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Department for Environment Food & Rural Aff

Evidence Project Final Report

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Project identification

1. Defra Project code: BD5210
2. Project title: Effects of winter-long provision of seed-rich habitats on seed-eating farmland birds
3. Contractor organisation(s): Royal Society for the Protection of Birds
4. Total Defra project costs (agreed fixed price): £ 249,212
5. Project: start date 01/04/2012
   end date 31/10/2015

6. It is Defra's intention to publish this form.

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

1. The loss of seed-rich habitat from agricultural landscapes has been one of the main drivers of widespread population declines affecting farmland birds across the UK and Europe. Conservation measures designed to provide winter seed for seed-eating birds (like wild bird seed mixtures) are usually depleted of seed well before the end of winter leaving a late-winter 'hungry gap'.

2. Allowing ryegrass (Lolium spp) to flower and set seed has recently been developed as a conservation measure to provide winter seed and potentially fill the 'hungry gap' in early spring (Buckingham et al. 2011). However, the seeded ryegrass (SRG) option has only been tested in a relatively intensive mixed farming context (West Midlands of England), and the potential impact of SRG provision on target bird populations is untested. This study aimed to test the feasibility of adopting SRG as a conservation measure across a pastoral-dominated landscape, and whether SRG provision in combination with other seed-producing measures, could have a positive impact on population growth of priority bird species.

3. The study was conducted in the pastoral landscape of North Wales where the extent of arable cultivation is limited and where background levels of seed-providing conservation measures are low. Two experimental treatments plus a control were provided at the tetrad scale: wild bird seed mixture (WBSM) only (=SINGLE), a combination of WBSM and SRG (=MIXED) and a control entailing no provision of seed-rich habitat. For each experimental treatment, the target area of seed-rich habitat provision was 2% of all potential breeding and wintering habitat in the tetrad. If lack of late winter seed was limiting overwinter survival and recruitment of seed-eating birds, we predicted the MIXED treatment would generate more positive population growth than the SINGLE or CONTROL treatments. If lack of early winter seed was limiting overwinter survival and recruitment then we predicted the SINGLE treatment would generate more positive population growth than the CONTROL. The original aim was to replicate the two treatments plus the control across three study areas (three triplets). Problems with recruiting land owners/managers into the project resulted in a final design of two triplets (providing all three treatments) plus two doubles (one provided MIXED plus control, the other providing SINGLE plus control treatments). The treatments were imposed for either three (one triplet, both doubles) or two (one triplet) successive winters. Yellowhammer (red-listed in the UK and Wales, and included on Section 41 and 42 lists of priority species in England and Wales respectively) was the main target species for the interventions in North Wales.

4. The average area of WBSM and SRG established was only 17% (SINGLE) and 52% (MIXED) of target in the first winter, but was higher in the second and third winters (SINGLE: 34% & 33%; Mixed: 93% & 89%, respectively). During the second and third winters the area of treatment delivered was relatively consistent across study areas, although there was a larger area of WBSM in the Llyn study area (maximum difference between areas was 47% & 100% during the two winters). The reluctance of some farmers to devote areas of improved grassland for SRG was associated either with a lack of suitable grassland on the farm and/or the high perceived agronomic value of this limited land use. Some farmers were worried about producing insufficient animal feed (grass silage) to support their animals through the winter, a concern that was exacerbated by unusually severe cold weather during the first winter of the study when supplies of animal feed ran low. The average loss of silage yield associated with the SRG treatment across 10 plot-years was 12% (mean silage yield on SRG plot = 3.6 t DM / ha compared to 4.1 t DM / ha on control plots) with no detectable impact on D-value. This compares to a 26% loss of yield

measured on more productive swards in the English West Midlands.

5. Seed abundance (but not weight) on WBSM plots varied between winters and study areas (being four times higher in the Llyn study area compared to the Dyfi). Nearly all (98%) WBSM seed present in October had disappeared by January. Seed yield on SRG plots varied between winters and study areas, and seed head density was nearly twice as high on plots that were closed (mainly to grazing) between mid-May and mid-June. Compared to perennial ryegrass (PRG), Italian ryegrass (IRG) produced significantly heavier seeds and a higher density of accessible seed heads, and retained a higher proportion of accessible seed heads through until January. Seed head density on PRG swards was positively related to the cover of ryegrass in the swards, and only exceeded 200 heads per m^2 (for which the predicted probability of usage by yellowhammers was 0.41) on 1 out of 8 intervention plots. Ryegrass cover probably needs to exceed 75% on PRG swards in order to produce a seed head density likely to attract foraging birds (i.e. >300 seed heads per m^2, equivalent to a usage probability of 0.67) but only 3 out of 8 PRG intervention plots exceeded this 75% threshold. Two out of three Italian ryegrass plots produced seed head densities exceeding 500 per m^2 (predicted probability of usage = 0.85) and these plots were consistently used by foraging birds. Ryegrass seed head density, and retention of seed heads into January, was lower in North Wales than in a previous study in the West Midlands. This regional difference in seed yield and retention could have been a consequence of insufficient ryegrass cover, grazing rather than mowing management prior to sward closure or the cooler, damper growing conditions in Wales.

6. Intervention crops (WBSM & SRG) supported higher densities of foraging yellowhammers and reed buntings than any other habitats in the landscape and, together, accounted for 60% and 90% respectively of all winter foraging records in the North Wales landscape. Chaffinches made less usage of intervention crops (restricted mainly to WBSM) which accounted for 16% of all winter foraging records. Usage of WBSM by buntings declined markedly between early and late winter, while usage of SRG was sustained through late winter. Usage of intervention plots by yellowhammers was positively related to seed head density, and for WBSM to seed density.

7. Bunting faecal samples confirmed that cereal and grass seeds dominated the winter diet. Broad-leaved weed seeds were also common in the diets of reed buntings. For both species, the importance of cereals declined during late winter while the importance of grass seed increased. The winter body condition of buntings in North Wales was similar to that recorded in two relatively food-rich arable and mixed farming landscapes in England. The body condition of individual yellowhammers increased with the proportion of grass seed remains in their faeces, suggesting that an abundant local source of grass seed allows body weight to be maintained.

8. All 30 within-winter movements of colour-ringed yellowhammers were less than 1.5 km, while 4 out of 5 winter-to-breeding season movements were within 3.5 km, suggesting this species is relatively sedentary in North Wales.

9. Breeding yellowhammers selected bracken and gorse habitats typical of Welsh ffridd, while woodland and improved grassland were avoided. Yellowhammer nests proved difficult to locate on ffridd habitats and the available staff time proved insufficient to measure breeding success.

10. There was no evidence that the experimental provision of seed-rich habitats affected changes in abundance of breeding yellowhammers. This was true of both treatments after allowing for variation in distance of breeding localities from intervention crops and for variation in the quantity of seed produced on intervention crops. Between 2012 and 2015 the abundance of breeding yellowhammers declined by 31% across all 92 tetrads included in the study.

11. Conclusions. This study has clearly demonstrated that both intervention crops provided important winter foraging habitats for seed-eating birds in the pastoral-dominated landscape of North Wales. SRG was particularly important during late winter when seed resources on WBSM had been exhausted. IRG was a much more reliable source of grass seed, and was more heavily used by foraging birds, than was PRG. Provision of seed-rich habitats had no effect on the abundance of breeding yellowhammers even in areas such as the Llyn Peninsula where target areas of seed-rich habitat were successfully deployed over two successive winters. These findings suggest that populations of breeding yellowhammers in North Wales are probably limited by factors other than winter seed availability.

12. Recommendations. Further work is needed to identify the full range of factors affecting seed yield from PRG swards. As a provisional 'rule-of-thumb', the SRG option should probably only be deployed on PRG swards where the cover of ryegrass is at least 75%, and the sward was sown within the last 5 years. IRG and hybrid ryegrasses provide a more predictable source of winter seed for farmland birds; seed yield on IRG plots remained high at just 52% ryegrass cover and with closure dates as late as mid-June. Seed yields are expected to decline as IRG swards age although in this study large, abundant seeds were produced in third winter IRG crops. Further work is needed to identify the factors limiting the breeding densities of yellowhammers and other priority farmland birds in pastoral-dominated landscapes. Given that factors limiting farmland bird population size may vary between regions or landscapes, conservation efforts should aim to provide a suite of potentially limiting resources (i.e. packages) rather than focus on a single category of resource that is considered to be limiting in some landscapes.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the objectives as set out in the contract;
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   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Exchange).

1. Background and objectives

The loss of seed-rich wintering habitat and associated reduced over-winter survival rates is considered an important driver of population declines amongst seed-eating farmland birds (Robinson & Sutherland, 2002; Peach et al., 1999; Siriwardena et al., 2007). In Western Britain regional agricultural specialisation has resulted in landscapes dominated by grassland, where seed-eating bird species have been subject to high rates of local extinction (Chamberlain & Fuller 1999). In this region, grassland intensification and loss of arable crops, notably cereals, have greatly reduced winter seed resources (Evans et al., 2004). Furthermore, modern agricultural management aims to prevent grassland from producing seed (Hopkins, 2001), and thus seed-eating birds are largely absent from grassland in winter (Buckingham et al., 1999, 2006; Perkins et al., 2000; Wilson et al.1996). The sensitivity of seed-eating farmland bird densities to relatively small areas of seed-rich habitat in grassland-dominated landscapes probably reflects the lack of seed resources on livestock farms (Robinson et al. 2001).

Traditional conservation measures for seed-eating farmland birds, such as low input cereal stubbles and wild bird seed mixtures (WBSM), are often depleted of seed by late winter and may therefore leave a late winter 'hungry gap' when seed availability continues to limit overwinter survival (Siriwardena et al. 2008). A potential solution to this is to allow existing ryegrass (*Lolium*) swards to produce seed. A pilot study (Buckingham & Peach, 2006) and a replicated trial (Buckingham et al. 2011) show that abundant seed can be produced from perennial and Italian ryegrass swards as long as defoliation is prevented after key cut-off dates. Seed remained abundant on seeded plots throughout the winter, and bird usage was sustained until March and beyond (Buckingham et al. 2011). Birds whose winter diet was dominated by ryegrass seed had a similar body condition to those on high quality seed-rich habitats in arable-dominated areas, suggesting that ryegrass seed does provide an adequate diet. On the basis of this evidence, in 2013 Defra adopted seeded ryegrass (SRG) as an option within the Entry Level Stewardship scheme in England.

While previous studies demonstrate the utility of SRG as a food resource for seed-eating birds and have clarified some key management requirements, there has been no assessment of the effectiveness of this measure as a means of filling the late winter hungry gap or of any consequent impacts on bird breeding population size. There has also been no assessment of farmer attitudes to the implementation of an SRG conservation measure on livestock farms. The broad aim of this study was to assess whether the provision of SRG can fill the late winter 'hungry gap' in pastoral landscapes, where seed-rich habitat is otherwise lacking and where seed-eating farmland birds have undergone a large population decline. The study area was North Wales. Yellowhammers (YH) have declined by 57% in Wales between1995 and 2014 (Harris et al. 2015), resulting in marked range contraction and an increasingly fragmented distribution (Balmer et al. 2015). Specific objectives of the current study were as follows:

1. To assess the practicality of providing WBSM and SRG in a pastoral landscape at a scale that has the potential to generate population growth
2. To assess the impact of WBSM and SRG on the foraging, diet, body condition and survival of seed-eating farmland birds
3. To assess the impact of winter seed provision on the breeding productivity of yellowhammers in Welsh pastoral landscapes
4. To test whether population growth of seed-eating farmland birds is dependent on the provision of seed-rich habitats during early or late winter
5. To measure any agronomic impacts of allowing ryegrass to set seed on silage production in the following year

Here we report on all of these objectives except objective 3 which proved impractical due to the difficulty in finding sufficient nests.

