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Pollutant Burdens and Reproductive Success of Golden Eagles *Aquila chrysaetos* Exploiting Marine and Terrestrial Food Webs in Scotland

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The breeding success of the Golden Eagle, *Aquila chrysaetos*, in Scotland has been consistently higher in the Eastern Highlands than in the West or on the Island of Rhum (Table 1, Figure 1: Corkhill 1980, Dennis *et al.* 1984, Everett 1971, Lockie & Ratcliffe 1964). Furthermore, breeding success may vary in a consistent way between nearby pairs. In this paper we consider whether these differences might be due to effects of toxic chemicals.

Diets of Golden Eagles differ markedly among the three areas (Table 2). In part, the diets reflect the availability of prey species among the areas. There are no lagomorphs, sheep, or Ptarmigan *Lagopus mutus*, and few Grouse *L. lagopus*, on Rhum. Densities of lagomorphs and game birds are much lower in West Scotland than in the Eastern Highlands. Seabird prey, however, is abundant on Rhum and is exploited by the eagles.

Mercury and the PCBs are both found predominantly in marine animals and are accumulated to high concentrations in seabirds (Bourne 1976, Furness & Monaghan 1987). Mercury levels are much higher in Golden Eagles on Rhum than in the Eastern Highlands (Figure 2). PCB levels are also comparatively high in Golden Eagle eggs from Rhum, and seem to have increased considerably in recent years (Figure 3), although sample sizes are small and analytical methodologies were not uniform over the period of the study.

DDE and HEOD levels in Golden Eagle eggs from Rhum are higher than found in other areas, although both have declined since restrictions in use of these pesticides during the mid-1960s (Figures 4 and 5). Elevated levels of HEOD found in West Highland eagles in the early 1960s were thought to have been the cause of a temporary reduction in breeding productivity in that area, since productivity improved when HEOD levels declined after the restriction of use of dieldrin in sheep dips (Lockie *et al.* 1969). Shell thickness of eggs from the Western Highlands was significantly reduced over this time (Ratcliffe 1967, 1972). Since dieldrin and DDT are not used on Rhum, which is a National Nature Reserve, the local eagles must obtain DDE and HEOD primarily from seabird prey.

These compounds, like the PCBs, are now global contaminants in marine food webs, distributed primarily through the atmosphere.

The relatively high mercury and PCB burdens of Golden Eagles on Rhum, resulting from the limited availability of live, terrestrial animals and dependence on seabirds as food, could be the cause of the poor breeding success, although sensitivity of eagles to these compounds is unclear. Henriksson *et al.* (1966) suggested that levels of about 10-20 ppm mercury in feathers of Sea Eagle

Haliaeetus albicilla corpses collected in the Baltic region indicated that mercury accumulation had caused the deaths of these birds. Golden Eagles on Rhum have feather mercury levels approaching this range. High pollutant uptake, however, may simply correlate with low breeding success because both are due to the shortage of lagomorph and grouse prey.

