Appendix 11 of BD5104
Bird modelling

The purpose of this Appendix is to further describe the statistical methods and findings relating to the modelling of the impacts of management on key upland bird species (see Section 4.5, and specifically Sections 4.5.4 and 4.5.5, in the main report). This is based on the measurement of craneflies (*Diptera*: *Tipulidae*) during 2014 – 2016 using emergence traps at the monitoring plots (i.e. under different management) and slope locations (i.e. without a specific management but within the burnt or mown catchment and therefore within the habitat of both adult craneflies and birds feeding on them) and on observation transects for adult/flying craneflies across the sub-catchments. The below sections are divided in individual data analysis sections and the detailed statistical method and outputs are provided in each section.

Projected Tipulid abundance under climate chance and management scenarios (Section 4.5.5.2 in main report)
(by Rachel Pateman, Stockholm Environment Institute, York)

The aim of this work was to use established relationships between water table depth and soil moisture, and soil moisture and Tipulid abundance to predict the effects of changes in climate and management on Tipulid abundance and consequently upland bird abundance.

Method

Projected future climatic conditions (SRES emissions scenario A1B) were derived from the UKCP09 weather generator projections for the 5 x 5 km grid squares in which the three field sites sit for the period 2017-2089. These climate data were combined with observed climate data from Automated Weather Stations (AWS) at the three sites for 2011-2016 and observed monthly data from Moor House for 1914-2010 (a similar blanket bog site), adjusted for the three field sites using offsets derived from comparisons of Moor House data from 2010-2015 to the field site AWS data from 2011-2015. This climate data, along with topographic information (slope, aspect, elevation) was entered into the MILLENNIA model (see Carroll et al., 2011; 2015) to derive predicted monthly water table depth for the period 1914-2089 for each 50 x 50 m grid square in the 5 x 5 km landscapes in which the three field sites are located. Monthly data were used to calculate an annual summer mean water table depth (July – September) as soil dryness during this period is a driver of Tipulid larvae desiccation and mortality and hence a driver of Tipulid abundance in the following year (see Carroll et al., 2011; 2015 and Appendix 10). These monthly summer water table depth data were then used to calculate a mean summer water table depth for the periods 1961-90 (as a baseline) and 2051-80 (as an indication of future climatic conditions) for each 50 x 50 m square in the three landscapes.

Moorland management is known to affect water table depth. We used data collected using automated dipwells throughout the period of the experiment to estimate the magnitude of this effect on mean water table depth (see Section 4.2.7 in the main report). The offset during the average post-management period (across all three sites but removing one burnt plot for Whitendale with very low water tables overall) of +1.94 cm in mown areas where brash was left, +0.94 cm in mown areas where brash was removed, and +0.10 cm in burnt areas, all relative to areas where there was no management (uncut plots), was applied to the water table depth estimates for the different time periods. Moreover, soil moisture measurements were taken at Tipulid trap locations each time Tipulid traps were checked. Traps were located next to automated dipwells. We used this information to produce regression equations for the relationship between soil moisture and water table depth for each management technique (mown with brash left, mown with brash removed, no management and burning) in each of the three landscapes separately (see Appendix 10). For each 50 x 50 m square in the three landscapes, these regression equations were used to translate project water table depth into soil moisture for baseline and future climate under the four management scenarios.

Information on total annual Tipulid abundance for each trap and mean annual soil moisture at each trap location was pooled across all sites and all years to produce on equation to represent the relationship between soil moisture and Tipulid abundance (see **Figure A.10.1** in Appendix 10). This equation was used to translate soil moisture for each 50 x 50 m square in the three landscapes to average total annual Tipulid abundance per m^2 for baseline and future climate under the four management scenarios.

To project upland bird abundances, we used relationships between cranefly and bird abundances derived by Carroll et al. (2015) for the South Pennines in northern England. These relationships describe the predicted number of individuals of three bird species (golden plover, dunlin and red grouse) in a 1 × 1 km for a given average abundance of craneflies m^{-2}; these three bird species were selected because they are particularly reliant on craneflies during the breeding season:

$$\text{Golden plover} = \exp^{(-0.587 + 0.045(\text{cranefly abundance}))}$$

$$\text{Dunlin} = \exp^{(-3.873 + 0.086(\text{cranefly abundance}))}$$

$$\text{Red grouse} = \exp^{(1.494 + 0.022(\text{cranefly abundance}))}$$

We took our 50 × 50 m square estimates of cranefly abundance m^{-2} for each of our four management scenarios and under baseline and future climatic conditions, and averaged these to produce a mean cranefly abundance m^{-2} for each of the 25 1 × 1 km squares (i.e. 5 x 5 km area) within our three focal landscapes. We then used the equations above to predict the abundance of these bird species (see **Figures 134-136** in the main report) based on these cranefly abundance estimates (see **Figures 131-133** in the main report).

Modelling the impact of mowing / burning treatments upon craneflies and golden plovers (Sections 4.5.4 and 4.5.5.1 in main report)

(provided by Dr. James W. Pearce-Higgins, British Trust for Ornithology)

Introduction

Cranefly abundance was assessed in two ways, using 10 m line transects on 4-5 occasions during the season and counting emerged individuals (e.g. Douglas & Pearce-Higgins 2014), and using an array of emergence traps (e.g. Carroll *et al.* 2011), which were deployed in 2014, 2015 and 2016. Traps were deployed each year during April until July, covering the cranefly emergence period and were visited every 3-4 weeks. Line transects capture abundance data from a larger spatial scale, but therefore abundances may be less closely tied to conditions along the transects and are also more subject to variation in ambient conditions. Traps should provide a better indication of true abundance at each trap site through the season. Both were analysed to test the hypothesis that cranefly abundance is enhanced by mowing treatment over burning. Trap data were then additionally used to test for difference between mowing treatments. The results of the analysis of transect data were then used to consider the potential implications of any significant effects upon golden plover breeding success and population change, using the model of Pearce-Higgins (2011).

