# SESSION 4: Marine mammals

## T. Haug[1] and V. Svetochev[2]: Seals in the Barents Sea

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### Introduction

Six seal species occur regularly in the Barents Sea. Three of these have adapted to life in the Arctic such that they spend their entire lives in the northernmost (Svalbard – Franz Jozef Land) and east-southeastern (Novaja Zemlja – Pechora) range areas of the sea: walrus, bearded seals and ringed seals. In the southern areas, grey and harbour seals reside on the Norwegian and Murman coasts. Following severe overexploitation, walruses were given total protection in the area in 1952. For ringed, bearded, grey and harbour seals, a certain amount of game hunting has continued in some areas to the present day. Only one seal species in the area has been subject to large-scale commercial exploitation: the harp seal*. The species is by far the most numerous and ecologically also the most important seal in the Barents Sea ecosystem. It has been exploited and managed jointly by Norway and Russia during the past two centuries. In the following, therefore, we focus only on harp seals.

### Stock characteristics

### Distribution

Harp seals are a wide-ranging, migratory species. Three stocks (Figure 1) inhabit the North Atlantic Ocean, whelping on the pack ice off Newfoundland and in the Gulf of St. Lawrence (the Northwest Atlantic stock), off the east coast of Greenland (the Greenland Sea or West Ice stock), and in the White Sea (the Barents Sea or East Ice stock) (Lavigne and Kovacs 1988). During the spring, harp seals display a set sequence of activities - whelping (in March-April), followed by 12 days of intensive lactation, then mating, after which the females wean their pups. Adults and immature seals moult north of each whelping location after a further lapse of approximately four weeks. The location of these events in the Northeast Atlantic is either the fringe of winter ice, lying seawards of the heavier Arctic ice off the east Greenland pack, located between the latitudes 69°N and 75°N (the West Ice stock, Øritsland and Øien 1995), or the White Sea and south-eastern parts of the Barents Sea (the East Ice stock, Haug et al. 1994). When the moult is over, the seals disperse in small herds to feed. Their location at this time of the year is heavily dependent on the configuration of the drifting sea ice. Seals from the West Ice disperse over the drift ice along the east coast of Greenland, from the Denmark Strait or farther south, northwards towards Spitsbergen, and into the Barents Sea. The East Ice seals follow the receding ice edge during summer, gradually moving northwards and north-eastwards in the Barents Sea. Overlap between harp seals from the West Ice and East Ice occurs in the northern Barents Sea during summer and autumn, which are the most intensive feeding periods for the species. The movement towards the breeding areas (in the Greenland Sea and White Sea for the West Ice and East Ice stocks, respectively) begins in November-December.


**Figure 1. Locations of North Atlantic harp seal stocks. Green spots mark the whelping and moulting areas for the Barents Sea/White Sea (also called the East Ice) stock (the White Sea), the Greenland Sea or West Ice stock (West Ice), and the northwest Atlantic stock (Front and Gulf areas). Dark blue marks the entire area of distribution.**

### Size

The Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP) met at ICES headquarters, Copenhagen, Denmark, on 2-6 October 2000 to assess the most current status of the stocks of Barents Sea/White Sea and Greenland Sea harp seals (ICES 2001a).

Russian aircraft and helicopter surveys of Barents Sea/White Sea harp seal pups were conducted in the White Sea in March 1998 and 2000 using traditional strip transect methodology and multiple sensors (ICES 2001a, Poteov et al. 2003). Black and white, ultraviolet and thermal infra-red scanners were employed. The estimates are considered to be negatively biased since they were not corrected for pups, which might have been hidden from the camera, or for pups missed by the readers. Furthermore, the survey estimates were not corrected for the temporal distribution of births.Actual pup production may therefore be higher than the estimates presented below:

| Year | Pup production estimate | c.v. |
|---|---|---|
| 1998 | 286 260 | .073 |
| 2000 | 322 474 | .089 |
| 2000 | 339 710 | .095 |

These pup production estimates were used by WGHARP to assess the entire population on the basis of a population dynamics model that estimated the development of future population size, for which statistical uncertainty was provided for various catch options (ICES 2001a). The age structure of the model was restricted to two age classes, 0 (pups) and 1+ (one year old or older), because of limited information on catch at age and age structure for the populations in question, and because of the fact that catches were rather small compared to population size in the years for which catch at age is known. The model requires estimates of mortality and reproductive parameters that include variance. Using the historical catch data and estimates of pup production, the model estimates mortality ($M_0$ and $M_{1+}$) and a birth rate in the 1+ population of females (f). The freedom with which the model can estimate these parameters is dependent upon the standard deviations provided. The model is fitted to pup production estimates weighted inversely to their variance in cases where more than one estimate is available.

The possibility of including multiple pup production estimates in the assessment model is an improvement on previously used estimation programmes. However, models of this nature do not estimate parameters well when pup production estimates are derived from a limited period in time compared to generation time. The model has the option of allowing estimates of population size and sustainable catch to be made, but when given no prior information about $M_{1+}$ and f, the model treats these parameters as independent parameters. To stabilize the model, the range of these parameters had to be constrained. As a result, the estimates of uncertainty may be negatively biased, and the confidence intervals for future population sizes may be too narrow.

