

The Impact of White-tailed Eagles on Sheep Farming on Mull

Final Report

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1. SUMMARY

- 1.1. White-tailed eagles (WTE) were formerly widespread throughout Britain but became extinct around 1918, as a result of persecution. The species was re-introduced to Scotland in the mid-1970s and some birds settled on Mull where they sometimes kill lambs during the breeding season. There is good anecdotal evidence that some of these are 'viable' lambs and thus represent an economic loss to the farmers concerned. As a result of pressure from the local farming community on Mull, the Minister agreed a package of measures for WTE management, including compensation, positive management and research. This report details the outcome of research commissioned by SEERAD in 1999-2002, with reference where relevant, to the results of research commissioned by Scottish Natural Heritage, 1998-2002.
- 1.2. The research set out to achieve five objectives:
 - *To provide evidence that WTEs are responsible for killing live (viable) lambs as opposed to scavenging carcasses or preying on non-viable lambs.*
 - *To establish whether specific birds are responsible for deaths, or whether the population will opportunistically kill lambs.*
 - *To make estimates of the number of lambs being killed on an annual basis on Mull*
 - *To recommend positive management measures that might be implemented on Mull to reduce the impact of WTEs on the local farming community.*
 - *To consider whether there are generic lessons that can be learned from the WTE re-introduction programme that might be applied to future re-introductions.*
- 1.3. There was good evidence that WTEs killed some live lambs to judge from heavy localised bruising associated with talon punctures in the skin of fresh lambs from nests. However most carcasses show evidence of scavenging. There was circumstantial evidence that many of the lambs killed were not viable because, compared with live lambs they were small for their age and similar to lambs lying dead on the hill from other causes. The larger lambs that were killed could have been viable but also could have been predisposed to predation by disease (predominantly tick borne disease).
- 1.4. Counts of ewes and lambs at three spatial scales showed no pattern of high lamb losses associated with the close proximity of WTE pairs. This was either because the lambs killed by eagles would have otherwise died of other causes, or because the number of lambs killed was small and swamped by the large overall mortality.
- 1.5. Not all WTEs killed lambs and the birds that killed most, killed more in 1999 than in 2000 or in 2002. For six of the eight eagle pairs monitored intensively, at least one lamb carcass showed evidence of having been killed. Thus killing was not entirely confined to one pair – the population might opportunistically kill lambs. If so, it suggests that the predation of lambs by eagles was largely determined by the predisposition of those lambs killed rather than the propensity of particular eagles.

- 1.6. We calculated from the numbers of eagles present, the numbers of lambs they consumed, and the proportion that were killed as opposed to scavenged, that the WTE population on Mull killed between 33 and 37 lambs each year. This takes no account of the viability of these lambs. The calculation assumes that the WTEs for which we had data were typical of all those on Mull. Compared with overall lamb losses of thousands, relatively few were killed by WTEs. The predation of lambs by WTEs on Mull could not have been damaging to sheep farming on a broad scale but this does not preclude damage on a small spatial scale.
- 1.7. The way to reduce eagle predation on lambs is to keep lambs remote from eagles but this is impractical on many parts of Mull. We suggest management trials to determine the cost-effectiveness of deterring WTEs in lambing areas using scaring devices or close-shepherding. We further suggest using feeding sites in late winter to encourage WTEs to nest as remote as possible from lambing areas. However, the most positive management to increase lamb production would involve removing those factors predisposing lamb predation and deaths from other causes - by improvement of ewe nutrition and reducing tick infestation.
- 1.8. There are generic lessons to be learned from the WTE re-introduction programme:
 - that re-introductions not only enhance biodiversity but can give added value for wildlife tourism if facilities are provided for viewing and information.
 - that the process of re-introduction can be quicker and cheaper by releasing many individuals in a short time into the best quality habitat available.
 - that re-introductions should involve wide consultation among potential stakeholders and rational fears should be incorporated into a risk assessment.
 - that the risk assessment should anticipate problems and have mechanisms in place for monitoring, evaluation and remedial management if necessary.

These lessons have already been learned, to judge from the protocols now in place for recent and planned re-introductions.

2. INTRODUCTION

2.1. Background

White-tailed eagles (WTE) were formerly widespread throughout Britain but became extinct around 1918, as a result of persecution (Love 1983). The species was re-introduced to Scotland in the mid-1970s and by 1999 at least 20 pairs were established with at least 16 pairs breeding. Some birds on Mull kill lambs during the breeding season. There is good anecdotal evidence that some of these are 'viable' lambs and thus represent an economic loss to the farmers concerned. As a result of pressure from the local farming community on Mull, the Minister agreed a package of measures for WTE management, including compensation, positive management and research. This report details the outcome of research commissioned by SEERAD in 1999-2002, with reference to the relevant results of research commissioned by Scottish Natural Heritage in 1998-2002.

2.2. White-tailed eagles in Scotland and their diet

The WTE population is slowly increasing in Scotland. By 2002 there were at least 25 pairs established with 24 breeding. Breeding success however, is still poor with only eight successful pairs in 2002 producing a total of 12 young.

The diet of WTEs is varied. Elsewhere in their geographical range, these eagles mainly occupy coastal and wetland habitats, preying on fish, large birds and medium-sized mammals, scavenging the carcasses of larger mammals and stealing items from other predators (reviewed in Love 1983). Diet varies seasonally with proportionately more mammalian foods scavenged in winter and spring. However, the diet varies most according to the availability of local foods. Fish have predominated in dietary studies in Romania and Sweden, mammals in parts of Russia, and birds elsewhere in Russia, in Iceland, Greenland, Norway and Germany (papers in Helander & Marquiss, in prep.).

Historical records for Great Britain suggested White-tailed eagles mainly took birds and fish in summer and mammalian foods in winter (Love 1983). Since the re-introduction, Watson, Leitch & Broad (1992) examined the composition of pellets and prey remains suggesting that the diet of two pairs was mainly hares, rabbits, seabirds and waders with some large mammals and fish. Sheep remains were more frequent in summer. Since 1998, funded by SNH, we have examined dietary material from 15 eagle pairs; a total of 37 successful nests in 1998-2002 (Marquiss, Madders & Carss 2000, 2002, 2003, Marquiss & Madders 1999, 2000). Nests were emptied of food remains on nest visits or at the end of the season after the young had fledged, so the items we recorded were those that had been delivered to nestlings from late April to August. We could thus look at variation in diet between pairs and between years, as well as trends over the nestling period.

From over 2350 food items, we have recorded 15 species of mammal, 51 of bird, 23 of fish, and 5 others (toad, squid, curled octopus and prawn *nephrops*). The diet in Scotland (as elsewhere) is extraordinarily species-diverse, suggesting that WTEs are

'generalist' predators and scavengers. Nevertheless, only three species contributed more than half of items, northern fulmar, rabbit and lamb, due to the apparent 'specialism' of individual eagle pairs. Fulmar was the predominant food species of seven pairs, rabbit or mountain hare the main food of two pairs, and lamb for two pairs. Fish predominated for only one pair. Compared with the large differences between eagle pairs, differences between years were minor. There were marked seasonal trends with lambs and sheep afterbirths in late April and May, and progressively more birds and rabbits in June, July and August. This is broadly consistent with the idea that diet is predominantly influenced by the relative abundance of potential foods, eagles switching between species according to what are most available.

2.3. Objectives of the present work

At the start of the SEERAD funded research (October 1999) there was general agreement that WTEs do eat lambs but no consensus as to how many are killed as opposed to scavenged, or whether specific adult birds or immatures were responsible. Neither was it known what management measures might be employed to limit any negative impact of birds on the local farming community on Mull.

The objectives of the project were therefore:

1. To provide evidence that WTEs are responsible for killing live (viable) lambs as opposed to scavenging carcasses or preying on non-viable lambs.
2. To establish whether specific birds are responsible for deaths, or whether the population will opportunistically kill lambs.
3. To make estimates of the number of lambs being killed on an annual basis on Mull.
4. To recommend positive management measures that might be implemented on Mull to reduce the impact of WTEs on the local farming community.
5. To consider whether there are generic lessons that can be learned from the WTE re-introduction programme that might be applied to future re-introductions.

The research on WTE predation of lambs has so far has included Scottish Natural Heritage funded studies of the breeding season diet of WTEs in Scotland with intensive work on Mull, 1998-2002. SEERAD funded studies have examined lamb productivity on Mull in 1999 and 2000 using IACS data and additional sample lamb to ewe counts in 1999, 2000 and 2002. We have also looked in detail at the seasonal pattern of lamb losses and the growth of live lambs in 2000. In 2001, the outbreak of 'Foot and Mouth disease' in Scotland did not extend to stock in areas occupied by WTEs but the restrictions imposed on access did affect the research work. We collected no information on sheep or lambs on Mull in that year but there were collections of prey remains from successful eagle nests and the material was sent to us for scrutiny.

In this report we use the results of the work on diet, on seasonal lamb losses, and on sheep productivity to address objectives 1, 2 and 3. We also give information on lamb growth in pursuance of objective 4. Objective 5 is addressed by reviewing the WTE re-introduction to Scotland in the light of our results, together with discussion of the literature and some current re-introduction programmes.

3. THE NUMBERS OF LAMBS KILLED BY WTEs ON MULL

The number of lambs killed by WTEs was estimated using three sorts of data:

- The number of WTEs on Mull during the period when lambs might be vulnerable (last week of April to August).
- The number of lambs that had been consumed by eagles found at or in the vicinity of WTE nests with young. Our weekly visits to nests with young enabled us to measure the rate at which lambs were taken through the season (Marquiss & Madders 2000) and from these statistics we could calculate the numbers taken throughout the time that lambs were available.
- The proportion of these lambs with evidence of eagle predation (as opposed to the scavenging of already dead lambs) derived from the examination of fresh remains at and in the vicinity of WTE nests (Marquiss & Madders 2000).

3.1. The numbers of WTEs on Mull

These data were collected annually by RSPB staff and others, and reported in each year's *Sea Eagle Project Newsletter*. The numbers of settled territorial pairs was known accurately from observations of birds seen repeatedly in particular areas of activity. Each year most of these pairs had nests, and some had young (Table 1). The number of non-breeding pairs was more difficult to monitor as, without an active nest, their location was less focused. Nevertheless, most of these birds carried identifying wing tags preventing confusion on the occasions that they travelled a few kilometres. Although many pre-settlement immature eagles also carried wing tags, they were generally so itinerant on Mull and elsewhere that it was difficult to be sure of their residency on the island.

Table 1. The numbers of WTEs in Spring and Summer on Mull, 1998 to 2002.

	1998	1999	2000	2001	2002
Successful breeding pairs	1	2	2	2	4
Unsuccessful breeding pairs	4	3	3	4	3
Nonbreeding pairs	2	2	2	2	2
Immatures*	5	4	4	3	2
Total eagles	19	18	18	19	20

* Over the years, seven of these immatures have become established on Mull, as new pairs or in replacing lost adults. The number in 2002 is provisional pending the publication of observations of wing-tagged birds.

