Heterocope borealis in Norway - A copepod on the move, or on the edge of its natural distribution?

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The calanoid copepod *Heterocope borealis* has been assumed to have an extremely northern distribution in Norway, limited to the north-eastern parts of Finnmark county. The recent records of the species in Lake Fustvatn and Lake Røssvatn in Nordland county was therefore quite unexpected. These lakes are located roughly 700 km south-west of the known distribution area in Norway. There is data on planktonic and/or littoral microcrustaceans from several hundred lakes between the known localities in Finnmark and the two new records in Nordland. The distribution of *H. borealis* in Finland and Sweden shows a scattered occurrence both in the northern and southern parts of the countries. Possible explanations for the occurrence of the species in the two lakes in Nordland are discussed.

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INTRODUCTION

The calanoid copepod *Heterocope borealis* (Fischer, 1851) has a palearctic distribution, occurring from Sakhalin and Kuril Islands as well as the arctic Wrangel Island in the east (Dussart & Defaye 2002, Vinarski et al. 2015), through Siberia (Sars 1902, Illies 1978, Fefilova et al. 2013), the Baltic states (Illies 1978.) and Fennoscandia (Ekman 1922, Särkkä et al. 1990, Rahkola-Sorsa 2008, Persson et al. 2009, Svensson and Hårding 2010) with Norway as the western border of its distribution (Sars 1902). In Europe it has been recorded as far south as the Alps/southern Germany (Elster 1936, Einsle 1993). However, in some localities in the Alps/southern Germany it has disappeared. Thus in Lake Constance in Germany, *H. borealis* was reported from the 1920s up to 1963, but in later studies it has been missing, allegedly as a result of eutrophication (Straile & Geller 1998). Also in Lake Chiemsee in southern Germany it has disappeared (Einsle 1993).

In Norway, Sars (1902) reported *H. borealis* from the eastern part of Finnmark county where the species occurred commonly in small tarns and ditches near the city of Vardø and also at Matsjok in the municipality of Lebesby. This northern distribution was later on confirmed by records from the municipalities of Kvalsund, Porsanger and Tana (Jensen J.W. unpubl., Halvorsen and Walseng unpubl.) Thus, the species has been considered to have a northern distribution in Norway, limited to Finnmark (70° N). However, here we report two recent records from Lake Fustvatn and Lake Røssvatn in Nordland county, far from its supposed natural distribution area in Norway (Figure 1). We also discuss potential explanations for the occurrence of the species in these two more southern lakes.

Species identification

Heterocope borealis resembles the very common species *H. saliens* (Lilljeborg, 1862). It gives, however, an immediate impression of being more robust. At a closer look one will find

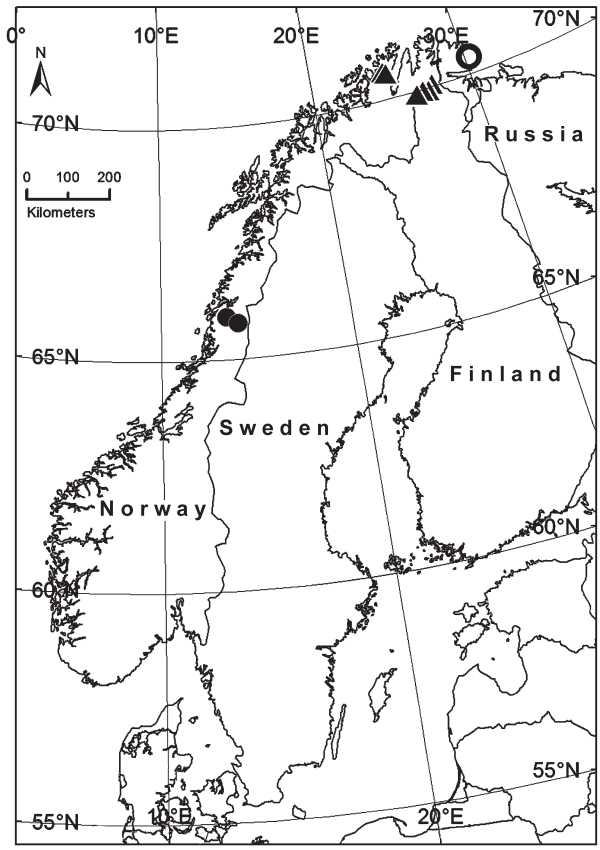

Figure 1. Map of Scandinavia showing records of *Heterocope borealis* in Norway. Filled circles: Lake Fustvatn and Lake Røssvatn. Filled triangles: Earlier records in Finnmark (18 localities) Open circle: Area near Vardø where the first records of the species were done (Sars 1902).

that the caudal rami are shorter and broader than in *H. saliens*, and widening distally. The proximal part of the apical setae are considerably thicker at the base and more dilated (Figure 2).

