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Population growth, reproductive rate and neo-natal morbidity in a re-establishing harbour seal colony

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Summary. – Harbour Seals, *Phoca vitulina vitulina*, were exterminated from the Tees estuary in north-east England during the industrial revolution in the middle of the 19th century. Industrial chemical plants now occupy reclaimed land on much of the former estuarine sand flats. Since the 1980s a breeding colony of harbour seals has been re-establishing together with a small, non-breeding group of grey seals, *Halichoerus grypus*. Between 1989 and 1997 the harbour seals increased from about 24 to 50 individuals, although the birth rate has been < 10 % of the population.

Of 12 pups born live between 1989 and 1997, seven have stranded in a moribund condition, while five have appeared healthy at approximately one month of age. Observations of the seven non-viable pups revealed a common pattern of apparently normal maternal care, but gradual weakening of the pup with progresse inability to follows its mother preceding the final stranding. Analyses for chemical contaminants of the tissues of the first three pups revealed elevated levels of polychlorinated biphenyl compounds (PCBs) in the blubber. Analyses of local fish and invertebrates revealed elevated levels of PCBs. A possible causal link between the elevated PCB levels and the poor reproductive performance is suggested.

Résumé. – Les phoques veau-marin, *Phoca vitulina vitulina*, furent exterminés de l'estuaire de la Tees, dans le nord-est de l'Angleterre, pendant la révolution industrielle du milieu du dix-neuvième siècle. Aujourd'hui, des usines chimiques occupent des espaces conquis sur la plus grande partie des bancs de sable qui constituaient l'estuaire. Depuis 1980, une colonie reproductrice de phoques veau-marin se développe à nouveau, associée à un petit groupe non reproducteur de phoques gris, *Halichoerus grypus*. De 1989 à 1997, les effectifs des veaux-marins augmentèrent de 24 à 50 individus, bien que le taux annuel de naissance ait été inférieur à 10 % de la population.

Des 12 nouveaux-nés vivants produits entre 1989 et 1997, 7 se sont ensuite échoués moribonds, tandis que 5 atteignaient l'âge d'un mois dans un état de santé convenable. L'observation des 7 jeunes trouvés moribonds révéla un schéma commun de soins maternels apparemment normaux, mais un affaiblissement graduel avec incapacité progressive de suivre sa mère précédant l'échouage final. Les analyses de contaminants chimiques effectuées sur les tissus des trois premiers jeunes trouvés échoués révélèrent des niveaux élevés de composés organochlorés (BCP) dans le lard. Des analyses similaires réalisées dans les poissons et les invertébrés de l'estuaire révélèrent également des taux élevés de PCB. Une possible relation causale entre ces taux de PCB et les faibles performances de la reproduction est suggérée.

KEY WORDS : *Phoca vitulina*, N-E England, breeding colony, PCBs contaminants.

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INTRODUCTION

The harbour seal, *Phoca vitulina vitulina*, was once numerous in the Tees estuary, NE England. Records of seals taken for Episcopal feasts date back to the 14th century. The population in the early 19th century was estimated at about 1,000 animals, breeding in the estuary and hauling out in groups of about 30 animals, mainly on «Seal Sand» on the northern side of the estuary (Lofthouse 1900).

The seals' demise in the estuary coincided with the start of land reclamation in the early 19th century and the rise of the Cleveland iron trade and Middlesbrough shipping industries around 1830. The decade 1830-40 was thought to have effected «the final extinction of the Seal as a permanent resident of Yorkshire», although individuals and small groups were occasionally noted (and often captured or shot) until the 1860s (Lofthouse 1900). Today, the intertidal area of the estuary is less than 10 % of that originally existing and the estuary shore has been largely reclaimed for petrochemical and other heavy industrial use (Fig. 1).

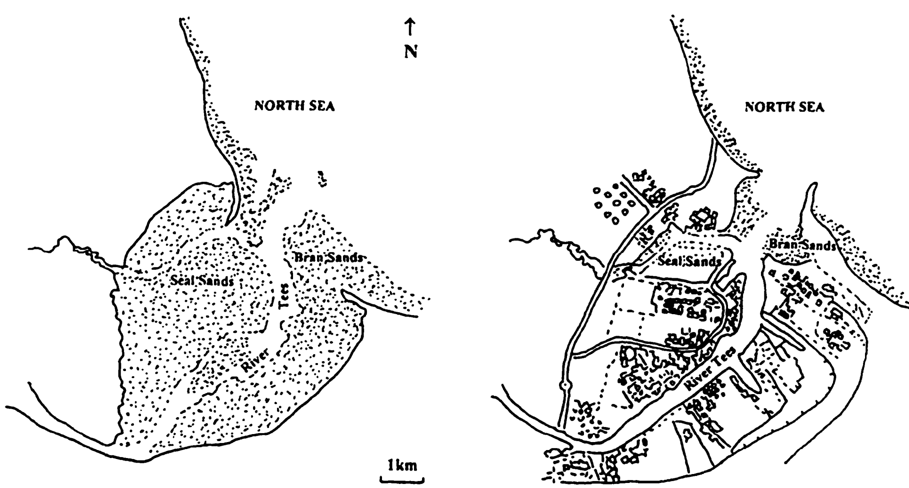

Fig. 1. – The Tees estuary from 1974 to present time compared to its appearance in the mid-19th century.

