Status and biology of ringed seals (*Phoca hispida*) in Svalbard

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ABSTRACT

The ringed seal is the most abundant mammal in the Svalbard area. Annual pup production in this area is estimated to be 20,000. No systematic harvest records exist, but some few hundred seals are taken annually, mainly for dog food. The ringed seals in Svalbard are protected from hunting in the period 15 March - 15 April. Peak pupping season is the first week of April. New-born ringed seals weigh an average of 4.6kg. They are nursed for about 39 days, and weaned at an average body mass of around 22kg. During the period of maternal care pups consume a total of about 54 litres of milk, that is composed of approximately 38% fat and 10% protein. Asymptotic standard lengths and body masses for adult ringed seal males and females are 131.5 and 127.8cm, and 52.6 and 59.9kg, respectively. The maximum values recorded for lengths of males and females in Svalbard are 157cm and 107kg, respectively. There is marked seasonal variation in body mass in both sexes with the highest mass records being recorded in early spring before pupping occurs, and with minimum values in the summer after the breeding and moulting seasons. The observed variation in mass is mainly due to changing blubber thickness of the seals. Ringed seal males attain sexual maturity at the age of 5 - 7 years, while females reach maturity when they are 3-5 years of age. The oldest seal collected in Svalbard was aged 45. Ringed seals in the Svalbard area feed on a variety of prey organisms, the most important of which are polar cod (*Boreogadus saida*) and the crustaceans *Parathemisto libellula, Thysanoessa inermis* and *Pandalus borealis*. Ringed seal pups start diving during the nursing period while they are still white-coats, and spend about 50% of the time in the water prior to weaning. They are capable of diving for up to 12min and dive to the bottom of the study areas (max. 89m). Nursing females spend more than 80% of their time in the water. Maximum recorded dive duration for mothers was 21.2min. In order to produce a weaned pup, the net energy expenditure for a ringed seal mother is 1,073MJ. This energy value corresponds to the consumption of 185kg of polar cod or 282kg of *P. libellula*. The annual gross energy consumption for adult males and females is calculated to be 5,600MJ and 7,300MJ, respectively. The main predators of ringed seals in Svalbard are polar bears (*Ursus maritimus*) and Arctic foxes (*Alopex lagopus*). In addition, both glaucous gulls (*Larus hyperboreus*) and walruses (*Odobenus rosmarus*) are documented as predators of ringed seals in this area. Heavy predation pressure is probably the main factor explaining why pups of this species start diving at such a young age, why they have access to so many breathing holes (8.7 on average) and why they keep their white coat long after its thermoregulatory properties have vanished. Pollution levels in ringed seals from Svalbard are, generally speaking, similar to levels in other areas of the Arctic.

INTRODUCTION

Svalbard, which includes Bjørnøya (Bear Island), is an Arctic archipelago situated between 74° - 81°N and 10° - 35°E (Fig. 1). In English literature Svalbard and Spitsbergen are often, incorrectly, used as synonyms. Spitsbergen is actually the name of the largest island in Svalbard. Svalbard consists of 62,700km^2 of land area, of which 54% percent is covered by glaciers. The west coast of Svalbard is influenced by relatively warm waters from the North Atlantic Current (the "Gulf Stream"), which gives this area a mild climate and a high diversity of species compared to other areas in the Arctic at similar latitudes. Large numbers of seabirds transport nutrients from the ocean to their colonies and thereby increase the biological productivity in the land areas as well. The northern and eastern parts of Svalbard are colder and drier and in these areas we find the highest coverage of glaciers. The southern limits of Svalbard are the northern boundaries of the Barents Sea, which is also a highly productive marine area. Svalbard experiences about four months of midnight sun in the summer from about mid April to mid August, and a corresponding period in the winter where the sun is below the horizon.

Svalbard was officially discovered in 1596 by Willem Barents. There were no aboriginal peoples inhabiting the area. After its discovery the marine mammals in this area were heavily exploited. The Spitsbergen stock of bowhead

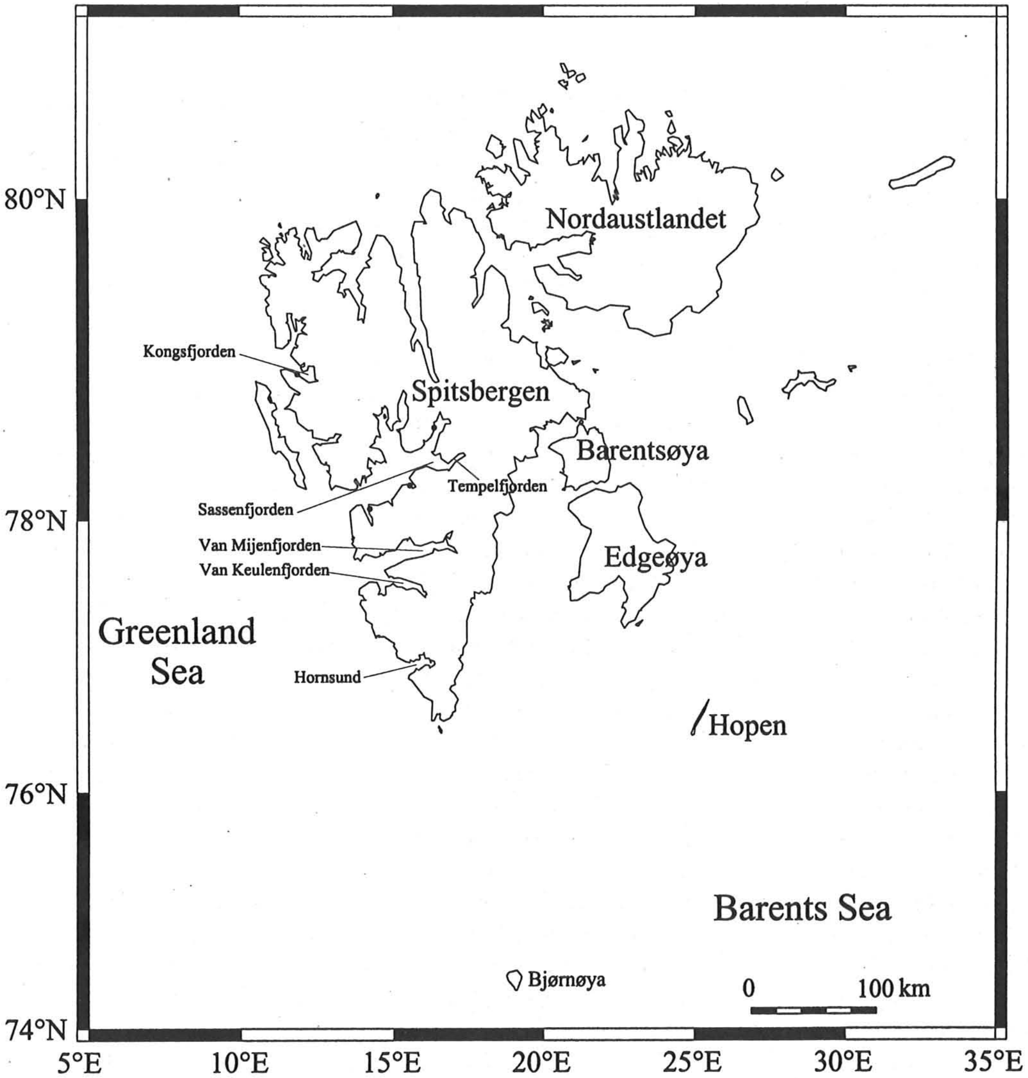


Fig. 1
Map of Svalbard showing place-names referred to in the text.

