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ORIGINAL PAPER

Treatment of foot rot in free-ranging mouflon *(Ovis gmelini musimon)* populations—does it make sense?

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Abstract Prevalence and incidence of foot rot disease in free-ranging and captive bovine wild ruminant populations are increasing worldwide. Even species in which the disease has not been described in the past are presently affected by the co-working pathogens *Dichelobacter nodosus* and *Fusobacterium necrophorum*. This paper discusses disease control measures and the expense for a successful treatment of affected populations of mouflon. The rationale and perspectives of treating foot rot disease in wild mouflons are discussed.

Keywords Mouflon · Disease control · Transmissible disease · Treatment protocol

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Introduction

Expanding use of wildlife habitats by humans has caused habitat fragmentation and isolation of wildlife populations. Areas of overlapping use by both humans and their livestock and wildlife species are increasing especially in Europe. One consequence of this is an increasing rate of infectious diseases being transmitted between wild and domestic animals (Gortázar et al. 2007). A case of a bacterial infectious disease is foot rot affecting both wild and domestic ruminants. Foot rot infections are transmitted to wild ruminant populations from infected sheep and goat (Giacometti 2003). Foot rot is the common name of the purulent ovine and caprine panaritium caused by two interacting anaerobic pathogens, the keratolytic *Dichelobacter nodosus* and the necrotizing *Fusobacterium necrophorum* (Geisel 2008). The disease begins with an inflammation of the inter-digital cleft accompanied by lameness of different degrees (Bostedt and Dedié 1996). Normally, not all feet are affected to the same extent (Volmer and Herzog 2003).

Primary infections often show a dramatic development and can cause the death of huge parts of the infected population. The survivors do not build up a long-standing immunity (Selbitz and Moos 2006). The disease can therefore evolve into a chronic phase of several months or years. Subsequently, the animals produce a hyperplastic foot horn, show lameness and often feed in a recumbent position (Volmer and Herzog 2003). From an animal welfare perspective, foot rot is a relevant disease because it causes pain and suffering for a longer time (Kümper and Stumpf 2000). Pathogen control in wildlife has two traditional forms, culling and vaccination (Dobson and Grenfell 1995). However, more data from experimental studies are needed on which to base recommendations for disease control in and the management of affected populations (Gortázar et al. 2007). If there is agreement on the need for action, a typical sequence of steps is initiated. These include measures against dispersal of pathogens by prohibiting the immigration of herds of livestock, compulsory vaccinations or treatment of domestic animals, and finally, depending on the ecological or economic value of the wildlife population, treatment and/or vaccination of wildlife species are the steps involved (Cleaveland et al. 2001). Generally, only a few studies have demonstrated significant positive outcomes of such measures because the mode of crisis management does not allow controls with untreated animals (Woodroffe 1999). The aims of the present study were to study whether it was possible to control foot rot incidences in mouflon populations efficiently by a composition of management, vaccination with a population specific vaccine and treatment measures.

Materials and methods

Study populations

We studied three different foot rot incidents occurring in free-ranging mouflon populations (the so-called Hinterland, Vogelsberg and Donnersberg populations) in Germany (federal states of Hessen and Rheinland-Pfalz) between 1994 and 2005. The populations were established in the 1950s/1960s with 10 to 20 founder animals. A fourth population ('Laubach') founded in 1938 was observed from 1981 to 2005 under different aspects. In 1986, this population was also affected by foot rot, but no catching and treatment was conducted, so it was only used for comparing the trend of population decline with the three populations in which treatment was performed.

The mouflon habitats are typical low mountain ranges with basalt/bunter (Vogelsberg, Laubacher Wald), bunter / schist (shale, slate, Hinterland) and rhyolite (Donnersberg) bedrocks. Average rainfall is between 600 and 700 mm per year. Beech forests (*Fagus sylvaticus*) are the main type of vegetation. The first foot rot incidents were registered in the late 1980s and early 1990s in the 'Hinterland' and in the 'Vogelsberg' populations and in 1999 in the "Donnersberg" population. Initial outbreaks showed dramatic courses with extremely high morbidity (>95%) and a high mortality. Field data in the form of field protocols were collected over a period of several years in each case by local mouflon experts including hunters, gamekeepers and forest wardens. Data for the evaluation of body condition and clinical data were obtained by the authors during catching and treatment procedures. Statistical validation of population data was performed by testing proportions of binary variables 'treatment needs' and 'survival success' of captured mouflons by χ^2 tests (Petrie and Watson 1999) using the software package Winstat®. Adjusted level of significance was set at $p<0.017$.