The effect of treatment upon cranefly abundance

Traps

In order to model the effect of treatment upon cranefly abundance cranefly count was modelled as a function of treatment (T: mown sub-catchment or C: burnt sub-catchment), plot or slope (P or S), year (2014, 2015, 2016), survey period (split into four visit periods for 2014 and 2016 (1-4) and five for 2015 (0-4) as factors) and air temperature, the latter accounted for variation due to ambient conditions. In this analysis, treatment included data from all trap locations within the treatment sub-block, and from both treatment plots and slopes, and therefore could be regarded as considering the large-scale impacts of treatment. The slope areas are located within the managed areas and thus are hydrologically connected (to some degree) but also are part of the mix of vegetation structure available to adult craneflies to lay their eggs. Site and transect number were random effects. The model included interactions between year and period (to account for annual variation in phenology), treatment (to account for annual variation in treatment effects), and plot (to account for annual variation in abundance between plots and slopes). The model was conducted in SAS using PROC GLIMMIX, and using the Kenward-Rogers correction for df.

```
proc glimmix data=trap  ;
class year site treatment period trap plot block;
model tip = plot treatment year period year*period year*treatment year*plot temp/
error=poisson ddfm=kr solution;
random site*trap;
lsmeans treatment;
run;
```

The model identified significant interactions between year and both period and treatment, as well as impacts of plot and temperature upon cranefly abundance. The full model was:

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
plot	1	243.3	41.05	<.0001
treatment	1	243.2	0.33	0.5683
Year	2	2930	102.65	<.0001
period	4	2930	36.47	<.0001
Year*period	6	2930	103.98	<.0001
Year*treatment	2	2930	22.16	<.0001
Year*plot	2	2930	0.67	0.5138
temp	1	2930	41.21	<.0001

This model simplified to the following:

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
plot	1	222.2	40.23	<.0001
treatment	1	242.9	0.32	0.5701
Year	2	2932	103.58	<.0001
period	4	2932	36.38	<.0001
Year*period	6	2932	103.95	<.0001
Year*treatment	2	2932	22.23	<.0001
temp	1	2932	40.87	<.0001

Removal of the year*treatment interaction showed that there was no overall impact of treatment upon cranefly abundance:

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
plot	1	222	39.73	<.0001
treatment	1	219.1	1.11	0.2928
Year	2	2934	113.20	<.0001
period	4	2934	39.17	<.0001
Year*period	6	2934	105.17	<.0001
temp	1	2934	53.04	<.0001

Back transformation of the parameter estimates from this model yielded an average 0.36 craneflies per control trap (95% CI 0.31 – 0.43) and 0.32 (0.28 - 0.38) per treatment trap. The simple conclusion of the analysis was that mowing did not have a significant impact on the abundance of emergent craneflies. However, plotting the annual variation in estimated effects (**Figure A11.1**) suggested that there was a significant positive effect of treatment upon cranefly abundance in the first year (2014) by 50%, no significant impact in year 2, and a negative effect of treatment in the third year (2016) by 50%.

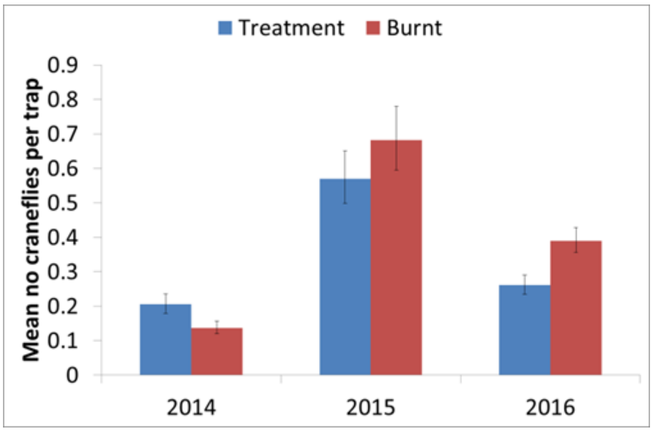


Figure A11.1 Modelled effect of mowing (Treatment) versus burning (Burnt) across the mown and burnt sub-catchments (i.e. including all plot level managements and unmanaged slope areas) upon the abundance of craneflies in emergence traps in each of the three years of the study. Estimated effect sizes are from a model that accounts for temporal variation in phenology between years. Error bars show standard errors.

It was possible to refine this analysis further by separating data from individual traps into those from control burns (excluding slope areas), those from uncut areas within treatment sub-blocks, and those from the mown, treatments, also from within treatment sub-blocks, using a 3-level factor.

```
proc glimmix data=trap  ;
class year site treatment2 period trap plot block;
model  tip  =  plot  year  period  treatment2  year*treatment2  year*period  temp/
error=poisson ddfm=kr solution;
random site*trap;
lsmeans year*treatment2;
run;
```

This model identified significant interactions between year and treatment, and year and period as follows:

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Plot	0	.	.	.
Year	2	1537	74.51	<.0001
period	4	1537	24.94	<.0001
treatment2	2	127.1	0.79	0.4562
Year*treatment2	4	1537	18.82	<.0001
Year*period	6	1537	63.00	<.0001
temp	1	1537	34.98	<.0001

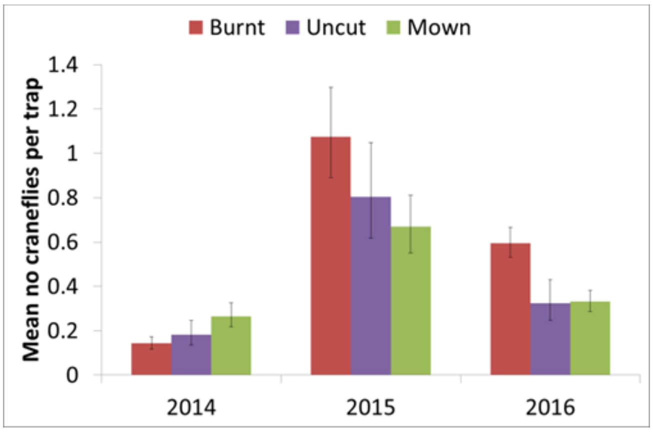


Figure A11.2 A comparison of the mean abundance of craneflies in traps in burnt control areas (Burnt), mown treatment areas (Mown) and unmown / unburnt areas within the treatment sub-blocks (Uncut) in emergence traps in each of the three years of the study (i.e. excluding slope areas). Estimated effect sizes are from a model that accounts for temporal variation in phenology between years. Error bars show standard errors.

