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Towards a better understanding of predation on breeding meadowbird populations

Phase1, Year 2: Monitoring wader nest success in relation to predation at Stanny House Farm

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EXECUTIVE SUMMARY

- A total of 53 nests were located and marked, 32 in 2012 and 21 in 2013. A temperature sensor (iButton) was placed in the nest cup of all nests.
- Seven nests were also monitored using a nest camera in 2012, and five in 2013.
- The mean clutch size was 3.71 eggs in 2012 and 3.83 in 2013, within the average indicated by the Nest record Scheme (NRS) long-term data 1966-2012.
- The number of nests was not equally-distributed across fields in 2012 and 2013, but no fields contained more nests than others.
- The number of nests found in each field each year varied across the period 1989-2013.
- Field 2 had increasingly more nests between 1989 and 2011, whilst F11, F12a and North field had fewer, although the nest-searching effort between years varied and might have biased the results.
- The number of nests within fields in 2012 or 2013 did not relate to rain fall in January, February or March, considered the months potentially affecting the decision of the birds on where to nest.
- In 2012, sixteen nests hatched successfully (52%) and 15 failed (48%), four of which were monitored with cameras. In 2013, 11 nests hatched (52%) and 10 failed (48%), including two monitored with cameras. No predation event was caught on camera in 2012, but in 2013 cameras produced images of Carrion Crows predating nests in both unsuccessful nests monitored with this equipment.
- Failure in 2012 occurred predominantly at night (63%) indicating predation by mammals, whilst 90% of nests in 2013 failed during daytime, suggesting avian predation (Carrion Crow).
- Nest failure did not differ between fields; it was not correlated with number of nests within a 100 metre radius, nor to their proximity to the nearest field margin in either year.
- Hatching success was positively correlated with rainfall in 2012 but showed no significant correlation in 2013.
- Future studies should continue to concentrate on nest failure but also investigate post-hatching success. In particular, on the fate of Lapwing chicks through radio-tracking studies. Causes of breeding failure in other waders, such as Redshank, should also be investigated.

INTRODUCTION

Many breeding wader species have undergone dramatic declines in the last 30 years (Piersma 1986; Brindley *et al* 1998; Wilson *et al* 2005). In England, wet grassland breeding waders such as Redshank *Tringa totanus*, Lapwing *Vanellus vanellus* and Snipe *Gallinago gallinago* have declined by 29%, 38% and 61%, respectively, between 1982 and 2002, and 64% have become restricted to a few key areas (Wilson *et al* 2005). These population declines are associated with habitat loss due to drainage and intensification of grassland management (Wilson *et al* 2004). Whilst re-introduction of wet features is one of the key elements for management (Smart *et al* 2006; Eglington *et al* 2009; Eglington *et al* 2010), it has been suggested that an increasing predation rate of nests and chicks is also an important component in the decline of wader populations (Chamberlain & Crick 2003; Milsom 2005).

Lapwing decline started in the mid-1980s (Baillie *et al* 2011) (Fig 1). A BTO/RSPB survey in England and Wales in 1998 revealed a population decline of 49% between 1987 and 1998 (Wilson *et al* 2001), whilst a survey in Northern Ireland revealed over 60% decline between 1987 and 1999 (Henderson *et al* 2002). In lowland wet grassland in England and Wales decline reached 38% between 1982 and 2002 (Wilson *et al* 2005). The main cause of decline appears to be reduced breeding productivity due to habitat loss and degradation associated with intensification of farming (e.g. Galbraith 1988a; Shrubb 1990; Hotker 1991; Hudson *et al* 1994; Siriwardena *et al* 2000; Taylor & Grant 2004; Wilson *et al* 2005; Milsom 2005; Fuller & Ausden 2008).

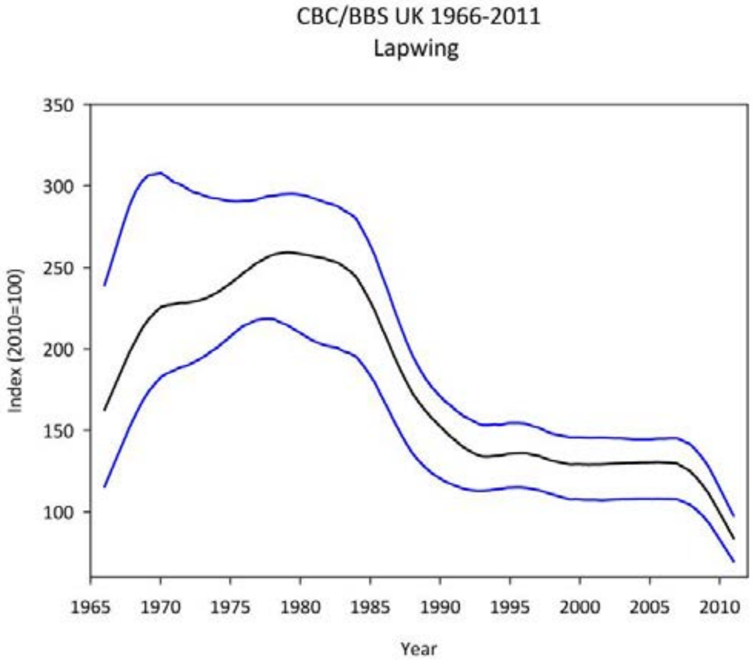


Figure 1. Abundance trend for breeding Lapwing in the UK 1966-2010. Data from Common Bird Census and BTO/JNCC/RSPB Breeding Bird Survey. The blue lines indicate the 85% confidence limits (Reproduced from Baillie *et al* 2012).

Winter counts from the Wetland Bird Survey (BTO/Royal Society for the Protection of Birds/Joint Nature Conservation Committee (JNCC) (in association with the Wildfowl and Wetlands Trust)) showed an increase in Lapwing on coastal sites in Britain in the 1980s and 1990s, but the same survey is now showing a rapid decline (Holt *et al* 2011). Lapwing is also experiencing strong declines in Europe (PECBMS 2009, 2011). The decline of the Lapwing in the UK appears to be related to decreased productivity (Peach *et al* 2004), with decreased hatching and fledging success both having been suggested as a mechanism (Sharpe *et al* 2008; Shrubb 2007). Data from the BTO/JNCC Nest Record Scheme (NRS) suggest clutch size has been constant between 1966 and 2012 (Fig 2a), while failure at egg stage has increased over the same period (Fig 2b).

Lapwing eggs and chicks are targeted by both avian and mammalian predators including Carrion Crow (*Corvus corone*), Grey Heron (*Ardea cinerea*), raptors, Red Fox (*Vulpes vulpes*), and mustelids (e.g. Seymour *et al* 2003; Bolton *et al* 2007; MacDonald & Bolton 2008; Teunissen *et al* 2008; Amar *et al* 2010; Bodey *et al* 2011). Predation rate at the egg-stage can vary across years and habitats (e.g. Bolton *et al* 2007). Radio-telemetry studies have suggested that predation is an important factor in chick survival, and 60-87% of wader chick mortality is due to predators (Grant *et al* 1999; Junker *et al* 2004; Schekkerman *et al* 2009). An experimental exclusion of ground predators using electric fences in Switzerland and radio-tracking of chicks showed that survival of chicks to fledging was higher within than outside fences, especially at night, suggesting that foxes were important predators of chicks (Rickenbach *et al* 2011).

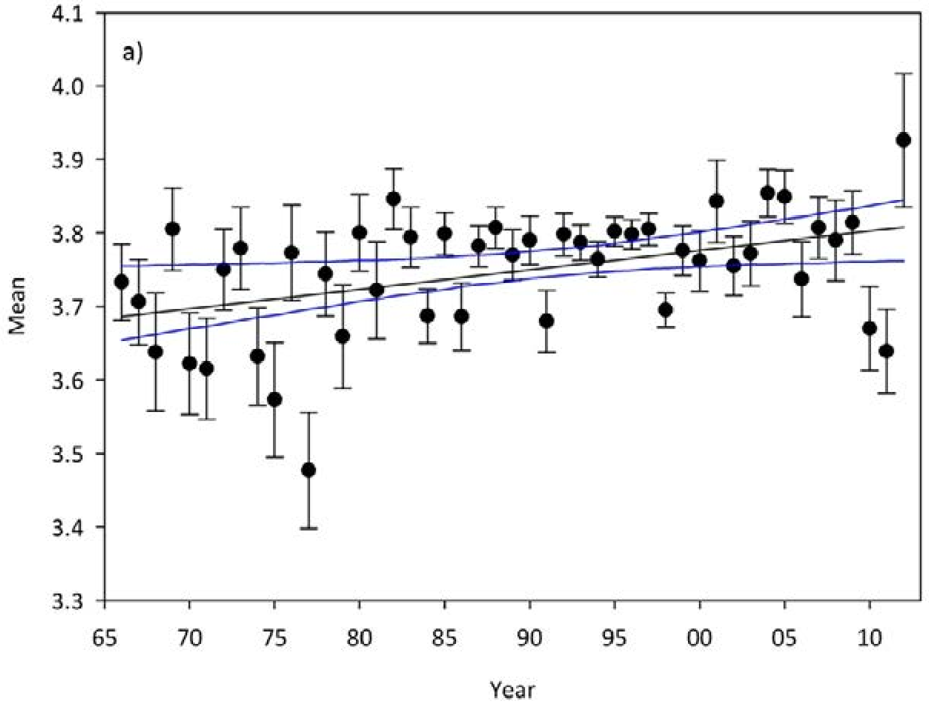
The present study investigated Lapwing breeding success and the effect of predation through the incubation period. Cameras placed at a sample of nests aimed to identify nest predators, whilst temperature sensors were used more widely to determine the timing of nest failure, thus indicating the type of predator involved on a larger scale than nest cameras. Habitat features such as distance to field edge/ditch were recorded at every nest, and measurements of density of other waders in the field were also noted. Analysis of these data in relation to successful/predated nests examined any patterns in predator habitat use.

Objectives

1. To assess the distribution of nests within the study area.
2. To identify the main cause of nest failure in Lapwing (i.e. predation, desertion, flooding).
3. To identify the main predator of wader nests and stage at which predation occurred.

Hypotheses

1. The number of nests is not equal across all fields.
2. The total number of nests varies between years and across fields.
3. The distribution of nests across fields varied between years according to rainfall.
4. Failure at egg-stage occurs predominantly at night (indicating mammalian predators).
5. Failure at egg-stage is more frequent in early and late breeding attempts.
6. Failure at egg-stage decreases with an increased number of pairs in the same field.
7. Failure at egg-stage is higher in the proximity of field margins.



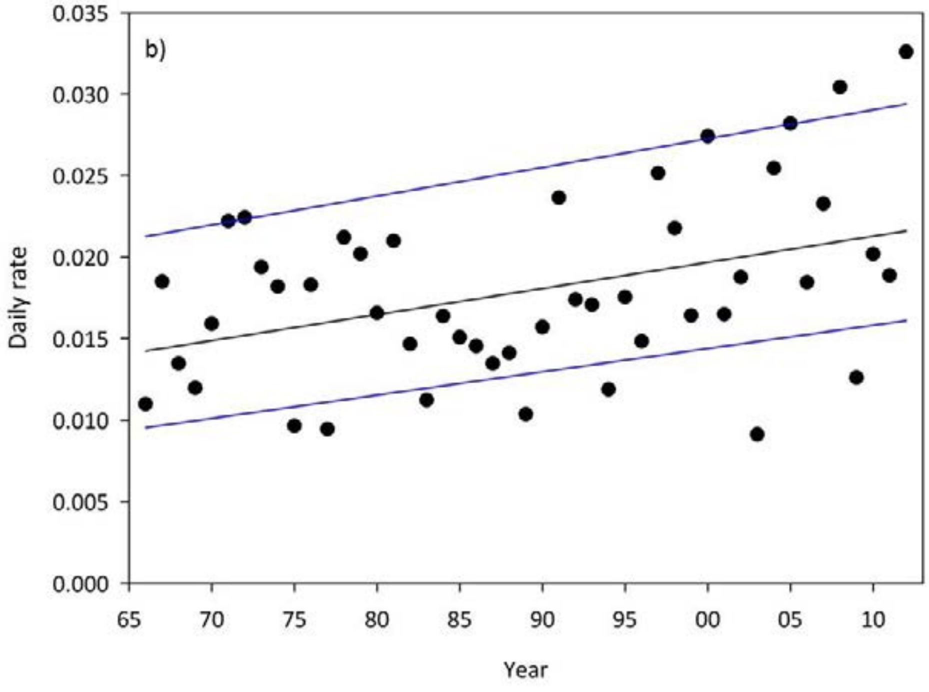


Figure 2. Mean number of eggs per nest (a) and daily failure rate during incubation (b). Black lines indicate long-term trends, blue lines indicate 95% confidence intervals. Data from the BTO/JNCC Nest Record Scheme (www.bto.org/birdtrends).