The years of the seals' initial return to Seal Sands were not documented. There were four counts of 9-17 seals in June-July 1984 and six counts of 12-22 seals between June and October 1986 (Smith 1988), but species identification was not always certain and there were no reliable records of seals breeding. The Tees Seals Research Programme to assess the *status quo* of the population was initiated in the Autumn of 1988 (Kackson and Wilson 1990). This paper summarises the main findings from the first nine years of this study programme.

METHODS

The number of visits to the colony are summarised in Table 1. Observations of the seal colony were made during the 6-hour period around low water from an observation point Ob on the north shore of Seal Sands from which most of Seaton Channel and all the seal-haul-outs A, B, C and D may be scanned. Haul-outs at site D were also observed at closer range from a second position (Fig. 2). Observations on pups were made mainly from the point between Tioxide and Graythorp Dock and occasionally from the south side of Seal Sands. Observations were made using a telescope or high power binoculars. Photographs were taken from the observation points using a 500 mm lens with a X2 converter.

TABLE 1. – Number of bimonthly visits and hours of observation (February 1989 - January 1998).

	F/M	A/M	J/J	A/S	O/N	D/J
No. visits/*mean observation time (hrs)*						
1989	14/2.5	14/1.8	26/2.7	26/1.6	28/2.6	14/1.7
1990	14/1.1	-----	19/4.2	21/3.8	-----	-----
1991	-----	1/3.9	14/2.8	14/2.7	17/1.8	13/2.0
1992	15/2.0	17/2.2	26/2.2	20/1.9	19/1.7	19/1.8
1993	15/2.2	19/2.2	22/2.4	17/1.8	8/2.1	8/2.0
1994	18/4.1	21/3.3	21/2.9	12/2.6	6/2.0	7/2.3
1995	33/3.7	16/3.1	44/2.7	42/2.9	12/2.9	5/2.6
1996	3/2.0	4/2.6	44/3.0	41/2.7	3/ -	8/1.3
1997	8/1.1	3/1.7	41/2.2	19/2.6	2/1.5	2/0.8

All visits to the colony for the purposes of counting and observation were grouped into bimonthly categories, as shown in Table 1. Maximum counts for each species were made at each visit. Subadult seals were distinguished on the basis of size, pelage appearance and behaviour. The presence of seals with distinctive scars or pelage appearance was noted at each visit. Behaviour of the seals, particularly mothers with pups, was recorded and all instances of boat traffic or other forms of human disturbance were noted.

Gross post-morterm examinations were carried out by veterinary specialists (Hodgson and Hall, Stanhope-in-Weardale) on two pups that stranded and subsequently died in 1989 and 1991 respectively. Histopathological examination of the tissues of these two pups were subsequently carried out (at the Veterinay Research Laboratories, Department of Agriculture, Northern Ireland). Immunoprecipitation tests for morbillivirus antibodies were conducted on a blood sample from the 1989 pup, while immunoperoxidase examination for morbillivirus antigen was carried out on blood from the 1991 pup (at the Department of Biology, Queens University of Belfast). Blubber samples from these two pups and a third pup that stranded and died in 1993 were analysed for organochlorine contaminants. Liver samples from these same three pups were analysed

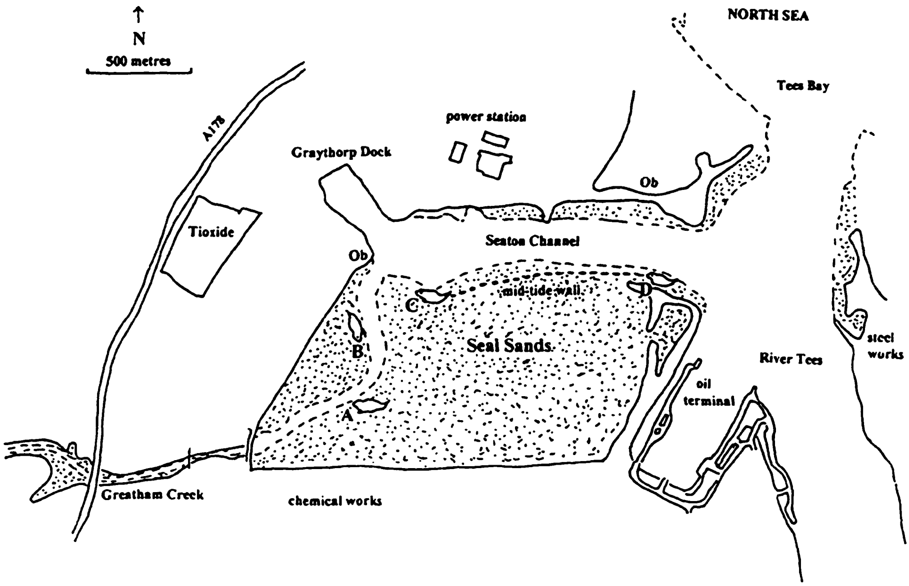

Fig. 2. – Location of main seal haul-outs (A, B, C, D) and observation points (0b) at Seal Sands.

for metal concentrations (at MAFF (1) Fisheries laboratory at Burnham-on-Crouch, Essex in 1989, and at Analytical and Environmental Services (AES), Newcastle-upon-Tyne in 1991 and 1993). Three pups that stranded in 1995 and 1997 were successfully rehabilitated at a specialist facility (Scarborough Sea Life Centre) and subsequently returned to Seal Sands.