2. Methods

2.1 Experimental design

In order to ensure landscape-scale variation in the type and extent of the winter seed resources, we manipulated the availability of seed-rich habitat at the British national grid-based tetrad (2 x 2 km) scale. This reflected the approximate scale over which YH are expected to range during the year (Siriwardena 2010). In 2012 we established a trio of experimental treatments; two of these involved tetrad-scale interventions ('Single' = WBSM only; 'Mixed' = WBSM plus SRG) while the third was a control (no intervention). The Single treatment provided an assessment of the adequacy of the existing UK agri-environment measure for seed-eating birds in grassland dominated landscapes, with WBSM being available in Wales through the Glastir agri-environment scheme (AES). The Mixed treatment was intended to assess the potential benefits of providing additional seed from SRG especially during late winter. Control tetrads contained low background levels of seed-rich habitat.

This design allowed us to evaluate the following predicted treatment outcomes. If lack of late-winter seed limits overwinter survival and population size of Welsh farmland birds (i.e. the 'hungry gap' is important), then we might expect sustained usage of seeded ryegrass plots during late winter, enhanced late-winter body condition and increased abundance of breeding birds under the Mixed treatment. If, on the other hand, alternative sources of seed allow birds to survive the late winter period then we might expect no difference in late winter body condition and population changes between Single and Mixed treatments. In this case, the wider habitat assessments (below) should identify the key late winter foraging habitats. Comparing the Mixed treatment with the control will indicate whether WBSM provision alone can enhance breeding abundance.

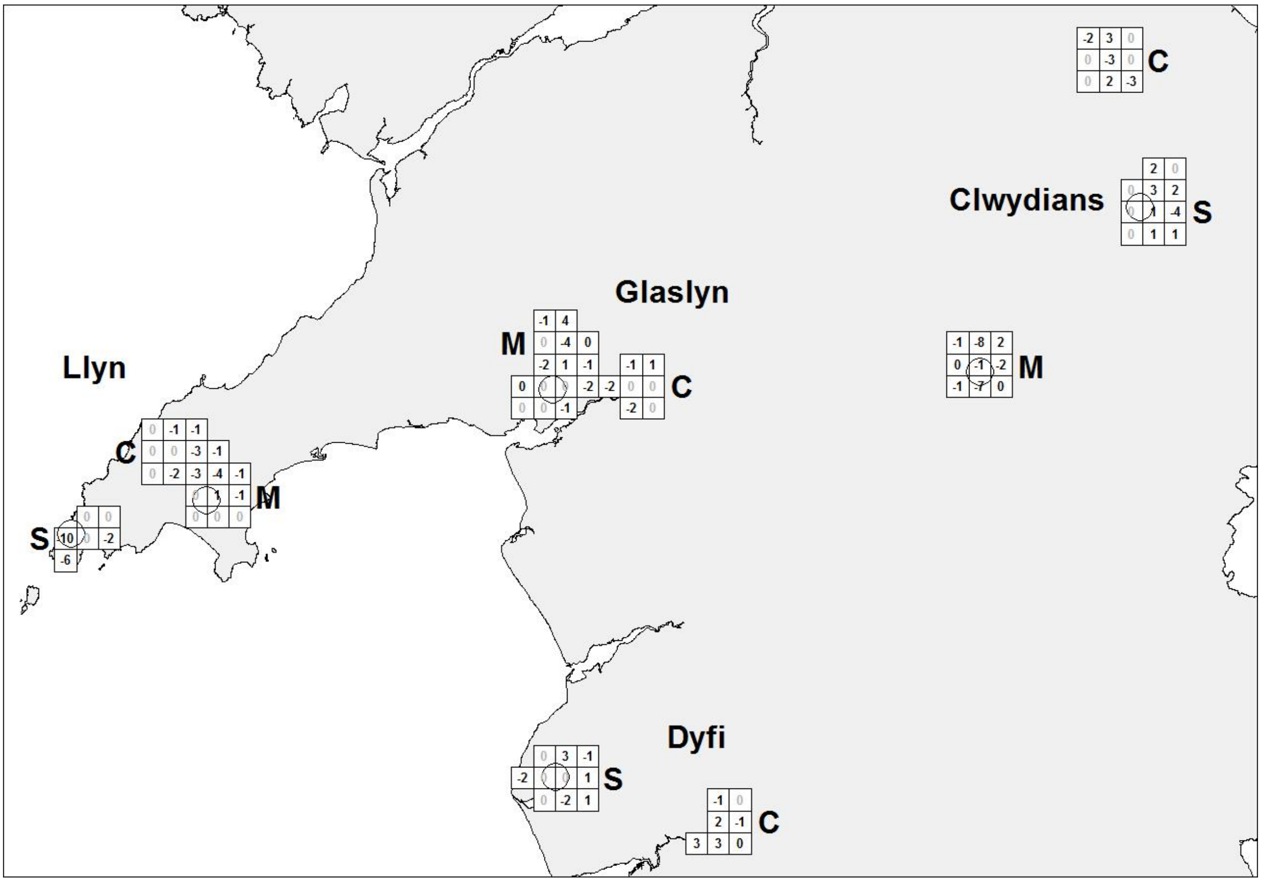
Triplets of experimental tetrads were initially replicated across three geographic regions in North Wales (Llyn – West Gwynedd, Glaslyn – mid Gwynedd, Dyfi – south Gwynedd; Fig 1). In 2013 we established an additional triplet (Clwydians - Denbighshire) because of poor farmer recruitment in two study areas (Dyfi Mixed and Glaslyn Single). The farmers in these two areas were reluctant to devote any of their limited area of productive land to our experimental measures due to fears of having insufficient animal feed over winter. We retained the Dyfi and Glaslyn control tetrads for comparison with remaining treatment tetrads in those regions, so the resulting design comprised six intervention and four control tetrads spread over four regions (Fig. 1). This modest replication reflected the relatively high cost of establishing landscape-scale treatments. These regions are known to support important remnant populations of YH and included improved land, ffridd (a Welsh term for semi-natural habitat mosaics characterised by bracken and gorse) and mountain pasture. Ffridd is a breeding habitat favoured by YH in Wales (Brenchley et al. 2013). Farming was dominated by sheep production with some suckler beef cattle and dairy units, and grass silage was a common form of cropping on improved grassland. Intervention tetrads within each triplet were spaced at least 2 km apart (to minimize any movements of birds between treatments) but no more than 10 km apart (to ensure landscape similarity), and were selected to be similar with respect to habitat character, farming system and physical relief. Treatments were allocated to tetrads at random.

2.2. The practicality of providing WBSM and SRG in a pastoral landscape at a scale that has the potential to generate avian population growth

Within each intervention tetrad, we aimed to provide seed-rich crops at a density of approximately 2% of potentially suitable breeding or wintering habitat (i.e. ffridd plus improved farmland). This scale of provision is as recommended under the Farmland Birds Package for seed-rich habitat (Winspear et al. 2010), and is based on experience in mixed/arable farmland that contains higher densities of seed-eating birds than pastoral-dominated landscapes. A lower level of provision might therefore be adequate in pastoral landscapes. Allowing for the presence of unsuitable habitats like woodland and upland pasture (assessed using Phase 1 NVC data) we estimated an average of 6.7 ha of seed-rich crop was required in each intervention tetrad to meet this target (i.e. an average of 1.7 ha per km^2 or 1.7% of the landscape).

We contacted around 80% of the farmers in each intervention tetrad. Face-to-face meetings were conducted to discuss management proposals and farmer responses were recorded. Formal management agreements were drawn up between RSPB and participating farmers. Annual payment rates were £525 and £700 per ha for WBSM and SRG respectively in 2012, rising to £700 per ha for both options in 2013 & 2014. WBSM was established annually in spring under agreements which specified the use of fertiliser and (where necessary) lime. SRG crops received normal early season fertilizer applications and were established through the cessation of grazing or mowing and leaving swards undisturbed from mid-late May until the following March, when any accumulated vegetation was removed by grazing (Buckingham et al. 2011). SRG plots were largely perennial ryegrass (PRG) although some were Italian ryegrass (IRG).

Figure 1. Breeding survey and intervention tetrads. Values in squares show change in territory abundance between 2012/13 and 2015 (values in grey indicate zero counts during both surveys). Treatments in each region are indicated by S (single), M (mixed) and C (control). The mean locations of intervention crops are shown as open circles.



2.3. The impact of WBSM and SRG on the foraging, diet and body condition of seed-eating farmland birds

Seed yield and retention was measured on 6, 22 and 24 WBSMs and on 4, 6 and 10 SRG plots during the three study winters (52 WBSM and 20 SRG plot-years, respectively), with measurements taking place during October and January. The plots were evenly distributed across all intervention tetrads. On each WBSM and SRG plot in October, we measured the density of seed-bearing cereal and grass inflorescences within ten 50cm x 50cm quadrats distributed along two parallel transects located in the centre of each plot. These standing inflorescence counts distinguished different cereals (e.g. oats and triticale) and different grass genera (e.g. *Lolium, Phleum, Festuca, Holcus, Alopecurus, Arrhenatherum* and *Poa*). Ten crop seed-heads were collected at random from each of the ten quadrats, dried in the lab, threshed, seeds removed, counted and weighed. Visible fallen seed on the ground was counted within twenty 10cm x 10cm quadrats. Vegetation height (4 HFRO sward stick measures) and cover were measured at five of the ten quadrat locations. Vegetation cover was measured using a gridded quadrat of side 0.7m, subdivided into 49 grid squares of side 10cm. The number of occupied grid squares (>= 25% cover within each grid square) was counted for the following categories: all grass, all forbs, bare ground, *Rumex, Cirsium/Carduus, Rannunculus, Stellaria & Poa annua*. In a separate one-off exercise in February 2015, the same gridded quadrat method was used to measure the percentage cover of ryegrass on all 11 SRG intervention plots plus 5 additional improved ryegrass fields recruited to the study in 2014. The assessment was based on vegetative features and was conducted by an expert botanist who surveyed 20 such quadrats on each of the 16 plots / fields. We used these data to test whether variation in seed yield across SRG plots was related to the proportion of ryegrass persisting in the swards.

In January, the same procedure was followed for WBSM. A different procedure was followed for SRG plots where most available seed is located in areas of exposed lodged vegetation (Buckingham et al. 2011). Here we estimated the cover of five different sward structural components: standing seed heads, exposed lodged seed head mats, concealed lodged seed head mats, bare ground and vegetative grass without seed heads. Within each category, 10 randomly selected ryegrass seed heads were assigned to three classes based on the number of spikelets that still held seed: 0, $\leq$5 and >5 seed-bearing spikelets identified by feeling the spikelets between thumb and forefinger (Buckingham et al. 2011). Seed heads were missing from many culms, so we estimated percentage losses for each category.

