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Abstract

Capsule: The winter diet of common buzzards on a red grouse moor was dominated by small mammals, whilst grouse were a minor prey item.

Aims: To assess winter buzzard diet from pellets collected at roost sites on and around a managed red grouse moor, and to explore temporal, spatial and age-related variation in diet composition.

Methods: Forty-four winter roost sites were located during two winters using a combination of observations from vantage points and individual buzzards equipped with either radio or satellite transmitters. Pellets were collected between October and March each winter and analysed to assess dietary composition.

Results: Small mammals were the main prey in both years, comprising 60-67% of items and occurring in 88-92% of pellets. Diet varied between years, with more lagomorphs and birds (passerines, corvids and pigeons) but less red grouse eaten when grouse abundance declined. Grouse formed 1.1% and 0.6% of prey items, and occurred in 3% and 2% of pellets from each winter respectively.

Conclusion: Buzzards rely on small mammal prey during winter. When available, red grouse are a minor dietary component, the amount of which reflects their abundance in the environment. The opportunism of buzzards can result in temporal variation in winter diet.
**Introduction**

Assessment of dietary composition is an important component of many ecological studies, including assessing the impact of raptors on gamebirds (Park *et al.* 2008), which is a contentious and topical issue (Lees *et al.* 2013; Elston *et al.* 2014; Parrott 2015). Most studies of raptor diet are conducted during the breeding season, owing to the concentration of activity at a nest (Lewis *et al.* 2004). However, raptor diet varies between seasons (Mañosa & Cordero 1992; Amar *et al.* 2003) and their impact on gamebirds can occur year-round (Redpath & Thirgood 1999). The dearth of raptor diet studies during the non-breeding season therefore presents a gap in our understanding of the potential impact of raptors on gamebirds.

In Britain, the common buzzard *Buteo buteo* (hereafter ‘buzzard’) has extended its winter range by an estimated 74% in the last 30 years (Balmer *et al.* 2014). In most areas this represents a recolonisation of previously occupied range, following decades of persecution and indirect organo-chlorine poisoning (Newton 1979; Dare 2015). Buzzards are now the most abundant diurnal raptor in Britain (Clements 2002), with a recent population estimate of 56-77,000 breeding pairs (Musgrove *et al.* 2013). This population increase and range expansion has reignited conflict between stakeholders concerned with raptor conservation and those involved in gamebird management (Lees *et al.* 2013; Parrott 2015). During the summer, buzzards eat red grouse *Lagopus lagopus scotica* alongside their preferred small mammal and lagomorph prey (Graham *et al.* 1995; Francksen *et al.* 2016), yet their winter diet is relatively unknown (Schindler *et al.* 2012).

Several studies have investigated buzzard habitat use during the winter in continental Europe with reference to its effects on diet (Wuczyński 2005; Wikar *et al.* 2008; Schindler *et al.* 2012; Baltag *et al.* 2013), yet none of these assessed diet composition itself. Whilst Mañosa & Cordero (1992) analysed buzzard stomach contents during winter to obtain diet composition data, this method required access to recently deceased birds and is therefore not feasible for many studies of diet. The winter diet of raptors has also been assessed by conducting carcass searches (Watson *et al.* 2007); by radio-tracking individuals to kill sites (Kenward *et al.* 1981) and by analysing regurgitated pellets collected from roost sites (Clarke *et al.* 2008; Rexer-Huber & Bildstein 2012). Here we used satellite and radio-tracking, supplemented with observations, to locate winter buzzard roosts on and around a moor managed for red grouse shooting. We explored whether buzzards roosted alone, or communally as they do in Central Europe when exploiting sporadic food sources outside the breeding season (Newton 1979). From these roost sites, we collected pellets to determine winter buzzard diet composition. Raptor diet composition can vary over time as abundances of prey in the environment
fluctuate (Redpath & Thirgood 1999). Therefore, we hypothesised that any changes in buzzard diet between successive winters would reflect fluctuations in their main field vole *Microtus agrestis* or alternative red grouse prey. We also hypothesised that buzzard diet composition would vary according to local habitat composition, which influences the availability of different prey types to raptors (Thirgood *et al.* 2003), and with variation in buzzard age, which can affect hunting proficiency and prey choice (Rutz *et al.* 2006; Penteriani *et al.* 2013).