There are reports that pup mortality rates may vary substantially in the White Sea region, and that in recent years these rates have been very high. For this reason, the abundance of White Sea/Barents Sea harp seals in 2000 was estimated under two different assumptions about the ratio $M_0/M_{1+}$:

| Parameter | Estimate | 95% CI |
|---|---|---|
| $M_0/M_{1+} = 3.0$ | | |
| 1+ population in 2000 | 1 727 000 | 1 550 000 – 1 910 000 |
| Pup production | 319 000 | 286 000 – 351 000 |
| $M_{1+}$ | 0.10 | 0.07 – 0.12 |
| $M_0/M_{1+}$ | 3.0 | Fixed |
| F (birth rate for 1+ females) | .42 | Fixed |
| | | |
| $M_0/M_{1+} = 5.0$ | | |
| 1+ population in 2000 | 1 676 300 | 1 500 000 – 1 850 000 |
| Pup production | 314 000 | 283 000 – 346 000 |

| | | |
|---|---|---|
| $M_{1+}$ | 0.09 | 0.07 – 0.11 |
| $M_0/M_{1+}$ | 5.0 | Fixed |
| F (birth rate for 1+ females) | 0.42 | Fixed |

When the Advisory Committee on Fishery Management (ACFM) reviewed the results of the WGHARP assessments at its autumn 2000 meeting (ICES 2001b), the conclusion was that the stock was within safe biological limits, that numbers were estimated to be increasing, that catches through the 1990s had been below quotas, and that there was some evidence that densities may have been so high that biological processes such as rate of maturation may be showing density-dependent effects.

During the period 1977-1991, about 17 000 harp seal pups were tagged in a comprehensive mark-recapture experiment in the Greenland Sea (Øien and Øritsland, 1995). Updates of the mark-recapture-based pup production estimates indicated a pup production in 1991 of 67 300 (95% CI 56 400-78 113) (NAFO, 1995). Aerial surveys performed in 1991 suggested a minimum pup production in this year in excess of 55 000 (Øritsland and Øien, 1995). When assessing the present status of the stock, WGHARP used the new population dynamics model described above, and calculated a projected 2000 pup production estimate of 76 700 (95% CI 48 000 – 105 000) and a total size of the 1+ population of 361 000 with a 95% confidence interval ranging between 210 000 and 629 000 animals (ICES, 2001a). In its review of the WGHARP assessment, ACFM concluded that the Greenland Sea stock of harp seals was within safe biological limits, and that recent removals had been well below the recommended sustainable yields (ICES 2001b).

**Position in the food web**

Barents Sea harp seals display opportunistic feeding patterns in that different species are consumed in different areas and at different times of the year. However, the bulk of the harp seal diet is comprised of relatively few species, in particular capelin, polar cod, herring *Clupea harengus*, krill *Thysanoessa* spp. and the pelagic amphipod *P. libellula*. The crustaceans appear to be of particular importance as food for harp seals during their summer and autumn feeding in the northern parts of the Barents Sea (July-October). As the ice cover expands southwards in late autumn and winter, the southward-migrating seals appear to switch from crustaceans to fish (particularly capelin and polar cod) as their preferred food (Nilssen et al. 1995a; Lindstrøm et al. 1998). In the southernmost areas of the Barents Sea, where the seals occur during winter and early spring, herring is also an important forage fish (Nilssen et al. 1995b). Several fish species may serve as prey for harp seals during the late autumn and winter. Nilssen et al. (2000) calculated the total food consumption by harp seals in the Barents Sea using data on energy intake, diet composition, energy density of prey and predator abundance. The food consumption of around two million harp seals was calculated for periods with a high and low capelin stock (both situations occurred in 1990-1996, the period during which the seal diet data was collected). Assuming that there are seasonal changes in metabolic rate associated with changes in body mass (blubber deposition), and that the field metabolic rate of the seals corresponded to two times their predicted basal metabolic rate, the annual food consumption of the harp seals was estimated to be within a range of 2.69 - 3.96 million tonnes of biomass. Distribution of the harp seals' energy requirements across a representative mix of prey species gave point estimates of 1.22 million tonnes of crustaceans, 808,000 tonnes capelin, 605,000 tonnes polar cod, 212,000 tonnes herring and a mixture of gadoids and other more Arctic fishes of circa 500,000 tonnes (Figure 2). A low capelin stock (as in 1993-1996) led to a switch in harp seal diet, with increased consumption of other fish species, in particular polar cod, other gadoids and herring.