Bird usage of seeded plots was assessed on multiple occasions during each winter (4 in winter 2012-13, 7 in winters 2013-14 & 2014-15) spread evenly between late October and mid March on 5, 16 and 16

WBSM plots and on 3, 6 and 8 SRG plots each winter (37 and 17 plot-years respectively). Survey plots were evenly distributed across all intervention tetrads. Usage was assessed by counting all birds using plots during a 45-minute period (starting between 0800 and 1300 hours), followed by a flush transect to ensure all birds on the ground within plots were recorded. Seed-eating birds in adjacent boundaries were also included. Usage of seeded plots was compared against usage of control plots comprising of improved grass, located nearby and having a similar boundary type. We attempted to check all YH for colour-rings.

Wider habitat usage by seed-eating passerines was assessed by recording distribution of birds along fixed transects 2 km in length per tetrad, that passed through landscapes dominated by enclosed farmland. Birds on the ground and in field boundaries were recorded within 50 m of the transect line. Transects traversed field types typical of local farmland and included at least one example of each intervention type along its length, as well as other potential sources of seed (farm yards, gardens, fields with supplementary fed out-wintered stock, arable crops). Data were collected as follows: 4-6 visits to six transects (winter 2012/13), 7 visits to 15 transects (2013/14), 7 visits to 17 transects (2014/15). All visits were evenly spread between early November and mid March. We attempted to check all YHs for colour-rings.

Body condition and diet of YH and reed buntings (RB) was assessed by catching birds in localities under all three treatments during winter. Catching effort was targeted in intervention tetrads in two study regions (Llyn and Glaslyn). Birds were caught at WBSM and SRG plots, and at other locations such as gardens. We attempted to catch birds during early (Nov-Dec) and late (Feb-March) winter. All birds caught were measured and weighed, with faecal samples obtained while birds were held in cloth bags. YH were fitted with colour rings, allowing subsequent identification of individuals seen in the field.

2.4. Testing whether population growth of seed-eating farmland birds was influenced by the provision of seed-rich habitats during early or late winter

We measured change in the breeding abundance of seed-eating passerines using standard breeding bird surveys. Baseline surveys were conducted in 2012 and 2013, covering 92 tetrads spread evenly across the four study regions and known to have recently been occupied by YH. Each tetrad was surveyed twice between mid-April and mid-August following the field methods developed by Wotton et al (2010) for cirl buntings. A single observer surveyed all suitable breeding habitat (mainly farmland and ffridd) by walking to within 100 m of any potential nesting habitat and recording all farmland passerines using standard activity, age and sex codes. Surveys utilized public rights of way and open access, supplemented by access permissions where necessary, and the recording of survey routes enabled comparable repeat survey in 2015. For most tetrads, both surveys were conducted by the same individual surveyor. The following broad habitat categories were mapped in each tetrad during both baseline and repeat surveys: bracken, gorse, heather, semi-natural grass, improved grass, arable and yards/gardens. The surveys covered landscapes dominated by improved farmland, ffridd and mountain pasture. Survey results were expressed in two ways. First, the number of records of males and females showing evidence of breeding (e.g. singing male, adult with food and family group) averaged across the two surveys in each year, and second, the number of presumed territories each year, where records of breeding behaviour greater than 200 m apart were assumed to come from different territories. Territories spanning tetrad boundaries could potentially have been counted twice. To avoid this, we assigned such territories to the tetrad containing the majority of records on which they were based. These surveys allowed us to test whether our experimental treatments had differential impacts on the local abundance of breeding birds. The habitat recording allowed us to consider breeding habitat associations of key species, and consider the extent to which available breeding habitat may have been limiting distribution.

2.5. Agronomic impacts of allowing ryegrass to set seed on silage production in the following year

The impact on subsequent silage yield of allowing ryegrass to set seed and remain undisturbed during winter may depend on sward composition and restoration method (Buckingham et al 2011). We therefore gathered data on silage yields to inform AES option development and costing. Just prior to mowing in May, the standing crop of grass was cut by hand within four 1m x 1m quadrats in the SRG plot, and in another four quadrats in an adjacent control plot subject to typical silage-aftermath grazing during the previous year. SRG and control plot pairs were evenly distributed across the three intervention tetrads and between years. Fresh and dry weight of grass were recorded for each of the four quadrat samples, while a single D-value was measured for each plot (from a combined plot sample). Four sward samples were obtained from 7 treatment/control plot pairs in each of 10 plot-years (one plot-pair contributed data in two years and one in three years).

2.6. Statistical Analysis

Sources of variation in seed head density and seed yield were assessed for WBSM and SRG separately using a generalised linear mixed model (GLMM) with a normal error distribution. Plot identity was fitted as a random factor to allow for multiple measures within plots and repeated usage of plots across years. Fixed factors included winter, region and cereal mix (4 level factor: barley, barley/oats mix, oats and oats/triticale mix and triticale) plus associated interactions. For SRG, plot identify was fitted as a random effect and fixed factors included winter, region, closure date (2 level factor: within 2 weeks of target closure date or outside this, 7 early, 2 late), sward age (2 level factor: $\leq$5 or >5 years since reseeding) and grass type (2 level factor: PRG or SRG) plus associated interactions. Retention of seed within SRG crops was assessed by comparing percentage losses between October and January using univariate GLMMs with plot identity specified as random. Similar analyses compared vegetation and seed variables between plots in North Wales and comparable data for plots in Shropshire (Buckingham et al. 2011). Percentages were arcsin square root transformed.

Analyses of bird plot usage were conducted for the two bunting species (YH and RB) and summed buntings (BU) as species of conservation concern, and for chaffinch (CH) as an example of a widespread seed-eating species not expected to benefit from SRG. Analyses tested whether plot usage varied between treatments (WBSM, SRG and control) and between early (before 1 January) and late (after 1 January) winter, after allowing for any winter or region effects. Analyses involved fitting GLMMs with a Poisson error distribution and the natural logarithm of the area watched fitted as an offset variable. Plot identity, which linked intervention and adjacent control plots, was fitted as a random factor. Models were rescaled to correct for over dispersion when χ^2/df exceeded two.

For analysis of wider habitat usage, counts of birds within 50 m of transect routes were used to model bird density in relation to habitat availability. We were primarily interested in differences in the density of birds between habitat types and on the relative importance of our intervention crops. We were also interested in how habitat usage varied seasonally and between species (YH, RB and CH). Habitat usage was modelled using a Poisson GLM in which the species-specific bird count for each habitat parcel was the dependent variable with the natural logarithm of the parcel area as an offset. In order to achieve model convergence we grouped habitats into four categories; WBSM, SRG, farmyards and gardens, and all other habitats (ranked by availability: improved grass, semi-natural grass, woodland, stubble) where relatively few seed-eating birds were recorded. We also tested for effects of winter, season (before or after 1 January) and species (YH, RB and CH) and associated interactions. Transect identity was specified as a fixed rather than a random factor to enable models to converge.

3. Results

3.1. Uptake of experimental crops

3.1.1. Crop delivery

WBSM and SRG crops were successfully delivered across all intervention areas (Appendix 1), but because farm boundaries did not coincide with tetrad boundaries and some farmers with land within intervention tetrads offered plots outside of tetrad boundaries, some interventions were located just outside target tetrad boundaries. Intervention crops within a single intervention area were therefore clustered within a minimum of two and a maximum of six OS tetrads. Although plots were more than 1 km from target OS tetrads in just seven out of 72 plot-years involving three plot locations, a further 38% of plot-years (27 at 15 plot locations) were located within 1 km of target tetrad boundaries leaving 52% of plot-years within target tetrads. The extent of seed-rich habitat provision by intervention type, crop type and winter is summarised in Fig 2. Most WBSM crops (42%) were of mixed cereal types, with pure barley (31%), triticale (16%) and oats (11%) also occurring. Mechanisms other than Defra funding accounted for some WBSM (in particular, 5 plots summing to around 2 ha annually in Dyfi funded by Snowdonia National Park Authority). Control tetrads had no seed delivery through cereal crops in any study winter.

SRG was largely perennial ryegrass (PRG), with three Italian ryegrass (IRG) swards being included in two regions (Clwydians and Llyn). SRG was represented by 11 PRG plot-years on 9 different plots and 8 IRG plot-years on three different plots. All of the experimental SRG plots in intervention tetrads were grazed by cattle and/or sheep during the months preceding closure, despite requests to avoid grazing and manage only for silage cuts. All SRG plots except one received applications of inorganic fertilizer prior to closure (during March-May). Spring restoration of SRG plots following winter closure was entirely carried out through grazing usually during March. At two PRG plots the absence of significant accumulated vegetation and dead litter meant that no spring restoration management was required.

In terms of total crop extent, mean crop delivery fell short of our target but improved across winters and was higher in mixed than in single treatment tetrads (single: 17, 34, 33% of target, mixed: 52, 93, 89% of target; Appendix 1). The ratio of SRG to WBSM in mixed treatment tetrads varied between winters (2012/13=0.60, 2013/14=0.53, 2014/15=0.78), with SGR making up between one third to almost half of the seed resource provided. Some ryegrass fields offered for the project were of lower than anticipated quality based on seed yield. Following Project Advisory Group (PAG) agreement, five additional SRG crops were established in 2014 outside of our study regions using swards that were no more then five years since reseeding. The purpose of these five additional study crops was to evaluate the seed delivery potential of relatively young PRG mixes under local growing conditions. Two of these five additional plots remained ungrazed prior to closure, one taking a silage cut in late April and one taking a hay cut in mid-June. Four of the 5 additional PRG plots received applications of inorganic fertilizer during March-May.

3.1.2. Farmer attitudes

Negative responses of farmers to our proposal to provide SRG were assigned to seven categories (Table 3.1.2.1). No single response predominated, but ‘no suitable land’ and ‘land too valuable’ accounted for 48% of such responses. ‘Payment not enough’ accounted for just 7% of responses (the offered rate of £700/ha was more than double that offered in the new English CS scheme: £331/ha). The 25% of responses in the ‘not interested’ category is likely to include a range of factors.

3.2. Seed yield and retention

3.2.1. WBSM

Analysis of WBSM seed yields in October, and seed retention between October and January, identified several significant sources of variation (Appendix 2). Seed yield varied between winters (highest in 2013/14, lowest in 2012/13) and study areas (the mean October standing seed count was more than four times higher in Llyn than in Dyfi). There was also a marked decline in seed availability on WBSM plots between October and January which was consistent across years and cereal types (Fig.3). Average seed depletion on WBSM plots between October and January was 98%.

Figure 2. Uptake of intervention crops in different regions, treatments (mixed vs. single) and winters (A&B: 2012-13; C&D: 2013-14; E&F: 2014-15). Data include crops provided through funding from this project and other mechanisms (see text).

