentheses show 95% confidence limits.
into the season, the prolonged, heavy rainfall is likely to have reduced the time available for feeding, particularly for young chicks, which are not capable of thermoregulation and therefore require cover from the parent during times of wet or cold (Beintema & Visser 1989). In these conditions, chicks often show retarded growth and poor body condition, and may eventually die of starvation (Baines 1990; Pearce-Higgins & Yalden 2002). Future management of wet grasslands for breeding waders is likely to be greatly influenced by the quantity and timing of rainfall; too little rain during the breeding season will greatly reduce prey availability and too much may directly reduce chick survival.

Conclusions

The installation of shallow wet features in the management, and re-creation of lowland wet grasslands, is likely to benefit the productivity of northern lapwing populations, as they support higher densities of invertebrate prey and provide better foraging conditions for chicks than the surrounding vegetation. These wet features are of particular importance later in the season when they are likely to be the main source of water in the landscape. Provision of wet features is likely to be increasingly important if the changing seasonality of precipitation in temperate Europe makes summer drought conditions more frequent, while periods of heavy rainfall can also greatly reduce chick condition. Managed wet features provide a mechanism to buffer against periods of low rainfall, ensuring densities of invertebrate food remain high, even when surrounding areas become dry. Chicks with access to wet features are thereby able to grow rapidly and maintain good body condition that may help them survive during periods of heavy rainfall which preclude foraging, and which could compromise the survival of poorly nourished chicks.

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