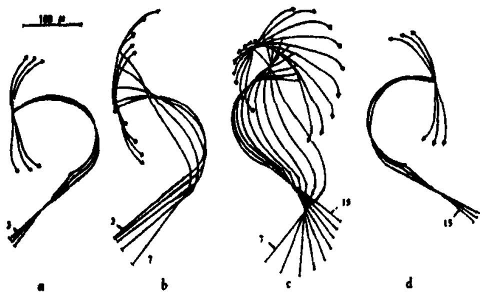

Fig. 2.

Not only the fork of the tail but also the body of the cercaria can produce a weaker propulsion and a stronger backward thrust (Fig. 2b). In this case the body works on the principle of the fish-tail, but bending is largely replaced by oscillation around a joint-like area. As the cercaria swims forward (Fig. 1c and d) the folded fork branches function like an elastic tail fin. The connexion between body and tail has lost its flexibility and is now actually rigid. As a result of new properties of resistance a wave passes along the cercaria from the body to the tail end with all striated muscles equally active (Fig. 1c and d). This results in propulsion. The maximum speeds for animals swimming backwards or forwards are 1·4 mm/sec; the distance covered in 1 sec corresponds to about three body lengths.

Swimming backward and forward by means of an adjustable forked tail has been reproduced in a model (built by H.-G. Beckmann and called "Cercaria I"). A forked tail made of rigid material with a joint as in Fig. 1f is sufficient to produce backward movement which can be converted to propulsion and vice versa, even in the model, by folding backwards the branches of the transverse oar blade and by retaining the limited range of the joint (Fig. 1g). Models of this kind could perhaps be applied to mixing tasks and driving mechanisms in engineering.

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Decrease in Eggshell Weight in Certain Birds of Prey

THE incidence of broken eggs in nests of peregrine falcon *Falco peregrinus*, sparrowhawk *Accipiter nisus* and golden eagle *Aquila chrysaetos* in Britain has increased considerably since 1950. In 109 peregrine eyries examined in 1904–50, there were only three instances of egg breakage, compared with forty-seven in 168 eyries examined in 1951–66. Two of thirty-five golden eagle eyries examined in 1936–50 contained broken eggs, compared with twelve out of forty-eight examined in 1951–63. One breakage was found in twenty-four sparrowhawk nests in 1943–50, but eight in twenty-seven nests in 1951–60. Peregrines have been witnessed eating their own eggs[1], and most recent egg breakages in all three species appeared to involve parental destruction.

Eggshell thickness was investigated by measuring weight and size of blown eggs of varying age, using specimens cleanly emptied through a hole not exceeding 7 mm in diameter, thus rejecting heavily incubated eggs. In peregrine and sparrowhawk, eggshell weight/size ratio decreased significantly and suddenly in 1946–50, and has not recovered. Since 1947, the only "normal" peregrine eggshells were four of the seven available from the East Highlands. After 1946, sparrowhawk eggshells from Surrey were significantly lighter than those from Cumberland, Dorset and Hampshire. Golden eagle eggshells from West Scotland are slightly yet very significantly lighter but East Highland eggshells remain unchanged. Fewer golden eagle eggs were available, but change during 1945–50 is again indicated.

The eggshells as measured consisted largely of calcium carbonate (about 90 per cent in "normal" eggs), the remaining fraction being shell protein[2], adherent shell membranes, and residual film of contents. The decrease in eggshell weight has involved mainly the calcium carbonate fraction. Decrease in shell thickness rather than density is implied, but this has not been measured directly.

Thickness of eggshells and production of eggs vary according to diet (especially calcium) and condition in poultry; eggshell thickness is also genetically influenced, and diminished by disease and increasing age[3]. Certain chemicals, for example sulphanilamide[4], cause decrease in eggshell thickness, as can stress; severe fright can stop poultry laying for a time. Occasional thin-shelled eggs may be laid by any wild bird species, but before 1946, mean eggshell weight and size for clutches from the same female raptor, year by year, were fairly constant, though weight/size of eggshells within one clutch was less consistent.

Decrease in eggshell weight in peregrine and sparrowhawk was synchronous, rapid and widespread. It occurred in successive clutches of the same female peregrines at four different eyries, but three other females laid at least one clutch of normal weight after they had produced light eggs. General ageing or genetic shift in the population are thus not likely to be involved, while the synchronous effect on three raptors with different ecology and distributions, and the varying geographical response, make disease an unlikely explanation.

Decrease of calcium carbonate for eggshell formation could result from reduced food consumption, but no decline in available food supply for these raptors was known in 1940–50. Loss of hunting efficiency could cause an effective food shortage, or change in metabolic regulation could induce internal shortage of calcium, without less food being consumed. A different possibility is premature extrusion of eggs, known in poultry (personal communication from C. Tyler).