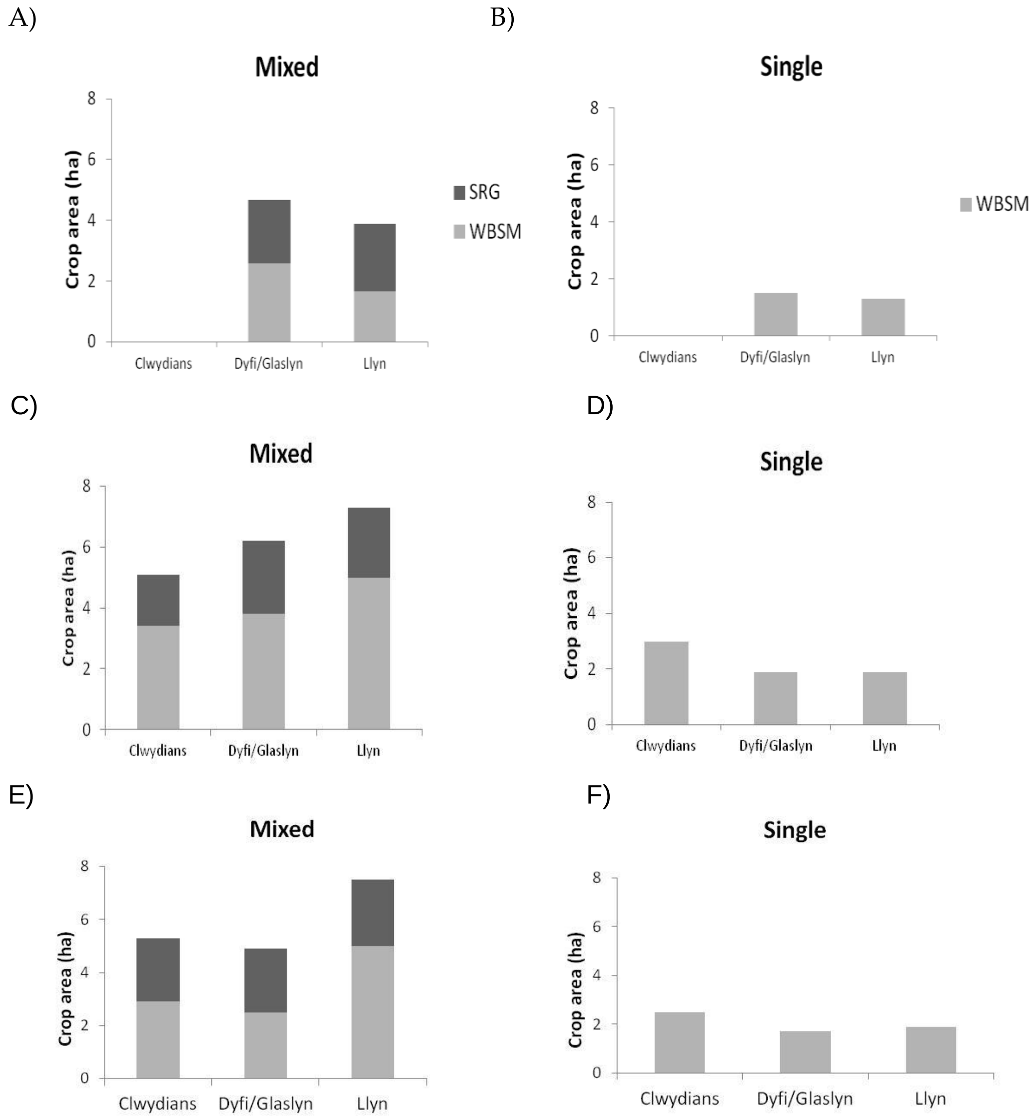
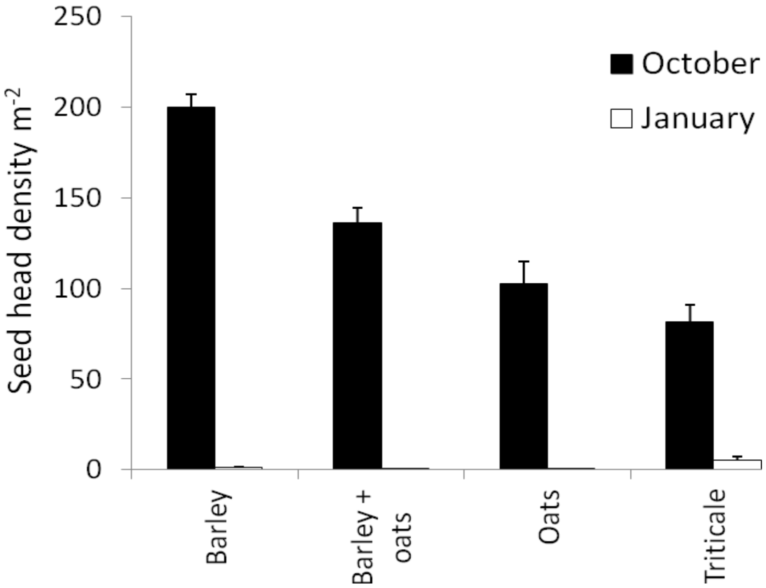


Table 3.1.2.1. Reasons given by land owners for not wishing to participate in SRG provision based on a set of 60 negative responses during conversations about participation.

Region	No suitable land	Not interested	Land too valuable	Conflicts with Glastir	Payment too low	Organic (no NPK use)	No machinery for reseeding
Dyfi	4	4	6	3	1	1	2
Glaslyn	2	1	3	2	0	0	0
Llyn	2	2	2	1	3	0	0
Clwydians	2	3	0	2	0	0	0
Additional plots	7	5	0	0	0	2	0
Sum	17	15	11	8	4	3	2
%	28	25	18	13	7	5	3

Figure 3. Mean seed head density in WBSM crops during October and January. Error bars are +1 SE.



3.2.2. SRG

Seed production on SRG plots varied between winters and regions, and these effects were consistent across three different measures of seed yield (Table 3.2.2.1). Of particular interest was the strong effect of time of closure on seed head density, with yield being highest when closure was within 2 weeks of the target date (mean within = 113.8, mean outside = 65.5 seed heads m^{-2}). IRG produced significantly higher seed weights than PRG (IRG = 24.0, PRG = 10.6 g m^{-2}) although seed and seed head density did not differ between species. (Table 3.2.2.1). Unbalanced data prevented the fitting of some interaction terms (especially those involving winter) although all fitted interaction terms were non-significant

Table.3.2.2.1. P-values for sources of variation in SRG seed yield. Significant P-values values are highlighted in bold.

	Response variable		
Term	Seed head density (m^{-2})	Seed density m^{-2}	Seed weight (gm^{-2})
Winter	**<0.0001**	**0.0342**	0.0783
Region	**0.0066**	**0.0424**	**0.0118**
Closure	**<0.0001**	0.1835	0.2537
Sward age	0.8930	0.8546	0.9233
Grass species	0.1515	0.3223	**0.0279**

Analyses of SRG seed retention showed significant effects of winter and species with more seed heads (43% vs. 23%), and more accessible seed heads (26% vs. 12%), remaining in January in IRG than in PRG crops (Appendix 3A).

The percentage of ryegrass in PRG swards (measured in February 2015) was a significant predictor of average seed head density in October (annual means; $F_{1,12}$=4.45 P=0.059) although the relationship with seed density was weaker ($F_{1,12}$=3.00 P=0.111) (Fig 4). Percentage ryegrass composition did not differ between IRG and PRG crops, and this persisted even when the five additional plots outside of our study regions, which had all been reseeded no less than five years previously, were included in the analysis. As most SRG plots were grazed prior to closure we lacked good data to assess the impacts of grazing. The two ungrazed PRG plots (both additional plots outside of intervention tetrads) produced similar seed head densities as grazed PRG plots closed at similar times (Fig. 5a) with one plot being closed too late (16 June) to generate significant amounts of seed (Fig. 5B). Figures 4 & 5 also highlight the greater seed producing potential of IRG compared to PRG; these IRG fields were grazed by cattle or sheep during late February and March, inorganic fertilizer was then applied and a silage cut was taken between mid-May and mid-June. Two IRG plots cut for silage as late as 13 June still produced abundant seed (Fig. 5), confirming the findings of the previous study that IRG can be cut later than PRG without compromising seed yield (Buckingham et al. 2011). The PRG plot that produced the highest seed weight of any SRG plot (Fig. 5B) was an ungrazed newly sown sward (<12 months old), but the early closure date (30 April) combined with vigorous subsequent growth would probably have rendered most of the abundant seed inaccessible to birds during the following winter (this plot was not located inside an intervention tetrad and therefore bird usage was not assessed).

Data from Wales (this study) and Shropshire (BD1455, 1-cut plots only) were analysed to test for differences in sward condition and seed availability (accessibility) in October, and seed retention between October and January. Ryegrass seed delivery was higher in Shropshire than Wales (mean October seed head density was 316 and 149 m^{-2} respectively, or 47% lower in Wales), and that IRG tended to outperform PRG in both seed yield (mean October seed head density: 314 vs. 142 m^{-2}) and retention (Appendix 3B).

Figure 4. Relationship between percentage ryegrass cover (measured in February 2015) and the density of (A) ryegrass seed heads and (B) ryegrass seeds (mean annual values measured in October). Circles show PRG plots (open = intervention plots, filled = additional crops recruited in 2014), while triangles show intervention IRG plots.

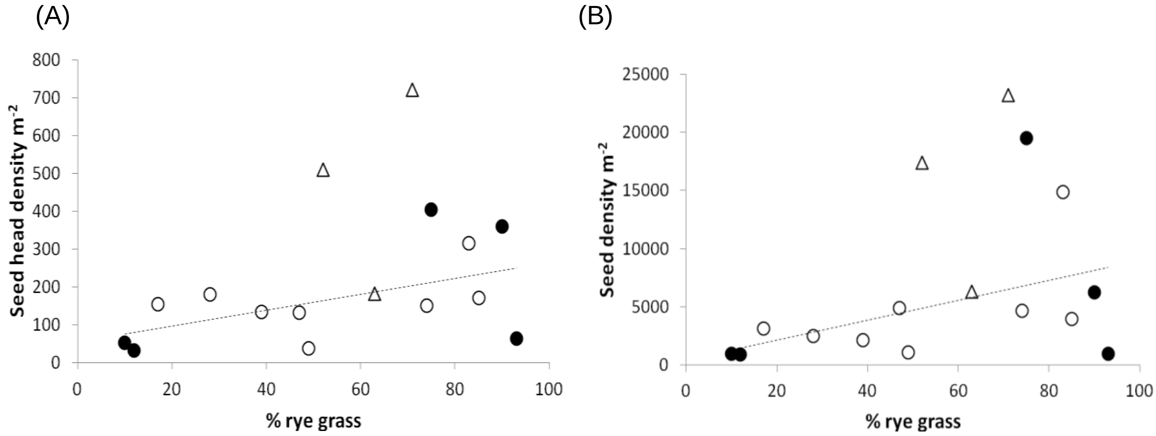
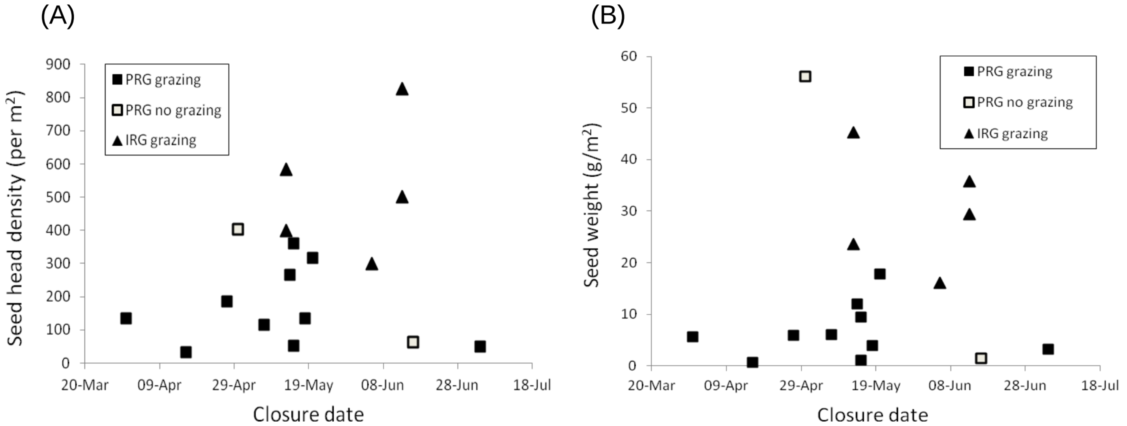


Figure 5. Effect of closure date, species and spring grazing on (A) seed head density, and (B) seed weight in SRG plots. Each point relates to a single plot in a single year.