**Methods**

**Study site**

The study was conducted on approximately 221-km² of moorland at Langholm in south-west Scotland (55.1 – 55.3°N, 3.0 – 2.8°W), including 76-km² designated as the Langholm – Newcastleton Hills Site of Special Scientific Interest and Special Protection Area. The site included 120-km² managed under the Langholm Moor Demonstration Project (LMDP) (Langholm Moor Demonstration Project 2014), plus a 2-km buffer zone to include roosts of buzzards which may hunt on the LMDP area (Graham *et al.* 1995). The study site was a mosaic of heather *Calluna vulgaris* dominated moorland and acidic grassland, with improved grassland and commercial coniferous and mixed deciduous woodland dominating the buffer zone (Francksen *et al.* 2016). Management for red grouse, including control of corvids, red foxes *Vulpes vulpes*, stoats *Mustela erminea* and weasels *M. nivalis*, as well as burning, cutting and re-seeding of heather, was undertaken by a team of five gamekeepers within the LMDP area. The study was conducted during two winters (October – March inclusive) in 2013/14 & 2014/15. Both winter periods were similarly mild and wet with no significant periods of snow cover (www.metoffice.gov.uk).

Small mammals, especially voles *Microtus spp.*, are a main component of buzzard diet throughout Europe (Valkama *et al.* 2005), and the abundance of field voles fluctuates on an approximately three – to four-year cycle at Langholm Moor (Redpath & Thirgood 1997). For this study, vole abundance was assessed each March (at the end of each winter period) from 50 snap-traps set over two nights at 10 sites across the site, i.e. 1000 trap nights per annum (see Redpath *et al.* 1995). Traps were set unbaited in vole runways at approximately 10m intervals. Data were expressed as the number of voles caught per 100 trap nights.

We used line-transect distance sampling (Buckland *et al.* 2001; Warren & Baines 2011) to survey red grouse. Grouse were counted each March or early-April on ten 0.5km² blocks containing line-transects spaced 150-m apart, and on 18 separate line-transects (mean transect length = 1.95 km,
range = 0.96 – 3.46) across the study site. Surveyors walked each transect whilst systematically working a pointer dog on both sides of the transect line. When grouse were located, all birds were counted and the perpendicular distance from the transect line to the grouse was measured using a GPS. We analysed data separately for each year using the program DISTANCE 6.0 (Thomas et al. 2010). Frequency histograms of the perpendicular distance of grouse from the transect line were plotted with candidate detection probability models during the exploratory stage of the analysis. We used the conventional distance sampling analysis engine with a half-normal key function and cosine adjustment, and selected models giving the best fit based on minimum Akaike’s Information Criterion (AIC) scores and χ² goodness-of-fit tests (Warren & Baines 2011). The models provided detection probabilities, expressed as effective strip widths (ESWs), of 40.0m and 47.7m for 2014 and 2015 respectively. Mean densities (grouse/km²) were then calculated for each block or transect using:

\[
Grouse \text{ density } = \frac{\text{Total grouse counted}}{\text{Total transect length} \times (\text{ESW} \times 2)}
\]

Mean abundances of voles on the ten trapping lines, and of grouse on the 28 count areas (blocks and transects combined), were compared between years with paired t-tests.

Identification of roost sites

To help locate roosts, we fitted remote tracking tags to nine buzzards between October 2013 and January 2014. Birds were caught as non-target species in pre-baited live-catching traps (a.k.a. ladder-traps) used to control carrion crows Corvus corone by the LMDP gamekeepers. Five buzzards were fitted with satellite (GPS) tags (model: Ecotone SAKER-4 GPS/GSM): three immature birds, i.e. two or three years old (two males and one female); and two juveniles (one male and one female). The other four were fitted with radio (VHF) tags (model: Biotrack TW-3 2/3AA): three immature females and one juvenile male. All traps were checked at least once a day by field workers or gamekeepers, and any buzzards caught were tagged and released on discovery.

