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Movements and diving of adult ringed seals (*Phoca hispida*) in Svalbard

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Abstract Seven post-moulting adult ringed seals (*Phoca hispida*) were equipped with Satellite Linked Dive Recorders in Svalbard in July 1996 to determine if ringed seals conduct long-distance post-moulting feeding excursions, and to obtain details of their diving behaviour. The mean duration of tags was 206 days (range 103–325). Two seals swam 400 km north to the drifting pack ice (82°N). The rest undertook more local movements. Forty-eight percent of all dives were shallower than 20 m and 90% were shallower than 100 m. Ninety-five percent of all dive durations were shorter than 10 min, and 99.5% were shorter than 15 min. This study has shown that adult ringed seals undertake varying patterns of post-moulting excursions.

Introduction

Ringed seals (*Phoca hispida*) are found throughout most of the Arctic Ocean and bordering seas (Frost and Lowry 1981; Reeves 1998). They associate closely with land-fast ice and drifting pack ice for large parts of the year, and may be found in waters of all depths (Reeves 1998).

Ringed seals are known to undertake movements and migrations, from one area to another (Smith 1987). This may be a response to unfavourable conditions, searching for food or dispersal of immature seals to new areas. Some ringed seals may undertake long-distance movements of up to 1000 km and, in one case, more than 2000 km (Smith 1987; Heide-Jørgensen et al. 1992; Kapel et al. 1998; Teilmann et al. 1999).

Ringed seals are the most abundant marine mammal in the Norwegian high-arctic archipelago of Svalbard. They can be seen hauled-out in the spring in all the fjords (Lydersen 1998). Peak pupping in Svalbard occurs in the 1st week of April (Lydersen 1998) and is followed by a lactation period of more than 1 month (Hammill et al. 1991). Thereafter, the seals mate and moult. Moulting occurs at the same time as the fast ice breaks up, and large numbers of moulting seals gather on the last remaining fast-ice areas (Lydersen 1998). In summer, most of the seals seem to disappear from the fjords, likely to feed offshore, possibly in the Barents and Greenland Seas (Lydersen 1998), but they are numerous again in the fjords the following spring.

Ringed seals are believed to feed intensively from late summer to early spring to replenish their fat losses in connection with breeding and moulting (Ryg et al. 1990; Lydersen 1998; Reeves 1998). Prey type varies according to region and season, but pelagic schooling fish dominate the diet from late autumn to spring, while in late summer and early autumn pelagic crustaceans dominate (Reeves 1998).

Virtually nothing is known about ringed seal movements or diving behaviour in Svalbard outside the breeding period. It is hypothesised that adult ringed seals in the fjords of Spitsbergen conduct prolonged feeding excursions, lasting up to several months, either to the offshore banks or to the drifting pack ice. In this study this hypothesis is investigated using satellite telemetry.

Materials and methods

Seals were caught in St. Jonsfjorden, Spitsbergen (78°30′N 13°E) (Fig. 1) during July 1996 using land-based seine or coarse-grid fishing nets. The equipment was set from the heads of small promontories or at narrow entrances to small secluded bays that