METHODOLOGY

Study site

The study was conducted at Stanny House Farm near Iken, Suffolk, UK (TM 432554). The site is privately owned and consists of coastal wet grassland (Fig 3) for which management includes grazing sheep. However, livestock are excluded from fields where Lapwings are known to nest until their breeding season is over. The study site was divided into 16 fields which follow approximately the natural division created by the presence of ditches between fields (Fig 4). Predator control is carried out non-systematically on Red Foxes and Carrion Crows. Other potential predators on the site are Marsh Harrier (*Circus aeruginosus*), Grey Heron and Kestrel (*Falco tinnunculus*), as well as other potential mammalian predators such as small rodents and Hedgehog (*Erinaceous europaeus*).

Figure 3. View over F8. The site is characterised by wet grassland (Photo: Rodney West)

Monitoring Lapwing abundance

A survey of breeding Lapwings was carried out following the methodology of Bolton *et al* (2011). In summary, five visits were made at approximately three-week intervals between the middle of March and early July, with each taking place between 10 am and 4 pm. Adults were counted to establish breeding population size (visit 1 to 3 – Appendix 1a &b), as well as adults with chicks, families and number of chicks at different growth stages (newly-hatched, part-grown, well-grown and fledged) to establish productivity. Each of the five survey visits at each field was no longer than 30 minutes, in order to keep a constant observation effort between visits and avoid biasing the results towards an increased number of birds counted with increased observation time.

Nest location and clutch size

In 2012, nine of the 16 fields (Fig 4) were searched systematically by teams of four to seven people walking them in a line over four dates between 7 and 15 April (Table 1a). The other fields were not surveyed in the same way due to lack of people available to survey the field quickly to minimise disturbance to nearby existing nests. In 2013 a similar approach was used, but a further field to the west, 'Pump field' (Fig 4), was also monitored for nests by 'walking' it (Table 1b). Nests in the remaining fields were located by observers scanning for sitting birds from the field edges who could then guide a second observer to the nest site. This technique was used for all fields later in the season to minimise disturbance.

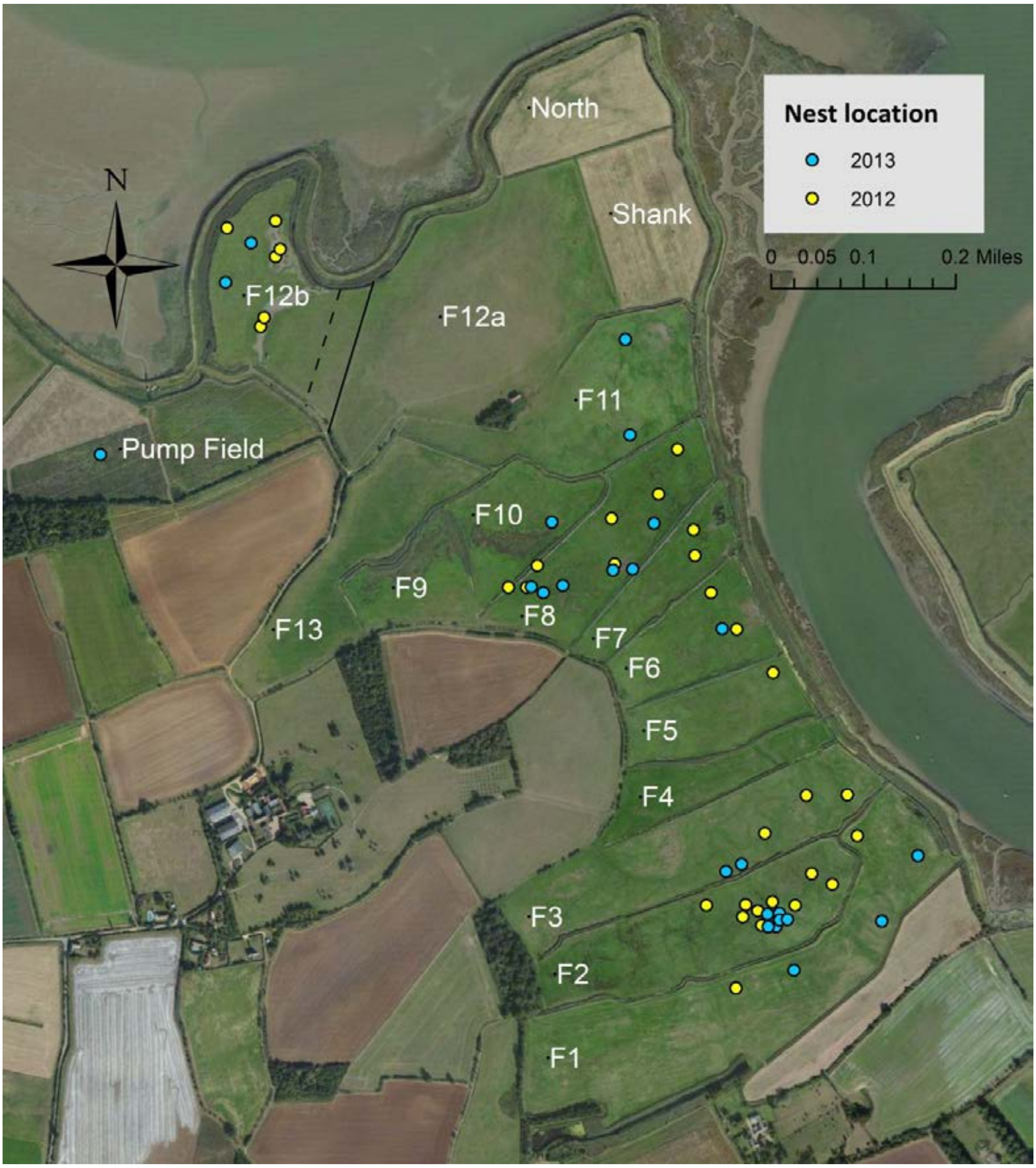


Figure 4. Nest locations in 2012 and 2013 and name of each field. The black lines between F12a and F12b demarcate the fence that constituted the boundary between fields in 2012 (solid line) and 2013 (dashed line).

Table 1. Date, team size and effort (in hours/visit) of field surveying using the 'walking the fields' method in 2012 (a) and 2013 (b). Note the late start in 2013 which due to inclement weather moving the breeding season forward two weeks.

(a)

Date of visit	Team size (people)	Effort (approx. time spent per day) (hours)
7 April	7	5
11 April	4	4
14 April	7	5
15 April	6	5

(b)

Date of visit	Team size (people)	Effort (approx. time spent per day) (hours)
20-Apr	5	4
21-Apr	7	4
24-Apr	3	2
26-Apr	3	2
27-Apr	4	3
28-Apr	2	1
03-May	3	1
04-May	2	1
06-May	3	1
16-May	3	2
01-Jun	2	2
03-Jun	2	2

Each nest location was marked using a bamboo stick placed 20 metres to the north to avoid attracting predators, as suggested by Galbraith (1987). Nest location was recorded with a GPS (Garmin) and coordinates used to re-locate the nests and to plot them on a map. Nests were checked every four days. However, if a single visit to an individual field reached 30 minutes, all activities were stopped and the field was vacated for the rest of the day to minimise disturbance to breeding birds. For this reason some nests in 2012 were not checked for over a week, although the mean among those that were not visited every four days was seven days (±2 days). However, five nests that did not have a camera on were left unchecked for up to three weeks to avoid disturbance to nearby nests that had already been checked within the allocated time (nest 1 in F3 (15 days), nest

30 in F5 (16 days), nest 27 in F8 (20 days)), or disturbance to the Avocet colony (nest 6 in F12b and nest 11 in F12b (16 days)).

During the systematic search Redshank nests were occasionally located and marked.

All maps and distance between points were plotted in a Geographical Information System (GIS), using ArcMap v.10.0 (ESRI). Maps of nest location for the periods 1989 to 1992, 1995 to 2001 and 2004 to 2011 were provided by Rodney West and were used to test whether some fields were preferred historically by Lapwings. From each map it was possible to obtain the number of Lapwing nests in each year.

The clutch size was recorded at each nest and at each visit, together with whether the eggs were cold of warm (indicating that they had been incubated and hence the clutch was complete).

Nest cameras

Nest cameras can provide detailed information on the identity of predators. Seven nests were monitored via camera throughout the site in 2012 and five in 2013. In 2012 the two types of cameras deployed were: digital video cameras (DTV 2 channels Mini SD Card DVR) (three cameras available) and trap cameras (Bushnell trophy Camera HD) (two cameras available), whilst in 2013 the trap cameras were substituted with another model of digital camera designed by RSPB.

The Bushnell trail cameras were self-contained and powered by four AA batteries. They were mounted on a wooden stick *circa* 1.5 metres from the nest and set to take photographs when activated by the movement sensor. The first digital cameras, which have been used in previous BTO projects, including monitoring of Stone Curlew nests, consisted of a Sunkwang Miniature Camera, containing motion sensors, connected via a 15-metre cable to a recording unit, which saved footage to a 16GB SD memory card. The camera was mounted on a camouflaged stick 60 centimetres high and which was placed in the ground at approximately 1.5 metres from the nest to minimise the risk of potentially attracting predators, although some studies have found that the opposite may be true (reviewed in Richardson *et al* 2009). The second type of digital camera, deployed only in 2013, was similar to the first model, but was placed at 25 centimetres from the ground and 40 centimetres from the nest (Fig 5) and smaller area for the triggering of the recording sensor was set compared to the first camera type. The cameras could also detect and record night-time activity. Each lens had a small shading canopy surrounding it to protect it from bright sunlight and rain. The recording device was powered by two 12V rechargeable lead-acid batteries, replaced every four days, and placed in a camouflaged plastic box at least five metres away from the nest. The box was partially dug into the ground to make it as inconspicuous to Lapwings and predators as possible and the cable was camouflaged. All the cameras could detect activity in the dark.

Before leaving the field completely, the adult was observed to confirm that it had returned to the nest were the camera had just been placed. The choice of which nest to monitor with the camera was not random between fields. Selected nests ideally had to be at the pre-incubation period, because probability of nest failure decreases the later in the incubation period the nest is monitored (Mayfield 1961), but if the nest had been found later in the season, the camera was still placed as soon as the nest was located and a camera was available. Furthermore, nests in field that were not already being monitored were preferred, in order to cover as much of the site as possible.

Figure 5. Second model of digital video camera used in 2013. The lens is set closer to the ground and to the nest than the first model, therefore the area of focus of the lens could also be restricted to avoid non-target objects activating the recording sensor. (Photo: Mark Bolton)

Temperature sensors

Temperature readers were used to ascertain the time of nest failure, and so provide information about the identity of potential predators, as avian activity is generally limited to daylight hours. Maxim's iButtons DS1921G (iButtons from here on) were used to investigate time of nest failure in both years. Each iButton was programmed to take a reading every 30 minutes, thus accommodating the period from egg-laying to hatching within the memory limits of the device. In 2013, two iButtons were used in three nests (SEG15/40 in F1 on a Lapwing nest, SEG16/39 in F2 on a Lapwing nest and SEG33/34 on F6 on an Oystercatcher nest) and programmed to take a reading every 10 minutes, to estimate with greater precision when the bird was leaving the nest and for how long. Previous authors had found that temperature loggers can be removed by the sitting adult or a predator (Hartman & Oring 2006), therefore it is essential to secure the iButton to the nest. In 2012 each temperature reader was covered in a thin plastic mesh and secured to a 67 millimetres metal nail using wire, whilst in 2013 each iButton was attached to the nail using epoxy adhesive glue which was less labour-intensive than the plastic mesh technique, but was still effective. When a nest was found, eggs were lifted carefully and the nail with the attached iButton was pushed into the ground in the centre of the nest cup. The iButton was then covered by a few strands of nest material, reducing its visibility and preventing the hard edges damaging the eggs, but allowing the temperature to be recorded accurately (Fig 6). A single iButton was also inserted in 2012 in one of the central fields to record ambient temperature on the site, whilst in 2013 four iButtons, two in each of two fields at either side of the site, were placed in the ground to take background temperature.

Each iButton trace was interpreted for success or failure using a combination of methods: i) camera evidence; ii) nest visits – change in nest contents indicated laying dates and from it hatching date could be estimated; iii) ambient and nest temperatures were plotted together to identify time of day when final drop from elevated nest temperature to ambient had occurred (Fig 7); iv) date of point (iii) was related to range from NRS data to identify failures which occurred early in the season; v) remnants of small pieces of egg shell were also used to identify hatching success, following the findings of Green *et al* (1987). Fragments present in the nest were approximately 1-3 millimetres long and 1-2 millimetres wide, and were often partially covered by some nesting material, which did not differ in appearance from when the eggs were present (i.e. no signs of disturbance) (Fig 8).

Predicted hatching date

Hatching date in both years was estimated using data from the BTO Nest Record Scheme, and in addition in 2013 the hatching date for each clutch was predicted by estimating the density of egg days following the formulae developed by Galbraith (1988b):

Days until hatching= 150.84 x egg density – 140.68 (Equation 1)

In which:

Egg-density= mean egg weight/mean egg volume (Equation 2)

In which

Egg volume = length x breadth^2 x 0.457 (Equation 3)

For each egg, the length and breadth were measured, and a note taken of the nest number (identified by its iButton and field number) and the date of the measurement. This measurement was used to identify whether an empty nest had likely hatched or been predated, according to whether the date of the event had occurred three days either side to the predicted hatching date (Fig 9).