3.3. Winter bird usage of intervention plots

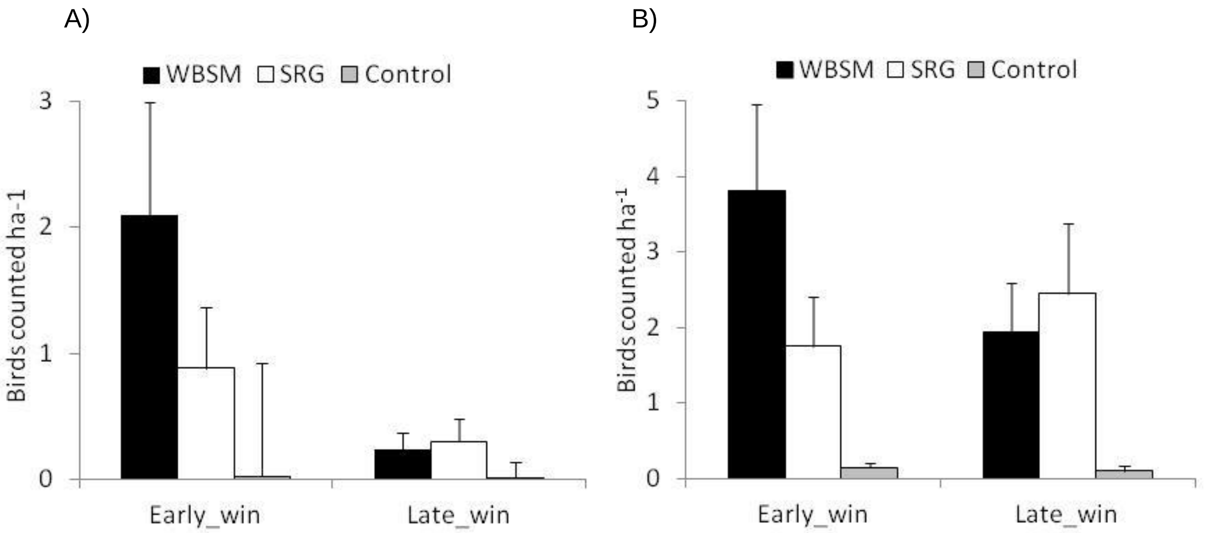
3.3.1. Effects of treatment on plot usage by birds

Both intervention crops were used significantly more frequently by buntings and chaffinches than control plots (Table 3.3.1.1). Usage by YH of both WBSM and SRG declined markedly between early and late winter, although the decline in WBSM was greater than that in SRG (Fig. 6). Total bunting usage declined on WBSM but was sustained on SRG plots (Fig. 6). Chaffinches made significantly greater usage of WBSM plots than control plots (there were too few CH records in SRG plots for GLMMs to converge).

Table 3.3.1.1. P-values for model terms explaining plot usage for yellowhammer (YH), all buntings (BU) and chaffinch (CH) (significant effects shown in bold). – indicates a term excluded from the model. For CH the treatment effect compared only WBSM against control plots.

	Species		
Term	**YH**	**BU**	**CH**
Winter	**0.0099**	0.9934	0.1755
Region	0.1771	-	0.0931
Season	**0.0008**	0.3654	**0.0436**
Treatment	**<0.0001**	**<0.0001**	**0.0002**
Treatment*Season	**0.0463**	**0.0074**	0.3616

Figure 6. Significant interactions between treatment usage in early and late winter for (A) yellowhammers and (B) buntings. Error bars are +1 SE.



3.3.2. Effects of covariates on bird plot usage

A second similarly structured analysis was carried out to determine the extent to which seed yield influenced bird usage of intervention plots. For yellowhammers and buntings, usage of WBSM plots was positively related to seed head density and seed density (Table 3.2.2.1, Fig. 7a), but not seed weight. In contrast there were few significant effects of seed yield on bird usage of SRG in North Wales (Table 3.2.2.1). SRG plot usage by yellowhammers showed a positive (quadratic) relationship with seed head density (Fig.7b). The relationship is similar to that described in a previous study for all buntings in Shropshire (Buckingham et al. 2011).

3.4. Wider habitat use in winter

Yellowhammers and reed buntings were recorded most often in SRG followed by WBSM which were relatively scarce habitats (Table 3.4.1). In contrast, the majority of chaffinches were recorded in Other habitats (mainly improved or semi-improved pasture) which accounted for more than 75% of the study area.

Bird density in the wider landscape varied significantly between winters, and habitat associations varied between species (Table 3.4.2). Foraging yellowhammers and reed buntings were recorded mainly in intervention crops and occasionally in farm yards and gardens; very few were recorded in other habitats (Fig. 8). Chaffinches were recorded mainly in WBSM and yards/gardens, with little usage of SRG or other habitats. Given the scarcity of farmyards and gardens in the wider landscape (accounting for 6.3%, 14.7% & 12.7% of surveyed land each winter), these habitats constituted important winter habitats for chaffinch and yellowhammer (Fig. 8).

Table 3.3.2.1. P-values for the significance of different measures of seed yield in predicting winter plot usage by yellowhammers (YH) and all buntings (BU). Bold type indicates significant effects.

		WBSM		SRG	
Seed yield variable	Terms	YH	BU	YH	BU
Seed head density m^{-2}	Winter	0.5202	0.0908	0.5057	0.2718
	Region	0.4580	**0.0449**	0.4828	0.2485
	Seed yield	**0.0161**	**0.0169**	**0.0150**	0.5123
	Seed yield^2			**0.0210**	
Seed density m^{-2}	Winter	0.4399	0.2394	0.3446	0.2771
	Region	0.2724	0.2208	0.0986	0.2016
	Seed yield	**0.0093**	**0.0112**	0.1281	0.4847
Seed weight (gm^{-2})	Winter	0.7361	0.1158	0.4222	0.2668
	Region	0.3177	**0.0173**	0.1113	0.2169
	Seed yield	0.9302	0.9588	0.2608	0.4871

Figure 7. Relationships between YH plot usage and seed head density for (A) WBSM and (B) SRG. Filled points show individual plots, while solid lines are predicted relationships. In (B), circles show PRG, squares show IRG, while open triangles and the dashed line show the equivalent relationship for SRG plot usage by buntings in Shropshire (from Buckingham et al. 2011).

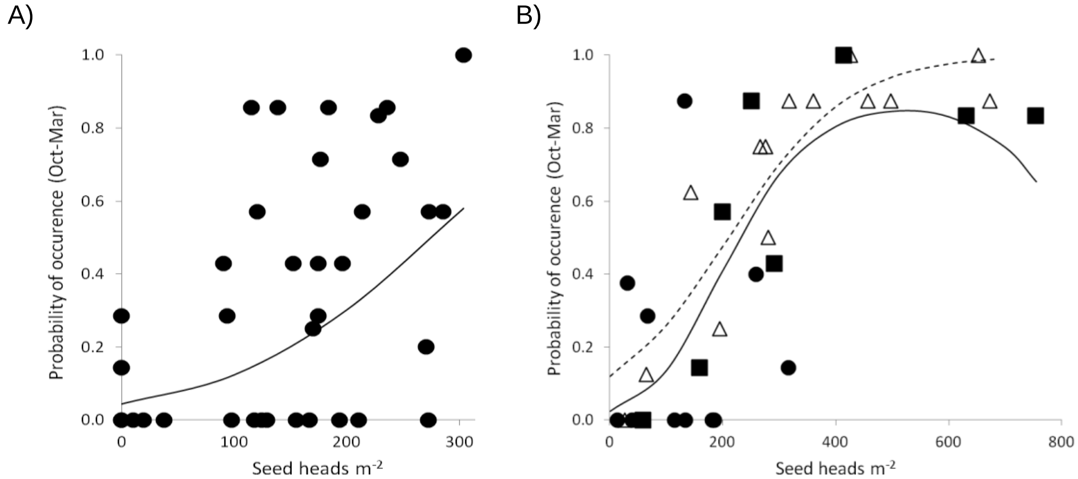


Table 3.4.1. Number of records of each bird species in habitats surveyed during transect counts of the wider landscape. The area of each habitat surveyed is also given. Both area and counts are summed across transects and winters.

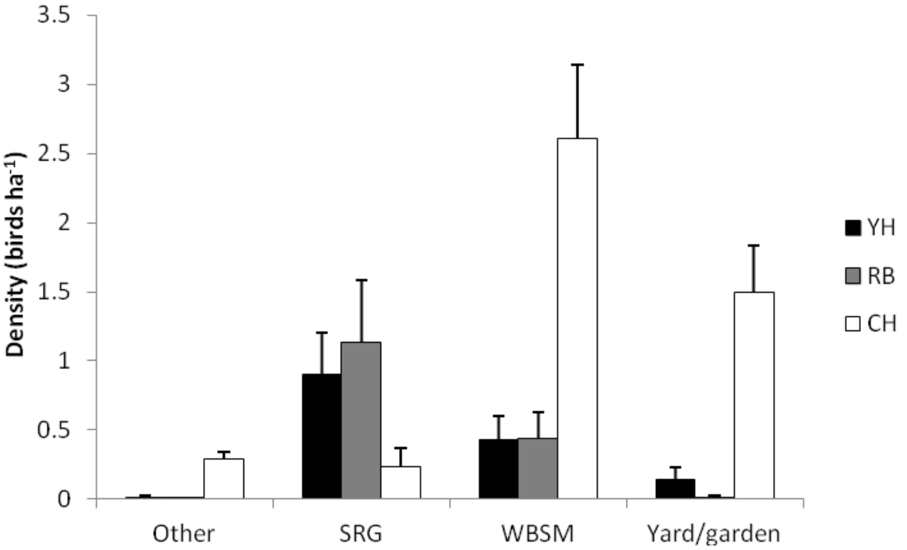
		Species		
Habitat	**Area (ha)**	**YH**	**RB**	**CH**
WBSM	117	88	69	427
SRG	85	106	139	26
Yard/garden	668	34	3	716
Other	4260	97	20	1652

Table 3.4.2. Factors affecting the density of wintering seed eating birds in the wider landscape.

