Environmental pollutants and shell thinning in eggs of the Guillemot *Uria aalge* from the Baltic Sea and the Faeroes, and a possible relation between shell thickness and sea water salinity

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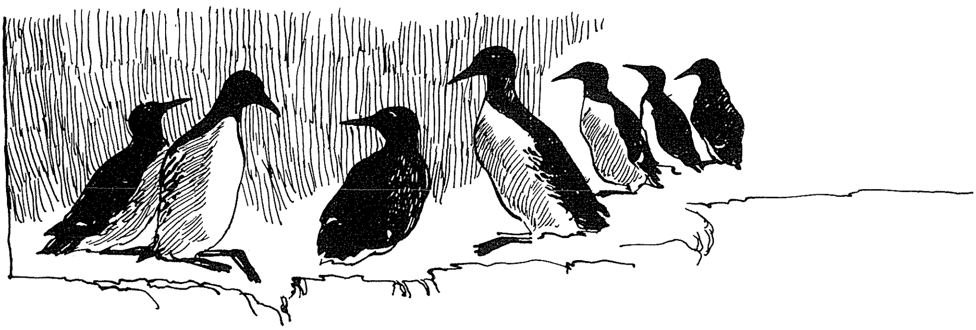
(Med et dansk resumé: Miljøgifte i og skalfortynding af Lomvieæg fra Græsholmen og Færøerne, samt en mulig sammenhæng mellem skaltykkelse og havvandets salinitiet)

Fredningsstyrelsens forskningsrapport nr. 25 fra naturreservaterne



INTRODUCTION

The heavy pollution of the Baltic Sea and the attempts in recent years to reduce this pollution emphasizes the need to monitor annual concentrations of pollutants in some organisms on high trophic levels in the food chains.

The Guillemot *Uria aalge,* which lives mainly on small fish, is placed relatively high in the marine food chains and is, therefore, well suited for monitoring environmental pollutants. This abundant and widely distributed species occurs in both the Atlantic and Pacific Oceans, which makes comparisons of pollutant levels in different regions possible.

The population inhabiting the Baltic Sea is morphologically distinct (Wijs 1978). The only Danish breeding colony is on Græsholmen, an islet situated close to Christiansø, an island in the southwestern Baltic Sea. This paper describes the measurements of pollutants in eggs collected annually in this colony from 1971 to 1976 and compares them with the contents of eggs from a colony in the Faeroes in the open Atlantic Ocean.

Data on eggshell thickness are also presented and compared to pollutant levels. In order to elucidate some unexpected correlations which appeared in the course of the study, it became necessary to investigate also for possible effects of water temperature and salinity on eggshell thickness.

MATERIALS AND METHODS

10-12 eggs were collected annually on Græsholmen in late May or the first half of June.

In the large colony on Skúvoy in the Faeroes, thousands of eggs used to be taken each year by fowlers. In 1972, 20 such eggs were taken for analysis during the census of the Faeroese Guillemot population (Dyck & Meltofte 1975).

Chemical analyses were performed on the homogenized contents of the eggs after the embryos, if present, had been removed (very small embryos were not removed).

The content of the persistent organochlorinated compound DDT and its fat soluble metabolites DDE and DDD, as well as PCBs, was determined by gas chromatography as described by Kraul & Karlog (1976).

Total mercury was determined by a modification of Skare's (1972) method. The basis for this method is digestion of the tissue with concentrated sulphuric acid at 60° C in the presence of potassium permanganate. The excess permanganate is reduced by hydroxylammonium chloride. Finally, the mercury is reduced to metallic mercury with stannous chloride and the vapours are pumped through an absorption cell in a flameless atomic absorption spectrophotometer (Coleman Model MAS-50 Mercury Analyzer).

The analyses of methylmercury were carried out with gas chromatographic detection using a Varian 1400 fitted with a ^{63}Ni-ec-detector and an all-glass column (6' × ⅛") packed with 10% Carbowax 20 M on Chromosorb W (aw, DMCS, 60/80 Mesh) (Newsome 1971).

After the eggshells had been rinsed and dried, the shell indices were determined according to Ratcliffe (1967). Determinations of the shell indices of older eggs were performed on eggs in the collections of the Zoological Museum in Copenhagen.

RESULTS

Residues of DDE and PCBs are comparable in the Baltic eggs; the yearly means vary respectively between about 350 and 600 ppm and about 400 and 600 ppm (Tab. 1). In contrast, the Atlantic eggs show DDE residues which are approximately 100 times lower and PCB residues which are approximately 50 times lower (Tab. 1). Dieldrine levels in the Baltic eggs are approximately 200 times lower than DDE levels.

Both DDE and PCB show the highest levels in 1972, while dieldrine shows the highest level in 1971 (but the level was not determined in 1973). Highest and lowest residues in single eggs were: DDE (Baltic) 835 and 252 ppm, DDE (Faeroes) 9.6 and 3.7 ppm, Dieldrine (Baltic) 6.6 and 1.6 ppm, PCB (Baltic) 810 and 290 ppm and PCB (Faeroes) 28 and 5.9 ppm.

The yearly means of methylmercury in the Baltic eggs vary between 0.21 and 0.32 ppm and those of total mercury between 0.25 and 0.37 ppm, with highest levels in 1971 and 1974 (Tab. 2). The Atlantic values are about two-thirds of this level (Tab. 2). Highest and lowest residues in single eggs were: methylmercury (Baltic) 0.43 and 0.17 ppm, (Faeroes) 0.28 and 0.12 ppm, total mercury (Baltic) 0.47 and 0.22 ppm and (Faeroes) 0.28 and 0.11 ppm.

A linear regression analysis suggests a decrease in the DDE content of the Baltic eggs during the six-year period (42 ppm DDE decrease per year; $0.02 < p < 0.05$; two-tailed). The annual means of dieldrine and mercury do not suggest any upward or downward trend during the period.

When compared with the indices of eggs collected prior to the introduction of DDT, the shell indices of Baltic eggs collected in 1971, 1972 and 1974 are significantly lower, while eggs collected in 1976 show no difference (Tab. 3). The largest reduction in shell index is shown by the 1971 sample: 12%. No change was found in the shell indices of the recently collected Atlantic eggs (Tab. 3).

Shell thickness and shell index of the Baltic eggs from 1971-1976 are positively correlated ($p < 0.0005$). The slope of the regression line indicates that a 10% reduction in shell index corresponds to a 9.2% reduction in shell thickness. The other eggs were not tested for the presence of this relationship.