Several species of fish and invertebrates taken from the Tees estuary were analysed for organochlorine and metal contaminants (Table 2). Pooled samples of each species were prepared for analysis according to MAFF guidelines (Allchin *et al.* 1989) and deep frozen. The organochlorine analyses were carried out by M-Scan (Ascot) using MAFF guidelines and methods (Law *et al.* 1991).

RESULTS

Seal populations trends

The number of harbour seals counted at the haul-out site has increased from a maximum of 23 in 1989 to 49 in 1996 and 1997 (Fig. 3a and b). Analysis of variance on the daily counts indicated that the number of seals present was significantly greater in the late summer (August/September) moulting season than in the early summer (June/July) pupping season ($P = 0.0000$) and also that there was a significant year effect ($P = 0.000$). Year by year multiple comparison indicated a significant increase from 1989 to 1990 in both early and late summer (2), but no further significant annual

(1) Ministry of Agriculture, Fisheries & Food for England and Wales.
(2) A step-wise increase in the total number of *P. vitulina* was noted in March 1990, which brought the maximum count from 23 to 28.

TABLE 2. – Tees biota collected for analysis of contaminants, August-October 1990.

Species	no. individuals/(location)		size/weight
Mussel I (*Mytilus*)	54	(South Seal Sands)	x = 34cm
Mussel II (*Mytilus*)	14	(East Seal Sands)	x = 38cm
Periwinkle (*Littorina*)	144	(South Seal Sands)	N/A
Shrimp (*Crangon*)	118	(mid-estuary*)	N/A
Shore crab (*Carcinus*)	16	(mid-estuary)	x = 4x5cm
Sprat (*Sprattus*)	99	(Seaton Channel**)	x = 8cm
Herring (*Harengus*)	25	(Seaton Channel)	x = 10-15cm
Saithe I (*Pollachius* whole	43	(mid-estuary)	x = 8cm
Saithe II (*Pollachius*) liver	5	(outer estuary***)	52-412g
Whiting I (*Merlangius*) whole	57	(mid-estuary)	x = 7cm
Whiting (II) (*Merlangius*) liver	29	(outer estuary & Seaton Channel)	110-210cm
Flounder I (*Platichthys*) liver	7	(mid- & outer estuary & Seaton Channel)	32-415g
Flounder II (*Platichthys*) liver	6	(Eaglescliffe****)	164-262g

* mid-estuary sampling carried out on National Rivers Authority (NRA) sampling trip
** Seaton Channel samples taken from Power Station intake
*** outer estuary samples donated by anglers at South Gare Pier
**** Eaglescliffe flounder collected by NRA. Eaglescliffe is a upriver site.

increase until 1995 and again in 1996 (95 % Student-Newman-Keuls interval). The annual maximum number of grey seals counted varied between 15 and 27, but a consistent increase over the nine-year period was not observed.

The average proportion of the total harbour seal colony to be counted at the haul-out site in each bimonthly period was calculated by the «bounded count» method (Olesiuk *et al.* 1990) from the formula :

$$P_{av} = C_x / [C_{max} + (C_{max} - C_{max-1})]$$

where P_{av} is the average proportion of seals that were hauled out and C_x C_{max} and C_{max-1} are the mean, the highest and the second highest of the replicate counts, respectively. During the harbour seal moult in August/September, about 75 % of the harbour seals were hauled out and usually about 60-70 % at other times. Estimated abundance for each bimonthly period was then calculated from C_x/P_{av} (e.g. Thompson *et al.* 1997) and was found generally to be slightly higher than the maximum count (Fig. 3).

Composition of the haul-out group

The average percentage of subadults (i.e. animals of subadult size and juvenile pelage, excluding newborn pups) in the harbour seal population in June-July has ranged from about 12 % in 1993 to about 38 % in 1996. Small juveniles in their first or second year (excluding newborn pups) were recorded on only five separate occasions between 1989 and 1993, but since 1995 small juveniles may have comprised about 3-