Term	**F_{df}**	**P**
Winter (12/13, 13/14, 14/15)	$6.67_{2,20564}$	**0.0013**
Season (early, late)	$0_{1, 20564}$	0.9897
Species (YH, RB, CH)	$15.91_{2,20564}$	**<.0001**
Habitat (WBSM, SRG, yards & gardens, other)	$32.28_{3,20564}$	**<.0001**

Habitat *Season	0.39 $_{3,20564}$	0.7621
Habitat *Species	8.64 $_{6,20564}$	**<.0001**
Habitat*Season*Species	1.21 $_{8,20564}$	0.2885
Transect Identity	3.96 $_{23,20564}$	**<.0001**

Figure 8. Differences in the density of wintering seed eating birds in different habitats in the wider landscape. Aggregate habitat availability (area) is shown in Table 3.4.1.



3.5. Winter diet, body condition and movements of buntings

During the three winters, 120 YH and 17 RB were caught and faecal samples were obtained from 57 individuals (40 YH and 17 RB). For each one, a sample of 50 food fragments were assigned to one of four types (Table 3.5.1) whilst suspended in water between two microscope slides and examined under a 40x binocular microscope following Buckingham et al. (2011). The dominant food types for both YH and RB were grass and cereal, together accounting for 95% and 67% of food items respectively (Table 3.5.1). RB faecal samples contained more broad-leaved weed seeds, while the YH samples contained more cereal seed. For both species there was evidence of a decreasing cereal seed component to the diet, and an increasing grass seed component, as the winter progressed (Table 3.5.2).

Table 3.5.1. Mean diet composition and incidence based on 40 YH and 17 RB faecal samples from birds captured on intervention plots during winter (data pooled across years).

	Percentage of diet (SE)		**Incidence (% of samples)**	
Food type	**RB**	**YH**	**RB**	**YH**
Cereal	18.1 (6.6)	41.5 (4.6)	9 (52%)	30 (75%)
Grass	48.7 (7.7)	53.7 (4.2)	17 (100%)	37 (92%)
Broad-leaved weed seed	31.3 (7.9)	4.7 (1.6)	13 (76%)	10 (25%)
Arthropod	1.9 (0.9)	0.7 (0.6)	4 (23%)	2 (5%)

Table 3.5.2. Difference in mean percentage diet composition between early (Oct-Dec) and late winter (Jan-Mar) for YH and RB.

Species	**Season**	**N**	**Cereal**	**Grass**	**Broad-leaf weed**	**Arthropod**
YH	Early	29	43.0	51.4	4.6	1.0
YH	Late	11	37.5	59.5	4.9	0.0
RB	Early	10	27.2	44.0	27.4	1.4
RB	Late	**7**	5.1	55.4	36.9	2.6

Firstly, we compared the body condition of YH and RB in North Wales occupying a mix of improved grass and semi-natural habitats with that of two other UK populations monitored in recent winters (studies located in arable-dominated Cambridgeshire: 2003/04-2008/09; improved grass-dominated Shropshire: 2007/08-2008/09). The analysis controlled for any effects of variation in wing length (as a proxy for structural body size), time of capture (as weight increases through the day as birds accumulate energy to survive the night), and any seasonal effects (two-level factor: early winter Oct-Dec, late winter Jan-Mar). We fitted a normal error GLMM with plot identity (9 & 7 levels), and ringer identity (16 & 8 levels) declared as random factors for YH and RB respectively. Body weight was strongly positively related to wing length and time of day, but did not differ between seasons or study areas (Table 3.5.3). Thus the winter body condition of YH and RB in North Wales was typical of that measured in other UK populations with contrasting farming systems.

Table 3.5.3. Factors affecting body mass of (A) yellowhammers and (B) reed buntings in three UK regions (North Wales, Shropshire, Cambridgeshire).

A)

Effect	F	P	Direction
Wing	$95.48_{1,286.6}$	**<.0001**	+ve
Hour	$31.59_{1,271}$	**<.0001**	+ve
Season	$0.07_{1,4.638}$	0.8569	
Study	$0.07_{2,4.7}$	0.9349	

B)

Effect	F	P	Direction
Wing	$101_{1,110.9}$	**<.0001**	+ve
Hour	$8.5_{1,115.1}$	**0.0044**	+ve
Season	$1.1_{2,97.43}$	0.3018	
Study	$0.3_{2,3.9}$	0.7332	

Secondly, we tested whether body condition in North Wales yellowhammers differed between intervention crops (WBSM vs. SRG). Only YH were captured on both crop types (WBSM n=116, SRG n=35). In order to minimise any confounding effects of birds moving between crop types, we repeated this analysis based on the recent diet of captured birds derived from faecal samples. Diet was inferred from the percentage of grass seed (arcsine square root transformed) which was strongly negatively correlated with percentage of cereal seed (r_{41}=-0.84). The nuisance variable plot identity (3 levels) was included as a fixed effect, while ringer identity (2 levels) was excluded to allow model convergence. Results provided no evidence for an association between body condition and crop type at capture, but there was a positive relationship between yellowhammer body condition and the percentage of grass seed in the recent diet (Table 3.5.4, Fig. 9). It was not possible to distinguish Lolium from other grass seeds in the faecal remains.

Table 3.5.4. Effect on YH body condition of (A) crop type and (B) proportion of grass seed in the diet.

(A)

Effect	F	P	Direction
Wing	$11.8_{1,35}$	**0.0016**	+ve
Hour	$0.1_{1,35}$	0.7064	
Season	$0.3_{1,35}$	0.6218	
Crop	$0.0_{1,35}$	0.9823	

(B)

Effect	F	P	Direction
Wing	$14.75_{1,35}$	**0.0005**	+ve
Hour	$0.39_{1,35}$	0.5338	
Season	$0.07_{1,35}$	0.7997	
% grass seed	$8.24_{1,35}$	**0.0069**	+ve

We checked whether body condition varied through the winter season by including interaction terms between crop type or percentage grass seed and season (before or after 1 January). All such interaction terms were non-significant (P>0.1397) indicating that no such variation could be detected.

The movements of colour-ringed buntings are summarised in Table 3.5.5. A total of 115 YH were fitted with colour rings, of which 36 were re-sighted after a mean of 41 days (range 14-74). Of these re-sightings, 79% were re-sighted in the same winter, 16% were seen at breeding sites and 5% were seen in a subsequent winter. One reed bunting was recaptured on a breeding site outside of our study area. Most re-sightings involved birds moving between intervention plots within individual tetrads. No within winter movements exceeded 1.5 km (Table 3.5.5) implying limited within winter dispersal. Four YHs were recorded breeding in ffridd 1.5-3.5 km from winter food plots, and one was recorded breeding 12 km from the site of winter capture (Table 3.5.5).

Figure 9. Relationship between yellowhammer body mass and the percentage of grass seed in faecal samples. The line shows the predicted relationship (from a GLM including mean wing length) and the triangles show the raw data.

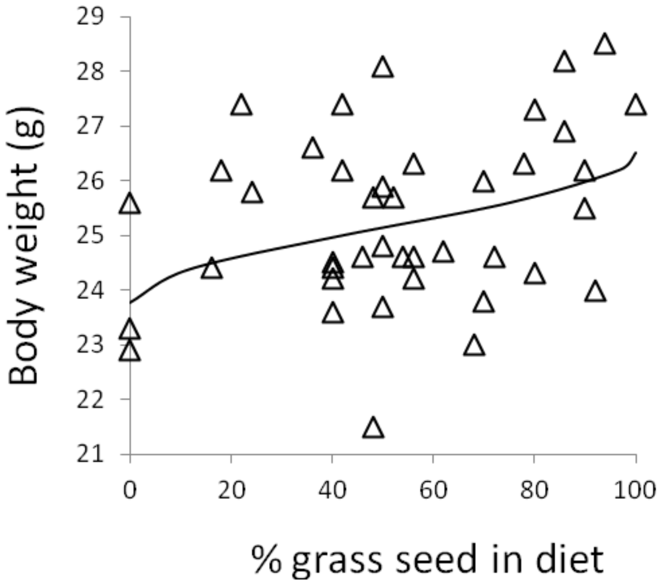


Table 3.5.5. Movements of individual buntings based on re-sighting of ringed birds.

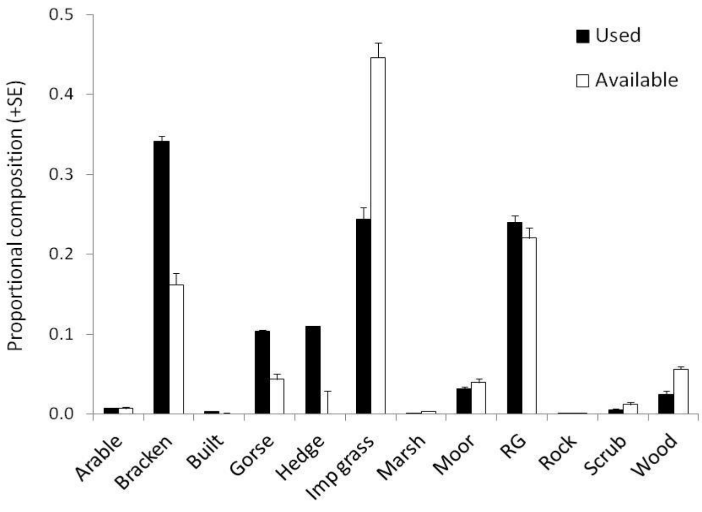
Species	Distance (km)	Number			Total
		Within Winter	Winter to Breeding	Winter to Winter	
YH	0	2			2
YH	<0.5	6			6
YH	1.0-1.5	22			22
YH	1.5-3.5		4		4
YH	12		1		1
YH	23			1	1
YH	40			1	1
RB	40		1		1
Total		30	6	2	38

3.6. Breeding habitat selection

Habitat composition within 150 m radii of territory centres (utilized habitat) was compared to that available across the whole of the tetrad in which each territory was located (available habitat). Only baseline breeding territory distribution data from 2012/13 were included in this analysis. Compositional analysis was used to test for habitat selection using MANOVA and randomisation tests (with 1000 replicates) following Aebischer et al. (1993). Compositional analysis was carried out using the Adehabitat package (Calenge 2006) within R (R development core team 2013).

Yellowhammer territory distribution was significantly non-random (MANOVA: Wilk's $\lambda = 0.24$ df=11 $P<0.001$). Bracken and gorse habitats were most strongly selected (ranked 1 and 2: both are key components of ffridd), while woodland and improved grassland were strongly avoided (ranked 10 and 11; Appendix 4, Fig. 10). Although rough grazing had a low rank (9), it was neither selected or avoided (Fig. 10); most rough grazing in this study was outside of land parcels containing ffridd mosaics. Hedges were a rare habitat but were positively associated with YH territories where they occurred (rank=3; in 8.3% of 312 territories).

Figure 10. Habitat composition within 150 m radii of 312 YH breeding territory centres and within the surveyed tetrads that contained them, based on baseline surveys.



3.7. Did treatment interventions influence changes in breeding abundance?

3.7.1. Effect of treatments on changes in abundance

We initially tested whether changes in the abundance of breeding YH was related to tetrad-level treatment categories (i.e. single, mixed or control). To do this we fitted a Poisson errors GLMM of the form:

Count = Region + Period + Treatment + Period*Treatment + Period*Region*Treatment

where Region was a four-level factor (Clwydians, Dyfi, Glaslyn and Llyn) and Period a two-level factor (baseline or repeat survey), with one row of data per tetrad per time period, and tetrad identity fitted as a random factor. Our two measures of breeding abundance (mean counts of territorial birds and the number of territories) were highly correlated (r_{184}=0.95), and we present here analyses of the number of territories. Analyses provided clear evidence for a significant decline in abundance between baseline and repeat surveys (-31% overall), which did not differ between regions or treatments (Table 3.7.1, Appendix 5).