To study the relationships between the shell index of Baltic eggs and pollutants, partial correlation coefficients of the second order were determined for DDE, PCB and methylmercury. Before computation, 0.17 ppm was subtracted from the methylmercury content. This figure is considered to be 'the natural methylmercury content of unpolluted Guillemot eggs' on the basis that 0.17 is both the mean content of the Atlantic eggs (Tab. 2) and the lowest content recorded in a Baltic egg. Formula 18.14

Tab. 1. Residues of dieldrine, DDE and PCB in Guillemot eggs from the southern Baltic Sea and the Faeroes. Concentrations in μg/g fat (mean ± S. D.). n.a. = not analyzed.
Dieldrin, DDE og PCB i Lomvieæg fra Græsholmen og Færøerne. Koncentrationer i μg miljøgift/g fedt (middel ± stand. afv.). n.a. = ikke analyseret for dette stof.

Locality *Lokalitet*	Year *År*	No. of eggs *Antal æg*	Dieldrine	DDE	PCB	Fat (%) *Fedt*
Faeroes	1972	15	n.a.	6.4 ± 1.6	11.9 ± 5.8	17.6 ± 4.3
Græsholmen	1971	9	3.4 ± 1.9	548 ± 113	523 ± 143	15.9 ± 3.5
Græsholmen	1972	12	1.7 ± 2.4	586 ± 166	580 ± 154	15.9 ± 5.5
Græsholmen	1973	9	n.a.	409 ± 67	424 ± 72	13.7 ± 2.0
Græsholmen	1974	12	2.0 ± 2.1	399 ± 87	486 ± 106	15.7 ± 2.7
Græsholmen	1975	8	1.0 ± 1.2	358 ± 91	429 ± 73	21.2 ± 8.1
Græsholmen	1976	10	2.4 ± 1.6	393 ± 68	408 ± 67	13.1 ± 1.5
Græsholmen	1971-1976	60[1]	2.1 ± 2.0	454 ± 135	480 ± 124	15.8 ± 4.8

1) Only 51 eggs were analyzed for dieldrine.

Tab. 2. Residues of methylmercury and total mercury in Guillemot eggs from the southern Baltic Sea and the Faeroes. Concentrations in μg/g wet weight (mean ± S.D.).
Methylkviksølv og kviksølv totalt i Lomvieæg fra Græsholmen og Færøerne. Koncentrationer i μg miljøgift/g våd vægt (middel ± stand. afv.).

Locality *Lokalitet*	Year *År*	No. of eggs *Antal æg*	Methylmercury *Metylkviksølv*	Total mercury *Kviksølv totalt*
Faeroes	1972	5	0.17 ± 0.07	0.20 ± 0.08
Græsholmen	1971	7	0.31 ± 0.07	0.37 ± 0.08
Græsholmen	1972	9	0.29 ± 0.05	0.32 ± 0.05
Græsholmen	1973	9	0.21 ± 0.03	0.25 ± 0.02
Græsholmen	1974	12	0.32 ± 0.06	0.34 ± 0.06
Græsholmen	1975	6	0.24 ± 0.05	0.30 ± 0.07
Græsholmen	1976	10	0.25 ± 0.05	0.31 ± 0.05
Græsholmen	1971-1976	53	0.27 ± 0.06	0.31 ± 0.06

Tab. 3. Shell indices (mg/mm^2) of Guillemot eggs from the southern Baltic Sea and the Faeroes (mean ± S. D.).
Skalindeks (et mål for æggeskallens gennemsnitlige tykkelse, enhed: mg/mm^2) i Lomvieæg fra Græsholmen og Færøerne (middel ± stand. afv.).

Locality *Lokalitet*	Year *År*	Number of eggs *Antal æg*	Shell index *Skalindex*
Faeroes	1857-1946	20	2.96 ± 0.33
Faeroes	1972	15	2.95 ± 0.28
Græsholmen	1934-1942	15	2.90 ± 0.24
Græsholmen	1971	9	2.55 ± 0.22**
Græsholmen	1972	10	2.69 ± 0.21**
Græsholmen	1973	9	2.77 ± 0.23
Græsholmen	1974	12	2.69 ± 0.27*
Græsholmen	1975	8	2.79 ± 0.15
Græsholmen	1976	10	2.92 ± 0.25
Græsholmen	1971-1976	58	2.73 ± 0.25

Significance of change since 1934-42: * $p < 0.05$, ** $p < 0.01$
(Mann-Whitney U-test)

in Hald (1971) was used, and the following values obtained (shell index = SI, methylmercury = MeHg):

$r_{SI,DDE}$= -0.02 (PCB and MeHg constant)
$r_{SI,PCB}$= -0.14 (DDE and MeHg constant)
$r_{SI,MeHg}$= -0.35 (DDE and PCB constant)

N= 52

Of these three values only the partial correlation coefficient with respect to methylmercury is statistically significant (0.01 ⟨p ⟨0.02; two-tailed).

Surface sea water temperatures at Græsholmen on 1 May, the approximate time of egglaying of the Guillemot, were 3.2, 4.0, 5.2, 5.4, 5.7 and 3.1° C in the years 1971-1976, respectively (oceanographical observations from Danish lightships and coastal stations; Det danske meteorologiske institut). Comparisons with Tabs. 2 and 3 suggest no correlations between sea water temperature and methylmercury concentration or the shell index.

Surface sea water salinities at Græsholmen on 1 May (mean of the period 21 April - 10 May) were 7.6, 7.75, 7.85, 7.9, 8.3, 8.25‰ NaCl in the years 1971-1976 (oceanographical observations from Danish lightships and coastal stations; Det danske meteorologiske institut). The presence of correlations was tested using the shell index and methylmercury concentrations (- 0.17 ppm) of the same 52 eggs from which the partial correlation coefficients of the second order were determined. The following regression equations were obtained:

$MeHg - 0.17 = - 0.124 \times sal + 1.096$ ppm
($r = -0.40$; $df = 50$; $p < 0.01$, two-tailed)
$SI = 0.356 \times sal - 0.084$ mg/mm^2
($r = 0.34$; $df = 50$; $p < 0.02$, two-tailed)

Thus, both the methylmercury concentrations and the shell index are correlated with sea water salinity (Figs. 1, 2) in such a way as to partly explain the observed correlation between methylmercury and the shell index. According to the regression equations, a salinity of 7.6‰ corresponds to a MeHg conc. of 0.32 ppm and a shell index of 2.62 mg/mm^2, and a salinity of 8.3‰ corresponds to a MeHg conc. of 0.235 ppm and a shell index of 2.87 mg/mm^2.

