Polar Biol (1999) 21: 179–185

ORIGINAL PAPER

M. Andersen · A.M. Hjelset · I. Gjertz
C. Lydersen · B. Gulliksen

Growth, age at sexual maturity and condition in bearded seals (*Erignathus barbatus*) from Svalbard, Norway

Accepted: 28 July 1998

Abstract The aim of this study was to describe growth, determine age at sexual maturity and investigate the condition of bearded seals (*Erignathus barbatus*) collected in the fjords of Spitsbergen, Svalbard, Norway. Morphometric data, teeth and sex organs were collected from 110 animals. Age was determined by reading the cementum layers in hard longitudinal sections of canine teeth. Sexual maturity in males was determined according to the size of the testes and bacula. Females were defined as being sexually mature according to findings of mature follicles or *corpora lutea/albicantia*. Von Bertalanffy growth curves were applied to both standard length and body mass, and asymptotic values for males and females were 231.1 ± 11.4 cm and 269.9 ± 26.2 kg, and 233.1 ± 7.5 cm and 275.3 ± 47.8 kg, respectively. Maximum recorded lengths and masses were 254 cm and 313 kg in males and 242 cm and 358 kg in females. All males older than 6 years were found to have been sexually mature. Females were found to attain sexual maturity at about 90% of the asymptotic length, corresponding to an age of 5 years. In males a significant decrease in condition was observed from June to August, with a subsequent increase in September. In adult females, condition decreased from May to June and increased again from June to September. The conditional changes seen are likely to be due to the extra energetic cost and reduced food intake associated with reproduction, lactation and molt.

M. Andersen · A.M. Hjelset · B. Gulliksen
Norwegian College of Fishery Science, University of Tromsø, N-9037 Tromsø, Norway

M. Andersen · A.M. Hjelset · B. Gulliksen
The University Courses on Svalbard, N-9170 Longyearbyen, Svalbard, Norway

I. Gjertz
Norwegian Polar Institute, P.O. Box 5072 Majorstua, N-0301 Oslo, Norway

C. Lydersen · M. Andersen (✉)
Norwegian Polar Institute, N-9005 Tromsø, Norway
e-mail: magnus.andersen@tromso.npolar.no,
Fax: + 47-77606700

Introduction

The bearded seal (*Erignathus barbatus*) is a large phocid seal, with a circumpolar and boreoarctic distribution (King 1964), which has received less attention from scientists than most other arctic seal species. Aspects of its biology have, however, been described from several parts of the Arctic region. Growth, reproduction, population structure and feeding of bearded seals have been studied in several different geographical areas (Chapskii 1938; McLaren 1958; Benjaminsen 1973; Fedoseev 1973; Potelov 1975; Lowry et al. 1980; Smith 1981; Burns and Frost 1983; Antonelis et al. 1994; Hjelset et al., in press). Recently, studies of diving, energetics, migrations and pup development have been conducted on bearded seals breeding in the fjords of western Spitsbergen, Svalbard, Norway (Hammill et al. 1994; Lydersen et al. 1994, 1996; Gjertz et al. 1995; Kovacs et al. 1996). Since understanding the ecology of a species is highly important for its management, vital aspects of its biology must be studied. To be able to follow trends in population structure through time and to evaluate the effects of interactions with other species or human exploitation of renewable and nonrenewable resources, information on growth patterns, reproductive characteristics and body condition is needed.

Benjaminsen (1973) investigated the growth and age distribution of a large sample of bearded seals from the Svalbard area and the Barents Sea. This is the only investigation covering Svalbard waters; however, most of Benjaminsen's sample was collected in the open ocean east of Spitsbergen.

In the present study we examined bearded seals collected from the fjords of western Spitsbergen, Svalbard, to establish basic knowledge of growth, size, age at sexual maturity and patterns of conditional changes.

