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Testing a novel agri-environment scheme based on the ecology of the target species, Montagu's Harrier *Circus pygargus*

ALMUT E. SCHLAICH,[1,2]* RAYMOND H. G. KLAASSEN,[1,2] WILLEM BOUTEN,[3] CHRISTIAAN BOTH[2] & BEN J. KOKS[1]

[1]*Dutch Montagu's Harrier Foundation, PO Box 46, 9679ZG, Scheemda, The Netherlands*
[2]*Conservation Ecology, Groningen Institute for Evolutionary Life Sciences, Groningen University, PO Box 72, 9700AB, Groningen, The Netherlands*
[3]*Computational Geo-Ecology, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, PO Box 94248, 1090GE, Amsterdam, The Netherlands*

Farmland birds are in steep decline and agri-environment schemes (AES) to counteract these biodiversity losses are expensive and inefficient. Here we test a novel AES, 'Birdfields', designed using detailed ecological knowledge of the target species, Montagu's Harrier *Circus pygargus*. Current AES, such as field margins, that aim to improve foraging conditions (i.e. vole densities) for harriers are inefficient, as prey are difficult to capture in tall set-aside habitat. 'Birdfields' combines strips of set-aside to boost vole numbers and strips of alfalfa, as voles are accessible after alfalfa has been harvested. We found that vole numbers were generally highest in set-aside. Montagu's Harriers fitted with GPS-loggers used 'Birdfields' intensively after mowing, preferring mown to unmown strips. Thus, prey availability appeared more important than prey abundance. Thus, 'Birdfields', as a targeted AES for Montagu's Harriers, is more effective than previous AES due to increased prey accessibility. An additional advantage of 'Birdfields' is that it is considerably cheaper, due to the harvest of alfalfa. We advocate that AES should always include monitoring and research activities, aiming at a more adaptive conservation approach.

Keywords: agri-environment schemes, biodiversity, *Circus pygargus*, Common Vole, conservation, farmland birds, GPS-tracking.

In recent decades, farmland breeding birds have experienced dramatic population declines as a result of the intensification of agricultural practices (Donald *et al.* 2001, Guerrero *et al.* 2012). In Europe, agri-environment schemes (AES) are widely used to counteract biodiversity loss in agricultural ecosystems. However, their effectiveness is often poorly monitored or could not be shown (Kleijn *et al.* 2001, 2004, 2006, Bradbury & Allen 2003, Kleijn & Sutherland 2003). Positive effects are mainly found when AES are targeted to a specific species (Peach *et al.* 2001, Perkins *et al.* 2011, Pywell *et al.* 2012, but see Bright *et al.* 2015). In a world that needs to feed an ever-increasing human population, the high expenses and apparently low effectiveness make current AES unsustainable, calling for cheaper and more effective measures (Vickery *et al.* 2004, Baker *et al.* 2012).

A rare example of a scheme that has led to an increase of the target species' population concerns the Montagu's Harrier *Circus pygargus* in East Groningen, The Netherlands (Trierweiler 2010). This Red-listed, ground-breeding raptor almost became extinct in The Netherlands at the end of the 1980s (Zijlstra & Hustings 1992). However, a population of nearly 30 breeding pairs established in East Groningen when farmland was set aside on a large scale in the early 1990s (Koks *et al.* 2007). This population further increased after the introduction of AES in 1997 (Koks *et al.* 2007) to around 60 breeding pairs in 2011. In East Groningen,

*Corresponding author.
Email: almut.schlaich@grauwekiekendief.nl

Montagu's Harriers rely greatly on the Common Vole *Microtus arvalis* and both laying date and clutch size are directly related to vole abundance (Koks *et al.* 2007). Moreover, annual population growth rate directly correlates with vole abundance (Koks *et al.* 2007).