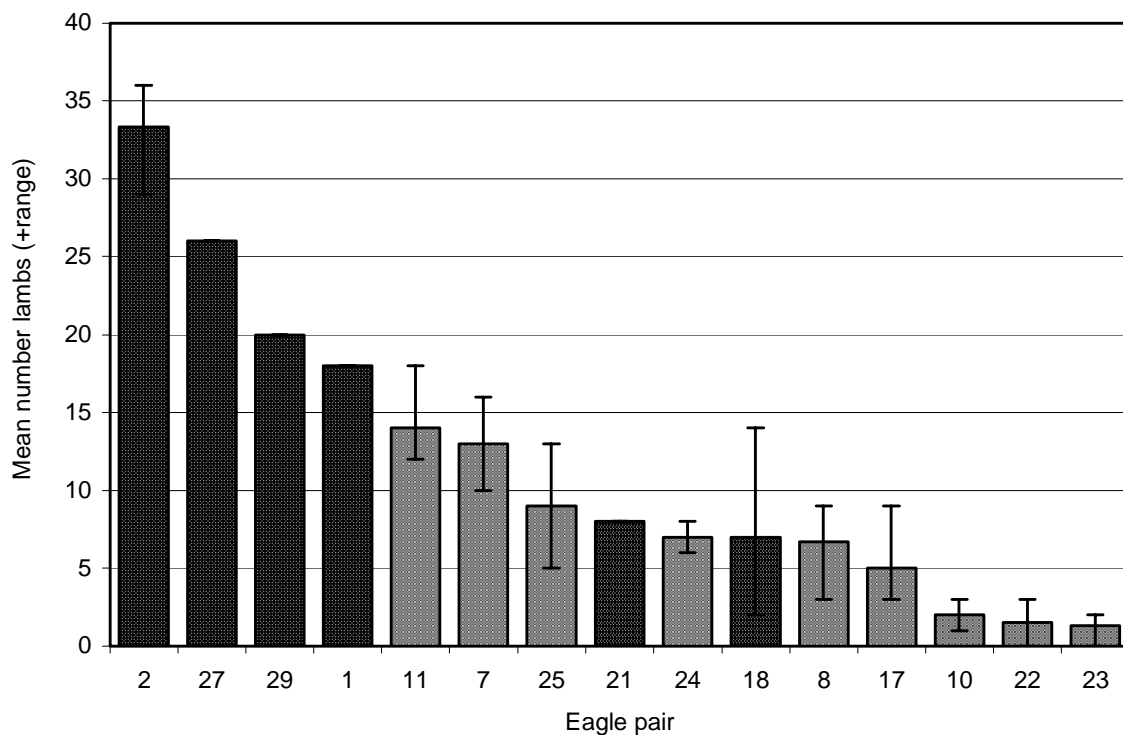
Long term radio telemetry studies of dispersing immatures in Norway (Nygard *et al.* in prep.) showed that at least in April and May many revisited their natal site and the

adjacent ground occupied by settled WTE pairs. Most then wander afar, but some stay on through the summer. Observations of immatures on Mull are consistent with this pattern - many young birds were seen once but only a few were seen repeatedly. The figures for immatures given in Table 1 represent the number of birds identified in the period April to June each year. We could not be certain that these birds were resident on Mull all season.

3.2. The numbers of lambs at WTE nests

A minimum estimate of the number of lambs taken by a pair of WTE can be derived from the remains of lambs in successful nests. Most successful breeding attempts have hatched young in the nest from late April through to August, so that the lambs taken by these WTEs are delivered to the nest and consumed there. Some bits are subsequently removed but only a short distance. By collecting remains from the nest and perching places in the near vicinity, we tallied the number of lambs brought in (Figure 1).

Figure 1. Number of lambs (estimated from bones) in the successful nests of 15 pairs of WTE in Scotland. Mull pairs dark-hatched.



Data from 37 nests, 1998-2002, five nests for pair 17, four nests for pairs 11, 18 & 23, three nests for pairs 2 & 8, two nests for pairs 7, 10, 22, 24 & 25 and single nests for pairs 1, 21, 27 & 29.

A GLM (Minitab 2000) analysis of variance of the numbers of lambs from the 37 successful breeding attempts (15 different pairs of WTEs) over five years (1998-2002) showed very large variation between pairs ($F_{14,16} = 15.06, p < 0.001$) compared

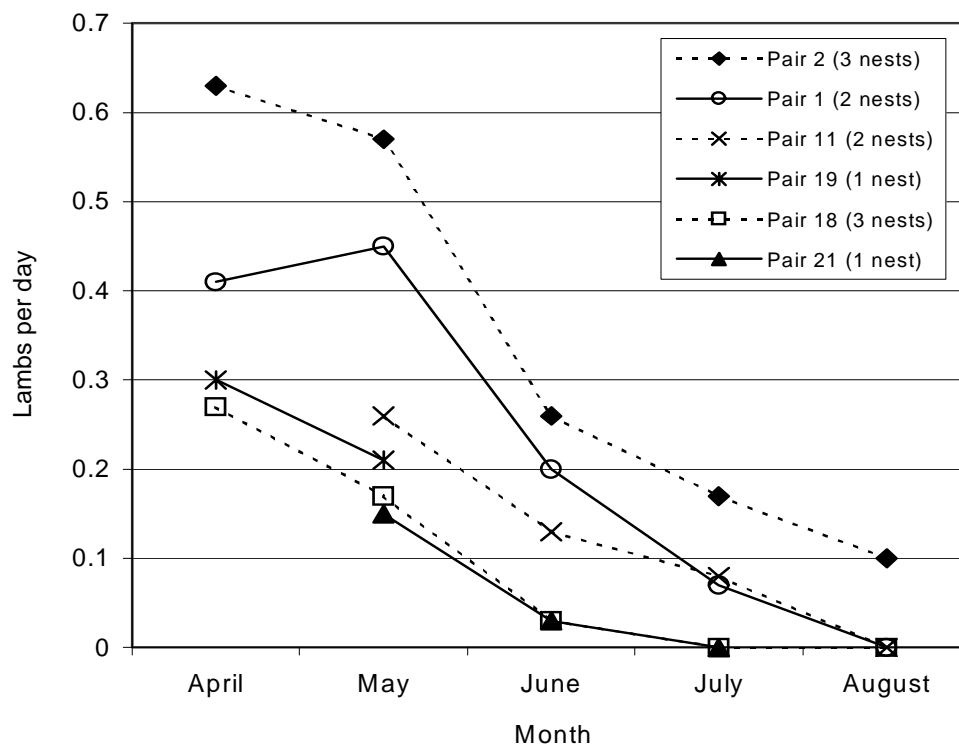
with little variation between years ($F_{4,16} = 1.97$, $p = 0.15$). Taking pairs and years into account, there was no significant variation between nests producing one young as opposed to those producing two ($F_{1,16} = 1.48$, $p = 0.24$). Thus, pairs of WTEs vary much in the extent to which they take lambs, some taking only a few annually but with others taking more than 30 (Figure 1) irrespective of the number of young in the nest.

We have data from six of the eight pairs on Mull, and their mean lamb tallies average more than those of the nine pairs from elsewhere in Scotland (GLM of average tally per pair, weighted for sample size: $F_{1,13} = 6.05$, $p = 0.03$).

3.3. The rates at which lambs were delivered to WTE nests

Repeated nest visits enabled us to measure seasonal patterns of the rate at which lambs were brought to nests. The nests of five pairs on Mull (ten nests 1999-2002) and one pair on Skye (nests in 2001 and 2002), were visited regularly at intervals of 7-10 days, enabling us to tally the numbers of lambs and calculate the numbers delivered per day each month during the breeding season. An analysis of variance for 'lambs per day' showed large differences between pairs ($F_{5,32} = 11.2$, $p < 0.001$) and between months ($F_{4,32} = 22.5$, $p < 0.001$) but no significant difference between years. The seasonal trend was for lamb deliveries at the nests of any one pair to be high in April (last few days) and in May, falling rapidly in June to virtually none in August (Figure 2).

Figure 2. Seasonal trends in daily delivery rate of lambs by six WTE pairs. Mull



pairs 1, 2, 18, 19, 21 and Skye pair 11. Missing data – the young of pairs 11 & 21 did not hatch until the end of April and the eaglet of pair 19 died in May.

For nine nests we calculated the total number of lambs taken over the whole period that lambs were available, from April 21st to August 10th (Table 2). This included those not delivered to nests by assuming the daily consumption rates over the last ten days of April were equal to the daily delivery rates we recorded in the days after their young had hatched. Comparing the sums calculated with the observed tallies of lambs at nests suggested the latter could have underestimated the total consumed by about 13.2% (se = 4.6%). There was no significant difference between years in the numbers of lambs recorded at nests (above) so we then averaged the annual number lambs consumed for six pairs of WTE on Mull (pairs 1, 2, 18, 21, 29 & 27; Table 2). A seventh pair (pair 19) did not rear young successfully but we did record their lamb delivery rate in May 2000, when they fed an eaglet that subsequently died. We used the general relationship between the measured delivery rate in May and the calculated total taken (Total taken = 66.9 x lambs/day – 1.41; adj r² = 0.79) to calculate the total taken by pair 19.

Table 2. The mean annual consumption of lambs (scavenged or killed) by seven pairs of WTE on Mull. Calculated from the numbers found at successful nests (six pairs) and from the rate at which lambs were delivered in May (pair 19).

WTE pair	number of years data	calculated total of lambs per year
1	2	26.9
2	3	38.0
18	3	8.9
19	1	12.6
21	1	7.9
27	1	31.7
29	1	23.7

The number of lambs calculated to have been consumed each year thus varied almost fivefold from pair to pair but averaged 21.4, or about 10.7 lambs per eagle. If we assume that these figures from 14 birds were representative of the whole population on Mull (18 to 20 birds), then the annual consumption was of the order of 193 to 214 lambs. Clearly lambs were an important food for eagles but not all of them were killed by eagles. Many could have been the scavenged carcasses of lambs that had died of other causes.

3.4. The proportion of lambs killed by eagles as opposed to scavenged.

The remains of lambs consumed by eagles are characteristic. After the flesh is consumed there remains sometimes the vertebral column, usually some of the skull and often the lower parts of all four limbs still attached to the body skin. There are talon puncture holes in the skin and often in the skull. The jaws, palate and nasal bones are usually removed to leave only the skullcap, and the ribs neatly removed leaving the bare vertebral column (Rowley 1970). The conventional method used as evidence of the lamb having been killed by the eagle is whether or not there is heavy

localised bruising or bleeding associated with the talon punctures in the skin or skull. (Rowley 1970, Wiley & Bolen 1971, Hewson 1984, Davies 1999). Such evidence suggests a lamb was still alive when seized by the eagle. Bruising can be seen easily provided the remains include sufficient material (skin) and are not rotten. The remains of dead lambs scavenged by eagles have talon holes but no associated bruising or blood pooling. Moreover, there is often evidence of a scavenged carcass having been handled by other predators or scavengers. Corvids and gulls have difficulty in breaking the skin and leave peck marks on the surface. They usually remove the lamb's eyes and tongue, and enter the carcass through holes around the umbilicus or anus. Mammalian carnivore predators and scavengers leave marks of their canine teeth on the skin. They chew off the ears and nose and often bite the carcass in two.

Over the four years 1999 to 2002, we examined the remains of 333 lamb carcasses. Of these, 45 from the open hill (well away from eagle nests) showed no evidence of having been eaten by eagles. Of the remaining 288, only 133 could be diagnosed as showing evidence of eagle predation or conversely of eagle scavenging. The others were undiagnosed, mainly because there was insufficient material (not enough of the skin) or because it had degraded (was rotten).

Sixteen of the diagnosed carcasses were from nests on Skye. None of them had evidence of being killed by eagles - all had been scavenged, apparently from fox meals (see Marquiss, Madders & Carss 2002). There were thus 117 diagnosed lamb carcasses from Mull. Two had been consumed by Golden eagle; one killed and one scavenged. A third showed evidence of eagle predation but was remote from any established WTE pair so we could not ascribe it to a specific eagle. This left us with a sample of 114 diagnosed carcasses from the nests of, or in the close vicinity of eight WTE pairs (Table 3).

The samples of diagnosed carcasses were small for individual years and pairs but there was significant variation. A logistic regression model analysis of 'diagnosis' (killed as opposed to scavenged) comparing WTE pairs and years, showed that carcasses from pair 2 were more likely to have evidence of having been killed than carcasses from the other pairs ($Z = 2.59$, $p = 0.01$). Carcasses from 2000 were less likely to be diagnosed as killed than those from other years ($Z = 3.03$, $p = 0.002$). The latter result was heavily influenced by the samples from pair 2. Samples from other pairs were insufficiently spread between years to be sure that they showed a similar pattern.