Materials and methods

A total of 110 bearded seals was collected in the fjords of Spitsbergen during the period 1987–1996 (Fig. 1). Of these, 50 were males, 59 females, and for one individual gender was not recorded. The seals were shot from small boats, either when hauled out on ice or when swimming in the water, during the period from May to September. Local trappers sampled material and took measurements from 68 of the seals, while the remainder were collected during scientific cruises.

Standard body length (SL) and axillary girth (AG) were measured to the nearest cm using standard methods (American Society of Mammalogists 1967). Body mass was determined to the nearest kg, using one or two Salter 300-kg spring scales (±1.0 kg) suspended from a tripod, and allowing no compensation for blood loss. Blubber thickness was measured to the nearest mm at a point dorsally, located 60% of the length along a straight line from the tip of the nose. The blubber thickness at this point has been shown to be highly sensitive to changes in body condition in ringed seals (*Phoca hispida*; Ryg et al. 1988) and harp seals (*Phoca groenlandica*; Beck et al. 1993). Canine teeth from the upper or lower jaws were taken for age determination. From the males, intact pairs of testes and the baculum were dissected out, and from the females, ovaries and in some cases the uterus. Some of these samples were preserved in a 4% formaldehyde solution, and the rest were stored frozen. This variation in handling of the material was due to the fact that the sampling was performed by different people working under various conditions. For the same reasons complete sets of data were not available for all of the seals collected.

For age determination, jaws were boiled for 30 min before the canines were extracted. Generally, adult bearded seals have small and worn-down teeth, especially in the lower jaw. These teeth are difficult to cut and the quality of the sections is often poor. Teeth pulled from the upper jaw, however, are not as worn and give