whales (*Balaena mysticetus*) was almost exterminated during a commercial hunt that started in the 17th century. The same thing happened to the once large populations of walruses (*Odobenus rosmarus*). From the early 1700s the Russians started trapping in the Svalbard area, followed by the Norwegians about a century later. The trappers killed walruses and other seals for ivory and blubber, reindeer (*Rangifer tarandus platyrhynchus*) for meat and hides, and polar bears (*Ursus maritimus*) and Arctic foxes (*Alopex lagopus*) for fur. In addition, they collected down from the eider (*Somateria mollissima*). Ringed seals (*Phoca hispida*) did not appear to play an important role in the early harvests. The trappers preferred to kill larger seals, such as the bearded seal (*Erignathus barbatus*) or if possible walruses, which gave greater yields of blubber and meat per bullet.

The following is an overview of the published literature on ringed seals in Svalbard. Little information is available concerning population size or demographics, but the general ecology of ringed seals in this area has received considerable attention.

DISTRIBUTION AND ABUNDANCE

The ringed seal is the most abundant mammal in the Svalbard area. During spring ringed seals are observed hauled out on the fast ice in all the fjords in the archipelago. However, in the summer most of them disappear from the fjords, probably to feed in the Greenland and Barents Seas. However, their summer distribution has not yet been documented.

Fig. 2
Dog survey for ringed seal lairs in prime breeding habitat in Svalbard, which are areas close to glacier fronts where bergy bits and growlers from the glaciers are frozen into the fjord ice. (Photo I. Gjertz)

A recent estimate for the total ringed seal population in the Svalbard area was presented by Jødestøl and Ugland (1993). They suggested a total population of 200,000 individuals and considered this number of animals to be the carrying capacity of this area, as there is no sealing nor are effects of pollutants likely to influence the population dynamics of this ringed seal population.

Estimates of breeding populations of ringed seals in local areas in Svalbard have been conducted in connection with impact studies in relation to industrial activities. A stratified random sampling regime was used to estimate ringed seal densities based on numbers of breathing holes and lairs in two different areas in Spitsbergen (Lydersen *et al.* 1990, Lydersen and Ryg 1991). Trained dogs were used to find ringed seal structures within selected plots and the total number of structures was estimated by extrapolating these hole and lair densities to the whole study area. Van Mijenfjorden was found to be a poor breeding area for ringed seals, containing only about 125 adult seals during the breeding period (Lydersen *et al.* 1990). The reason for this is probably shallow snow depth and lack of structures such as pressure ridges and frozen-in glacier calvings where sufficient snow will accumulate for the ringed seals to make lairs. In Tempelfjorden and Sassenfjorden, further north on the west coast of Spitsbergen, a similar study was conducted. It was found that this area was inhabited by about 300 adult ringed seals in the breeding season, with a maximum pup production of 185 pups (Lydersen and Ryg 1991).

Based on the two studies mentioned above, densities of breeding females in different ice habitats could be calculated. Prime breeding habitat is found in areas close to glacier fronts in sheltered fjords and bays (Fig. 2). In such areas breeding female densities are approximately 2.6/km^2 (Smith and Lydersen 1991). The flat fjord ice, which represents most of the breeding habitat, was found to have a breeding female density of 0.98/km^2. Based on satellite images from several years, the mean area covered by these two types of ice was calculated for all waters around Svalbard. Based on these calculations, ringed seal pup production for the whole of Svalbard was estimated to be about 20,000 (Smith and Lydersen 1991).

In addition to the investigations mentioned above, an aerial survey of ringed seals during the moulting period was conducted in Van Mijenfjorden and Van Keulenfjorden in 1986 by Jensen and Knutsen (1987) who found a lower density of hauled out seals in the inner parts of the fjords compared with the outer parts. In Fritjofhamna, a small bay on the north side of the mouth of Van Mijenfjorden, 600 ringed seals were hauled out in an area smaller than 4km^2. This was in July after the ice had disappeared from the rest of the study area. Based on this observation it was concluded that more than 1,200 ringed seals used the fast ice in Fritjofhamna to haul out during July. A similar observation was made in July 1995 (Lydersen *et al.* unpublished data), when all ice had left Van Mijenfjorden except in the inner parts of Rindersbukta, a small bay in the southern end of the fjord. Some 500+ ringed seals were hauled out on the small area of remaining fast ice. This, in addition to observations made by a local trapper who has lived in this area for many years (L. Nielsen pers. comm.), indicates that such high densities of ringed seals on the last remains of the fjord ice during the moulting period in July is a common event in this area.

FEEDING

Based on a cross-sectional study, where material from Svalbard was included, the average nursing period for ringed seals was found to be 39 days (Hammill *et al.* 1991). The duration varies considerably, depending on when the fast ice breaks up because this results in the separation of mother and pup. Under stable ice conditions, nursing periods lasting up to two months have been recorded (Lydersen and Hammill 1993a). During an average nursing period a pup drinks a total of 54 litres of milk (Lydersen and Hammill 1993b). The composition of this milk based on one longitudinal milk sample, is 48.6% water, 38.1% fat and 9.9% protein (Lydersen *et al.* 1992). Interpretations of time-depth recorder (TDR) readings indicate that pups are nursed on average three times per day (Lydersen and Hammill 1993a), giving an average meal size of 460ml milk.

Ringed seal diets in the Svalbard area have been studied on several occasions by analyses of stomach and intestine contents from shot animals. In one study from Kongsfjorden, the spring diet was found to consist mainly of polar cod (*Boreogadus saida*) and different decapods and amphipods (Gjertz and Lydersen 1986a). This study was based on material from 284 shot animals, out of which 39 stomachs and 85 intestines had identifiable contents. Remains of squid were found in one stomach, and otoliths from fishes such as Arctic char (*Salvelinus alpinus*) and long rough dab (*Hippoglossoides platessoides*) were also occasionally found.