Data from tagged individuals were collected after four days had elapsed following capture and release to allow resumption of normal behaviour (Kenward 2001). All data were collected between November 2013 and March 2014. GPS tags were set to record bird locations four times per day, but during periods of low light levels the solar panel did not charge causing batteries to drop below operating voltage. Data from GPS tags were received via the GSM (European mobile telecommunication) network to an online server before downloading. A mean of 146 points were
obtained from the five GPS tags (range: 66 – 260). VHF tagged individuals were triangulated to an accuracy of circa 100 m three or four times per week. A mean of 40 points were obtained from the four VHF tagged birds (range: 33 – 48). Any positions with an error >100 m (n = 9) were excluded from analysis (Kenward 2001). To reduce the risk of autocorrelation of positions, no two positions were obtained within three hours of each other for both tag types. Roosts of each tagged bird were identified from dawn and dusk locations, whilst repeated fixes at three to five day intervals confirmed continued use of the roost.

To increase the sample of roost sites, vantage point watches were conducted at dawn and dusk overlooking apparently suitable sites. To confirm buzzard presence at roosts, all sites were searched for faecal droppings, freshly moulted feathers and down, and fresh pellets (Hardey et al. 2013).

Twenty-three buzzard roost sites were found during the 2013/14 winter, including one roost site for each of the nine tagged individuals. During the following winter (October 2014 – March 2015) these roosts were revisited, whereby 19 were found to still be used and a further two were found, giving 25 separate roosts and 44 roost-years in total.

Pellet collection and analysis

Roosts were searched fortnightly for pellets between October and March each winter. Pellets were dried and frozen prior to analysis. Remains were identified to the lowest possible taxonomic level. Mammal hairs and bones were identified using descriptions in Teerink (1991) and Yalden (2009). Feathers and feather fragments were identified using descriptions in Brown et al. (2003) and matched against reference samples. Invertebrate prey were identified from the presence of undigested appendages and wing-cases of hard-bodied Coleoptera or from chaetae of earthworms (Yalden 2009). Remains of prey in pellets were assumed to represent one individual unless it was obvious that more than one individual was present. Prey were assigned to one of six groups:

1. Small mammals (field vole Microtus agrestis; bank vole Myodes glareolus; European mole Talpa europaea; common shrew Sorex araneus; pygmy shrew Sorex minutus; small mammal remains unidentified to species).
2. Lagomorphs (European rabbit Oryctolagus cuniculus; brown hare Lepus europaeus). Identification of these two species is only reliable by examining the hair cortex widths at the microstructural level (Wolfe & Long 1997) and so were not separated here.
3. Invertebrates (beetles Coleoptera spp. (largely Carabidae spp. and Scarabidae spp.); earthworms Megadrilacea spp.).
4. Pheasants Phasianus colchicus.
5. Red grouse.


Since pellets usually contained more than one prey item, two measures of prey frequency were derived (Redpath et al. 2001): (i) the frequency of a given prey type as a mean percentage of all identified items in pellets between roosts (‘mean % of prey’), and (ii) the percentage of all pellets containing a given prey type irrespective of the amount in each pellet (‘% occurrence’). Data from pellets are poor at predicting the contribution of prey types to total biomass of raptor diet (Redpath et al. 2001), and so data were not converted to biomass here.