The paradox of the successful Montagu's Harrier conservation is that although AES harbour higher vole densities (Koks *et al.* 2007), hunting Harriers capture most prey on intensive grasslands, where prey is less abundant but more accessible directly after mowing events (Trierweiler 2010). Hence, prey availability seems more important than prey abundance alone (e.g. Douglas *et al.* 2009). Based on these observations, we designed a novel AES, coined 'Birdfields', which combines both increased prey abundance and enhanced prey availability. 'Birdfields' consist of alternating strips of set-aside and alfalfa *Medicago sativa* (see Fig. 3 and S2). Set-aside consists of a mixture of cereals, grasses and herbs (Wiersma *et al.* 2014, Table S1), and its most important function is to enhance local densities of voles. Alfalfa is harvested three times per year, and its main function is to enhance prey availability (i.e. during and directly after mowing). An additional advantage of alfalfa is that it reduces the overall costs of 'Birdfields', making this a more economical alternative to current AES (see Discussion).

Here we evaluate 'Birdfields' by describing the ecological determinants of Montagu's Harrier response to this novel AES. This pilot study provides an example of how detailed knowledge of the ecology of the target species has helped to design a more efficient AES for Montagu's Harriers, advocating that ecological research is fundamental to enhance the effectiveness of AES.

METHODS

'Birdfields'

Two 'Birdfields' were created in spring 2011 in the Vriescheloërvennen, East Groningen, The Netherlands, close to a core breeding area of the Montagu's Harrier, one at Polderweg (16 ha, 53.09°N, 7.12°E) and another at Bisschopsweg (20 ha, 53.09°N, 7.11°E, Fig. S1). Half of each field was sown with set-aside and the other half with alternating strips of alfalfa and set-aside (Fig. S2). Birdfields were monitored in subsequent seasons (2012–2013) after the vegetation had fully developed. Alfalfa and, within the context of this particular pilot study, half of the set-aside were mown twice during the Harrier breeding season (in 2012 Polderweg was mown on 22 June and 30 July, Bisschopsweg on 12 June and 30 July; in 2013 both fields were mown on 10 June and 25 July). After each mowing, all edges of mown and unmown parts were georeferenced and digitized maps were created in ArcGIS 10.1 (Fig. S2).

Vole abundance

The relative abundance of voles in different crops was estimated by counting all vole burrows within 1 m of a 100-m transect line (Franken 2012). Six transects were counted per field, with two transects placed in the middle and four transects within 10 m of the edges of the field. Average field size was 12.4 ha (4.4–17.6, 1st–3rd quantiles, $n = 160$) in 2012 and 13.9 ha (6.3–18.0, $n = 79$) in 2013. We did not distinguish between active and inactive vole burrows as a pilot study revealed that even burrows we deemed inactive were used by voles. Counting vole burrows is known to be a relatively inaccurate method (Delattre *et al.* 1990) but it is the only practical method that allows monitoring voles throughout the large home-ranges of Montagu's Harriers. Counts were performed in all common crops in the study area (winter cereals, summer cereals (2012 only), alfalfa, extensive grassland, intensive grassland, rapeseed) and in AES (field margins, set-aside fields, 'Birdfields'). In total, 184 and 89 fields were counted in 2012 and 2013, respectively (Fig. S3).

The relative abundance of voles in set-aside and alfalfa was estimated directly after each mowing event by counting all signs of voles (vole burrows, runways between burrows and small food collection places consisting of pieces of herbs and grasses) in 1-m^2 plots. Plots were counted every 20 m, aligned in the centre of mown strips. In total, 2335 and 3849 plots were counted in 2012 and 2013, respectively. To gain insight on the nature and diversity of potential prey species, all small animals killed or disturbed by the mowing machine were counted during each mowing event, by walking directly behind the mowing machine; 20.6 and 73.3 km were covered in 2012 and 2013, respectively.