The main problem in assessing these figures was small sample size. The only samples of ten or more diagnosed carcasses came from pair 1 in 1999 and pair 2 in 1999, 2000 & 2002. For other years and pairs the samples were too small to show differences. The highest figure was for pair 2 in 1999 when the proportion of diagnosed carcasses with evidence of predation by eagles was 0.62. In 2000 the proportion fell to 0.16. This was the only pair that persistently gave evidence of lamb predation but at least one lamb carcass with evidence of predation was recorded for six of the eight pairs for which we had data. The paucity of data meant that persistent killing could not be ruled out for some others (e.g. pair 20). There was certainly insufficient data to estimate the numbers of lambs killed by every pair, in each year.

Table 3. The numbers of lamb carcasses with evidence of having been killed as opposed to scavenged, by WTE pairs on Mull, 1999-2002.

WTE pair	Year	'killed'	'scavenged'
1	1999	1	10
	2002	0	4
2	1999	13	8
	2000	3	16
	2001	3	2
	2002	4	9
18	1999	0	2
	2000	1	5
	2002	0	6
19	1999	1	3
	2000	0	4
20	1999	2	1
	2000	0	2
21	2002	0	5
27	2001	0	1
29	2001	1	3
	2002	0	4
Total all pairs	All years	29	85

3.5. A calculation of the numbers of lambs killed by WTEs on Mull

At least for pair 2 we had reasonable samples. This pair had a reputation for killing lambs when the study began and had the highest totals of lambs at the nest during the study. The high delivery rate of lambs to the nest meant we recovered more fresh lambs from our weekly visits and more could then be diagnosed. In 1999 the tally of lambs at the nest was highest, as was the proportion of diagnosed carcasses that showed evidence of predation. Our calculations suggest that up to 30 lambs could have been killed there in that year. The lowest tally for pair 2 was in 2000 when the proportion with evidence of eagle predation was also lowest producing an estimate of only five killed. The year 2002 was intermediate with an estimate of 11 killed.

Estimates for the other pairs of eagles were lower (Table 4) either because they had low lamb tallies at nests (e.g. pairs 18 & 21), or because despite high tallies, the proportion of carcasses diagnosed as having been killed was low (e.g. pairs 1 & 29).

Table 4. The estimated numbers of lambs killed annually by seven pairs of WTE on Mull. Estimated from the calculated numbers consumed (Table 2) and the proportions of carcasses diagnosed as predated as opposed to scavenged by eagles (derived from data in table 3).

WTE pair	calculated lambs taken per year	mean proportion of carcasses with evidence of eagle predation	calculated average number of lambs killed per annum
1	26.9	0.045	1.2
2	38.0	0.421	16.0
18	8.9	0.056	0.5
19	12.6	0.125	1.6
21	7.9	0.000	0.0
27	31.7	0.000	0.0
29	23.7	0.125	3.0

The numbers of lambs killed by the whole WTE population on Mull can be estimated if we assume that our sample was representative. Only one lamb was diagnosed for pair 27. The average figures for the other six pairs in Table 4 totalled 22.25 lambs per year, i.e. 1.85 lambs per eagle. The population of 18 to 20 WTEs on Mull in this period could thus have killed between 33 and 37 lambs annually. The main problem with this calculation is that the data on the proportion of lambs killed are derived from very small and disparate samples. The number killed would be larger if there were more eagles that behaved like pair 2 or conversely, smaller if predation by pair 2 was exceptional in 1999. Moreover, we have little data from immature WTEs. The food remains at their roosting places and the contents of their oral pellets suggest that they probably consumed more hares and less lamb than did most established adults (Marquiss, Madders & Carss 2002). Nevertheless, we have no information as to whether or not they killed lambs.

4. THE ‘VIABILITY’ OF LAMBS KILLED BY WTEs ON MULL

Lamb productivity is relatively low in the ‘hill’ sheep farms of Western Scotland, where rough grazing predominates. Average lamb percents at marking in early June can be as low as 60 or 70 lambs per 100 breeding ewes (Gunn & Robinson 1963, Eadie 1970, Mather 1978). This contrasts with the high lambing percents of over 150 in enclosed and intensive pastoral units on lowland. The lambs killed by WTEs on Mull are therefore only a small part of overall losses and need be evaluated within this context. In particular we need to know whether the lambs killed by eagles are in addition to other losses or whether they would have in any case died from other causes. Only the losses of otherwise viable lambs can be viewed as damaging to commercial lamb productivity.

In this section we investigate the viability of the lambs lost to eagle predation by searching for spatial patterns in lamb productivity in relation to the proximity of WTEs. If losses to eagles are in addition to those from other causes, we would expect to find unusually low productivity of lambs close to established WTEs, pair 2 in particular. The analysis was conducted on three spatial scales. We used IACS data (1999 & 2000) and transect data from across Mull (1999) to see whether holdings close to WTEs had lower than expected numbers of lambs. In 2000, we then looked more closely at lamb productivity in sample areas at one-kilometre intervals in distance zones radiating out from specific WTE pairs. In 2002, we mapped lamb productivity within one holding surrounding WTE pair two – the only pair so far shown to kill lambs persistently. As background to this spatial analysis, we document the seasonal pattern and proximate causes of lamb loss. Finally we examine the size of lambs killed by eagles to see if they differ significantly from live lambs or those dead from other causes.

4.1. The seasonal trend in lamb to ewe ratio

In 2000, we counted lambs and ewes on eleven holdings weekly from April to July, then again in August. We counted the numbers of sheep within view on each occasion and calculated the lamb to breeding ewe ratio, adjusting for the proportion of hogs in the area. The identification of hogs at a distance was not always easy so we compared our calculated lamb to breeding ewe ratios with those derived from the midsummer gather on each holding to test the accuracy of our estimates. Our estimates from counts immediately prior to the midsummer gather were highly correlated with the lamb to ewe ratio for the whole holding ($r^2 = 0.84$) and not significantly different in magnitude (paired comparisons, $t=1.59$, $p= 0.14$).

In plotting seasonal trends we standardised the series of estimates for each holding by expressing each ratio as a proportion of the June figure. This meant that the plotted seasonal trends (Figure 3) were average trends taking into account overall differences between holdings. On some holdings sheep were sorted at the midsummer ‘gather’ and moved so the data thereafter were restricted to only five holdings.

The lamb to ewe ratio increased from late April through May with lamb births, and then decreased gradually but significantly ($F_{1, 8} = 9.3$, $p < 0.02$) over the summer. On the five holdings for which we had comparative counts, the ratios for August were on

average 0.043 lower than in June. This represents a loss of about four lambs for every hundred ewes over a nine-week period following the midsummer gather. The highest lamb losses are well known to occur during birth and soon after. The present analysis demonstrates that losses persist throughout the summer into autumn. Consequently we need to take account of season by controlling for the date of counts, when sampling lamb to ewe ratios to estimate the potential impact of eagle predation.

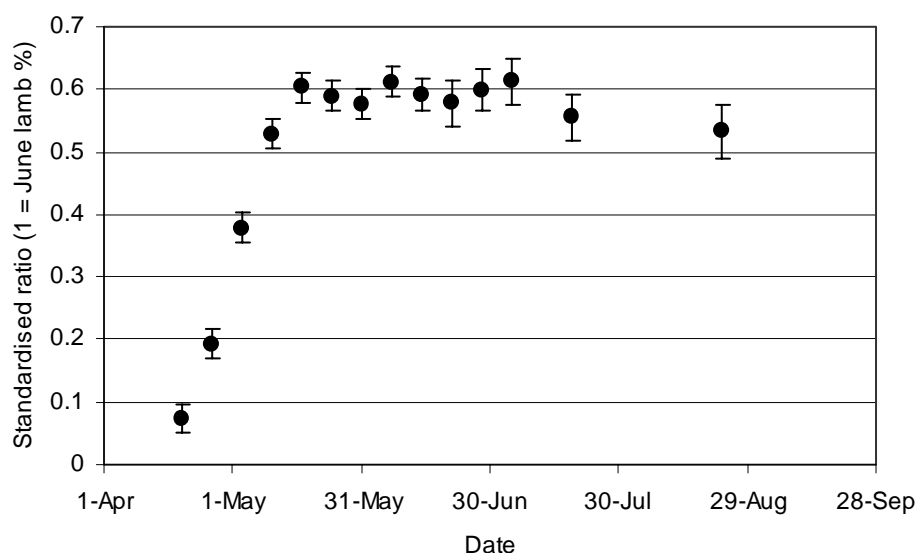


Figure 3. Seasonal trend in mean (+se) lamb to ewe ratios in 2000

4.2. Spatial patterns in lamb productivity relative to the proximity of WTEs.

4.2.1. IACS data: patterns of lamb productivity across Mull.

IACS data provides information on land types (rough grazing, woodland, etc.) and stock numbers for each holding on Mull. We analysed the data received from SEERAD to look for factors affecting lambing percent (lambs/ewes) and investigated whether there was any relationship with distance from the nearest WTE pair. To account for variation in management we fitted holding as a random effect in a generalised linear mixed model (GLIMMIX, SAS Institute Inc. 1989).

Inspection of the data showed the group of farms most remote from WTEs (>9 km) had higher lambing percents than all others. If a separate parameter was fitted for this group (predominantly farms along the Ross of Mull, $F_{1,94}=25.48$, $p<0.001$) then there was no significant effect of distance from the nearest WTE pair ($F_{1,94}=0.08$, $p=0.773$ Figure 4). The mean lamb:ewe ratio for farms on the Ross of Mull was 1.42 (se= ± 0.06) and for the other farms was 0.90 (se = ± 0.02). There was no significant difference between 1999 and 2000 in lambing percents. There was also no effect of farm size, probably because this is taken care of by fitting holding as a random effect in the model. (The random effect of holding was quite well estimated judging from

the tightness of the confidence limits which can be interpreted as meaning that the lambing percents varied between farms ($\text{estimate}_{(\text{holding})} = 0.022$; cl. 0.013-0.043).

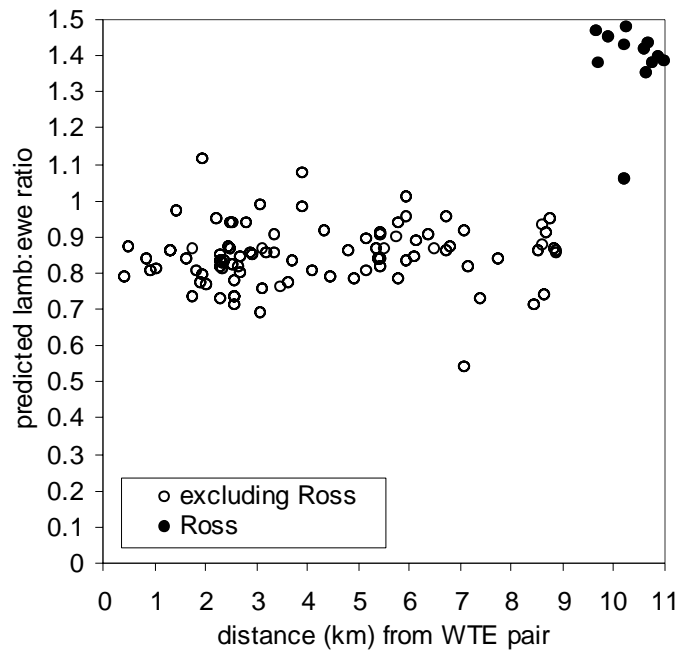


Fig 4 a) The relationship between predicted lamb to ewe ratio and distance from the nearest white tailed sea eagle nest. Predicted values are from a generalised linear mixed model using 'holding' as a random variable.

Given that there seemed to be differences between holdings we used information about land type to investigate whether reduced lambing percents were associated with poor quality pasture. There was an effect of the proportion of rough grazing with lambing percent declining by about 13% as the proportion of rough grazing increased from 0 to 100% ($F_{1,94}=3.27$, $p=0.04$, one-tailed test, Fig 4b).