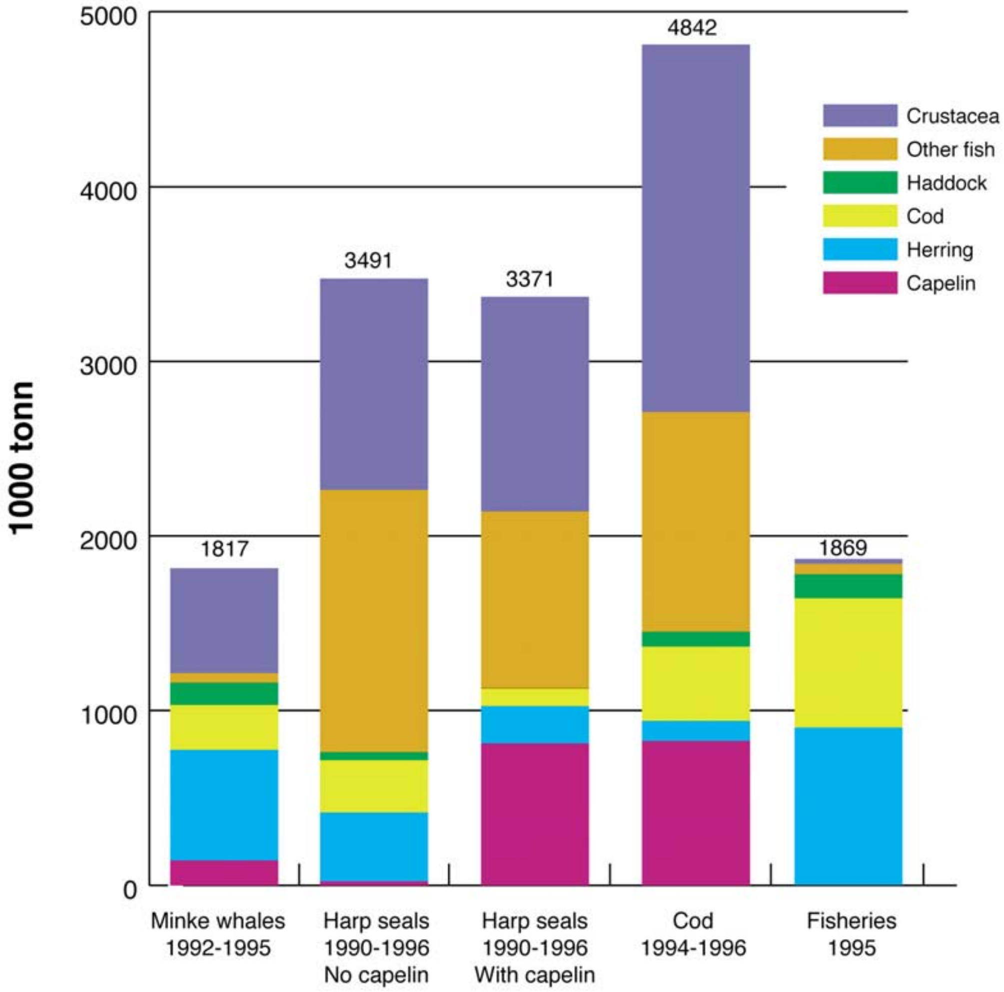


**Figure 2. Estimated annual consumption by East Ice harp seals in the Barents Sea in the early 1990s. Scenarios with and without capelin are shown, and comparison is also made with the annual consumption of minke whales and cod, and with total fishery removals in 1995. Based on data provided by Bogstad et al. (2000).**

Recent observations from satellite tagging experiments suggest that Greenland Sea and Barents Sea harp seals likely overlap in their feeding range during the summer and autumn (June-October) in the northern Barents Sea (Lars P. Folkow, University of Tromsø, Norway, pers. comm.). This means an additional pressure on the Barents Sea resources which need to be added to the results given by Nilssen et al. (2000).

Due to seasonal variation in food availability the body mass of many marine mammals feeding in the Arctic, including harp seals, varies substantially in an annual cycle. There is a regular seasonal pattern of deposition of energy reserves as fat in the subcutaneous blubber layer. This is well illustrated in Barents Sea/White Sea harp seals (see Nilssen et al. 1997), which are generally thin in spring and early summer (May – June). Their condition improves over the summer, and they are quite fat by September – October. The energy stores built up during the summer and autumn are maintained until February, but then the seals become thinner as their stores of blubber diminish rapidly during the breeding and moulting period (March-June). How these variations in deposited fat affect body weight is illustrated by the case of harp seals - an adult (165 cm long) harp seal which would weigh 80 kg in June weighs 145 kg in October, a change of 81.5% (Nilssen et al. 1997). The ability to store large amounts of energy and sustain significant periods of fasting is an essential adaptation for most Arctic mammals.

**Ecosystem changes and density dependency**

Ecosystem changes that may affect marine mammal populations, e.g., through changes in food or habitat availability. The winter/spring harp seal invasions to coastal areas of North Norway may serve as a useful example of one type of interaction (see Haug et al. 1991, Haug & Nilssen 1995). Since 1978, Barents Sea harp seals have appeared in large numbers in Finnmark, North Norway, from February until May. The size of the seal invasions increased dramatically in 1987 and 1988 when huge herds of seals (hundreds of thousands) were observed along the coast of North Norway between January and August. The seal invasions gave rise to seal-fisheries conflicts. In addition to consuming fish, the seals caused substantial damage to gill nets and gill net catches. The presence of seals may also have resulted in the emigration of commercial species from traditional fishing grounds to deeper strata or areas unsuitable for fishing. Reduced recruitment to the seal population seems to have prevailed during most of the seal invasion period, particularly during 1986-1988, when first-year mortality may have been almost total. Food shortage, particularly of the three important prey species capelin, polar cod and herring, probably caused the coastal invasions. The following scenario has been suggested as an explanation of this phenomenon. A series of cold years in the Barents Sea initially led to a more westerly winter distribution of a growing population of harp seals. A food shortage, possibly resulting from the 1985-1986 collapse in the capelin stock and a generally low stock of polar cod, following intensive fisheries for both species in the 1960s and 1970s, may have intensified the problem by forcing large numbers of harp seals to leave their traditional wintering areas in the south-eastern Barents Sea in favour of the coast of North Norway in 1987 and 1988. Mortality, particularly of young animals, appears to have risen, leading to reduced recruitment to the population. Substantial increases in the abundance of immature Norwegian spring spawning herring in the south-eastern Barents Sea may have resulted in the establishment of a suitable alternative winter food resource for the harp seals, thereby contributing to the reductions in the size of the seal invasions observed since 1988. In the 1990s, improved stocks of capelin and polar cod may also have contributed to reducing the seal invasions (Nilssen et al. 1998).