Estimated hatching success and productivity from survey visits

Hatching success was estimated using the equation suggested by Bolton *et al* (2011):

Hatching success % = 17.98 * maximum count of families/pairs + 24.66 (Equation 4)

in which the maximum counts of families and pairs were obtained during the five visits to monitor Lapwing abundance.

Productivity was estimated by dividing the total number of well-grown and fledged chicks across all visits by the number of pairs.

Rainfall data

Rainfall was calculated as the average monthly rain (in mm), taken from daily rainfall data, for each of three months: January, February and March (encompassing the period when most pairs chose their nest site (Shrubb 2007)) of the same year. Data on rainfall were downloaded from the nearest weather station with historic data (Aldeburgh), situated about seven kilometres from the study site.

Figure 6. Installing an iButton in a nest. The nail was pushed in the ground so that it would not damage the egg, and the temperature sensor was covered with a thin layer of grass to disguise the iButton and cushion the eggs, which were then replaced in the nest. (Photo: Maggie Grenham)

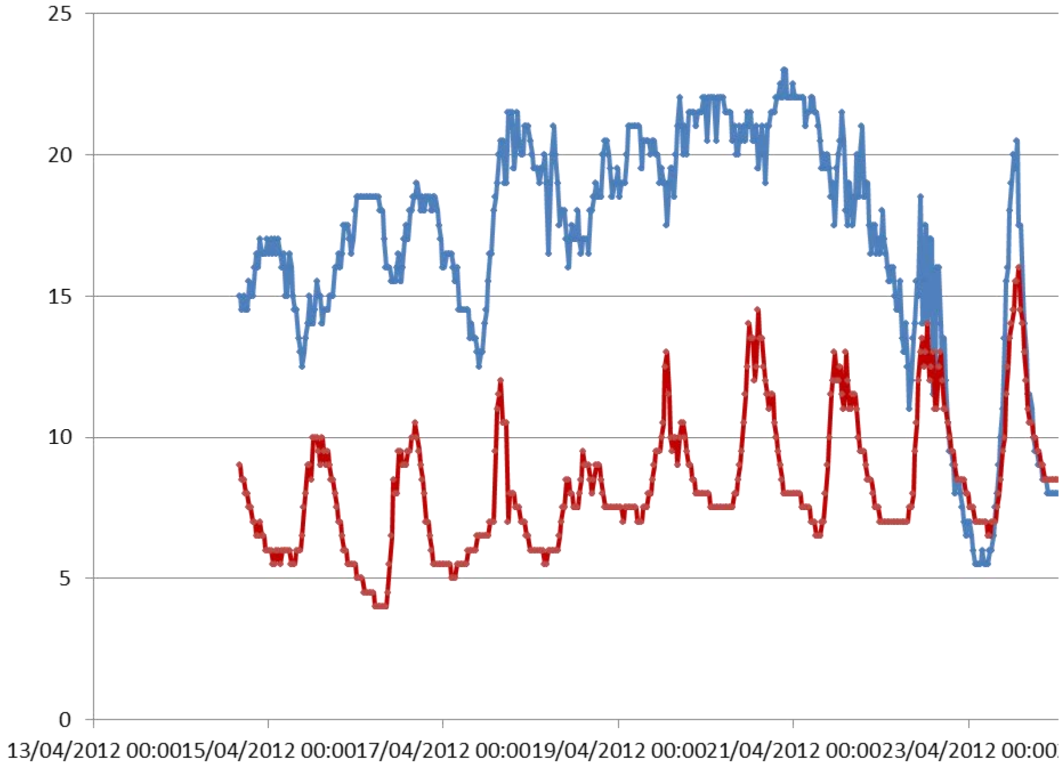


Figure 7. Example of a failed nest. The iButton trace of the nest (blue line) meets ambient temperature (red line) at night, indicating nest failure, as chicks do not leave the nest at night (Shrubb 2007).

Figure 8. a) Egg fragments found in nests with hatched eggs in 2012; b) chicks that died probably following a hail downpour in 2012, but note the egg fragments produced by the hatching chick. (Photos: Maggie Grenham)

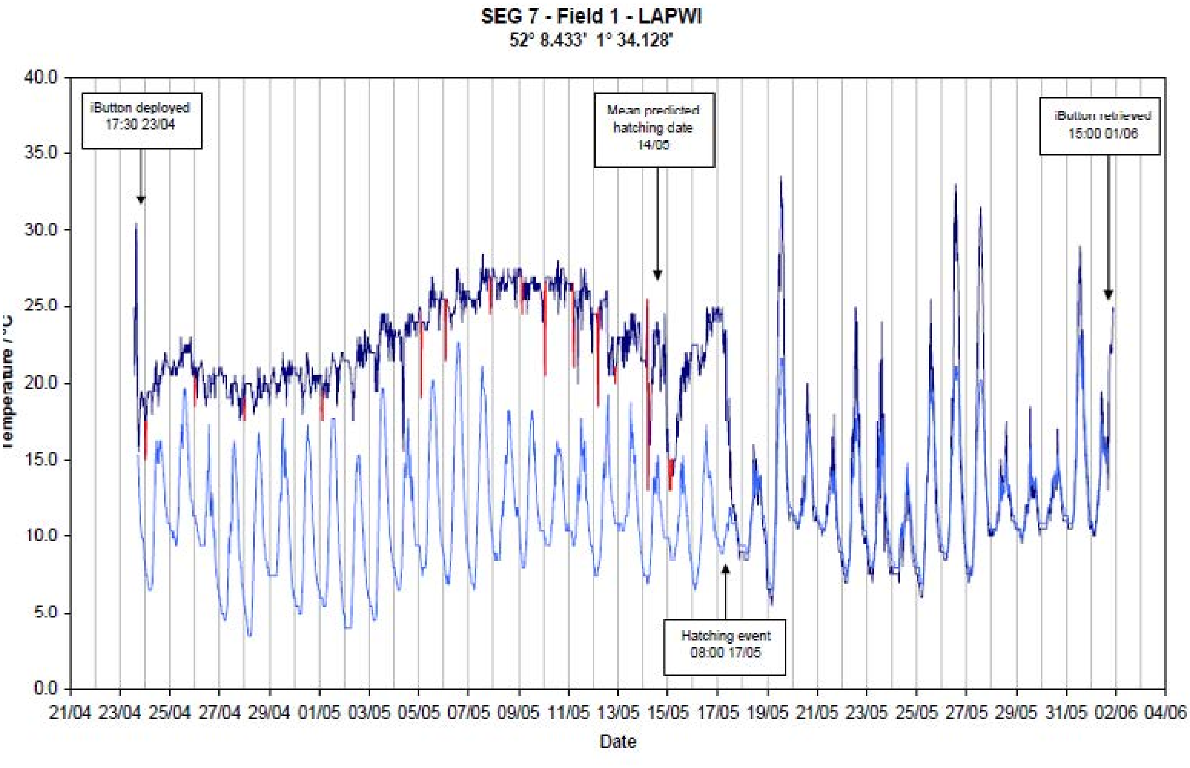


Figure 9. IButton trace (dark blue line) and background temperature data (light-blue line) for one of the nests monitored in 2013. The mean predicted hatching date following Galbraith (1988a) and the actual hatching date are shown on the graph.

Statistics

Nest location

Variation in the number of nests between fields in 2012 was calculated with a X^2 test. The difference in size between fields was controlled for by multiplying the number of nests in each field by the proportion of the area occupied by that field over the total study area. Fields that departed from the expected value were identified based on their relative contribution using their residuals from the X^2

test and the threshold value for the X^2 distribution. Fields preferred over the years were also investigated, using historic data (see 'Nest location' section above). A variable that included the number of nests in each field per each year was used as response variable in a Generalised Linear Model (GLM), with year (as a continuous variable), field identity and their interaction (to take into account the increased nest search efforts in later years) as explanatory variables, with differences in size of fields (indicated as logarithm of the area) accounted for; Poisson error distribution was specified. The significance of the interaction between field identity and year was tested using a 'step-down' regression method by comparing the model with and without the interaction term.

Fields preferred within each single year were tested with a separate GLM for each year, using the number of nests found in each field as response variable, field identity as explanatory variable and controlling for the different size of each field (indicated as logarithm of the area) with Poisson error. A full model was constructed with number of nests as response variable, and field identity, year, the three rain categories (January, February and March), and their interaction with field identity as explanatory variables, specifying Poisson error. The model was simplified using a step-down regression method.

Failure at egg stage

Difference in hatching success across fields was investigated using a GLM model, specifying binomial errors and using a logit link function, with proportion of nests failed as response variable, and field identity as explanatory variable. Distance from ditches was calculated in ArcMap (version 10) using the measuring tool based on British National Grid. Distance in metres to the nearest ditch was used as explanatory variable in a GLM model which had nest outcome (failure or success) as explanatory variable and binomial error distribution. The relationship between hatching success and progress of the breeding season was investigated by correlating the proportion of failed nests in all fields at weekly intervals with week, and its quadratic value to reflect the non-linear relationship, as explanatory variables and binomial as error. The variables were analysed using a GLM with number of active nests on each day as weight to control for this variable, and binomial errors. The effect of group size within a field on hatching success was tested by using the proportion of failed nests as response variable and number of active nests in the field and day of the breeding season as explanatory variables, with error family binomial. The effect of mean rainfall on hatching success was calculated with a GLM model with proportion of failed nests as response variable and amount of daily rain (in cm) as explanatory variable, with number of active nests as weight to control for bias; binomial error distribution was specified. Time of day (24-hour cycle) was defined as 'day' (one hour after sunrise to one hour before sunset, as indicated in www.timeanddate.com), 'night' (one hour after sunset to an hour before dawn) and two twilight periods: one hour before and after sunrise for morning twilight, and one hour before and after sunset for the evening twilight. Differences in time of day at failure was calculated using a GLM, in which the observed number of nests failing in each day category was used as the response variable, and time of day as explanatory variable, with Poisson error. The residual variance was then compared to the critical chi-square value for the appropriate degrees of freedom indicated in the GLM output.

All analyses were carried out in R 2.15.0 (R Development Core Team 2012).

RESULTS

Monitoring Lapwing abundance

During the survey visits between mid-April and mid-May in 2012 64 adult Lapwings were seen, which translated to 32 pairs, but no families or newly hatched chicks were seen and a total of only five well-grown chicks were counted during the five visits (Appendix 1a). The hatching success as devised by Bolton *et al* (2011) could not, therefore, be calculated as no families were recorded, either because all chicks had died (unlikely as well-grown chicks were recorded), the chicks had moved from the site, or the habitat was not suitable for this method (see 'Discussion'). However, counts of adults reflected the number of nests found, therefore the method provided results for adult abundance.

The maximum adult count in 2013, between visit 2 and visit 3, the key visits suggested by Bolton *et al* colleagues (2011) to establish breeding population numbers, was 43 adults (Appendix 1b), suggesting 22 pairs. The maximum count of families was two, therefore hatching success was 26.29%, using Equation 4. The number of well-grown and fledged chicks across all visits was 24, suggesting a productivity of 1.09 chicks per pair.

Nest location and clutch size

A total of 32 Lapwing nests was located in 2012 (Fig 4). Eighteen nests were found when the clutch was complete (indicated by warm eggs), and the remaining 14 were found as incomplete clutches (fewer than three eggs and/or cold). The mean clutch size was 3.71 eggs (standard error 0.031, n=28), slightly lower than the 3.93 eggs at a national scale in 2012 from NRS data, but similar to the long-term (1966-2012) NRS mean of 3.75 eggs (± 0.04, n=47) (Fig 10).

In 2013, 21 Lapwing nests were located (Fig 4), 16 of them as full clutches and five incomplete. The mean clutch size was 3.83 eggs (standard error 0.034, n=21), and whilst data at the national scale have not been compiled yet for 2013 and therefore a direct comparison is not possible, the Stanny House Farm 2013 average was higher than the long-term NRS mean.

