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Can Food Supply explain Variation in Nesting Density and Breeding Success amongst Golden Eagles *Aquila chrysaetos?*

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ABSTRACT

This paper describes part of an extensive study of Golden Eagles and land-use in the Scottish Highlands over the period 1982-85. A key objective was to seek to explain variation in density and breeding performance across the species' range. Population parameters were measured for more than 100 pairs of eagles each year and indices of food abundance were derived from 3,500 km of line transects. Principal food items recorded were tetraonids and lagomorphs which together constituted the bulk of live prey taken. Dead deer and sheep were also counted since these were frequently eaten as carrion. Correlation analysis revealed no significant relationship between the total amount of food and either nesting density or breeding success. However there was a significant positive correlation between nesting density and amounts of carrion. Furthermore breeding performance was positively correlated with amounts of live prey. These findings reflect seasonal differences in the diet of Golden Eagles in Scotland where proportionately more carrion is eaten in winter and more live prey in summer. We suggest that winter food supply may explain much of the variation in nesting density whilst differences in breeding performance can be better explained by food availability in summer.

INTRODUCTION AND AIMS

During the 1960s there were several key studies of Golden Eagles *Aquila chrysaetos* in Scotland (Brown & Watson 1964, Lockie 1964, Lockie, Ratcliffe & Balharry 1969). In the most comprehensive of these, Brown & Watson 1964 sought to explain differences in Golden Eagle breeding density in terms of food supply. They concluded that differences in eagle numbers across the species' range in Scotland could not be accounted for by differences in total amounts of food available. Over the past 25 years there have been wholesale changes in land-use in the uplands of Scotland with a movement away from hill sheep farming towards commercial forestry, as well as more subtle changes in the management of Red Deer *Cervus elaphus*. In acknowledgement of this and in recognition of the lack of contemporary information on factors affecting eagle numbers and performance in Scotland, the Nature Conservancy Council commissioned a study of eagles and land-use (Watson, Langslow & Rae 1987).

In order to appreciate the effects of land-use changes on eagles, it was first necessary to describe and explain variation amongst population measures which already existed across the species' range. To this end we asked the following questions:-

1. Is there variation in Golden Eagle nesting density and breeding performance across the species' range in Scotland?
2. Are there differences in available food which might explain differences in density and performance?

STUDY AREAS

Fieldwork was done in six study areas, each extending over about 1,000km^2, and encompassing a representative range of ecological and land-use variation in the Scottish Highlands. The range of ecological variation is described in Brown & Watson 1964, who worked in four study areas representing four ecological zones. We followed their divisions but added two other areas. Full descriptions of all our study areas are given elsewhere (Watson, Langslow & Rae 1987). Key differences between study areas are reflected in the types of land-use prevalent in each. The primary land-uses of the Highlands are management for Red Deer, hill sheep farming and commercial forestry. In general, Red Deer are the dominant feature of the east Highlands, there is a mixture of sheep and deer in varying proportions in the north and west, and in the south-west sheep farming exists alongside large-scale and expanding forestry operations. Two of our areas were in the north-west, two in the south-west and one in the east. The sixth area was intermediate, both ecologically and in terms of land-use, between the north-west and the east.

METHODS

Assessments of food abundance were made, using a series of line transects which were stratified across each area using the 10 x 10 km National Grid. Line transects were walked in eight or more of the 10 x 10 km squares in each study area. Routes were selected at random within each square and, where possible, each route totalled 20 km in the form of a 5 x 5 km square. Where necessary, modifications were made to avoid stretches of open water, mature forestry plantations and precipitous slopes. All transects were done on foot and between 25 February and 31 May each year. More than 95% of transects were done between 1 March and 15 May. For each study area a selection of transects was repeated in successive years and some new areas were covered in most years.

For each transect counts were made of species likely to be taken as 'living' prey, particularly Red Grouse *Lagopus lagopus*, Ptarmigan *Lagopus mutus*, Mountain Hare *Lepus timidus* and Rabbit *Oryctolagos cuniculus*. In addition, records were kept of all carcasses of sheep and deer, since these provided a source of food in the form of carrion.