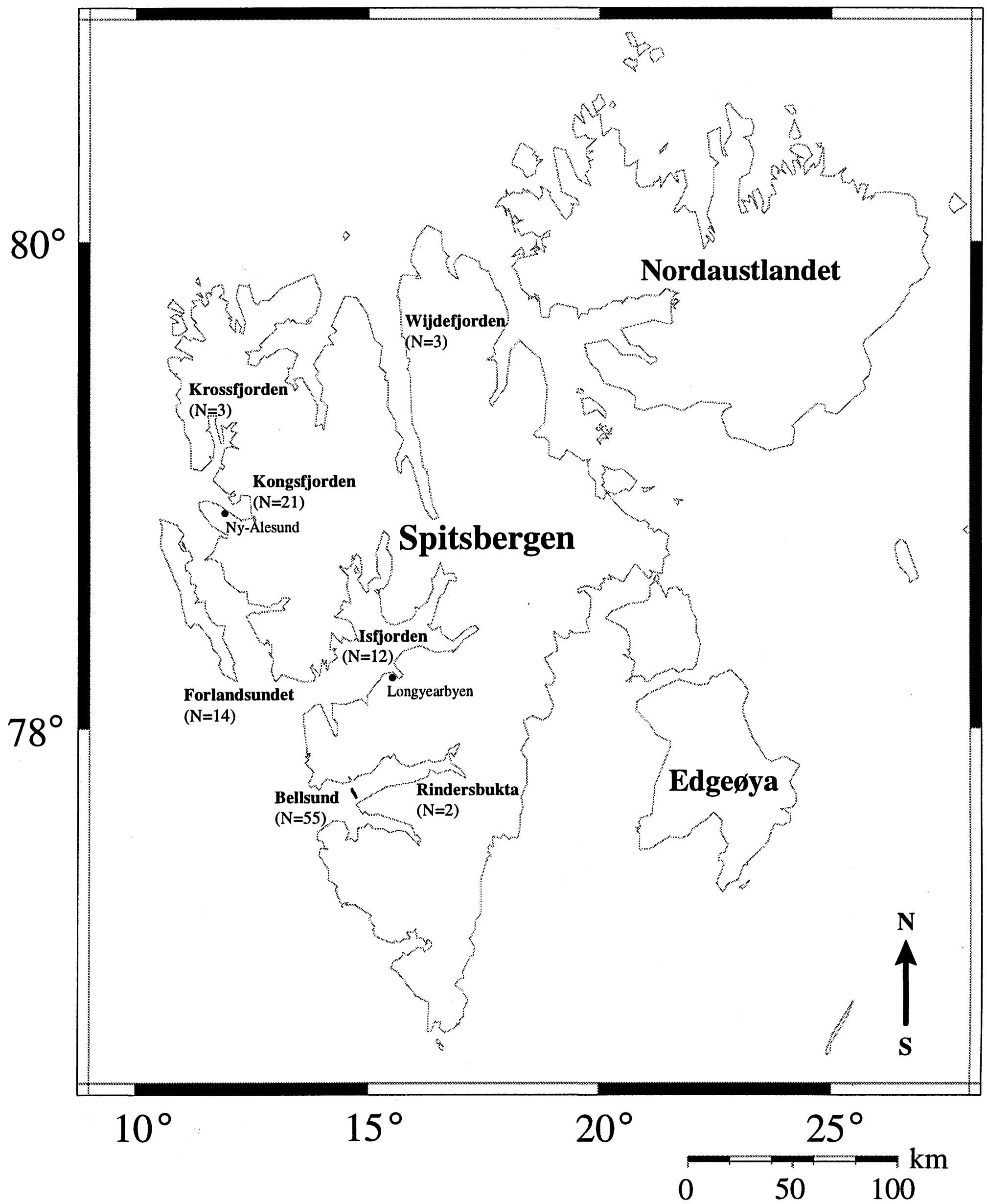

Fig. 1 Map showing the areas in the Svalbard archipelago where bearded seals were collected. The numbers in parentheses refer to the number of seals (*N*) collected in each area

better, more easily-read sections (Benjaminsen 1973), and are therefore preferred for age determination. Due to inconsistent sampling, some of the teeth used in this study are from upper jaws, and some from lower jaws. Sections of 0.15–0.16 mm thickness were cut longitudinally through the center of the tooth using a saw with two parallel circular steel blades. The sections were then washed in 96% ethanol, dried and mounted on glass-slides using Eukitt (Assistent-histokitt). Incremental layers in the cementum were counted with the aid of polarized light using a binocular dissecting microscope (Wild Heerbrugg M8) at 10 × and 50 × magnification. In addition, incremental layers were also counted using a micro-projector (Leitz Micro Promar), where the images of the sections, enlarged about 15 times, were projected onto a white sheet of paper lying on the table beside the projector. Each tooth section was read a minimum of two times. In cases where the quality of the section and/or the distinctness of the cementum layers were poor the ages were read four times. All age determinations were conducted by the same person who was specialized in age reading (Institute of Marine Research in Bergen, Norway). Age and gender data were available from 88 seals; 42 males and 46 females. Mean ages and 95% confidence intervals (c.i.) are given.

The body growth was described using von Bertalanffy growth curves (von Bertalanffy 1957; Schnute 1981):

$$L_x = L_\infty \left(1 - e^{a(x-x_0)}\right)^b ,$$

$$W_x = W_\infty \left(1 - e^{a(x-x_0)}\right)^b ,$$

where L_x and W_x are body length and mass, L_∞ and W_∞ are the asymptotic values corresponding to adult SL and body mass, x is the age of the animal, x_0 is an estimated constant for prenatal growth, and a and b are constants being fitted to the data by regression, where a determines the rate of approach to the asymptote and b determines the curvelinearity of this approach (McLaren 1993). The value 0.72 for x_0 (the time before birth at which the embryo starts growing after the delayed implantation) used in this study is based on data summarized by McLaren (1993). All growth curves were fitted using the NONLIN program of SYSTAT (Wilkinson 1990). Data on body length were available from 84 seals; 41 males and 43 females. Body mass data were available from 26 animals; 16 males and 10 females. The asymptotic values found and the parameters estimated for use in the curves describing body growth, are given with a 95% c.i. Body size differences between adults of both genders were examined using Mann-Whitney U-tests.