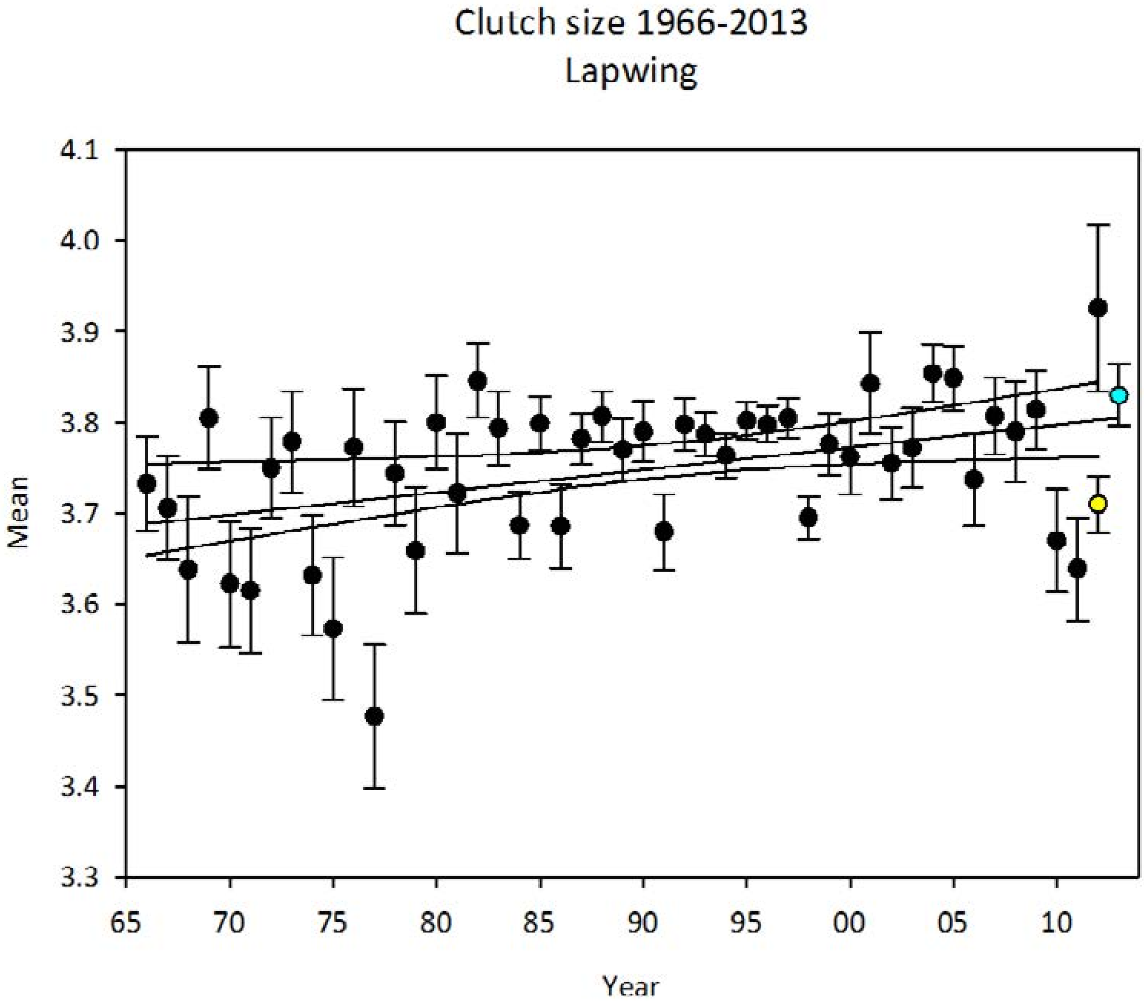


Figure 10. Mean clutch size (and standard error) of Lapwing nests at Stanny House Farm in 2012 (yellow dot) and 2013 (blue dot) in relation to the mean (and standard error) clutch size of Lapwings in the UK based on NRS data from 1966 to 2013. The 2013 NRS average is a preliminary figure based on a small sample size.

Field preference

There was an uneven distribution of nests across fields in 2012 (X^2 =50.01 , p<0.001, df=15) and 2013 (X^2 =41.36, p<0.001, df=16). However, none of the fields contained more nests than others as none of the fields' residuals met the formal threshold for significance of 24.99, based on the critical values of the X^2 distribution table with 15 degrees of freedom (Table 2) in 2012 and 16 degrees of freedom in 2013. There was no significant difference in number of nests between fields in 2012 nor 2013, once size of field was taken into account. Within each year in the period 1990-2013 some fields contained more nests than others (Table 3, row-wise). The interaction between year and field was strongly significant in explaining variation of nests across fields between years ($F_{304,319}$=-76.77, p<0.01) (Table 4), but only F12a and North field differed significantly and contained fewer nests as years progressed (Table 5). In terms of rainfall, none of the three rain periods (January, February and March) explained the difference in nest number across fields in 2012 or 2013.

Table 2. Residuals of the X^2 test on number of nests in 2012 and 2013. No fields contained more nests than others, as no values reached the critical value of 24.99 based on 15 degrees of freedom of the X^2 table.

Field	Residuals 2012	Residuals 2013
F1	-1.0337	-0.7104
F2	4.771035	-0.7076
F3	0.168899	-0.2899
F4	-1.02574	-0.2896
F5	-0.01055	-0.25903
F6	0.423585	-0.0966
F7	1.221549	-0.0913
F8	2.683268	-0.02693
F9	-0.95762	0.066671
F10	-1.26974	0.235424
F11	-1.38116	0.27422
F12a	-1.77131	0.31911
F12b	1.850628	0.352127
F13	-1.49859	0.673821
North	-1.24554	0.716461
Shank	-1.19852	0.82056
Pump	na	-0.7104

Table 3. Summary of changes in nest number between fields between 1990 and 2013. Significant changes were considered if $p < 0.05$. Significant changes are in bold with an asterisk.

Year	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12a	F12b	F13	Nth	Shnk	Tot	X^2
1990	0	0	0	0	1	0	0	0	0	0	1	2	0	0	0	0	4	17.61
1991	0	1	0	0	1	**3***	0	0	0	0	1	2	0	0	0	0	8	**25.15***
1992	1	0	0	0	0	0	0	2	0	0	1	4	1	0	0	1	10	16.43
1995	0	0	0	0	0	0	0	0	0	0	**3***	**4***	**3***	0	2	1	13	**27.82***
1996	1	0	3	0	0	0	0	0	0	0	0	4	3	0	2	0	13	23.38
1997	4	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	7	18.08
1998	2	2	1	0	1	0	1	2	0	0	0	0	0	0	0	0	9	14.82
1999	4	0	3	0	0	0	0	0	0	0	3	5	3	0	0	0	18	23.21
2000	3	2	0	0	0	0	1	0	1	0	2	3	3	1	0	0	16	14.60
2001	**7***	1	3	0	0	0	2	4	0	0	3	0	4	0	0	**4***	28	**26.77***
2004	2	**6***	2	0	2	4	2	**7***	0	3	1	0	1	1	0	0	31	**33.56***
2005	7	0	5	2	0	**6***	**4***	4	2	4	2	0	5	0	0	0	41	**35.64***
2006	4	5	2	0	3	3	0	**7***	1	3	0	0	3	1	0	0	32	**28.05***
2007	3	**7***	4	0	2	**5***	3	4	0	4	4	0	3	0	0	0	39	**33.04***
2008	6	4	4	0	**4***	**6***	1	7	0	3	4	0	3	0	0	0	42	**31.90***
2009	5	6	3	0	2	3	1	3	2	5	1	0	3	0	0	1	35	23.73
2010	6	5	3	0	2	4	**4***	6	1	0	1	0	3	0	0	0	35	**32.82***
2011	6	4	3	0	2	3	**4***	**8***	1	5	0	0	3	0	0	0	39	**35.04***
2012	2	9	3	0	1	2	2	7	0	0	0	0	5	0	0	0	31	**50.01***
2013	3	5	1	0	0	1	0	5	0	1	2	0	2	0	0	0	21	**41.36***

Table 4. Significance of the interaction term in the model explaining variation of number of nests among fields between 1990 and 2013.

Model	Residual DF	Residual Deviance	DF	Deviance	P-value
`value ~ Field + Year + Field * Year - 1 + offset(log(Area))`	304	401.76			
`value ~ Field + Year - 1 + offset(log(Area))`	319	478.54	15	-77.76	<0.001

Table 5. Summary of the interaction between years and fields to explain changes in nest numbers among fields between 1990 and 2013. Significant changes in bold.

Interaction	Estimate	Std. Error	z value	Pr(>|z|)
`Year:F2`	0.047	0.037	1.259	0.209
`Year:F3`	0.005	0.038	0.141	0.888
`Year:F4`	0.000	0.129	-0.003	0.998
`Year:F5`	0.013	0.048	0.268	0.789
`Year:F6`	0.028	0.039	0.714	0.476
`Year:F7`	0.039	0.048	0.809	0.419
`Year:F8`	0.049	0.035	1.383	0.168
`Year:F9`	0.050	0.078	0.636	0.525
`Year:F10`	0.078	0.050	1.567	0.118
`Year:F11`	-0.048	0.038	-1.281	0.201
`Year:F12a`	-0.178	0.041	-4.332	**0.000**
`Year:F12b`	-0.021	0.034	-0.611	0.541
`Year:F13`	-0.035	0.098	-0.359	0.720
`Year:North`	-0.178	0.091	-1.966	**0.050**
`Year:Shank`	-0.095	0.063	-1.503	0.134

Failure at egg-stage

Thirty-two iButtons were retrieved in 2012, although one was not working probably due to water-logging. All 21 iButtons were retrieved and had worked in 2013. It was possible to assess the outcome of all nests for which we had working iButtons (31 nests in 2012 and 21 in 2013). In 2012, 16 nests hatched (52%), and 15 nests failed at the egg stage (48%) (Fig 12; Table 6).I In 2013 11 nests hatched (52%) and 10 failed (48%). Causes of failure in 2012 could be divided into abandonment before incubation (three nests, 10%), desertion during incubation (daytime failure) (two nests, 7%) and probable predation (10 nests, 32%). For the 2013 breeding season all failures appeared to be due to predation, as eggs had disappeared from the nest without signs of hatching. In 2012, eight failures (probable predation of eggs) occurred at night, two during the day and two during twilight hours (Table 7a). In 2013 most failures occurred in daylight (nine) with only one during twilight in the morning (Table 7b). One instance of desertion during incubation (all eggs intact) occurred in the morning in 2012. Failure (excluding desertion before incubation, which could not be attributed to a precise time of the day) occurred predominantly in daytime over the two years combined ($X^2_{,2}=9.9$, $p<0.01$) and when 2013 data were considered ($X^2_{,2}=14.6$, $p<0.001$) but predominantly at night in 2012 ($F_{,4}=5.882$, $p<0.001$).

Seven nests were monitored with nest cameras in 2012 (four with video cameras and three with Bushnell cameras) and five Lapwing nests in 2013, two with a video cameras as in the previous year (two successful and one predated nest), and two with the second design of camera that were placed closer to the nest and lower on the ground (one nest successful and one predated). Four nests with cameras failed in 2012, two monitored with a digital video camera (both failed during the day (morning)) and two with Bushnell cameras (one at night and one during the day (morning)) and two in 2013 predated by corvids (Fig 13). In 2012 three of the four failures were due to desertion, but it was not apparent from the images on camera why the bird had deserted the nest, whilst the lens of the camera on the nest that failed at night steamed up and hence no photos of the predator are available.

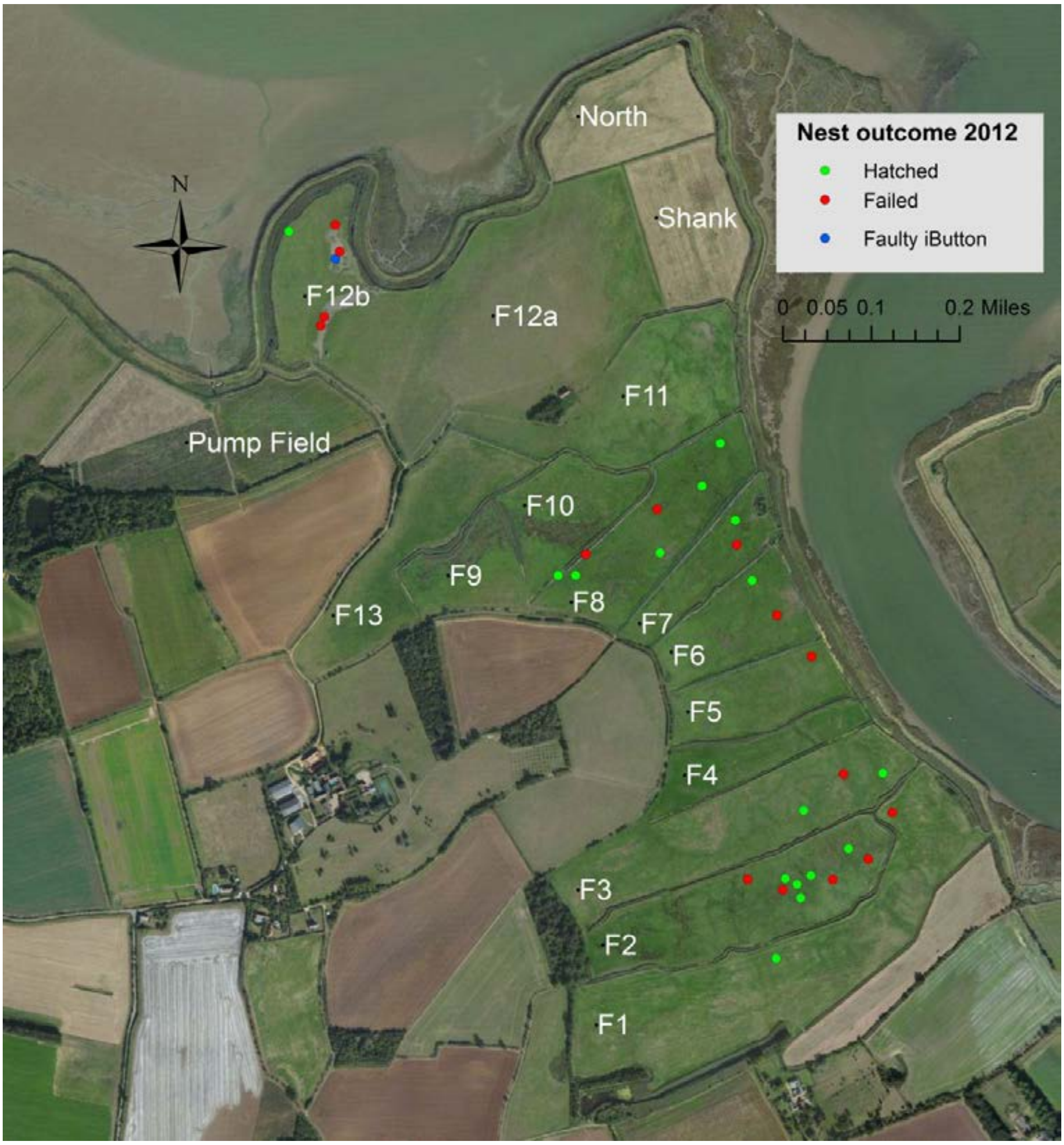


Figure 11. Outcome of nests at egg stage in 2012. Green – hatched, red – failed, blue – iButton faulty.