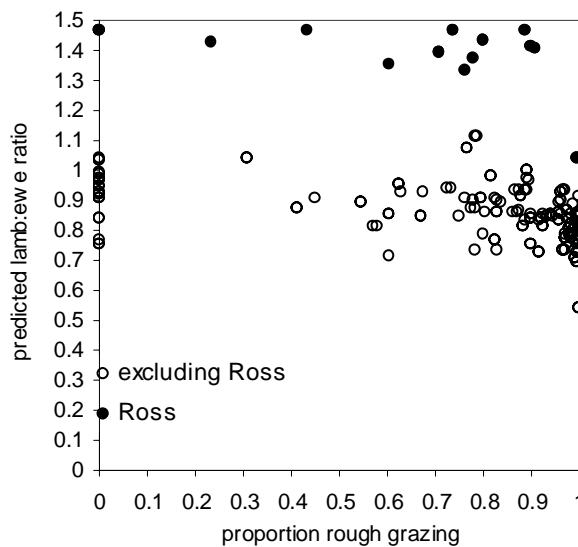


Fig 4 b) the relationship between predicted lamb to ewe ratio and the proportion of rough grazing on the holding. Predicted values are from a generalised linear mixed model using 'holding' as a random variable.

Analysis of lamb percents at the whole of Mull scale using the IACS data showed that there was much variation mainly associated with specific holdings. There was a group of holdings with particularly high lamb productivity. These were mainly at the west end the Ross of Mull, are remote from WTEs and support small sheep flocks on rich grazing. This analysis indicated that more information is needed on individual holdings (or count area husbandry practices) to account for the variation in management effects on lambing percents before attempting to detect the effect of WTEs. In the absence of such detail we needed to search for WTE effects within holdings - by comparing lamb percents on the same holding but at different distances from WTE nesting pairs.

4.2.2. 1999 transect data: detecting effects on farms closer to WTE pairs.

The second approach was to analyse lambing percent data from counts of ewes and lambs (excluding hogs & tups) on 21 farms, in up to five 1km transects per farm. Sheep breed was recorded to allow for differences in fecundity between breeds. For each transect, the habitat quality was recorded as shore, field, in-bye or hill. Furthermore, the proximity of the sheep counted to the road was recorded as either remote or roadside to allow for any bias eagles may have against hunting close to the road. Finally, the mean altitude for each 1 km transect was also recorded to allow for any bias in lamb mortality associated with poorer conditions at higher ground. For each transect, the distance to the nearest WTE pair (and their identity) was recorded.

We analysed the data to look for factors affecting the lamb:ewe ratio and investigated whether there was any relationship with altitude, nearest eagle pair or distance from the nearest white tail eagle nest. To account for any variation in management we fitted farm as a random effect in a generalised linear mixed model (GLIMMIX, SAS).

The best fit model showed a negative effect of distance ($F_{1,83} = 4.72$, $p = 0.03$) from the nearest WTE pair after correcting for farm as a random effect. There was no significant effect on lamb:ewe ratio of breed, habitat, closeness to the road, altitude, or WTE pair. The data showed that lamb:ewe ratios are highest close to the roost or nest of WTE (Figure 5). We explored whether the relationship with distance was non-linear in that lamb:ewe ratios may be affected more at intermediate distances or altitudes by including a distance squared term. This was not significant although there was a tendency for this to be true ($F_{1,82} = 3.6$, $p = 0.06$). The effect was largely due to the position of WTE nests and roosting places, which in 1999 were predominantly adjacent to some lowland farms where some sheep were on improved grasslands.

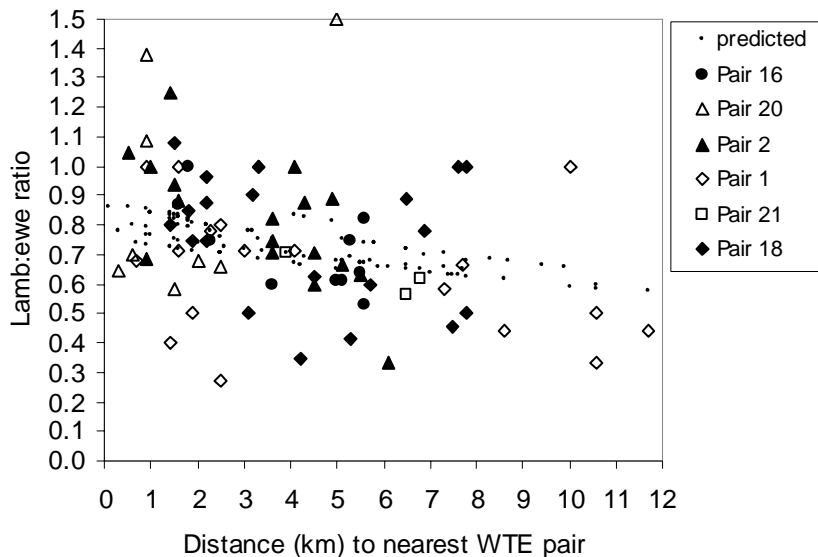


Fig 5. The relationship between distance from the nearest pair of WTEs and the lamb:ewe ratio. The variation in the predicted values can be interpreted as the variation in the lamb:ewe ratio due to differences between farms and is due to fitting farm as a random effect in a generalized linear mixed model. The covariance parameter estimate for farm was small but well estimated as determined from the tightness of the confidence limits (estimate_(farm)=0.009, ci= 0.128-0.003).

As with the analysis of IACS data, the present analysis of transect data indicated that the large differences in lamb percents between farms predominated, preventing the detection of any overall WTE effect or for a specific pair of eagles. For transect data, nesting eagles tended to be closer to areas of higher lamb productivity but there was no strong pattern in lamb productivity associated with a particular nesting pair. Lamb productivity varied from farm to farm relatively independent of which pair was closest. It was therefore clear that we needed to collect lamb to ewe data on a smaller spatial scale (within holdings) searching for patches of low lamb productivity close to specific WTE pairs.

4.2.3. Nest focussed radial transects: detecting effects around established WTE pairs.

The above two analyses had not conclusively demonstrated an effect of the proximity to a WTE nest in explaining the variation in lamb:ewe ratio. The suggestion so far was that the intrinsic nature of the ground, together with its management (included in the models as a random ‘farm’ effect) probably had the greatest effect on lamb:ewe ratio. However, any effect of WTEs should be quite localised and therefore hard to detect without data of higher resolution at the appropriate spatial scale. We therefore next investigated the relationship between distance from the nest and lamb:ewe ratio by focussing on radial transects across concentric rings spaced at 1 km intervals, emanating out from a nesting pair. The expectation was that within holdings, lamb:ewe ratio would increase with distance from the nest of a pair of WTEs that was killing otherwise viable lambs.

Ewes and lambs were counted on transects both in areas with nests as a focus and areas where no WTEs were nesting. Radial transects were repeated three times at

monthly intervals from June until August. One pair of WTEs (pair2) was known to kill lambs but the others were not, so analysis of this factor might increase the sensitivity of the analysis in detecting a WTE effect on lamb:ewe ratio. We used a generalised linear mixed model with the holding by month interaction as random effects. This allowed for variation in lamb:ewe ratio due to differences between holdings. Month was included to allow for the seasonal decline in lamb:ewe ratio (section 4.1. above) and any management intervention between one count and the next, such as sorting or moving the flock.

The best fit model indicated an effect of site such that the lamb:ewe ratio was highest around pair 2 ($F_{3,43} = 5.47$, $p = 0.003$; Table 5).

Table 5. Mean lamb to ewe ratios from counts along radial transects from four pairs of breeding WTE, one nonbreeding pair and in two places with no WTEs.

site	mean lamb:ewe ratio	standard error
WTE pair 2 (successful)	0.825	0.030
WTE pair 18 (successful)	0.624	0.021
WTE pair 19 (failed)	0.542	0.044
WTE pair 20 (failed)	0.633	0.092
Nonbreeding WTE pair	0.558	0.021
Area K (no WTE)	0.587	0.033
Area L (no WTE)	0.593	0.041

There was the expected tendency for lamb:ewe ratio to be lower in zone 1 than in the other zones though not significantly so ($F_{4,39} = 2.21$, $p = 0.086$). The covariance estimates for the random effect of holding*month was well estimated as 0.03566 (lower=0.0149, upper=0.169). However, the zone 1 effect is due to only two of the four holdings. In one of these there could not be an effect caused by eagles because the lambs were taken to the hill after the eagle nest had failed and at least one of the birds had left. It was therefore difficult to have confidence that an eagle effect was detected. For the other two pairs no data were available within 1km of the nest because of the proximity of a loch in one case and a closed forest canopy in the other. To take account of this, counts from zone 1 & 2 were combined and counts from zones 3, 4 and 5. This allowed a comparison of lamb:ewe ratio at distances less than 2km and greater than 2km. This showed no effect of distance ($F_{1, 47}=0.00$, $p>0.9$; Figure 6). Counts in areas without nesting eagles were not significantly different.

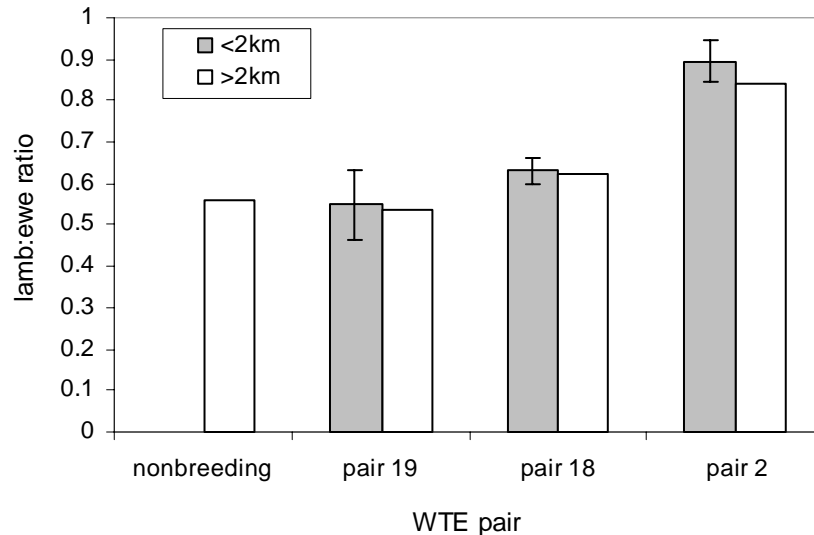


Fig 6. The mean (and standard error) lamb:ewe ratios in areas less than 2 km (open bars) and greater than 2 km (grey bars) from 3 WTE pairs and a nonbreeding pair. The nonbreeding pair had no sheep within 2 km of their roost.

These radial transects had looked at variation in lamb productivity on a smaller scale. The analysis suggested a result in the right direction but still failed to show a significant effect of proximity to WTE nests. Moreover, an effect for pair 19 was ruled out because lambs were not moved onto the hill close to this pair until late in May – after the eaglet of this pair had died and at least one of the adults had left the immediate nest vicinity. The evidence for pair 2 was more compelling, particularly because this pair had a history of lamb killing. However, the lamb:ewe ratio close to this pair was high as they had chosen a nest site on the boundary between two holdings, one of which had good grazing and associated high lamb percent. In 2002 pair 2 moved to nest in the centre of the main hill sheep area – a single holding – where it successfully raised eaglets. This then provided a rare opportunity to investigate the pattern of lamb productivity within a single management unit and on a sufficiently fine scale to detect an effect of WTE predation.

4.2.4. Mapping lamb productivity around the nest of WTE pair 2.

In 2002 we concentrated our counts around pair 2. This pair was selected for three reasons: First, the nest was situated centrally to an area grazed by sheep. Second, all the surrounding land belonged to one holding and was therefore under the same management. Third, this pair was known to kill lambs persistently (section 3). On this basis, if the killing of lambs by WTEs causes added lamb losses the power to detect it was greatest for this pair at this location.