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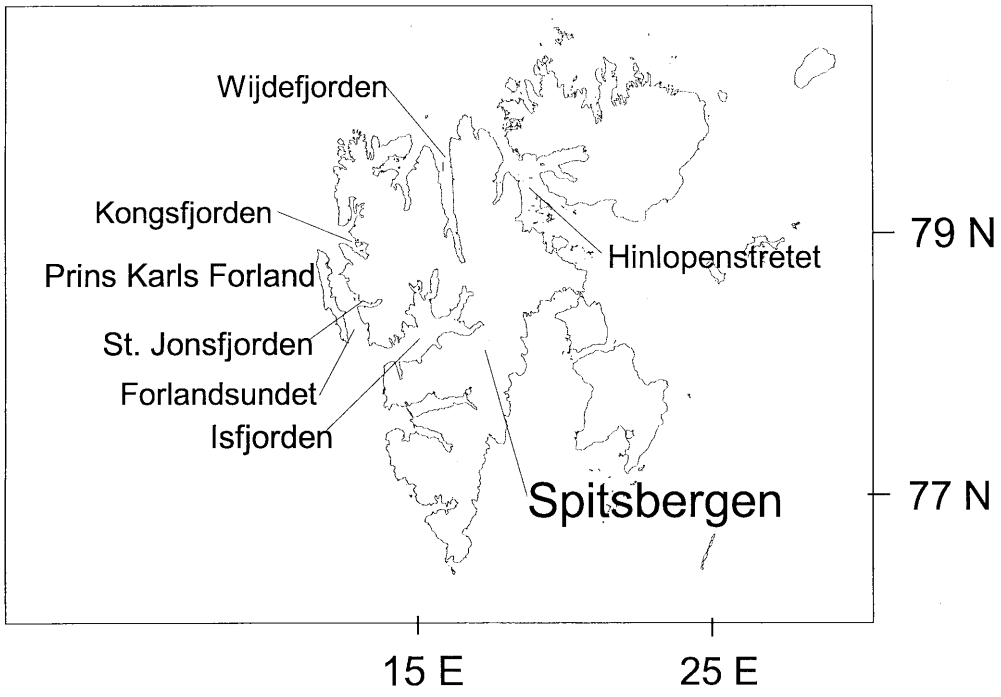

Fig. 1 Map of Svalbard. Places mentioned in text are indicated on map

contained remaining fast ice. The nets were guarded continuously and, if a seal was caught, it was removed immediately from the net. Seals that were still moulting or those that were classified as subadults (based on body size, see Lydersen and Gjertz 1987) were flipper-tagged and released at once. Suitable adults were restrained on the beach in a large dip net, weighed, sexed, tagged and equipped with a 0.5-W Satellite Linked Dive Recorder (SLDR) (SDR-T6, Wildlife Computers, Redmond, Wash.).

The transmitters were programmed to transmit every other day. The transmitters had a depth range of 0–470 m and a resolution of 2 m. They were programmed to sample dive depth and dive duration in 14 bins. Depth bin lower limits were: 4, 8, 12, 16, 20, 30, 40, 50, 100, 150, 200, 300, 400 and >400 m. Duration bin limits were: 1, 2, 3, 4, 5, 6, 8, 10, 15, 20, 30, 40, 50 and >50 min. The Time-at-Depth option built into the transmitter was not used. The minimum depth to be considered a dive was set to 2 m. A specially constructed SASPC computer program (SAS Institute, Cary, N.C.) compared all ARGOS positions and selected the daily position of highest quality for use in the present analysis. When several positions had equally high rank then the first such position of that day was selected.

Results

Seven adult ringed seals (six females, one male) (Table 1) were equipped with satellite transmitters. The SLDRs lasted from 103 to 325 days (mean 206) (Table 1). The seals displayed variable patterns of movement (Fig. 2).

Seal no. 1 swam 400 km north to the pack ice (82°N). The tag on this seal ceased functioning in October while the seal was more than 300 km from the tagging site.

Seal no. 2 stayed in the St. Jonsfjorden-Forlandsundet area throughout the study period and the tag ceased transmitting in the beginning of January. Seal no. 3 stayed in the St. Jonsfjorden-Forlandsundet area, but also undertook some short excursions off the coast of Spitsbergen before the tag failed in Forlandsundet at the end of January.

Seal no. 4 stayed in the St. Jonsfjorden-Forlandsundet area before moving to the inner part of Isfjorden where the tag failed at the end of January. Seal no. 5 also stayed in the St. Jonsfjorden-Forlandsundet area before making a 110-km excursion to the inner part of Isfjorden. When this tag failed, in late November, the seal was back in St. Jonsfjorden. Seal no. 6 swam 400 km north to the pack ice (82°N) but returned to the vicinity of the mouth of St. Jonsfjorden on 6 December, and then moved into the northern part of Isfjorden, thus covering a minimum total distance of more than

Table 1 Ringed seals equipped with satellite transmitters 1996–1997. All seals tagged in St. Jonsfjorden, Svalbard