Table 3.7.1. The effects of treatment on change in the number of YH territories.

Term	F	P	Direction
Region	$1.64_{3,71.32}$	0.1886	
Period	$5.38_{1,175}$	**0.0216**	Baseline > repeat
Tetrad treatment	$0.75_{2,75.04}$	0.4782	
Period * Tetrad treatment	$1.49_{2,1}$	0.5017	

3.7.2 Effect of distance from intervention tetrads on changes in abundance

Logistical constraints over the placement of intervention crops coupled with only a very limited knowledge of typical dispersal distances between wintering and breeding areas (Table 3.5.5), encouraged us to analyse potential responses of breeding abundance to the distance from winter crops. In this analysis we assigned each tetrad to one of three distance categories for each of the main treatments (single and mixed): (i) within 2 km of an intervention crop cluster (INTervention), (ii) 2-4 km from an intervention crop cluster (ADJacent) or (iii) more than 4 km from an intervention crop cluster (FAR). Distances were calculated from the centre of each survey tetrad to the nearest geometric centre of each type of intervention cluster. The model (a Poisson GLMM in which tetrad identity was a random factor) tested whether temporal changes in the number of YH territories differed between intervention, adjacent and far tetrads and was defined as:

Count = Region + Period + Single + Period*Single + Mixed + Period*Mixed + Period*Single*Mixed

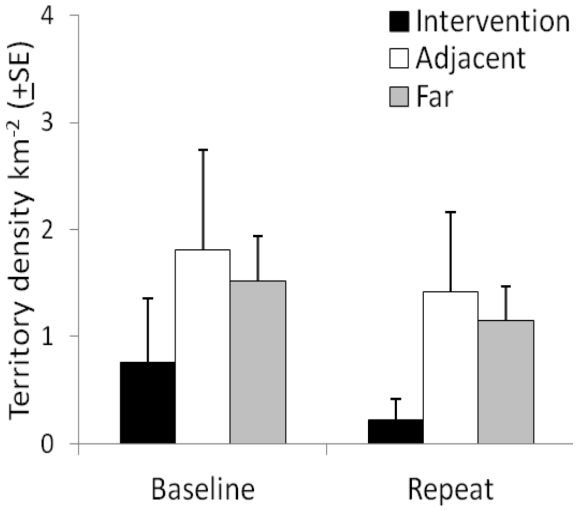
where both Single and Mixed were three-level factors (INT, ADJ, FAR). The model failed to converge when the 3-way interaction was included, but did converge once this term was dropped. As with the previous analysis, there was clear evidence of a reduction in YH abundance between baseline and repeat surveys (significant period effects) but no evidence that changes in the breeding abundance of YH was related to distance to winter habitat provision (Table 3.7.2, Fig 11).

Table 3.7.2. The effects of distance to single and mixed treatments on change in the number of YH territories.

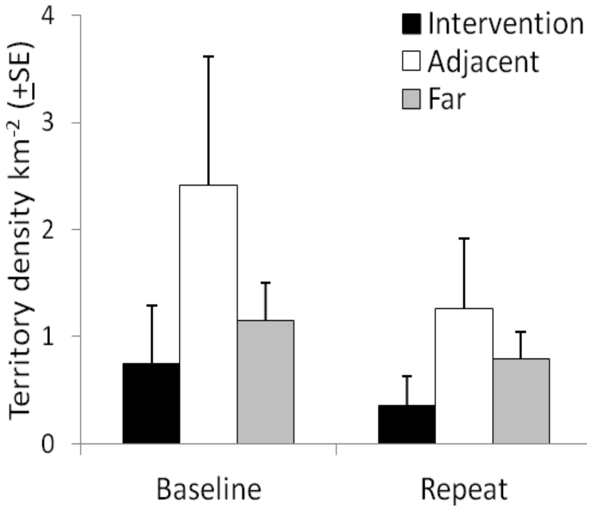
Effect	F	P	Direction
Region	$1.7_{3,70}$	0.1758	
Period	$6.51_{1,171}$	**0.0116**	Baseline > repeat
Single	$1.41_{2,80.1}$	0.2491	
Period*Single	$1.67_{2,1}$	0.4801	
Mixed	1.7 2,74.7	0.1889	
Period*Mixed	$1.06_{1,1}$	0.5655	

Figure 11. Changes in the mean density of breeding YH territories between baseline and repeat surveys in tetrads within 2 km of intervention crop (Intervention), 2-4 km from crops (Adjacent) and further than 4 km away (Far). The data were analysed separately with respect to single (WBSM only; A) or mixed (WBSM + SRG; B) treatments.

A) Single



B) Mixed



3.7.3. Effect of intervention crop quantity and quality on changes in abundance

Each intervention cluster was scored according to delivery of SRG seed and separately for WBSM seed. The seed delivery score was the October seed weight per plot (estimated from plot area and seed weight m^{-2}) summed across plots and averaged across winters. We then derived a seed availability score for each crop type (AWBSM and ASRG) in each surveyed tetrad. This was based on the seed delivery score, and the distance between the centre of the tetrad and the geometric mean location of the crops (WBSM or SRG) making up the nearest intervention area. All tetrads within 3 km of intervention tetrads (which contained the geometric mean location of each intervention cluster) were assigned the full seed delivery score (fully available), while tetrads 3-6 km away were assigned half the score (partly available), and tetrads more than 6 km received a zero score (unavailable). Based on examination of frequency distributions, each of these seed availability scores were categorised into two 3-level factors: Low (zero), Medium (>0 but <2) and High (>2). We then tested for an effect of seed availability category on change in YH breeding territory count in each tetrad between baseline and repeat survey:

Count = Region + Period + Period*AWBSM + Period*ASRG + Period*AWBSM*ASRG

where Region and Period are as described in 3.7.1, and ASRG and AWBSM are factors describing the availability of seed from each crop type averaged across winters (see description above). We also modelled ASRG and AWBSM effects as continuous variables using the same model structure. Other than the significant decline in abundance identified in previous analyses, the results again showed no significant effects of winter food provision on breeding abundance (Table 3.7.3). Exclusion of the 3-way interaction resulted in 2-way interactions having increased P-values (i.e. weaker effects).

Table 3.7.3. Effects of intervention crop quality and availability on changes in YH breeding abundance. Separate models were fitted with seed availability defined by three-level factors, and by continuous variables.

Terms	Seed availability (categorical variable)		Direction	Seed availability (continuous variable)		Direction
	F	P		F	P	
Region	$1.95_{3,84.6}$	0.3053		$1.84_{3,77.7}$	0.1469	
Period	$1.97_{1,173}$	**0.0027**	Baseline>repeat	$0.19_{1,173}$	0.6638	
Period*AWBSM	$0.35_{2,173}$	0.1993		$0.89_{2,173}$	0.4108	
Period*ASRG	$0.38_{2,173}$	0.4498		$0.14_{2,173}$	0.8678	
Period*AWBSM*ASRG	$0.12_{2,173}$	0.6707		$0.45_{2,173}$	0.6395	

3.8. Impact of SRG management on silage yield

We tested whether silage yield (DM t ha^{-1}) in the year following our SRG management differed between grassland plots managed under SRG management and nearby plots or fields subjected to normal mowing and aftermath grazing management. A simple Normal errors GLMM was employed with plot-year pair specified as a random factor which controlled for site and year effects. We also included a Treatment*Year interaction in case treatment effects varied between calendar years. Silage yield was significantly lower on SRG compared to control plots ($F=7.4_{1,73.8}$, P=0.0081) averaging 12% lower across all years (predicted mean yield = 3.6 t ha^{-1} on SRG plots and 4.1 t ha^{-1} on control plots). Although yield varied between years ($F=26.17_{2,77}$ P<0.0001), the effect of SRG management on yield did not differ between years (interaction P=0.566). There were too few data to test for any effect on yield of the number of years under SRG management, although there was no indication of any such effect in the raw data (Appendix 6).

Data on silage quality (D-values) were available for the same plots, although sward sample replicates were pooled prior to laboratory analysis, restricting sample size further. D-values from crops on SRG treatment plots were marginally lower than crops on control plots (raw means: 56.9 vs. 57.8), but a paired t-test showed this difference was not statistically significant ($t_8=0.90$ P=0.39).

4. Discussion

4.1. The practicality of providing WBSM and SRG in a pastoral landscape at a scale that has the potential to generate population growth (Objective 1)

Many farmers in our North Wales study areas were reluctant to devote valuable enclosed, improved low-lying agricultural land to our intervention measures WBSM and SRG crops (Table 3.1.2.1). The extent of such land is limited by topography in North Wales. It is used mainly to produce winter feed for livestock and the view of many farmers was that devoting such land to conservation measures like WBSM or SRG risked them running short of animal feed during winter. This view was exacerbated following the unusually (for recent years) cold winter of 2012/13, when extended periods of snow cover made it difficult for some farmers to buy in animal feed. This reluctance of farmers to devote low-lying productive land to conservation measures was the main reason we failed to meet the area targets for seed provision (of 6.7 ha per tetrad, Fig. 2). Although we achieved 89-93% of intervention crop delivery in mixed tetrads during the second and third winters, we only achieved 33-34% delivery in the single treatment tetrads (Fig. 2). Nevertheless, given that the target areas were based on higher densities of seed-eating passerines typical of lowland arable and mixed landscapes in England (Gillings et al. 2005), we consider our intervention crop delivery should have been adequate to meet the population level food requirements of seed-eating birds in most mixed tetrads. However, intervention provision in single treatment tetrads may well have been too low to meet the dietary requirements of bird populations, especially if seed yield in those intervention crops was low or modest (as was the case in the Dyfi and Clwydians study regions).

This study identified several factors affecting seed yield on SRG. First, closing the sward within 2 weeks of 31 May had a large positive impact (+74%) on SRG seed delivery and emphasizes the need for landowners to adhere to the management guidelines for this option. PRG seed yield was particularly sensitive to closure date with relatively low seed weights recorded on plots closed after 20 May or before 8 May (Fig. 5). Second, as in the previous Shropshire study (BD1455, Buckingham et al. 2011), seed yield was generally much higher on IRG than PRG swards. Compared to perennial ryegrass (PRG), Italian ryegrass (IRG) produced significantly heavier seeds (+126%) and a higher density of accessible seed heads in October (+345%), and retained a higher proportion of accessible seed heads through until January (26.3% vs. 11.9%) (Table 3.2.2.1, Appendix 3). Third, the seed yield of both IRG and PRG was lower in Wales than in Shropshire (47% lower seed head density). Seed head density on PRG swards was positively related to the cover of ryegrass in the swards (Fig. 4) and it is possible that the lower seed delivery on Welsh PRG swards (relative to that in Shropshire) was associated with lower average PRG cover, perhaps linked to the older average sward ages on the less intensive Welsh livestock farms. Most of the Welsh SRG plots were grazed (rather than cut as in previous SRG studies) prior to closure and this might also have had a negative impact on seed production.

Observed patterns of seed depletion and retention were largely as predicted. WBSM had lost 98% of its seed by January (Fig.3) and bird usage declined sharply in late winter (Fig. 6). SRG retained much more seed into late winter and bird usage was sustained into late winter (Fig. 6). The study confirms therefore that SRG has the potential to benefit seed-eating birds by filling the late winter hungry gap.