The generalist and opportunistic nature of buzzards (Tubbs 1974) can result in large variations in diet between individuals, largely related to local habitat composition (Swann & Etheridge 1995; Rooney & Montgomery 2013). Therefore, we assessed habitat composition in order to explore its effects on buzzard diet. Habitat composition was assessed within an area approximating to the core home range around each of the 19 repeat sampled roosts. Core ranges were estimated from locations of eight of the nine tagged individuals (data from one individual were excluded due to inadequate sample size). The ranges were centred on each roost, excluding excursive locations, which can cover many kilometres and are not directly linked to resource use (Kenward 2001). The average core range area was estimated as a circle with radius 926-m, using cluster analysis of the 95% core range in RANGES V (Kenward & Hodder 1996). This average radius was rounded up to 1 km, giving an average core range area of 3.1 km². Within these areas around each of the 19 roosts, we estimated the broad habitat composition using data from the Centre for Ecology and Hydrology Land Cover Map (LCM) 2007 dataset (Morton et al. 2011). These data consist of a 25 × 25-m grid, each square categorized by its dominant vegetation class. Data were incorporated into ArcGIS version 10.3 to calculate the habitat proportions in each core range. Heather moorland (aggregate class ‘mountain, heath, bog’ in the LCM2007 dataset), grassland (aggregate class ‘semi-natural grassland’) and woodland (aggregate classes ‘coniferous and broadleaf woodland’) together comprised an average of 97% of total habitat composition across all roost sites (range: 94 – 99%). Heather moorland and woodland cover were significantly negatively correlated ($r = -0.73$, $P < 0.001$). To avoid collinearity between habitat types, we excluded woodland since buzzards are primarily hunters of open country and forests with open canopies (Tubbs 1974; Kenward et al. 2001; Hardey et al. 2013), whilst much of the forest on our study site was closed canopy commercial coniferous stands, and so the other habitat types were deemed to be biologically more relevant to our exploration of buzzard diet. Our conclusions would not have differed had woodland cover been included in the models. Because heather moorland and
grassland together comprised an average of 79% of total habitat composition around roosts (range: 53 – 97%), we log transformed the ratio of heather moorland to grassland to create a single habitat variable.

Hunting efficiency may increase with age in raptors (Newton et al. 1981; Krüger 2005) which can affect prey choice (Rutz et al. 2006; Penteriani et al. 2013), and so we also explored the effect of buzzard age on diet composition. The buzzard using each roost was aged from plumage patterns on the breast, tail and greater coverts (Svensson et al. 2009; Hardey et al. 2013) and categorised as ‘adult’ (individuals over 3 years); ‘immature and juvenile’ (individuals less than 3 years); or ‘unknown age’. Data from tagged individuals showed that buzzards were faithful to one roost on 89% of occasions (range: 74% – 100%). Therefore, we assumed that pellets from each roost came from a different individual.

Statistical analysis

To examine the factors affecting the composition of buzzard diet, compositional analysis was used (Aebischer et al. 1993). As the proportions of each of the six prey types identified in pellets from each roost when summed equalled one, and therefore could not be considered independent from each other, data were transformed into five log-ratios with ‘other birds’ used as the denominator in the transformation. The choice of denominator does not affect the outcome of the analysis (Aebischer et al. 1993b). Any zeros in the dataset were replaced with 0.1 to allow calculation of log-ratios. Log ratios were then analysed with multivariate analysis of variance (MANOVA), specifying year (two-level) and buzzard age (three-level) as factors and habitat as a covariate. Interaction terms between all effects were tested and main effects were tested with non-significant interaction terms removed. Significance values were tested with Wilk’s Lambda statistic. Only the 19 roosts that were sampled in both years were included in this analysis. To identify which prey groups caused any differences found in the MANOVA, a ranking matrix was constructed by comparing the pairwise differences between log-ratios using contrast analysis (Aebischer et al. 1993). Analyses were conducted using the ‘manova’ function in the nlme package of ‘R’ statistical software (Pinheiro et al. 2014).

Results

Mean field vole abundance per 100 trap nights did not differ between March 2014 (5.3 ± 0.8 SE) and March 2015 (4.4 ± 1.3 SE) (t = 0.65, n = 10, P = 0.53). Over the same period, grouse abundance
declined from 86.6 / km² (± 5.9 SE) in March/April 2014 to 69.8 / km² (± 5.2 SE) in March/April 2015
(t = 3.54, n = 28, P = 0.001).

