Echinococcus multilocularis on Svalbard: introduction of an intermediate host has enabled the local life-cycle

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SUMMARY

The taeniid tapeworm *Echinococcus multilocularis* is here reported for the first time at the Svalbard Archipelago in the Norwegian Arctic. This new finding is interesting because the establishment of *E. multilocularis* is due to a recent anthropogenic introduction of its intermediate host – the sibling vole *Microtus rossiaemeridionalis* at Svalbard. The parasite itself has probably become naturally transferred to Svalbard due to migratory movements of its final host – the arctic fox *Alopex lagopus* between source areas for *E. multilocularis* in Siberia and Svalbard. We report macroscopically determined prevalence of *E. multilocularis* from a sample of 224 voles trapped in August in 1999 and 2000. The prevalence was among the highest ever recorded in intermediate hosts and was dependent on age and sex of the hosts approaching 100% in overwintered males. The high prevalence and the simplicity of the vole – arctic fox – *E. multilocularis* system at Svalbard makes it an eminent model system for further epidemiological studies.

Key words: *Echinococcus multilocularis*, rodents, *Microtus* voles, arctic fox, parasites, Svalbard.

INTRODUCTION

Echinococcus multilocularis is a taeniid tapeworm having a life-cycle with 2 mammalian hosts. In the circumpolar arctic regions the definitive host usually is the arctic fox, *Alopex lagopus*, and in mainland Europe the red fox *Vulpes vulpes*. Also other canids (domestic dog, wolves) and cats can harbour *E. multilocularis* (e.g. Eckert & Deplazes, 1999). Many species of rodents can be intermediate hosts, though voles and lemmings of the subfamily Arvicolinae are the most characteristic ones (Rausch, 1995).

E. multilocularis is found in most of the arctic regions (Rausch, 1995). It is also endemic in Central Europe where the distribution seems to be expanding (Eckert & Deplazes, 1999; Romig *et al.* 1999*a*). However, the species has never been found on the Fennoscandian mainland (Finland, Norway, Sweden, adjacent areas of Russian Karelia, and probably not on Kola Peninsula); we and our colleagues have studied tens of thousands of arvicoline rodents during past decades, and none of the National Veterinary Institutes in Finland, Norway and Sweden has ever reported *E. multilocularis* in red foxes. This is quite intriguing because the species is already found east of the White Sea through northern Russia and Siberia (Rausch, 1967, 1995).

The Svalbard archipelago, also often known by the name of the main island Spitzbergen, lies in the Arctic Ocean half way between northern Norway and the North Pole (see Fig. 1). Svalbard belongs to Norway, but countries that have signed the Svalbard Treaty have the right for research and mining. Consequently, Russians have had several coal mining communities on the islands, but only one is presently inhabited. These communities were usually quite isolated and self-supportive. They used to have their own dairy cattle and horses for the mines; the forage was brought from mainland Russia, mainly from St Petersburg or Murmansk.

The arctic fox is common on Svalbard (e.g. Frafjord & Prestrud, 1992; Fuglei, Prestrud & Vongraven, 1998). In summer, foxes breeding along the coastline rely heavily on the seabirds that nest in large colonies on the bird cliffs. In winter, arctic foxes roam widely on the pack ice, and migration between Svalbard and Siberia has been demonstrated by an arctic fox ear-tagged in Svalbard and recaptured at Novaja Zemlja (P. Prestrud, personal communication). There are no native rodents on

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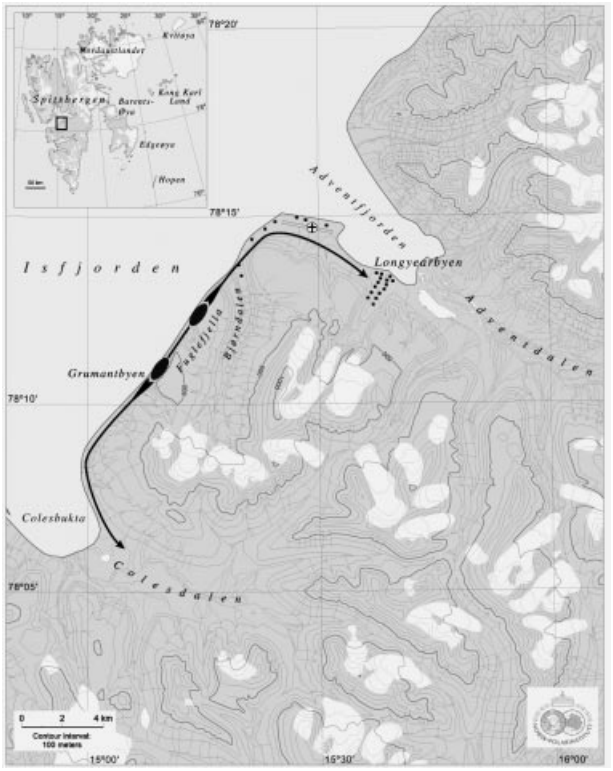