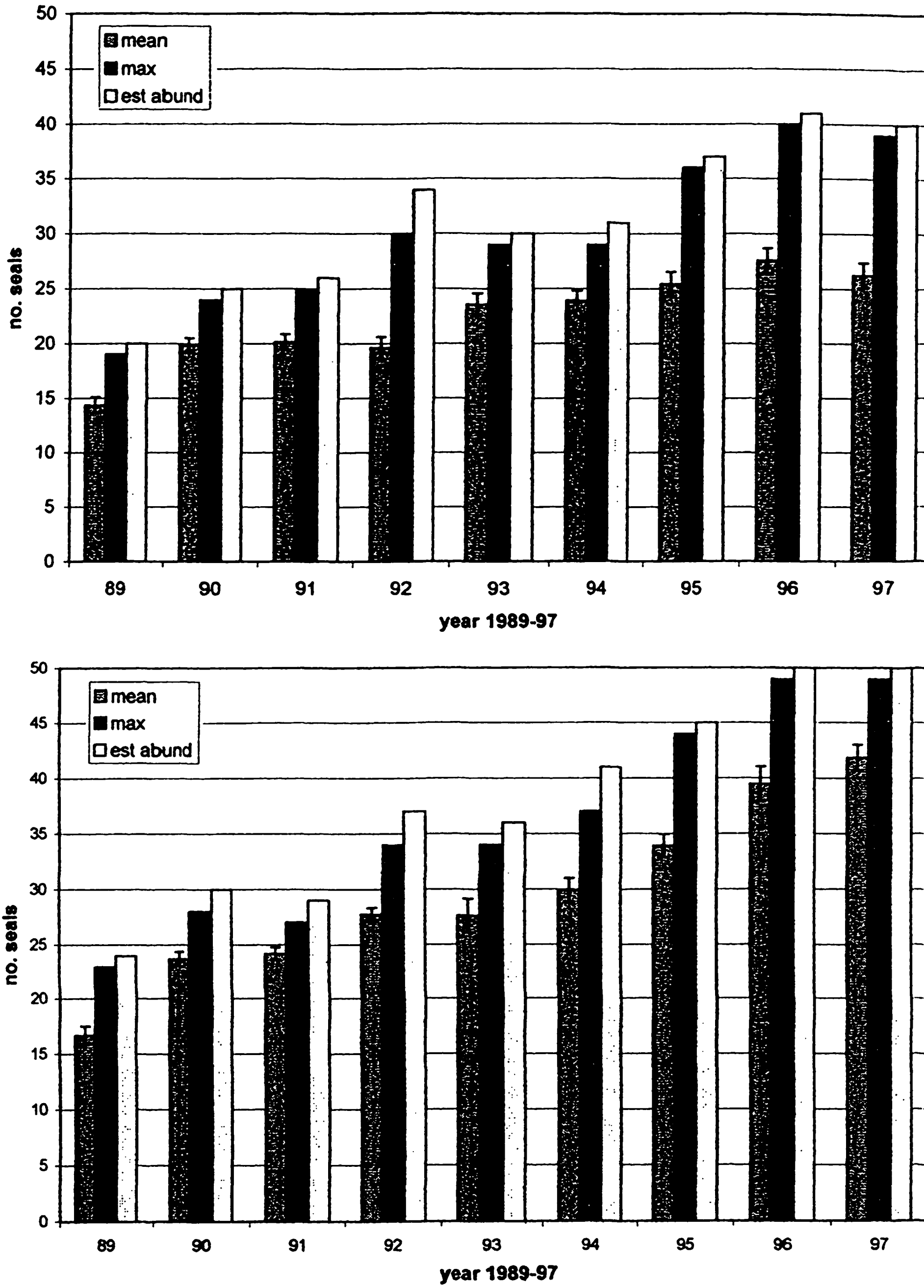

Fig. 3. – Counts of harbour seal during early and late summer 1989-97, showing the bimonthly means with standard error, maxima and abundance estimates. (Top : June-July ; bottom : August-September).

4 % of the total harbour seal count (Wilson *et al.* 1995 ; Smurthwaite 1997). One individual adult male, recognisable by a large pink skin lesion across his left shoulder, was identified regularly since the start of the study in 1989 and several other distinctively marked adults have also been seen in successive years.

Harbour seal breeding record

The percentage of births in the population has varied between zero and 10 %, with an average of 4 %. In Fig. 4 the number of pups born each year is compared with the expected number of births based on an estimated normal 87 % of adult females bearing young (de Jong *et al.* 1997). The number of pups surviving to weaning each year is also shown. For the first 5 years of the study the seals failed to breed successfully. Although a single pup was born in 1989, 1991 and 1993, none survived more than a few days. Then in 1994 two pups were born and both survived to weaning at one month of age, and both appeared healthy. Two pups were also born in both 1995 and 1996, but in each only one was successfully weaned, the other stranding. In 1997 four births were recorded. One was a still-birth, one was successfully weaned and two others stranded.