We counted sheep in individual groups of ewes and lambs over the entire holding in one day and marking these on a 1:25000 map. This was repeated three times at weekly intervals from 30th May until 12th June. Each sheep group was allocated to a “count area” which represented a landscape feature that was judged to encapsulate a number of sheep. For example, these areas might be a valley associated with a burn

or a hollow on the hillside, or the area below or above a fence line. For each count area, the altitude and the mean distance from the nest was measured. The locations of lamb remains showing evidence of having been consumed by eagles were also noted. Spatial patterns in lamb productivity (lamb:ewe ratio) and the sites where lambs were taken (by eagles) were investigated by recording the grid reference of each count area and dead lamb and plotting the data on a map.

The lamb:ewe ratio was analysed using logistic regression with a logit link. Pockets of low productivity were investigated by determining if the ratio varied significantly between areas after controlling for variation due to counting error. The latter was fitted to the model as a categorical variable with three levels representing counts 1, 2 and 3. We tested whether the ratio varied within count areas over the three counts and between areas. Areas with persistent low ratio would indicate low productivity. The hypothesis that lamb productivity is lower near the nest of pair 2 was tested by investigating the relationship with distance after correcting for altitude.

Lamb:ewe ratio was explained by a model fitting count, area and the interaction between count*area. As expected from overall seasonal trends (section 4.1), the lamb:ewe ratio declined from count 1 to count 3 ($\chi^2 = 4.7$, $df = 2$, $p=0.047$, one-tailed test). The mean productivity in the three counts was 63.4% (± 2.9) for the first, 62.3% (± 3.1) in the 2nd to 56.5% (± 2.5) in the third. There was significant variation between areas ($\chi^2 = 88.9$, $df = 47$, $p = 0.002$) but no consistent pattern between areas as demonstrated by the significant interaction ($\chi^2 = 93.2$, $df = 65$, $p = 0.012$). From the outset we were concerned that lambs might be obscured as the bracken grew higher leading to underestimated lamb counts. The effect of increasing bracken height over the counting period was therefore investigated in a subset of the data for which bracken presence was recorded. There was no evidence of a bracken effect on the lamb productivity ($p>0.75$).

The above analysis indicated that the number of sheep using an area varied greatly between counts. Therefore, in order to detect any differences between areas, it is necessary to have larger numbers of sheep in the areas or to pool areas into bigger geographical spaces to increase the sample size. Adopting the latter strategy, we stratified the areas into sheep 'hefts' using our knowledge of the movements of sheep. Two approaches were taken. First we identified six hefts and pooled the rest of the sheep (seven groups). Second we divided the rest of the sheep into seven further hefts (13 groups in total). We then fitted the hefts as 'group' in the model with area fitted afterwards to determine if there were differences between groups that were consistent across counts. The area term allowed for a comparison of the between area variation compared to the between group variation. The interactions of group with count tested whether the lamb:ewe ratio in each group differed with count, and the count*area interaction was the residual variation in lamb to ewe ratio determined presumably by other factors.

For both the above grouping strategies, neither the group term nor the count*group was significant in the model which meant that there was no variation in productivity between groups due to the count date and that productivity did not differ between groups. The residual variation identified by the significant area*count term may be because of other biological factors such as the topographical positioning of the areas. To investigate this we looked at the relationship between lamb:ewe ratio and distance

from the WTE nest. There was no significant relationship between distance and lamb productivity ($p > 0.5$). However, if distance squared was fitted with the linear distance term then there was a negative relationship (for distance, $\chi^2 = 5.64$, $df = 1$, $p = 0.018$ and for distance*distance, $\chi^2 = 5.19$, $df = 1$, $p = 0.023$). However, because the nest was at medium altitude, it might be the eagles had better access to sheep at this altitude than sheep higher up, and that the sheep furthest away were at the lowest altitudes. Indeed, inspection of the data showed that productivity appeared to have been highest for medium altitudes. Correcting for this pattern by including altitude and altitude squared and then fitting a linear term for distance produced the best fit model for the spatial relationships with productivity (for altitude $\chi^2 = 12.74$, $df = 1$, $p = 0.0004$; for altitude*altitude, $\chi^2 = 12.75$, $df = 1$, $p = 0.0005$; and for distance $\chi^2 = 3.33$, $df = 1$, $p = 0.068$). Although the distance term is not significant, because we are dealing with the whole population around the nest, p values are not informative.

The mean productivity for each area was categorised into four levels (0-25%, 56-50%, 51-75%, and 76-100%). These and the grid references for lambs consumed by eagles were plotted on a map (Figure 7). Six out of these ten lambs were found within 1 km of the nest and the other four were less than 1.5 km from the nest. All were between 90m and 150m above sea level. Four were within heft group 1, two in heft group 3, two in heft group 11, one in heft group 8 and one in heft group 2.

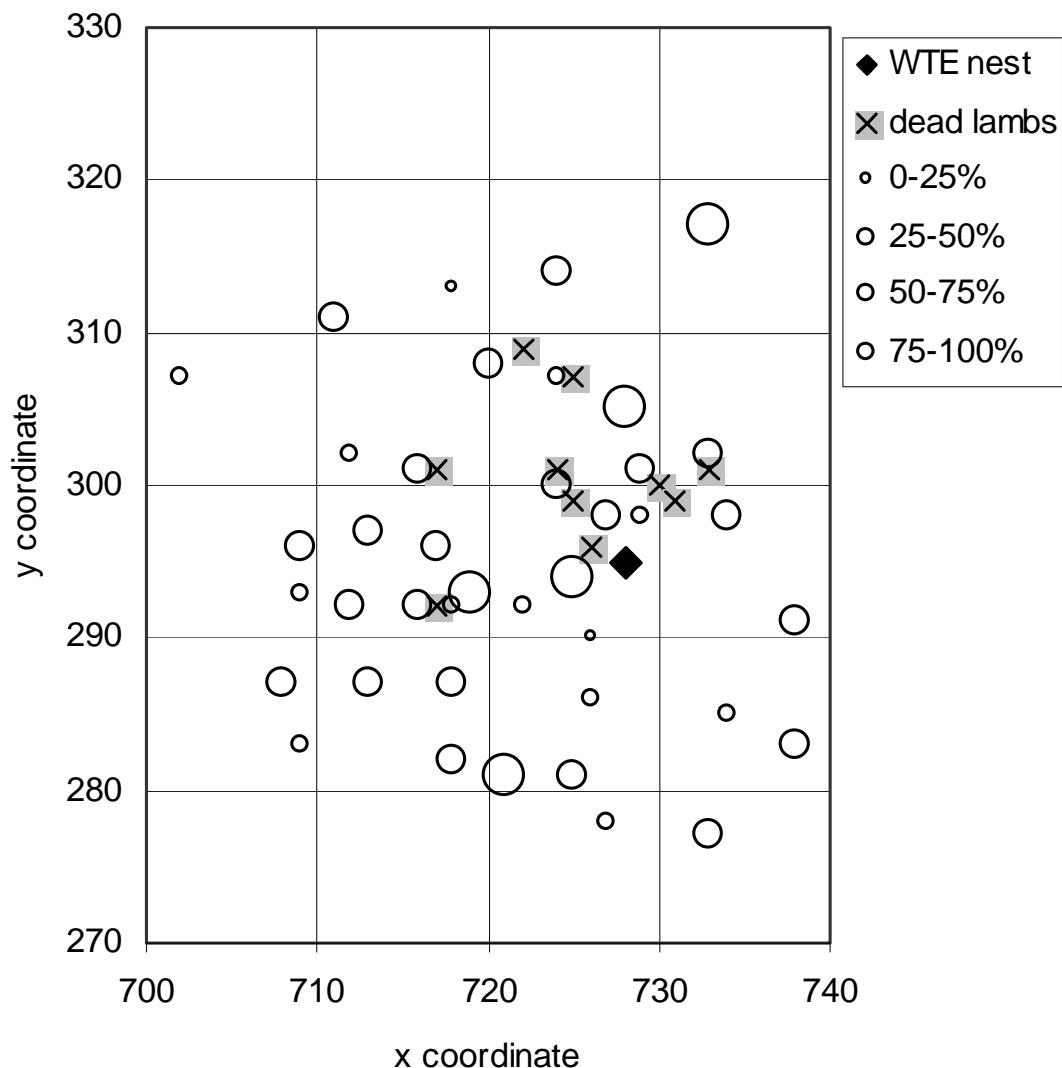


Figure 7. Lamb productivity (percent lambs per ewe) for count areas around the nest (filled diamond) of WTE pair 2 in 2002. The bigger the circle the higher the lamb productivity. Sites where we found the remains of lambs eaten by eagles (both scavenged and killed) are indicated by a cross. Mapping grid is at one kilometre intervals.

Discussion

The main finding was that lamb productivity was low at around 60% but increased with distance from the WTE nest after taking into account altitude. This finding can be interpreted as lamb productivity being lowest down by the shoreline and on the tops of the ridges and highest on the intermediate slopes and that these intermediate slopes are more productive the further they were from the nest. Generally we observed few sheep on the tops of the ridges but the logistic regression takes this into account by weighting the data for the number of ewes observed.

WTEs may not of course forage with uniform effort in any direction and attempts to identify “pockets” of low productivity were investigated at the ‘counting area’ scale and at the ‘sheep heft’ scale. Neither of these approaches identified any consistent area or group that had low productivity over the three counts. At the fine scale there was significant within area variation and between area variation. So although the productivity dropped with advancing date (count) this was not consistent across areas as indicated by the significant interaction. At the heft scale (group) productivity did not vary between groups or between counts in a systematic fashion indicating that there was no variation in productivity between these groups. Even limiting the groups to the major hefts did not reveal any systematic pattern.

The fine scale variation in productivity in time and space may be caused by locally important sheep movements caused by weather. Counting error such as failure to identify lambs because of the increasing height of bracken may still have been a problem but there was no indication of this from our data.

The distribution map of productivity and dead lamb locations is not conclusive yet the proximity of WTE scavenged lambs to the nest site indicates that eagles do take lambs locally (within two km) if available. However, the low lamb productivity indicated that there had been substantial lamb mortality probably caused by a variety of reasons and spread throughout the post lambing period. Therefore detecting the impact of WTE remains difficult. In 2002, pair 2 was estimated to have killed only about 11 lambs. Had predation levels been higher (as in 1999) we would have had a greater chance of demonstrating an effect of WTE predation. Conversely it is probable that at least some lambs were predisposed to predation by poor maternal care or disease. On our counts in 2002, we observed incapacitated lambs limping and falling behind the ewe - one symptom of tick pyaemia. Moreover, several of the carcasses recovered from the eagle nest had heavy tick infestation, some with subcutaneous pustules and puss-filled joints. There is thus still the possibility that lamb mortality would not necessarily have been lower had WTEs been absent.

4.3. The sizes of lambs killed and scavenged by WTE compared with live and dead lambs.

From the fresh remains of many of the lambs eaten by eagles we could categorise them as either showing evidence of eagle predation or of eagle scavenging. We wished to know whether or not eagles killed 'viable' lambs, i.e. those that would otherwise have lived. If this were the case, we would not expect them to resemble lambs lying dead on the hill, but rather to resemble those living. Conversely, if eagles killed lambs that would have died in any case from other causes, we would expect the killed lambs to most closely resemble those lying dead. Those lambs diagnosed as scavenged should be similar to lambs lying dead on the hill.

Unfortunately, from the remains of lambs consumed by eagles we could get relatively little information on disease or body condition. This was because the remains of eagle meals rarely included soft parts; infrequently flesh and almost never viscera or brain. However, skin and limbs were usually present so we could measure the size of the lambs we diagnosed. For comparison we used the sizes of dead lambs found on hill transects and of live lambs from two hefts, including both hill and coastal rough grazing. In this section we compare the measurements from these samples.

4.3.1. The growth of live lambs

It was anticipated that the increase in hindfoot length and in body weight would slow with age whereas fleece should continue to grow linearly (Mike Thompson pers. obs.). Thus the size of lambs should be best indexed from the length of hindfoot and age from the length of fleece. A plot of one against the other would indicate lambs that were small (or large) for their age. We therefore measured the hindfoot length and body weight of live lambs of known age and took a sample of fleece from the mid-dorsal area of the rump. In the laboratory the length of ten intact wool fibres from each fleece sample were measured.