Fig. 1. Distribution of the sibling vole on Svalbard, with locations of more or less permanently occupied areas (core areas indicated with black ovals), and main colonization routes (arrows) used by voles during peak years. Glaciers are shown in white; most of the inland area is polar desert except for the main valleys (Colesdalen, Bjørndalen and Adventdalen). The live-trapping programme in 1989–2000 took place in the south-west core area, where the *Echinococcus multilocularis* survey was done in 1999. The north-east core area was surveyed in 2000. There are human settlements (dots) at Longyearbyen and around the airport area.

Svalbard. However, in the 1960s and 1970s there were observations of *Microtus* voles in several places at Svalbard. Before 1990 authors referred to this vole as common vole, *M. arvalis*, but chromosome analysis (Fredga *et al*. 1990) has shown it was in fact the sibling vole *M. rossiaemeridionalis* (earlier called *M. epiroticus*). Voles were found close to Russian mining communities (Nyholm, 1966; Alendal, 1977; Bolshakov & Shubnikova, 1988; Krumpal *et al*. 1991; Ims & Yoccoz, 1999) suggesting that they had probably been introduced with forage for cattle and horses. The Russian mining towns of Grumantbyen and Coles Bay have been abandoned since the 1960s, and a survey done in 1989/1990 (Yoccoz, Steen & Ims, 1990) showed that voles have become extinct except in the surroundings of Grumantbyen, some 10 km west of Longyearbyen, the main Norwegian settlement of Svalbard (see Fig. 1).

The steep slopes near the coast in this area form a narrow belt of lush graminoid vegetation, that results from large seabird colonies on the cliffs directly above the slopes and represents the core area of the present vole population on Svalbard. This area contrasts the otherwise barren habitats on Svalbard. In years of high abundance, the distribution of voles occasionally extends up to Longyearbyen to the east and Coles Bay to the west (Fig. 1).

The dynamics of *M. rossiameridionalis* at Grumantbyen have been monitored since 1990 (Ims & Yoccoz, 1999; Yoccoz & Ims, 1999) and are characterized by violent fluctuations in abundance and spatial distribution. Voles breed in summer and sometimes in winter. A highly variable survival rate during the winter and occasional winter breeding makes the multi-annual population dynamics as a whole very much winter dependent (Yoccoz & Ims, 1999). It seems that winter climate and, in particular, the snow conditions, is the main determinant of the population change. In certain winters the vole habitat on the slopes around Grumantbyen is completely covered by ice following freezing rain, which leads to the crash of the vole population. There are no mammalian predators of voles other than the arctic fox, and no birds of prey nest on Svalbard.

Associated with the normal population monitoring of voles with live trapping in summer 1999, we snap-trapped an additional sample to find if they had brought any parasites with them from the mainland. Except for gamasid mites, no intestinal helminths, fleas or blood parasites were found (Henttonen *et al*., unpublished data). However, *E. multilocularis* was found to be common. Its occurrence on Svalbard had not been known before. Here we report the details of this finding, as well as additional results obtained in summer 2000.

MATERIALS AND METHODS

Two different areas were surveyed for *E. multilocularis* in 1999 and 2000 (Fig. 1). During 5–10 August 1999 we trapped voles on the slope that they mainly inhabit and which, on the basis of earlier work, is known to be the core area for the rodents close to Grumantbyen (Ims & Yoccoz, 1999; Fig. 1). The site where most of the voles were caught is approximately 100 m above the sea level, immediately north of Grumantbyen ruins (78° 11′ N, 15° 8′ E). In addition, they were trapped on some small patches at 300 m above sea level 3 km south of Grumantbyen where they had survived during a previous crash (Ims & Yoccoz, 1999). Voles were caught using snap-traps (Finnish model) except for 17 obtained using live-traps. These voles came from the long-term monitoring and were either sacrificed and checked for *E. multilocularis* because their appearance suggested infection by this worm, or were found dead in the traps. Those voles have been included in the presentation of results in Table 3, but given the difference in sampling methods they were not included in the estimation of prevalence