The middle seta is somewhat longer than the other two. The bristles on the outside of the setae are comparatively longer and thicker than in *H. saliens*. On the female genital segment there is a toothlike (dentiform) projection on each side of the genital area which is not found in *H. saliens*. Adult females in both species are about 3 mm long.

The male also resembles *H. saliens* but has a more robust appearance. A good criterion to separate males of the species is a knoblike prominence on the second joint of the right leg of the fifth pair of legs (p5) in *H. borealis*. The terminal joint of the left leg of p5 in *H. borealis* is narrower and more elongated than in *H. saliens*, exceeding in length the two preceding joints combined. Species identifications are in accordance with Sars (1902).

Lake Fustvatn and Lake Røssvatn

Lake Fustvatn (65° 54′ N, 13° 23′ E), which is situated 38 m a.s.l., has a surface area of 10.7 km^2 and a maximum depth of 70 m. The lake is the lowermost and largest of four lakes in the Fusta catchment area. Values of total nitrogen and phosphorus from water samples taken in August 2014 of < 70 µg/L and 2 µg/L, respectively, indicate oligotrophic conditions. The catchment area is dominated by sparsely vegetated mountains and the lake is surrounded by spruce forest and scattered farmland. With the exception of a rotenone treatment in 2012, the lake is little influenced by human activities.

Lake Røssvatn (65° 45′ N, 14° 01′ E) is situated 383 m a.s.l., has a surface area of 219 km^2 and a maximum depth of 240 m. After a regulation for hydroelectric purposes in 1957, the lake became Norway's second largest. The regulation height of the lake is 12,5 m. The catchment is dominated by sparsely vegetated mountains and the lake is surrounded by coniferous and deciduous forest and scattered farmland. Lake Røssvatn is oligotrophic with total nitrogen and total phosphorus concentrations of 101 and 2 µg/L, respectively. Lake Røssvatn is located approx. 30 km south-east of Lake Fustvatn.

MATERIAL AND METHDODS

Lake Fustvatn

As part of a program studying effects of fish removal on the invertebrate fauna in Lake Fustvatn, zooplankton was sampled by vertical net hauls (mesh size 90 µm) and a plexiglass tube sampler on three stations in the deepest part of the lake and by horizontal net hauls on three stations in the littoral zone. In addition, crustaceans were collected from bottom fauna net samples in the littoral. The sampling took place in August every year in the period 2011 – 2016. The lake was treated with rotenone in the fall of 2012, in order to exterminate the fish parasite *Gyrodactylus salaris*. The collected material is incorporated in the collections of the NTNU University Museum.

Lake Røssvatn

In 2016 Lake Røssvatn was part of the surveillance monitoring of large lakes in Norway. Investigations of the microcrustacean zoooplankton community, including the littoral species, was part of the program. The lake was sampled five times from June to October 2016. Qualitative sampling was conducted with zooplankton nets of different diameter and mesh size (small net: 30 cm diameter/90 µm mesh size, large net: 110 cm diameter/500 µm mesh size). Pelagic samples were taken over the deepest part of the lake as vertical net hauls. Samples from the upper 10 and 50 m were taken with the smallest net. The entire water column was sampled with the large net to capture larger species. The littoral zone was sampled on two dates by horizontal net hauls with the small net over different types of substrate on 10 stations located around the lake.

Figure 2. *Heterocope borealis* (left) and *H. saliens* (right) males. Inserted enlargements show differences in the shape of caudal rami and proximal parts of apical setae in the two species. Photo: Aina Mærk Aspaas.

RESULTS

Lake Fustvatn

Except for 2013, *H. borealis* was recorded all years in the investigation period. In 2013, the first summer after the rotenone treatment, copepods were totally absent from the samples, but the material from later years indicates that all species survived the treatment. *H. borealis* was represented in tube samples and vertical net hauls as well as in horizontal net hauls and net samples of bottom animals from the littoral.

The recorded numbers of *H. borealis* were low all years. The highest abundance was found in 2016, with an estimated density of 100 – 600 individuals m^{-2} in the pelagial, based on tube samples. It was only found in the epilimnion, in samples from depth intervals 0 – 5 and 5 – 10 m. Littoral samples were not quantitative; however, they indicate low abundance too. Other *Heterocope* species were not found.

