Correlation between number of human cases of myiasis caused by the reindeer warble fly (*Hypoderma tarandi*) and weather conditions during summer in northern Scandinavia

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Abstract

The reindeer warble fly *(Hypoderma tarandi)* causes myiasis in reindeer and caribou (*Rangifer tarandus* and subspecies) and aberrant hosts such as humans. Of 22 human cases reported 1982-2016, 16 were children and 18 were residents in or visited northern parts of Norway or Sweden. Of a series of 39 new human cases in Norway 2011-2016 (reported 2017), 32 were children, 32 were resident in Finnmark (northernmost county of Norway), one was a visitor to Finnmark (most likely infested there), 17 were infested in 2012 and 10 in 2013. There are to our knowledge no human cases reported from Finland, although the *H. tarandi* infestation level in reindeer is high in the reindeer husbandry area of the country and many people live there. Consequently, the differences in geographical distribution and in distribution between children and adults, and between years, relative to where *Rangifer* and *H. tarandi* live, strongly indicate the presence of important identifiable drivers affecting the number and distribution. Meteorological data for June-August 2011-2016 from five meteorological stations in Finnmark applied in statistical analyses demonstrated that low proportion of days suitable for *H. tarandi* flying in July-August, combined with low proportion of days with rain in August, resulted in high number of cases in the particularly cold summer 2012. In contrast, in the particularly warm summer 2013, high proportion of days suitable for *H. tarandi* flying during July-August gave a high number of cases, and particularly high mean temperature in June tended in the same direction.

Key words: *Hypoderma tarandi*, *Rangifer tarandus*, reindeer, myiasis, human, children, temperature, rain.

Introduction

Reindeer warble fly (*Hypoderma tarandi*) larvae parasitize reindeer and caribou (*Rangifer tarandus* and subspecies) in nearly all northern hemisphere regions where these animals live (Alaska, Canada, Greenland, Norway, Sweden, Finland, Russia) (Colwell et al. 2006). Aberrant hosts reported for *H. tarandi* larvae are red deer (*Cervus elaphus*) (Nilssen and Gjershaug 1988), roe deer (*Capreolus capreolus*) (Skjenneberg 1968), moose (*Alces alces*) (Ågren and Chirico 2005), muskoxen (*Ovibos moschatus*) (Jansen 1970; Samuelsson et al. 2013) and humans (e.g. Bergman 1919; Lagacé-Wiens et al. 2008). Myiasis denotes the condition where fly larvae have infested an animal and feed on its tissues. In humans, myiasis caused by *H. tarandi* can lead to *ophthalmomyiasis interna* (OMI), a condition where the larva has invaded the eye globe, often resulting in damage to the eye (Lagacé-Wiens et al. 2008). Of 22 human cases reported 1982-2016 (Bangsø et al. 2016; Chirico et al. 1987; Faber and Hendrikx 2006; Gjötterberg and Ingemansson 1988; Gryseels et al. 1991; Kan et al. 2012; Kan et al. 2013; Kan et al. 2010; Kearney et al. 1991; Lagacé-Wiens et al. 2008; Rukke et al. 2014; Syrdalen et al. 1982; Syrdalen and Stenkula 1987), 16 were children. Of the 22, 18 were resident in or visited northern parts of Norway or Sweden, one visited a reindeer area of southern Norway (Hardangervidda), two were reported from northern Canada and one from Greenland. Of a series of 39 new cases in Norway 2011-2016 (Landehag et al. 2017), 32 were children, 32 were resident in Finnmark (northernmost county of Norway) and one was a visitor to Finnmark for grouse hunting and most likely infested there (resident in southern Norway county where there are no reindeer). The remainder six were resident in or visited mid- and southern parts of Norway where there are reindeer and *H. tarandi*. Seventeen were infested in 2012, 10 in 2013.

To our knowledge, there are no reported human cases from Finland, the neighbour country of Norway and Sweden, although Finland has a high *H. tarandi* infestation level in reindeer (Åsbakk et al. 2014). The uneven occurrence in children and adults, between years and with respect to geographical distribution in relation to where *Rangifer* and *H. tarandi* live, indicate that there are important identifiable drivers for the infestation in humans. Our hypothesis is that the prevalence and distribution is affected by weather conditions during the major times for pupal development (June) and oviposition (July, August). The time span for the 39 cases (6 years) (Landehag et al. 2017) is low as a time series for statistical analyses, but still the longest reported human case series. It is not possible to perform experiments of drivers for the infestation in humans. Based on what was known for the 39 cases 2011-2016 (gender, age, occupation, residence or reindeer area visited, year of infestation), and weather data from meteorological stations in Finnmark (temperature for five stations and rain for four stations during June-August), we performed statistical analyses with the purpose of revealing possible drivers for human infestation.

Materials and methods

Cases and setting

The study encompassed the human *H. tarandi* myiasis case series (*n* = 39) in Norway 2011-2016 reported in 2017 (Landehag et al. 2017). Symptoms were transitional dermal swellings of the head or face, lymphadenopathy, periorbital oedema, with or without eosinophilia, associated with history of residence in or visit to a reindeer-inhabitated area in summer or autumn. All were seropositive for antibodies (IgG) against Hypodermin C, an enzyme secreted by the *H. tarandi* larva during migration in the host. All baseline characteristics (gender, age, occupation, residence, travel history, clinical history) were known in most cases.

In early December 2012, after diagnosis of the first three cases in early November 2012 (symptom onset September-November 2012), we informed about *H. tarandi* myiasis (letter) to primary care physicians in Finnmark and to the Departments of Paediatrics and Ophthalmology at the University Hospital of North Norway (UNN), Tromsø. News media (Norway, Sweden, Finland) and presentations at medical meetings and reindeer husbandry conferences promoted information about the disease (December 2012 until end 2013). Two children, with symptom onset in September and November 2011, respectively, were diagnosed in December 2012 following information via media.