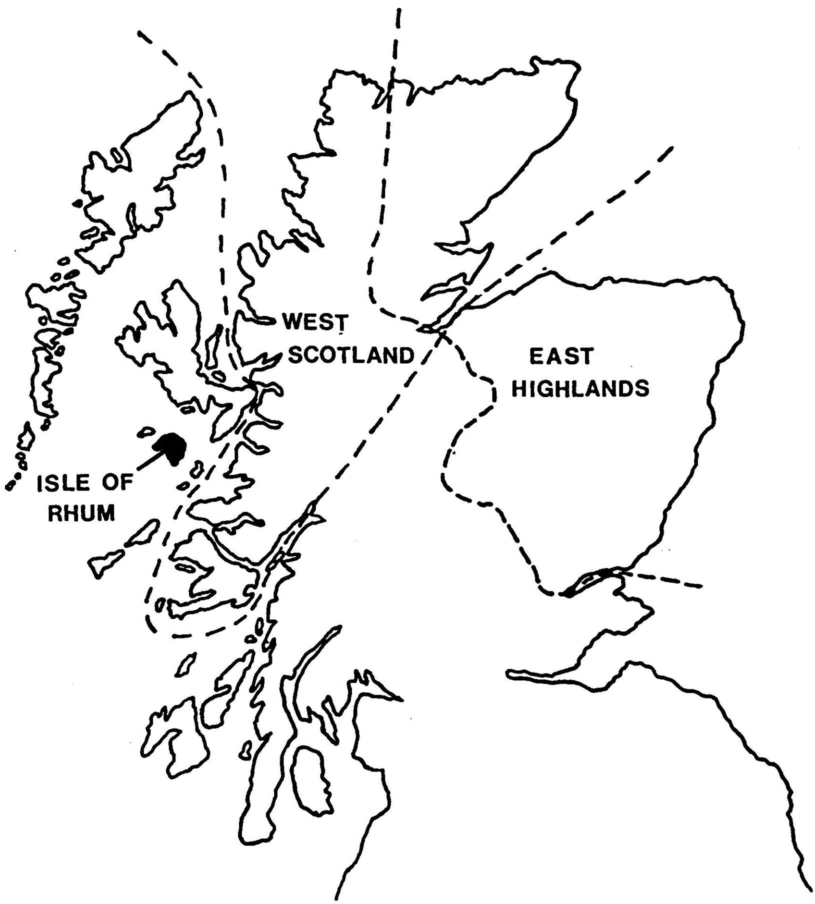


FIGURE 1. Map of Scotland showing the location of the Isle of Rhum, and of the areas labelled East Highlands and West Scotland for the purposes of comparing eagle breeding performance.

TABLE 1. Breeding success of Golden Eagles on Rhum, in West Scotland and the Eastern Highlands, expressed as chicks reared per occupied territory.

	Rhum (Corkhill 1980)	West Scotland Dennis et al. (1984)	Eastern Highlands Dennis et al. (1984)
Pair-years	80	184	30
Chicks per occupied territory	0.29	0.47	0.80

(Closely similar patterns between areas have also been indicated by other studies of Golden Eagle productivity such as those listed in the references and by annual reports of the Raptor Working Groups in Scottish Birds)

TABLE 2. Diets of Golden Eagles in Scotland together with notes on the relative levels of mercury and PCBs in the tissues of the prey animals. +++ = major prey, ++ = regular prey of less importance, + = rare items. Data on diet abstracted from Corkhill (1980), Brown & Watson (1964) and Lockie *et al.* (1969). Mercury levels are classified as follows: LOW = 0.001 to 0.05 ppm, MODERATE = 0.05 to 0.1 ppm, HIGH = 0.1 to 2.5 ppm. PCB levels are low in terrestrial species but elevated in marine species.

Prey	Importance at each locality:			Mercury and PCB levels in tissues
	Rhum	West Scotland	East Highlands	
Red Grouse	+	+	+++	LOW
Ptarmigan		+	+++	LOW
Rabbit		+	+++	LOW
Mountain Hare		+	+++	LOW
Sheep		+++	+	LOW
Red Deer	+++	+++	+	LOW
Voles			+	LOW
Hooded Crow	+	+		MODERATE
Fox		+		MODERATE
Feral Goat	++			LOW
Brown Rat	++			LOW
Fulmar	+++			HIGH
Manx Shearwater	+++			HIGH
Large gulls	+++			HIGH
Kittiwake	+			HIGH

When the breeding performance of the four territories on Rhum is compared, it is clear the pairs with the highest consumption of seabirds have the lowest breeding success (Figure 6).

Everett (1971) suggested a figure of 0.5 young per pair as being adequate to maintain a viable Golden Eagle population. Eastern Highland eagles are more than meeting this requirement. By contrast, Rhum Golden Eagles would be unable to maintain themselves and would depend on immigration from more productive areas (Table 1).

In general, it would appear from this preliminary review that eagles dependent on marine prey show reduced breeding productivity and high contaminant burdens, a pattern that is not found in eagles feeding at the top of the terrestrial food chain in Scotland. This observation suggests that it would be valuable to make a more detailed investigation of contaminant levels, particularly mercury and the PCBs, in coastal eagle populations in Scotland. It also suggests that a reintroduction of the Mountain Hare on to the Island of Rhum would be highly beneficial to the local population of eagles by providing food with low contaminant levels in its tissues.

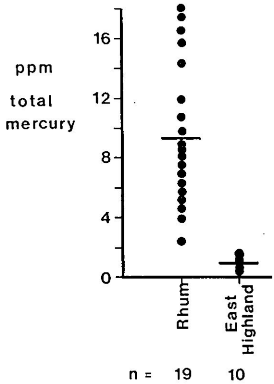


FIGURE 2. DDE concentrations (ppm wet weight) in Golden Eagle eggs 1964-1986 for Rhum, West Scotland and Eastern Highlands. Rhum data points each represent individual eggs, whereas data for the other areas are geometric mean concentrations. Data for 1964-74 from Cooke *et al.* 1982 and Lockie *et al.* 1969, data for 1975 from Corkhill 1980.