This re-enforced the previous treatment effect from across sub-blocks, that in the first year, mown areas were associated with the highest emergence of craneflies and newly burnt areas, the lowest (**Figure A11.2**); this pattern was reversed in 2015, when counts were higher and more variable, and particularly in 2016 when the greatest numbers of craneflies were recorded from the burnt plots.

In order to test the potential for *Sphagnum* treatment or brash removal to increase cranefly abundance, we conducted an additional analysis of variation in cranefly abundance on traps within mown treatment areas. We used two predictor variables to identify those which had been seeded with *Sphagnum* (sphag) and those with brash removal (brash), and considered both simultaneously in a single model. Due to convergence problems it was not possible to include site*trap identity as a random effect, which instead was included as a factor in the analysis as follows.

```
proc genmod data=trap;
class year site treatment period trap plot block sphag brash;
model  tip  =  site  plot  year  period  sphag  brash  sphag*year  brash*year  temp/
error=poisson type1 type3 dscale;
run;
```

Although this model did not fully account for the non-independence of traps between sites, and the repeated nature of the sampling, the results suggested that whilst there was no significant interaction between *Sphagnum* treatment and year, there was a significant interaction between brash treatment and year as follows.

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Site*Trap	45	557	6.79	<.0001
Year	2	557	14.02	<.0001
period	4	557	6.96	<.0001
Year*period	6	557	28.62	<.0001
Year*sphag	2	557	1.98	0.1387
Year*brash	2	557	11.11	<.0001
temp	1	557	0.86	0.3553

This model simplified to the following, with a significant interaction between brash removal and year, such that cranefly abundances were higher from mown plots with brash removal in 2014, but lower by 2016 (**Figure A11.3**).

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Site*Trap	46	560	2.74	<.0001
Year	2	560	14.55	<.0001
period	4	560	4.25	0.0021
Year*period	6	560	11.71	<.0001
Year*brash	2	560	4.52	0.0113

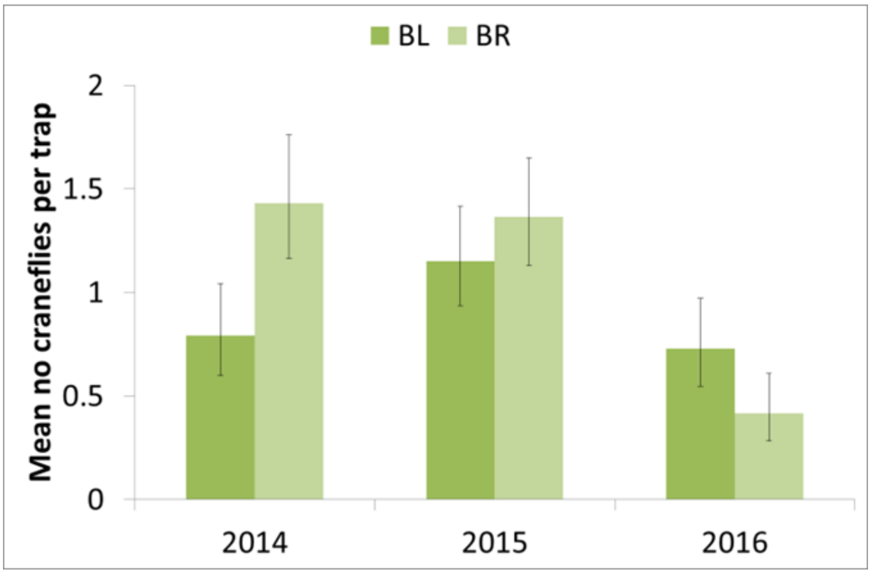


Figure A11.3 Modelled effect of brash removal (BR) upon the abundance of craneflies in emergence traps in each of the three years of the study, compared to mown plots were brash was left (BL). *Sphagnum* pellet addition treatments (±Sp) were combined. Due to problems of model estimation, effect sizes do not account for temporal variation in phenology between years. Error bars show standard errors.

Transects

In order to model the effect of treatment upon cranefly abundance cranefly count was modelled as a function of treatment (T or C), plot (P or S), year (2014, 2015, 2016), survey period (split into four visit periods for 2014 and 2016 (1-4) and five for 2015 (0-4) as factors) and air temperature, the latter accounted for variation due to ambient conditions. Site and transect number were random effects. The model included interactions between year and period, treatment and plot. The inclusion of slope plots represents the habitat range available to adult craneflies across a rotationally managed moor with patches of heather age classes. The model was conducted in SAS using PROC GLIMMIX, and using the Kenward-Rogers correction for df.

```
proc glimmix data=transect;
class year site treatment period transect plot block;
model  tip  =  treatment  plot  year  year*period  year*treatment  year*plot  temp  /
error=poisson ddfm=kr solution;
random transect*site ;
run;
```

The model identified significant effects of treatment, plot, year*period (to account for temporal variation in abundance in the two years as a nuisance term), and temperature, but with no effect of year on the treatment or plot effects:

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
treatment	1	83.4	7.37	0.0081
plot	1	81.06	7.37	0.0081
year	2	1072	77.83	<.0001
year*period	10	1072	37.14	<.0001
year*treatment	2	1072	0.12	0.8906
year*plot	2	1072	0.92	0.4003
temp	1	1072	214.44	<.0001

This model simplified to the following:

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
treatment	1	70.24	8.59	0.0046
plot	1	68.68	7.84	0.0066
year	2	1076	78.57	<.0001
year*period	10	1076	37.27	<.0001
temp	1	1076	216.88	<.0001

which identified a significant positive effect of treatment on cranefly abundance, with the following estimates of abundance on transects in the two treatments. In this model year had to be dropped to estimate parameters for year*period:

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
treatment	1	70.24	8.59	0.0046
plot	1	68.68	7.84	0.0066
year*period	12	1076	65.15	<.0001
temp	1	1076	216.88	<.0001

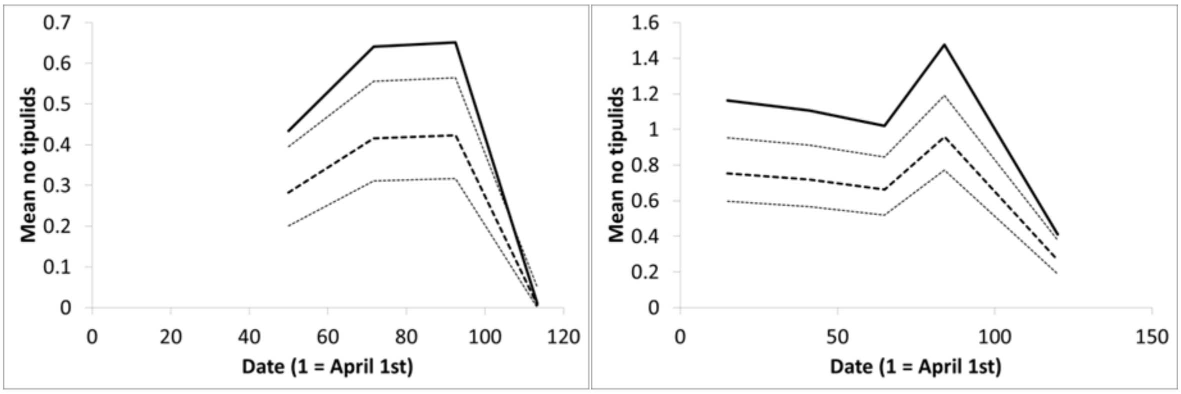
Back transformation of the parameter estimates yields an average 0.55 craneflies per control (burn sub-catchment) transect (95% CI 0.43 – 0.70) and 0.81 (0.64-1.03) per treatment (mown sub-catchment) transects of 10m in length. Note that these estimates should be doubled to produce results equivalent to the 20m transects used by Pearce-Higgins & Yalden (2004) to link cranefly abundance to golden plover chick survival, and population change. The conclusion of the analysis is that 67% more craneflies were recorded from transects through mown than burnt heather sub-catchments, with no significant variation between years.

Modelling treatment effects on cranefly abundance through the season

In order to link variation in cranefly abundance to golden plover productivity, as an index of wider ecological impacts, it was necessary to model the daily encounter rate of golden plover chicks with craneflies through the season. This was done by using the year*period interaction to model temporal variation in cranefly abundance in each year, and then incorporating the additive impact of treatment onto that. Thus, phenologies varied between years, but not between treatment and control. Temperature was excluded from this model as we wanted to predicted cranefly abundance as encountered by the birds, not after accounting for potential variation in temperature.

```
proc glimmix data=transect;
class year site treatment period transect plot block;
model tip = treatment plot year*period / error=poisson ddfm=kr solution;
random transect*site ;
lsmeans treatment;
lsmeans year*period;
run;
```

This model contained a significant effect of treatment ($F_{1,\ 71.03}$ = 11.72, *P* = 0.001) and plot ($F_{1,\ 69.46}$ = 9.49, *P* = 0.003), and a non-significant effect of year*period to account for variation in the phenology of craneflies between years ($F_{12,\ 1}$ = 49.56, *P* = 0.11). This produced the following predictions, which were used to create a Tipulid profile through time for each year for treatment and controls by predicting abundance for the central date in each period, and providing linear interpolation between dates (**Figure A11.4**). The overall effect of treatment from this model, excluding the effects of temperature, were similar to those described above from the model with temperature; 0.55 craneflies per control sub-catchment transect (95% CI 0.47 – 0.75) and 0.91 (0.73-1.15) on the mown treatment sub-catchment transects.



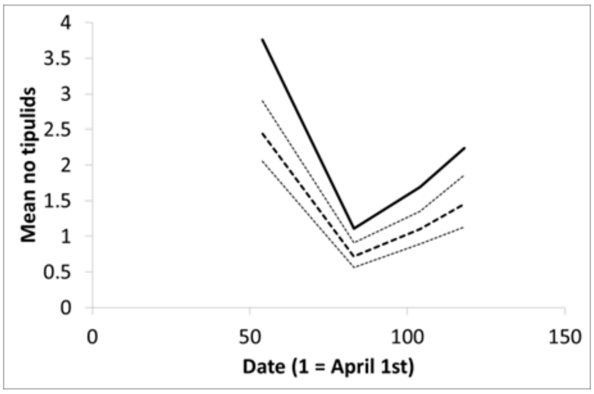


Figure A11.4 Modelled temporal variation in cranefly abundance in 2014 (**top left**), 2015 (**top right**) and 2016 (**bottom left**) on transects along burn sub-catchments (dotted-line) and mown treatment sub-catchments (solid-line). Estimates for the burnt were calculated from a model that tests for significant differences between mown and burnt, and hence 95% CI (thin lines) were only produced for the burnt sub-catchment data. When the treatment line fell outside the 95% CI, there was a significant effect of mowing.

Predicting impacts of treatment upon golden plover productivity and population change

The published golden plover model predicts daily survival of young (<9 day old, when most mortality occurs; Pearce-Higgins & Yalden 2004) golden plover chicks as a function of daily cranefly abundance. The daily predictions of cranefly abundance for treatment and control in each year described above were therefore used to predict daily golden plover chick survival, assuming a constant golden plover nesting phenology matching that from Pearce-Higgins (2011). Variation in daily cranefly abundance is a function both of the phenology of cranefly emergence and overall cranefly abundance. Both vary widely between years, for example as a result of variation in temperature (Pearce-Higgins et al. 2005, 2010), as shown by **Figure A11.4**. We therefore used predicted values of daily cranefly abundance from **Figure A11.2** to model the impact of treatment upon golden plover breeding success, after accounting for the background variation in cranefly abundance and phenology. Predicted productivity per 100 pairs was converted into a predicted population change from year n to year n+1 using the following formula: ln(population change) = 0.0111x-1.0336 (Pearce-Higgins, 2011), where population change is the count (n) in year (y+1) over the count in year y.