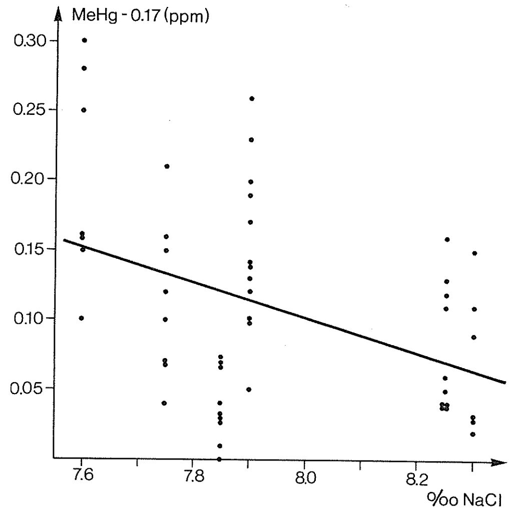


Fig. 1. Residues of methylmercury (MeHg) in Baltic Guillemot eggs against sea water salinity at the time of egglaying. The regression line is shown. From the methylmercury concentrations have been subtracted 0.17 ppm (compare text).
Methylkviksølvkoncentrationerne (MeHg) af Lomvieæg fra Græsholmen afsat som funktion af overfladevandets salinitet på æglægningstidspunktet. Regressionslinien er vist. Fra de målte methylkviksølvkoncentrationer er trukket 0,17 ppm, der antages at repræsentere »normalkoncentrationen i et ikke-forurenet Lomvieæg«.

DISCUSSION

Pollutant levels

Tab. 4 shows that the levels of DDE are much higher in eggs from the Baltic Sea and from a Californian locality than in eggs from localities in the Atlantic Ocean and the North Sea. PCB levels are also elevated in eggs from the Irish Sea. The mercury level in eggs from northern Norway is particularly low, while it appears higher at Stora Karlsö than at Græsholmen. This finding is supported by feather data (Jensen et al. 1972b, Somer et al. 1974).

Razorbill *Alca torda* eggs from Stora Karlsö, 1970, contained about 700 ppm of both DDE and PCB. Eggs from the Archipelago of Stockholm, 1970 and 1972, contained about 600 ppm of both substances (Andersson et al. 1974), while the levels were much higher in 1971 (1600 ppm DDE and 1300 ppm PCB). Mercury levels were considerably higher than those in Guillemot eggs (3.5-6 ppm dry weight, roughly corresponding to 1-1.5 ppm wet weight). As with Guillemot eggs, Razorbill eggs from northern Norway show very low mercury

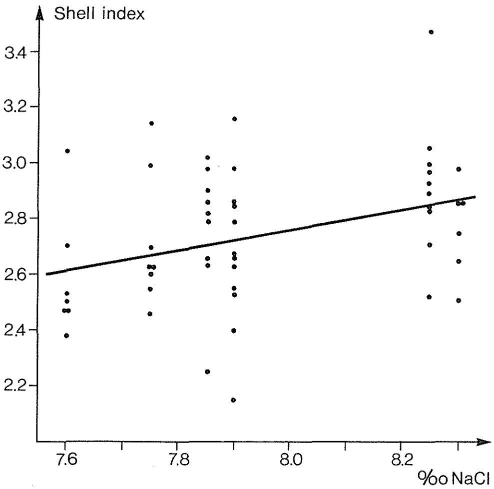


Fig. 2. Shell index (mg/mm²) of Baltic Guillemot eggs against sea water salinity at the time of egglaying. The regression line is shown.
Skalindeks (mg/mm²) af Lomvieæg fra Græsholmen afsat som funktion af overfladevandets salinitet på æglægningstidspunktet. Regressionslinien er vist.

residues (⟨0.10 ppm wet weight) (Fimreite et al. 1974).

A Puffin *Fratercula arctica* egg from the Faeroes (1972) contained 0.13 ppm dieldrin, 5.5 ppm DDE, 10 ppm PCB, 0.47 ppm methylmercury and 0.45 ppm total-mercury. Thus, it had the same level of DDE and PCB as had the Guillemot eggs from the same locality, but the mercury levels were nearly three times as high. Similar mercury levels have been reported in Puffin eggs from St. Kilda (Parslow et al. 1972).

The ratio of total mercury in eggs to total mercury in feathers can be determined for three localities from data given by Jensen et al. (1972b), Somer et al. (1974) and from our study. Feather data from the breeding season of a certain year must be compared with egg data from the previous year, because new feathers are grown during the autumn. The ratios for Græsholmen (1972/73), Stora Karlsö (68/69) and the Faeroes (72/73) are 0.12, 0.093 and 0.18, respectively.

Changes in pollutant levels

The DDE level in Græsholmen eggs peaked in 1972 and strongly declined between 1972 and 1973 (30% relative to the 1972 figure). In Herring Gull *Larus argentatus* eggs from Græsholmen, DDE-concentrations decreased 45% from 1972 to 1973 (Jørgensen & Kraul 1974).

The changes in PCB levels in Græsholmen eggs over the six years resemble those of the DDE levels, except that the PCB level shows a secondary maximum in 1974 (Tab. 1). In Herring Gull eggs from Græsholmen, PCB concentrations decreased 40% from 1972 to 1973 (Jørgensen & Kraul 1974).

Newton & Bogan (1978) have shown that concentrations of DDE and PCB in the yolk of Sparrowhawk *Accipiter nisus* eggs increase when the embryo grows. Whether or not year-to-year variation may be related to variations in the time of egg collection must therefore be considered. In 1972 and 1976 the majority of the eggs analyzed contained either no visible embryo or a very small one, while in the other four years the majority contained well-developed embryos. If yolk concentrations also increase with embryo size in the Guillemot, relatively low DDE and PCB concentrations would be expected in 1972 and 1976. This effect is definitely not observed (Tab. 1) and therefore, the possibility that variations from year-to-year in the collection of eggs has contributed in an important way to the year-to-year variations in DDE and PCB contents is unlikely.