Pinniped age is usually estimated from counts of growth layers deposited in teeth, and the longevity of harp seals is 20-40 years (Bowen et al. 1983, Kjellqwist et al. 1995). In stock assessment, age at maturity is a parameter of vital importance. Age at maturity is not an absolute value in animal populations in that it varies in response to environmental changes. This is nicely exemplified in the northwest Atlantic population of harp seals, where a significant decrease in mean age at maturity from 5.8 years in the early 1950s to 4.6 years in the early 80s coincided with a harvest-driven reduction in population size from three to 2.4 million animals with an intermediate low of 1.8 million animals in the early 1970s (Shelton et al., 1996; Sjare et al., 2000). Some early studies suggested that this was a simple density-dependent relationship between population size and age at maturity in harp seals, which might then serve as a convenient indicator of trends in stock abundance (Bowen et al., 1981; Lett et al., 1981). However, a substantial increase in the Northwest Atlantic harp seal population to 5.3 millions in 1997 was only accompanied by a modest increase in mean age at maturity to 5.6 years in 1995-97 (Sjare et al., 2000), suggesting that a more complex relationship exists. The essential principle of density dependence is one of resource limitation. In an ice-breeding species like harp seals the limiting resource is probably food rather than breeding space, as is also suggested by observations of negative correlations between body growth rates and age at maturity in both Northwest Atlantic and Barents Sea (East Ice) harp seals (Innes et al., 1981; Kjellqwist et al., 1995, Chabot et al., 1996). Food limitation might result from an increase in population size as well as changes in ecosystem carrying capacity due to density independent changes in prey availability or levels of competition from other consumers, including man.

Starting from similar values (5.4 - 5.6 years) in the early 1960s, age at sexual maturity appears to have followed different trends in the two stocks of Northeast Atlantic harp seals (Frie et al., 2003). In the West Ice stock no long-term trend was found whereas in the East Ice stock mean age at maturity had increased to 8.2 years in the early 90s (Figure 3). Present knowledge of population fluctuations and general ecology of these two stocks is too incomplete to fully understand the possible causes for the observed differences, but both density-dependent and density-independent factors are likely to be involved. The different trends in age at sexual maturity (and also growth rates) between the two Northeast Atlantic harp seal stocks indicate that maturing animals from the two stocks have experienced different food-availability scenarios in the 80s and perhaps even before that time. In the case of the Barents Sea stock, it is generally thought that the implementation of a series of catch regulations allowed the stock to increase from a historical low in the early 1960s (Sergeant 1991, ICES 2001a), and this may have contributed to the observed changes in growth and age at maturity. However, Frie et al. (2003) emphasize that the observed changes may be due to changes in the Barents Sea ecosystem, in particular occasional low availability of important forage fish such as capelin *Mallotus villosus* and polar cod *Boreogadus saida* during the winter and early spring. Little is known about the ecology and trends in abundance of the West Ice stock, although it is acknowledged that the stock must have increased since the early 1960s (Ulltang and Øien, 1988; Øien and Øritsland, 1995, ICES 2001a).

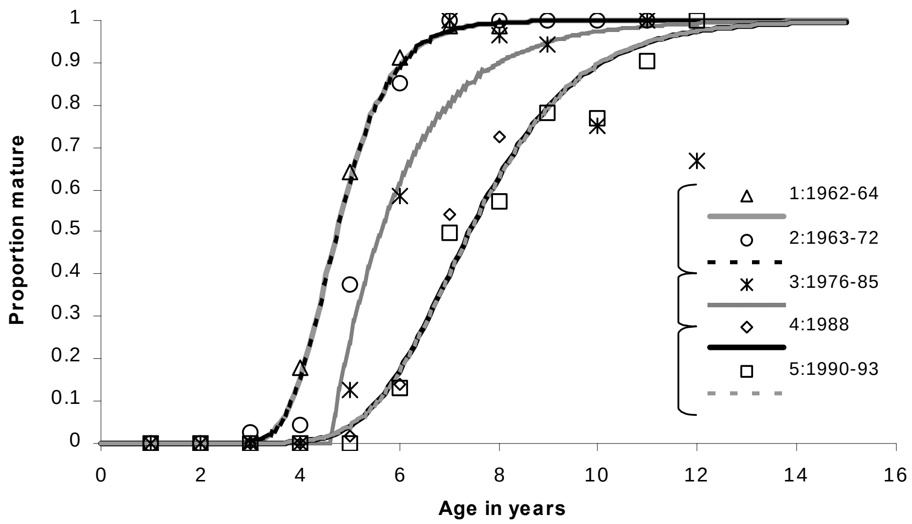


**Figure 3. Changing age at sexual maturity in East Ice harp seals. An increase in mean age seems to have prevailed from 5.6 years in the two first periods (1962-64 and 1963-72) to 8.2 years in the last (1990-93) period. From Frie et al. (2003).**

## Catch history

In their historical assessment, Skaug and Øien (in prep) noted that the Barents Sea/White Sea (East Ice) stock of harp seals had been hunted by Norwegian and Russian sealers over a long period of time, probably since the 12th century, and that documentation of these catches was scarce. The fishery was originally shore-based, taking place along the coasts of the White Sea and around the Kanin Peninsula (see Sergeant 1991). Offshore hunting started when vessels from North Norway caught harp seals in 1867 (Iversen 1927); they were joined by vessels from Western Norway from 1919 onwards and by Soviet vessels during the 1920s. Prior to 1875 there were many years without catch information at all, but Iversen (1927) assumed that the catches were probably quite small, supposedly annually in the hundreds. After 1875 total catches increased, with levels of between 15 000 and 60 000 up to around 1900, above 100 000 after that year, and with the largest catches taken in the 1920s and 1930s (annual average of 200 000 - 300 000 animals, and a top in 1925 when nearly 470 000 seals were taken) (Iversen 1927, Sivertsen 1941, Nakken 1988, Skaug and Øien in prep.).