In 2000, 25 breeding Blackface ewes from each of two hefts (Croggan and Kinlochspelve) were retained in large enclosed areas of permanent, unimproved grassland. In the week of birth, both lamb and ewe were given matched ear-tags, and dye-marked according to birth week. These sheep were gathered and the lambs measured each week for four weeks then released to the hill. At six subsequent hill 'gathers', all dye-marked lambs were weighed and measured and a fleece sample taken on each occasion.

From the initial 50 retained ewes, 42 lambs survived birth for the measured sample, 21 from both hefts. Three of these lambs were 'cross Cheviot' leaving a sample of 39 Blackface lambs. Subsequent to their release to the hill, sheep were gathered and lambs measured on 23rd June, 27th/29th of June, 5th July, 21st July, 10th September and 2nd October. We were most interested in the variation in growth during the period when eagles took most lambs (April, May and June). In 2002, an additional sample of seven Blackface lambs from the Kinlochspelve area was measured but only during May (first four weeks from birth).

The initial data analysis involved stepwise regressions to test the idea that size (body weight) was best predicted by hindfoot length, and age by the mean length of fleece. The cube root of body weight was used, as this should vary isometrically with linear dimensions. As expected, stepwise regression selected fleece length as the single best predictor of age (age = 0.138 fleece length – 1.95). The linear model fitted well explaining 65% of the overall variation ($r^2 = 0.651$). The inclusion of body weight and hindfoot length improved it little, adding only a further 8%. Hindfoot length was the best predictor of body weight (cuberoot weight = 0.0145 hindfoot – 0.811), explaining 78% of the overall variation. This meant that the two measures from the remains of lambs could be plotted one against the other as an index of size for age.

4.3.2. *Dead lambs on the hill and at WTE nests.*

In 2000, we searched for dead lambs by walking set 4-5 kilometre routes on five of the holdings where we counted sheep. These walks were conducted weekly from late April to early July, twice in July and then once in mid August. The hindfoot length of all dead lambs found was measured, a fleece sample taken from the rump and the limbs marked with plastic tags for identification. The position of carcasses was noted and each revisited on subsequent dates. In 2002, we searched all parts of the holding encompassing the nest of WTE pair 2 in the second and fourth weeks of May, and again in the first two weeks of June. We measured the dead lambs that we found and removed a fleece sample from each.

We measured the hindfoot of almost all the lambs diagnosed as killed or scavenged by WTEs but started collecting fleece samples only after our work on live lambs had suggested its usefulness (from 2000 onwards). We still had many of the diagnosed lambs from the 1999 season stored frozen so we took fleece samples from these. This gave us paired measurements of hindfoot and fleece for a sample of 122 Blackface lambs, 36 dead on the hill, 63 scavenged by WTEs and 23 killed (Table 5).

Table 5. Sample sizes of Blackface lambs , for which we had measurements of both hindfoot and fleece.

Year	Dead on the hill	Scavenged by WTEs	Killed by WTEs	Total
1999	3	7	13	23
2000	24	19	2	45
2001	1	10	5	16
2002	8	27	3	38
Totals	36	63	23	122

The measurements of these lambs were compared with our measurements of live lambs at the same time of year during May, June and July. The comparison was made using an analysis of variance in a General Linear Model, with hindfoot as the response variable and fleece length as a covariate. An additional squared term was used for fleece length because the relationship between hindfoot and fleece length is

curvilinear (Figure 8). The analysis tested for differences in the measurements of the four categories of lambs (live, dead, eagle scavenged and eagle killed) and for differences between the four years. There was a substantial difference between lamb categories ($F_{3,207} = 11.93$, $p < 0.001$) but no evidence of differences between years ($F_{3,207} = 1.47$, $p = 0.224$). Comparisons between categories of lambs showed that the significant difference was solely due to the greater hindfoot lengths of live lambs compared with the others (Table 6).

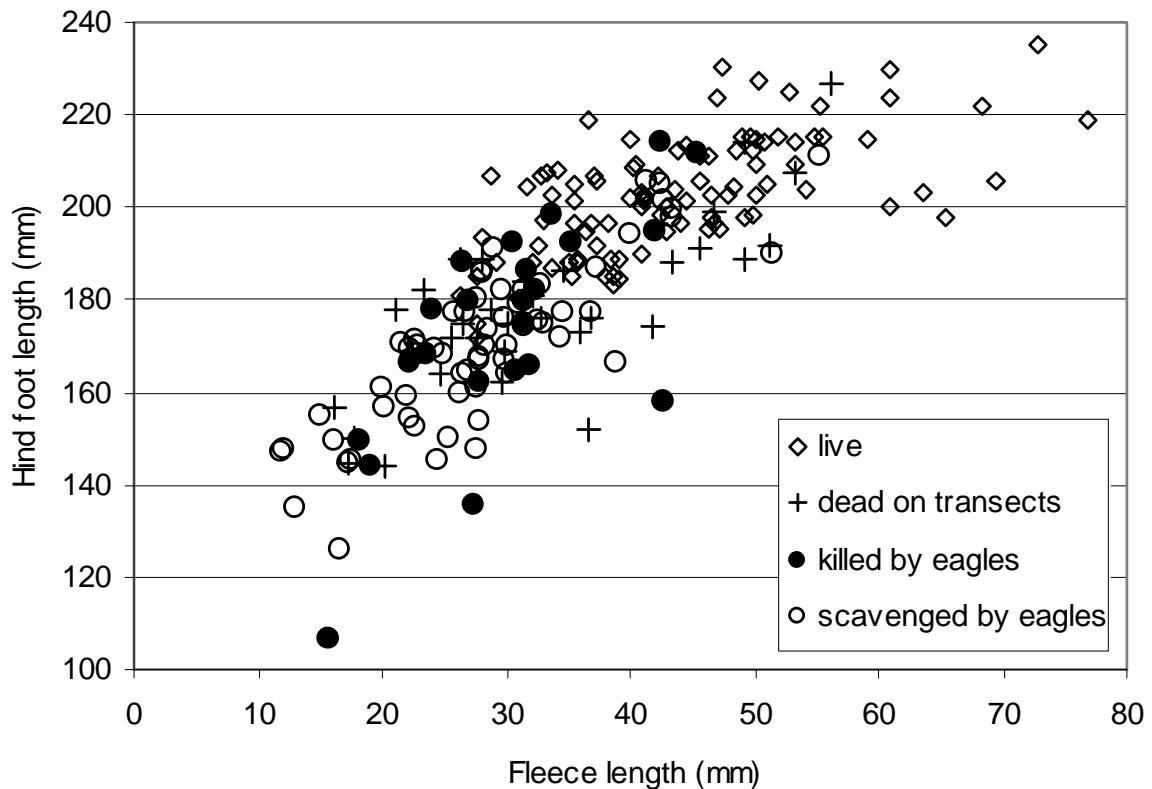


Figure 8. The hind foot and fleece lengths of live and dead Blackface lambs compared with those diagnosed as killed or scavenged by WTEs

Table 6. The mean hindfoot of live lambs compared with those found dead on the hill and those showing evidence of having been scavenged or killed by WTEs. The mean values are those calculated for lambs with fleece lengths of 36 mm (derived from the curvilinear relationship: $hindfoot = 109.0 + 2.985 \text{ fleece} - 0.0223 \text{ fleece}^2$).

Category	Mean hindfoot	SE mean
Live lambs	194.6	1.91
Dead on the hill	183.2	2.22
Eagle scavenged	182.1	1.69
Eagle killed	179.1	2.57

4.3.3. Discussion

The lambs consumed by WTEs, both those diagnosed as killed and those scavenged, were small, resembling those lying dead on the hill. The live lambs we measured were larger. The main problem in interpretation is that we do not know whether the live lambs were representative of the wider population of hill lambs on Mull. They came from two hefts including hill and coastal rough grazing pasture but were not immediately adjacent to WTEs nests. There is a possibility that keeping them in enclosed ground during May, away from high elevation pasture meant they had better than average growth associated with good forage and less exposure to poor weather. We were not able to measure the growth of live lambs under more 'typical' conditions as this would have meant persistently gathering sheep from the hill during lambing, or catching individual lambs frequently, both activities with concomitant disturbance. Although we cannot rule out the possibility that the live lambs we measured grew atypically well, we do not believe this was the case. The growth we recorded was not particularly high because the average weights between birth and ten weeks of age were lower than found in Hewson's study (1984) of live weight gain in free ranging Blackface lambs in mainland Argyll.

Despite our reservation, it was clear that the lambs diagnosed as killed by WTEs on Mull were small on average and of similar 'size for age' to dead lambs, consistent with the idea that they might have died in any case. Several other studies of lamb predation have found that predators took small lambs or those predisposed by poor nutrition and poor parental care (Alexander et al. 1967, Rowley 1969, Houston 1977, Hewson 1984). Against this, the spread of values for killed lambs (Figure 8) was wide. Many were much smaller in both hindfoot and fleece than the live lambs and we suppose they were small at birth and grew hardly at all prior to their death. However, a third of the values lay within the bounds for live lambs. These were apparently well-grown lambs and could have been viable unless diseased. We could not assess disease properly for lack of material but commonly found evidence of tick borne infection. During our lamb and ewe counts in both 2000 and 2002 we regularly observed lambs limping heavily and falling behind the ewe. Two individuals could not run and two had partial paralysis of the hindquarters suggesting spinal abscess (Henderson 1990). This would certainly predispose them to predation by eagles.

The dead lambs we found early in May were usually very small, some were premature, some had apparently died at birth and others had evidence of corvid or gull attacks. It was not until late May and early June that we found symptoms of tick borne disease. Two of the animals found dead in mid June had badly swollen puss-filled joints of the foreleg, a symptom of tick pyaemia. Of lambs consumed by eagles, we had five cases of scavenged lambs with heavy tick infestation in the last week of May and the first two weeks of June. Three of these had swollen, puss-filled joints and one also had subcutaneous pustules on the thorax associated with tick bites. One of the lambs diagnosed as killed by eagle similarly had a heavy tick burden, subcutaneous pustules and a swollen foot joint. In August we found four dead lambs with symptoms of disease. One had been seen when still alive with partial paralysis of the hindquarters. Another was newly dead but was infested with large maggots

associated with extensive skin lesions, suggesting 'blowfly strike'. The two others had copious nasal discharge suggesting respiratory infection.

Despite these observations we had insufficient information to say whether or not eagles selectively took diseased lambs. We were unable to accurately measure the the proportion of diseased lambs amongst those alive on the hill or those taken by eagles.

5. THE IMPACT OF WTEs ON SHEEP FARMING ON MULL AND THE POTENTIAL FOR MITIGATION MANAGEMENT

We have found that WTEs commonly feed on lambs and those birds on Mull particularly so. Eagles had scavenged most of the lambs we were able to diagnose but some were killed. However, we found that only one of the WTE pairs we examined killed many lambs, and they killed more in 1999 than in 2000 and 2002. Assuming the eagles we investigated intensively were typical, there were relatively few lambs killed per annum compared with the substantial mortality due to other causes. We estimated that less than fifty lambs were killed by WTEs each year compared with overall losses of thousands (>20 lambs per 100 breeding ewes on rough grazing). Previous investigations of lamb predation by eagles have similarly found that eagles do kill lambs but that losses attributable to eagles were small compared with other sources of mortality and the numbers killed varied from year to year (Table 7).

Table 7. Published studies of the impact of eagle predation on livestock. With one exception* estimated losses were small (0-3%) compared with overall mortalities of 20-30%. Matchet & O’Gara (1987)* found higher levels of predation in two of twelve years, associated with a population ‘crash’ of eagles’ usual food (jackrabbit *Lepus* spp.).