Response of Montagu's Harriers

Since 2009, 30 Montagu's Harriers have been equipped with UvA-BiTS GPS-loggers (Bouten *et al.* 2013) for ongoing studies of home-range size and habitat selection (Klaassen *et al.* 2014). Birds were trapped close to the nest using a mist-net baited with a stuffed raptor. GPS-loggers were attached using a 6-mm Teflon harness. In 2012, six male Montagu's Harriers equipped with GPS-loggers were breeding within 10 km of the 'Birdfields', of which one's nest failed in the incubation phase. Of the remaining five, four males regularly visited the 'Birdfields' (individuals ID#677, ID#669, ID#704, ID#505). The nest of ID#677 was predated during the incubation period. In 2013, only four birds fitted with a GPS-logger bred within 10 km of the 'Birdfields', three returning birds and one other individual (ID#669, ID#704, ID#505, ID#582). All four visited the 'Birdfields'. The distance between the nests and 'Birdfields' ranged from 2.7 to 5.6 km.

The frequency with which GPS locations are collected can be changed remotely with UvA-BiTS. GPS-loggers normally collected GPS positions every 5 min during the day and every hour during the night. At mowing events, GPS-loggers collected GPS positions at 3-s intervals ('high resolution measurements') when entering the area of the 'Birdfields'.

For analysis of the general use of 'Birdfields', high-resolution data were subsampled to a 5-min interval. Subsequently, daytime hunting positions were selected, assuming that all positions where the bird was flying were related to hunting. Although these hunting positions include some commuting flights, the proportion of time spent commuting is less than 5%, as commuting flights generally are relatively fast (A.E. Schlaich, R.H.G. Klaassen unpubl. data). The instantaneous speed obtained along with each GPS registration (Bouten *et al.* 2013) was used to distinguish between flying and sitting, using a threshold of 1.2 m/s (minimum of a two-peaked frequency distribution of speed values). Subsequently we calculated, per day, the percentage of hunting positions on 'Birdfields' relative to the total number of daily hunting positions. To evaluate whether the intensity of the use of 'Birdfields' was affected by mowing, the daily proportion of the use of 'Birdfields' was averaged over three periods: (1) 3 days before mowing, (2) the day of mowing and 2 days thereafter, and (3) 3–5 days after mowing. For this analysis, data for all four mowing events and the two 'Birdfields' were combined.

For analysis of habitat selection of Harriers within 'Birdfields', all GPS data, including high-resolution data in period (2) (i.e. 72 h after start of mowing, cf. above), were used. To evaluate whether Harriers preferred mown strips over unmown strips and whether they showed a preference for mown alfalfa or mown set-aside, the percentage of positions on mown alfalfa, mown set-aside and unmown set-aside was calculated and compared with the availability of these habitats, as calculated from the digital ArcGIS maps.

Statistical analyses

All analyses were performed in R 2.15.2 (R Core Team 2012). Model selection and validation followed recommendations in Zuur *et al.* (2009).

The mean number of vole burrows per transect in different crops was modelled with a generalized linear model using the R function *glm.nb* in package *MASS* version 7.3-35 (Venables & Ripley 2002). Using the mean of six transects per field, the number of vole burrows per field was explained by fixed effects *year* and *crop type* under a negative binomial distribution (count data with a small mean (12.7) and much larger variance (1059.3), thus with overdispersion). As the model including the interaction term *year* and *crop type* had a higher Akaike information criteria value (1641.7 vs. 1636.5), the interaction term was removed from the final model. A multi-comparison *post-hoc* test was performed to evaluate differences between the crops using R function *testInteractions* from package *phia* version 0.2 (De Rosario-Martinez 2013).

Vole abundance in the different 'Birdfield' habitats was modelled with a generalized linear mixed model using the R package *MCMCglmm* version 2.21 (Hadfield 2010). Because 57% of all observations were zeros, we used a zero-inflated model with a Poisson distribution. Signs of vole activity were modelled as a function of the fixed effects *year* and *habitat*, with *field* and *mowing event* as random effects. The model including the interaction between *year* and *habitat type* had a higher DIC-value (Hadfield 2010), and therefore the interaction term was removed from the final model.