Seal no.	Sex	Weight (kg)	Tagging date	Date of last location	Stopped transmitting	No. days transmission
1	F	68	010796	111096	111096	103
2	F	51	040796	181296	070197	187
3	M	70	050796	310197	310197	215
4	F	60	060796	281196	310197	212
5	F	52	060796	141196	261196	143
6	F	52	080796	290597	290597	325
7	F	69	100796	240397	240397	258
Mean ± SD		60 ± 9				206 ± 73

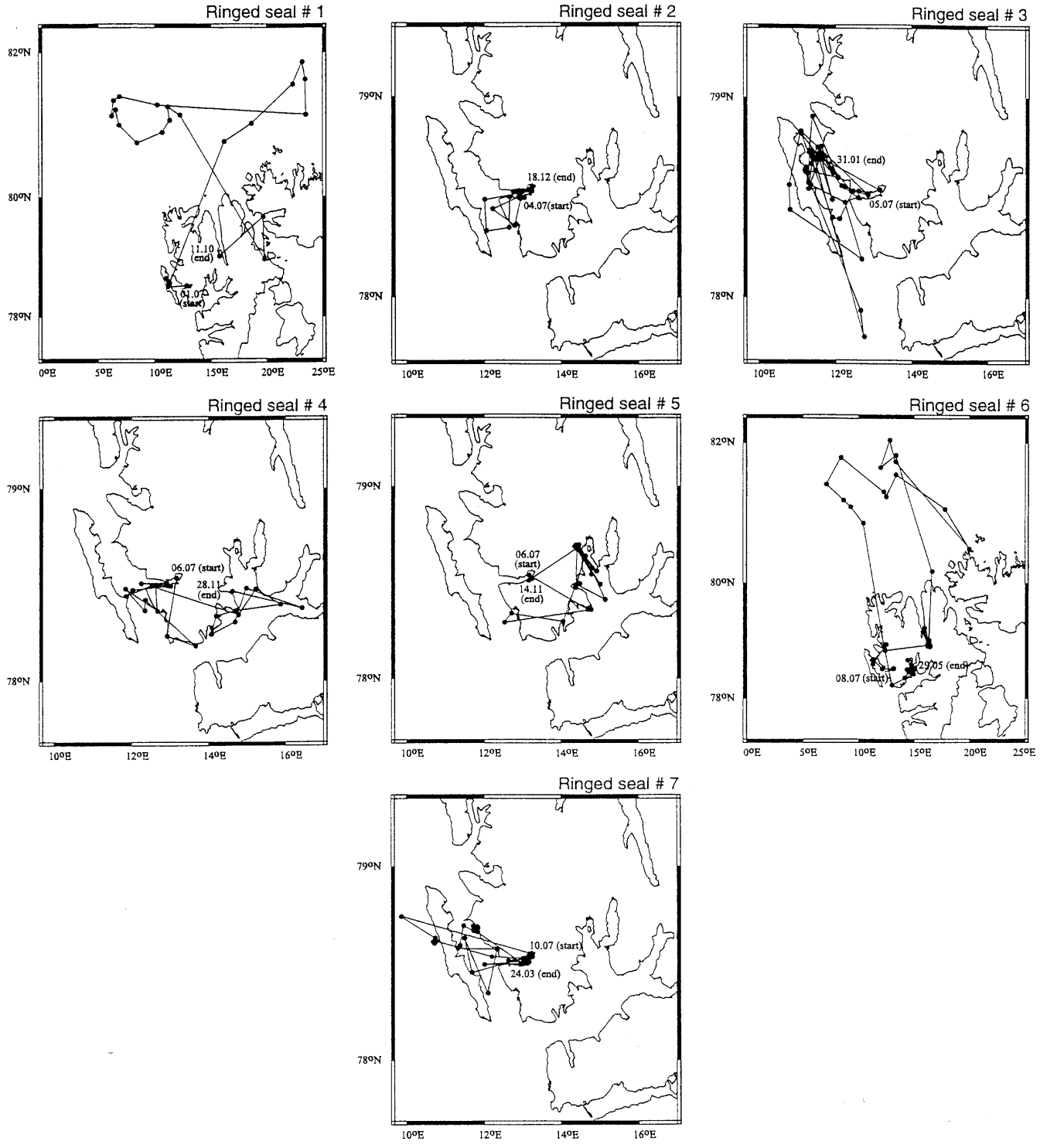

Fig. 2 Maps of Svalbard indicating the movements of each of the seven tagged ringed seals. Starting points and ending points are indicated