In another analysis of ringed seal stomach contents from Kongsfjorden and the drifting pack ice of the eastern part of Svalbard, polar cod and crustaceans such as *Pandalus borealis*, *Parathemisto libellula* and *Thysanoessa inermis* were the most important prey species, and a total of 24 different prey taxa were identified (Weslawski *et al.* 1994). This material was collected in the period from February to September, comprising 115 seals from Kongsfjorden and 19 from eastern Svalbard.

In addition to these studies, material from five ringed seal stomachs were included in a wider multi-predator study in Hornsund in September (Lydersen *et al.* 1989). In these samples polar cod was the main prey item, followed by *P. libellula* and *Mysis oculata*.

GROWTH AND MATURITY

Ringed seal foetuses grow according to the equation: foetal body mass$^{1/3}$(g) = 0.075(days) - 1.23 ($r = 0.997$) (Lydersen 1995). This equation is based on measurements from 17 foetuses, where collection date is used to calculate age, and implantation date is set to 3 August (Lydersen 1995). The mean mass of new-born ringed seal pups from Svalbard is 4.55kg (Lydersen *et al.* 1992). Based on a cross-sectional study of growth in nursing ringed seal pups, they were found to have a daily mass gain of 0.43kg and a daily increase in length of

0.64cm (Hammill *et al.* 1991). The pups are weaned approximately 39 days later at a body mass of about 22kg (Hammill *et al.* 1991). Two longitudinal studies where mass gain during lactation was included found a daily mass gain of 0.39 ± 0.10 and 0.35 ± 0.08kg respectively (Lydersen *et al.* 1992, Lydersen and Hammill 1993a)

A study of age and reproductive status of 283 ringed seals collected mainly in Kongsfjorden was conducted in the early 1980s (Lydersen and Gjertz 1987). Ringed seals were aged by reading growth layers in the cementum layer of decalcified and stained canine tooth sections. Ovaries were analysed macroscopically for follicles, *corpora lutea* and *corpora albicantia.* Females were defined as sexually mature based on findings of follicles larger than 6mm in diameter, or the presence of *c. lutea* or *c. albicantia.* Stained cross-sections of testes and epididymis were examined microscopically for presence of sperm. Males were defined as sexually mature when spermatozoa were found in either testes or epididymis.

From these analyses females were found to attain sexual maturity between 3-5 years of age. The corresponding figure for males was 5-7 years. The seals in this study were relatively old; an average age of 11.3 years for males and 14.9 years for females. The oldest animal in this sample was a female that was 45 years old. She had no follicles or *c. lutea* in her ovaries. However, old *c. albicantia* were found. The sex ratio of ringed seals based on this sample was not significantly different from 1:1. Mortality rates were not calculated in this study, since the sample size was too small to allow for a meaningful estimate of this parameter (283 animals distributed over 45 age groups).

The asymptotic body length for ringed seal females from Svalbard is 127.8cm. The corresponding figure for males is 131.5cm (Lydersen and Gjertz 1987). This difference is not statistically significant. Asymptotic body mass for ringed seal females was 59.9kg and for males 52.6kg (Lydersen and Gjertz 1987). This difference between the sexes, which is statistically significant (Mann Whitney U-test, $p < 0.0003$), may be a sampling artefact. The sample was collected from March-June, including the breeding season. The difference in body mass therefore could be due to differences in behaviour during the breeding season resulting in different mass loss rates.

The largest female collected in Kongsfjorden during all of the studies conducted there had a body mass of 92kg and a body length of 154cm. The largest male had a body mass of 107kg and a body length of 146cm. This male specimen was shot in September; longer males have been shot in the spring time (max. length 157cm), but with lower body masses than this individual.

BREEDING

The peak pupping period for ringed seals in Svalbard is the first week of April (Lydersen 1995). The earliest recorded birth in this area is 17 March. Most pups are born in subnivean lairs dug out by their mothers, but occasionally, due to poor snow conditions, some pups are born on the open ice (Gjertz and Lydersen 1983). The birth lairs protect new-borns against harsh weather conditions, and to some degree against predation. The temperature inside lairs varies from 0°C to -2°C, independent of the outside temperatures (Taugbøl 1984). The preferred habitat for birth lairs is inside the many fjords close to glacier fronts where bergy bits and growlers from the glaciers freeze into the fjord ice, and on the wind and leeward side of these pieces of glacier-ice enough snow accumulates to allow for the digging of lairs. Lairs are also found on the flat fjord ice in places where enough snow accumulates. The mean size of birth lairs was found to be 4.3 ± 2.6m^2 which was significantly larger than lairs used by rutting ringed seal males of 2.4 ± 1.4m^2 (Mann Whitney-U test, $p<0.001$)(Lydersen and Gjertz 1986). The snow covering the roofs of the birth lairs was significantly thicker than for adult male lairs (Mann Whitney-U test, $p<0.01$), indicating that the breeding females get or pick the best spots for lairs (Lydersen and Gjertz 1986).

Rutting male lairs could be distinguished from other types of lairs by the strong odour emanating from the rutting males and sticking to the breathing holes and lairs used by them. This

Fig. 3
Rutting ringed seal males secrete a substance from their facial region that gives them a strong smell and a dark face mask. (Photo C. Lydersen)

smell comes from large sebaceous glands in the facial region that secrete a substance with a strong smell (Fig. 3, Hardy *et al.* 1991). Extracts of this substance show high concentrations of a tertiary amine, three aminoalcohols, two hydrocarbons and several organosulphur compounds (Ryg *et al.* 1992). It is the latter compounds that we smell and since they develop only after sexual maturity is reached and then are produced only during the period in which the adult males are thought to defend territories, the function is thought to be related to reproduction and territorial defence (Ryg *et al.* 1992). The rutting males are believed to mark their breathing holes and haul-out lairs with their individual specific smell.

In an attempt to estimate territory size for breeding ringed seals, distances between lair complexes were measured (Lydersen and Gjertz 1986). A lair complex was defined as all lairs of the same type within a distance of 200m. All lairs were plotted on a map based on laser range-finder measurements, and distances between lair complexes were then measured on the map. Based on this method average distance between birth lair complexes was found to be 513 ± 336m, and between different rutting male structures 598 ± 252m (Lydersen and Gjertz 1986).