The methods for determining numbers of eagles and breeding performance in specific areas were similar to those used in a recent national survey (Dennis *et al.* 1984). All available historical information was collated to indicate the maximum number of eagle nesting territories in each study area. A nesting territory was defined as a collection of eyries known from historical breeding records to belong to a pair of eagles which were distinct from all neighbouring pairs. In 1982 all such nesting territories were examined for occupancy and all apparently suitable areas which had no record of nesting eagles were also searched. Finally, in each study area searches in apparently unoccupied territories were repeated during subsequent years.

All active nests which contained eggs were visited or checked from a distance at least once during incubation. Nests with chicks were visited at least twice, once between mid-May and mid-June and once after chicks were gauged to be more than 8 weeks old. In a few cases nests were not visited after fledging and for these the number of chicks at 8 weeks old was taken as the number fledged. Since less than 2% of chicks were known to have died between 8 weeks and fledging, any overestimate here will be minimal. Pairs which failed early, before mid-April, were visited at least once more to check for re-nesting. There was only one case of confirmed re-laying during the study and this was considered as though it were the original attempt.

Throughout the study several measures of breeding performance were recorded. Those which proved most useful, and for which most comparable information was obtained for different areas and years, were the proportion of pairs which bred successfully (% successful breeders) and the number of young reared to fledging per pair of eagles known to occupy nesting territories (young/pair).

RESULTS

Assessment of food abundance

A measure of food abundance based on the line transects done in the six areas, pooled over the four years, is shown in Figure 1. These figures express the cumulative results from nearly 3,500 km of line transect work. Three prey categories are shown, namely live prey (tetraonids and lagomorphs), dead sheep and dead deer, and the total amount of food detected is given in kg/100 km walked. Conversion of numbers of items to weight permits direct comparison between areas. The procedure for conversion to weight is described elsewhere (Watson, Langslow & Rae 1987), but broadly followed that described by Brown & Watson 1964 for the same range of prey species. As well as taking into account weight differences between species, we made allowance for differences in the amount of wastage.

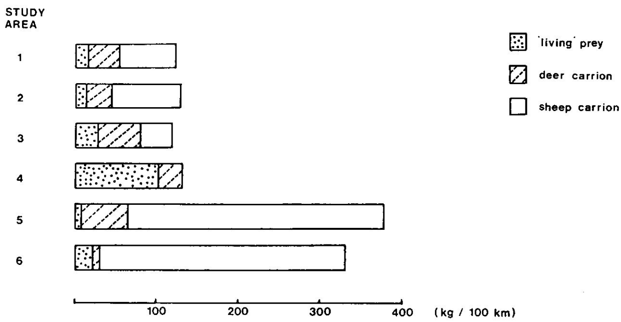

Figure 1: Total amounts of potential prey recorded (kg/100 km) in spring on line transects, and proportions of 'living' prey, deer and sheep carrion in six study areas.

The six areas fell into three types which were broadly consistent with their geographical location. Areas 1, 2 and 3 were in the north and north-west Highlands and showed comparatively low figures for total prey (< 150 kg/100 km) with more than 75% as carrion. Area 3 was the most easterly of the northern group and was intermediate between Areas 2 and 4. The latter was a true east Highland representative and had comparatively low absolute amounts of prey but more than 75% of this total was live prey. The western and south-western areas both had much larger amounts of total food (> 300 kg/100 km) and carrion here accounted for over 80%. The two most significant features of these results were the massive amounts of sheep carrion available to eagles in the south-western Highlands and the comparatively high levels of live prey in the east Highlands compared with elsewhere.