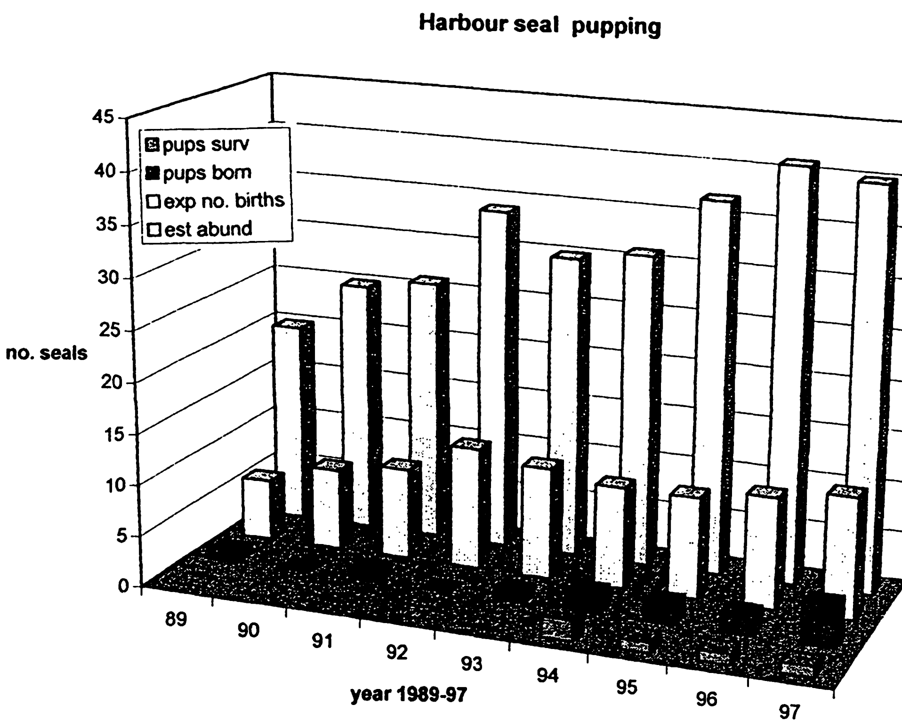

Fig. 4. – The number of harbour seal pups born and surviving to weaning (1989-97) compared to the abundance estimates for June/July and the expected number of births.

Observations of the seven non-viable pups born live between 1989 and 1997

Table ~~3~~ gives the dates of birth and stranding weights of the seven non-viable pups. All seven of these pups were observed to bond normally with their mothers in the neonatal period and in all but one of the cases (pup 12) the mother continued to give apparently normal maternal care until just before the pups stranded.

The first time pup 1 stranded, on post-natal day 4, he was evidently in a weakened condition, despites having being seen to nurse regularly. He failed to follow its mother back into the water and remained in a hunched, prone position despite repeated efforts by the mother to coax him to follow her (Fig. 5). He later reunited with mother and nursed for 16 min, but stranded the following day weighing 7 kg and died shortly after being collected. The photographs in Fig. 5 bear witness to the fact that the weakened condition was the *cause* of the mother-pup separation and not its consequence. Post-mortem histopathological examination of the lung revealed congestion, but no evidence of pneumonia. Mild fatty change was seen in the liver, but no significant changes in kidney or brain. Immunoprecipitation tests on blood did not reveal any antibodies to morbillivirus (S. Kennedy, pers. comm.).

Pup 2 was only seen alive on the evening of her birth, when she engaged in prolonged nosing interaction with her mother and was subsequently active in the water, being chaperoned by her mother. Two days later her body, weighing only 6 kg, was found on the beach. Ventral bruising was found around the chest and neck, which could have occurred either pre- or post-mortem. There was no trauma to the head and no external wounds. Milk was found in the intestines and a mass of lanugo fur and faeces were compacted in the colon. There was no lung congestion or signs of pneumonia and the liver, heart, lungs and thoracic cavity were all of normal appearance. Histopathology of lung, liver, kidney and adrenals revealed no significant lesions and immunoperoxidase examination for morbillivirus antigen was negative (S. Kennedy, pers. comm.).

The photographs of mother-pup pair no. 3 illustrate the normal maternal care and pup following behaviour observed on the first three post-natal days (Fig. 5). The pup was found stranded on the fourth day and died shortly afterwards weighing 7.5 kg. There was no external trauma or wounding. A post-mortem examination was not carried out.

The analyses of blubber samples from these three dead pups revealed that the range of PCB concentrations in the blubber layer was 6-114 mg/kg lipid weight, while the range of DDT and metabolite concentrations were lower, at 2-9 mg/kg (~~Table 3~~). In the liver samples the range of copper concentrations was 8-26 mg/kg wet weight, while the range of zinc levels was 60-112 mg/kg. Other organochlorine compounds and metals were found to exist in undetectable or very low levels ~~and have therefore been excluded from Table 4~~.

The four non-viable pups born in 1995-97 stranded later than the first three pups (post-natal day 7-24). All four showed some difficulty in nursing. A weakened condition was first noticed in pup 7 on day 21, when she was first seen without her mother. Pup 9 appeared weak and unable to follow her mother into the water on day 9. Although she nursed during the next two days, she was found stranded on the outer estuary later on day 11 with an apparent bite injury to the head. However, as with the earlier pups, it was clear that the weakness *preceded* the separation of mother and pup and was not a consequence of the separation. For the last two pups (11 and 12), nursing difficulties appeared to be an important factor in the eventual separation and stranding. Pup 11 was seen attempting to nurse from a juvenile on day 2 before it was reclaimed by its mother. The next day the mother was seen searching for the absent