Pollutants in the food of the Guillemot

The food of the Guillemots breeding on Stora Karlsö consists mainly of sprat *Clupea sprattus* (Hedgren 1976). The mean concentration in fifteen sprats collected in the Christiansø area from 1969 to 1971 was 1.2 ppm DDT compounds (18% DDE, 23% DDD, 59% DDT) and 1.2 ppm PCB compounds (concentration in lateral musculature, ppm fresh tissue) (Jensen et al. 1972a). The 1:1 ratio between the DDT- and the PCB compounds in the fish corresponds well to the ratio present in the Guillemot eggs (Tab. 1), but here only DDE is present.

Year-to-year variation in pollutant concentrations could only be studied in the related herring which in this part of the Baltic Sea contains these compounds in concentrations similar to those found in the sprat, with the exception of proportionately more DDT compounds, especially DDE (Jensen et al. 1972a). However, no correlation was found between concentrations of PCB and DDT in herrings caught in spring in the southern Baltic Sea (data from K. Voldum-Clausen) and concentrations in Guillemot eggs during the six-year period.

Shell thinning and pollutants

DDE is generally acknowledged to be the main factor responsible for shell thinning (Cooke 1973). The present finding that the shell index is negatively correlated with methylmercury but not with DDE is noteworthy. However, DDE probably does influence shell thickness in the Guillemot because a reduction in shell index of about 12% and a DDE -concentration of about 300 ppm (fat) were found in eggs from the Farallon Islands (Gress et al. 1971). These authors give no data for mercury content, but since these islands are situated in the open Pacific Ocean 40 km west of San Francisco, these eggs are unlikely to contain mercury in concentrations comparable to those of the Baltic Sea eggs.

No reduction in shell index was found in Guillemot eggs from Great Britain (Ratcliffe 1970); a finding which fits with rather low DDE concentrations (Tab. 4). In western Norway a negative correlation between shell thickness and DDE concentration was found only in one colony. However, DDE levels were low (Tab. 4) and no correlation was found in the three other colonies studied, although the DDE levels were higher here. Therefore Fimreite et al. (1977) considered the single correlation as artificial. In two of the four colonies, shells were about 20% thinner than in the other two.

A lack of correlation between shell thinning (12%) and DDE concentrations has also been found for Razorbills which breed in the Baltic Sea (Andersson et al. 1974).

In gulls and terns only some studies suggest a negative correlation between shell thinning and DDE-content. Thus, no correlation was found in a Canadian colony of the Common Tern *Sterna hirundo* where the eggs on the average contained about 50 ppm DDE (fat) (Switzer et al. 1971), but in another study of the same species in the same region, Fox (1976) found a highly significant negative correlation (egg concentrations about 30 ppm DDE (fat)). In the Herring Gull in North America a negative correlation was found in one study, where DDE concentrations were about 1000 ppm (fat), but there were none in two other studies where egg concentrations were about 30 and 2,500 ppm, respectively (review in Anderson & Hickey 1972). Studying intercolony instead of interclutch variation two North American studies (Hickey & Anderson 1968, Gilbertson 1974) revealed significant correlations.

In the Herring Gull population of Græsholmen, Jørgensen & Kraul (1974) found a significant negative correlation between shell thickness and DDE concentration in one year, while in the previous year no such correlation was found, the figures in fact suggesting a positive correlation.

Of nine Norwegian Herring Gull colonies with DDE concentrations of approximately 10 ppm, seven suggested negative correlations between DDE concentration and shell thickness, but only one of these correlations was significant ($p < 0.01$). Two colonies suggested a positive correlation (one with $p < 0.05$). In neither this study (Fimreite et al. 1977) nor an earlier one (Bjerk & Holt 1971) was a significant correlation established between DDE concentration and shell thickness on an intercolony basis.

Clearly, a confusing picture emerges of the relationships between the degree of eggshell thinning and DDE concentrations in some charadriiform species. Undoubtedly one of the complicating factors is that DDE may influence shell quality in multiple ways. Fox (1976) compared shells of Common Tern eggs in which the embryo died with shells of eggs from which chicks hatched. He found a number of abnormalities in the former group: mammiliae fewer and of more variable size and shape; pores fewer; and palisade disorganized, sometimes with cavities and globular projections on the outer surface. These shells contained three to four times more phosphorus than normal. Interestingly enough the eggs with dead embryos showed no reduction in shell thickness index compared to pre-1945 eggs, while the overall material showed a 4% reduction, and dented eggs a 13.5% reduction. Five dented eggs contained about 40 ppm DDE (fat), while a random egg sample from the colony had a geometric mean of about 10 ppm DDE (fat). Fox concludes for the Common Tern that organochlorines, particularly DDE, can affect eggshells in several ways to induce embryonic mortality independent of shell thinning. Furthermore, these mechanisms operate at residue levels lower than those associated with marked shell thinning and are probably far more effective in reducing hatching success.

The Græsholmen Guillemot eggshells have not been studied with respect to the possible presence of structural abnormalities. Scanning electron microscopy of Græsholmen Herring Gull eggshells revealed thinning of the spongy layer and in the thinnest and thickest eggs studied, minor defects in the mammillary layer (Jørgensen & Kraul 1974).

The correlation of thin eggshells (low eggshell indices) with high methylmercury residues has not been previously reported in field studies. Fimreite et al. (1970) found no correlation between elevated levels of mercury (probably predominantly present as methylmercury) and eggshell thinning in the Prairie Falcon *Falco mexicanus,* while Blus et al. (1971) found a positive correlation between eggshell thickness and mercury content in the Brown Pelican *Pelecanus occidentalis.* In an experimental study, Peakall & Lincer (1972)

Tab. 4. Residues of environmental pollutants in Guillemot eggs from various parts of the world. Concentration units as in Tabs. 1 and 2. Sources: a: Jensen et al. (1972b), b: This paper, c: Parslow & Jefferies (1975), d: Fimreite et al. (1974), e: Fimreite et al. (1977), f: Pearce et al. (1979), g: Gress et al. (1971).
Miljøgifte i Lomvieæg fra forskellige geografiske områder. Koncentrationer som i Tab. 1 og 2. Kilder: se den engelske tekst.