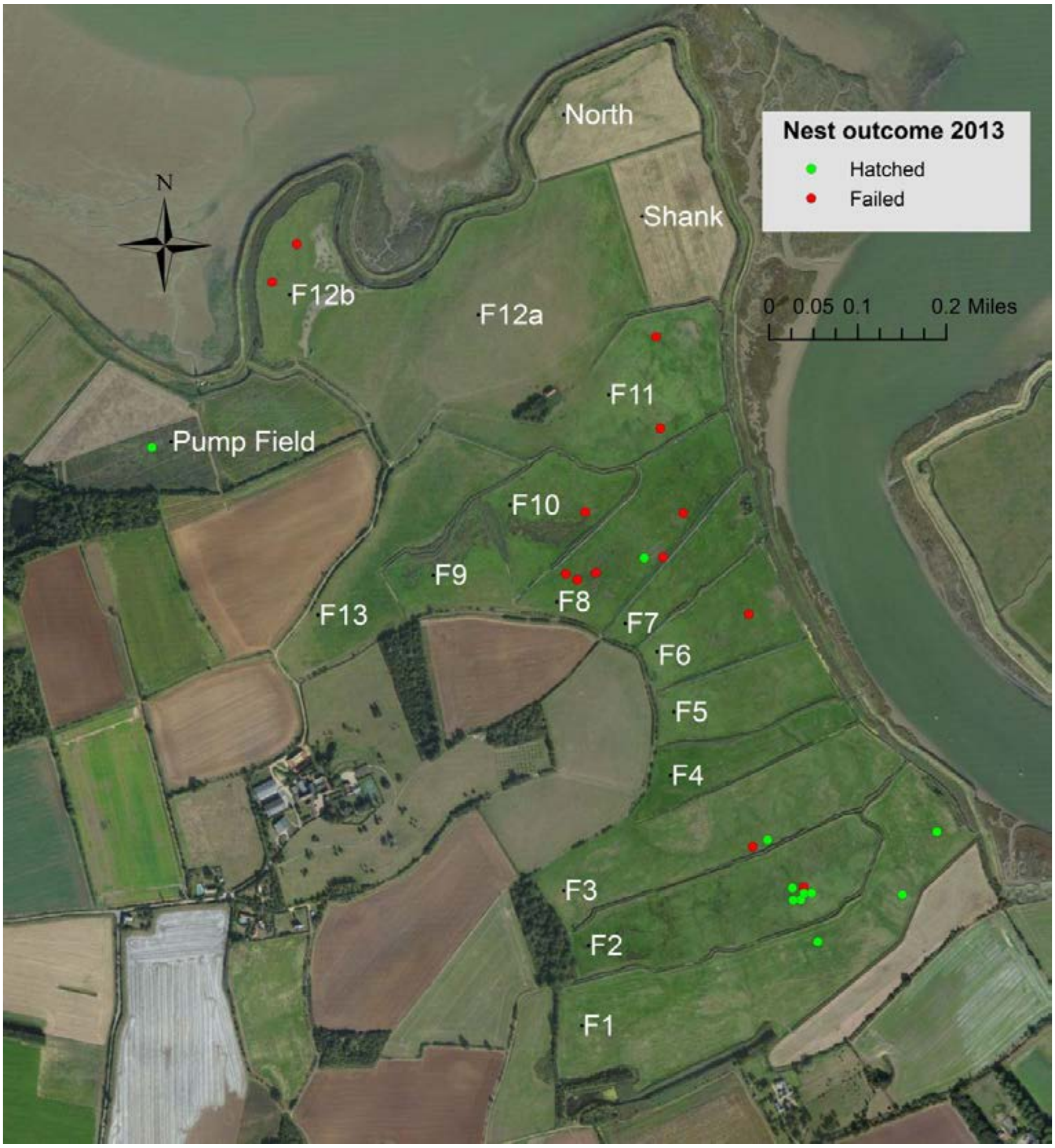


Figure 12. Outcome of nests at egg stage in 2013. Green – hatched, red – failed.

Table 6. Failure of nests, at egg stage, per field in 2012 and 2013.

Field	Success 2012 (%)	Failure 2012 (%)	Total number of nests 2012	Success 2013 (%)	Failure 2013 (%)	Total number of nests 2013
F1	50	50	2	100	na	3
F2	56	44	9	100	na	5
F3	67	33	3	100	na	1
F4	na	na	0	na	na	0
F5	0	100	1	na	na	0
F6	50	50	2	0	0	1
F7	50	50	2	na	na	0
F8	71	29	7	20	80	5
F9	0	0	0	na	na	0
F10	0	0	0	0	100	1
F11	0	0	0	0	100	2
F12a	0	0	0	na	na	0
F12b	20	80	5	0	100	2
F13	0	0	0	na	na	0
North Field	0	0	0	na	na	0
Shank Field	0	0	0	na	na	0
Pump Field	na	na	na	100	0	1
Total	**16**	**15**	**31**	**11**	**10**	**21**

Table 7. Summary of nest outcome in (a) 2012 and (b) 2013 . 'na' indicates nests that were not incubated, therefore time of day of failure was not applicable.

(a) 2012

Nest outcome	Day	Twilight (evening)	Twilight (morning)	Night	na
Failure	2	2	0	8	3
Success	16	0	0	0	0

(b) 2013

Nest outcome	Day	Twilight (evening)	Twilight (morning)	Night	na
Failure	9	0	1	0	3
Success	8	0	3	0	0

Table 8. Summary of GLM investigating time of failure for 2012 and 2013 combined.

	Estimate	Std. Error	z value	Pr(>|z|)
Day	0.6927	0.6502	1.065	0.287
Night	-2.7262	1.3469	-2.024	0.043*
Twilight	0.9087	1.1614	0.782	0.434

Failure was equally spread across all fields, and no field had higher success than others, when controlled for the total number of nests present in a field in 2012 and 2013. There was also no significant relationship between the chance of failure and the progression of the season over the two years, when year was accounted for (Fig 14; Fig 15; Table 9). There was also no evidence of the effect of group-defence, as probability of failure did not vary with the number of active nests present within 100-metre radius in 2012 ($z_{1,30}$=-0.419, P=0.68) nor 2013 ($z_{1,21}$=1.03, P=0.3) or when the two years were combined and pseudoreplication of year and field were taken into account ($z_{1,51}$=1.38, P=0.17). The outcome of the nest at egg stage was not correlated with distance from the nest to the nearest ditch in 2012 or in 2013 or when the two years were combined together and year was accounted for. Hatching success was positively correlated with daily rainfall in 2012 (slope=0.05±0.02, $F1_{,28}$=2.29, p<0.05) but not in 2013.

Figure 13. A crow predating nest DIL 4 in field F12b in 2013. Image obtained using the second design of digital video camera placed nearer to the ground and closer to the nest than the other camera type used.

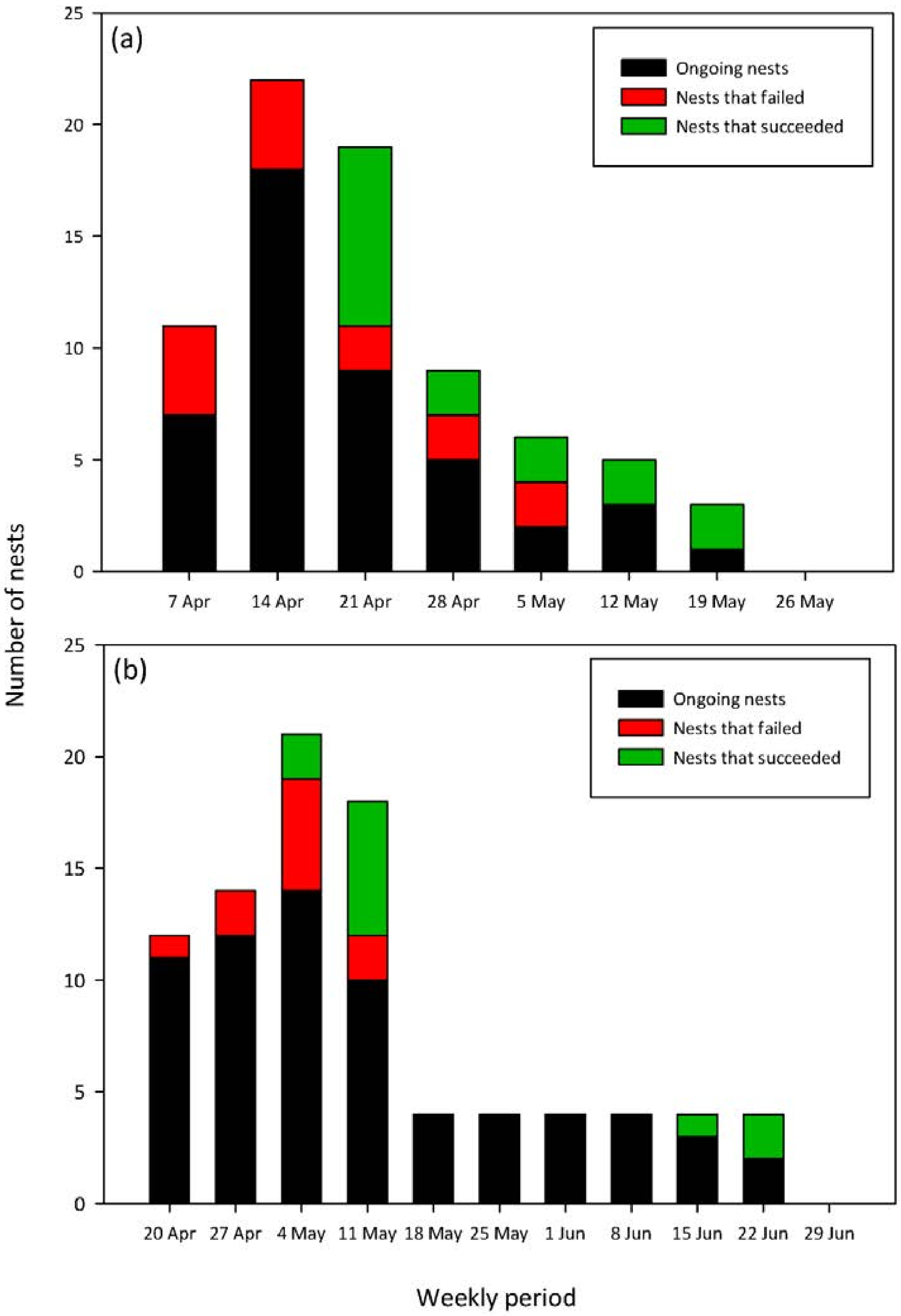


Figure 14. Breakdown of number of nests per week and their outcome in 2012 (a) and 2013 (b). Note the different date scales because of the late and prolonged season in 2013.

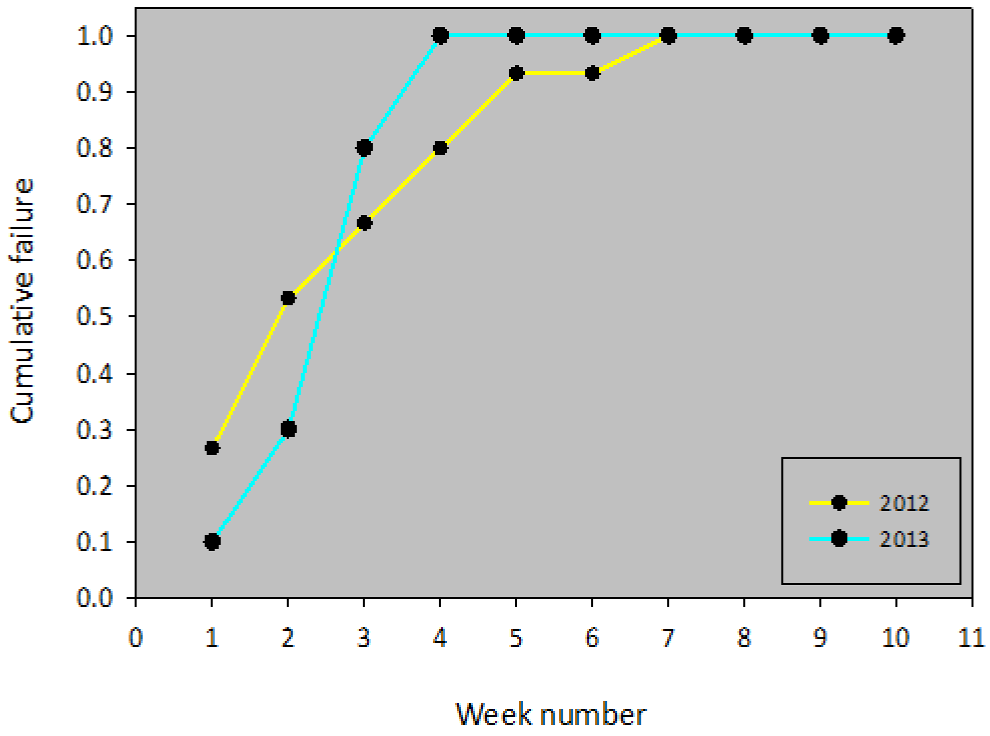


Figure 15. Cumulative proportion of failed nests per week (week 1 denotes when the first nest was found in either year) for 2012 and 2013. Failure rate decreases as the season progresses in both years, as indicated by the progressively shallower slope between each successive point.