Of the 39 cases, 32 were resident in Finnmark and one was a visitor (resident in a southern Norway county where there are no reindeer) to Finnmark in August 2012 for grouse hunting (symptom onset September 2012). We later refer to these 33 as the Finnmark group. The remaining six (non-Finnmark group) were resident in or visitors to counties of mid- and southern Norway where there are reindeer and *H. tarandi*.

Meteorological data

Meteorological data were obtained from the Norwegian Meteorological Institute (MET) (eKlima 2016) for five meteorological stations in Finnmark: Hammerfest (airport, 70.68°N, 23.68°E, 81 m above sea level [asl.]), Alta (airport, 69.97°N, 23.36°E, 3 m asl.), Suolovuopmi (69.58°N, 23.53°E, 381 m asl.), Karasjok (Markannjarga, 69.46°N, 25.50°E, 131 m asl.) and Pasvik (Svanvik, 69.45°N, 30.04°E, 27 m asl.) (Figure 1). The data were: the normal monthly mean temperature for June-August (normal period 1961-1990), the daily mean temperature (from daily measurements at 7:00, 13:00 and 19:00 Norwegian Standard Time, i.e. 6:00, 12:00 and 18:00 Coordinated Universal Time, UTC) and the daily maximum temperature for June-August 2011-2016 (all stations), and the daily mean precipitation (rain, 12 hr, 6:00-18:00 UTC) from the stations with complete recording (all except Alta).

Hypoderma tarandi fly at temperatures ≥12-15°C and preferentially in dry weather (Anderson and Nilssen 1996; Nilssen and Anderson 1995b; Nilssen and Haugerud 1994). Therefore we calculated the proportion (scale: 0-1) of days in July and August with maximum temperature ≥12°C, and days with rain (>0 mm), with the five and the four stations treated as one group, respectively, for temperature and rain.

Statistical analyses

The JMP statistical software package (ver. 14.0, SAS Institute Inc., 2013) was used (descriptive statistics, ANOVA, t-test, correlation and regression analyses). The α-level was set to 0.05.

Results

Gender, infestation year and geographical region

Of the 39 cases, 32 (82%) were children (3-12 years old, 13/32 girls), seven were adults (20-66 years old, 3/7 women), 17 were infested in 2012 and 10 in 2013 (Figure 2). Thirty-three (85%, Finnmark group) were resident in Finnmark ($n = 32$) or visited Finnmark ($n = 1$). All non-Finnmark group cases ($n = 6$) were children (5-9 years old, 3/6 girls).

Statistical analysis after grouping ($n = 39$) by infestation year and gender showed that the number was similar in females and males (t-test, $t_{10} = 0.7$, $p = 0.5$). The number was significantly higher in 2012 compared to the other years (ANOVA, grouping by infestation year and gender, $F_{5,6} = 12.4$, $p < 0.03$). The number was significantly higher in 2013 compared to the other years except 2012 ($p < 0.05$). After including age (child, adult) in the grouping, the number was significantly higher in children compared to adults (ANOVA, $F_{1,22} = 7.2$, $p = 0.01$).

The symptom onset time was known for 35/39 cases (Table 1). It was generally earlier in 2013 (July-August: 22%, September-October: 78%) compared to 2012 (September-October: 50%, November-December: 50%).

Temperature

There are differences in normal monthly mean temperature between the five meteorological stations (altitude and geographic location differences) (Figure 3). Figure 4 illustrates the monthly mean temperature for June-August 2011-2016 for the five stations.

We restricted the analyses to the Finnmark group cases ($n = 33$). Figure 4 shows high degree of concurrence in mean monthly temperatures 2011-2016 between the stations. Since we could not know where in Finnmark the infestations took place, we treated the temperature data for the five stations as one group. Table 2 shows the daily mean temperature for the stations during June-August 2011-2016 together with the corresponding ANOVA results. The mean was significantly lower in 2012 compared to the other years, and significantly higher in 2013 compared to the other years. When looking at the months individually, the mean in June was significantly lower in 2012 compared to 2011 and 2016, similarly low in 2014 and 2015, whereas it was significantly higher in 2013 compared to the other years. The mean in July was significantly higher in 2014 and significantly lower in 2015 compared to the other years, whereas it was significantly lower in 2012 compared to the other years except 2015. The mean in August was significantly higher in 2013 compared to the other years except 2015, whereas it was significantly lower in 2012 compared to the other years except 2016.

Table 3 shows the proportion of days with maximum temperature ≥12°C during July-August 2011-2016 for the five stations, and the corresponding ANOVA results. The proportion was significantly lower in 2012 compared to the other years except 2015 (similarly low in 2012 and 2015). In 2013 it was significantly higher compared to the other years. When looking at the months individually, the proportion in July was similarly low in 2012 and 2015, similarly high in 2013, 2014 and 2016, and significantly higher in these three years compared to 2012 and 2015. The proportion in August was similarly low in 2011, 2012, 2014 and 2016, similarly high in 2013 and 2015, and significantly higher in 2013 and 2015 compared to the other years.

Rain

Table 4 shows the proportion of days with rain during July-August 2011-2016 with the four stations that recorded rain treated as one group, together with the corresponding ANOVA results. The proportion was significantly higher in 2013 and 2016 compared to 2012, 2014 and 2015. When looking at the months individually, the proportion in July was similarly high in 2011, 2013 and 2016 while it was similarly low in 2014 and 2015. In August, the most striking feature was that the proportion was significantly lower in 2012 compared to the other years. The proportion was similarly high the other years.

Correlation and regression analyses

Since the weather conditions in June-August of the two years with the majority of cases (2012, 2013) appeared considerably different, we performed two analyses including the Finnmark group cases in order to demonstrate pairwise correlation between number of cases and weather data, with all years included except either 2012 or 2013 (Table 5). The table shows numerous strong negative and positive pairwise correlations. However, with 2012 excluded, regression analysis demonstrated a significant positive correlation between number of cases and proportion of days with maximum temperature ≥12°C in July-August ($r = 0.94$, $p = 0.02$). With 2013 excluded, regression analysis demonstrated a significant negative correlation between number of cases and proportion of days with maximum temperature ≥12°C in July-August ($r = -0.89$, $p = 0.04$), and a significant negative correlation between number of cases and proportion of days with rain in August ($r = -0.95$, $p = 0.01$).