The effect of mowing (periods *before*, *mowing* and *after*) was tested in a generalized linear mixed model using the R function *glmmPQL* in package *MASS*. The average percentage of 'Birdfield' use was modelled as a function of the fixed effect *period*, with *individual* and *year* as random effects with a binomial distribution.

To test if Harriers preferred mown strips, a compositional analysis was conducted (Aebischer *et al.* 1993) using the R function *compana* in the *adehabitat* package version 1.8.15 (Calenge 2006). Proportions of surface area (based on digital habitat maps) were averaged per habitat category over the two mowing events and the two 'Birdfields' ('habitat availability'). Proportions of habitat use (based on the number of GPS positions in alfalfa, mown set-aside or unmown set-aside) were averaged per individual over the two mowing events and the two 'Birdfields' ('frequency of habitat use'). Subsequently, frequency of habitat use was compared with habitat availability in the compositional analysis including four birds and three habitat categories. Separate analyses were conducted for the 2 years.

RESULTS

At least five times more vole burrows were found in set-aside habitats compared with all other crops (Fig. 1a, Table S2, glmm: difference in deviance 311.97, df = 6, $P < 0.001$, for *post-hoc* test see Table S3). Also within 'Birdfields', there were more signs of vole activity in set-aside than in alfalfa strips (glmm: $P < 0.001$; Fig. 1b, Table S4). This emphasizes the importance of set-aside for high prey densities.

By walking behind the mowing machine, a rough impression about the nature and diversity of potential prey species in 'Birdfields' was obtained. In total, 197 small mammals were encountered, 176 Common Voles, six Common Shrews *Sorex araneus*, one Bank Vole *Myodes glareolus* and one