Disease control scheme of foot rot in mouflon populations

The treatment concept for the mouflon populations involved three measures. The first was the protection of the free-ranging mouflons from the introduction of foot rot pathogens by migrating domestic sheep herds. In all cases studied, the first foot rot incidences started some weeks after migrating sheep herds had crossed mouflon habitats in spring. All controlled sheep herds showed different proportions of lame animals, and veterinary inspection found clinical signs of foot rot. None of the shepherds were willing to avoid mouflon habitats voluntarily. Therefore, disease control, treatment and restriction orders were necessary to protect mouflon populations. In the Donnersberg population, some mouflon rams visited fenced domestic herds searching for sheep in estrus and could have been carriers of pathogens too.

The second measure was the capture of as many individuals as possible from the infected mouflon population and its vaccination with a population-specific vaccine as a prophylactic and metaphylactic procedure (Cleaveland et al. 2001). The third measure was the treatment of individual animals that showed claw alterations because the alterations of the horn shoe are definitely advanced and a spontaneous restitutio ad integrum is not possible (Volmer and Herzog 2003). The ultimate goal was the release of double-vaccinated animals with healthy claws (Fig. 1).

Capture of mouflons

The first method for capturing free-ranging mouflons is the use of a catching lattice, a kind of a kraal. We used a round or oval wooden or netting wired fence, 15 m in diameter with a catching funnel on one side and a gate vis-à-vis.

Fig. 1 Diseased and healthy claws from the same mouflon

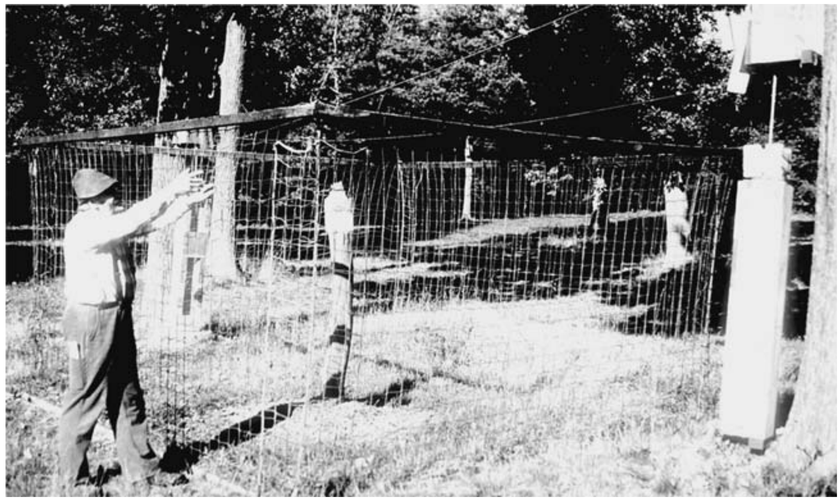

Fig. 2 Details of the net trap, frame lifted up; weight is shown on the right side

Behind the door is a food box, and the door is fixed only slightly in the open position with a twig plugged into the ground. When the mouflons crowd together at the food box, they push down the twig or push against the door, which closes automatically and is locked by a bar. Complete herds can be caught in this way.

The second catching system used in this study was a net trap (Fig. 2). It was positioned between two larger trees and consisted of a wooden rectangular frame (4×4 m) around which a roofer's safety net was fastened. The frame and net lay in a small trench and were covered with dry leaves. The frame with the fastened net was lifted by the force of two falling weights at wire ropes and rollers, which were released by a person in a hide. The net cage had a lateral entry of overlapping net parts, and the caught mouflons were handled through this entry. In the center of the trap, which was positioned near a favourite haunt of the population, an attractive lure for all seasons, normally a salt lick, was positioned.

Caught mouflons were kept for about 6 weeks in a field corral (area of 15,000 m^2) with an internal catching funnel. Within that period, treatment control, vaccinations (two

Table 1 Positions and costs

	Position	Amount	Costs
"Kraal" (15 m diameter)	Netting wire	50 m, height 2,00 m	200.–
	Wooden posts (oak)	15, height 2,80 m	75.–
	Raw stakes (spruce or pine)	150 m	150.–
	Tension wire, nails, bolts		100.–
	Material catching funnel		250.–
	Hands (30.– Euro per hour)	20	600.–
Net trap system	Roofers' safety net	16.00 m	130.–
	Lath—wood	60 m	60.–
	Solid boxes (weights)	2	100.–
	Wire strand, transverse beam, release mechanism		50.–
	Rollers, material		50.–
	Hands (30.– per hour)	18	540.–
	Prefabricated raised hide	1	5,00.–
Quarantine corral (area 1,5 ha)	Netting wire	500 m, height 2.00 m	2,000.–
	Posts	120, height 2.80 m	600.–
	Raw stakes	1,500 m	1,500.–
	Tension wire, material		300.–
	Material for 2 capture funnels		500.–
	Hands (30.– per hour)	120	3,600.–
Vaccine	2 doses for 25 animals	100 ml	150.–
Veterinarian	Treatment per animal	15 min	15.–
Medication	Antibiotics etc per animal		5.–
Total treatment costs	Per animal		26.–

Fig. 3 Lateral view of a normal healthy horn shoe from a mouflon

Fig. 5 Wall and sole of a mouflon hoof with beginning foot rot

times) and examination were performed. Running water was temporarily available. Because of the danger of over-supply of nutrients and subsequent indigestions and bacterial infections (*Clostridia* ssp.) of the intestinal tract, mouflons received only 1–2 kg of hay pellets or cobs per animal, while additional drinking water was supplied ad libitum. Feeding costs ranged between were €0.40 and €0.80 per animal and day (Table 1).