Discussion

The first three of the 37 cases infested 2012-2016 were diagnosed in early November 2012. For 12 of the 17 infested and diagnosed in 2012, the diagnosis was in November or December. For the two infested in 2011, the diagnosis was in December 2012, more than a year after symptom onset. Since the information to the medical environments and the public was promoted after most of the cases in 2012 already had been diagnosed (Landehag et al. 2017), we consider the many cases in 2012 an "outbreak" rather than as resulting from the spread of the information. Although the information most likely increased the medical awareness of the condition, we find it likely that there were identifiable drivers for the many cases associated with the summers 2012 and 2013. The generally earlier symptom onset time in 2013 (100% in July-October) compared to 2012 (100% in September-December) suggested the presence of important drivers in 2013 different from those in 2012.

The findings of a significantly higher number of cases in children compared to adults, and no difference in prevalence between females and males, were in agreement with previous reports (Kan et al. 2013; Kearney et al. 1991; Lagacé-Wiens et al. 2008; Syrdalen et al. 1982). The number in each of the years other than 2012 and 2013, ranging from two to four, indicated that the infestation occurs regularly in small numbers and potentially can be diagnosed each year in northern Norway. In support, by the time of final preparation of this report (November 2018), we are aware of five new diagnosed unpublished cases (clinical findings and serology, two in 2017 and three in 2018; four in northern Norway and one in Sweden, one with a larva identified as *H. tarandi* removed from an eye).

June-August was particularly cold in 2012. The analyses demonstrated that low proportion of days suitable for *H. tarandi* flying in July-August, combined with low proportion of days with rain in August 2012, correlated significantly with the high number of cases this year. June-August was particularly warm in 2013. The analyses demonstrated that high proportion of days suitable for flying in July-August this year correlated significantly with the high number of cases, and the particularly high mean temperature in June this year also showed high correlation (although not significant) with number of cases.

The significant negative correlation between proportion of days with temperatures ≥12°C in July-August and number of cases (Table 5) indicated that when the proportion of such warm days in July-August was particularly low, the number of cases was high in the particularly cold year 2012. Also the other strong negative correlations (although not significant) between number of cases and proportion of days with temperatures ≥12°C during the individual months and the periods June-August and July-August supported the observation, and further showed that low temperature during the summer tended to result in many cases. The mean temperature in June was particularly low in 2012 and particularly high in 2013. Mature *H. tarandi* larvae drop from the reindeer host in May-June (Nilssen and Haugerud 1994). After one to nine weeks as pupae, depending on temperature, the adult flies emerge (Nilssen 1997). The males die after mating (Weintraub 1961) and the females seek reindeer for oviposition. The difference in temperature in June between 2012 and 2013 gives reason to believe that the cold June in 2012 could give longer pupal development time compared to a warmer June like in 2013. Due to the significantly lower proportion of days in July and August with temperatures high enough for flying in 2012 compared with most of the other years, the females could face greater problems in finding reindeer for oviposition in 2012 compared to warmer summers. In cold and rainy weather, flies on the ground can move towards laying reindeer and attach their eggs on the host body by walking or jumping up from the ground (Skjenneberg 1968). Suppose that the flies oviposit on human scalp hair like on hair of reindeer, children (low of height) could be more prone to a strategy where the flies walk or jump up from the ground, especially during play on the ground. Adults could be more prone to such a strategy for instance during resting on the ground. Personal experience (Nilssen, Åsbakk) of sudden presence, without any prior notice (large fly in the air), of a *H. tarandi* female in the scalp hair during resting on the ground in weather too cold for *H. tarandi* flying supports this apprehension. The experience also demonstrated that the fly suddenly could show up in the hair without any notice of the presence (discovered in the hair by others).

It is reasonable to believe that the flies can oviposit on hairs of the leg or arm. However, in that case it is likely that migrating dermal swellings would occur on those parts of the body. Among the 39 cases 2011-2016, dermal swellings occurred only in the head region. We thus find oviposition on leg or arm hairs unlikely as an important way of oviposition on humans, although oviposition on legs is common in reindeer. In addition, most children have little hair on their legs, and children are likely to wear pants on cold summer days in northern Norway, particularly in a cold summer like 2012. Transfer of larvae directly from hairs of caribou or reindeer to the human eye through close contact with animal pelts is suggested (Kearney et al. 1991). We find this unlikely as an important way of infestation, since most people infested cannot report any close contact with reindeer aside from living in or visiting an area with reindeer (Landehag et al. 2017). Most of the cases reported in the literature 1982-2016 (before Landehag et al. 2017) involved OMI, and eyebrows and eyelashes were suggested as possible targets for oviposition (Kearney et al. 1991). However, recent reports (Kan et al. 2013; Landehag et al. 2017) clearly indicate that OMI is a more uncommon condition following the infestation. Eggs of *H. tarandi* take 4-7 days to develop and hatch, depending on the temperature where they develop (Karter et al. 1992), and thus we find it unlikely that eggs (approx. 1 mm long, shining yellow and often in a row) could develop on eyebrows, eyelashes, legs or arms without notice.

We have no record of how the infested people (Kan et al. 2013; Kan et al. 2010; Landehag et al. 2017) live or how often they wash their hair. As tourists from European countries or as residents in different parts of Norway, the lifestyle of the majority most likely involves body- and hair wash once a week or more. For one of the cases, we know that body and hair wash was done several times a week, suggesting that eggs can resist and survive normal body wash. In two cases where *H. tarandi* eggs were identified in the hair (Kan et al. 2013), it was noticed that the eggs could not be removed with a lice comb.