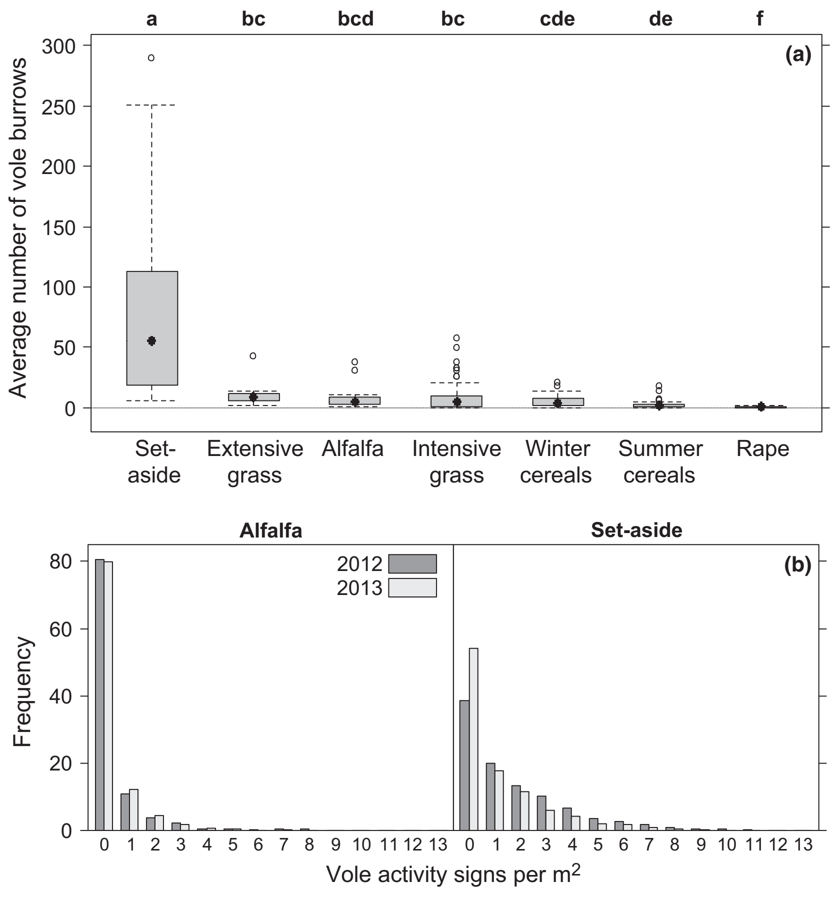

Figure 1. (a) Average number of vole burrows as counted along 100-m transects in different crops in 2012 and 2013 ($n = 272$ fields). Boxplots show median (dot), 25th and 75th quantiles (box), extremes (whiskers) and outliers (points). For sample sizes see Table S2. There was no significant difference between years (glm: difference in deviance 1.12, df = 1, $P = 0.29$). Crop types sharing letters did not differ significantly. (b) Frequency distribution of signs of activity of voles in 1-m^2 plots ($n = 6184$) on 'Birdfields' in 2012 and 2013, for alfalfa and set-aside. Less vole activity was recorded in 2013 than in 2012 (glmm: $P < 0.001$; Table S4).

Wood Mouse *Apodemus sylvaticus*. Twelve mammals could not be identified. In all, 135 amphibians were recorded: 102 Common Toads *Bufo bufo* and 33 frogs *Rana* sp. Furthermore, two juvenile Common Whitethroats *Sylvia communis* and one juvenile Reed Bunting *Emberiza schoeniclus* were found. In 2013, 62 grasshoppers *Tettigonia viridissima* were encountered. Although amphibians were relatively abundant, they form a negligible fraction of the Harrier diet (Koks *et al.* 2007).

Montagu's Harriers fitted with GPS-tracking devices varied greatly in their general use of 'Birdfields' and this variation did not seem to be related to the distance to their nests (Fig. 2a, Fig. S4). For example, in 2012, of the three males (ID#669, ID#704, ID#505) breeding at approximately the same distance, only ID#505 used the 'Birdfields' intensively (Fig. 2a; ID#677 was a failed breeder). However, mowing had a strong effect on the intensity of the use of 'Birdfields' in all individuals. Harriers visited 'Birdfields' more during and after mowing than before (glmm: $t = 5.506$, df = 17, $P < 0.001$ and $t = 2.204$, df = 17, $P = 0.042$, respectively; Fig. 2b). In addition, Harriers selected mown set-aside over mown alfalfa, but primarily selected harvested habitats (alfalfa and harvested set-aside) over unmown habitat (unmown set-aside, compositional analysis: in 2012: $\lambda = 0.036$, df = 2, $P < 0.01$; in 2013: $\lambda = 0.075$, df = 2, $P < 0.01$; Figs 3 & 4).