Significant increases in golden plover productivity on treatment vs control plots were predicted in all years (**Figure A11.5**; left), reflecting the differences in cranefly abundance. These differences were greatest in 2014, when overall cranefly abundance was lowest, and were too small to be meaningful in 2015 and 2016, when overall cranefly abundance was highest (**Figure A11.4**). The differences between years was consistent with the hypothesis that the effect of management upon cranefly abundance may be increasingly important in years of low overall abundance (when it is the main driver of productivity) rather than high overall abundance (when food is not limiting; Pearce-Higgins 2011). The same patterns were reflected in predictions of golden plover population change (**Figure A11.5**; right).

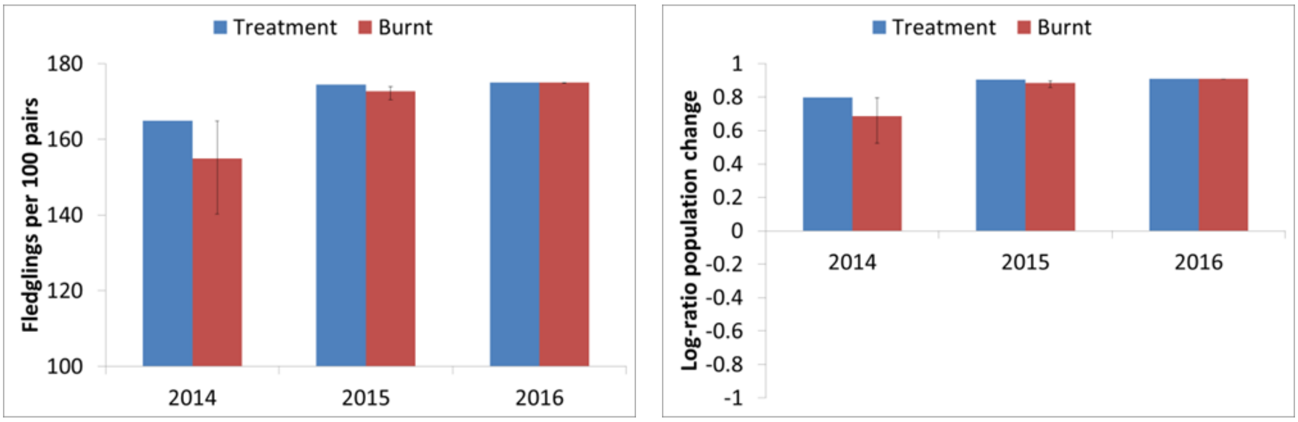


Figure A11.5 Modelled variation in golden plover productivity (**left**) and in golden plover population change (ln (n_{y+1}/n_y)) (**right**) based on modelled cranefly abundances across transects in treatment (mown) and control (burnt) sub-catchments, with annually varying background cranefly abundances and phenologies. The error bars for the control areas indicate 95% CI relative to the treatment estimates, and demonstrate significant differences in all cases.

Modelling the effect of moorland burning/mowing treatments on craneflies, vegetation height and golden plovers: report on analyses using 2014-16 data (Section 4.5.5.1 in main report)

(provided by Dr. David Douglas, Royal Society for the Protection of Birds, RSPB)

Aims

1. Analyse variation in cranefly abundance between burning/mowing treatments
2. Using treatment-specific values of cranefly abundance, predict golden plover productivity (the probability of a pair fledging young in each treatment)
3. Analyse variation in vegetation height between burning/mowing treatments
4. Using treatment-specific values of vegetation height, predict golden plover breeding density per treatment

Methods

1. Analyse variation in cranefly abundance between burning/mowing treatments

This used cranefly data from transects. These were 10 m transects but values are based on two counts per transects on each counting visit and the width of cranefly recording on the transects was in effect two people standing with outstretched arms (touching finger tips) and the effective survey width was therefore 4-5 m. The predictive model for aim 2 required data from 20 m transects, however as each transect was counted twice over an at least 4 m width, the obtained transect counts could be used.

Cranefly counts were analysed using a Generalised Linear Mixed Model (GLMM) in R 3.2.0, with poisson errors, log-link and count per transect as the response variable. Fixed effects were burning/mowing treatment, Julian date of count, a factor of plot/slope transects, air temperature on day of count, year and including two-way interactions of Julian date x year and treatment x year. Random terms were transect ID nested within site. This model was reduced to a Minimum Adequate Model by removal of non-significant terms (**Table A11.1**).

The final model showed a significant treatment effect on cranefly abundance (χ^2_1 = 9.40, P = 0.002), with no evidence that this treatment effect differed significantly between years (treatment x year χ^2_1 = 0.97, P = 0.614). Mean fitted counts per transect were: burning = 1.00, 95% CI = 0.92 – 1.07; mowing = 1.64, 95% CI = 1.51 – 1.77 (**Figure A11.6**). Thus mean cranefly abundance was estimated to be 64% higher within mowing treatments than burning.

2. Using treatment-specific values of cranefly abundance, predict golden plover productivity (the probability of a pair fledging young in each treatment)

This approach used a Minimum Adequate Model produced by Douglas and Pearce-Higgins (2014), which relates the probability of a pair of golden successfully fledging young to cranefly abundance. Parameter estimates from this model were combined with treatment-specific means of cranefly abundance from the current study, using appropriate transformation for predicting probabilities bounded between 0 and 1. The probability of a pair fledging young within the burning treatment was predicted to be 0.55, 95% CI = 0.53 – 0.58, and within the mowing treatment as 0.73, 95% CI = 0.70 – 0.76 (**Figure A11.7**). Thus fledging probability per pair was predicted to be 33% higher in the mowing treatment based on higher modelled cranefly abundance.