Anecdotal reports from Finnmark indicate that there are more cases among adults than the relatively few cases (compared to number reported in children) reported in the literature. This may indicate differences between adults and children in manifestation of symptoms, possibly due to immunological differences and differences in in symptoms. It might also be that a child's skin is easier for the larva to penetrate. There may also be differences in level of threshold for seeking medical help between adults and children, and many *H. tarandi* infestations may have remained *morbus mysticus*, unidentified disease. Since *H. tarandi* preferably oviposits on reindeer summer hairs (thinner and shorter than winter hairs), so that the eggs are attached close to the skin surface (Karter et al. 1992), it could be that hair length differences may affect which animal species or person can be infested. The small (0.6 mm long) (Karter et al. 1992) newly hatched *H. tarandi* larva is sticky, dries out easily, and must rapidly reach the skin surface and penetrate it. Larvae of *H. lineatum*, (species closely related to *H. tarandi* infesting cattle) that were unable to find a suitable entry place within 15 min, slowed the activity and appeared dead in another few minutes (Nelson and Weintraub 1972).

Female *H. tarandi* could have problems in finding reindeer for oviposition in a cold summer particularly if the reindeer have moved a long distance from where the larvae dropped. Under such circumstances, infestation of humans could be more frequent simply due to lack of natural hosts, particularly if the flies emerged in an area where many people live or frequent. Indeed, most cases in Finnmark 2011-2016 were people living in major human settlements; the towns Hammerfest, Alta and Lakselv. Given that the pupal development time is long when June is cold, the reindeer could have moved particularly far away from where the pupae developed in a year with a particularly cold June like 2012. It is a characteristic for the reindeer husbandry in Norway that natural pastures is used throughout the year (Landbruksdirektoratet 2017), and reindeer are herded between different pastures between the various grazing seasons (Paine 1994). In Finnmark, the migration route from winter (inland) to summer (coast) pastures is 10 – 500 km long (Tyler et al. 2007). Since traditional migration is often a heavy burden for the reindeer, and pregnant females must have arrived at spring pastures before the calving starts in April-May, nowadays transport is often by road, in contrast to earlier times when the animals were herded between the seasonal pastures. Although *H. tarandi* females are excellent flyers (Nilssen and Anderson 1995a), the distance the females must complete to find reindeer is of significance for infestation levels in reindeer (Folstad et al. 1991; Nilssen and Haugerud 1994). If reindeer reach the summer pastures before May 1, almost all the larvae come along, but if the arrival is postponed until June 20, the majority of larvae have left the animals more or less far away from the summer pastures (Nilssen and Haugerud 1994). This suggests that with long distance between the emerging adults and the reindeer, the flies could be "forced" to oviposit on aberrant hosts such as humans. August 2012 was a combination of low mean daily temperature, low proportion of days with maximum temperature ≥12°C, and significantly lower proportion of days with rain in August compared to August of the other years. The significant negative correlation between proportion of days with rain in August and number of cases demonstrated that a particularly dry August combined with temperatures too low for flying gave a high number of cases in this particularly cold year. We hypothesize that days with temperatures too low for flying, combined with no rain, represent conditions particularly used for oviposition by the strategy involving walking or jumping up on the potential host from the ground. Perhaps the flies could be extra stimulated to such activity in August when the oviposition season goes towards the end. A contributing driver could be that people spend more time outdoors on days when it is not raining.

The significant positive correlation between number of cases and proportion of days with temperatures ≥12°C in July-August 2013 (Table 5), indicate that high proportion of days with such high temperatures during these months could give a high number of human cases in a particularly warm summer like 2013. The strong positive correlations between number of cases and daily mean temperature, although not significant, demonstrated that the many cases in 2013 tended to be associated with conditions largely opposite to those in 2012. Aside from our hypothesis above, that the warm June in 2013 could result in earlier emerging of the flies from the pupal stage and earlier onset of the oviposition period compared to 2012, the correlations suggested that the particularly warm summer of 2013 could make more people stay outdoors and thus more exposed to the flies. We are not aware of any data from slaughterhouses in Norway telling about *H. tarandi* infestation levels in reindeer in 2012 and 2013 compared to other years. There is however a report on infestation level with larvae of the nose bot fly (*Cephenemyia trompe*) in reindeer in Norway (Nilssen and Haugerud 1995) showing a significantly higher infestation level after a warm summer compared to after a cold summer, interpreted as resulting from prevention of flying in cold weather and rain. There is however a considerable difference in life style between *C. trompe* and *H. tarandi*, since *C. trompe* sprays live larvae into the nostrils and eyes of the host. The strategy by walking or jumping onto the host may thus be less relevant for this species.

The reindeer husbandry area of Finland covers 36% of the country, and many people live in the area. All reindeer owners in Finland are members of a reindeer herding co-operative; paliskunta or bálgosat, of which there are 54, each with strictly defined boundaries. One responsibility for the co-operative is to prevent the reindeer from trespassing on to other co-operative areas. The individual reindeer thus live in the same restricted area throughout the year. The larvae thus drop and develop into adult flies in the same area as the reindeer live throughout the year, and the continuous presence of the natural host could thus simply give no need for the flies to oviposit on aberrant hosts. The *H. tarandi* infestation level in reindeer is up to 100% in calves-of-the-year in the northernmost herding co-operatives of Finland (Åsbakk et al. 2014). Of the 39 cases 2011-2016 (Landehag et al. 2017), only one had noticed the presence of a bumble-bee-sized insect compatible with *H. tarandi* that could be associated with the infestation. The contact was, however, during ear tagging of reindeer calves, demonstrating that the flies can oviposit on humans despite no lack of available natural hosts. The lack of diagnosed human cases in Finland may also suggest that physicians do not report cases.

Only seven of the 39 cases 2011-2016 (Landehag et al. 2017) were members of reindeer husbandry families. Personal contact (Landehag, Åsbakk) with Sami people leave the impression that myiasis caused by *H. tarandi* is largely unknown as a problem among Sami people, in agreement with previous reporting (Kearney et al. 1991). Sami people have however the protective habit and tradition of covering the hair when outdoors.