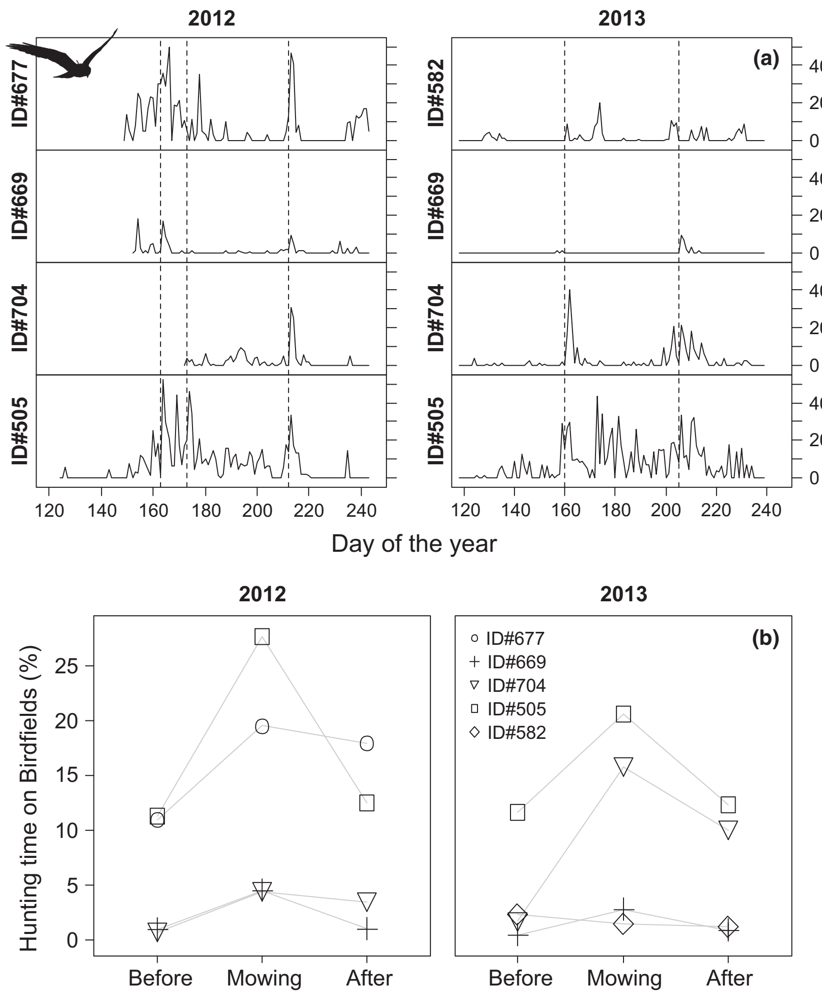

Figure 2. (a) Use of 'Birdfields' by four male Montagu's Harriers in 2012 and 2013 as percentage of their daily hunting time. Dashed lines indicate mowing events on 'Birdfields'. (b) Mean use of 'Birdfields' by male Montagu's Harriers as a percentage of their daily hunting time during the 3 days before mowing, day of mowing and 2 days thereafter, and 3–5 days after mowing.