Golden Eagle nesting density

Not all habitats in the Highlands offered suitable hunting ground for eagles. Brown & Watson 1964 identified closed canopy woodland, open water and inhabited farmland as areas which eagles generally avoided. For each study area the extent of these exclusions was measured from 1:50,000 maps and updated where necessary to include all plantation forestry up to 1979. Most woodland planted since then probably still remained sufficiently open to offer some potential hunting ground for eagles. Nesting density was then calculated simply by dividing the number of occupied nesting territories by the amount of suitable hunting ground and then multiplying by 1,000 to give the number of pairs/1,000 km^2.

There was considerable variation in nesting density between the six study areas. The lowest density occurred in the east Highlands (14.7 prs/1,000 km^2) and the highest in the south-west (26.1 prs/1,000 km^2). In four of the six areas the number of pairs remained precisely the same throughout, and in the other two the only change was the addition of a single pair in one of the four years. For the present analysis the lower figure for these two areas was used.

Because the number of eagles remained so consistent over the short study period, we confined our analysis of nesting density to differences between areas. Correlation analysis was done on the relationship between nesting density and three assessments of food abundance. There was no significant relationship between density and both total amounts of food and live prey on its own (rs=0.714, n=6, and rs=0.700, n=6, respectively). In fact the slope of the regression line for live prey was negative ($y=20.58-0.063x$). However there was a significant positive correlation between carrion alone and eagle density ($r_s=0.944$, n=6, $p<0.01$). This relationship is shown in Figure 2.

Golden Eagle breeding performance

In the following analysis the measure of breeding performance used was the number of young fledged/pair, and the average for all pairs within each study area was considered separately for each year. Unlike nesting density, the overall breeding performance across the country varied considerably between years. In general, however, the pattern of variation across the study areas was repeated in successive years with areas of high breeding performance consistently higher than the others. In 1982, for example, success ranged from 0.32 to 1.05 young/pair and in 1983 the range was 0.19 - 0.65. In both years the poorest figures were from Area 5 in the western Highlands and the best figures from Area 4 in the east.

We found no positive correlation between breeding performance and either total amounts of food or amounts of carrion. There was however a significant relationship between the amount of live prey alone and breeding success ($r=0.633$, df=20, $p<0.01$), as shown in Figure 3. The live prey indices were transformed to log values because the relationship was curvilinear. The considerable scatter of points in Figure 3 would suggest that other factors were influencing performance. There was evidence even in this short study that one such factor may have been weather early in the breeding season (Watson, Langslow & Rae 1987).

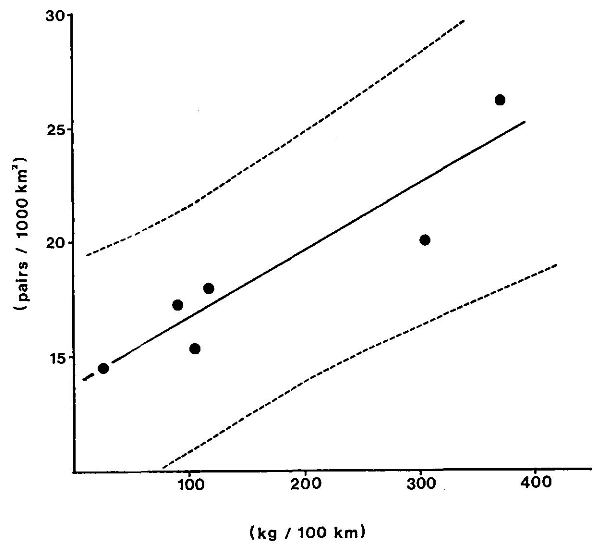

Figure 2: The relationship between Golden Eagle nesting density and indices of carrion abundance in six study areas. The regression is shown with 95% confidence intervals for an individual value of x.