Species	Locality	Studies
Golden eagle <i>Aquila chrysaetos</i>	Scotland USA Norway	Lockie 1964 Leitch 1986 Weir 1985 Bolen 1975 Murphy 1977 Matchet & O’Gara 1987* Phillips & Blom 1988 Bergo 1987 Nyback, Kjelvik & Kvam 1999
Black eagle <i>Aquila verreauxii</i>	South Africa	Davies 1999
Wedge-tailed eagle <i>Aquila audax</i>	Australia	Leopold & Wolfe 1970 Brooker & Ridpath 1980
Bald eagle <i>Haliaeetus leucocephalus</i>	USA	Packard & Bolen 1969
White-tailed eagle <i>Haliaeetus albicilla</i>	Norway	Bergo 1987 Folkestad 1998

There is therefore no doubt that the predation of lambs by WTEs on Mull could not have been damaging to sheep farming on a broad scale. However, this does not preclude damage on a smaller spatial scale. The recorded locations where lambs were taken by WTE pair 2 in 2002 were within two km of the nesting site (Figure 7) so it

could be presumed that most (if not all) of the impact of their depredation fell on one holding. It is possible that a WTE that killed lambs but did not have a nest with young might remove lambs from a much wider area including several holdings but under these circumstances the impact on any one holding would be much less. Commercial damage to sheep productivity, if it occurs, is therefore likely to be confined to particular places and particular years (e.g. see Matchett & O’Gara 1987) and so might be amenable to localised mitigation management.

The main problem in devising such management is that WTEs mainly took free ranging Blackface sheep that are not traditionally close shepherded. On Mull there is insufficient enclosed and improved ground to lamb the whole flock inbye. Very few lambs are born indoors or in fields; most are born on the hill where they are vulnerable to a variety of mortality factors. The WTEs that settled initially on Mull, did so on the largest of holdings with the greatest proportion of hill ground and rough grazing, some of the largest sheep flocks and some of the lowest of lambing percents. The reason could have been the higher sheep mortality on such ground, eagles settling in places where they had ewe carrion readily available during late winter and early spring when other foods are least available. This would predispose eagles to a diet of lambs in May, some of which they might then kill.

Published studies of eagles and livestock conflict (Table 7) suggest similar circumstances. Conflicts arise where large eagles are present on extensive livestock range, where stocking densities are high and where alternative (‘natural’) foods are scarce. We attempted to measure the food available to WTEs on Mull but were compromised with little information on their favoured foraging patches. (Unlike Golden eagles which have exclusive defended foraging ranges, WTEs have large overlapping home ranges with favoured foraging patches sometimes remote from their nesting and roosting areas.) We collected some data on eagle foods in 1998 and 1999 on transects across the terrain surrounding nests and roosts, but the data were too sparse to establish associations with diet (Marquiss & Madders 2000). There was some anecdotal evidence. WTE pair 2 killed most lambs in 1999 a year when rabbits were reputed to be scarce due to disease. They killed far fewer in 2000 when rabbits were abundant and formed a major part of nestling diet in summer (Marquiss, Madders & Carss 2000). However, in this year the nest was close to the coast and a kilometre away from the immediate vicinity of hill lambing areas, so we could not distinguish between the effects of the greater availability of rabbits and the lower availability of lambs.

Irrespective of the underlying causes of WTE settling pattern, the outcome is that most lamb killing takes place where mitigation management is most difficult because the simplest short-term solution involves keeping eagles remote from lambs. However, there are two fundamentally different approaches to reducing predation, the likelihood of success dependent on whether predation is primarily driven by the propensity of the predator or the predisposition of the prey. If it is the former, then management should strive to remove the predator or change its behaviour. If the latter, then management should attempt to remove those factors that render the prey vulnerable.

Three pieces of evidence indicate that the problem of lamb killing by WTEs is largely driven by the predisposition of lambs to predation. Firstly, although most lambs were

killed by one pair of WTEs, the extent to which they killed lambs varied from year to year, and six of the eight pairs of eagles monitored intensively had at least one lamb carcass that showed evidence of killing. This suggests that lamb killing was not the result of the predatory habits of particular birds but rather, that all WTEs might opportunistically kill lambs. If so, the observed pattern of greater killing in some places and years reflected the predisposition of lambs to predation rather than the presence of a 'killer' pair of eagles.

Secondly, we found that the lambs killed and scavenged by eagles were small individuals, much the same size as those we found dead on the hill and smaller on average than those living lambs that we measured. Even the larger individuals killed by eagles could have been predisposed to predation by disease so their 'viability' could not be assumed. Thirdly, we failed to detect a spatial pattern of higher losses of lambs associated with the proximity of WTEs and one reasonable explanation might be that relatively few of the killed lambs were otherwise viable.

If (as suggested by this evidence) lamb predisposition drives predation, then the best management to reduce predation involves husbandry to improve the condition and growth of lambs, and to reduce disease. However, in the present situation there is insufficient direct evidence to exclude the possibility that lamb predation occurs simply because specific eagles have a propensity for killing them. Our suggestions for mitigation management should therefore include trials aimed at deterring predation by specific eagles:

- *Removing eagles.* It is almost certainly unacceptable to kill WTEs under licence (no matter how much agricultural damage is claimed) because of the UK international obligations for the conservation of this species. An alternative, the licensed translocation of offending eagles, is perhaps possible but would be impractical. The birds would have to be removed very large distances to prevent them returning. When tried in the USA, translocation of golden eagles proved expensive and ineffective (Matchett & O'Gara 1987).
- *Deterring eagles.* Eagles might be discouraged from foraging in lambing areas by increased shepherding or the use of bird scarers. Management test trials would be necessary because the cost in shepherding is high and eagles might not be easily deterred, as they can habituate to scaring devices or to regular shepherding rounds (Matchett & O'Gara 1987, Lowney 1999). Another technique involves the use of distasteful chemicals or emetics provided on lamb carcasses to discourage specific eagles from feeding on lamb. This technique (conditioned taste aversion) apparently works well on captives (American kestrels *Falco sparverius* and cormorants *Phalacrocorax carbo*) but still requires refinement (Nicholls *et al.* 2000, McKay *et al.* 1999).
- *Moving sheep.* An obvious alternative seems to be to remove sheep from eagle areas during lambing. This is not easy on many of the larger holdings on Mull, because there are insufficient resources to bring in all ewes to lamb under the protection of indoor lambing sheds or close shepherding in fields. Nevertheless, where possible, ewes could be moved away from those lambing areas immediately adjacent to where WTEs have chosen to nest. This is impractical in places where

the traditional eagle nesting areas are in the immediate vicinity of the best lambing 'parks'.

- *Moving eagles.* Where there is no option of moving sheep some thought should be given to encouraging eagles to nest elsewhere. This need not involve destroying traditional nests, or scaring during early nest building. It might be possible to attract WTEs to the nest sites most remote from lambing areas by providing food in February and March. However, the provision of supplementary food does attract other scavengers such as gulls and corvids (crows and ravens). Increased numbers of these birds might lead to further lamb losses. Using 'Larsen' traps and large 'crow cages' can be effective in reducing the numbers of corvids in the short-term but increasingly become less effective as the numbers of 'trap shy' individuals accrues.

Management trials, involving the manipulation of both eagles and lambs, would be worthwhile, particularly if a simple and cheap solution to localised predation can be found. However, it does not address the problem of lambs being predisposed to predation. If the aim is simply to reduce lamb losses, management to reduce predation by eagles could only have limited success because on Mull it was not the main cause of lamb mortality. Most lambs that died did so at birth or soon after, then at an age of three to five weeks associated with tick born infections. Losses continued through the summer into autumn (section 4.1). Previous investigations of lamb mortality in Scottish hill sheep have suggested poor nutrition as a major factor involved (Gunn & Robinson 1963, Houston & Maddox 1974, Hewson & Verkaik 1981). Poor nutrition of the ewe leads to difficult birthing, poor milk yield and poor parental care. This not only results in lamb deaths during birth and from starvation, but also predisposes them to predation, and probably disease through lowered immunocompetance. Thus the most cost-effective management to increase lamb production might best concentrate on the improvement of ewe nutrition and the reduction of tick infestation.

6. GENERIC LESSONS FROM A RETROSPECTIVE REVIEW OF THE RE-INTRODUCTION OF WTEs TO SCOTLAND

6.1. Introduction

There are lessons to be learned from the re-introduction of WTEs to Scotland, largely because it has been well documented and now (25 years on) we have the benefit of hindsight and much more published information. In the mid-1970s there were no established guidelines on re-introduction and limited information on methods or in depth knowledge of raptor ecology. WTEs were given priority amongst potential re-introductions because at that time they were in decline globally. In retrospect, the re-introduction proceeded much in line with current formal IUCN Guidelines (IUCN 1996). Importantly it fulfilled the six requirements basic to all re-introduction schemes which are now recommended for all member states of the EC (Recommendation No. R (85) 15 of the Council of Europe, adopted in 1985, Centre Naturopa 1996):

- That there should be good historical evidence of former natural occurrence,
- That only species lost through human agency and unlikely to re-colonise naturally should be considered,
- That factors causing extinction should be rectified,
- That there should be suitable habitat of sufficient extent to which the species can be re-introduced,
- That re-introduced individuals should be from a population as genetically close as possible to that of the former native population,
- That their loss should not prejudice the survival of the donor population.

In 1975 it was well established that WTEs were formerly widespread in Scotland and had been exterminated by human agency - persecution and collecting. At that time, the nearest breeding population was in Norway from where there was little chance of colonisation through natural spread of the geographic breeding range. In Scotland, there was an abundance of coastal and wetland habitat for the birds. The donor population (Norway) was apparently genetically similar to the former Scottish population, and could readily accommodate the loss of the required nestlings.

6.2. A retrospective review of the WTE re-introduction.

6.2.1. The process of WTE re-introduction to Scotland

The process of WTE re-introduction to Scotland has been successful in that many of the released birds have survived, are now producing young and the population is increasing. However, the success of a re-introduction should be judged on the long-term persistence of the species without further intervention (Seddon 1999, Fischer & Lindenmayer 2000). To judge success for a long-lived species such as WTE, the population needs to be followed for far longer than the single generation time of the original (released) cohort. Breeding success in Scotland is not as high as elsewhere in Europe and the poor production of young has meant that population increase has been slow. A population viability assessment (Green *et al.* 1996) suggested that projected

population growth was most sensitive to the survival probability of full-grown birds. With the recent loss of some of the original breeders, the population projection needs to be revised using contemporary estimates of survival. The present production of young is undoubtedly sufficient to replace losses of old birds but might not additionally fuel rapid population growth.

In retrospect, perhaps releases of WTEs into richer habitats (large estuaries and wetlands of eastern Scotland) would have led to higher initial breeding performance and thus to earlier and more rapid population growth. As it was, population growth was so slow that a decline was anticipated as the original released birds progressively died, so more birds were released to optimise the probability of persistence. In hindsight, the project might have been shorter (and cheaper) if birds had been released in larger groups and provided with winter feeding stations. This would have led to greater social cohesion, less straying, higher survival to breeding age and fewer 'spare' birds (non-breeding singletons or the third party in a trio). In 1975, there was insufficient knowledge to anticipate these problems and remedy them.

6.2.2. *Restoration of biodiversity.*

The underlying aim of a re-introduction is to reinstate biodiversity so that ecological communities are restored to their intrinsic richness. This has been achieved in as much as WTEs are now established on Mull, Skye and elsewhere but it is still not clear whether or not the addition of this species will lead to detectable change in other organisms. This should not be an issue if the only aim is to restore biological richness, but in practice an impact of a re-introduced species on others of conservation concern would question the basic premise. As yet too few WTEs are present to properly gauge their impact on the populations of wild prey or competitors. Substantial impact seems unlikely but e.g. it is possible that WTEs compete with Golden eagles for prey or nesting sites and might oust them from some areas. As yet there is no clear evidence of it (Whitfield *et al.* in press) and monitoring continues.