1500 km, where the SLDR ceased functioning in May. Seal no. 7 stayed for some time in the St. Jonsfjorden-Forlandsundet area, before making a 70-km excursion offshore of Prins Karls Forland and then returning to the tagging area.

The first 5 months constitute 83% of all dive-depth recordings received from the satellite. The month with the most depth recordings was August, with about 21% of all recordings. July, September and October all had about 16% each, while November had 14%.

Seal no. 2 stayed in the tagging area until the transmissions ceased. The other six seals moved out of the tagging area for some period during the study. Comparisons were made between dive depths and dive

durations for the same individual seals while in different areas. Diving, both depth and duration, were significantly different (χ^2 $P < 0.001$ for all seals) when compared between different geographical areas.

A total of 103,330 dive depths were recorded for the 7 tagged seals with records in all depth bins (Fig. 3). Forty-eight percent of all dives were shallower than 20 m and 90% were shallower than 100 m.

All but two of the seals remained in the fjord and coastal areas of western Spitsbergen. Seal nos. 1 and 6 were both in the pack-ice areas north of Spitsbergen from 15 July to 7 September and 29 July to 13 September, respectively. In this period 87% and 83% of all dives were shallower than 50 m. Seal no. 1 thereafter spent from 9 to 29 September in Hinlopenstretet, the deep strait dividing Svalbard's two largest islands. Here, 43% of the diving was shallower than 50 m and 50% of the diving was from 100 to 200 m. After being in the pack ice, seal no. 6 spent from 29 September to 2 November in Wijdefjorden. Here, 53% of the dives were shallower than 50 m and 30% were deeper than 100 m. For both seals, diving was significantly shallower when in the pack ice compared with diving in coastal and fjord areas (χ^2 $P < 0.001$).

A total of 100,872 dive durations were recorded for all 7 seals, with records in all 14 bins (Fig. 3). Ninety-five percent of all dive durations were shorter than 10 min, and 99.5% were shorter than 15 min. The dive durations for all seals combined showed a bi-modal distribution with 30% of the dives lasting less than 2 min and 46% of the dives lasting between 5 and 10 min.

Two of the adult females had SLDRs that lasted until the breeding season. Seal no. 6's satellite tag lasted through the normal pupping period and ended in late May, while seal no. 7's tag lasted until the end of March, just 1 week before the peak pupping period for ringed seals in Svalbard (Lydersen 1995) (Table 1). The quantity and quality of the data received during this part of the year were, however, poor.