Interestingly, *H. tarandi* is absent in Iceland, although the reindeer there are descendants of reindeer imported from Finnmark in four rounds between 1771 and 1787, and *H. tarandi* larvae most likely were brought along with the reindeer (Sigurdarson and Haugerud 2004). The *H. tarandi* infestation level in reindeer (calves studied) increases with increasing latitude in the reindeer herding area of Finland, demonstrating how well adapted the species is to the low temperatures of the northern hemisphere circumpolar region (Åsbakk et al. 2014). A contributing reason why *H. tarandi* obviously did not establish in Iceland could possibly be that the weather was too warm, rainy or windy. One of the manifestations of global warming is that the Arctic heats more rapidly than other parts of the world, resulting in more precipitation and more extreme weather since warm air can hold more water and more water will fall (Anisimov et al. 2007). Given this, and that the oviposition strategy involving walking or jumping onto the host is important on days not allowing flying, one can imagine that global warming can increase the number of cases of human myiasis caused by *H. tarandi*. This could be especially true in areas where many people live or visit and where the distance can be large between where the larvae drop and where the reindeer are when the flies emerge from the puparium. Increased temperature giving reduced time for pupae development, and longer fly time in autumn, could also have an impact. The number of cases and years covered by the present report is small, and there is a need for longer time series and more research to understand the zoonotic dynamics of *H. tarandi*.

Compliance with ethical standards

The authors declare no conflict of interest.

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References

Anderson JR, Nilssen AC (1996) Trapping oestrid parasites of reindeer: The response of *Cephenemyia trompe* and *Hypoderma tarandi* to baited traps. Med Vet Entomol 10:337-346

Anisimov OA et al. (2007) Polar regions (Arctic and Antarctic). In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (Eds.) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the

Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp. 653–685.

Bangsø J, Thøgersen KF, Nejsum P, Stensvold CR (2016) The first case of *Hypoderma tarandi*-associated human myiasis in Greenland. Ugeskr Laeger 178:V10150796

Bergman AM (1919) Über die Oestriden des Renntieres (About the Oestrids of Reindeer). Zeitschrift für Infektionskrankheiten, Haustiere 20:65-116

Chirico J, Stenkula S, Eriksson B, Gjötterberg M, Ingemansson S-O, Pehrson-Palmqvist G, Stenkula E (1987) Renkorm, en styngflugelarv, orsak till tre fall av human myiasis (Reindeer warble fly larvae causing three cases of human myiasis). Läkartidningen 84:2007-2008

Colwell DD, Hall MJR, Scholl PJ (2006) The oestrid flies: biology, host-parasite relationships, impact and management. CABI Pub., Wallingford, UK

eKlima (2016) Norwegian Meteorological Institute's weather- and climate data from historical data to real-time observations. https://met.no/Klimadata+fra+eKlima.9UFRvY1M.ips. Accessed 3 May 2017

Faber TE, Hendrikx WML (2006) Oral myiasis in a child by the reindeer warble fly larva *Hypoderma tarandi.* Med Vet Entomol 20:345-346

Folstad I, Nilssen AC, Halvorsen O, Andersen J (1991) Parasite avoidance: the cause of post-calving migrations in *Rangifer*? Can J Zool 69:2423-2429

Gjötterberg M, Ingemansson SO (1988) Intraocular infestation by the reindeer warble fly larva: an unusual indication for acute vitrectomy. Br J Ophthalmol 72:420-426

Gryseels B, Mertens DAE, Mehl R (1991) An imported case of ophthalmomyiasis interna posterior in the Netherlands caused by a larva of the reindeer warble fly. J Infect Dis 163:931-932

Jansen JJ (1970) Hypodermatid larvae (Diptera: Hypodermatidae) from musk ox, *Ovibus moschatus*. Ent Ber Amst 30:222-224

Kan B, Otranto D, Fossen K, Åsbakk K (2012) Dermal swellings and ocular injury after exposure to reindeer. N Engl J Med 367:2456-2457

Kan B, Åsbakk K, Fossen K, Nilssen A, Panadero R, Otranto D (2013) Reindeer warble fly-associated human myiasis, Scandinavia. Emerg Infect Dis 19:830-832 doi:10.3201/eid1905.130145

Kan B, Åsen C, Åsbakk K, Jaenson TG (2010) Misstänkta lusägg i pojkes hår avslöjade farlig parasit (Suspected lice eggs in boy's hair revealed dangerous parasite). Läkartidningen 107:1694-1697

Karter AJ, Folstad I, Anderson JR (1992) Abiotic factors influencing embryonic development, egg hatching, and larval orientation in the reindeer warble fly, *Hypoderma tarandi.* Med Vet Entomol 6:355-362

Kearney MS, Nilssen AC, Lyslo A, Syrdalen P, Dannevig L (1991) Ophthalmomyiasis caused by the reindeer warble fly. J Clin Pathol 44:276-284

Lagacé-Wiens PRS, Dookeran R, Skinner S, Leicht R, Colwell DD, Galloway TD (2008) Human ophthalmomyiasis interna caused by *Hypoderma tarandi*, northern Canada. Emerg Infect Dis 14:64-66

Landbruksdirektoratet (2017) Fakta om reindrift. Forskjeller i flyttemønster (Facts about reindeer husbandry. Differences in migration routes). https://www.slf.dep.no/no/reindriften/fakta-om-reindrift/forskjeller-i-flyttemonster. Accessed 15 May 2017

Landehag J, Skogen A, Åsbakk K, Kan B (2017) Human myiasis caused by the reindeer warble fly, *Hypoderma tarandi*, case series from Norway, 2011 to 2016. Euro Surveill 22:pii=30576. doi:http://dx.doi.org/10.2807/1560-7917.ES.2017.22.29.30576

Mook R (1994) The climate way north. In: Møller JJ, Reymert PK, Steinlien Ø (eds) Earth Science, vol Second edition. University of Tromsø, Trømsø museum, Tromsø, Norway, pp 17-25

Nelson WA, Weintraub J (1972) *Hypoderma lineatum* (De Vill.) (Diptera: Oestridae): Invasion of the bovine skin by newly hatched larvae. J Parasitol 58:614-624