Some physiological change evidently followed a widespread and pervasive environmental change around 1945–47. Increasing radioactive contamination fails to account for geographical variations in eggshell change, whereas these match the developing regional pattern of contamination by chemical pollutants during this period. Among urban-industrial pollutants, one waste product in smoke, the persistent polychlorinated biphenyl (PCB), has been found in tissues of fish, eagles and humans in Sweden, and was first detected in 1944 in an eagle[5]. There was a notable boom in organic insecticides, fungicides and herbicides, containing chlorine, mercury, phosphorus and sulphur after 1945, and environmental contamination by persistent residues has been widespread[6]. British peregrines, sparrowhawks and golden eagles have shown widespread contamination by *pp'* DDT, *pp'* DDE, γ-BHC, dieldrin and heptachlor epoxide[7-9]. The introduction of

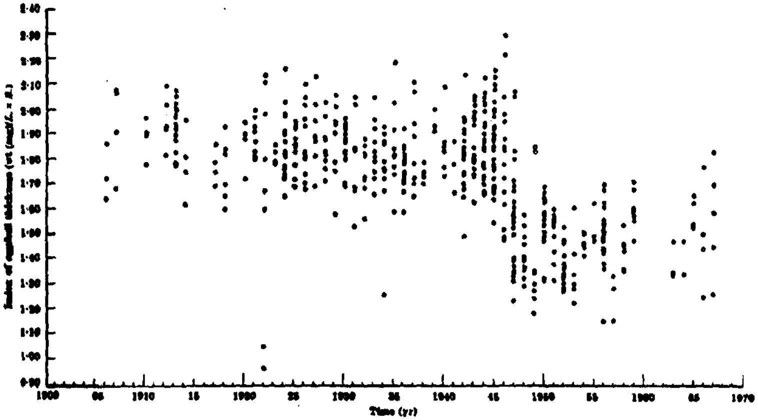

Fig. 1. Change in the ratio of weight to size (index of thickness) in eggshells of the peregrine falcon in Britain. Circles represent eggshells from the central and eastern Scottish Highlands, and dots represent eggshells from other districts (see Table 1).

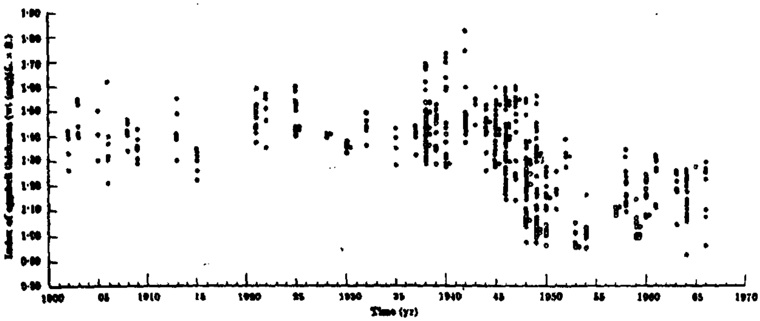

Fig. 2. Change in the ratio of weight to size (index of thickness) in eggshells of the sparrowhawk in Britain. Circles represent eggshells from south-eastern England, and dots represent eggshells from other districts (see Table 1).

DDT into general use (about 1945–46) coincided closely with onset of the eggshell change. Dieldrin, aldrin and heptachlor appeared 10 yr later and, like DDT and γ-BHC, have been used extensively ever since. Contamination of birds by persistent organo-mercury compounds has received little attention in Britain, but in Sweden the introduction of these as seed dressings paralleled the substantial increase in mercury content of raptor tissues during the 1940s (ref. 10).

Calcium metabolism in birds is controlled by oestrogen and parathyroid hormone[9], and is thus potentially sensitive to any chemical disturbing hormone regulation. Jefferies[11] has demonstrated a significant correlation between intake of pp' DDT by the Bengalese finch *Lonchura striata* and delay in ovulation, and interprets this as a hormonal effect. One dithiocarbamate fungicide affects eggshell thickness in poultry[12], but is non-persistent and of unknown relevance to raptors.

The time correlation between decrease in eggshell weight and increase in egg-breakage suggests a causal connexion. In the peregrine and golden eagle there is also geographical correlation, for in the East Highlands decrease in eggshell weight is slight or unknown and egg breakage unusual. Eating eggs is probably an instinctive adaptive response to unfavourable circumstances arising after laying, and seldom invoked before 1946. Other bird species normally eat or destroy their damaged eggs[13], and lighter raptor eggs are probably more prone to accidental damage than "normal" eggs. Yet, often, raptors have evidently destroyed undamaged eggs, perhaps in response to a calcium "hunger". Domestic fowl which have broken and eaten an egg often develop an incurable appetite for their eggs. While calcium is obviously implicated, in several raptor instances the egg contents had been eaten and most of the shell left.