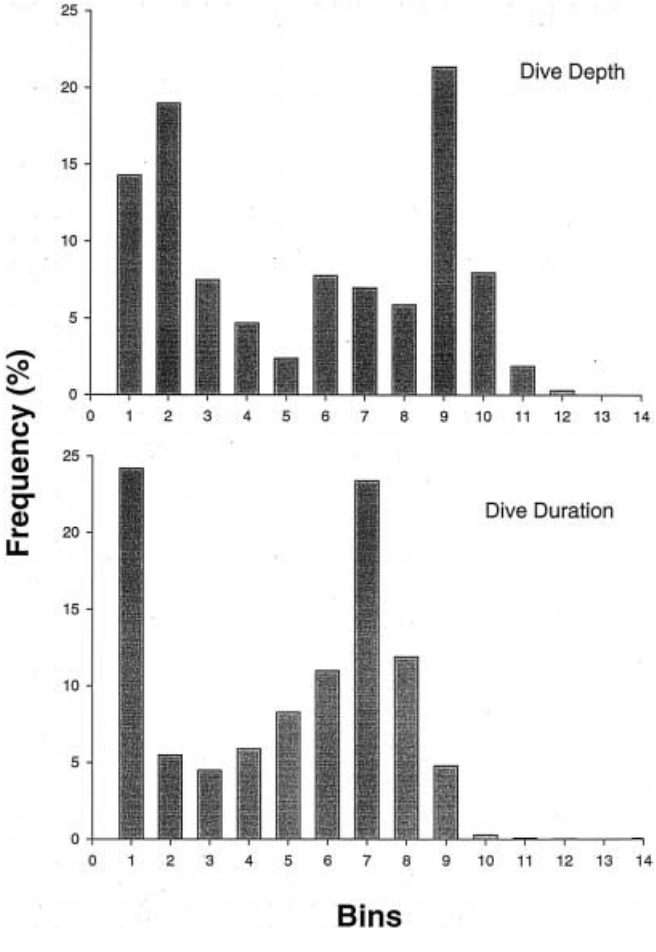

Fig. 3 Frequency distributions of ringed seal diving, both depth and duration, according to 14 histogram bins. Frequency is based on combined dives for all seals, 103,330 dive depths and 100,872 dive durations. Duration bin upper limits were: 1, 2, 3, 4, 5, 6, 8, 10, 15, 20, 30, 40, 50, >50 min. Depth bin lower limits were: 4, 8, 12, 16, 20, 30, 40, 50, 100, 150, 200, 300, 400, >400 m

Discussion

St. Jonsfjorden was chosen because it is one of the fjords on the west coast of Spitsbergen where some fast ice lasts until the first spring tides in July. In addition, it is near enough to Kongsfjorden to allow comparison with relevant data from this fjord, where many years of research on ringed seals has been conducted.

The transmitters lasted on average more than 6 months, a good result compared with other ringed seal studies with average results of 99 days (Teilmann et al. 1999) and 69 days (Heide-Jørgensen et al. 1992). This may be because the equipment has improved after Heide-Jørgensen et al.'s (1992) pioneer project, and because the present study only deployed transmitters on adult animals. Attachment should be better on the backs of larger animals, with less chance of the transmitter loosening at the edges. Two transmitters lasted through the winter and into the breeding season. The received data at this time were, however, poor. This may be because the animals were in areas of fast ice and seldom hauled out. In addition, when ringed seals visit breathing holes often only the head is exposed, and transmitters attached to the backs cannot, therefore, transmit.

This study is based on only seven tagged seals, but has shown that adult ringed seals in Svalbard undertake varying patterns of post-moulting movements. Most seals do not move far from the tagging areas and remain in the coastal and fjord areas, some occasionally making short coastal excursions. However, two of the tagged seals left the coast and went into the pack-ice areas north of Spitsbergen, presumably on feeding excursions since ringed seals gain a lot of body mass at this time (Ryg et al. 1990). Both seals returned to the fjords.

The overall results, showing little movement from the tagging areas, are comparable with satellite telemetry

observations on ringed seals from Greenland. A total of 12 ringed seals were tagged with satellite transmitters in 1988 and 1996 (Heide-Jørgensen et al. 1992; Teilmann et al. 1999). However, unlike in Svalbard where all the tagged seals were adults, only 2 of the 12 tagged Greenland seals were adults. One Greenland seal crossed Baffin Bay and moved 2000 km from the tagging site (Teilmann et al. 1999), but most of the other seals undertook shorter coastal movements until they left the fjord areas in September/October and moved offshore into the North Water polynya. These movements were apparently related to the formation of land-fast ice in the fjords (Teilmann et al. 1999). This indication of limited movement is supported by Kapel et al. (1998), who found that 31 of 38 recaptured tagged ringed seals in Greenland were caught within 120 km of the tagging site up to 14 years after tagging.

Transmitters were deployed from 1 to 9 July and the first transmitter ceased functioning on 11 October. Most of the total number of dives in this study were recorded within the first 5 months, with August being the month with the highest number of dives. The total number of days with dive information was, however, fewer for July and October than in August and September. Adjusted for this, total number of dives per month is fairly constant from July through to October. This suggests that feeding is also relatively constant at this time, and supports the view that ringed seals feed intensively from late summer to early spring (Reeves 1998).