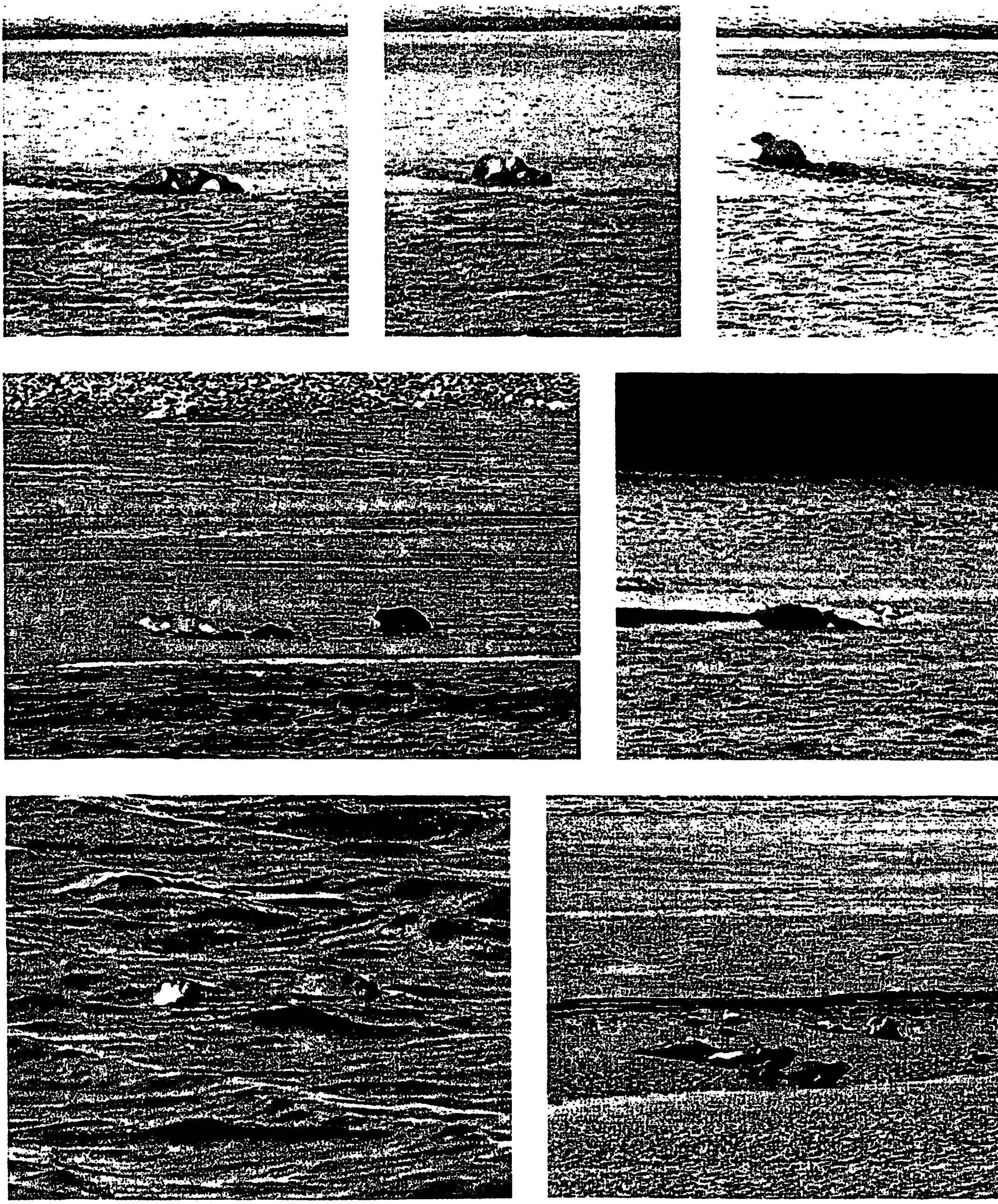

Fig. 5. – Images of Mother and Pup no. 1 (1989) and no. 3 (1993).
Top : mother with pup 1 on mud-flats near site A ;
Median : from left to right : mother leading pup 3 on to haul-out site C, nosing pups top of head, engaging it in nose-to-nose contact ;
Bottom, left : ~~mother nursing pup 3 ; right~~ : pup 3 following mother as mother leads it from site B to site C.
(Photographs : S. Wilson).

TABLE 3. – Average proportion of the Teesmouth harbour seal/grey seal population hauled out at Seal Sands (method of calculation from Olesiuk *et al.*, 1990).

	Bimonthly periods					
	D/J	**F/M**	**A/M**	**J/J**	**A/S**	**O/N**
1989	.58/.29	.49/.26	.60/.25	.72/.39	.73/.28	.76/.15
1990	.50/.13	.51/.21	-	.79/.41	.79/.37	-
1991	-	-	-	.78/.56	.86/.43	.77/.31
1992	.71/.20	.67/.27	.80/.20	.58/.37	.75/.45	.52/.16
1993	.75/.25	.73/.24	.64/.28	.79/.49	.84/.29	.63/.22
1994	.69/.24	.65/.35	.63/.16	.79/.48	.74/.59	.81/.46
1995	.59/.33	.60/.18	.67/.22	.69/.43	.75/.45	.67/.22
1996	.20/.57	.55/*	.74/.63	.67/.36	.79/.38	.92/.42
1997	.71/.35	.57/.28	.87/.40	.66/.37	.84/.35	-

* only 1 *H. grypus* hauled out in this period

pup, which subsequently stranded on day 7. Pup 12 displayed nursing difficulties from day 2 and the mother snapped and rushed away when the pup tried to nurse. Nevertheless, the pup was seen from time to time with her mother until she stranded on day 23 weighing only 9 kg. Table 3 compares the weight of the seven pups at stranding with an estimated normal weight based on a conservative estimate of 0.4 kg per day normal weight gain (0.6 kg/day ; Bonner 1989) and 11 kg normal viable birth weight (King 1983).