Other bird species in which egg-breaking is unusual (hobby *Falco subbuteo*, merlin *F. columbarius*, buzzard *Buteo buteo*, carrion crow *Corvus corone*, golden plover *Charadrius apricarius*, greenshank *Tringa nebularia*, guillemot *Uria aalge*, and razorbill *Alca torda*) show no

Table 1. MEASUREMENTS OF EGGSHELLS OF THREE BRITISH RAPTORS, 1900–1967

Species	District 1 1900–46	District 2 1947–67	No. of eggs 3 1900–46	No. of eggs 4 1947–67	Mean eggshell weight (g) 5 1900–46	Mean eggshell weight (g) 6 1947–67	* Mean index of eggshell size, length (mm) × breadth (mm) 7 1900–46	* Mean index 8 1947–67	† Mean index of eggshell weight (mg)/$L \times B$ 9 1900–46	† Mean index 10 1947–67	Probability of significant difference between data in columns 9 and 10
Peregrine	S. England, N. England, Wales, Scotland, Ireland	S. England, N. England, S. Scotland	371	156	3·81	3·09	2,072	2,102	1·84	1·47	< 0·001
	As above	C. and E. Scottish Highlands	371	7	3·81	3·59	2,072	2,096	1·84	1·71	—
Sparrowhawk	S. England, Midlands, N. England, Wales, Scotland	S. England, Midlands, N. England, Wales, Scotland	229	108	1·84	1·54	1,298	1,299	1·42	1·19	< 0·001
	Sussex, Surrey, Kent	Surrey	25 (Included in above totals)	51 (Included in above totals)	1·81	1·38	1,278	1,292	1·42	1·07	< 0·001
Golden eagle	Western Central and Eastern Highlands	Galloway and Western Highlands	107	28	14·37	13·19	4,553	4,563	3·16	2·89	< 0·001
	As above	C. and E. Highlands	107	14	14·37	14·45	4,553	4,590	3·16	3·12	—

* These measurements show a sufficiently close relationship to surface areas of the eggshells to justify using the more simply derived length × breadth ($L \times B$) as an index of size.
† This is presumed to indicate thickness, but it could also indicate density of eggshell.

change in eggshell weight. In kestrel *F. tinnunculus* and raven *Corvus corax*, the eggs of some individuals show a slight decrease, but not the whole population samples.

For the species examined, frequency of egg-breakage, scale of decrease in eggshell weight, subsequent status of breeding population, and exposure to persistent organic pesticides are correlated. The possibility that these phenomena are links in a causal chain is being investigated. Recovery of locally depleted populations of peregrine began in 1946 and continued for several years after eggshells became lighter and egg eating frequent, even in districts, such as Dorset, where both changes were obvious. Population "crashes" in peregrine and sparrowhawk after 1955 probably involved greatly increased adult mortality, but later factors contributing to low breeding success would tend to prevent recovery.

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Moisture Sensitivity, Mechanical Injury and Gibberellin Treatment of Beta vulgaris Seeds

"RUBBING" ("shearing") is a mechanical process used to separate the fruit clusters of *Beta vulgaris* L. (sugar beet or beetroot) into more or less even-sized segments, each with one or two seeds, by grinding away some of the hard tissue surrounding the seeds with an assembly of abrasive disks. The investigation here reported followed the almost complete failure of a rubbed sample of beetroot seeds to germinate in a field in which a different rubbed sample of the same cultivar ('Detroit Globe'), sown at the same time, germinated satisfactorily. Neither sample contained any obviously damaged seeds and no damage was found when embryos excised from imbibed seeds were examined under the microscope. Natural (unrubbed) seeds from the same sources (Lot 1, good; Lot 2, bad) were later obtained. In a series of laboratory experiments we found that: (1) Germination of unwashed seeds can be depressed by insufficient moisture (Fig. 1*A*). (2) When beetroot seeds are washed and then immediately placed on wet filter paper scarcely any will germinate; but if they are washed, dried and then placed on moist filter paper they germinate well (Table 1). (3) Similarly, germination can be depressed when seeds are placed on a substrate which is even slightly wetter than necessary (Fig. 1); this effect is particularly pronounced with unwashed seeds (Fig. 1*A*) but can be alleviated by adding small quantities of hydrogen peroxide (Table 2). Warburg respirometer results show that the respiration of beet seeds is appreciably suppressed in a slight excess of water. (4) Natural seeds from Lot 2 germinate at least as satisfactorily as seeds from Lot 1, but rubbing depresses the performance of seeds from Lot 2, though not of those from Lot 1 (Fig. 1*B*). (5) Shaking the seeds for 45 min in a glass bottle has an effect on germination similar to that

Table 1. EFFECT OF DRYING AFTER WASHING

Seed lot	Seed treatment	Drying (h)	ml. water per dish 4 — Per cent germination	ml. water per dish 6 — Per cent germination
1	Natural	0	33	4
1	,,	24	95	62
2	,,	0	30	15
2	,,	24	97	77
2	Rubbed	0	32	0
2	,,	24	73	39

Fifty actual seeds in 9 cm diameter Petri dish on three Whatman No. 1 filter papers. Six replications. 20° C.

Table 2. EFFECT OF HYDROGEN PEROXIDE ON GERMINATION OF *Beta vulgaris* L. (DETROIT) SEEDS

Hydrogen peroxide in germination water	Per cent germination: Natural seeds	Per cent germination: Rubbed seeds	Mean
0	61	39	50
2%	86	77	82†
Mean	74*	58	

* $P = 0·01$.
† $P = 0·001$.
Fifty actual seeds were placed in a 9 cm diameter Petri dish on top of three Whatman No. 1 filter papers with 3 ml. water for natural and 6 ml. for rubbed clusters, quantities excessive for satisfactory germination of the respective type of cluster. 20° C.