Ringed seals in Svalbard were found to dive relatively shallow; 90% of all the recorded dives were shallower than 100 m, and half were less than 20 m. Significant differences in depth were found between diving conducted in different fjord and coastal areas. This is likely due to a combination of local bathymetric conditions and local prey distribution. Since dive depth and duration are usually intercorrelated (Schreer and Kovacs 1997), this may explain why dive durations also varied.

Ringed seal feeding studies from summer and autumn in Svalbard show that polar cod (*Boreogadus saida*), large amphipods, especially *Themisto libellula*, decapods, krill and mysiids are the most important prey (Lydersen et al. 1989; Weslawski et al. 1994; Wathne et al. 2000). In winter, more benthic prey is taken (Weslawski et al. 1994). During ice break-up and in the open-water period the seals prefer pelagic prey (Weslawski et al. 1994). Polar cod are common in the coastal areas of Spitsbergen (Falk-Petersen et al. 1986). This species is semi-pelagic in areas without ice cover and is therefore found both pelagically and near the bottom. There may be abundant ice-related fauna in the pack-ice areas. In July to September, seal nos. 1 and 6 were in the pack-ice areas north of Spitsbergen, in areas partly over very deep water (1000 m). While in the pack ice these seals predominantly dove shallower than 50 m. Their shallow diving suggests that they fed primarily on ice-associated prey items or zooplankton. Little is, however, known about available prey species from this area. When these two seals moved into the fjords, their diving changed and became deeper, suggesting that they might be after different prey from that offshore, or the same prey but found at different depths coastally.

Almost all diving in the present study was shorter than 15 min, and $\sim$ half of the diving was between 5 and 10 min. The theoretical aerobic dive limit for the Svalbard seals is about 8 min based on calculations by Lydersen et al. (1992). The diving results are comparable with results of ringed seal diving studies in Canada (Kelly and Wartzok 1996). They found that median dive duration was less than 10 min for all seals studied, but that it varied between adult males and females. For adult females this was 7.5 min while for males the median dive duration was 4 min (Kelly and Wartzok 1996). This latter study was conducted in shore-fast ice and during the breeding season, which may have influenced the seals behaviour. Teilmann et al. (1999), in a study more similar to that conducted in Svalbard, found that 90.4–99.9% of subadult ringed seal diving lasted less than 6 min, while 94% of all dives were shorter than 9 min for the only adult studied. The observed difference between subadults and adult were attributed to differences in body mass (Teilmann et al. 1999). The result of the adult diving in Greenland is similar to that found in the present study, where 95% of the dives were shorter than 10 min.

Dives were recorded in all 14 duration bins, suggesting that ringed seals occasionally were diving up to 50 min or longer. This is well in excess of the theoretical maximum breathhold capacity of $\sim$24 min for a 60-kg ringed seal, according to an equation by Lydersen et al. (1992). Since 99.5% of all dives were shorter than 15 min, then it is likely that dives with these extreme durations are incorrect. They may possibly represent several consecutive dives that have been joined together, or malfunction in the dive recorder.

Two females left the fjords and went out into the pack ice. One of these returned and wintered in Isfjorden where it stayed until the breeding season. Ringed seals are thought to prefer stable land-fast ice for breeding (McLaren 1958; Lydersen 1998), but are also known to breed in the pack ice of the eastern Canadian Arctic and Barents Sea (Finley et al. 1983; Wiig et al. 1999). If pack ice is suitable for breeding, then why do the seals return to the fjord areas and not just stay in the pack ice all year? The annual fast-ice stability found in the prime breeding sites in Svalbard may be preferential to the more unstable conditions found in the pack ice. The suckling pups, which depend on their mothers while they are gaining diving and feeding skills, are also more liable to be separated from their mothers in the pack ice than in land-fast ice areas in the fjords.

Adult ringed seals seem to choose different post-moulting feeding strategies. Some individuals spend long periods offshore feeding under pack ice and in the water column, while others stay along the coast and in the fjords feeding at various depths.

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