Table 9. Summary of model of the relationship between nest failure and progression of the breeding season in 2012 and 2013.

	Estimate	Std.Error	z value	Pr(>|z|)
(Intercept)	-2.3765	3.3048	-0.719	0.472
Week	1.0375	2.1944	0.473	0.636
Week^2	-0.2009	0.3246	-0.619	0.536

Redshank nesting failure

IButtons were placed in three Redshank nests in 2012 and six in 2013. In the first year, two nests hatched at least one egg and one failed, whilst in 2013 one hatched at least one egg and five failed. Five of the six failures occurred at night, but the numbers are too small to perform statistical analyses. One video camera was deployed in 2013 on a Redshank nest, which hatched successfully and no predation events were seen.

DISCUSSION

Monitoring Lapwing abundance

The number of pairs calculated from the formula devised by Bolton *et al* (2011) agreed with the number of nests found in the field in both years. However, in 2012 there were too few data to estimate hatching success reliably because no family parties were seen. This could be attributed either to erroneous low counts of chicks at 'newly fledged' stage, as this category is the most likely to be under-recorded during the survey (Bolton *et al* 2011), or to low post-hatching survival. Birds are often at the opposite end of the field to the observer (*pers. obs.*), unaffected by the presence of the observer and it may therefore be difficult to see small chicks.

In 2013 the hatching success calculated from the survey suggested just over 26% hatching success, which is classed as 'low' (Bolton *et al* 2011). This would equate to just over five pairs hatching at least one chick (26% of 22 pairs). The total number of chicks hatched following these calculations would range from about five (one per pair) to about 22 chicks, if we considered that all five nests hatched all eggs, with a mean clutch size of 3.71 eggs. This would equate to a mean number of hatched chick per nest in 2013 ranging from less than one (six chicks over 22 pairs), to about one chick hatched per pair (22 chicks over 22 pairs). The productivity estimate (number of chicks fledged), based on the Bolton *et al* method (2011) is also of one chick per pair on average, but this would equate to 100% survival of the chicks hatched, which is not realistic. One explanation is that the methodology Bolton and colleagues (2011) have suggested does not take into account pseudoreplication of chick survey, those instances in which the same chicks are counted more than once in subsequent visits. This probably occurred at Stanny House Farm in 2013, when in visit 4 and visit 5 recently-fledged birds were observed in F12b and F14 on both visits, but the methodology required the number of recently-fledged birds to be added from all visits regardless of potential pseudoreplication. Furthermore, the equation to calculate productivity requires the sum of well-grown chicks as well as fledged ones, running the risk of double-counting chicks that fall into the "well-grown" category during a visit and "fledged" during the following one.

The survey methodology did not seem to be producing reliable results at Stanny House in 2012 as no family parties were found. There was one instance during that year when, in the afternoon after the survey was completed, chicks that had not been seen during the survey were spotted in fields. The problem of young chick detectability was recognised by Bolton *et al* (2011), who suggested using the count of families in visit 4 + 0.32 divided by the number of pairs + 0.093. This would give a productivity of 0.12 chicks per pair in 2013. This discrepancy between the survey results and those recorded whilst carrying out other activities in the field may be due to two factors: lack of vantage point from which to observe all fields in their entirety and time of day. Observation from the end of a field at the same level leads to underestimation of birds, both of adults and small chicks, which are especially obscured by vegetation. Partially walking into the field for a better view may lead to chicks adopting a crouching defence position and hence becoming even less conspicuous.

The surveys took place between 10 am and 4 pm following Bolton *et al* (2011) to avoid counting transient birds that do not breed in the area. However, temperatures during that period could rise to a level that may have affected the survey results. For example, in 2012 temperature at midday from visit 3 was over 20°C, and bird activity was probably reduced compared to early morning or late afternoon. An alternative hypothesis is that parents have lead chicks away from the field as adults are known to lead chicks several hundred metres away from the nest sites, generally within the first three days after hatching, depending on the quality of the nesting area as feeding site (Redfern 1982).

The surrounding marshes to the east of the farm were scanned for presence of adults and chicks from vantage points on the sea wall, but no chicks were seen. This may be due to the actual absence of birds, or to the difficulty of seeing them from a distance on a substrate against which they are well camouflaged. Other means of ascertaining their presence would be needed to establish their movements.

As the survey did not apparently provide a reliable estimate of productivity in 2012 it is not possible to say whether it had been high enough to maintain the population. Previous authors had estimated that in order to maintain a stable Lapwing population, 0.83-0.97 chicks per pair were needed (Peach *et al* 1994) assuming adult survival around 80% (Peach *et al* 1994; Catchpole *et al* 1999). However, these values were based on the number of chicks at ringing age, which is within the first few days of life, and not of fledged ones; losses between these two periods are likely to be high. However, mostly-grown and fledged chicks are a similar size to adults, which are recorded well by the methodology, but the survey found a limited number of mostly-grown and fledged chicks in the last two visits in 2012 (Appendix 1).

The low number of families and chicks of any age recorded during the 2012 surveys may also indicate low chick survival, and one of the reasons may be predation. Predation is an important factor in wader chick survival, and radio-tracking studies have found that it accounted for 60-87% of chick mortality (e.g. Grant *et al* 1999; Junker *et al* 2004; Schekkerman *et al* 2009). A Dutch study showed that avian predators were responsible for 71% of chick mortality in Lapwing and Black-tailed Godwit (*Limosa limosa*) (Teunissen *et al* 2008) whilst a study in the north of England showed that Lapwing chicks were more at risk of Red Fox predation than eggs, because they were easier to locate (Seymour *et al* 2003).

In 2013 the survey suggested a productivity of just over one chick per pair, enough to maintain a stable population (Peach *et al* 1994). However, there are two potential caveats to this result. The first one is the possibility of double-counting, both between visits and as the chicks grow and are re-counted in different age categories; productivity is therefore likely to be lower than suggested by the Bolton *et al* (2011) method-based results. The second limitation is that the number of pairs in 2013 was lower than in the previous year. Whilst productivity suggested following the Bolton *et al* (2011) calculations indicate a sufficient productivity to keep a stable population, this number would be based on a lower-number of birds recorded in 2013 compared to any of the previous years, based on 2012 and historic data of the past 10 years (for historic data see Table 3).

Nest location

The number of nests found was comparable with the number of pairs estimated from the survey visits in 2012 and 2013. Nest distribution in each field was not random in either year, even when controlled for size, but no fields contained more nests than others. One explanation is the presence of wet features within the fields. Unfortunately accurate measurements of these features were not collected because of lack of time. However, it should be investigated in future, as wet features are widely recognised as important characteristics of Lapwing breeding on wet grassland (Smart *et al* 2006). They provide suitable feeding habitat for chicks (Milsom *et al* 2002, Eglington *et al* 2008) as they support a higher density of terrestrial and aerial invertebrates (Eglington *et al* 2010) and they are not used by mammalian predators as clues to hunt for chicks (Eglington *et al* 2009).

Data on the number of nests found each year for most of the 1990s and the early 2000s indicated that one field had an increasing number of nests and three had fewer. However, differences in un-quantified nest-finding effort between years, in particular between the early and the later ones, may bias this result as it cannot be controlled for.

Rainfall was not correlated to the number of nests or their distribution between fields. This may be due to the relative limited spatial variation within the study site and the lack of data on ground water at each field's level. This information, together with mapping of wet features within fields, would allow a more effective investigation of the effect of rainfall on number of nests. Wet features within the landscape are important foraging areas for Lapwing chicks as they provide high invertebrate abundance (Smart *et al* 2006; Bellebaum & Bock 2009; Eglington *et al* 2009; Eglington *et al* 2010).

Failure at egg-stage

Failure rates at egg stage on this site indicated that 48% of nests monitored in both 2012 and 2013 failed, a result that is low compared to other studies. In Germany, Bellebaum & Bock (2009) found that over two wet grassland sites failure of Lapwing nests ranged from 92% to 37%, whilst in England, Eglington *et al* (2009) reported 58% failure on marshes.

In the UK there are two groups of predators of Lapwing- avian and mammalian (Green *et al* 1987; Bolton *et al* 2007). Failure at night can be attributed to mammals, whilst day-time predation can be attributed to both avian and mammalian species (Eglington *et al* 2009). In 2012 egg stage predation occurred predominantly at night (eight nests out of 12 failures – the remaining three nests were abandoned and not predated), indicating mammalian predators. This result is not surprising, as mammals have been identified as the main predators of eggs of grassland waders, while predation of chicks is mainly due to avian predators (Teunissen *et al* 2008). In Germany, 65% of unsuccessful nests were lost at night (Bellebaum & Bock 2009), while in England predation occurred at night in 77% of the predation events based on a study on Berney marshes in eastern England (Eglington *et al* 2009). The same study found that mammalian predation accounted for 50% of failures at the egg stage (Eglington *et al* 2009), while an eight-year study on seven sites within eastern England and Wales found that predation, predominantly mammalian, accounted for 50% of egg failure (MacDonald & Bolton 2008a). Another study on 11 sites in England and Wales found that control of Red Fox and Carrion Crow increased hatching success in some sites but not in others (Bolton *et al* 2007). A study on Rathlin Island, off the northeast coast of Northern Ireland, recorded only a 15% failure rate (Bodey *et al* 2011), although this may be due to a restricted range of predator species present, which did not include Red Fox. Predation has been identified as the cause of egg-stage failure of 58% of Lapwing nests throughout Europe (MacDonald & Bolton 2008b).

The second cause of failure in 2012 was desertion of the nest before incubation and during incubation in daytime, but it was not possible to ascertain the reasons for this behaviour.

By contrast, in 2013, 90% of predation events at egg stage had occurred during daytime, suggesting avian predation, substantiated by a predation event caught on camera (Fig 13). The shift from mammalian to avian predation is difficult to interpret, but one possibility is that cold weather at the beginning of the breeding season, and associated slow growth of grass at Stanny House (Rodney West pers. comm.), might have made nests and birds sitting on eggs more evident to aerial predators. However, no data on grass height during either field season are available and this remains an hypothesis that may need further testing in future years.

Egg stage failure did not relate to proximity to field ditches which delimit each field in either year, as expected if predators used these features to move around a field. Some studies have found that nests further away from the field edge had a lower predation rate (MacDonald & Bolton 2008a), although others did not find a relationship (Eglington *et al* 2009; Seymour *et al* 2003). Egg-stage failure rate did not change across the breeding season. This was unexpected, as a study of BTO Nest Records for Lapwings from 1966 to 1999 found that early and late breeders had lower success

(Chamberlain & Crick 2003), possibly through decrease in the benefits of group defence (Dyrcz & Witowski 1987). Increased nest survival in the middle of the breeding season was also found in a Dutch study (Thorup 1998), whilst nest failure was higher in early breeders in Ruff, Black-tailed Godwit and Snipe (Green 1988) and increased as the season progressed in Redshank breeding on coastal meadows in Sweden (Ottvall 2005). However, the result in the current study may be due to the small sample size.

A surprising result was the lack of effect of number of synchronous active nests in the field on nest predation. A possible explanation is the small number of nests and/or the scale at which this was considered. The spatial variation may not have been great enough to test whether nests in different parts of the study site responded differently to the presence of neighbouring birds. Sites with higher number and density of Lapwing nests have fewer predation events (Berg *et al* 1992; Šálek & Šmilauer 2002; Seymour *et al* 2003; MacDonald & Bolton 2008a; Eglington *et al* 2009; Bodey *et al* 2011), due to increased group defence (Berg *et al* 1992; Šálek & Šmilauer 2002; Seymour *et al* 2003). However, some authors have raised the question of whether defence against nocturnal predators increases with nest density, or whether nest density is higher in areas with lower predator density (MacDonald & Bolton 2008a), as breeding densities can increase between years in apparent response to predator control (Bolton *et al* 2007a). The behaviour of different predator species can influence the predation rate: Red Foxes, for example, spend on average 57 seconds per hectare patrolling a field, but their ability to detect nests is restricted to a range of 1-2 metres radius (Seymour *et al* 2003). Loss of nests to Red Foxes accounted for 73% of predation events in one study in the north of England (Seymour *et al* 2003), but an experiment involving removal of this mammalian predator found no overall effect on Lapwing nests because other mammalian predators were responsible for nest loss in the absence of foxes (Bolton *et al* 2007a). This suggests that the dynamics of Lapwing/mammalian predator interaction are difficult to modify. Studies of the effect of nest cameras on predators have found different results. Richardson *et al* (2009) and Eglington (2008) found than no nests monitored with cameras were predated, whilst other authors recorded predation events (Bolton *et al* 2007b; Teunissen *et al* 2008).