In 1924-1939, Norwegian seal hunting in the White Sea and in the southeastern part of the Barents Sea was conducted under Soviet licence, and up to 1933 the Norwegian harvest exceeded that of Soviet sealers. Mean annual Norwegian harp seal catches in 1920 -1933 were 170 000 animals, whereas the Soviet mean catch was about 102 000 animals. During 1934 – 1939, the Norwegian annual harvest was reduced to 43 000. According to Surkov (1957), the distribution of harp seal whelping patches changed within the White Sea area from the mid 1930s. Simultaneously, the number of sealing vessels was reduced. Nevertheless, Soviet catches rose. After World War II the seal catch licences for Norwegian vessels in the White Sea region were not renewed. For this reason, Norwegian catches began to be based on taking animals on drifting ice in the Barents Sea. The mean annual Norwegian seal harvest in 1946 - 1964 was 15391 animals, the results of each year's harvest being particularly dependent on effort (number of vessels and trips), hydrometeorological conditions (weather, current and ice) and various features of breeding ground distribution.

While exploitation was low during World War II, the total hunting pressure increased substantially from 1946 onwards (Figure 4), and the population was probably reduced from 1.25-1.5 million individuals in the 50s (numbers based on aerial surveys on the moulting grounds in 1952-1953 and in 1959; (Surkov 1957, 1963)) to less than 500 000 in the mid-60s (Bowen et al. 1981). According to Dorofeev (1939, 1956), aerial surveys performed on the moulting grounds in 1927-1928 suggested that the population at that time may have been 3.0-3.5 million individuals. Quotas for the Soviet catches were introduced unilaterally in 1955 (100 000 seals, Yakovenko 1963) and were gradually reduced until 1965, when a quota of 34 000 seals was imposed for the total catch (taken by Norway and Soviet together). Adult females were protected in the whelping patches in 1963, and Soviet catches of 1+ seals stopped in 1965 (Kjellqwist et al. 1995). Minimum pup production was estimated at about 100 000 in 1965 (Benjaminsen, 1979), which by projection of population models gave an estimated pup production of 170 000 in 1978, corresponding to a total population of around. 800 000, which was estimated to increase by 5% per year. This projection assumed a median age at first whelping of five years. Assuming a median age at first whelping of six years, which is more in line with recent estimates (Frie et al. 2003), the projected pup production in 1978 was 141 000. However, as the 95% confidence interval of the 1965 pup production estimate ranged from 74 000-221 000 these calculations can hardly be taken to indicate an increasing trend in pup production. In the 1980s, Russian aerial surveys of whelping females and age composition data indicated reduced recruitment (Krylov, 1986; Ulltang and Øien, 1988; ICES, 1992, 1994; Kjellqwist *et al.*, 1995; Timoshenko, 1995), which was corroborated by the near absence of the 1986-1988 year-classes in later Norwegian catches from the moulting grounds (Kjellqwist *et al.*, 1995, Nilssen *et al.*, 1998). Some caution is warranted, because surveys of whelping females rely heavily on the accuracy of correction factors for the proportion of females in the water, which may vary considerably with time of day, meteorological conditions and perhaps also local food availability, since female harp seals have been found to feed opportunistically during lactation (Nilssen et al. 1995b, Lydersen and Kovacs 1996). Increased catches in the late 70s and in 80s (annual quotas increased to 50 000 in 1977, 60 000 in 1981, 75 000 in 1982, reaching a maximum of 82 000 in 1983, then decreasing to 80 000 in 1984-1987) and large bycatches of harp seals in Norwegian gill net fisheries in the period 1986-1988 may also have influenced the status of the stock (Haug and

Nilssen, 1995; Kjellqwist *et al.*, 1995). The total quota was reduced to 70 000 in 1988 and further down to 40 000 in 1989-1998. Although there is no hard evidence of changes in the siz of the population of Barents Sea/White Sea harp seals from the 60s onwards, there may be some reason to expect an increase in numbers, owing to the implementation of several catch regulations such as full protection of whelping females from 1963, a stop in Soviet catches of 1+ animals and a general decrease in catches due to a new quota system from 1965 (Benjaminsen, 1979, Sergeant 1991). As seen from Figure 4, the majority of catches in 1965-2002 were pups.