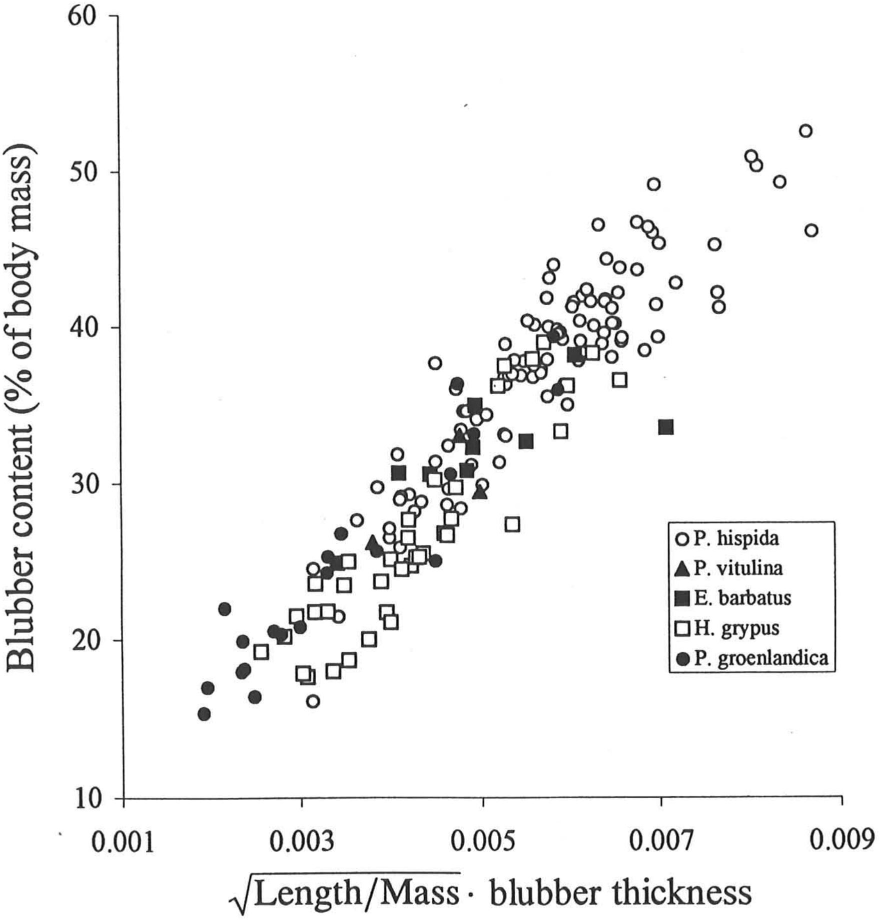
Ovulation rate, defined as number of females with a *c. luteum* present in relation to the total number of sexually mature females, was found to be 0.91.

THERMOREGULATION

Neonates do not have an insulating layer of subcutaneous blubber, but can survive brief immersions in the ice-cold water due to relatively large stores of brown adipose tissue (Taugbøl 1984). As lactation progresses and the pups accumulate blubber, they enter the water and dive voluntarily (Lydersen and Hammill 1993a). Rectal temperatures of dry white-coated ringed seal pups have been found to be stable at ~37.5°C in air temperatures ranging from +5°C to -35°C (Smith *et al.* 1991). However, if the white-coated pup was immersed in ice water for 15min, the rectal temperature dropped to 35.5°C and after immersion in ice water for 30min it dropped to 33.0°C (Smith *et al.* 1991).

In a study of the topographical distribution of blubber in ringed seals, Ryg *et al.* (1988) found that the ratio of blubber thickness to body radius was nearly constant over the body, thereby maximising the blubber available for insulation. The hind part of the body had a higher thickness to radius ratio and was therefore considered to

Fig. 4
Relationship between blubber content and the LMD index (from Ryg et al. 1990a)



be "over-insulated". During periods of mass loss, fat was found to be lost most quickly from these over-insulated areas, thereby reducing the negative thermal effects of the fat loss. Formulas for calculating heat loss in marine mammals were also provided. According to this study, thermal stability can be maintained when blubber is lost if mass is simultaneously lost from the body core.

An index (LMD-index) for estimation of blubber content in phocid seals was developed by Ryg *et al.* (1990a, Fig. 4) based on dissections of several seal species, including ringed seals. The blubber content (B%) could be estimated with a standard error of only 3% by the expression $B\% = 4.44 + 5{,}693\ (L/M)^{1/2} \times d$, where L is standard length (in m), M is body mass (in kg) and d is blubber thickness (in m) measured dorsally at a spot about 60% of the standard length behind the snout.

Another study scaled variables influencing insulation (surface areas, area of appendages, sculp thickness and mass) in eight species of marine mammals ranging in size from ringed seals of 35kg to fin whales (*Balaenoptera physalus*) of 30,000kg (Ryg *et al.* 1993). The heat loss in 0°C water was found to be higher than the predicted basal metabolic rates for small species such as the ringed seal, while the larger whales would probably not need to raise their metabolic rates to keep warm. At rest, 10-30% of the heat production was found to be lost through flippers, fins and flukes. This value would increase to 70-80% during moderate exercise.

DIVING

All diving studies on ringed seals in Svalbard have been conducted during the breeding season. Dive analyses have been published for lactating ringed seal females and pups. In addition, both rutting males and juveniles have been instrumented with TDRs during the spring period, but only juvenile dive data have been recovered (Lydersen unpublished data).

One dive-related study on ringed seals calculated their oxygen stores and estimated the aerobic dive limit based on these stores (Lydersen *et al.* 1992). The oxygen store in the lungs, blood and muscles for an average adult ringed seal (standard length 129cm, body mass 73.7kg) was found to be 4.5 litres. From this value, the aerobic dive limit and the maximum breath-hold capacity were calculated to be 8.9min and 26.1min respectively. Fewer than 4% of all recorded dives for adult ringed seals exceed the calculated aerobic dive limit.

White-coated, nursing ringed seal pups were instrumented with TDRs (Mk 5, Wildlife Computers), and more than 1,000hrs of activity including more than 7,500 dives were recorded (Fig. 5, Lydersen and Hammill 1993a). The pups spent 50% of their time in the water and the rest hauled out on the ice. Most of the dives were shallow and of short duration. Mean dive duration was 59.1 ± 63.3sec, with a maximum record of 12min. Maximum depth recorded was 89m, which was equal to the maximum depth in the study area. The average duration of haul-out sessions was 6.3hrs, and the average time between these was 8.2hrs. The mean number of breathing holes found per pup was 8.7. The large proportion of time spent in the water, the development of diving skills at an extremely young age, the use of multiple breathing holes, and the prolonged white-coat stage are all interpreted to be evolutionary responses to strong predation pressure, mainly from polar bears.