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Table 1. Numbers of individual voles infected by *Echinococcus multilocularis* out of numbers sampled (in parentheses) by years and functional groups

Sex	Functional category	1999	2000
Males	Overwintered adults	16 (26)	6 (6)
	Adults of the year	0 (50)	0 (2)
	Subadults and juveniles	0 (11)	0 (9)
Females	Overwintered adults	8 (29)	17 (18)
	Adults of the year	1 (32)	0 (0)
	Subadults and juveniles	0 (14)	0 (10)

Table 2. Numbers of individual voles infected by *Echinococcus multilocularis* out of numbers sampled (in parentheses) by years and length classes

Body length class	1999	2000
$67 \leqslant$ length $\leqslant 78$	0 (14)	0 (6)
$79 \leqslant$ length $\leqslant 89$	0 (15)	0 (10)
$90 \leqslant$ length $\leqslant 100$	0 (28)	0 (4)
$101 \leqslant$ length $\leqslant 111$	4 (65)	18 (19)
$112 \leqslant$ length $\leqslant 122$	21 (40)	5 (5)

rates (Tables 1 and 2). During 2–6 August 2000 we trapped 45 voles on the slope 5 km north-east of the previous core area (Fig. 1). We did not trap in this area during the period 1990–99, but visits made by 2 of us (R.A.I. and N.G.Y.) in different years, and trapping by Alendal (1977) have shown that voles were present in this area in most years.

After *E. multilocularis* had been found, we were told that 'mice' (sibling voles) had been seen at dog yards at Longyearbyen, and an extra trapping was organized there in late August 1999 and the following winter. There were no reported findings of voles in the dog yards in summer 2000.

Traps were checked twice a day, and voles were dissected immediately after capture. The whole *E. multilocularis* mass was preserved in ethanol, which was changed after 24 h. The degree of infection was ranked into 4 classes: young (few vesicles), developing (vesicle coverage about $0{\cdot}5 \times 0{\cdot}5$ cm), great (about half or more of the liver infected) and massive (most or the whole liver infected). Our field investigations were macroscopical, but later microscopical and genetic studies were made on the material.

At dissection of voles, body weight and length were recorded. Age determination was based on the combined information on the body size, hair length and moulting patterns inside the skin (Myllymäki, 1977) and reproductive status in young animals. Voles were placed in functional groups (e.g. Myllymäki, 1977; Haukisalmi, Henttonen & Tenora, 1988) on the basis of age and breeding status. As earlier shown by Haukisalmi & Henttonen (1999), Haukisalmi, Henttonen & Batzli (1995), Haukisalmi *et al*. (1988), functional groups are the most natural way to structure characteristically heterogeneous small mammal populations for parasitological analyses because infection parameters vary significantly depending on the age, sex and breeding status of voles. We used 6 functional groups. (A) Breeding voles, (1) overwintered males and (2) females; (3) breeding males and (4) females of the year (adults of the year); (B) non-breeding voles; (5) subadults (voles which on the basis of their age could have bred but have delayed the maturation); (6) juveniles (juvenile pelage, < 1 month old).

Statistical analysis

We did not formally compare the different years or area, because they were not sampled in the same years and therefore year and area are confounded. We chose therefore to present results by year–area. We assessed the relationships between prevalence, functional groups and body measurements using logistic regression (Cox & Snell, 1989). Analyses were done in S-Plus (Venables & Ripley, 1999).

RESULTS

After our original macroscopical studies, we later confirmed the characteristic hook-like structure of *E. multilocularis* from microscopical preparations. Also the ongoing genetic work on this material by A. Dinkel and T. Romig (personal communication) showed that the DNA sequence within the mitochondrial 12S rRNA gene (as described in Dinkel *et al*. 1998) was identical between the Svalbard isolates and Central European isolates of *E. multilocularis*.