The sizes of the bacula and testes were used to estimate age at sexual maturity in males (McLaren and Smith 1985; Ryg et al. 1991). Bacula were available from 17 males of known age, while the testes were available from 24. Each baculum was weighed to the nearest 0.1 g, and its length was measured to the nearest mm. The volume of testis with epididymis attached was measured to the nearest cubic centimetre, as displacement volume, and when both of the testes from any one animal was available, the average was found. In cases where age classes contained multiple testes, mean values (with 95% c.i.) were calculated.

Sex organs were available from 19 females. Ovaries were examined macroscopically for the presence of mature follicles, *corpora lutea* or *corpora albicantia*. If the ovary contained any of these structures, the female was considered to have been sexually mature (McLaren and Smith 1985). In cases where a fetus was found in the uterus, the ovaries were not examined. Age was known for only a few of the females in the age groups where sexual maturity had been achieved. However, SL data was available for all 19, and length at sexual maturity was therefore determined (Laws 1956). Animals were classified into length groups according to the percentage of achieved asymptotic female length found in this study. The age corresponding to the asymptotic length at sexual maturity was estimated from the female length growth curve.

Seasonal variation in the condition of adult bearded seals was analyzed based on blubber thickness measurements (Ryg et al. 1988) and by using a condition index (CI) (American Society of Mammalogists 1967):

$$CI = (AG \times 100) \cdot SL^{-1}$$

Only sexually mature seals were included in the condition analysis; these included all seals found to have been sexually mature based on age and/or sex organ analysis. In cases where age data and/or sex organs were missing, seals larger than 90% of the asymptotic length were also included. Condition data from all sexually mature seals from all areas and years were grouped according to the month of collection. Blubber thickness data were available from 32 males and 41 females, while CI data were available from 30 males and 42 females. To test for differences in blubber thickness measurement values and CI values, between months, Mann-Whitney U-tests were applied.

Results

The mean age of the males was 8.8 ± 2.0 years (95% c.i.), and of the females 8.8 ± 1.4 years (95% c.i.). The oldest male was 27 years old, while the oldest female was 18. The growth curves (Fig. 2) show that bearded seals attain their asymptotic SL and body masses at between 5 and 10 years of age. The asymptotic length for males was 231.1 ± 11.4 cm (95% c.i.) and for females, 233.1 ± 7.5 cm (95% c.i.; Table 1). The maximum recorded SL for males and females was 254 cm and 242 cm, respectively. The asymptotic body mass for males was 269.9 ± 26.2 kg (95% c.i.; Table 1), with a maximum of 313 kg. For females the asymptotic body mass was 275.3 ± 47.8 kg (95% c.i.; Table 1), and the maximum was 358 kg. No significant differences in adult length or body mass between the genders were found ($P = 0.258$ and $P = 0.126$, respectively).