Nilssen AC (1997) Effect of temperature on pupal development and eclosion dates in the reindeer oestrids *Hypoderma tarandi* and *Cephenemyia trompe* (Diptera: Oestridae). Environ Entomol 26:296-306

Nilssen AC, Anderson JR (1995a) Flight capacity of the reindeer warble fly, *Hypoderma tarandi* (L), and the reindeer nose bot fly, *Cephenemyia trompe* (Modeer) (Diptera, Oestridae). Can J Zool-Revue Canadienne de Zoologie 73:1228-1238

Nilssen AC, Anderson JR (1995b) The mating sites of the reindeer nose bot fly: not a practical target for control. Rangifer 15:55-61

Nilssen AC, Gjershaug JO (1988) Reindeer warble fly larvae found in red deer. Rangifer 8:35-37

Nilssen AC, Haugerud RE (1994) The timing and departure rate of larvae of the warble fly *Hypoderma* (=*Oedemagena*) *tarandi* (L.) and the nose bot fly *Cephenemyia trompe* (Modeer) (Diptera: Oestridae) from reindeer. Rangifer 14:113-122

Nilssen AC, Haugerud RE (1995) Epizootiology of the reindeer nose bot fly, *Cephenemyia trompe* (Modeer) (Diptera, Oestridae), in Reindeer, *Rangifer tarandus* (L), in Norway. Can J Zool 73:1024-1036

Paine R (1994) Herds of the tundra: A portrait of Sami reindeer pastoralism. Smithsonian Institution Press, Washington and London

Rukke BA, Cholidis S, Johnsen A, Ottesen P (2014) Confirming *Hypoderma tarandi* (Diptera: Oestridae) human ophthalmomyiasis by larval DNA barcoding. Acta Parasitol 59:301-304 doi:10.2478/s11686-014-0242-2

Samuelsson F, Nejsum P, Raundrup K, Hansen TVA, Kapel CMO (2013) Warble infestations by *Hypoderma tarandi* (Diptera; Oestridae) recorded for the first time in West Greenland muskoxen. Int J Parasitol: Parasites and Wildlife 2:214-216

Sigurdarson S, Haugerud RE (2004) "Wild reindeer" in Iceland. In: Ulvevadet B, Klokov K, Eds. Family-based reindeer herding and hunting economies, and the status of management of wild reindeer/caribou populations. Tromsø: Centre for Sami Studies, University of Tromsø, 159-162.

Skjenneberg S, Slagsvold L. (1968) Reindriften og dens naturgrunnlag (The reindeer husbandry and its natural resource base). Universitetsforlaget, Oslo/Bergen/Tromsø,

Syrdalen P, Nitter T, Mehl R (1982) Ophthalmomyiasis interna posterior: report of case caused by the reindeer warble fly larva and review of previous reported cases. Brit J Ophthalmol 66:589-593

Syrdalen P, Stenkula S (1987) Ophthalmomyiasis interna posterior. Graefes Arch Clin Exp Ophthalmol 225:103-106

Tyler NJC et al. (2007) Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-arctic social-ecological system. Global Environ Chang 17:191-206 doi:10.1016/j.gloenvcha.2006.06.001

Weintraub J (1961) Inducing mating and oviposition of the warble flies *Hypoderma bovis* (L.) and *H. lineatum* (De Vill.) (Diptera: Oestridae) in captivity. Can Entomol:149-156 doi:10.439/Ent93149-2

Ågren E, Chirico J (2005) Reindeer warble fly larvae (*Hypoderma tarandi*) in a moose (*Alces alces*) in Sweden. Acta Vet Scand 46:101-103

Åsbakk K, Kumpula J, Oksanen A, Laaksonen S (2014) Infestation by *Hypoderma tarandi* in reindeer calves from northern Finland - prevalence and risk factors. Vet Parasitol 200:172-178

Figure legends

Fig. 1. Map showing Fennoscandia, with Finnmark county in Norway outlined. White lines indicate municipality borders.

Fig. 2. Thirty-nine cases of human myiasis caused by *H. tarandi* 2011-2016 by year and age. The age range was 3-12 years for the children, 20-66 years for the adults.

Fig. 3. Normal monthly mean temperatures (normal period 1961-1990) for June-August for the five meteorological stations.

Fig. 4. Monthly mean temperatures June-August 2011-2016 for the five meteorological stations.