In 1999, 36 of 179 voles were infected by *E. multilocularis*. Excluding those live-trapped (11 infected out of 17), the prevalence was 15%. In the sample obtained in 2000, the prevalence was much higher (51%; 23 infected of 45). The prevalence varied significantly among functional groups (1999: $\chi^2 = 53{\cdot}2$, D.F. $= 2$, $P < 0{\cdot}001$; 2000: $\chi^2 = 54{\cdot}0$, D.F. $= 2$, $P < 0{\cdot}001$). In 1999, the prevalence was clearly highest in the largest (and oldest) overwintered males (Fisher's exact test on sex difference in overwintered individuals in 1999: $P = 0{\cdot}015$), and much lower in the breeding voles of the year (Table 1). In 2000, nearly all overwintered voles irrespective of sex, were infected. Infection by *E. multilocularis* could not be macroscopically detected in the youngest age/size groups. Notice that there were far fewer young breeding adults of the year in 2000 than in 1999 – most likely because voles reproduced during spring 1999, but not during spring 2000. There is a large variation in the timing of the breeding in the spring in this population (Yoccoz & Ims, 1999). Body weight and length were strongly related to prevalence rates (weight: 1999: $\chi^2 = 68{\cdot}1$,

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Table 3. Distribution of *Echinococcus multilocularis* infection size classes in the different functional groups and years

Vole functional group	Size 1	Size 2	Size 3	Size 4
1999				
Overwintered adults	4	9	11	8
Adults of the year	3	1	0	0
Subadults and juveniles	0	0	0	0
2000				
Overwintered adults	3	1	6	13
Adults of the year	0	0	0	0
Subadults and juveniles	0	0	0	0

$P < 0{\cdot}001$; 2000: $\chi^2 = 51{\cdot}7$, $P < 0{\cdot}001$; length: 1999: $\chi^2 = 54{\cdot}5$, $P < 0{\cdot}001$; 2000: $\chi^2 = 50{\cdot}1$, $P < 0{\cdot}001$; Table 2).

The tapeworm infections varied from light, with only a few vesicles, to massive, indicating that infections had apparently been acquired in all seasons. The distribution of infection classes of *E. multilocularis* in different functional groups is given in Table 3. In young breeding voles, only lighter infection classes were found, whereas in old voles all infection classes occurred.

Trapping at dog yards resulted in 24 voles. All were macroscopically negative for *E. multilocularis*.

DISCUSSION

The finding of *E. multilocularis* on Svalbard was, at first thought, surprising. Even though arctic foxes may roam on the pack ice between Svalbard, Novaja Zemlja and the Siberian mainland where the tapeworm is present, Norwegian authorities have not considered *E. multilocularis* as a potential risk on Svalbard. However, it is possible, even probable, that arctic foxes infected elsewhere have immigrated onto Svalbard and expelled infective eggs. Although the infection is self-limiting in arctic foxes (Rausch, 1995; Thompson, 1995), foxes can migrate long distances in few months (e.g. Rausch, Fay & Williamson, 1990). However, in the absence of native rodents (i.e. voles or lemmings) on Svalbard the life-cycle could not have been established before the sibling vole had been introduced to the island.

The voles have probably arrived from the St Petersburg area and that must have happened sometime between 1920 and 1960 (Fredga *et al.* 1990). Murmansk obviously cannot be the source because the distribution of the sibling vole does not extend so far in northwestern Russia. Above we suggested that *E. multilocularis* has been introduced to Svalbard by migrating arctic foxes. An alternative explanation could be that it first arrived with the introduced voles and thereafter succeeded in establishing itself with involvement of local arctic foxes. However, to our knowledge, there are no reports of *E. multilocularis* in the St Petersburg region (Vasilev, 1949). Also, the prevalence of *E. multilocularis* in *Microtus* voles in the endemic areas in Central Europe is low (for a review see Romig, Bilger & Mackenstedt, 1999*b*), and therefore the possibility that any infected voles could have reached Svalbard and survived there long enough to have been able to transmit the parasite to arctic foxes, does not seem high. Thus, we conclude that it is most likely that the source of spread of *E. multilocularis* to Svalbard is naturally migrating final hosts (i.e. arctic fox), but that the reason for establishment of the parasite is due to an anthropogenic introduction of an intermediate host (i.e. the sibling vole). This is an interesting example of how an accidental introduction of an intermediate host can contribute to the establishment of a dangerous parasite.