One study using acoustic telemetry to monitor ringed seal behaviour was performed on a lactating female in Kongsfjorden in the spring of 1989 (Lydersen 1991). In this study 150hrs of activity, including 1,321 dives, were recorded. Fifty-five percent of the recorded time was spent diving, while the rest was spent hauled out on the ice. Mean dive duration was 2.7 ± 2.7min, with a maximum recorded duration of 17min. Maximum dive depth was 40m which represents the bottom depth in the study area. Some dive data from another lactating female equipped with Mk 5 TDR was reported by Lydersen (1995). Through 17 days of continuous recording this female spent 82% of her time diving. The maximum dive duration recorded for this female was 21.2min (Lydersen unpublished data).

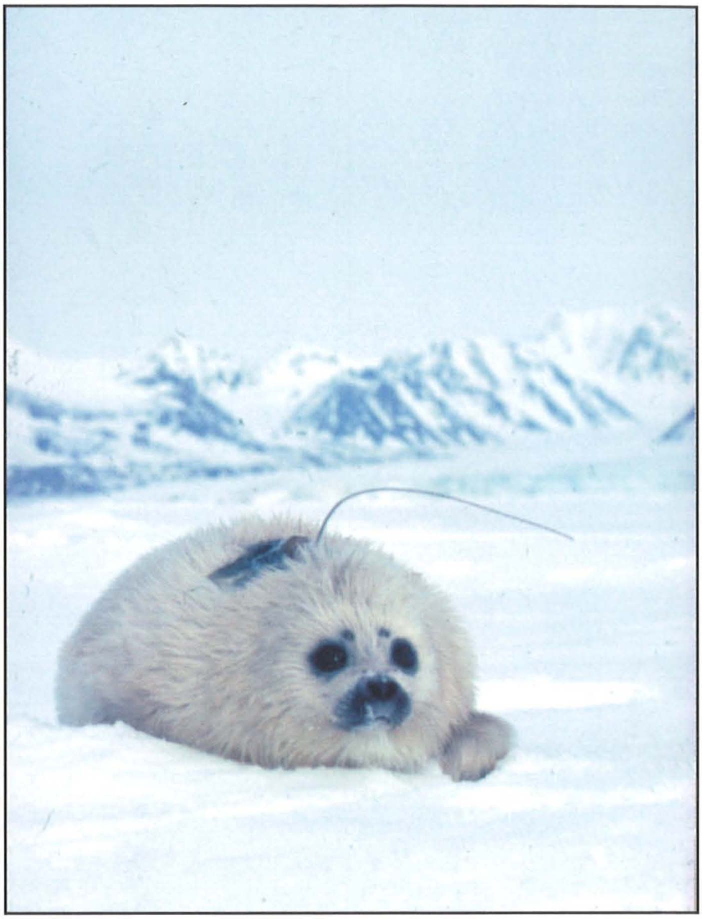


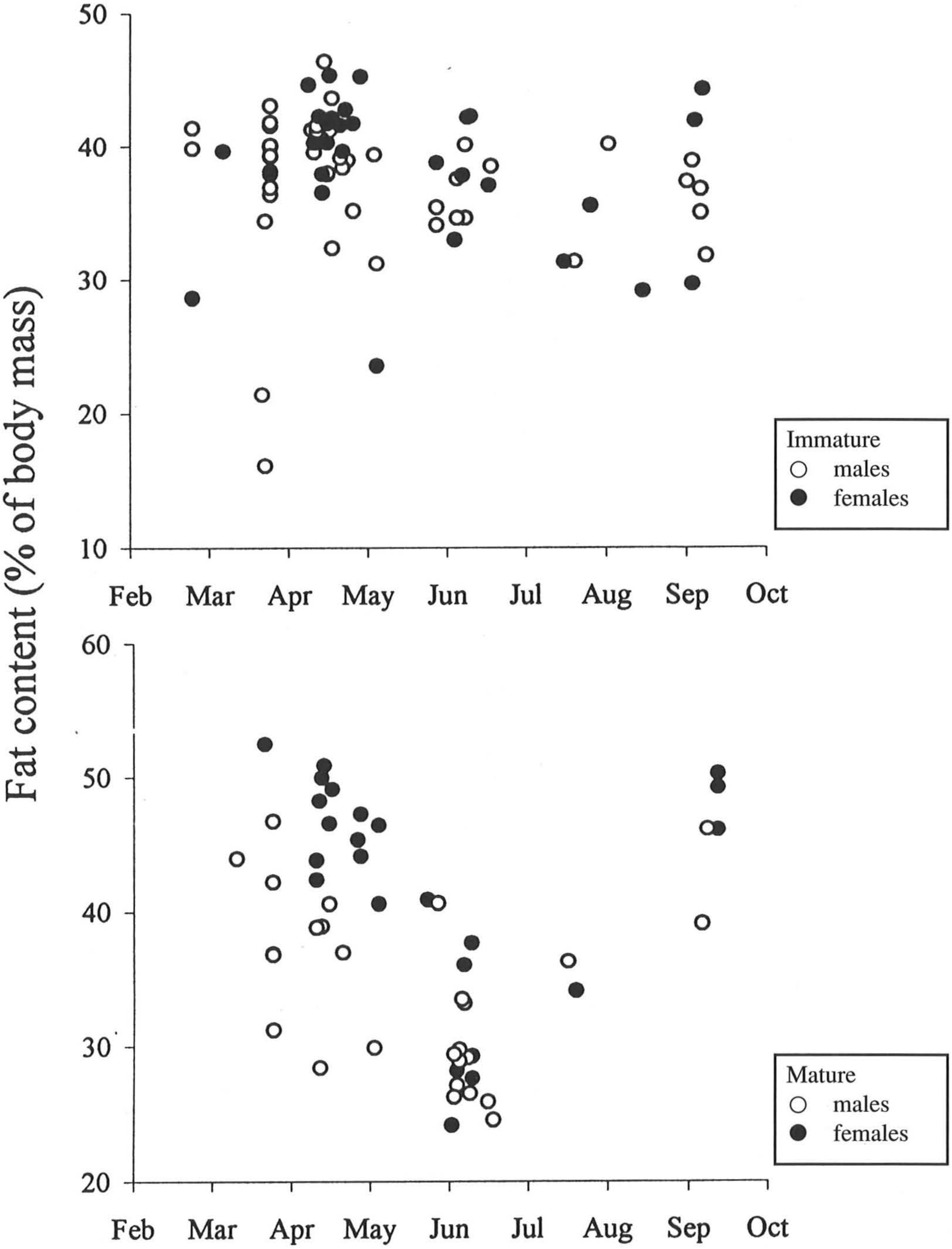
Fig. 5
Ringed seal pup with VHF transmitter and time-depth recorder used in a dive activity study .(Photo K. Kovacs)

ANNUAL CYCLE AND SEASONAL CHANGES

The sequence of events in a female's annual reproductive cycle has been established from studies of reproductive tracts from Canada and Svalbard (see Lydersen 1995). If 1 April is defined as the nominal birth date in the Svalbard area, the average dates for ovulation, weaning and implantation would be 6 May , 9 May and 3 August, respectively.