Locality *Lokalitet*	Year(s) *År*	Dieldrine	DDE	PCB	MeHg	Hg
Baltic Sea: Stora Karlsö	1968-69a	?	590	225	?	0.52
Baltic Sea: Græsholmen	1971-76b	2.1	450	480	0.27	0.31
England: East coast	up to 1974c	?	9.8	36-56	?	?
England: South-west	up to 1974c	?	12-24	61-170	?	?
Irish Sea	up to 1974c	?	21-29	130-220	?	?
Eire: West coast	up to 1974c	?	8.3	39	?	?
Scotland: (incl. St. Kilda)	up to 1974c	?	6.3	16	?	?
Shetland	up to 1974c	?	7.0	14	?	?
Faeroes	up to 1974c	?	6.5	15	?	?
Faeroes	1972b	?	6.4	12	0.17	0.20
N. Norway	1972d, e	?	4.7-6.7	13-20	0.07	0.07
S. Norway	1972e	?	3.2	9.1	0.07	0.07
Canada: Quebec	1971f	0.12	12	13	?	0.12
California: Farallon Islands	1968g	0.02	300	170	?	?

found no effect of methylmercury on eggshell thickness in the Ring Dove *Streptopelia risoria* and the American Kestrel *Falco sparverius.*

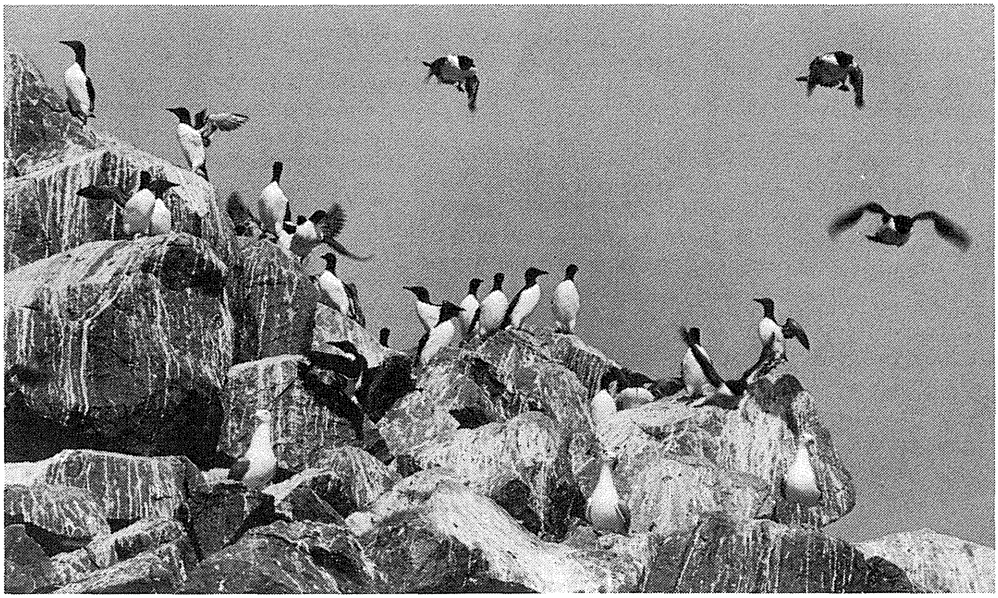
Some feeding experiments of galliform species have yielded reduced breaking strength or thickness of eggshells. However, the doses of MeHg compounds used (mostly 10 and 20 ppm) were of a magnitude which resulted either in mercury concentrations in the eggs higher than those of the Guillemot eggs (Scott et al. 1975) or would have resulted in no egg production and high mortality of the birds had not selenium been added to the food simultaneously with the MeHg (Stoewsand et al. 1977, 1978). These findings are, therefore, probably not relevant to the present study. In conclusion no evidence was found that concentrations of methylmercury in eggs similar to those reported in Baltic Sea Guillemot eggs cause eggshell thinning.

On this basis, the recent thinning of the Græsholmen Guillemot eggshells is probably not caused by elevated residues of methylmercury in the female parent birds, although a species difference cannot be ruled out. Bjerk & Holt (1971) suggested that differences in the mean temperatures during the breeding season of the Herring Gull, rather than effects from total content of DDE and PCB in the eggs, are responsible for the differences in shell thickness between colonies. The present investigation, however, finds no correlation between the shell index and surface sea water temperature at the time of egglaying.

However, both methylmercury and the shell index appear to be correlated with sea water salinity. The possibility arises that the correlation between methylmercury and the shell index is not causal but due to a respective causal correlation with sea water salinity. This possibility will now be discussed.

Sea water salinity and methylmercury

Jensen (1937) found that the annual mean of



Pesticide levels are high in Guillemots breeding at Græsholmen; but the relationship between pesticide load and egg shell thinning is complex. Photo: Erik Thomsen.
Græsholmens Lomvier har et højt indhold af miljøgifte, men belastningen lader sig ikke uden videre aflæse af skalfortyndingen hos æggene.

surface salinity at Christiansø (Græsholmen) over a fifteen year period was negatively correlated with the sum of precipitation over the Baltic plus the quantity of water originating from the surrounding terrestrial areas minus the amount of water evaporating from the Baltic. The numerically largest correlation was found when the latter sum was taken over a year which started 6 or 9 months earlier than the year over which mean salinity was calculated. Similarly, Wyrtki (1954) found that salinity at the Finnish coast (Helsinki and Utö) taken as five-year overlapping means was negatively correlated with precipitation and flow from a river. Studies have established (especially from Sweden; e.g. Johnels et al. 1967) that rivers leading into Baltic Sea are polluted with mercury. Somer (1977) estimated the annual inputs in tons of mercury to the Baltic Sea as: domestic sewage, 4; industrial waste, 20; river water, 6 and precipitation, 4. Therefore, some evidence exists that high annual precipitation both washes relatively large amounts of mercury into the Baltic Sea, and results in lowered salinity.

Somer (1977) is, however, of the opinion that practically all the mercury which has been discharged over the years into the Baltic Sea is found in the sediments of coastal discharge areas. Thus, according to Somer's viewpoint, the year-to-year variations in the input of mercury to the Baltic Sea are not reflected in variations in the mercury concentrations of sea water and pelagic organisms.

Changes in the mercury concentration of the sea water will probably be reflected in corresponding changes in the mercury body burden of Guillemots. Hannerz (1968) found that the accumulation of mercury by various fish species is fast (significant uptake occurs during the first 30 days), and mainly directly from the water through the outer epithelia.