The prevalence of *E. multilocularis* on Svalbard is among the highest found in arvicoline rodents. High prevalences have been found in muskrats, *Ondatra zibethica*, (Romig *et al.* 1999*a*), and in water voles, *Arvicola terrestris*, (Gottstein *et al.* 1996; Hofer *et al.* 2000) in Europe, and in root (tundra) voles, *Microtus oeconomus*, (Rausch *et al.* 1990) on St Lawrence Island in the Bering Strait. In the common vole, *Microtus arvalis*, in Central Europe the prevalence is usually quite low, usually 1 % or less (Delattre *et al.* 1988) as well as in lemmings and voles in arctic Siberia (Jushkov, 1995). One reason for the high prevalence of *E. multilocularis* in voles on Svalbard may be the high density of a final host that regularly feeds on voles. There is a concentration of arctic fox feeding in the large seabird colonies, and there are yearly 1–3 active fox dens in the immediate vicinity of the main vole trapping sites near Grumantbyen (R. A. Ims and N. G. Yoccoz, personal observations). Fox scats are commonly found in the vole habitat and analyses of their contents have revealed that voles are a relatively common part of the fox diet in this area (Frafjord, 2001).

The presence of *E. multilocularis* at Svalbard has subsequently been confirmed also by screening of a sample of the human population for antibodies (of which there were 2 seropositive cases but without lesions) as well as faecal samples of arctic foxes and sledge dogs with coproantigen test (positive cases in both).

The *E. multilocularis* larvae attain their alveolar form in 12 days and visual identification can be made at the 10th day after the infection (Rausch, 1995). Thus, we should have been able to observe infections that had taken place before mid-July. We had some obviously young and developing infections both in old voles and in the voles born in spring – early summer, but the bulk of the infections, and all heavy infections, were in old, overwintered animals. It seems that voles are infected year round, but the probability of infection is not very high because

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among the breeding voles born in early summer, being 2–3 months old, the prevalence was less than 2%. On the other hand, there was a clear difference in prevalence between the sexes among breeding voles. The reason for higher prevalence in breeding males is probably due to their much greater activity and home ranges than found in females (R. A. Ims, H. Steen and N. G. Yoccoz, unpublished radio tracking data; Norrdahl & Korpimäki, 1998).

Both the prevalence patterns of *E. multilocularis* and the population dynamics of voles differed in the 2 years. The first year of our study (1999) was a typical increase year when breeding in early spring, already under snow, had taken place. In contrast, in the second year (2000), when the prevalence of *E. multilocularis* in voles was higher and particularly so in overwintered females (see Table 1), the population had been declining since the previous year and the onset of breeding was late. Thus, *E. multilocularis* dynamics should be considered in relation to the fluctuations in density and age structure of the rodent hosts.

Rausch & Schiller (1956) studied the seasonal dynamics of *E. multilocularis* on St Lawrence Island in the Bering Strait. The prevalence was highest in spring after the snow melt and declined in summer. Mean age of voles was probably highest in spring, and declined along the breeding season when young age classes entered the population. The prevalence of EM could also have been higher in spring in the vole population at Grumantbyen. Also, the heaviest infections had probably already perished by August.

Some of the infections were so severe that there was no or very little original hepatic tissue remaining. In some of these animals the massive liver infection could be observed externally because of the swelling of the middle part of the body. Yet we were amazed to observe how some old females with heavy infections were still both lactating and pregnant at the same time. Rausch & Schiller (1956) showed that most massive infections ultimately kill the voles. Also, the massive infection can disturb the locomotion and escape ability of the voles making them more susceptible to predation by arctic foxes. The high prevalence with massive infections in the breeding cohort as we observed in 2000 had clearly the potential of affecting the demography of the voles due to parasite-induced mortality or reduced fecundity.

Predation on voles is probably most intense during the autumn after the seabirds have left and before the slope is covered by snow or ice in winter. The vole population is at this time of the year usually at its seasonal peak, and is thus likely to trigger a functional response in the fox. The autumn could therefore be the most intensive transmission time of *E. multilocularis* parasite to foxes.

The *E. multilocularis* focus in voles at Svalbard offers good opportunities for further studies on interactions within the vole–fox–*E. multilocularis* system. The system is very simple as it consists only of 1 species each of final and intermediate host. The suitable habitat for voles and thus the arena for the interactions is spatially well defined and restricted. The demography of the vole population, including its spatial and temporal dynamics, is also well known based on a long time-series of capture–recapture data (Ims & Yoccoz, 1999; Yoccoz & Ims, 1999). Also the abundance, movements, diet and infection status of arctic foxes in the area could easily be monitored (Prestrud, 1992; Frafjord, 2001).

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