The positive correlation of nest success with mean daily precipitation in 2012 is difficult to interpret, as the relationship was not significant in 2013. One explanation could be the relationship with amount of rainfall and related invertebrate availability. In 2012 the ground was wet for longer than in 2013 (pers. obs.) and wet features are widely recognised as important characteristics of Lapwing breeding on wet grassland (Smart *et al* 2006) and they provide suitable feeding habitat for chicks (Milsom *et al* 2002, Eglington *et al* 2008) as they support a higher density of terrestrial and aerial invertebrates (Eglington *et al* 2010). Other authors have found that wet sites had higher hatching success than drier fields in the same area (Bellebaum & Bock 2009).

CONCLUSIONS AND FURTHER WORK

The first two years of study on Lapwing productivity at Stanny House Farm showed that egg-stage failure is similar, and possibly slightly lower, than that recorded in other published studies (e.g. MacDonald & Bolton 2008b; Eglington *et al* 2009s). The time of predation changed from predominantly at night in 2012, suggesting mammalian predators, to almost exclusively diurnal, suggesting avian predators were involved. Weather conditions during 2012 were extremely unusual, with record amounts of rain falling in April, therefore it is difficult to determine whether these results reflect the average situation at Stanny House Farm, although the breeding season for all species appears to have been very late (NRS preliminary results 2013, www.bto.org/volunteer-surveys/nrs/results/nrs-preliminary-results-2013)). Rainfall in January, February and March did not explain hatching success or failure rate in 2013 and when the two years were combined, confirming that 2012 was an unusual year.

Despite almost half of clutches hatching successfully, no family parties were observed in the study area during the productivity surveys in 2012 and a maximum of five chicks were found during the nest monitoring fieldwork. In 2013 productivity as measured by surveys suggested just over one chick per pair, although this may be an over-estimate because the same chick may be counted in a subsequent visit. At Stanny House Farm the areas of saltmarsh to the northeast and southwest of the breeding fields (Fig 4) may provide good foraging opportunities as well as cover for the young, so it is possible the chicks are being moved to the saltmarsh. Alternatively, juvenile numbers may be lowered substantially by post-hatching predation, which has been identified as the primary cause of chick mortality in previous studies (Schekkerman *et al* 2009, Teunissen *et al* 2008, Galbraith 1988a, Baines 1989). The difficulties in making direct observations of the young birds were evident when undertaking the field surveys to calculate a productivity estimate, but radio-tracking chicks would help to quantify both post hatching survival rates and potentially the timing of any predation events that did occur, which may in turn infer predator identity. Furthermore, the dispersal rate and distance of family parties could also be estimated, and use of the saltmarshes as a feeding habitat quantified.

The quality of the feeding habitat available at the breeding site also has the potential to limit productivity, indirectly through adult condition, which may influence investment in both eggs and chick rearing, and directly through the availability of invertebrate food to the young. It is therefore important to maintain the habitat suitable for breeding Lapwings, with wet features and short vegetation. In 2012, work was started to quantify the extent of wet areas and relate their distribution to spatial variation in nesting success, but unfortunately the student involved was unable to complete the project for personal reasons. Lack of time prevented measurements of wet features in 2013. The draft protocol that was to be finalised during the field season is included in this report (Appendix 3). Work on nest predation started in 2012 would strongly benefit from a third year of study, as 2012 and 2013 were both characterised by some usual weather aspects (very wet in 2012 and cold, late-start in 2013), therefore a third year may help to ‘smooth’ those anomalies.

Recommendations for 2014 field season

The 2014 field season should address two aspects:

a) Identifying the fate of chicks. Hatching success is broadly similar to other studies, therefore further work should be aimed at understanding chick survival.

b) Adding a third year of data to the nest predation study conducted in 2012 and 2013 to understand whether results in the first two years, which showed predation by mammals one year and predation by Carrion Crows in the second year, are representative of the predation pattern at Stanny House Farm.

Work to be done to achieve this:

- Radio-tracking of chicks to quantify and describe dispersal and investigate the cause of any mortality.
- Observation of behaviour of avian predators during daytime using vantage points and hides.
- Continuing the monitoring of nests through iButtons and cameras if there is time and enough people to cover this aspect, to extend on the sample size achieved in 2012 and 2013.
- Study of nest predation of Redshank will also be targeted as the species may be affected by a different suite of variables to Lapwings.

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REFERENCES

Amar, A., Redpath, S., Sim, I. & Buchanan, G. (2010) Spatial and temporal associations between recovering populations of common raven *Corvus corax* and British upland wader populations. *Journal of Applied Ecology*, **47**, 253–262.

Baillie, S.R., Marchant, J.H., Leech, D.I., Renwick, A.R., Eglington, S.M., Joys, A.C., Noble, D.G., Barimore, C., Conway, G.J., Downie, I.S., Risely, K. & Robinson, R.A. (2012) BirdTrends 2011. BTO Research Report No. 609. BTO, Thetford. www.bto.org/birdtrends

Baines, D. (1989) The effects of improvement of upland, marginal grasslands on the breeding success of Lapwings *Vanellus vanellus* and other waders. *Ibis*, **131**, 497-506.

Bellebaum, J. & Bock, C. (2009) Influence of ground predators and water levels on Lapwing *Vanellus vanellus* breeding success in two continental wetlands. *Journal of Ornithology,* **150**, 221-230.

Berg, A., Lindberg, T. & Kallebrink, K.G. (1992) Hatching success of lapwings on farmland: differences between habitats and colonies of different sizes. *Journal of Animal Ecology,* **61**, 469–476.

Bodey, T.W., MacDonald, R.A., Sheldon, R.D. & Bearhop, S. (2011) Absence of effects of predator control on nesting success of northern Lapwings *Vanellus vanellus*: implications for conservation *Ibis,* **153**, 543-555.

Bolton, M., Tyler, G., Smith, K. & Bamford, R. (2007a) The impact of predator control on lapwing *Vanellus vanellus* breeding success on wet grassland nature reserves. *Journal of Applied Ecology,* **44**, 534–544.

Bolton, M., Butcher, N., Sharpe, F., Stevens, D. & Fisher, G. (2007b) Remote monitoring of nests using digital camera technology. *Journal of Field Ornithology,* **78**, 213–220.

Bolton,M., Bamford, R., Blackburn,C., Cromarty, J., Eglington, S., Ratcliffe, N., Sharpe, F., Stanbury, S. & Smart, J. (2011) Assessment of simple survey methods to determine breeding population size and productivity of a plover, the Northern Lapwing *Vanellus vanellus. Wader Study Group Bulletin*, **118**, 141-152.

Both, C., Piersma, T. & Roodbergen, S.P. (2005) Climatic change explains much of the 20th century advance in laying date of Lapwing *Vanellus vanellus* in the Netherlands. *Ardea,* **93**, 79–88.

Brindley E., Norris K., Cook, T., Babbs, S., Forster Brown C., Massey, P., Thompson, R. & Yaxley, R. (1998) The abundance and conservation status of Redshank *Tringa totanus* nesting on salt-marshes in Great Britain. *Biological Conservation*, **86**, 289–297.

Catchpole, E.A., Morgan, B.J.T., Freeman, S.N. & Peach, W.J. (1999) Modelling the survival of British Lapwings *Vanellus vanellus* using ring-recovery data and weather covariates. *Bird Study,* **46** (suppl.), 5–13.

Chamberlain, D.E. & Crick, H.Q.P. (2003) Temporal and spatial associations in aspects of reproductive performance of Lapwings *Vanellus vanellus* in the United Kingdom, 1962–99. *Ardea,* **91**, 183–196.

Dyrcz, A., Witowski, J. & Okulewicz, J. (1981) Nesting of timid waders in the vicinity of bold ones as anti-predator adaptation. *Ibis*, **123**, 542-545.

Eglington, S.M., Gill, J.A., Bolton, M., Smart, M.A., Sutherland, W.J. & Watkinson, A.R. (2008) Restoration of wet features for breeding waders on lowland grasslands. *Journal of Applied Ecology* **45**, 305-314.

Eglington, S.M., Gill, J.A., Smart, M.A., Sutherland, W.J., Watkinson, A.R. & Bolton, M. (2009) Habitat management and patterns of predation of Northern Lapwings on wet grasslands: the influence of linear habitat structures at different spatial scales. *Biological Conservation* **142**, 314-324.

Eglington, S.M., Bolton, M., Smart, M.A., Sutherland, W.J., Watkinson, A.R. & Gill, J.A. (2010) Managing water levels on wet grasslands to improve foraging conditions for breeding northern lapwing *Vanellus vanellus*. *Journal of Applied Ecology*, **47**, 451-458.

Fuller, R. & Ausden, M. (2008) Birds and habitat change in Britain. Part 1: a review of losses and gains in the twentieth century. *British Birds,* **101**, 644-675.

Galbraith, H. (1987) Marking and visiting Lapwing *Vanellus vanellus* nests does not affect clutch survival. *Bird Study,* **34**, 137–137.

Galbraith, H. (1988a) Effects of agriculture on the breeding ecology of Lapwings *Vanellus vanellus*. *Journal of Applied Ecology,* **25,** 487-503.

Galbraith, H. (1988b) Effect of egg size and compostion on the size, quality and survival of Lapwing chicks. *Journal of Zoology*, **214**, 383-398.

Grant, M.C., Orsman, C., Easton, J., Lodge, C., Smith, M., Thompson, G., Rodwell, S. & Moore, N. (1999) Breeding success and causes of breeding failure of curlew *Numenius arquata* in Northern Ireland. *Journal of Appied Ecology,* **36**, 59–74.

Green, R.E. (1988) Effects of environmental factors on the timing and success of breeding of common snipe *Gallinago gallinago* (Aves: Scolopacidae). *Journal of Applied Ecology,* **25**, 79–93.

Green, R.E., Hawell, J. & Johnson, T.H. (1987) Identification of predators of wader eggs from egg remains. *Bird Study,* **34**, 87–91.

Hartman, C.A. & Oring, L.W. (2006) An inexpensive method for remotely monitoring nest activity. *Journal of Field Ornithology*, **77**, 418–424.

Henderson, I.G., Wilson, A.M., Steele, D. & Vickery, J.A. (2002) Population estimates, trends and habitat associations of breeding Lapwing *Vanellus vanellus*, Curlew *Numenius arquata* and Snipe *Gallinago gallinago* in Northern Ireland in 1999. *Bird Study,* **49**, 17–25.

Holt, C.A., Austin, G.E., Calbrade, N.A., Mellan, H.J., Mitchell, C., Stroud, D.A., Wotton, S.R. & Musgrove, A.J. (2011) *Waterbirds in the UK 2009/10: the Wetland Bird Survey.* BTO/RSPB/JNCC in association with WWT, Thetford.

Hudson, R., Tucker, G. & Fuller, R. (1994) *Lapwing* Vanellus vanellus *populations in relation to agricultural changes: a review.* Peterborough: JNCC.

Hötker, H. (1991) Waders breeding on wet grasslands in the countries of the European Community - a brief summary of current knowledge on population sizes and population trends. *Wader Study Group Bulletin,* **61** (Suppl.), 50-55.

Junker, S., Krawczynski, R., Ehrnsberger, R. & Düttmann, H. (2004) Habitat use and chick mortality of radio-tagged Lapwings *Vanellus vanellus* and Black-tailed Godwits *Limosa limosa* in the Stollhammer Wisch, Lower Saxony. *Wader Study Group Bulletin,* **103**, 14.

MacDonald, M.A. & Bolton, M. (2008a) Predation of Lapwing *Vanellus vanellus* nests on lowland wet grassland in England and Wales: effects of nest density, habitat and predator abundance. *Journal of Ornithology* **149**, 555-563.

MacDonald, M.A. & Bolton, M. (2008b) Predation on wader nests in Europe. *Ibis,* **150**, 54–73.

Mayfield, H. (1975) Suggestions for calculating nest success. *Wilson Bulletin,* **87**, 456–466.

Milsom, T.P., Hart, J.D., Parkin, W.K. & Peel, S. (2002) Management of coastal grazing marshes for breeding waders: the importance of surface topography and wetness. *Biological Conservation,* **103**, 199-207.

Milsom, T.P. (2005) Decline of northern lapwing *Vanellus vanellus* breeding on arable farmland in relation to loss of spring tillage. *Bird Study*, **52**, 297–306.