Rather rapid uptake of mercury through food by birds is indicated by experiments by Borg et al. (1970) and Fimreite & Karstad (1971). Birds of prey fed mercury-contaminated food died within one to two months. Thus, changes in the mercury concentration of sea water may be reflected in corresponding changes in the mercury body burdens of Guillemots with a delay of, at most, two to three months.

Sea water salinity and shell thinning

A possible link between eggshell thickness and sea water salinity may be mediated through the salt gland. This gland can excrete surplus salt, and some evidence exists that the enzyme carboanhydrase, which occurs in large amounts in this gland, plays an important role in its function (Peaker & Linzell 1975).

The proposed scheme is that carboanhydrase catalyzes the formation of H_2CO_3 from metabolic CO_2. The H_2CO_3 in turn dissociates to protons and bicarbonate ions which are exchanged with sodium and chloride ions across the basal membrane (Peaker & Linzell 1975, p. 95).

In the shell gland carboanhydrase is also assumed to catalyse the formation of H_2CO_3 from CO_2 produced by the metabolism of the cells (Dacke 1979). In turn, H_2CO_3 dissociates to protons and carbonate ions, and the latter, with calcium ions, produce the calcium carbonate of the eggshell (Simkiss and Taylor 1971). One of the possible mechanisms whereby DDE causes eggshell thinning is by lowering the activity of carboanhydrase (Cooke 1973).

Thus, carboanhydrase apparently functions in an analoguous manner in both the shell and salt glands. This is further supported by the observation that the carboanhydrase inhibitor acetazolamide reduces both eggshell calcification (Dacke 1979) and salt gland secretion (Peaker & Linzell 1975).

The regulation of carboanhydrase concentrations of these two glands is still unknown. However, assuming that one or more regulatory factors affect the carboanhydrase concentration in the two glands in the same direction and that regulation is principally a response to salt intake, then eggshells are understandably thicker when sea water salinity is relatively high.

According to Dacke (1979), carboanhydrase appears to be involved in the action of the parathyroid hormone in organs such as bone and kidney and he suggests that the hormone also influences the enzyme in the avian oviduct. The possible influence of the parathyroid hormone on the shell gland is unknown (Peaker & Linzell 1975).

Additional support for a positive correlation between eggshell thickness and salt gland activity may be deduced from previous studies: In one of these studies, Anderson, Lumsden & Hickey (1970) found that the eggshells of the Great Northern Diver *Gavia immer* are thinner in inland populations than in coastal populations. Coastal breeding populations of this species feed partially at sea (Salomonsen 1967), and likely have a large intake of salt. The current evidence indicates that the divers are closely related to the charadriiformes (Boertmann 1980, Sibley & Ahlquist 1972). Divers possess a salt gland, some aspects of which are similar to those of alcids (Technau 1936).

In a second study Fimreite et al. (1977) measured eggshell thickness in nine Norwegian coastal Herring Gull colonies. Of these colonies the locality at Røst yielded the thickest eggshells. This locality also has the most oceanic position of the colonies studied. The Guillemot data of the same study do not fit with the hypothesis since Røst yielded the thinnest eggshells of the four Norwegian colonies studied. However, a possible correlation between eggshell thickness and breeding substrate has been suggested in a study of the related Brünnich's Guillemot *Uria lomvia*. Average eggshell thickness in a colony at the Murman coast was only 0.30 mm but 0.50 mm on Novaya Zemlya. This difference may be associated with the presence of sharp-edged slate on the breeding ledges of Novaya Zemlya, while at the Murman coast the eggs were laid on more level granite terraces (Belopolskii 1961).

Finally, Friend et al. (1973) found that DDE given in the diet reduced the rate of excretion of sodium chloride in Mallards *Anas platyrhynchos*. This reduction, however, was observed only in birds maintained on fresh water, not on birds maintained on one percent salt water.

A link between the activities of the shell and the salt gland has been suggested earlier (Risebrough et al. 1970, Cooke 1973). These early studies found that increased dietary chloride reduced chicken shell thickness, implying a correlation between salt and shell gland activity which is opposite of that suggested here for charadriiform species.

Other mechanisms for the formation of thin-shelled eggs have been suggested (Cooke 1973), and some of them, e.g. the inhibition of Ca-ATPase by DDE, are supported by experiments (Miller et al. 1976). At present the above suggestions of a connection between salt and shell gland activities are rather speculative. However, these speculations appear justified by the unexpected finding of a possible correlation between eggshell thickness and sea water salinity.

The possibility that the shell index is dependent on sea water salinity raises the question of whether the shells of post-1947 eggs are thinner than those of pre-1947 eggs only because the salinity has changed. Pre-1947 eggshells are from 1934, 1938 and 1942, years in which mean sea water salinities were low, viz. 7.14, 6.99 and 6.915‰, respectively (Nautical-Meteorological Annual; Det danske meteorologiske institut). Using the equation of the regression line depicting the correlation between shell index and salinity (p. 4), the shell indices for these three years are calculated to 2.43, 2.37 and 2.34 mg/mm^2 (weighted mean 2.375 mg/mm^2). Since the actual shell indices averaged 2.90 mg/mm^2, the recent shell thinning can be calculated to 18%.

Without correcting for salinity, the most pronounced shell thinning was observed in the eggs from 1971: 12% (p. 2). Gress et al. (1971) found a 12% reduction in shell index for eggs containing about 300 ppm DDE (fat). This value fits well with an 18% reduction for Græsholmen eggs, the DDE content of which averaged 454 ppm in the period 1971-76 (Tab. 1). If no correction for changing salinity is carried out, the unsatisfactory finding remains that Græsholmen eggs show less reduction of shell index, but higher DDE concentrations, than eggs from the Farallon Islands.

A reliable estimate of a possible correlation between the shell index and salinity could not be made for the pre-1947 eggs because of insufficient material.

Conclusion regarding shell thinning and pollutants

The presence of DDE in Guillemot eggs from the Baltic Sea causes low eggshell indices. Any possible correlation between DDE concentrations and the shell index is masked because of two factors: (1) the shell index is positively correlated with the sea water salinity and (2) the sea water salinity varies between the years. For climatic reasons relatively high methylmercury egg concentrations are correlated with low sea water salinities. In this way a noncausal correlation is formed between low shell indices and high methylmercury concentrations.