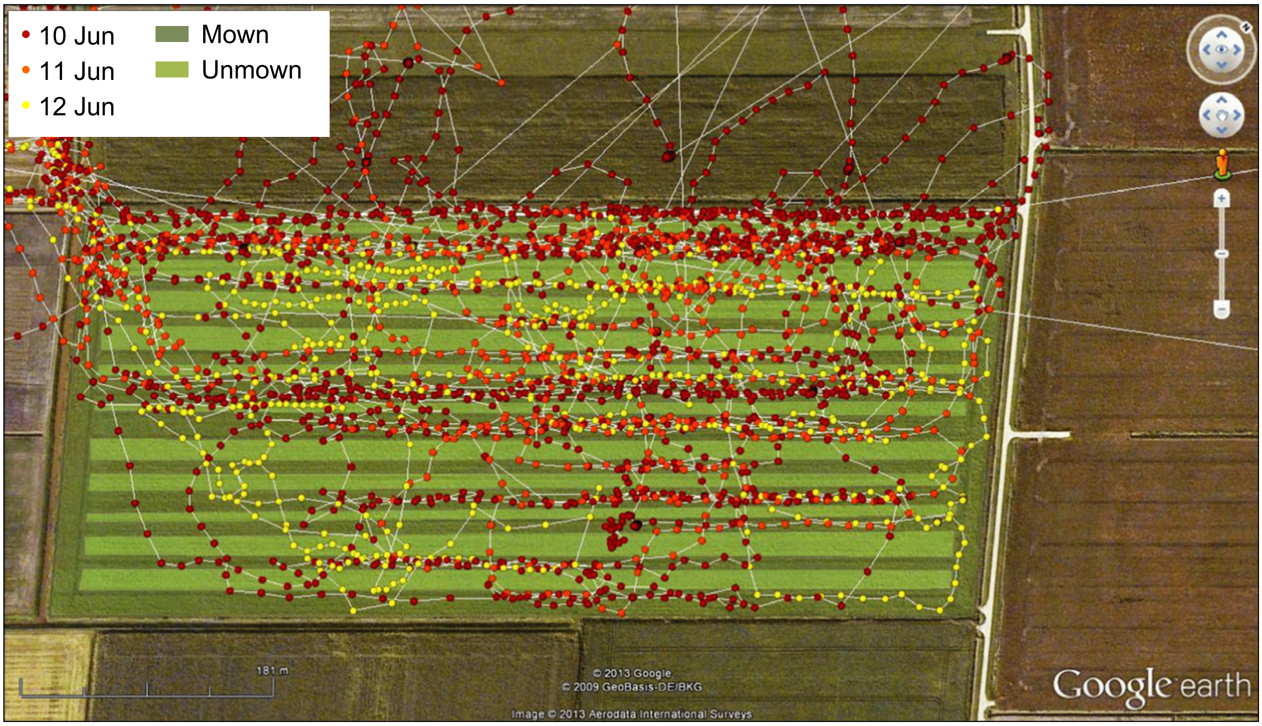

Figure 3. Example of the tracks of male Montagu's Harrier ID#704 hunting above a 'Birdfield' on the day of mowing (10 June 2013, red) and the 2 days thereafter (11 and 12 June 2013, orange and yellow). Note that the Harrier followed strips of mown habitat.

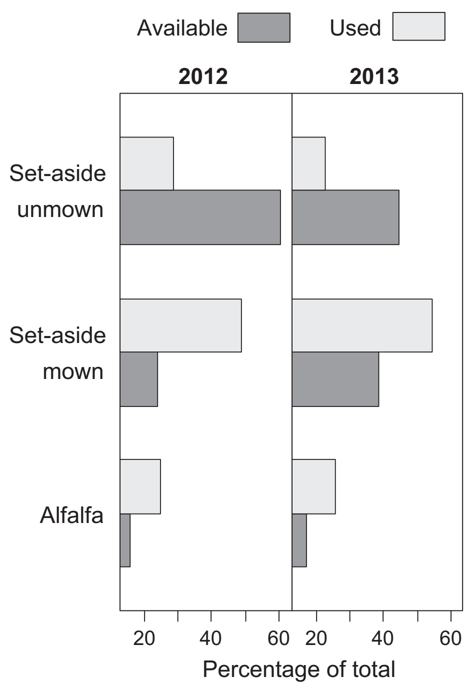

Figure 4. Habitat use of Montagu's Harriers hunting on 'Birdfields' compared with habitat availability.

DISCUSSION

Our results suggest that prey availability is more important for habitat selection than prey abundance alone, emphasizing the importance not only of enhancing prey densities but also of making this prey available. This result implies that it is important to measure prey availability (or hunting success) instead of prey abundance when evaluating the efficiency of AES.

The aim of this study was to show that the 'Birdfield' concept works in the sense that Harriers immediately respond when voles are made available, rather than quantifying the overall importance of 'Birdfields' for the reproduction or population growth of Harriers. The latter would require applying 'Birdfields' at larger spatial scales, comparing individuals breeding in areas with and without 'Birdfields'. This might be difficult as Montagu's Harriers in The Netherlands generally forego breeding in areas without AES. Nevertheless, evaluating the importance of 'Birdfields' for successful reproduction and population growth is an important next step, as we could imagine that 'Birdfields' are most effective in areas where

Harriers strongly depend on small mammals (e.g. in France: Millon *et al.* 2008, Millon & Bretagnolle 2008) and less effective in regions in which Harriers feed mainly on birds (e.g. Terraube & Arroyo 2011).