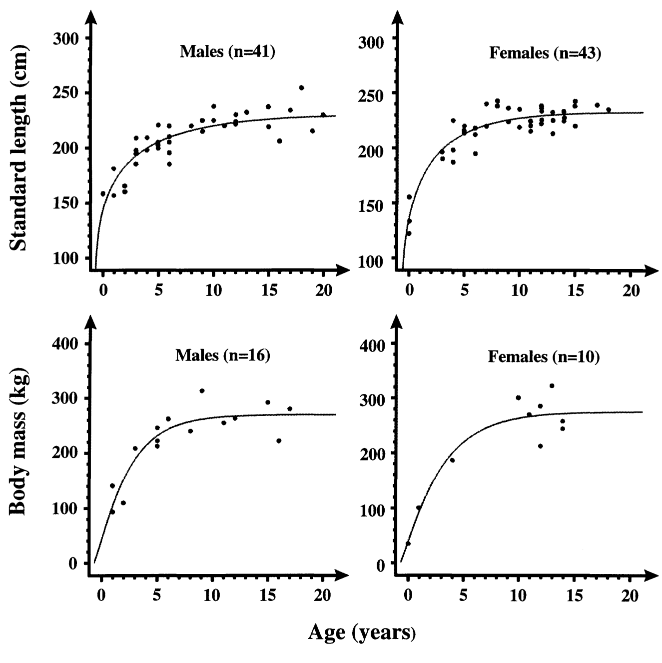

Fig. 2 Von Bertalanffy growth curves fitted to standard body length and body mass data from the bearded seals collected at Svalbard

Table 1 Parameters fitted for length and body mass growth curves for male and female bearded seals from Svalbard. All values are given with 95% confidence intervals; a and b are constants fitted by regression. *n* Number, L_∞ asymptotic body length (cm), W_∞ asymptotic body mass (kg)

Variable	*n*	L_∞ (cm)	W_∞ (kg)	*a*	*b*
Male length	41	231.1 ± 11.4		0.147 ± 0.114	0.208 ± 0.095
Female length	43	233.1 ± 7.5		0.229 ± 0.116	0.287 ± 0.090
Male body mass	16		269.9 ± 26.2	0.389 ± 0.302	1.326 ± 1.289
Female body mass	10		275.3 ± 47.8	0.312 ± 0.466	1.241 ± 1.744

Testes volume in male bearded seals showed a marked increase in size from 3 to 6 years of age (Fig. 3a). After 6 years growth of the testes showed no pronounced increase. The growth of the baculum showed a similar pattern (Fig. 3b, c). These indirect methods of determining age at sexual maturity indicate that all males are sexually mature at the age of 6 years. In addition, some males in the age group 3–5 years had both large testes and bacula and, in combination with their large size, it is therefore reasonable to assume that these individuals also were sexually mature.

Sex organ and age data were available from only five females younger than 10 years of age, and out of these, three were pups of the year. For the remaining two, a 4-year-old was found to have been sexually immature, while a 5-year old was sexually mature. In relation to sexual maturity (based on sex-organ analysis), SL was considered for 19 female bearded seals, and at SLs above 91% of the asymptotic length, all females were found to have been sexually mature. In addition, one female that had only attained 85% of the asymptotic length, was found to have been sexually mature based on sex organ analysis. When combining these findings with information from the female growth curve (Fig. 2), it seems that females older than 5 years are sexually mature.

The condition of bearded seals, as indicated by blubber thickness and CI, exhibited a seasonal variation during the period from spring to early autumn (Fig. 4). Male blubber thickness decreased from May to July/August and then increased from August to September. The blubber thickness values obtained in July were significantly lower than those obtained in May ($P = 0.016$), while the values in September were significantly higher than in July ($P = 0.031$). A similar pattern was found for the male CI, where the August values were significantly lower than the June values ($P = 0.025$). There is an increasing trend in the male CI from August to September; however, this difference was not significant. Female blubber thickness showed a decreasing trend from May to June, and an increasing trend from June to September. However, probably due to the high variability in this parameter within the months, no statistical significance was demonstrated. The female CI values showed a significant decrease from May to June ($P = 0.048$), and a significant increase from June to September ($P = 0.024$).