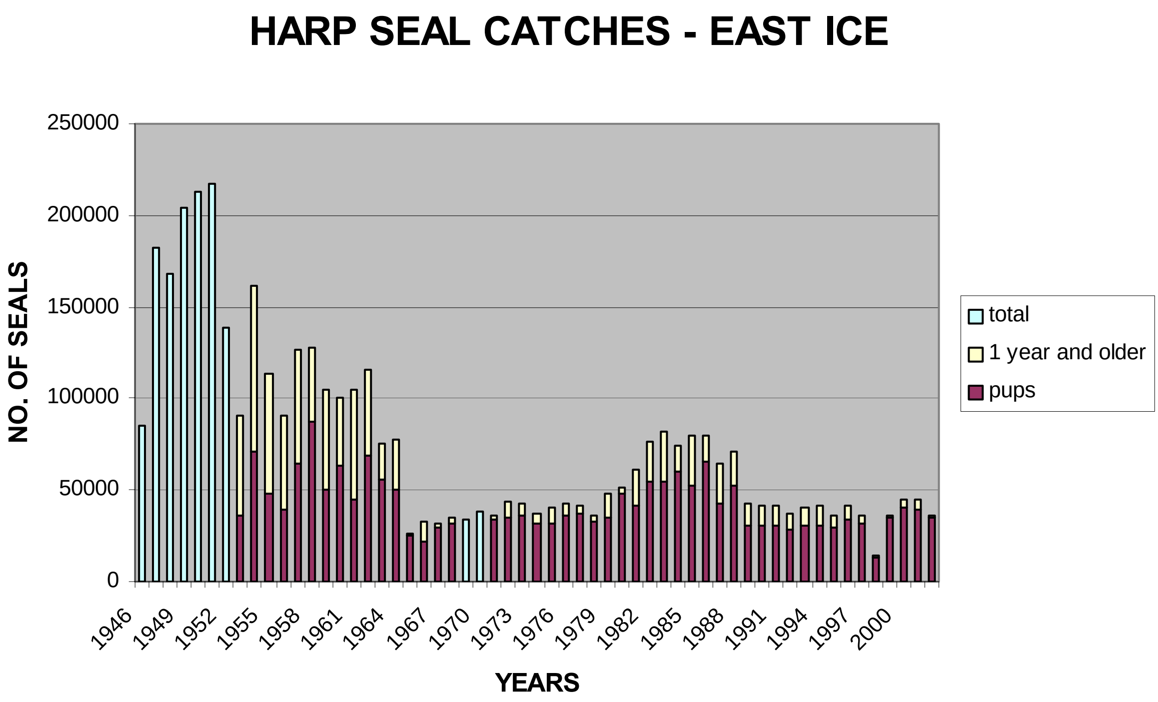


**Figure 4. Annual catches of East Ice harp seals after World War II (1946-2002). Whenever possible, the total catches are split into pups of the year and animals one year old and older.**

Aerial surveys of pup production in 1998 and 2000 indicated a total population of Barents Sea/White Sea harp seals of about 2 million animals in 2000 (CI: 1.8-2.3 million) (ICES, 2001a). However, the recent estimates are not necessarily comparable to earlier estimates obtained by other methods and thus tell us little about the population trajectory. Nevertheless, they have formed the basis for ACFM's advice on TACs from 1999 onwards (ICES 1999, 2001a, 2001b). For 1999 and 2000, the recommended TAC was 31 600 1+ animals, or an equivalent number of pups (one 1+ seal should be balanced by 2.5 pups). Russian authorities chose to set the quotas lower (21 400 and 22 700 1+ animals in 1999 and 2000, respectively). The recommended 2001-2003 quotas were 53 000 1+ animals (again one 1+ seal should be balanced by 2.5 pups). The quotas for the last period were similar to the recommended TACs, but catches (which have virtually all been of the same magnitude, i.e., 36 000 – 42 000 animals of which the majority were pups, since 1989) were only 31-39% of the recommended sustainable level that would stabilise the population.

The Greenland Sea (West Ice) stock of harp seals has been subject to commercial exploitation for centuries (Iversen, 1927; Nakken, 1988; Sergeant, 1991). The Greenland Sea hunt started as an offshoot of the Spitsbergen hunt for bowhead whales (*Balaena mysticetus*) in the late 17$^{th}$ century. Knowledge of the Greenland Sea catches in the 18$^{th}$ and the first two-thirds of the 19$^{th}$ century, made by Dutch, British, German and Danish ships, is poor.

Norwegian sealers appeared for the first time in the Greenland Sea in 1846, and have subsequently participated with increased effort. Exploitation levels reached a historical maximum in the 1870s and 1880s when annual catches of harp seals (pups and adults) ranged from 50 000 to 120 000 (Iversen, 1927). This assumed overexploitation probably drove the stock to an all-time low, and the competition for a limited supply of seals in the 1870s resulted in the disappearance of all non-Norwegian fleets (Sergeant 1991). It was evident that the catch levels in the 1870s were higher than the stock could sustain, and some regulatory measures (mainly designed to protect adult females) were taken in 1876 (Iversen, 1927). In the first decades of the 20th century, annual harp seal catches varied between 10 000 and 20 000 animals, whereas an increase to around 40 000 seals per year occurred in the 1930s (Iversen, 1927; Sergeant 1991). After a five-year hiatus in sealing during World War II, total annual catches rapidly rose to a post-war maximum of about 70 000 in 1948, but then followed a falling trend until quotas were imposed in 1971 (Sergeant 1991, ICES 2001a). From 1955 to 1994 a small proportion of the catches was taken by the Soviet Union/Russia, and the total annual catches have varied between a few hundreds to about 17 000 from 1971 until the present day (ICES 2001a).

**Management history**

In no population of harp seals were conservation measures introduced in time to prevent depletion (Sergeant 1991). In the history of exploitation there was a tension between the need to take the young as the most valuable product and the need to prevent undue disturbance of whelping and moulting and to conserve the stock; this generally resulted in the adoption of starting dates and closing dates as first conservation measures. Most early decisions concerning harp seal management were made on a unilateral basis. Since 1959, however, Norwegian and Russian sealing has been regulated on the basis of recommendations from annual meetings of the Norwegian-Soviet Sealing Commission, which were succeeded in 1984 by consultations under the Joint Norwegian-Soviet Fisheries commission (later the Joint Norwegian-Russian Fisheries Commission) (ICES 1987).