FIGURE 3. HEOD concentrations (ppm wet weight) in Golden Eagle eggs 1964-86. Sources as for Figure 2.

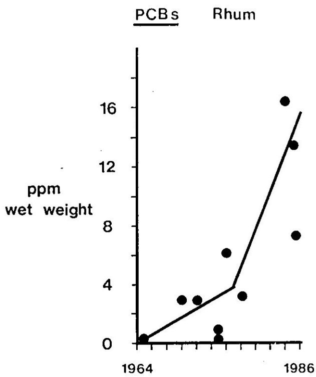
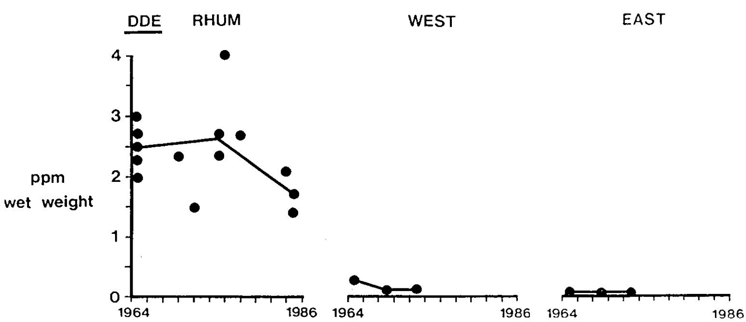


FIGURE 4. PCB concentrations (ppm wet weight) in Golden Eagle eggs from Rhum, 1964-86. Data for the 1960s and 1970s may be underestimates since the analyses were performed for DDE and HEOD.



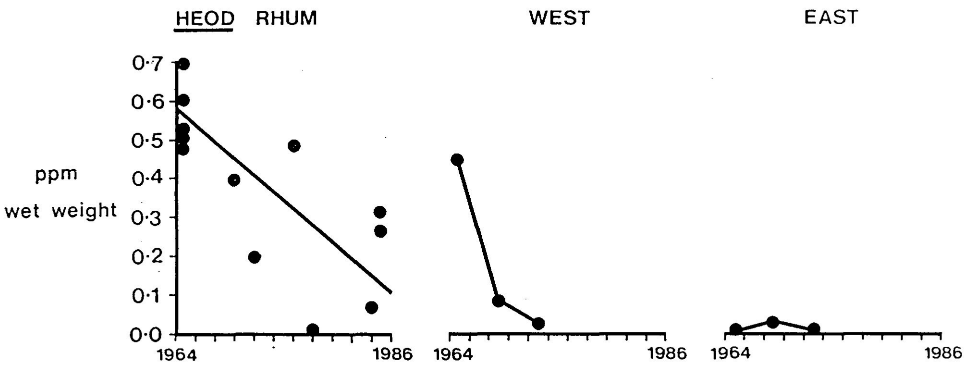


FIGURE 5. Total mercury levels (ppm fresh weight) in Golden Eagle feathers from Rhum and the East Highlands. Each point represents the total mercury content of an individual shed feather collected at a roost or nest site, and therefore each point does not necessarily represent a different bird. Both samples probably represent no less than six individuals and no more than ten. Analytical methods are outlined in Furness *et al.* 1986.

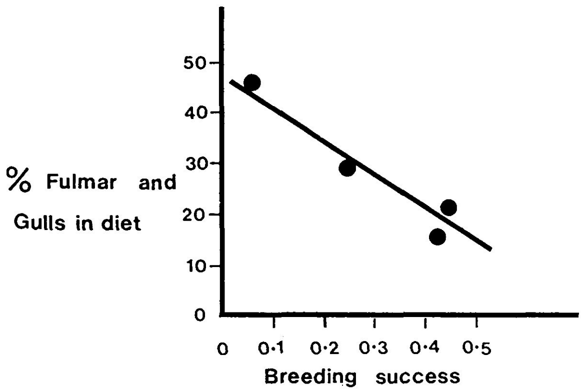


FIGURE 6. Breeding success (mean number of chicks fledged per breeding attempt) of Golden Eagles at the four breeding sites on Rhum averaged over the period 1957-79, plotted against the proportion of Fulmars and gulls in their breeding season diets. The decrease in breeding success with increasing proportions of seabirds in the diet is statistically significant.

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