Occasional disturbance of the seals during the pupping seasons, mainly by boats or bait diggers, was recorded, but this was not observed to cause any separation of mother and pup or undue extra time spent in the water.

Records for five pups successfully weaned between 1994 and 1997

Table 4 gives the duration of the nursing period and records of the pup's presence in the post-weaning period for each of the five surviving pups. Lactation apparently lasted about 34, 35, 29, 26 and 47 days respectively. Nursing problems were not recorded for these pups and they all appeared to be healthy and of normal size both during and after the nursing period. The mother of P5, P6 and P8 had rust-colooured fur in the head region and might possibly have been the same female.

Analysis for chemical contamination in Tees fish and invertebrates

The PCB concentration range in the fish and invertebrates was 1-18 mg/kg, with periwinkles, shrimps, and liver from herring, saithe and flounder all exceeding

TABLE 4. – Non-viable *P. vitulina* pups born live at Seal Sands, 1989-97.

Pup ID	DOB	age of stranding	wt	est. normal wt	% est. normal wt
1 (m)	89/7/10	5d	7 kg	12.6 kg	56%
2 (f)	91/7/9	2-3d	6 kg	11.4 kg	53%
3 (m)	93/6/25	4d	7.5 kg	12.2 kg	61%
7 (f)	95/7/9	24d	12 kg	20.2 kg	59%
9 (f)	96/7/8	11d	10 kg	15.0 kg	67%
11 (m)	97/6/29	7d	9 kg	13.4 kg	67%
12 (f)	97/7/5	24	9 kg	20.2 kg	45%

normal weight estimate based on birth weight of 11 kg and average weight gain of 0.4 kg/day

5 mg/kg, while the DDT range was uniformly lower at 0.1-1.5 mg/kg. The copper concentration range was 1-51 mg/kg, being highest in the periwinkles and crabs, while the zinc concentration range was 11-56 mg/kg, being highest in mussels and flounder ~~(Table 4)~~. Other organochlorine compounds and metals were founds to exist in undetectable or very low levels.

DISCUSSION

The growth of the harbour seal colony over the past nine years

The results from monitoring seal numbers indicate that harbour seal numbers have increased consistently over the nine-year study period. This increase must have been due principally to immigration, since the number of surviving pups born in the colony during that time (eight, including three pups rehabilitated and released) cannot account for the increase of 26 in the maximum number counted. The possibility that female from the Tees are pupping elsewhere has been considered, but no other harbour seal haul-outs within 100 km north or south of the Tees have so far been found. The reason for the increase might relate to an increasing number of fish returning to the River Tees in recent years as a result of improving water quality (Pomfret *et al.* 1988 ; Anon 1995).

The low reproductive rate

The reproductive rate of a harbour seal colony considered to be normal is approximately 20-30 % of the population (Reijnders 1982), with which the Tees rate of 0-10 % in the years 1989-97 compares unfavourably. Suggested possible explanations for the low reproductive rate in the Tees have included an abnormal population structure or «genetically inferior» seals in a newly establishing colony (Turner 1998). However, not all small, re-establishing groups have low fertility (Elder in prep.).

A more plausible hypothesis may be that low female fecundity may be linked to organochlorines or other contaminants in the seal's prey. It has been found experimentally that captive female harbour seals fed OC-contamined fish from the west Wadden Sea had an extremely low birth rate compared to a control group of females (Reijnders 1986). Recent work on harbour seal liver *in vitro* has shown that both progresterone metabolism in the female and testosterone metabolism in the male decrease markedly as liver PCB burden increases from 1-6 mg/kg fat weight (Troisi 1998). The PCB concentrations found in the dead pups in the Tees suggest this effect might be operating in the adult Tees seals. Olsson *et al.* (1975) suggested that the widespread infertility and disease syndrome seen in the Baltic seals from the 1970s were associated with PCB concentrations of > 13 mg/kg in prey species. The Tees shrimp, herring and flounder samples analysed in the Tees in 1990 indicated PCB contamination levels of this order of magnitude. Furthermore, sediment sampling in different parts of the Tees estuary in 1996 found PCB levels at sites beside the seal haul-out to be in the «contaminated» category of 21-100 ug/kg (Evans *et al.* 1997).