'Birdfields' were not only favourable for Montagu's Harriers. During the breeding season, other vole-eating species such as Common Buzzard *Buteo buteo*, Common Kestrel *Falco tinnunculus*, Western Marsh Harrier *Circus aeruginosus* and Hen Harrier *Circus cyaneus* regularly visited 'Birdfields' for hunting. Furthermore, substantial numbers of Skylarks *Alauda arvensis*, a species that has heavily declined in our study area (Ottens *et al.* 2013), were nesting in the 'Birdfields'. This is important as Skylarks generally avoid nesting in AES, making it difficult to preserve this species in agricultural landscapes (Kuiper *et al.* 2013, 2015). Other passerines may profit from breeding in set-aside, and thus mowing part of the set-aside during the breeding season is not recommended. Finally, in winter, 'Birdfields' were a magnet for passerines such as finches and buntings, which fed on the cereal-rich set-aside strips, and wintering raptors such as Rough-legged Buzzard *Buteo lagopus* and Hen Harrier.

An important additional advantage of combining set-aside with a harvestable crop is that this makes the measure interesting from an economic point of view, for both the conservationist and the farmer. The current cost to realize 1 ha of set-aside is €2100, which is roughly equal to what a farmer would gain from growing winter wheat. As 'Birdfields' consist of a mixture of set-aside and alfalfa, less is eventually paid per hectare of 'Birdfield'. For example, the current configuration of 'Birdfields' consists of 40% set-aside and 60% alfalfa, so the cost is only €840/ha (2100*0.4). Thus, 'Birdfields' are a cheaper AES than set-aside without alfalfa strips; more hectares of 'Birdfields' can be realized with the same amount of money (in the current example, 2.5 times as much). Alfalfa was harvested and collected by the local crop drier (B.V. Oldambt, Oostwold, The Netherlands) and used for the production of commercial animal food pellets. A farmer normally earns €750/ha from growing alfalfa. It is thus highly advantageous for a farmer to combine alfalfa with set-aside, as the profit from growing set-aside (€2100/ha) more than outweighs the loss of the production of alfalfa (€750/ha), and there might be an additional small financial gain if part of the set-aside is also harvested (in this particular case, half of the set-aside was harvested during the second alfalfa harvest). Altogether, the farmer earns €1290/ha. It should be stressed that 'Birdfields' are not a profitable alternative to winter wheat (from the perspective of the farmer) as the profit of growing wheat is €2100/ha.

In a world that needs to feed an ever-expanding human population, there will be increasing pressure on biodiversity, and hence the cost efficiency and ecological effectiveness of AES need to be improved. We advocate that AES can be more efficient when measures are designed according to the behaviour and specific ecological requirements of a target species. We have shown that combining areas with high food availability and making these available through common agricultural practices is a promising approach. This is only possible when detailed ecological knowledge of the target species is available, and implementation of AES should therefore always be combined with monitoring and research activities, aiming at a more adaptive conservation approach.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Figure S1. Location of the 'Birdfields' within the study area.

Figure S2. Distribution of mown alfalfa, mown set-aside and unmown set-aside after the first mowing events in 2012 and 2013.

Figure S3. Map of the locations of the vole burrow transect counts throughout East Groningen. Yellow boxes indicate the location of the 'Birdfields'.

Figure S4. Use of 'Birdfields' by Montagu's Harriers in relation to the distance from their nest.

Table S1. Seed mixture for set-aside strips.

Table S2. Vole abundance (mean number of vole burrows per field counted on six transects of 100 m length) in different crops in 2012 and 2013. Given are median, mean, minimum and maximum values and number of fields sampled (*n*).

Table S3. *P*-values of multiple comparison chi-square tests of the number of vole burrows in different crops.

Table S4. Number of vole activity signs (vole burrows, runways and food collection places) in 1-m^2 plots on 'Birdfields' in mown alfalfa strips (left) and mown set-aside strips (right) in 2012 and 2013. Given are mean, minimum and maximum values and number of plots counted (*n*) separated for the two fields and two mowing events.