Seasonal changes in body mass and composition of ringed seals from Svalbard have been described based on standard measurements and dissections of seals collected in the period from

Fig. 6
Seasonal variation in blubber mass of ringed seals from Svalbard. (from Ryg et al. 1990b)



February to September by Ryg *et al.* (1990b, Fig. 6). The blubber content of adult females decreased from a high of about 50% at the beginning of the breeding season to a low of 31% during the June moult. In adult males, the blubber content decreased from 41% in March to 29% in June. The blubber content in immature ringed seals was lower in June and July than in April, but the seasonal changes were less dramatic than in adult seals. No significant changes were found in the core mass of adults, and it was therefore suggested that the seasonal changes in body mass are due mainly to changes in fat content.

Masses of testes, prostate glands and bacula were compared to age, season and body size in ringed seal males from Svalbard (Ryg *et al.* 1991). There was significant seasonal variation in size of testes and prostate glands in sexually mature males, with maximum recordings in April. There was no seasonal change in the prostate gland of immatures, but some of the older immatures had elevated testes weights in April. Testes masses were significantly correlated with lean body mass, and the increase in testes masses with increasing body mass was greater for mature animals than for immatures. It is therefore suggested that some testicular growth and seasonal cycle exists in testes before they become endocrinologically functional.

ENERGETICS

New-born ringed seal pups, which in Svalbard have a body mass of 4.55kg, contain 4.75% fat and 70.1% water (Lydersen *et al.* 1992). Close to weaning, at a body mass of 21kg , the corresponding values are 41% fat and 42% water (Lydersen and Hammill 1993b). During the nursing period the mass gained by the pups is deposited as 76% fat, 6% protein and 18% water (Lydersen and Hammill 1993b). In this period while they still bear their white coat, the pups are active swimmers and divers spending about 50% of their time in the water swimming and diving (Lydersen *et al.* 1993, Lydersen and Hammill 1993a). The metabolic rate of these nursing pups is 0.55 ± 0.10 MJ/kg per day, which corresponds to 3.8 times the predicted basal metabolic rate based on body size (Lydersen and Hammill 1993b). The pups receive 931.5MJ of energy from their mothers via milk during an average lactation period; 36% of this energy is stored in the pups as new tissues. This is a low efficiency compared with other phocid seal pups, and is undoubtedly related to the active life style of the ringed seal pups during the nursing period.

In a cross-sectional study of mass loss in nursing ringed seal mothers, they were found to lose an average of 0.64kg per day from an average postpartum body mass of 81.2kg (Hammill *et al.* 1991). Two longitudinal mass records of nursing females, showed a daily mass loss of 0.62kg and 0.68kg respectively (Lydersen 1995). The energy represented by this mass loss, assuming it was all fat (which it is not), barely covers the expenses of milk production. Crude estimates of the energy lactating females must invest in order to balance their energy budgets add up to 12.5MJ corresponding to the consumption of 2.2kg of polar cod or 3.3kg of *P. libellula* daily (Lydersen 1995) both of which are major components of the ringed seal diet in Svalbard. The total energetic costs of producing a weaned pup include the energy content in the milk and its production, the energy content in the neonate and in the placenta, and the energy expenditure to maintain the metabolic requirements of the growing foetus (heat of gestation). Summing up, these values give a minimum estimate of the net energy required for a ringed seal female to produce one weaned pup of 1,073MJ (Table 1, Lydersen 1995). This value corresponds to 185kg of polar cod or 282kg of *P. libellula.*

Table 1. Minimum estimates of net energy required for a ringed seal female to produce a weaned pup. From Lydersen (1995).

Energy content of new-born	26.3MJ
Energy content of placenta	1.3MJ
Heat of gestation	113.4MJ
Milk energy output	931.5MJ
Total	1,072.5MJ

The blubber contents in adult ringed seal males decrease from 41% of the total body mass in March to 29% in June (Ryg *et al.* 1990). A cross-sectional approach gave an estimate of mass loss of 100g per day for adult males through the period from April to June. The same approach applied to lactating females gave a daily mass loss of 160g for the same period (Ryg *et al.* 1990). Since the latter is a clear underestimate of the real values for females, it may be assumed that this method also underestimates the mass loss of adult males.

A model for energy balance of seals was used to estimate the annual energy requirements of

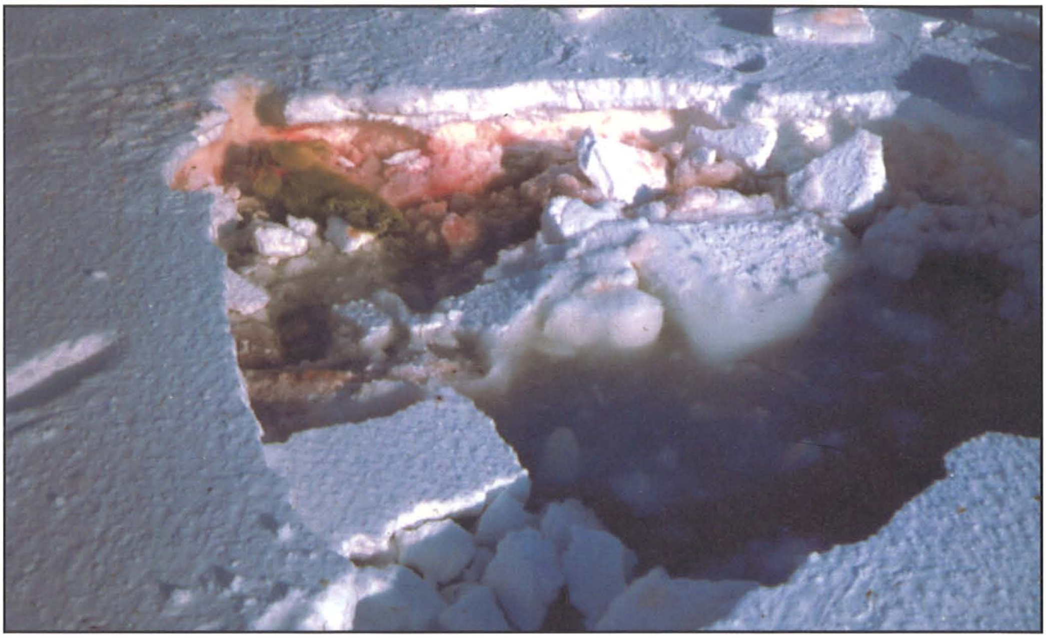


Fig. 7
Ringed seal pup in lair, killed by an Arctic fox. This lair was built on the flat fjord ice with little snow cover and therefore had a very thin roof which was crushed by the photographer. (Photo C. Lydersen)

ringed seals using biological and physical parameters as input (Ryg and Øritsland 1991). This analysis suggested that food intake by ringed seals is highly seasonal. In adult males it is low during the periods of territorial defence, mating and moulting, from March until June. During this period males lose body mass, mainly from fat. The model predicted that lactating females increase their food intake to some extent during the approximately six weeks of lactation. Food intake increases after ice break-up in both sexes, partly as a result of increasing maintenance energy requirements and partly because the body fat stores are rebuilt at this time. The annual gross energy consumption of adult males and females was calculated to be 5.6 x 10^3MJ and 7.3 x 10^3MJ respectively. For an average member of the population when all age groups were considered 4.6 x 10^3MJ would be required.