The point must be made, that the equation of the regression line depicting the correlation between the shell index and salinity assumes that DDE concentrations in eggs have been constant during the six years. They have not in fact been so, but the variation from year to year has been relatively smaller than the year-to-year variation in shell thinning (compare Tabs. 1 and 3). Therefore, as a first approximation, variation in DDE concentration may be neglected.

Clearly, additional data are needed to confirm or reject the preliminary conclusion, and if it is confirmed, to separate the effects of DDE concentration and sea water salinity on the shell index. Towards this end three years of additional data have been collected since this phase of the study. Shell indices have been determined for eggs collected in 1977, 1978 and 1979. Salinities during the three years were 7.85, 8.15 and 8.43‰ NaCl, respectively. Using the equation on p. 4, the mean shell index for the three years was calculated to, respectively, 2.71, 2.82 and 2.92 mg/mm^2. These values fit reasonably well with those measured: 2.83, 2.80 and 2.91 mg/mm^2.

Other effects of pollutants

Jefferies & Parslow (1976) found thyroid changes in Guillemots fed PCB for 45 days and suggested that PCB directly effects the pituitary. They suggest that sublethal effects result when the pituitary produces less thyrotropin and, possibly, also less of other hormones. They further suggest that the concentrations of PCBs present in some free-living Guillemots and other seabirds are of such a magnitude as to produce similar effects.

However, even the lowest dose rate used by Jefferies & Parslow (12 mg kg^{-1} day^{-1}) is considerably higher than that which can be estimated for Græsholmen Guillemots (0.4 mg kg^{-1} day^{-1}, assuming a daily food intake of 250 g (Parslow & Jefferies 1973, Swennen 1977), a PCB concentration of 1.2 ppm in the food and 750 g as the weight of the birds (Parslow & Jefferies 1973)). The lower intake of Græsholmen Guillemots may, however, be counteracted by a longer period of intake. The role of this factor can be estimated by a feeding experiment on Herring Gulls (Anderson & Hickey 1976), where caged juveniles were fed fish containing 1-2 ppm PCB. In the course of approximately one year, the birds eventually reached an equilibrium body burden of about 100 mg PCB/kg. Their data indicate that after the first 45 days, the body burden was about 10% of the body burden when equilibrium level had been attained.

Assuming that the Guillemot resembles the Herring Gull in the accumulation of PCB, the Græsholmen Guillemots may contain a body burden similar to what they would have obtained if fed $0.4 \times 10 = 4$ mg PCB kg^{-1} day^{-1} for a 45 day period.

This intake is one third of the lowest dose

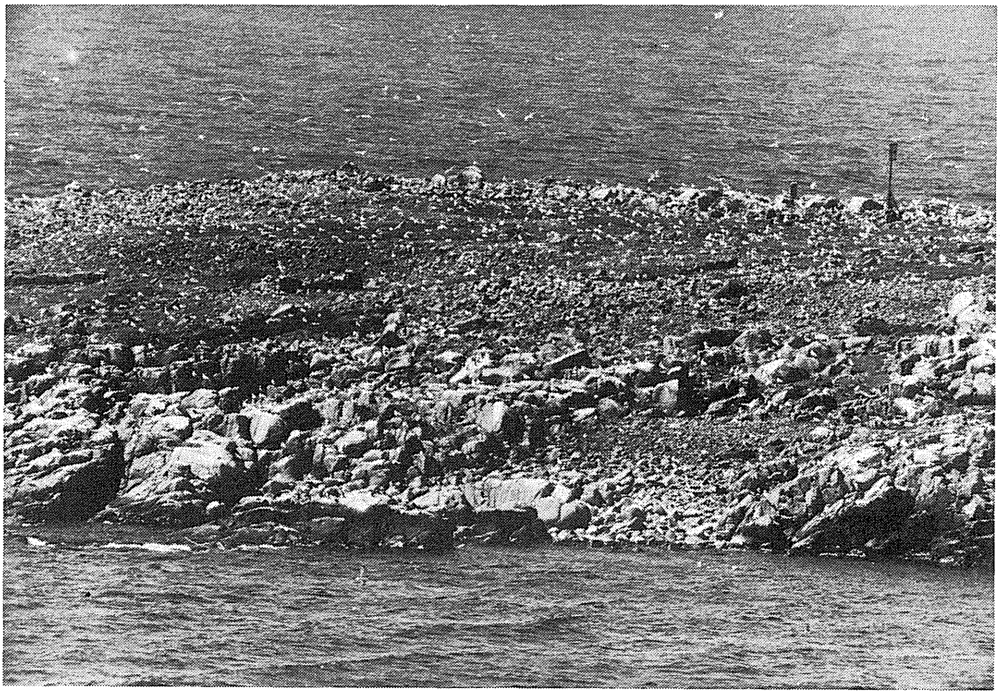


Fig. 3. The islet Græsholmen in the southern Baltic Sea is the only Danish breeding locality for the Guillemot and the Razorbill. The Herring Gull is a very numerous breeding bird on the islet. 2 June 1974.
Photo: P. Hald-Mortensen.
Græsholmen, den eneste danske yngleplads for Lomvie og Alk. Sølvmågen er en meget talrig ynglefugl på øen. 2. juni 1974.

rate used by Jefferies & Parslow (1976) and strengthens the possibility that effects similar to those of the experiment may also manifest themselves among Græsholmen Guillemots.

Fox et al. (1978) found, for Herring Gulls nesting in Lake Ontario, behavioural abnormalities, which probably were due to pollutant-induced endocrine dysfuntion. PCB concentrations in the eggs were two to three times higher than in the Græsholmen eggs (Gilman et al. 1977).

Finally, methylmercury concentrations of the Baltic Sea eggs are unlikely to be so high that hatchability was reduced. This conclusion is based on the work of Fimreite (1974), who found that Common Tern eggs with, on average, 0.8 ppm methylmercury apparently hatched successfully.

Population trends

Population data for the Græsholmen colony are meagre and difficult to obtain, largely due to the thousands of breeding Herring Gulls (Fig. 3) which take quick advantage of human disturbance to rob Guillemot eggs and chicks. Population size has not been accurately determined but appears to have been stable with about 1,000 pairs over the years 1971-76 (N. E. Franzmann, P. Hald-Mortensen and K. Paludan, pers. comm.). The population seems to have increased somewhat since the 1950s. Among breeding adults caught for ringing in the 1970s several tens of birds had been ringed as nestlings in the larger colony of Stora Karlsö (N. E. Franzmann, pers. comm.). Therefore, one cannot state with certainty that the recruitment within the Græsholmen colony itself is sufficient to maintain the population level. Young birds, however, are being produced in numbers every year, and the majority go to sea at the end of June (N. E. Franzmann, pers. comm.). Thus, field data are of little help when judging the significance of pollutants for the reproductive success of the Græsholmen colony.