The high neonatal pup morbidity

Although some stranded neonatal pups often occur even in healthy harbour seal populations, the cause is usually unknown. Possible causes of stranded pup starvation include accidental separation of mother and pup (due to human disturbance, inclement weather or other factors), inadequate maternal care or milk supply, low birth weight, or disease. The observations that have been possible on these individual Tees pups have enabled some of these possible causes to be eliminated. None of the cases could be ascribed to accidental separation of mother and pup due to human disturbance or to other misadventure, or (except in the case of pup 12) to maternal indifference or incompetence. No disease was detected either in pups 1 and 2 or in the three pups that were successfully rehabilitated. With the exception of pup 12, the pups seemed to be abandoned only *in extremis*, when they were finally too weak to respond to or follow their mothers.

However, observations of all the non-viable pups (except pup 2) indicated *either* that they were unable to nurse successfully *or* that they lost weight despite appearing to nurse regularly. This appears to be the most plausible reason for the weakening, starvation and eventual stranding of all these pups The very considerable estimated weight deficits of the seven pups at stranding (45-67 % underweight for their age) suggest the possibility that they may also have been underweight at birth as well as receiving inadequate nutrition from their mother's milk. Low birth-weight would seen to be the most obvious cause for the rapid post-natal death of pup 2 at only 6 kg.

The present study is unusual in having case history records for individual pups and it is these individual behavioural records which have enabled the abnormality of the pups' development to be detected. Although it may be argued that it is normal for some pups in a colony to lose their mothers and strand, it cannot be considered normal for pups to become progressively weaker while being cared for by the mother and nursed regularly. Neither can it be considered normal for seven out of twelve pups to become moribund due to low birth weight and/or an inadequate milk supply. The relatively small number of pups described here are not just a sample, but almost certainly represent *all* the pups born live in the colony over the nine-year study period. A larger sample of pups for investigation was therefore not possible. The small number of pups born is itself suggestive of a problem (as discussed above) which might be related to the high pup morbidity, and the results are, by necessity, qualitative.

Possible underlying causes of a problem with milk quality or quantity might include poor local food availability for pregnant females or physiological immaturity of a first-time mother. However, the resident adult and juvenile seals all appear well-fed, and it seems unlikely that a first-time mother scenario would be repeated seven out of twelve times over nine years. Another possible cause is a hormonal imbalance in the mother resulting in low birth weight and a poor milk supply. The gradual starvation of the pups observed while they were still being cared for by their mothers is remniscent of that observed in kits of the laboratory mink *(Mustela vison)* whose mother's feed before and after giving birth was experimentally dosed with organochlorine (OC) contaminants (Jensen *et al.* 1977 ; Wren *et al.* 1987 ; Kihlstrom *et al.* 1992). Furthermore, it has been demonstrated both in seals and in mink that PCB compounds stored in the mother's blubber are mobilised during lactation and passed to the young in the milk with a 50-70 % efficiency (Addison and Brodie 1987 ; Wren *et al.* 1987). The OC levels in the blubber of pups 1 and 3 were considerably elevated even though the pups had nursed for only 3-4 days before stranding. Reijnders (1982, 1985) attributed the high (60 %) pup mortality in the Rhine Delta region at least partly to PCB pollution during the 1975-80 period when that population became extinct (Reijnders 1982, 1985). It would therefore be quite plausible that both the low birth rate and the high pup morbidity observed have a common contributory cause of OC contamination.

If OC pollution has been a major factor underlying the poor reproduction, it is also possible that contamination by heavy metals might also be adding to the problem. The zinc levels in the liver of pups 1-3 were at the upper limit or beyond the usual range of 27-66 mg/kg (Law *et al.*, 1991), with the level of 112 mg/kg in pup 2) possibly representing a failure of the regulation mechanism (Law *et al.* 1992). The toxic effects of excessive zinc intake in domestic cows include inhibition of digestive enzymes, poor growth, fatigue and a decrease in lactation (Bartik and Piskac 1981). Some mussels and flounders in the 1990 samples were found to have zinc levels unfit for human consumption (> 50 mg/kg ; Franklin 1990), while Evans *et al.* (1998) also reported high levels of zinc, frequently exceeding 50 mg/kg, in sprat, flounder, whiting, shrimp and mussels from Seal Sands.

CONCLUSIONS

With the available data from this study it is not possible to conclude definitely that there has been a direct causal link between the OC contamination levels found in both local prey species and dead seal pups and the poor reproductive performance of the harbour seals between 1989 and 1997. Nevertheless, although other unidentified factors may well be involved, the data presented here strongly suggest that OC and metal contamination in the estuary of the order of magnitude found *could* pose a threat to the health of the seal colony by contributing to the low birth rate and low neonatal viability observed.

Successful re-establishment of the Tees colony may be of considerable strategic conservation importance for harbour seals on the east coast of Britain, since it bridges a gap of some 500 km which would otherwise extend between major breeding sites in the Tay estuary to the north and the Wash to the south. Furthermore, Seal Sands has double designation under domestic law as a Site of Special Scientific Interest and as a National Nature Reserve. There is therefore considerable justification for continuing to make strenuous efforts to minimise industrial pollution, since this could damage both the estuarine ecosystem and its seals. Monitoring of the site for chemical contaminants (e.g. Evans, 1998) should continue.

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