EXPLOITATION

Ringed seal hunting records from Svalbard which could have provided valuable demographic data are incomplete. Some annual reports concerning Norwegian fisheries (*Årsberetning vedkommende Norges fiskerier*) from 1946 onward do include landings of ringed seals from this region. These reports document ringed seals taken by over-wintering trapping expeditions, and those killed by summer boat expeditions to the "northern ice" between Svalbard and Frans Josef Land. The annual reported catches of ringed seals vary from 0 (several years) to a maximum of 745 (1973). Unfortunately, these records cannot be used as accurate indicators for the Svalbard ringed seal population in isolation, because the over-wintering expeditions include animals taken by over-wintering expeditions in Jan Mayen and Greenland, and the reports from the summer expeditions sometimes include ringed seals from the eastern parts of the Barents Sea. Additionally, large areas of the "northern ice" are outside the Svalbard area. These reports are therefore of little value as an aid to the assessment of annual ringed seal harvests in Svalbard.

PREDATION

In addition to man, the main predators of ringed seals in Svalbard are polar bears, Arctic foxes and glaucous gulls (*Larus hyperboreus*). Polar bear predation on ringed seals during the breeding period in spring has been studied in the Hornsund area and in Kongsfjorden (Gjertz and Lydersen 1986b, Lydersen and Gjertz 1986). Based on trackings and direct observations, 62 bear attacks on ringed seal lairs and 10 attacks on ringed seals hauled out on the open ice were recorded in Hornsund (Gjertz and Lydersen 1986b). The polar bears killed ringed seals in 6 of the attacks on lairs and in one of the attacks on hauled out seals. One of the captured seals was an adult, the rest were juveniles and pups. In Kongsfjorden, 13 ringed seal lairs were attacked by polar bears resulting in one kill (Lydersen and Gjertz 1986). In the same study, Arctic foxes attacked 19 ringed seal lairs and killed the pup in 6 of these cases (Fig. 7).

At some locations in Svalbard, depending on weather conditions, insufficient snow accumulates on top of the fast ice to permit females to dig out a birth lair. In such cases ringed seal pups are born on the open ice without the protection of a lair (Gjertz and Lydersen 1983). Mortality rates among these pups are high. Under such circumstances, glaucous gulls kill ringed seal pups (Lydersen and Smith 1989). In addition, glaucous gulls are important scavengers on seal carcasses, a role that is also assumed by ivory gulls (*Pagophila eburnea*), great skuas (*Stercorarius skua*) and Arctic foxes. Even a snowy owl (*Nyctea scandiaca*) has been observed eating a ringed seal pup carcass (Lydersen and Ryg 1990). The pup had been transported by the owl away from the place it was killed so it was impossible to say whether it was killed by the owl, or if the owl was scavenging a kill by another predator.

Walruses are potential predators of ringed seals but no investigation has been conducted in Svalbard to evaluate the impact of walruses as a predator of this species. However, photographic documentation exists of a walrus eating a ringed seal in the Svalbard area (Fig. 8, Born *et al.* 1995). In addition, clear avoidance behaviour has been documented by a ringed seal in Svalbard when walruses are present; the seal quickly climbed out of the water (Gjertz 1990). This suggests that ringed seals feel threatened by this potential aquatic predator. Other possible predators of ringed seals in the Svalbard area include killer whales (*Orcinus orca*) and Greenland sharks (*Somniosus microcephalus*). Killer whales have frequently been observed in the Svalbard area, but predation by this whale on ringed seals has not been documented. The same is true for Greenland sharks, and they have often been observed eating ringed seal sculps that trappers have left in shallow water to rinse.

In a broader context Smith and Lydersen (1991) identified a point of potential conflict between polar bears and ringed seals. An annual pup production of 20,000 (Smith and Lydersen 1991) is far too low to maintain a polar bear population of about 2,000 animals (Wiig 1995). This apparent discrepancy may be due to one or more of the following factors. Firstly, the pup production of 20,000 calculated by Smith and Lydersen (1991) accounts only for pups born on

Fig. 8
Walrus feeding on a ringed seal in Svalbard. (Photo M. Forsberg)

the fast-ice areas around the Svalbard archipelago. Any production in the drifting pack ice between Svalbard and Frans Josef Land, and between Svalbard and Greenland, is not included. Secondly, many of the 2,000 bears in Wiig's estimate (1995) are found in the pack ice between Svalbard and Frans Josef Land and between Svalbard and Greenland, and therefore hunt in areas beyond those included in the ringed seal analyses. Thirdly, even if the ringed seal is the most important prey species for polar bears in this area (Lønø 1970), other species such as the bearded seal (*Erignathus barbatus*) and the harp seal (*Phoca groenlandica*), also play an important role, although the predation on these species has never been quantified.

PARASITES AND DISEASES

In 1980 rabies was detected in a ringed seal pup that was found several hundred meters away from a breathing hole (Ødegaard and Krogsrud 1981). It was assumed that the seal got this infection after being bitten by a rabid Arctic fox. Diaphragms from 252 ringed seals from Svalbard have been examined for *Trichinella* sp. (Larsen and Kjos-Hansen 1983). None of these seals was found to be infected by this parasite. Parasites from the gastro-intestinal system have been collected from ringed seals from Svalbard on several occasions, but only one preliminary report has so far been presented (Vik 1986). Nematode larvae were found in some ringed seal stomachs, and cestodes, nematodes and acanthocephalans were found in the intestines. In addition, trematodes were found in the liver and gall bladder of one ringed seal.

In connection with the seal epizootic in northern Europe in 1988, samples from ringed seals from Svalbard, collected in 1986 before the outbreak, were tested for antibodies to canine distemper virus. No such antibodies were found (Dietz *et al.* 1989).