Hedgren (1980) found good reproductive success in the Stora Karlsö population, indicating that high levels of pollutants and reduced eggshell thickness do not adversely affect reproduction. PCB concentrations seem, however, to be somewhat lower than in Græsholmen eggs (Tab. 4). Therefore, a difference between the colonies with respect to reproductive success cannot be ruled out.

In Great Britain, Furness & Hutton (1980) found impaired breeding in Great Skuas *Stercorarius skua,* which they tentatively ascribed to elevated PCB and mercury levels in the eggs. PCB concentrations are, however, only 1/5 to 1/4 of those in Græsholmen eggs.

The colony on Skúvoy in the Faeroes may have declined by about 20% from 1961 to 1972 (Dyck & Meltofte 1975), with shooting and snaring considered the most likely contributing factors. The relatively low concentrations of pollutants make their contribution to the decline unlikely.

In summary, there are hardly conclusive indications that environmental pollutants affect Guillemots on the population level.

ACKNOWLEDGMENTS

Græsholmen is a scientific nature reserve and the National Agency for the Protection of Nature, Monuments and Sites of Denmark is thanked for granting access to the islet, where eggs were collected under license. Lic. scient. N. E. Franzmann collected most of the eggs, Dr. Jens Smed supplied us with literature on the hydrography of the Baltic Sea, civ. ing. K. Voldum-Clausen informed us about pollutant concentrations in fish from the Baltic Sea, civ. ing. E. Somer gave permission to quote his report, fil. dr. Stellan Hedgren, civ. ing. Helge Appelquist and dr. W. R. P. Bourne helped with various information, mag. scient. P. Hald-Mortensen supplied the photograph of Græsholmen, cand. scient. Henning Noer gave statistical advice and finally prof. Philippe and M. A., M. S. Elaine Grandjean as well as dr. Jon Fjeldså critisized the manuscript and corrected the language. We thank them all.

SUMMARY

During 1971-1976, Guillemot eggs were collected annually from the southern Baltic Sea and in 1972 from the Faeroe Islands. Concentrations of DDE, PCB and mercury in the Baltic Sea eggs were, respectively, approximately 100, 50 and 1.5 times higher than in the Faeroe eggs. The Baltic Sea eggs showed eggshell thinning, a finding that was positively correlated with the concentration of methylmercury, not the concentration of DDE. This relationship is not believed to be causal, but to be related to the correlation of both shell index and methylmercury concentration with sea water salinity at the time of egglaying. The strong similarity in the physiology of the salt and shell glands suggests that a common regulation of these glands influences eggshell thickness in response to changing salinity. Field data do not suggest a strong negative influence of the pollutants on reproductive success.

DANSK RESUMÉ

Miljøgifte i og skalfortynding af Lomvieæg fra Græsholmen og Færøerne, samt en mulig sammenhæng mellem skaltykkelse og havvandets salinitet

Siden 1971 er der årligt blevet indsamlet Lomvieæg fra kolonien på Græsholmen i den sydlige Østersø. Artiklen beskriver miljøgiftkoncentrationerne i årene 1971-76 og sammenligner dem med koncentrationerne i færøske Lomvieæg fra 1972. Koncentrationerne af DDE (DDT's omdannelsesprodukt) og PCB er, sammenlignet med værdier fra Lomvieæg fra andre områder på den nordlige halvkugle, meget høje i æggene fra Græsholmen (Tab. 4). Kviksølvværdierne her er også højere end, hvad der er målt andre steder, men sammenlignet med hvad der er målt i andre marine fugles æg, også fra andre danske farvande, er de dog ikke påfaldende høje. Koncentrationerne i de færøske æg af DDE, PCB og kviksølv var henholdsvis ca. 100, 50 og 1,5 gange mindre end dem i Græsholmen-æggene. DDE-koncentrationerne, men ikke PCB- eller kviksølv-koncentrationerne, i Græsholmen-æggene viser en nedadgående tendens fra 1971 til 1976 (Tab. 1 og 2).

Der er ikke foretaget populationsdynamiske undersøgelser af Græsholmen-bestanden, og det er derfor usikkert om miljøgiftene påvirker bestanden negativt. Imidlertid synes ynglebestanden at være stabil, og der produceres årligt unger. På Stora Karlsö ved Gotland er ynglesuccessen grundigt undersøgt i de senere år, og der er ikke her fundet tegn på en negativ effekt af miljøgiftene. Sandsynligvis gælder tilsvarende for Græsholmen, omend en forskel ikke kan udelukkes p.gr. af det højere PCB-indhold i Græsholmen-æggene.

Æggeskaller fra Græsholmen, men ikke fra Færøerne, viser skalfortynding (Tab. 3). Da skalfortynding almindeligvis antages at forårsages af DDE, ville man forvente en negativ korrelation mellem skaltykkelse og DDE-koncentration. Ejendommeligt nok er der ikke en sådan, men derimod en negativ korrelation mellem skaltykkelse og kviksølvkoncentration. Det antages, at forhøjede kviksølvkoncentrationer ikke er årsagen til skalfortyndingen, men at sammenhængen beror på at både skaltykkelse og kviksølvkoncentration er korrelerede med havvandets salinitet på æglægningstidspunktet. Fuglenes salt- og skalkirtler har fysiologisk set en del lighedspunkter, og antager man at de også har en fælles regulering, kan man herigennem se en mulig forklaring på en sammenhæng mellem skaltykkelse og salinitet (Fig. 2). Hvad angår korrelation mellem kviksølvkoncentration og salinitet (Fig. 1), kan den bero på, at når saliniteten et år falder p.gr. af øgede ferskvandstilførs-

ler som følge af stor nedbør, så tilføres der også øgede kviksølvmængder til Østersøen via vandløb. Den sandsynlige forklaring på den manglende korrelation mellem skaltykkelse og DDE-koncentration bliver herefter, at korrelationen udviskes på grund af de variationer i skaltykkelser, som skyldes de klimatisk betingede svingninger i havvandets salinitet fra år til år.

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MS received 26 May 1982

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