All identified roost sites were occupied by a single buzzard and the minimum between-roost
distance was 254 m, justifying our assumption that pellets from one roost came from one individual.

Searches of 23 roosts during 2013/14 yielded 409 pellets (mean pellets per roost = 18, range = 12 –
32), while 355 pellets were collected from 21 roost sites in 2014/15 (mean pellets per roost = 17,
range = 10 – 28). Categorising roost sites according to buzzard age in 2013/14 showed that 203
pellets were collected from eight roosts of young (immature/juveniles) buzzards, 117 pellets from
eight roosts of adult buzzards, and 89 pellets from seven roosts of buzzards of unknown age. In
2014/15, 139 pellets were collected from eight roost sites occupied by young buzzards, 157 from
nine roost sites occupied by adults and 59 pellets from four roost sites of unknown buzzard age.
Overall, 2,100 prey items were identified from all pellets (2013/14 = 1,107 prey items; 2014/15 = 993
pellet items). The mean number of prey items per pellet was 2.7 (range = 1 – 7) in 2013/14 and 2.8
(range = 1 – 8) in 2014/15. The majority of pellets collected from all 44 roosts contained small
mammals, which were also the most frequently occurring prey item in both years (Table 1a).
Invertebrate remains, which were predominately beetles *Coleoptera* spp., were the second most
important prey group in both years.

Data across years from the 19 repeat sampled roosts (Table 1b) showed that pellets from adult
buzzards contained more small mammals (adults = 66.6% of prey items, young = 60.4% of prey
items) and ‘other birds’ (adults = 5.0%, young = 4.7%), whilst pellets from young buzzards contained
more lagomorphs (adults = 8.0%, young = 11.1%), invertebrates (adults = 18.2%, young = 20.7%),
and red grouse (adults = 1.0%, young = 1.2%). However, after removing all non-significant interaction effects, the overall composition of prey in pellets did
not differ significantly with buzzard age category (Λ = 0.73, P = 0.47), and this remained non-
significant when buzzards of unknown age were removed (Λ = 0.88, P = 0.65). Variation in broad
habitat composition around each roost also had no detectable effect on overall composition of prey
in pellets (Λ = 0.88, P = 0.58).

The composition of prey in pellets differed significantly between years (Wilks’ Lambda (Λ) = 0.67, P =
0.03). A simplified ranking matrix from contrast analysis of prey groups (Table 2) showed an
increasing importance of prey groups in 2014/15 compared to 2013/14 in the order: Other birds >
Lagomorphs > Small mammals > Invertebrates > Pheasants > Red grouse. In 2014/15, buzzards ate
more ‘other birds’ (mostly small passerines, corvids and columbids) and lagomorphs, but fewer red
grouse (relative to other birds and lagomorphs), which reflected the decline in red grouse abundance during this period.

Discussion

The winter diet of raptors, including buzzards, is poorly understood compared to during the breeding season (Lewis et al. 2004; Schindler et al. 2012). In this study we demonstrated how remote tracking methods, supplemented with observations, could be used to identify winter roost sites of common buzzards for the purpose of collecting and analysing pellets for dietary composition data. We found no evidence that buzzards at Langholm Moor roosted communally, as can be found in Central Europe (Newton 1979). Pellets collected from roost sites indicated that small mammals were the favoured winter prey of buzzards, consistent with other studies in Britain during the breeding season (Swann & Etheridge 1995; Graham et al. 1995; Francksen et al. 2016) and buzzard diet in Spain during the winter (Mañosa & Cordero 1992). Invertebrates were also an important prey resource numerically, the majority of which were beetles and earthworms, which may reflect the increased time that buzzards spend hunting from the ground during winter (Tubbs 1974; Wuczyński 2005). Both winters of this study were mild with little snow cover, which probably meant that many ground dwelling invertebrates remained available. Numerous studies have recorded reptiles and amphibians in the summer diet of buzzards (Swann & Etheridge 1995; Selås et al. 2007; Rooney & Montgomery 2013; Francksen et al. 2016). However, we found no identifiable remains of reptiles or amphibians, which may reflect both a reduced availability of these prey outside of summer, and their underestimation in pellet analysis (Selås et al. 2007; Francksen et al. 2016).