4.2. The impact of WBSM and SRG on the foraging, diet and body condition of seed-eating farmland birds (Objective 2)

Our intervention crops (WBSM & SRG) supported higher densities of foraging yellowhammers and reed buntings than any other habitats in the landscape and together accounted for 60% and 90% respectively of all winter foraging records in the North Wales landscape. Chaffinches made less usage of intervention crops (restricted mainly to WBSM) which accounted for 16% of all winter foraging records. These data indicate that our intervention crops provided the main source of foraging habitat for buntings in our North Wales study areas. This conclusion was confirmed by the contents of faecal samples which showed that cereal and grass seeds dominated the winter diet of buntings. The only important winter foraging habitat (used particularly by chaffinches, but also by yellowhammers) was farmyards and gardens, where spilt livestock feed, weed seeds and garden bird feeding stations provided important sources of seed.

Buntings (YH and RB) made greater usage of WBSM during early winter, and usage declined significantly during late winter as seed resources were depleted. In contrast, SRG usage (which was lower than that of WBSM in early winter) increased during late winter (Fig 6). This supports our prediction that SRG provides an important source of winter food for bunting populations especially during late winter when other sources of seed may be used up or depleted. SRG therefore provides an important foraging habitat for buntings during the late winter hungry gap. These seasonal patterns of habitat usage were consistent with seed remains in faecal samples which showed declining consumption of cereals and increasing consumption of grass seeds as the winter progressed.

Usage of intervention plots by yellowhammers was positively related to seed head density, and for WBSM to seed density. Usage of WBSM showed a simple linear positive relationship, while that of SRG showed a more complex quadratic relationship similar to that found on SRG in Shropshire. Probability of usage of SRG remained low below a seed head density of 200 per m^2 (e.g. 0.135 at 100 seed heads per m^2, 0.41 at 200 per m^2), rose sharply to a threshold of approximately 400 heads per m^2 (0.804) but levelled off thereafter (e.g. 0.831 at 600 heads per m^2). Therefore, for SRG swards to be useful to foraging buntings, seed head density needs to exceed 200 per m^2 but there is little benefit in seed head density exceeding 400 per m^2 (Fig. 7). Combining this information with the effect of PRG cover on October seed head density (Fig. 4) indicates that PRG swards need on average to contain at least 75% ryegrass in order to produce seed head densities of 200 m^2 or more. Only 1 of our 8 PRG swards produced average seed head densities greater than 200 per m^2 and this probably explains their relatively modest usage by buntings (Fig. 7B). Two out of three of our IRG swards produced seed head densities higher than 500 per m^2, and both were heavily used by buntings. One of these high yielding IRG swards had a ryegrass cover of only 52% suggesting that ryegrass sward cover may be less important to ensure high seed yield on IRG swards.

The winter body condition of buntings in North Wales was similar to that recorded in food-rich arable and mixed landscapes in England suggesting that the Welsh landscape was able to sustain nutritionally the densities of buntings present. The positive relationship between body condition of individual yellowhammers and the proportion of grass seed remains in their faeces (Fig. 9) suggests that buntings feeding mainly on grass seed are able to gain body mass. Maintaining body mass during winter is likely to promote overwinter survival and may have additional fitness benefits during the following breeding season.

All 30 within-winter movements of colour-ringed yellowhammers were less than 1.5 km, while 4 out of 5 winter-to-breeding season movements were within 3.5 km suggesting this species is relatively sedentary in North Wales. Thus, our study design with most intervention areas separated from control areas, or different intervention areas, by at least 4 km (and usually much more, Fig. 1) should not have been compromised by significant numbers of movements of yellowhammers between study areas. These movement data are consistent with reported geometric mean natal dispersal of 2.0 km and breeding dispersal of 0.2 km for yellowhammers across the UK (Paradis et al 1998).

4.3. Testing whether population growth of seed-eating farmland birds is dependent on the provision of seed-rich habitats during early or late winter (Objective 4)

Breeding habitat preferences matched our expectation with bracken and gorse being most strongly selected (Fig. 10). Both are important components of Welsh ffridd, with which breeding YH are strongly associated in North Wales. Furthermore, both were among the more available habitats in the landscape (bracken 3rd most available and gorse 5th most available of 12 habitats assessed), and so the extent of these habitats is unlikely to be limiting breeding population size. Factors affecting the quality of these habitats for breeding yellowhammers are largely unknown but maintaining structurally heterogeneous mixed age swards is likely to promote the availability of invertebrate prey and safe nesting sites (Buckingham et al, 2006, Pearce-Higgins & Grant 2006).

The response of breeding yellowhammers to our interventions was tested in a series of increasingly subtle analyses. First, although there was evidence of a 31% decline in abundance between baseline and repeats surveys, we found no evidence that the rate of decline differed between intervention and control tetrad (Table 3.7.1). Second, there was no evidence for either treatment that between-year changes in abundance differed between intervention, adjacent and more distant tetrads (Table 3.7.2). Finally, an analysis that allowed for the amount of seed provision (seed weight) and availability (distance) also found that changes in yellowhammer breeding abundance were unrelated to the magnitude of local seed provision for either WBSM and/or SRG (Table 3.7.3). We conclude therefore, that our experimental provision of seed-rich habitats had no detectable impact over three winters on changes in the abundance of breeding yellowhammers.

There are several potential reasons why the provision of seed-rich habitat during winter did not affect changes in the abundance of breeding yellowhammers. First, the scale of our intervention may have been too small to have affected overwinter survival rates. While this is plausible for the single treatment (for which the area of intervention crops was only 33% of target), it seems much less likely for the mixed treatment where the area of provision was generally high (89-93% of target) and where crop quality (seed provision) was relatively high. The best example of this is the mixed treatment on the Llyn Peninsula where target areas of intervention crops exceeded target levels in the second and third winters, where seed yield delivery was high for both WBSM and SRG and usage of intervention crops by birds was high and sustained throughout the winter. For example, the maximum count of yellowhammers on intervention crops on the Lynn Peninsula mixed treatment was 30 individuals which is equivalent to 83% of the breeding population in 2012 (18 pairs). This implies our intervention crops were being used by a high proportion of the local population but, despite this, the breeding population still declined by a near average rate (by 28%, from 18 to 13 pairs in the Llyn mixed treatment). In the case of the mixed treatment on the Llyn Peninsula it seems likely that factors other than winter seed availability were limiting winter survival and/or recruitment of yellowhammers. For example, the quality of ffridd breeding habitats may have declined over time as a consequence of agricultural abandonment. This might have reduced the carrying capacity of the habitat (leading to fewer breeding territories) or the breeding performance / post-fledging survival of yellowhammers in the ffridd habitat.

A second possible explanation for the lack of impact of our interventions on population changes is that dispersal is more pronounced than our data suggest, and that breeding birds from all treatment levels have the same or similar access to intervention crops. While we cannot rule this out, all of the available data suggest this is unlikely. One of 5 winter-to-breeding movements was 12 km (the rest less than 3.5 km) and all 30 within winter movements were less than 1.5 km. These data suggest most, but not all, yellowhammers overwinter in sites within 4 km of breeding areas and are therefore unlikely to be roaming further to exploit seed-rich habitats.

A third possible explanation is that the limited duration of our study coupled with some exceptional weather events may have limited an intervention impacts on yellowhammer demography. March-April 2013 was a period of exceptionally cold weather with protracted snow cover in North Wales, and this may have reduced yellowhammer survival and perhaps breeding performance across all treatments. The exceptional weather in spring 2013 may also have affected treatment establishment and performance over the period 2013-14. Again this explanation seems unlikely to account for the lack of treatment effects in localities like the Llyn Peninsula where intervention crop extent and quality were high during the second and third winters of this study.

4.4. Agronomic impacts of allowing ryegrass to set seed on silage production in the following year (Objective 5)

The average impact of SRG on dry matter grass yields in following silage crops was a 12% reduction with no impact on silage quality (D-value). This negative yield impact is smaller than that measured on more productive swards in Shropshire/Cheshire where dry mass yield was reduced by 26% following single cut SRG treatments on PRG (means DM yields were 6.5 & 4.8 DM t per ha; Buckingham et al 2011). Average yield on control plots (no SRG management) were 60% higher on the Shropshire/Cheshire swards. Therefore yield impacts of SRG were considerably smaller on the relatively low yielding improved grasslands included in the North Wales study.

4.5. Recommendations for option delivery and deployment

This study broadly supports the criteria already laid out in the Countryside Stewardship guidance for field suitability and management of the seeded ryegrass option in England (GS3). The current study emphasizes the critical need for candidate PRG swards to contain at least 75% ryegrass cover, and to be closed no later than 31 May. Early closure of PRG swards (before 7 May) also risks vigorous sward re-growth which may make any following seed crop less accessible to foraging birds during winter. Seed production on IRG swards was generally less sensitive to ryegrass cover (cover as low as 52% produced abundant seed) or closure date (13 May to 13 June all produced abundant seed). Seed production on IRG swards remained high despite spring grazing prior to closure although the relatively low seed production on PRG swards might have been partly a consequence of such management (the highest PRG seed yield occurred on an ungrazed sward, Fig. 5).

This study also emphasizes the need for agri-environment type agreements that target farmland birds to include options to provide a range of key limiting resources at different times of year. Various studies conducted mainly in England have shown that population growth of seed-eating farmland birds is limited by lack of seed availability during winter (Gillings et al. 2005, Siriwardena et al. 2007). Despite sustained usage of winter seed providing options in North Wales there was no subsequent increase in the abundance of breeding buntings implying that other factors must be limiting population growth. The mix of factors that limit population growth may therefore vary regionally and between landscapes. Option packages that seek to provide safe nesting habitat, invertebrate-rich habitats in spring and summer and seed-rich habitats in winter (‘the Big Three’) will therefore have the best chance of delivering population growth of target species across regions and landscapes that may differ with respect to farming systems and availability of semi-natural habitats.

4.6 Recommendations for further work

This study has confirmed the potential role of SRG as a simple and effective conservation measure that can fill the late winter hungry gap affecting seed-eating birds wintering in agricultural landscapes. However, seed yields and bird usage were relatively low on Welsh PRG swards and this may be related to the generally low ryegrass cover (Fig. 4) on the relatively low yielding Welsh grass fields, and/or the grazing of swards by livestock prior to closure. Cooler and damper growing conditions might also have affected ryegrass seed production in Wales. Further work is needed to determine the main factors affecting seed yield on ryegrass swards (especially PRG) and the following variables should be considered: sward age, cover of PRG in the sward, soil fertility, management prior to closure (grazed or not), the timing of sward closure and the number of cuts, temperature and moisture. Until we have a better understanding of factors affecting seed yield on PRG fields, deployment of SRG on less productive agricultural grassland might be restricted to IRG swards.

Another question worthy of further research is factors limiting the abundance of seed-eating birds in pastoral landscapes. We predicted that seed availability might be a limiting factor but this study could provide no evidence to support this hypothesis. Such a study should consider potential impacts of changes in breeding habitat quality, changes in wider bird and predator communities (Davey et al. 2012) in the marginal uplands and weather impacts on breeding habitat suitability and on breeding success and post-fledging survival.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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