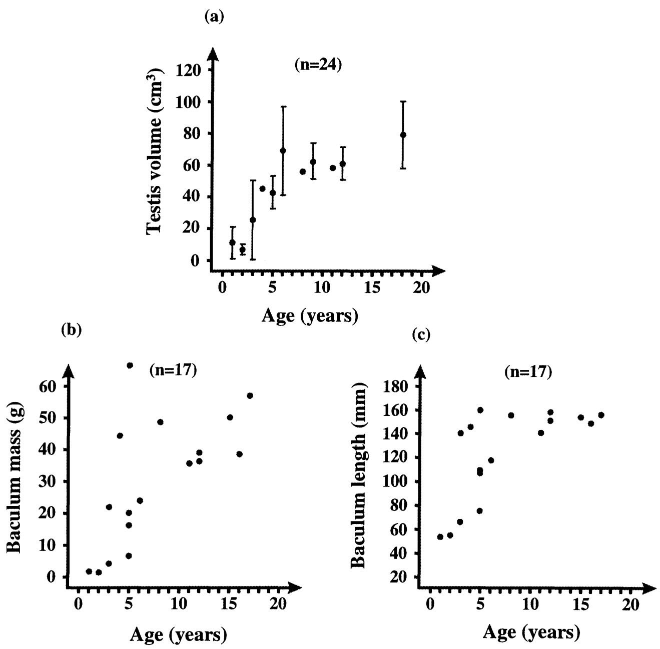

Fig. 3 Relationship between testis volume (**a**), baculum weight (**b**) and baculum length (**c**), and increasing age in bearded seals from Svalbard. The 95% confidence interval (c.i.) is indicated in **a**

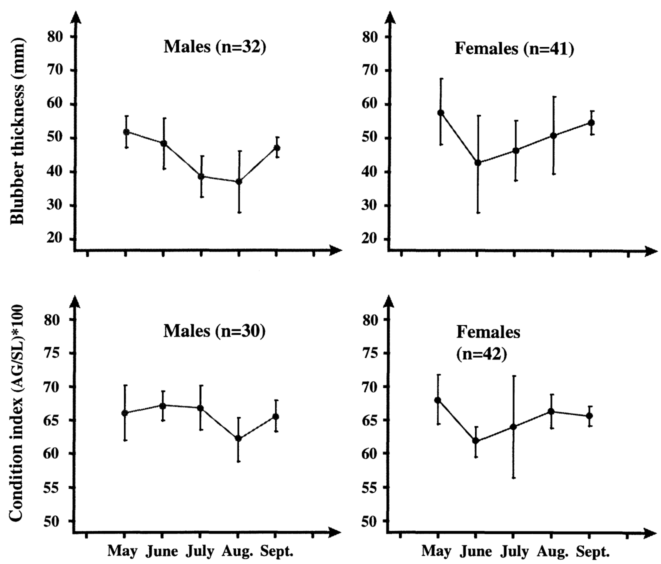

Fig. 4 Body condition in adult bearded seals from Svalbard, given as blubber thickness and condition index [CI = (axillary girth/standard length) × 100]. Means with 95% c.i. are shown per month. (*SL* standard length, *AG* axillary girth)

Discussion

The age distribution of the seals in the present sample show a low number of individuals in the younger age classes. According to the literature, coastal areas are often dominated by sub-adult and adult animals (Burns 1967; Benjaminsen 1973). In addition, bearded seals have been shown to make extensive offshore travels during their 1st years of life (Gjertz et al. 1995). Apart from what may be partly explained by age segregation within the population, the deviations from an expected age distribution seen in the present study probably reflect the relatively small sample size. The greater longevity apparent in males is probably also a sampling artifact, since no such gender difference has been found in other studies (Burns 1967; Benjaminsen 1973; Smith 1981). It should also be kept in mind that, although considered to be the best method for age determination, tooth analysis always will be associated with some degree of uncertainty.