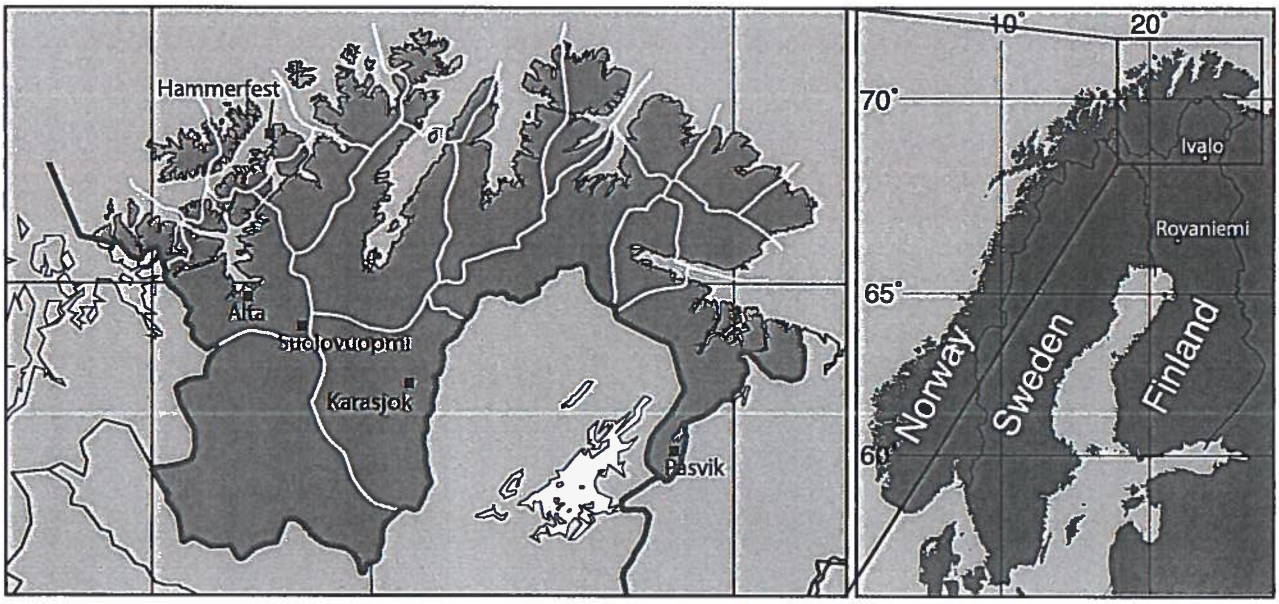
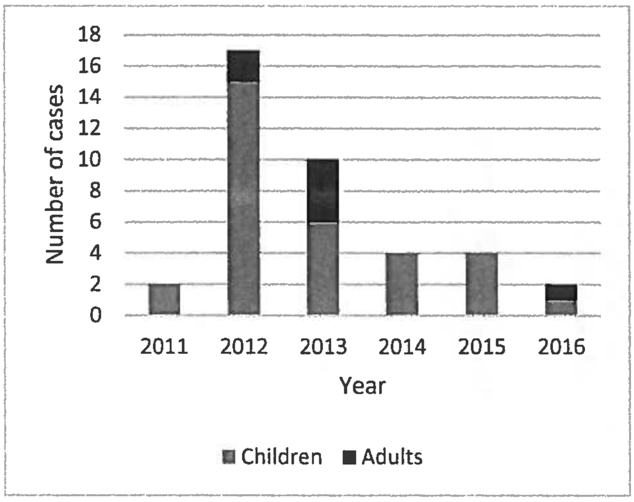
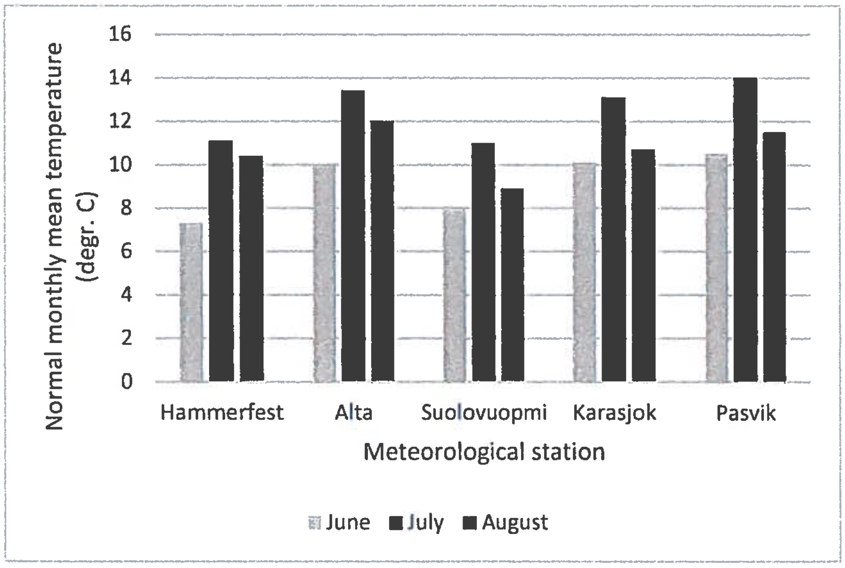

Hammerfest
Alta
Suolovuopmi
Karasjok
Pasvik
10°
20°
70°
65°
60°
Ivalo
Rovaniemi
Norway
Sweden
Finland

Fig. 2



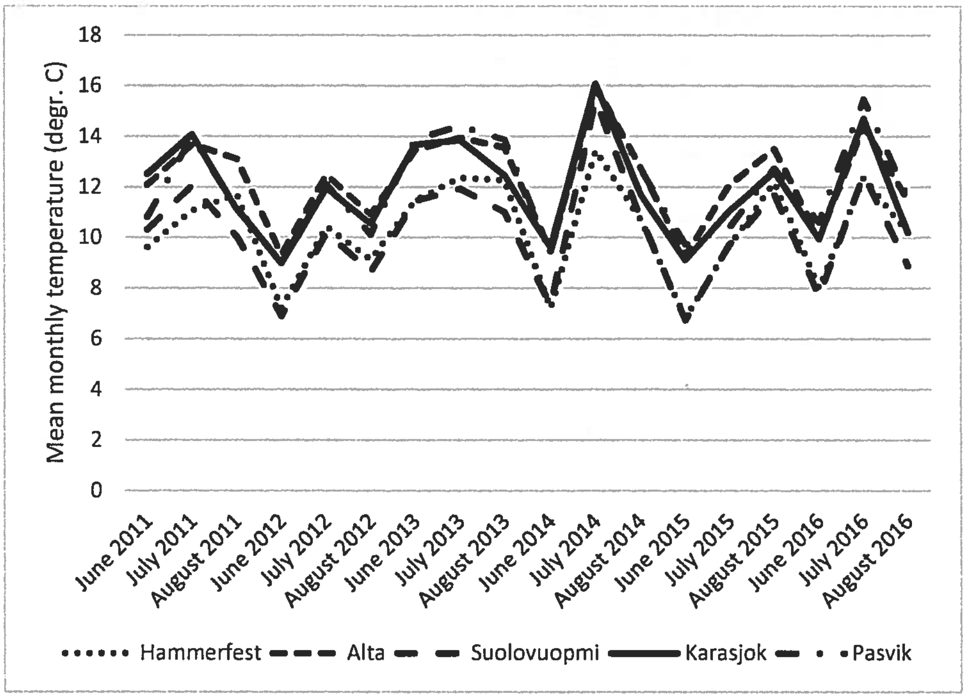
Number of cases
18
16
14
12
10
8
6
4
2
0
2011
2012
2013
2014
2015
2016
Year
Children
Adults

Fig. 3



Normal monthly mean temperature (degr. C)
16
14
12
10
8
6
4
2
0
Hammerfest
Alta
Suolovuopmi
Karasjok
Pasvik
Meteorological station
June
July
August

Fig. 4.