Current management of harp seals is based on assessments performed by the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP). The history of WGHARP is not particularly long (1984 until the present). Nevertheless, the group has been, and still is, crucial in the management of harp (and hooded) seals in the North Atlantic. The group started with a restricted geographical mandate (harp and hooded seals in the Greenland Sea) but expanded to include all harp and hooded seal populations in the north Atlantic (since 1989). Major topics included assessment of the status of the populations, provision of advice on sustainable harvest levels, and assessment of interactions with prey (i.e. ecological role of seals). Terms of reference (TORs) given to WGHARP are based on requests for information and advice related to management of the seal stocks, as provided to ICES or NAFO by commissions (e.g., NAMMCO) or member governments. Formulation of the TORs is the responsibility of the ICES Advisory Committee on Fisheries Management (ACFM) and the NAFO Scientific Council (NAFO SC). After its meetings, WGHARP reports the results of its deliberations to ACFM and NAFO SC. Subsequently, ACFM and NAFO SC provide the advice requested for the northwestern and northeastern stocks, respectively. At present, WGHARP is made up of 25 appointed members from Canada, Denmark (Faroe Islands and Greenland), Germany, Iceland, Norway, Russia, UK and USA.

Since the establishment of a working group to deal with issues related to the management and harvest of harp and hooded seals in the North Atlantic within the ICES framework in 1984, there has been an improvement in the availability of necessary assessment data. From an initial situation in which almost no relevant data were available for some of the stocks in question, the present state of the art is that at least some assessment data (certainly with variable quality) are available for all stocks.

In 1984-1988, the group met under the name Working Group on Harp and Hooded Seals in the Greenland Sea (ICES 1987, 1988), reflecting its geographical mandate. In meetings in 1985 and 1987, the group had to conclude, however, that due to the unavailability of historical data and information about current pup production and stock size for the two stocks in question, no sustainable or replacement yields could be calculated. The group was thus unable to provide scientific advice on catch options. Furthermore, the group noted that current information on the ecology of harp and hooded seals was insufficient to determine the extent of their interaction with commercial fisheries.

In 1988, the working group was renamed as the ICES Working Group on Harp and Hooded Seals, which meant that from now on it was given the additional task of examining data from the Barents Sea/White Sea harp seal population. When the renamed group met in 1989 (ICES 1990), it still had to admit that even though some results from aerial surveys and mark-recapture experiments were now available for harp seals both in the Greenland Sea and in the Barents Sea/White Sea, the uncertainties involved in both data collections and subsequent analyses were too large to allow calculations of sustainable or replacement yields to be made. Thus, the group was still unable to provide scientific advise on catch options. Although it was noted that greater efforts had been devoted to answering questions relating to seal–fisheries interactions, the group concluded that basic information on these issues was still insufficient to address these questions satisfactorily.

From the establishment of the working group in 1984, the possibilities of including the northwest Atlantic stocks of harp and hooded seals had been discussed. This would require coordination with NAFO. In its 1989 meeting, the working group concluded with satisfaction that ICES had officially recommended the establishment of a Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP). The group was established, with the following mandate:

" ... for the purpose of assessing the status of these stocks and providing related advice and information in the areas of both organizations. Contracting Parties to either organization or regulatory commissions who might desire advice on harp and/or hooded seals in a particular geographical area must refer their request to the organization (NAFO or ICES) having jurisdiction over or interest in that area. Advice based on reports of the Joint Working Group would be provided by ACFM in the case of questions pertaining to the official ICES Fishing Areas (FAO Area 27) and by NAFO Scientific Council in the case of questions pertaining to the legally-defined NAFO area. ICES will administer the Joint Working Group in terms of convening meetings, formulating terms of reference, handling membership and chairmanship, and processing, printing, and distributing Working Group reports."

The working group concluded that these developments should improve the basis for future work in assessing the status of any stock of harp and hooded seals and give management advice.

WGHARP met for the first time in 1991 (ICES 1992). At this meeting it became clearthat data from recent aerial surveys of pup production were available for both harp seal stocks in the northeast Atlantic. The Barents Sea/White Sea data, based on surveys of breeding females, were presented in a relatively incomplete form, without information about uncertainty, and could not be used in assessments either. For the Greenland Sea harp seals, however, information was now available both from mark-recapture experiments and from an aerial survey of pups, which enabled WGHARP to calculate reasonable minimum estimates of removals, which would stabilize stock size. Although the amount of data necessary to assess the ecology of harp and hooded seals had increased, WGHARP was still unable to determine the effect of seals on fish stocks or fisheries.

When WGHARP met in 1993 (ICES 1994), it considered the results of both mark-recapture experiments and aerial surveys to estimate the 1991 pup production of Greenland Sea harp seals. The former estimates were considered to be the most reliable and were therefore used to model stock status and catch options for the 1994 season. The group also called for greater efforts to evaluate the ecological role played by the seal stocks in the Barents Sea.

At a WGHARP meeting in 1997 (ICES 1998), updated pup production estimates, based on mark-recapture experiments in 1977-1991, were presented for the Greenland Sea harp seal stock, but these were within the range investigated at the WGHARP 1993 meeting and no new catch options were therefore calculated. Preliminary results of recent aerial surveys of harp seal pups and subsequent population modelling were presented for the Barents Sea/White Sea stock. However, these new results were in a rather preliminary form and could not yet be used by WGHARP to provide catch options.

At its 1998 meeting (ICES 1999), WGHARP concluded that no new estimates of pup production were available. However, revised updated pup production estimates for 1991 (based on mark-recapture experiments) were used to model the 1999 population size by extrapolation, and new catch options were given for the stock. For the Barents Sea/White Sea stock, the first complete aerial surveys of pup production had been conducted in 1998, and WGHARP was able to provide new catch options for the 1999 season based on these results.

At its 2000 meeting (ICES 2001a), using a new population model that estimates the development of future population size, WGHARP was able to provide advice on catch options for 2001 for both harp seal stocks in the northeast Atlantic. For Greenland Sea harp seals, updated values from the 1977-1991 mark-recapture experiments were used as input values. For harp seals belonging to the Barents Sea/White Sea stock, new results from aerial pup production surveys conducted in 2000 were applied. During the meeting, WGHARP held a preliminary discussion of the appropriateness of current and other possible biological reference points for harp seals. Recent diet and consumption studies on harp seals were also considered.