H. borealis was recorded on all stations, both in the littoral and pelagial. It therefore seems to be widely distributed in Lake Fustvatn.

Lake Røssvatn

H. borealis occurred in Lake Røssvatn in the littoral samples from the end of June (copepodid I stage) and in the pelagic samples from the middle of July to the middle/end of September. As the sampling was qualitative, it does not allow us to calculate densities, but numbers were highest in July and August.

In the littoral zone *H. borealis* co-existed with *H. saliens,* but in the pelagic zone we only found *H. borealis.* 83 % of the *Heterocope* specimens found in the littoral zone were *H. borealis.* It constituted up to 5.8 % of the total number of microcructaceans in samples from the pelagial zone. It occurred in all types of samples in July and August, but in September it was not found in the samples from the epilimnion (0-10 m). Also in Lake Røssvatn the species seems to be widely distributed as it occurred on the majority of the 10 littoral sampling stations.

DISCUSSION

The occurrence of *H. borealis* in Lake Fustvatn and Lake Røssvatn was quite surprising as its distribution in Norway was supposed to be limited to Finnmark (Sars 1902, NTNU University Museum and NINA unpubl.). NINA and the NTNU University Museum have compiled data on planktonic and/or littoral microcrustaceans from own investigations and literature from 308 lakes in Finnmark. The species was recorded in 18 of these localities. In addition there are data from 324 lakes in Nordland and 146 lakes in Troms (the county between Finnmark and Nordland), but *H. borealis* has not been reported from any of those. The records from Lake Fustvatn and Lake Røssvatn are approximately 700 km south-west of the nearest records from Finnmark.

In Scandinavia, *H. borealis* also occurs in Finland and Sweden (Ekman 1922, Lötmarker 1964, Nilsson & Pejler 1973, Silfverberg 1999, Rahkola-Sorsa 2008, Persson et al 2009, Svensson & Hårding 2010, Jouke Sarvala pers. com). In a compilation of Finnish zooplankton studies the species was recorded in 21 lakes and ponds (Jouke Sarvala pers. com.). Hence, it seems to be rather rare in the country. However, it does occur in lakes both in the northern and southern part of Finland, and there is also one record from the central part (Silfverberg 1999, Jouke Sarvala pers. com.).

In Sweden, *H. borealis* seems to have its main distribution in the ecoregion Sydsvenska höglandet ("South Swedish highland" which comprises the northern part of Småland county and the southern parts of Västergötland and Östergötland counties (Svensson and Hårding 2010). Ekman (1922) reported the species from four lakes (Mycklaflon, Övringen, Vidöstern, Stråken and one unnamed) in this region and Svensson and Hårding (2010) recorded it in Lake Bolmen (one individual; however, it was known to occur in this lake in the 19th century). Nilssen, J.P. (pers. com.) found it in Lake Raslången which is farther south, on the border between Skåne and Blekinge counties. In a recent study of 75 lakes located between latitude 57– 64°N from the Norwegian west coast to the Swedish east coast (Hessen et al 2017), *H. borealis* was not recorded in pelagic samples from any of the 31 Swedish lakes investigated (Walseng unpubl.). Other available literature does not state finds of the species in central Sweden either. In the northernmost part of Sweden, Norra Norrland (covering roughly the northern 1/4 of the country), it occurs again. In a review of zooplankton investigations from 1740 lakes in this region (Persson et al. 2009), *H. borealis* was recorded in five lakes, but lake names or coordinates were not given. At latitudes between 65 and 66°N there are a few records of the species. In the Lilljeborg collection stored at the Museum of evolution in Uppsala there is an original handwritten catalogue where *H. borealis* is listed with a question mark as found in 1879 in "Geautasjön" (now named Gäutan) in the Umeälven drainage area. Much later the species was recorded in the same watercourse in Lake Överuman (Lötmarker 1964), republished by Nilsson & Pejler (1973).