Mean monthly temperature (degr. C)
18
16
14
12
10
8
6
4
2
0
June 2011
July 2011
August 2011
June 2012
July 2012
August 2012
June 2013
July 2013
August 2013
June 2014
July 2014
August 2014
June 2015
July 2015
August 2015
June 2016
July 2016
August 2016
Hammerfest
Alta
Suolovuopmi
Karasjok
Pasvik

Table 1. Symptom onset month for 35/39 cases of *H. tarandi* myiasis in Norway 2011-2016.

	July	**August**	**September**	**October**	**November**	**December**
2011			1		1	
2012			5	3	5	3
2013	1	1	3	4		
2014			1	2		1
2015					2	
2016	1			1		

Table 2. ANOVA results for the daily mean temperature June-August 2011-2016 with the five stations (Hammerfest, Alta, Suolovuopmi, Karasjok, Pasvik) treated as one group.

Daily mean temperature (°C)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**ANOVA**
June-August	11.83[1]	9.89	12.92	11.95	10.53	11.23	2012 = other years: $F_{5,2754} = 38.3$, $p < 0.01$
							2013 = other years: $p < 0.001$
June	11.08	8.29	12.79	8.62	8.34	9.25	2012 = 2011: $F_{5,894} = 36.4$, $p < 0.001$
							2012 = 2016: $p < 0.03$
							2012 = 2014 = 2015: $p > 0.4$
							2013 = other years: $p < 0.0001$
July	12.98	11.44	13.30	15.36	10.61	13.89	2012 = other years: $F_{5,924} = 40.6$, $p \leq 0.03$
							2013 = other years except 2011 and 2016: $p < 0.0001$
							2013 = 2011 = 2016: $p > 0.1$
							2014 = other years: $p \leq 0.0001$
							2015 = 2012: $p = 0.03$
August	11.43	9.88	12.64	11.75	12.55	10.48	2012 = other years except 2016: $F_{5,924} = 20.4$, $p < 0.0001$
							2012 = 2016: $p = 0.09$
							2013 = other years except 2015: $p \leq 0.01$
							2013 = 2015: $p = 0.8$

Table 3. ANOVA results for the proportion of days with maximum temperature ≥12°C during July-August 2011-2016 with the five stations (Hammerfest, Alta, Suolovuopmi, Karasjok, Pasvik) treated as one group.

Proportion of days with maximum temperature ≥12°C	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**ANOVA**
July-August	0.84	0.78	0.94	0.86	0.82	0.84	2012 = other years except 2015: $F_{5,1854} = 6.6$, $p < 0.05$
							2012 = 2015: $p = 0.15$
							2013 = other years: $p < 0.01$
							2011 = 2014 = 2015 = 2016: $p > 0.1$
July	0.89	0.82	0.94	0.95	0.75	0.92	2011 = 2012: $F_{5,924} = 8.5$, $p = 0.05$
							2012 = 2015: $p = 0.08$
							2013 = 2014 = 2016: $p > 0.4$
							2012 = other years except 2011 and 2015: $p < 0.01$
August	0.78	0.75	0.94	0.77	0.88	0.76	2011 = 2012 = 2014 = 2016: $F_{5,924} = 6.6$, $p > 0.3$
							2013 = 2015: $p = 0.2$
							2013 = other years except 2015: $p < 0.001$
							2015 = other years except 2013: $p < 0.02$

Table 4. ANOVA results for proportion of days with rain July-August 2011-2016 with the four stations that recorded rain (Hammerfest, Suolovuopmi, Karasjok, Pasvik) treated as one group.

Proportion of days with rain	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**ANOVA**
July-August	0.66	0.52	0.72	0.54	0.59	0.75	2011 = other years except 2013, 2015 and 2016: $F_{5,1457} = 9.7$, $p < 0.01$
							2011 = 2013: $p = 0.1$
							2011 = 2015: $p = 0.1$
							2013 = 2016: $p = 0.5$
							2013 = other years except 2011 and 2016: $p < 0.005$
							2016 = other years except 2013: $p \leq 0.03$
							2012 = 2014 = 2015: $p > 0.07$
July	0.71	0.62	0.72	0.44	0.52	0.82	2011 = 2013 = 2016: $F_{5,715} = 11.2$, $p \geq 0.08$
							2011 = 2012 = 2013: $p > 0.1$
							2014 = 2015: $p = 0.2$
August	0.60	0.41	0.72	0.65	0.66	0.68	$F_{5,736} = 6.5$, $p < 0.003$
							2011 = 2013: $p = 0.04$
							2013 = 2014 = 2015 = 2016: $p > 0.2$
							2011 = 2014 = 2015 = 2016: $p > 0.1$

Table 5. Pairwise correlation (Pearson´s r) for the Finnmark group cases 2011-2016 (n = 33) versus meteorological variables for the years 2011-2016 with either 2012 or 2013 excluded from analysis.

			All years 2011-2016	
			except 2012[1]	**except 2013**[1]
Myiasis cases	**Meteorological variable**	**Month**	**Pearson's r**	
Finnmark group	Daily mean temperature[2]	June-August	0.72	-0.78
		June	0.72	-0.46
		July	0.01	-0.43
		August	0.67	-0.65
	Proportion of days with max. temp. ≥12°C[2]	July-August	0.94 *	-0.89 *
		July	0.26	-0.36
		August	0.83	-0.45
	Proportion of days with rain[3]	July	0.09	-0.10
		August	0.77	-0.95 *

[1]: Number of cases included in analysis: n = 18 with all years except 2012 included, n = 25 with all years except 2013 included.

[2]: Temperature data from the five meteorological stations (Hammerfest, Alta, Suolovuopmi, Karasjok, Pasvik) as one group.

[3]: Precipitation data from the four meteorological stations that recorded rain (Hammerfest, Suolovuopmi, Karasjok, Pasvik).

*: Correlation significant (p <0.05).