**Current management regime**

Management agencies have requested advice on "sustainable" yields for the harp seal stocks in question. ACFM noted that the use of "sustainable" in this context is not identical to its interpretation of "sustainable" as employed in advice on fish and invertebrate stocks (ICES 2001b). "Sustainable catch" as used in the yield estimates for seals means the catch that is risk-neutral with regard to maintaining the population at its current size.

The most current advice on harp seals for ACFM come from its autumn 2000 meeting (ICES 2001b). Based on the most recent assessments (ICES 2001a), ACFM offered catch options for two different catch scenarios for the Barents Sea/White Sea harp seal stock: current catch level (average of the catches in 1996 – 2000) and sustainable yield. The sustainable catches were defined as the (fixed) annual catches that would stabilise the future 1+ population. These were calculated under the assumptions that the ratio $M_0/M_{1+}$ was either 3 or 5. The catch options were further expanded using different proportions of pups and 1+ animals in the catches.

As a measure of the future development of the estimated population, a quantity that related future (2010) to the current (2000) 1+ population was used:

$$D_{1+} = \frac{N_{2010,1+}}{N_{2000,1+}}.$$

| Option # | $M_{0}/M_{1+}$ | Catch level | Proportion of 1+ in catches | Pup catch | 1+ catch | $D_{1+}$ | Lower 95% C.I. for $D_{1+}$ | Upper 95% C.I. for $D_{1+}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 5 | Current | 12.5% (current level) | 35000 | 5000 | 1.16 | 0.80 | 1.52 |
| 2 | 5 | Current | 100% | 0 | 40000 | 1.09 | 0.73 | 1.45 |
| 3 | 3 | Sustainable | 12.5% | 95000 | 14000 | 1.02 | 0.62 | 1.42 |
| 4 | 3 | Sustainable | 100% | 0 | 82000 | 1.02 | 0.61 | 1.45 |
| 5 | 5 | Sustainable | 12.5% | 69100 | 9900 | 1.02 | 0.68 | 1.35 |
| **6** | **5** | **Sustainable** | **100%** | **0** | **53000** | **1.01** | **0.66** | **1.37** |

Given recent reports of possible high pup mortality rates in the White Sea, ACFM recommended that managers considered the higher pup mortality options (catch options 5 and 6 ) when setting catch quotas, and concluded that a catch of 53 000 1+ animals, or an equivalent number of pups in 2001, would be sustainable (ICES 2001b). If a harvest scenario including both 1+ animals and pups was chosen, one 1+ seal should be balanced by 2.5 pups.

Using the same approach for the Greenland Sea stock of harp seals, ACFM defined the following catch options:

| Opt. # | Catch level | Proportion of 1+ in catches | Pup catch | 1+ catch | $D_{1+}$ | Lower 95% C.I for $D_{1+}$ | Upper 95% C.I for $D_{1+}$. |
|---|---|---|---|---|---|---|---|
| 1 | Current | 14% (1996-1999 level) | 3600 | 600 | 1.31 | 0.88 | 1.75 |
| 2 | Current | 51% (2000 level) | 2000 | 2200 | 1.30 | 0.86 | 1.74 |
| 3 | Current | 100% | 0 | 4200 | 1.28 | 0.84 | 1.72 |
| 4 | Sustainable | 14% | 17600 | 2900 | 1.00 | 0.52 | 1.49 |
| 5 | Sustainable | 51% | 8500 | 9000 | 1.01 | 0.51 | 1.50 |
| **6** | **Sustainable** | **100%** | **0** | **15000** | **1.00** | **0.50** | **1.50** |

ACFM emphasized that in 2001, a catch of 15,000 1+ animals (catch option 6), or an equivalent number of pups, would be sustainable. If a harvest scenario including both 1+ animals and pups is chosen, one 1+ seal ought to be balanced by 2 pups.

As illustrated by the lower confidence interval in the $D_{1+}$ values in the analyses, when "sustainable" catches were removed annually, in ten years the stocks might have fallen by sometimes as much as 50%, compared to size of the stock at present. The stock might also be as much as 50% larger. The crucial point was even at the lower confidence bound the population was so large that its future viability would not have been impacted. This contrasts with ICES use of "sustainable" in fisheries contexts, where ICES takes a risk adverse approach, to achieve at least a 95% probability of a population being above precautionary reference points (ICES 2001b). Future use of reference points in seal management is being discussed in WGHARP (ICES 2001a).

The advice given by ACFM in 2000 (ICES 2001b) has subsequently been used to set TACs and the national (Norway vs. Russia) shares of TACs for 2001-2003 by the Joint Norwegian-Russian Fisheries Commission. The Commission also sets opening and closing dates and areas of the catches, which in 2003 were: from 28 February to 20 April for Russian coastal catches in the White Sea, from 23 March to 20 April for Norwegian sealing ships in the southeastern Barents Sea, and from between 1 and 10 April until 30 June in the Greenland Sea. Adjustments of time periods are permitted in the case of difficult weather or ice conditions. Also, exceptions from opening and closing dates could be made, if necessary, for scientific purposes. There is a ban on killing adult females in the breeding lairs, and Norway does not permit any take of suckling pups.

WGHARP will meet again in Archangelsk, Russia, in September 2003 in oder to make a new assessment of Barents Sea/White Sea and Greenland Sea harp seals, and new advice from ACFM can therefore be expected for the 2004 season.

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