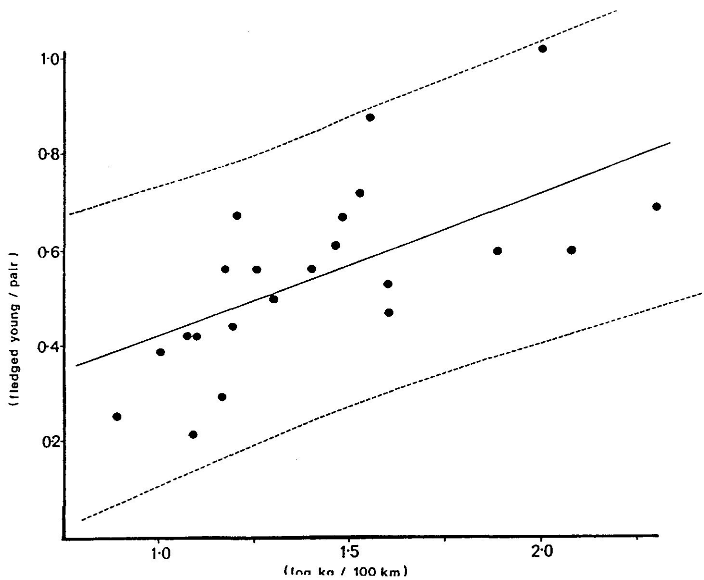

Figure 3: The relationship between Golden Eagle breeding success and indices of 'live' prey abundance in 22 study area-years. No transects were done in two of the study areas in 1982. The regression is shown with 95% confidence intervals for an individual value of x.

DISCUSSION

Brown & Watson 1964 concluded that nesting density of eagles in Scotland was not linked with overall food supply. Our study has reached a similar conclusion but took this finding a stage further. We found that nesting density was positively correlated with one source of food, namely carrion, whilst breeding performance was positively correlated with another, live prey. A curious, and possibly spurious, product of this finding was that breeding performance appeared to be negatively correlated with nesting density. Whilst we recognise that conclusions drawn from correlation studies need to be treated cautiously, there are sound ecological reasons for believing that the relationships identified may be causal.

The Golden Eagle in Scotland is highly sedentary (Thom 1986), and breeding pairs remain on their nesting territories year round. Advertisement and antagonistic behaviour in the form of spectacular skydancing display is much more frequent during the winter months (November-March) than during the breeding season (Watson, unpublished data). Golden Eagles in winter, at least in the western Highlands, depend heavily on carrion for food (Locke 1964, Watson, Langslow & Rae 1987). These factors, combined with the results from this study, support the conclusion that the amount of winter food, notably carrion, may be the single most important factor determining the number of pairs a given landscape can support. Such a conclusion poses some intriguing questions, about the balance between mortality and recruitment in high density areas where breeding performance is extremely poor. Could we be witnessing a population equation temporarily out of balance, but adjusting only slowly because of the inertia inherent in a long-lived, slow-breeding species? Could it be that immigration from better breeding areas is the only explanation needed or is there differential survival between areas? Only a longer study which had the benefit of marked breeding birds could hope to provide the necessary answers here.

Interpretation of the relationship between breeding performance and food is more straightforward. In all study areas very little carrion derived from carcasses of adult sheep or deer was taken to nest sites in summer, despite the fact that it was frequently available (Watson, unpublished data). This may be because of the difficulties of transporting such large items, or the poorer nutritional quality of a piece of meat from a carcass compared with a whole grouse or rabbit, or that such food 'goes off' much more quickly in summer, or indeed a combination of all three. Whatever the reason, the probability of successful breeding by a pair of eagles appeared to be unaffected by the presence of abundant carrion but was positively enhanced by a plentiful supply of grouse or rabbit.

A number of other raptor studies have shown relationships between food and nesting density (e.g. Gargett 1975, Mebs 1964, Newton *et al.* 1986) and links between food and breeding success (e.g. Cavé 1968, Gargett 1977, Murphy 1974). However we are unaware of any other study which has detected apparently quite separate effects of food at different times of year on breeding performance and nesting density. Other species in Britain which might merit closer study, particularly of winter food and its implications for nesting densities, are the Buzzard *Buteo buteo* and Red Kite *Milvus milvus.*

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