The diet of generalist predators, including buzzards, varies temporally in relation to changes in local prey abundance (Redpath & Thirgood 1999; Reif et al. 2004). We found that buzzard diet varied between years: compared to the first winter buzzards ate more lagomorphs and other birds, but fewer red grouse. The reduced importance of red grouse in the diet of buzzards in the second winter reflected lower grouse abundance. However, in the absence of data on the abundances of lagomorphs and other birds, we cannot conclude whether these results indicate shifts in foraging habits or merely a response to their greater availability as prey to opportunistic buzzards (Tubbs 1974; Newton 2013). Studies in Scandinavia have suggested that when preferred small mammal abundances are lower, generalist raptors switch to alternative prey, including more gamebirds (Reif & Tornberg 2004; Tornberg et al. 2012). We were unable to assess how buzzards respond functionally during winter to changing small mammal abundance, since vole abundances were similar during both of our study winters. This remains an important avenue of further research, and
will require information on the fluctuations in abundance of a range of alternative prey. Nevertheless, since red grouse occurred in just 2-3% of pellets and formed 1% of prey items, it suggests that grouse are merely incidental prey for buzzards during the winter. This figure is slightly lower than the 4% of total identified prey in buzzard pellets collected over three summers at Langholm (Francksen et al. 2016), which may also reflect the lower abundance of grouse during the winter (Ludwig et al. 2016).

Whilst our study has provided a potentially important insight into winter buzzard diet on a moor managed for red grouse, results and their inferences should be treated with caution. Firstly, whilst pellet analysis is widely used to assess raptor diet (Tornberg & Reif 2007), the high digestive efficiency of buzzards (Barton & Houston 1993) and the selective removal of indigestible parts (Dare 2015), means that pellet analysis can underestimate the occurrence of avian or soft-bodied prey (such as amphibians or earthworms), whilst overestimating conspicuous or indigestible remains such as wing-cases and exoskeletons of hard-bodied invertebrates (Francksen et al. 2016). Advances in molecular techniques for the identification of both predator and prey species (Mumma et al. 2014; Evans et al. 2016; Hopken et al. 2016) may complement traditional methods of understanding predator-prey interactions in the future. Secondly, our analysis of pellets was unable to distinguish between prey that have been scavenged and those that have been killed. Buzzards are known to scavenge carcasses as well as take live prey (Tubbs 1974; Parrott 2015). The possibility that pellets contain remains of scavenged prey, or kills that have been visited over multiple days, means that this method of diet assessment cannot provide accurate information about predation rates (Redpath et al. 2001). Nevertheless, our results can still provide information on dietary shifts and foraging behaviour, some of which we outlined here. Finally, our estimates of winter home range using remote telemetry would benefit from more data from a larger sample of individuals in order to improve accuracy. An average winter home range area was used to estimate habitat composition around each roost, however all tagged buzzards were either juvenile or sub-adult individuals, which in many raptor species have been shown to roam further than adults, a reflection of inexperience in hunting, mate searching or the lack of an established territory to defend (Newton 1979; Walls & Kenward 1998; Penteriani et al. 2013). Different estimates of winter home range may come from inclusion of telemetry data from adult buzzards, although the effect of long range excursions was minimised by considering core ranges only, and in the absence of alternative data it is the most appropriate estimate currently available on our study site.

Quantitative assessments of predation on gamebirds are crucial to finding remedies for minimizing conflict between people, predators and game (Elston et al. 2014), and assessing dietary composition
forms the basis of many studies investigating the impact of raptor predation on gamebirds (Park et al. 2008). We highlight that red grouse were a minor component of buzzard diet on our study site during the winter, and appeared to reduce in importance as red grouse abundance declined. Further research should assess the effect of fluctuations of a range of prey resources on dietary shifts and foraging habits of buzzards.

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