It has been suggested that *H. borealis* might be classified as a relict crustacean, invading areas in Sweden and Finland from the south-east at times when glacial lakes covered the landscapes and what today is the Baltic Sea (Särkkä et al. 1990). It is well known that many freshwater organisms, especially fish, migrated into the south-eastern and north-eastern parts of Norway through this route in postglacial periods. The actual species are now mostly referred to as ice age immigrants (Økland J. & Økland KA 1999). The occurrence of *H. borealis* in Lake Fustvatn and Lake Røssvatn does not fit into this pattern as both lakes have discharge westwards to the Norwegian Sea. The introduction to the lakes must have other explanations. Concerning Lake Fustvatn, there is a specific incident that is highly interesting in this connection. In this lake, another unexpected crustacean, the brackish water amphipod *Gammarus duebeni*, was recorded (Kjærstad

et al. submitted). This was mentioned in an interview in a local newspaper, whereupon an elderly man contacted the editorial office and reported that he in the 1960s had collected *Gammarus* sp. in Finnmark and transported the material by car in glass jars to release in Lake Fustvatn (Helgeland Arbeiderblad, 1 November 2012). This was done in order to improve the quality of salmonid fishes in the lake. The material was collected in the municipality of Vardø, in small water bodies close to the village of Smelror, where the first records of *H. borealis* were done by Sars (1902). Several of the more recent records of *H. borealis* from Finnmark also originate from this particular area. It is therefore possible that *H. borealis* came with the transport water and was unintentionally introduced together with *G. duebeni* to Lake Fustvatn. If this is the explanation for the occurrence of *H. borealis* in Lake Fustvatn, it is a premium example of unintended dispersal of a species by man (antropocore dispersal). The air-distance between Smelror and Lake Fustvatn is approximately 890 km.

If *H. borealis* really was introduced to Lake Fustvatn by man in the 1960s, it may have spread to Lake Røssvatn afterwards. This could have been mediated by birds or human activity. Although there is some discussion about the importance of birds as vectors for the spread of invertebrates between aquatic environments, there is no doubt that it happens from time to time (e.g. Coughlan et al. 2017). More specifically, birds have been suggested as a means for transport of copepods to new regions (Reid and Reed 1993). Furthermore, birds can transfer copepods in viable resting stages (Frisch et al 2007). Resting eggs of *H. borealis* could therefore potentially be transported by birds, but to our knowledge there are no reports on this for any of the *Heterocope* species. However, one cannot exclude that birds brought *H. borealis* to Lake Røssvatn. Human mediated transfer is another possibility. This could have taken place in many different ways. One possible mechanism is transfer with boats (Johnson et al 2001, Kerfoot et al. 2011). During the last few decades it has become quite common for sport fishermen to have their boats on trailers and transport them between lakes. Microcrustaceans may in that way be transferred live in small volumes of water left in the boats. Furthermore, *H. borealis* produces resting eggs, which endure drought and may stick to boats and equipment during transfer.

As shown, *H. borealis* seems to be a relatively rare species in our neighboring countries, too, with a scattered distribution from northern Finland to southern Sweden. It can therefore not be excluded that the species has existed in Lake Fustvatn and Lake Røssvatn for a long time as part of this scattered distribution pattern in Scandinavia. The isolated records from Lake Överuman and Lake Gäutan support this theory. These lakes are only 50 – 70 km north-east and east of Lake Røssvatn and part of the River Umeälven watercourse that ends in the Baltic Sea.

There is limited knowledge of the distribution of microcrustaceans in other lakes in the watersheds of Lake Fustvatn and Lake Røssvatn. We have some data from Lake Krutvatn, which is located close to the Swedish border and has its outlet to Lake Røssvatn (Koksvik & Dalen 1979) and from Lake Nedre Elsvatn from which a diversion tunnel leads water into Lake Røssvatn (Koksvik 1976). Lake Nedre Elsvatn is located in the Vefsna watercourse. There is evidence for dispersal of invertebrates between watercourses through tunnels built in connection with hydroelectric development in Norway, e.g. *Mysis relicta* (Koksvik & Reinertsen 2009, 2012). There is no zooplankton data from other lakes in the drainage area of Lake Fustvatn. Investigations should be carried out in order to find out whether *H. borealis* might have a wider local distribution.

In conclusion, the occurrence of *H. borealis* in Lake Fustvatn and Lake Røssvatn, far south of its previously known distribution area in Norway, may be a part of the scattered distribution of *H. borealis* in Scandinavia. However, the absence of the species in other lakes in Norway south of Finnmark might indicate that it has appeared in the two lakes recently. Although the species could have been introduced to the lakes by birds, we cannot exclude human mediated introduction as the explanation for the new records. The occurrence in Lake Fustvatn is particularly interesting in this connection. To disentangle these alternative explanations, future studies should sample other lakes and ponds in the watersheds and in the area, including the Swedish side of the border, to examine if the species occurs in more localities. Also, the relationship of *H. borealis* populations in general, and in particular populations in the Vardø area in Finnmark and those in Lake Fustvatn and Lake Røssvatn should be determined by DNA studies.

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