3. Analyse variation in vegetation height between burning/mowing treatments

This approach used data from the plot vegetation dataset, which should be useful for a scenario of up-scaling management impacts. Vegetation measurements were made in plots in 2016, but not in 2014 and 2015. Comparable average values per plot for 2014 and 2015 were based on best estimates of expected vegetation height (NB for a few plots this yielded negative estimates of height <0cm and these were coded as 0 cm for analyses). See below final section on vegetation height assessment.

Modelling was carried out using a Generalised Linear Model with Normal errors, identity link and vegetation height per plot as the response variable. Explanatory terms were treatment, site, block ID, plot/slope transect, plot number, year and including a two-way interaction of treatment x year (**Table A11.2**). This showed that vegetation height did not differ significantly between treatments ($F_{1,233} = 0.64$, $P = 0.424$). Mean height predicted in treatments was: burning = 27.6cm, 95% CI = 25.1 – 30.1; mowing = 27.6cm, 95% CI = 26.2 – 28.9 (**Figure A11.8**).

Note that although there were two broad treatments (burning and mowing), the mowing sub-catchments included a range of plot-level treatments. A coarse assessment of vegetation height between mowing treatments (T) suggested variation that may be masked by a simpler burning versus mowing assessment:

Burn (C) = 28.4 cm, T = 38.3, T1 = 21.2, T2 = 39.1, T3 = 21.7, T4 = 23.7, T5 = 22.7

Where treatments were allocated (in a random order) to:

C	Burnt (FI)
T1	Mown with brash left (LB)
T2	Uncut (DN)
T3	Mown with brash removal + Sphagnum (BRSp)
T4	Mown with brash left + Sphagnum (LBSp)
T5	Mown brash removal (BR)

It may therefore be useful to consider which plot-level mowing treatments were appropriate to assess separately.

4. Using treatment-specific values of vegetation height, predict golden plover breeding density per treatment

This approach uses a Minimum Adequate Model produced by Douglas and Pearce-Higgins (2014), which relates the breeding density of golden plover to vegetation height (controlling for altitude). Parameter estimates from this model were combined with treatment-specific means of vegetation height from the current study, assuming a standard 420 m altitude across treatments (median of 390 – 450 m range). Predicted breeding densities were back-transformed using an exponential transformation to ensure predicted count values were non-negative. Predicted breeding densities within the burning treatment were 0.33 pairs km^{-2}, 95% CI = 0.20 – 0.53, and within the mowing treatment were 0.33 pairs km^{-2}, 95% CI = 0.25 – 0.43 (**Figure A11.9**).

It should be noted that modelled vegetation heights in the treatments are relatively high compared to the study of Douglas & Pearce-Higgins 2014 (**Figure A11.10**), reflected in the low predicted breeding densities. Also, predictions were being extrapolated just beyond the range of vegetation height values from Douglas & Pearce-Higgins (2014) and should be treated with caution. However, considering individual mowing treatments may mean that average vegetation heights from some of these (see **Figure A11.11**) lay within the range of vegetation height values of Douglas & Pearce-Higgins (2014), allowing more robust predictions of breeding density to be made for some treatments.

Table A11.1 Output of GLMM analysing potential treatment effects on cranefly abundance. Plot/slope refers to transects along plot or slope areas within the burnt or mown sub-catchment.

Term	df	Chi-sq	P
Date†	1	115.18	<0.001
Treatment	1	9.4	0.002
Plot/slope	1	8.86	0.003
Air temp	1	84.58	<0.001
Year	2	22.25	<0.001
Date x Year	2	19.88	<0.001
Terms dropped:			
Treatment x Year	2	0.97	0.614

†This term was estimated from model in which Date x Year had been dropped

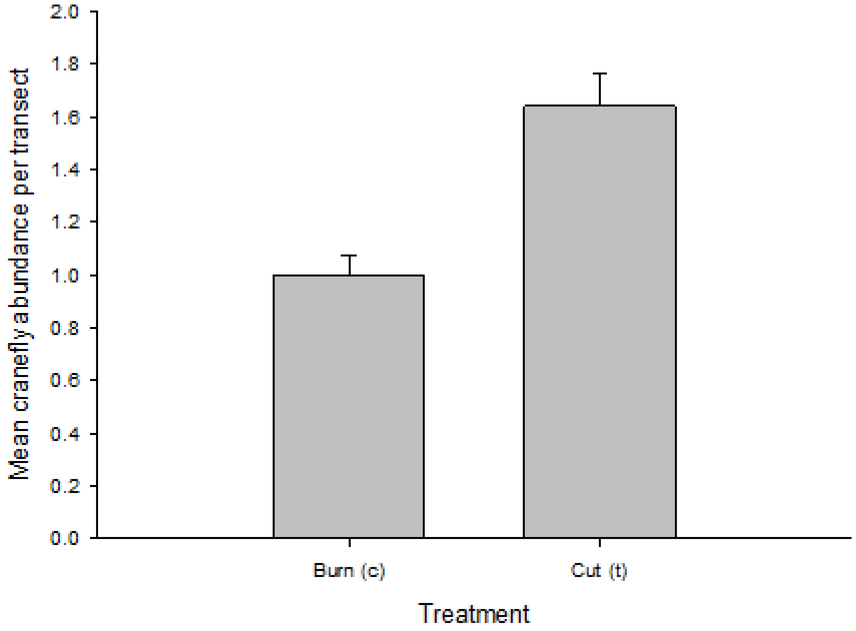


Figure A11.6 Mean cranefly abundance per sub-catchment transect under burning or mowing (cut) treatments; values predicted from GLMM.