In the present study a version of the von Bertalanffy growth curve recommended by McLaren (1993) was chosen to describe the length and mass growth patterns of male and female bearded seals. The analysis of growth using a cross-sectional dataset is based on the assumptions that the sample is representative for the bearded seal population in the Svalbard area, and that the conditions under which the animals live do not change substantially between years. Using a version of the von Bertalanffy growth function on data collected in the Barents Sea by Benjaminsen (1973), Sager and Sammler (1986) found the asymptotic length of bearded seals, when combining the genders, to be 227.0 cm. Considering the same data, but using another version of the von Bertalanffy function, McLaren (1993) found the asymptotic length of males and females combined to be 229.5 cm. Applying the same growth function to data from McLaren (1958), McLaren (1993) found the asymptotic lengths of bearded seals from the eastern Canadian Arctic to be 237.0 cm. Similarly, when using data from the Bering and Chukchi Seas (Burns and Frost 1983), McLaren (1993) found an asymptotic length of 223.0 cm, and data from the Okhotsk Sea (Fedoseev 1973) gave a length of 203.4 cm. Thus, there appear to be some regional differences in lengths of bearded seals, with the greatest asymptotic values found in the Canadian Arctic, followed by the Svalbard region, Barents, Bering and Chukchi Seas, and with the shortest animals found in the Okhotsk Sea. The values found in the Okhotsk Sea were the only ones that were significantly different from the others (McLaren 1993). According to the von Bertalanffy growth curves fitted to the data in the present study, bearded seals of both genders have a pronounced increase in length and mass from the time of birth to about 5 years of age. Between 5 and 10 years of age, the growth slows down, and most individuals reach their adult size at the end of this period. This is consistent with earlier findings (McLaren 1958; Burns 1967; Benjaminsen 1973).

Little information is available from the literature on body masses of bearded seals, and since no asymptotic body masses are available, a comparison with other Arctic regions, in this respect, cannot be made. Average body masses must therefore be used. In the present study average masses were 247.3 kg and 245.0 kg for sexually mature males and females, respectively. In the Alaskan Arctic the body mass of adult males during the summer was found to be 244.4 kg ($n = 11$; Burns and Frost 1983). In the same area the average body mass of adult females in late winter and spring was 250.3 kg ($n = 5$; Burns and Frost 1983), and in the summer, 228.6 kg ($n = 14$; Burns 1967). Lydersen et al. (unpublished material) recorded the body mass of 19 live adult females during the lactation period in Svalbard, with an average mass of 327 $\pm$ 51 kg. There seem to be a great variation in the average masses found, which may be partly explained by the substantial annual variation in blubber mass. It is important to realize, however, that little data is available on the subject.

In the present study we used indirect evidence to evaluate sexual maturity in male bearded seals. In a study of male ringed seals, Lydersen and Gjertz (1987) used both direct and indirect evidence, and found the start of sperm production to coincide with a marked increase in testis size, tubule diameter and epididymis mass. In bearded seals from Svalbard a pronounced increase in size of the testes and bacula is observed between the ages of 3 and 6 years, indicating that male seals older than 6 years have reached sexual maturity. The results of this study also indicate that some males mature at ages younger than 6 years. Several other studies conducted throughout the range of bearded seals have concluded that males generally become sexually mature at 5–7 years of (McLaren 1958; Tikhomirov 1966; Burns 1967; Fedoseev 1973; Potelov 1975; Smith 1981).When age at sexual maturity is based on growth of testes and/or bacula, it is usually defined as the lowest age class where all seals appear to have attained maturity. This method takes little account of individual variation, and the results are often influenced by how the investigator interprets the data. Taking these factors into consideration, in addition to the often small sample sizes investigated, it seems likely that male bearded seals from all investigated areas reach maturity at about the same age.

All female bearded seals in the present study had attained sexual maturity when reaching 91% of the asymptotic length, corresponding to an age of 5 years. Sexual maturity in female pinnipeds is generally attained at 80–90% of adult length, with an average of 87% (Laws 1956). The findings of the present study are in close agreement with sexual maturity occurring at 91% of SL for Canadian Arctic bearded seals, as reported by McLaren (1958), but higher than the 81% reported by Laws (1956). In surveys of bearded seal reproduction, conducted throughout the Arctic, females have been found to attain maturity between 3 and 7 years of age (McLaren 1958; Fedoseev 1973; Potelov 1975; Smith

1981). It is reasonable to believe that there is no difference in this parameter between the different regions. Generally, body size is thought to have more influence on sexual maturity than age, and this could explain much of the variation observed. This aspect, however, is seldom referred to in the literature on bearded seal biology.