6.2.3. *The impact on 'stakeholders'.*

Re-introductions are direct manipulations of the biota and there needs to be concern for any consequential impact on 'stakeholders' - people and their livelihood. The WTE re-introduction has had clear benefits for wildlife tourism but has caused some aggravation for sheep farmers.

The benefit for wildlife tourism is that the general public enjoys the now common spectacle of large eagles. Wildlife tours and nest viewing facilities on Mull and Skye have proved popular with undoubted benefits for the local community by boosting visitor numbers and providing direct employment. The WTEs provide an additional interest for regular visitors and attract some that would not otherwise have travelled to the islands. The benefit of eagle tourism will be sustained but only by providing facilities not available elsewhere in the UK. Eventually WTEs will be a familiar sight elsewhere in Scotland and the islands need to take advantage of their lead by progressively enhancing and upgrading eagle viewing facilities. The large scale of

present benefit in terms of wildlife tourism is a bonus. It could hardly have been anticipated when the re-introduction began in 1975.

The aggravation for sheep farmers stems from their perception of eagles as potential pests and the source of much dissatisfaction was the lack of consultation. The original re-introduction was not debated widely and publicly so local communities argue that they had no chance of input to the decision to release WTEs on Rum. The aggravation worsened once it was clear that WTEs commonly fed on lambs and there was anecdotal evidence of lamb killing. The debate became polarised and then expensive on time, effort and funding as formal discussion ensued and solutions were sought. The claim was that WTEs were causing economic loss to agriculture; the fear was that a pest had been re-introduced. The results of the present work show that this fear is unsubstantiated. Sheep farmers were correct in their claims of lamb killing but the scale of the problem is far less than originally thought.

In retrospect, could this aggravation for sheep farmers have been anticipated in 1975? There is some historical evidence that could have forewarned of eagle settlement in sheep farming areas with concomitant perceptions of lamb killing. The former range of WTE in Scotland included much sheepwalk and the birds had been persecuted in the past because of such perceptions (Love 1983). Eagle predation of lambs is an issue that persists despite repeated investigations that show that the problem is usually small and localised (Newton 1972, Watson 1997). However, most eagle/livestock problems involve *Aquila* eagles (Table 7). Very few involve *Haliaeetus* (bald eagle and sea eagles) and the current situation on Mull is unusual. In the 1970s, it was thought that WTEs brought into Rum would concentrate on fish and seabirds during the breeding season. The WTE populations around the North Atlantic seaboard were in Greenland, Iceland and Norway where lamb killing was not an issue. It is therefore debatable as to whether or not the issue of lamb killing should have been foreseen. Nevertheless, it might have arisen had there been wider public consultation prior to the 1975 release.

6.3. Other re-introductions

Re-introductions are now commonplace; in their recent global review, Fischer and Lindenmayer (2000) listed 180 published case studies. Re-introduction is now a powerful and successful tool used alongside habitat management in the process of restoring lost biodiversity (Dennis 1998, Sheail et al. 1997). The idea of restoring ecological communities as part of our natural heritage now seems largely accepted and for the most part welcomed, by both landusers and the general populace of the UK. The farming community in particular has embraced the restoration of wildlife habitat as it is now accepted that “farming must do more than simply provide food”. The *Forward Strategy for Scottish Agriculture* (2002) reflects this with a commitment to both protecting the environment and enhancing it. Nevertheless, enhancement of biodiversity does not always receive unanimous support and the re-introduction of large vertebrates is often contentious (e.g. wolf *Canis lupus* Yalden 1993 and beaver *Castor fiber* Anon 2000).

Across Europe there have been numerous re-introductions involving many species. Those of predatory and scavenging birds (reviewed in Cade 2000) include:

peregrine *Falco peregrinus* in Sweden and Germany,
lesser kestrel *Falco naumanni* in Spain,
osprey *Pandion halietus* in England,
griffon vulture *Gyps fulvus* in France and Israel,
bearded vulture *Gypaetus barbatus* in France,
monk vulture *Aegypius monachus* in France and the Balearics,
northern goshawk *Accipiter gentilis* in the UK,
red kite *Milvus milvus* in the UK,
Montagu's harrier *Circus pygargus* in Spain
white-tailed eagle *Haliaeetus albicilla* in Scotland and Israel, and
golden eagles *Aquila chryseatos* to the Republic of Ireland (O'Toole *et al.* 2002).

Other re-introductions of large birds include:
great bustard *Otis tarda* to England, and
capercaillie *Tetrao urogallus* to Scotland.

Re-introductions of mammals in Europe include:
European beaver *Castor fiber* in Sweden, Norway, France, Germany, the Netherlands,
Poland, Switzerland, Austria, Finland, Latvia, Estonia, Lithuania and Russia
(Macdonald *et al.* 1995),
lynx *Lynx lynx* in France, Germany, Italy and Switzerland (Yalden 1993),
brown bear *Ursus arctos* in France, and
wild boar *Sus scrofa* in England (Yalden 2001).

To judge from published reports, none of these re-introductions have resulted in losses to native flora or fauna. The only serious problems published have involved re-introduced lynx and sheep farming. The conflict and the management to resolve it are well researched and documented (Breitenmoser & Haller, 1993, Stahl *et al.* 2001a, 2001b, 2002). Of concern is the establishment of free-living wild boar in England, which might present problems for agriculture in the future (Yalden 2001). Also it is claimed that northern goshawks are damaging to game bird interests through their predation of released pheasants (Tapper 1999). These latter instances involve rational perceptions that deserve investigation. Assuming the problems are substantiated, research might enable solutions. However, it must be born in mind that the fears of stakeholders are not always realised. In two of the releases of red kites in Scotland, gamekeepers on and adjacent to the release sites have found that the birds do not damage game interests (Lorcan O'Toole, Richard Mearns *pers comm.*). Despite initial fears, the kites do not kill young pheasants or disturb adults. They are apparently now seen as useful scavengers, removing the carcasses of dead pheasants that had previously attracted the attention of foxes *Vulpes vulpes*.

The relatively few problems associated with re-introductions of native species contrast starkly with the magnitude of problems due to introduced alien species (Welch *et al.* 2000). Of 267 native terrestrial and freshwater vertebrate species in Scotland, 22 (9%) have been the subject of attempts to control their populations as they were considered to be pests. Of 38 alien species, 12 (32%) have been subject to attempts at population control (often eradication) because of their impact on crops, livestock or natural heritage. Just three examples of alien impacts with a current high profile are:

- The ousting of red squirrels *Sciurus vulgaris* associated with the spread of greys *Sciurus carolinensis*,
- The extermination of water voles *Arvicola terrestris* from many parts of Britain through predation by American mink *Mustela vison*, and
- The declines in breeding success of ground nesting birds in the Western Isles due to nest predation by introduced hedgehogs *Erinaceus europaeus*.

The re-introduction of native species is not free of risk but it is small compared with the threats posed by alien species. It is therefore understandable if in the past it has been assumed that the biodiversity benefits of re-introductions far outweigh any deficits. This attitude is now superseded with the move towards wide consultation amongst potential stakeholders (e.g. see Scott-Porter Research 1998, for the consultation process on the re-introduction of beaver to Scotland). In line with IUCN guidelines, consultation and risk assessment is now embedded in the process of re-introduction.

6.4. Generic lessons from the WTE re-introduction that might be applied to future re-introductions.

- The re-introduction of WTEs to Scotland has enhanced biodiversity and provided additional benefits for wildlife tourism. Re-introductions are a useful way to enhance biodiversity but where practical, future re-introductions should attempt to provide viewing facilities to give added value.
- The re-introduction of WTEs was slow and therefore costly. Future re-introductions should attempt to speed the process by releasing many individuals, in a short time and in the best quality habitat available.
- The re-introduction of WTEs did not anticipate that the perception of lamb killing would prove to be such a problem. Future re-introduction plans should involve wide consultation among potential stakeholders and any rational fears should be incorporated in a risk assessment.
- Risk assessment should anticipate problems and have mechanisms in place for monitoring, evaluation and remedial management.

In fact, these generic lessons have already been learned. Recent re-introductions within the UK have adhered rigidly to IUCN guidelines. The re-introductions of red kites to England and Scotland and ospreys to England (from Scotland) have enhanced biodiversity and provided added value. There are viewing facilities and also web sites to inform. The re-introduction of kites in particular has used larger numbers of birds over shorter time periods than did the WTE re-introduction (Carter *et al.* 2002). The relatively few ospreys released in England in the initial year were due to a problem of supply but this was remedied in later years (Dennis & Dixon 2001). The current re-introduction of golden eagles to Ireland has similar problems with the supply of donor birds from Scotland (Lorcan O'Toole *pers. com.*). It is to be hoped that this will be remedied from 2003 onwards. Both the osprey and kite re-introductions have been to

habitat of high quality. The average breeding success of re-introduced kites exceeds that of kites in their traditional refuge of upland Wales.

The most recently planned re-introduction of beaver to Scotland has widely consulted and taken onboard some rational fears of stakeholders. Proposed management trials include monitoring and evaluation, though it is not clear whether risk assessments have included remedial measures if required. The latter would minimise the risk that inevitably offsets the substantial benefits to be gained from the proactive enhancement of biodiversity.

7. CONCLUSIONS

This research set out to achieve five objectives:

1. *To provide evidence that WTEs are responsible for killing live (viable) lambs as opposed to scavenging carcasses or preying on non-viable lambs.*

We found evidence that WTEs killed some live lambs as well as scavenging carcasses (section 3.3). There was circumstantial evidence that many of the lambs killed were not viable because, compared with live lambs they were small for their age (section 4.3.2) and there was no spatial pattern of high lamb losses associated with the close proximity of WTE pairs (section 4.2). The larger lambs that were killed could have been viable but we cannot be sure that even they might have been predisposed to predation by disease (section 4.3.3).

2. *To establish whether specific birds are responsible for deaths, or whether the population will opportunistically kill lambs.*

It was clear that not all WTEs killed lambs and that the birds at one site did so in every year they were monitored (section 3.3). However, for six of the eight eagle pairs monitored intensively, at least one lamb carcass showed evidence of having been killed. Thus killing was not confined to one pair – the population might opportunistically kill lambs. If so, it suggests that the predation of lambs by eagles was largely determined by the predisposition of those lambs killed rather than the propensity of particular eagles.

3. *To make estimates of the number of lambs being killed on an annual basis on Mull.*

We calculated from the numbers of eagles present, the numbers of lambs they consumed, and the proportion that were killed as opposed to scavenged, that the WTE population on Mull killed between 33 and 37 lambs each year (section 3.4). This takes no account of the viability of these lambs. The calculation assumes that the WTEs for which we had data were typical of all those on Mull. Compared with overall lamb losses of thousands, relatively few were killed by WTEs.

4. *To recommend positive management measures that might be implemented on Mull to reduce the impact of WTEs on the local farming community.*

The predation of lambs by WTEs on Mull could not have been damaging to sheep farming on a broad scale but this does not preclude localised damage. The way to reduce eagle predation on lambs is to keep lambs remote from eagles but this is probably impractical on most parts of Mull (section 5). We suggest management trials to determine the cost-effectiveness of deterring WTEs in lambing areas using scaring devices or close-shepherding. We further suggest the use of feeding stations in late winter to encourage WTEs to nest as remote as possible from

lambing areas. However, the most positive management to increase lamb production would involve improvement of ewe nutrition and reducing tick infestation.

5. *To consider whether there are generic lessons that can be learned from the WTE reintroduction programme that might be applied to future re-introductions.*

There are generic lessons to be learned from the WTE re-introduction programme (section 6). These are

- that re-introductions not only enhance biodiversity but can give added value for wildlife tourism if facilities are provided for viewing and information.
- that the process of re-introduction can be quicker and cheaper by releasing many individuals in a short time into the best quality habitat available.
- that re-introductions should involve wide consultation among potential stakeholders and rational fears should be incorporated into a risk assessment.
- that the risk assessment should anticipate problems and have mechanisms in place for monitoring, evaluation and remedial management if necessary.

These lessons have already been learned, to judge from the protocols now in place for recent and planned re-introductions.

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