POLLUTION

Tissues from ringed seals have been collected in Svalbard on several occasions and analysed for various pollutants. Blubber from ringed seals from Svalbard and the Baltic were compared with respect to levels of PCB, PCC (polychlorinated camphenes = toxaphene) and DDT (Andersson *et al.* 1988). Concentrations of these three pollutants in ringed seals from Svalbard collected in 1980 were 10.0, 4.4 and 5.0mg/kg extractable lipid respectively, while the corresponding values for Baltic ringed seals were 75, 12 and 65 mg/kg extractable lipid. These measurements were part of a larger study that included birds, fish and other seal species. It is notable that concentrations of the various pollutants were found to be higher in Svalbard ringed seals than in harp seals from the Gulf of St Lawrence.

Concentrations of polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF) were determined in ringed seals collected in Kongsfjorden in 1986 (Oehme *et al.* 1988). Levels were lower than reported from the Baltic and comparable to levels found in harbour seals from the west coast of Sweden. The values of these compounds in ringed seals from Svalbard were, however, found to be surprisingly high, given that the closest source of PCDD and PCDF are several thousands of kilometres away. The PCDD and PCDF levels in Svalbard ringed seals suggested that contamination of this sort was now a problem of global concern. The same group published a re-evaluation of this paper in 1990, when they realised that the seals were sampled in Kongsfjorden where there is, and has been for most of this century, a settlement, and therefore the source of contamination might not be "thousands of km away" (Oehme *et al.* 1990). In this re-evaluation, sex and age data on the ringed seals were included and the levels of contaminants were compared to material published since their first publication in 1988. The conclusion was that the levels of PCDD and PCDF are similar to findings in other places in the Arctic and that there is no indication of bias from local emission in the measured levels in Kongsfjorden (Oehme *et al.* 1990).

Another study compared PCDD and PCDF in seals from the northern and southern hemispheres, including ringed seals from Svalbard collected in 1981 (Bignert *et al.* 1989). They found no differences in the levels of PCDD and PCDF in seal species from the northern hemisphere (ringed, harp, grey (*Halichoerus grypus*) and harbour (*Phoca vitulina*) seals). However, all these species had higher levels than crabeater seals (*Lobodon carcinophagus*) from the Antarctic.

Levels of persistent organochlorines normally increase in animals with increasing age. No such age effect was found by Bignert *et al.* (1989). Nor were there any sex effects. The levels in seal blubber were the same as those found in humans. Blubber samples from ringed seals collected in Kongsfjorden in 1981 were also used as baseline material for a study of concentrations of persistent chlorinated and brominated organic compounds in Swedish biota (Jansson *et al.* 1993).

Samples of seal blubber from several regions, including Svalbard, Iceland, the North Sea, the Baltic and Antarctica, have been collected and analysed for chlorinated hydrocarbon compounds (Luckas *et al.* 1990). Varying concentrations of organochlorine compounds (PCB, DDT and its metabolites) were found to lead to characteristic residue patterns. Evaluation of these data demonstrated significant geographical differences in both levels and patterns of contaminants analysed, thus giving insight into the global distribution of organochlorine pollution.

In order to determine background levels of persistent chlorinated hydrocarbons and inorganic elements in biological material from Svalbard before possible enhanced industrial activity in this area, tissue samples were analysed from a variety of different species, including ringed seals collected in Hornsund (Carlberg and Bøler 1985). Ringed seal blubber and liver samples were analysed for different pollutants including PCBs, DDT, toxaphene, chlordans and many heavy metals.

A study of different PCBs from various tissues in ringed seals collected in Kongsfjorden and Tempelfjorden showed clear differences in residue levels between mature males and females (Daelemans *et al.* 1993). Males had significantly higher concentrations, probably because females excrete lipids and associated xenobiotics during lactation. This study shows how important it is to include information on sex when comparing levels of PCBs between different samples. Another study found the same trend in relation to gender in PCB concentrations, but also a systematic variation within the blubber column of each individual ringed seal (Severinsen *et al.* 1995). The highest concentrations were found in the blubber closest to the skin, while lower levels were found in the deepest part of the blubber column close to the body core. This study indicates that standard methods or detailed descriptions for sampling of tissues from seals are needed for comparisons of concentrations to be done in a meaningful way.

In addition a study testing the viability of using microprobe analysis on dental tissues showed that lead and strontium were present in detectable quantities in teeth from ringed seals from Svalbard (Cruwys *et al.* 1994).

MANAGEMENT

According to the regulations concerning management of wildlife and freshwater fishes on Svalbard and Jan Mayen (*Forskrifter om forvaltning av vilt og ferskvannsfiske på Svalbard og Jan Mayen*) from 11 August 1978, ringed seals are protected against hunting in this area during the period 15 March - 15 April. This period is specified in order to protect lactating ringed seal mothers with dependent offspring. Since most of the ringed seals pup in the first week of April and the average nursing period is 39 days, this protection period should be adjusted to match the annual reproductive cycle of this seal species in this area. Therefore, a proposal for a new protection period is currently being evaluated, and will probably result in protection being shifted to the period from 20 March - 20 May. Outside this period ringed seals can be freely hunted with no restriction other than that hunting can only be conducted with high powered rifles.

In connection with a possible, mainly petroleum related, increase in industrial activities on Svalbard, an assessment system for environmental and industrial activities in Svalbard (MUPS) has been developed (Hansson *et al.* 1990). Before implementation of industrial activities in any specific area, the area in question will be subjected to an environmental survey and studies of potential impacts. Within this analysis system several "valued ecosystem components" or VECs have been defined. A VEC is defined as a resource or environmental factor that:

a) is important (not only economically) to local human populations, or
b) has a national or international profile, or
c) if altered from its existing status will be important for:
    - the evaluation of environmental impacts of industrial developments and
    - the focusing of administrative efforts.

A more simple definition is that "a VEC is something that gives a politician a headache if something happens to it" (Hansson *et al.* 1990).

The ringed seal is one of the VECs and, in that context, hypotheses of impacts on ringed seal populations caused by industrial activities have been evaluated. Those hypotheses found to be most valid have resulted in a set of recommendations for ringed seal investigations. If an industrial company wants to explore an area inhabited by ringed seals, it will have to pay for relevant ringed seal studies as defined within the MUPS system before proceeding. The outcome of these studies will then determine whether the proposed activity will be allowed to proceed.

OTHER STUDIES

Finally, two other studies should be briefly mentioned. In one study, eyes from ringed seals from Svalbard were collected and the corneal anatomy described and compared with eyes from other marine mammals (Pardue *et al.* 1993). In another study, the blubber of ringed seals from various areas, including Svalbard, was analysed for long chain polyunsaturated fatty acids (Käkelä *et al.* 1995). The fatty acids in the blubber of marine ringed seals were different from those in the blubber of freshwater ringed seals (from Lake Saimaa and Lake Ladoga), and these differences were probably due to differences in dietary fatty acids.

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