The seasonal variation in body condition, assessed as variation in blubber thickness or CI, follows a pattern found in most phocid seals. The seals are at their fattest before reproductive events and lactation begin, and at their leanest after the period of molting (Smith 1981; Ryg et al. 1990a). The period after molting is normally followed by intensive feeding, where the seals rebuild their energy stores again (Ryg et al. 1990a; Lager et al. 1994). In the present study the annual pattern of condition do not seem to be identical for the two genders. From May onwards, males gradually become leaner, with the lowest blubber thickness and CI values being attained in August (Fig. 4). Females show an abrupt decrease in both of these parameters from May to June, followed by a gradual increase in blubber stores during July to September. It is believed that male bearded seals defend territories during the breeding season (Ray et al. 1969). This period is probably associated with an increased use of energy and reduced food intake. The period of male sperm production in this species is from March to June (Potelov 1975). An extended breeding season could explain the rather long period of decrease in condition observed for male bearded seals.

Peak pupping for bearded seals in the Svalbard area is early May (Lydersen et al. 1994). The pup suckles for about 24 days, and the energetic cost of lactation in this species is extremely high (Lydersen et al. 1996). Even though females feed during the lactation period, the very high milk energy output causes a sharp decline in condition in May (Fig. 4). After weaning the females enter the period of molting, normally in June, which further decreases their condition due to reduced food intake in this period.

There was a high variability within each month in the parameters describing condition in bearded seals (Fig. 4). This variability is most pronounced for females and could be caused by a number of factors. Inaccuracy and errors during the sampling of measurements could have an impact when the grouped data are based on few values. It should also be kept in mind that, in the present study, body condition was investigated in a relatively small number of animals.

Since the energetic cost of lactation in bearded seals is very high (Lydersen et al. 1996), females that fail to reproduce or lose their pup early in the lactation period will use less of their blubber reserves compared with females that complete lactation. Two of the adult females included in Fig. 4 were found, based on analysis of their sex organs, not to have given birth during the season of collection. If they had been excluded from the analysis the 95% c.i., particularly for July, would have been considerably reduced.

Some of the variability in CI may have been due to the long time span during which the seals were collected (1989–1996). Interannual variation in condition over a 10-year period has been documented for adult harp seals from the Northwest Atlantic Ocean (Hammill et al. 1995), presumably due to interannual variations in food resources. However, the feeding habits of these two seal species are quite different. While harp seals rely on the presence of relatively few pelagic prey species, bearded seals feed on a wide range of benthic prey organisms (Hjelset et al. in press). This gives reason to believe that fluctuations in food availability are less likely to occur for bearded seals.

Blubber thickness and CI are relatively insensitive methods for analyzing condition (Ryg et al. 1990b). Direct measurements of the amount of fat, as mass of dissected blubber tissue, or estimated by the use of the LMD index (Ryg et al. 1990b), would provide a more sensitive and accurate evaluation of condition. It has also been shown that body core reserves are important sources of energy in periods of fasting and undernutrition in seals (Markussen et al. 1992).

In conclusion, the findings of the present study are in agreement with results from similar studies conducted in other Arctic regions, suggesting that male and female bearded seals grow to approximately similar sizes, that males at 6 years of age and females of 5 years have reached sexual maturity, and that body condition in adults decreases during the summer months.

Acknowledgements We would like to thank those who helped with the analysis of material and sampling of data for this study; Bjørn Bergflødt, Reidar Hovelsrud, Hans Lund, Louis Nielsen and Harald Soleim. Øystein Wiig is thanked for comments on the manuscript. The following institutions supported the work; the Norwegian College of Fishery Science, the Norwegian Polar Institute and the University Courses on Svalbard.

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