Ottvall, R. (2005) Breeding success and adult survival of Redshank *Tringa totanus* on coastal meadows in SE Sweden. *Ardea,* **93**, 225–236.

Peach, W.J., Thompson, P.S. & Coulson, J.C. (1994) Annual and long-term variation in the survival rates of British Lapwings *Vanellus vanellus. Journal of Animal Ecology,* **63**, 60-70.

PECBMS (2009) *The State of Europe's Common Birds 2008.* CSO/RSPB, Prague.
PECBMS (2011) *Population Trends of Common European Breeding Birds 2011.* CSO, Prague
Piersma, T. (1986) Breeding waders in Europe: a review of population size estimates and a bibliography of information sources. *Wader Study Group Bulletin*, **48** (suppl), 1–116.

R Development Core Team (2012) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL www.R-project.org/

Redfern, C.P.F. (1982) Lapwing nest sites and chick mobility in relation to habitat. *Bird Study,* **29**, 201–208.

Richardson, T.W., Gardali, T. & Jenkins, S.H. (2009) Review and meta-analysis on camera effects on avian nest success. *Journal of Wildlife Management*, **73**, 287-293.

Rickenbach, O., Grüebler, M.U., Schaub, M., Koller, A., Naef-Daenzer, B. & Schifferli, L. (2011) Exclusion of ground predators improves Northern Lapwing *Vanellus vanellus* chick survival. *Ibis,* **153**, 531-542.

Šálek, M. & Šmilauer, P. (2002) Predation on northern Lapwings *Vanellus vanellus* nests: the effect of population density and spatial distribution of nests. *Ardea,* **90**, 51-60.

Schekkerman, H., Teunissen, W. & Oosterveld, E. (2009) Mortality of Black-tailed Godwit *Limosa limosa* and northern Lapwing *Vanellus vanellus* chicks in wet grasslands: influence of predation and agriculture. *Journal of Ornithology,* **150**, 133-145.

Seymour, A.S., Harris, S., Ralston, C. & White, P.C.L. (2003) Factors influencing the nesting success of Lapwing *Vanellus vanellus* and behaviour of Red Fox *Vulpes vulpes* in Lapwing nesting sites. *Bird Study,* **50**, 39–46.

Sharpe, F. Clark, J. & Leech, D. (2008) Does variation in demographic parameters account for regional variation in the Northern Lapwing *Vanellus vanellus* population declines across Great Britain? *Bird Study,* **55**, 247-256.

Shrubb, M. (1990) Effects of agricultural change on nesting Lapwings *Vanellus vanellus* in England and Wales. *Bird Study,* **37**, 115-127.

Shrubb, M. (2007) *The Lapwing*. London: T & AD Poyser.

Siriwardena, G.M., Baillie, S.R., Crick, H.Q.P., Wilson, J.D. & Gates, S. (2000) The demography of lowland farmland birds. In *Ecology and Conservation of Lowland Farmland Birds* (eds. Aebischer, N.J., Evans, A.D., Grice, P.V. & Vickery, J.A.) , 117-133. British Ornithologists' Union, Tring.

Smart, J., Gill, J.A., Sutherland, W.J. & Watkinson, A.R. (2006) Grassland-breeding waders: identifying key habitat requirements for management. *Journal of Applied Ecology,* **43**, 454–463.

Taylor, I. & Grant, M. (2004) Long-term trends in the abundance of breeding Lapwing *Vanellus vanellus* in relation to land-use change on upland farmland in southern Scotland. *Bird Study,* **51**,133-142.

Teunissen, W., Schekkerman, H., Willems, F. & Majoor, F. (2008) Identifying predators of eggs and chicks of Lapwing *Vanellus vanellus* and Black-tailed Godwit *Limosa limosa* in the Netherlands and the importance of predation on wader reproductive output. *Ibis,* **150** (Suppl. 1), 74–85.

Thorup, O. (1998) Ynglefuglene på Tipperne 1928–1992 [in Danish with English summary: The breeding birds on Tipperne 1928–1992]. *Dansk Ornitologisk Forenings Tidsskrift,* **92**, 1–192.

Wilson, A.M., Vickery, J.A. & Browne, S.J. (2001) Numbers and distribution of northern lapwing *Vanellus vanellus* breeding in England and Wales in 1998. *Bird Study,* **48**, 2–17.

Wilson, A.M., Ausden, M. & Milsom, T.P. (2004) Changes in breeding wader populations on lowland wet grasslands in England and Wales: causes and potential solutions. *Ibis,* **146** (Suppl. 2), 32–40.

Wilson, A.M., Vickery, J.A., Langston, R.H.W., Smallshire, D., Wotton, S. & Vanhinsbergh, D. (2005) Changes in the numbers of breeding waders on lowland wet grasslands in England and Wales between 1982 and 2002. *Bird Study,* **52**, 55-69.

APPENDIX 1 – Abundance Surveys

Summary of the results of the five visits to establish population size and productivity of the site in a) 2012 and b) 2013.

a) 2012

	Fields																
Visit 1 - 30/3/12 10:05-14:40 (Observer: DD)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**North**	**Shank**	**Marshes**
Adult lapwings	5	14	5	5	3	4	4	13	0	1	5	1	7	0	3	2	8
Adults with young	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Families	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fields																
Visit 2 - 23/4/12 10:45-14:27 (Observer: DD)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**North**	**Shank**	**Marshes**
Adult lapwings	4	13	6	1	4	3	3	12	0	1	0	2	5	0	4	6	2
Adults with young	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Families	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fields																
Visit 3-16/5/12 10:30-12:30 + 15:00-16:00 (Observer: DD)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**North**	**Shank**	**Marshes**
Adult lapwings	1	4	2	0	0	1	0	1	0	0	0	3	4	0	0	3	0
Adults with young	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Families	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fields																
Visit 4-31/5/12 10:21-14:17 (Observer: DD)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**North**	**Shank**	**Marshes**
Adult lapwings	1	4	2	0	0	0	0	2	0	1	0	5	0	1	0	2	2
Adults with young	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Families	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fields																
Visit 5-24/06/12 10:05-13:50 (Observer: DD)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**North**	**Shank**	**Marshes**
Adult lapwings	1	3	2	0	0	1	0	1	0	0	1	6	2	3	2	2	2
Adults with young	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Families	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

b) 2013

	Fields																
Visit 1 - 22/4/13 12:00-16:00 (Observer: Rodney West)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**14**	**North**	**Shank**
Adult lapwings	5	5	5	0	0	2	3	6	0	4	5	12	4	0	2	1	1
Adults with young	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Families	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fields																
Visit 2 - 17/05/13 10:00-13:00 (Observer: Rodney West)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**14**	**North**	**Shank**
Adult lapwings	3	4	3	0	0	1	2	2	0	0	0	13	2	1	0	0	0
Adults with young	1	2	2	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Families	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	4	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Number well-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fields																
Visit3 - 09/06/13 11:00-14:30 (Observer: Rodney West)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**14**	**North**	**Shank**
Adult lapwings	4	2	2	0	0	0	0	0	0	0	4	5	6	0	20	0	0
Adults with young	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Families	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fields																
Visit4-28/06/13 10:00-15:00 (Observer : Rodney West)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**14**	**North**	**Shank**
Adult lapwings	4	0	2	0	0	0	0	0	0	0	2	3	8	0	57	0	0
Adults with young	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Families	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	0	0	4	0	10	0	0
	Fields																
Visit5-09/07/13 12:30-16:00 (Observer: Rodney West)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12a**	**12b**	**13**	**14**	**North**	**Shank**
Adult lapwings	1	0	2	0	0	1	0	0	0	0	6	0	15	0	47	0	0
Adults with young	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Families	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number newly hatched chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number part-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number well-grown chicks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number fledged chicks	0	0	0	0	0	0	0	0	0	0	1	0	6	0	3	0	0

APPENDIX 2 – Nest-based data collection protocol

Pre –season

- Individually number iButtons and calibrate, enabling sensors to be exchanged where required

- Trial effect of placing a rubber insulation layer under the iButton to minimise the impact of changes in soil temperature on results.

- Trial orientation of the iButton – different researchers have used different orientations and both have produced results, but one may be optimal in this situation.

- Fully test cameras to ensure that recording does not cease if equipment moved or if cards swapped mid-recording. All connections should be encased in waterproof tape and any that will be in contact with the ground should additionally be enclosed in a Tupperware box or equivalent to prevent moisture entering.

Nest monitoring

- An ambient temperature sensor should be placed at each end of the site (total n=2) to record temperature at half hour intervals through the project. This will need to be replaced at intervals during the season to ensure that the memory does not become full. Make sure that the ID of the buttons used is known so that equivalent temperatures can be determined using the calibration results

- All fields should be walked every fortnight from the third week of March through to the second week of May inclusive. This should take place over as short a period as possible (e.g. within a single weekend) with equivalent search effort in each part of the site. Effort per field should be recorded as observer hours to allow post-hoc adjustment and comparison between years – time spent performing additional activities (e.g. placing sensors) should not be included. If the duration of the visit is of concern, the nests could be located on one day and the equipment positioned during a subsequent visit later in the day. Additional nests may be located by scanning with telescopes for sitting birds at any point – again, it would be useful to record time spent doing so. The method by which each nest is located should be recorded.

- Positions of individual nests found should be recorded with a GPS. Each nest should also be marked with a stick placed at a standard compass direction 10m away from the cup (Galbraith 1987 showed that marking had no effect on nest outcome).

- On locating a nest, density of eggs should be calculated to enable hatch date to be predicted, in accordance with the methodology outlined in Galbraith (1988b)

- A temperature sensor, set to record at half hour intervals, should then be inserted as high as possible in the centre of each nest – there should only be a few strands of material between the iButton and the eggs. All buttons should be secured to nails to prevent removal as per the methodology in this report. After calibration, iButtons can be exchanged so we strongly advise that the first few sensors are switched at a second visit, allowing data to be downloaded and the quality to be assessed, informing future placement.

- Cameras should be placed at a subset of nests, preferably distributed as widely as possible both spatially and temporally. Cameras should be attached to a stick and fitted with a hood as detailed in this report and should be positioned 1m – 1.5m from the nest, facing south. The camera should be positioned so that < 20% of the image contains sky to minimise the contrast effects. The box containing the battery and the recording device should be placed as far away from the nest as possible and camouflaged by vegetation/netting. Turf can be lifted and cables placed underneath, but the Tupperware box should remain above ground. To record, connect the recording box to the car battery and the camera lens cable. Check that the recording device is recording on the right memory card by checking that the AV-1 channel light is on and the AV-2 channel light is off. Hold up a card with time and date written on it as soon as recording starts as changing batteries resets the clock.

- Batteries will need to be changed every four days. Disconnect the recording device and camera, replace the memory cards with new ones and re-connect to the new battery, checking again that the recording channel is correct and that the camera is still in position. Contents of the memory card should be downloaded on return from the field to check that recording is taking place and that image quality is sufficient.

- All nests should be inspected every five days, regardless of whether they are being monitored by sensors and cameras. Establishing presence of a sitting bird would be sufficient to determine whether the nest is still active, so this could potentially be done remotely (e.g. via telescope after careful approach/from hide). Where possible, e.g. while changing camera batteries), nest contents should be recorded (no. eggs, warm or cold).

- Once inactive, temperature sensors should be removed from the nest immediately and the data downloaded and plotted on return to the lab. Nest lining should be removed, bagged and labelled to enable extraction of eggshell fragments at a future date.

APPENDIX 3 – DRAFT Protocol for invertebrate sampling and mapping of wet features

Hypothesis: There is a limited window for laying of replacement broods following predation/bad weather as food availability declines over the season, either because pools dry up or because of invertebrate phenology.

i) *Wet feature mapping*

The aim here is to identify available area of wet features, which chicks are known to utilise for feeding, and monitor how it changes over time – need to balance the accuracy of the estimate with the time spent in the field.

- Sampling intervals –this should be repeated every two weeks. Check what changes occur over the first fortnight and then judge intervals needed.
- At each visit, stand in middle of each wet feature and take GPS reading
- If regular in shape, estimate two longest dimensions in metres to give approximate area
- If irregular, make sketch and annotate relevant dimensions so approximate surface area can be calculated.
- Categorise the wet feature: e.g. open water pool, vegetated pool, saturated ground
- If standing water, measure depth at central point with ruler

ii) *Invertebrate traps*

- Need to work out how many fields, how many features and how many traps per feature – look at previous sampling densities and calculate how much time one will have to process samples bearing in mind the trapping frequency.
- Sample once a week – consider how long one is planning to leave the samples out and what preservative one is planning to use.
- Set at uniform distance from edge of wet feature –two distance bands could be considered to look at sphere of influence. Extra traps at the edge could also be placed as pools recede – that way one can keep absolute and relative positions constant.
- Use bulb planter to dig hole – retain soil core to look at soil inverts (could take a core on every visit if there is time but this would be lower priority).
- Have cups ready for placement in labelled planting tray so that they can be swapped quickly each time and decanting, etc., performed away from the field.
- Suggest painting the rain guard a bright colour so they can be easily found.
- Pre-numbered sticky traps positioned close to each pitfall trap and swapped at each collection visit
- Soil moisture reader – take reading next to each trap on each visit