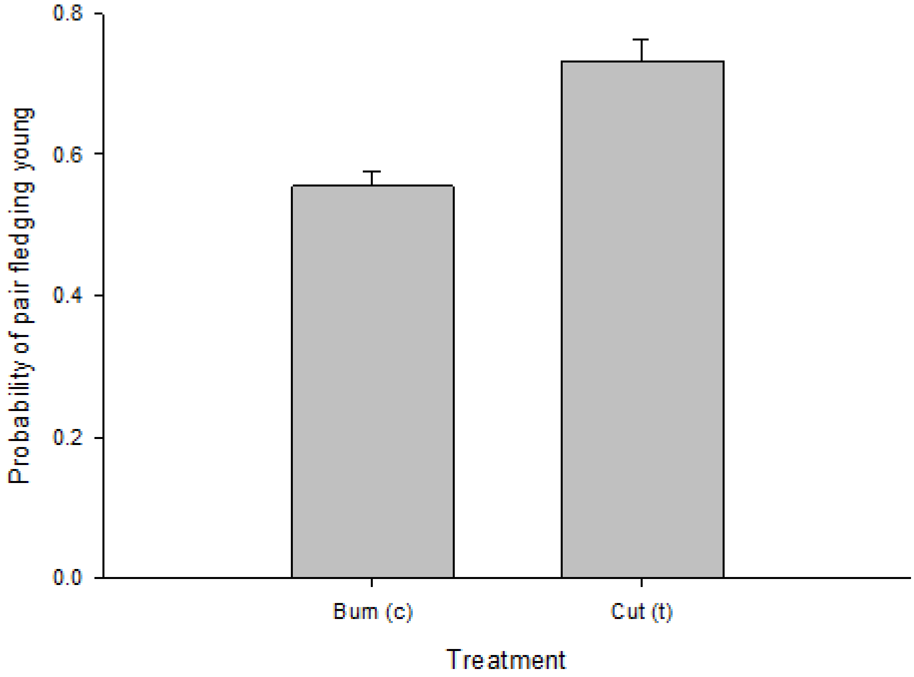


Figure A11.7 Predicted probability of a pair of golden plover successfully fledging young, based on treatment-specific values of cranefly abundance for either burnt or mown (cut) sub-catchments.

Table A11.2 Output of GLM analysing potential treatment effects on vegetation height. Plot/slope refers to transects along plot or slope areas within the burnt or mown sub-catchment.

Term	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	1	58	58	0.64	0.424
Site	2	3350	1675	18.49	<0.001
Block	3	1820	607	6.70	<0.001
Plot/slope	1	7735	7735	85.38	<0.001
Plot number	27	5252	195	2.15	0.001
Year	2	8129	4065	44.87	<0.001
Residuals	233	21109	91		
Non-significant terms dropped:					
Treatment x Year	2	10	5	0.05	0.949

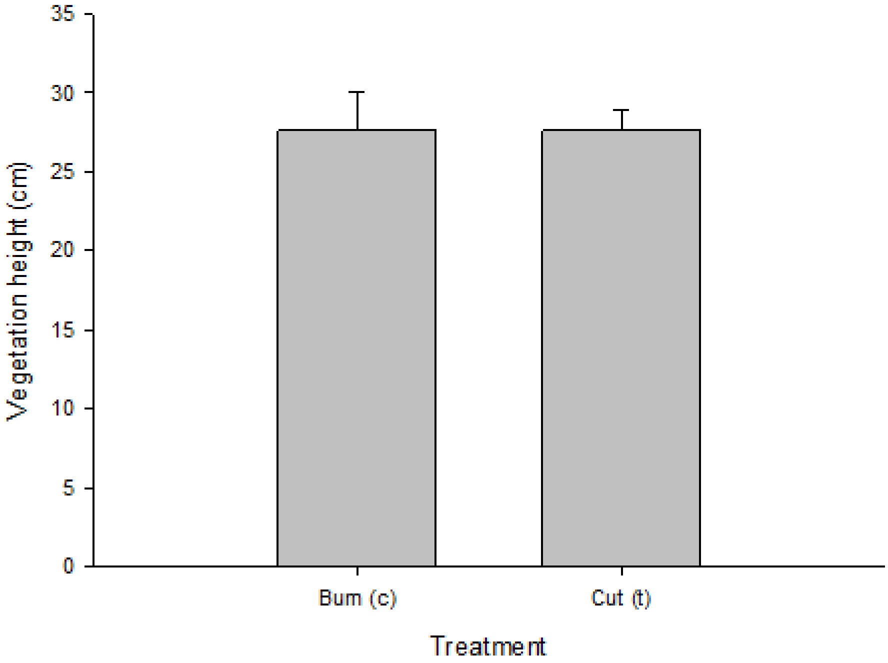


Figure A11.8 Mean vegetation height in burnt or mown (cut) treatment sub-catchments based on slope and plot level information as predicted from GLM.

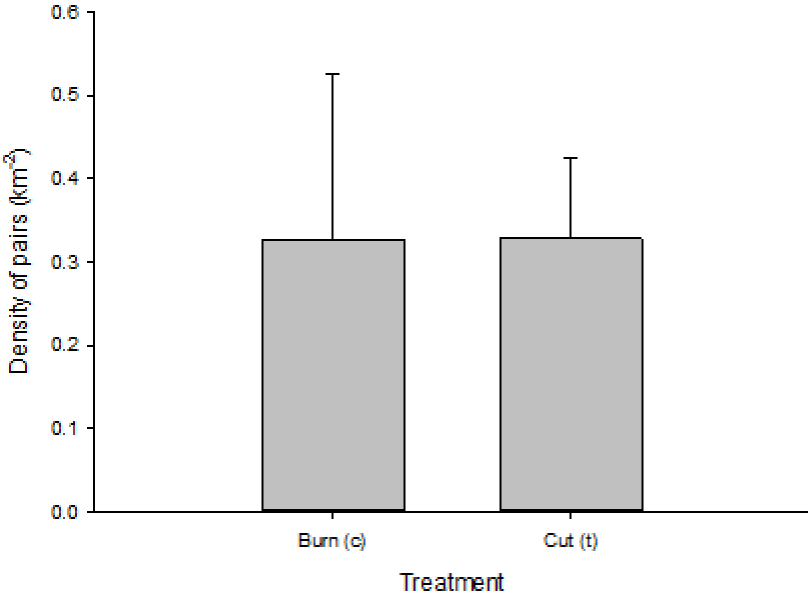


Figure A11.9 Predicted golden plover breeding density between treatments based on modelled vegetation height across either burnt or mown sub-catchments including plot and slope vegetation height information.

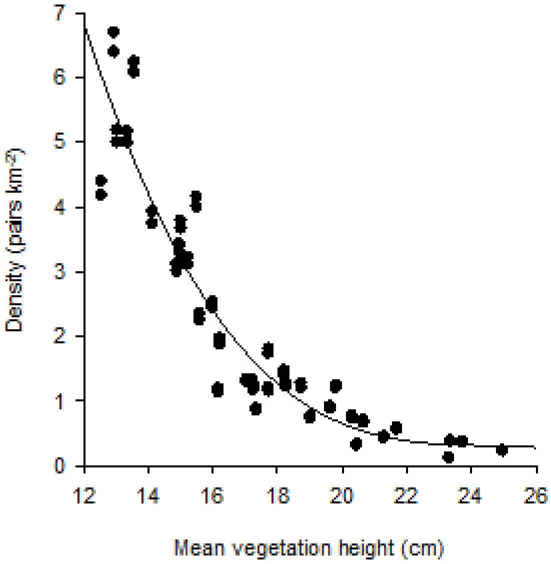


Figure A11.10 Relationship between golden plover breeding density and mean vegetation height within 1-km^2 survey squares, reproduced from Douglas & Pearce-Higgins (2014).

Vegetation height:

Vegetation height was measured in 2016 to the nearest cm at equal distances into the middle of plots and down each side of the slopes (slope transect) and along transects to and from plot areas as shown in **Figure A11.11**. Height (in cm) was measured with a 1 m ruler at the point where the ruler was placed (at about equal distances along each stretch). For plots this was a total of 20 points (4 stretches of 5 points), for transects this was also 20 (2 stretches of 10 points alongside the monitoring areas). For grasses the top of the seeds was measured standing them up if they were leaning over from moisture. For sedges, height was taken for vertical stems not ones that were leaning over. Height of heather and rushes was measured at the point where the ruler was placed. Vegetation heights for 2015 and 2014 had to be estimated based on correcting the 2016 data for growth rates observed across each plot. This used recorded heather heights and height estimates for other vegetation (grass/sedge) using the photographs taken at each plot (with the known maximum heather height as a scale). For transects, the growth rates for either burnt, mown or uncut areas were used for the respective management at each slope location. The average reductions per management per site were applied to each plot assuming similar growth rates applied across all plots.

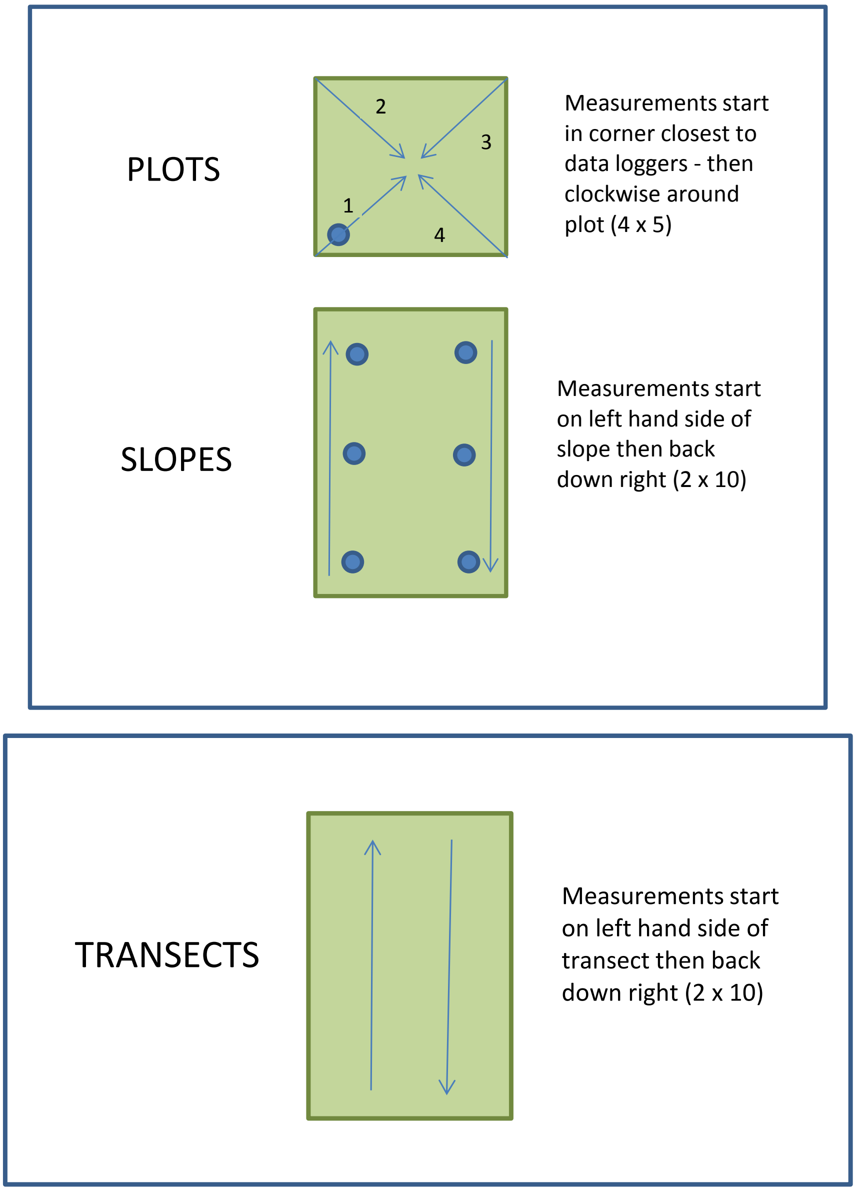


Figure A11.11 A schematic diagram of the way vegetation height was recorded at the (**top**) plots and slope transects and the (**bottom**) transects to and from monitoring plot areas (blocks each containing five plots). In each instance a total of 20 vegetation height point measurements were made.

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