Treatment of mouflons

Treatment of animals from foot rot-diseased flocks was done in a standardized way.

Initially, each captured animal was injected intramuscularly with a penicilline–streptomycine preparation (1–3 ml of Tardomyocel III comp®) for all caught animals. In case of bad general condition (sepsis, fever, emaciation), a supplementary treatment was performed including the injection of dexamethasone (0.5–1.5 ml of Voren® suspension), roborans (2–5 ml of Catosal® solution) and infusions (50–150 ml of glucose 4% and/or 25–50 ml of calcium-borogluconate 24%). In addition, all animals received a macro-cyclic lactone preparation (0.2 mg/kg of Ivomec®) as an anti-parasitic treatment.

Focal treatment of infected and wounded toes was done by extensive resection of all altered parts of the horn capsule, taking care to preserve the physiological shape of the horn shoe (Figs. 3, 4, 5, 6, 7, and 8). After the resection procedure, the whole hooves were wetted with an antiseptic fluid (Kodan®-Tincture). Altered claws with excavations, florid processes and fistulas were treated by an additional antibiotic infiltration. A procaine penicilline solution of 5.0 ml (Procain Penicillin G®) was injected into the toes at the plantar area of the inter-digital cleft. A control and if necessary a second systemic and/or topical treatment was performed after 2 or 3 days. Four to 6 weeks after the first resection, a final restoration of the physiological shape of the horn shoes and an inspection whether white lines of unaltered shoes were completely intact were performed (Fig. 9). After this procedure, the animals were released.

Fig. 4 Wall and sole of a mouflon hoof with beginning foot rot

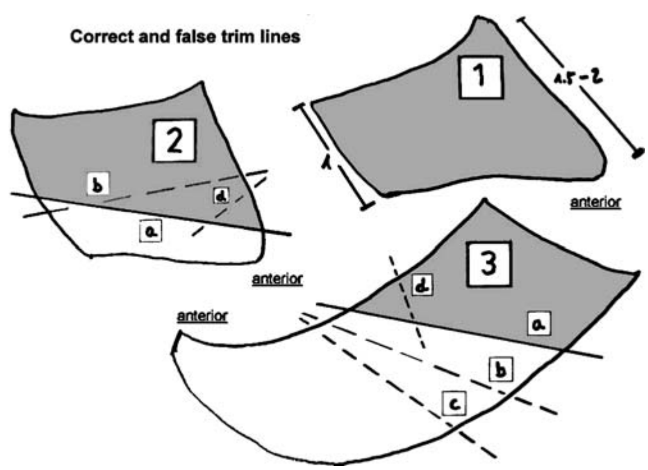

Fig. 6 Shape of normal (*1*) and diseased (*2*, *3*) horn shoes with correct (*a*) and false (*b*, *c*) trim lines and warp (*d*)

Fig. 7 Over-grown foot rot claws at front legs before resection

Fig. 9 White line after cutting the marginal wall

Vaccine production and costs of vaccination

The production of population-specific vaccines was an essential component of the treatment against foot rot. For that purpose, swab samples were taken from excavations and florid processes of the claws during the resection procedure in diseased animals. Swabs were directly streaked on agar media containing 5% defibrinated sheep blood such as Schaedler agar, Dextrose–blood agar after Zeissler or Schaedler agar containing Kanamycine® (100 µg/ml) and Vancomycine® (7.5 µg/ml). In the field, agars were promptly transferred into a GasPak® vessel (Beckton & Dickinson) with the addition of a bag of Anaerocult®. After incubation for 3–5 days at 37°C, bacterial colonies were sub-cultured and identified at the generic level as *Dichelobacter* and/or *Fusobacterium* based on morphological and biochemical criteria using the rapid ID32A® test kit (Sebald and Petit 1994). Isolated anaerobic species were multiplied on 20 Schaedler media per isolate and incubated for 4 days. The multiplied bacteria were washed from the agars with an isotonic NaCl solution containing 3% formaldehyde. Suspensions were mixed, and to check whether all bacteria had been killed, a new subculture agar was incubated. The density of the bacterial suspension was set at no. 3 of McFarland's scale (Burkhardt 1992).

Mouflons were vaccinated twice at an interval of about 4–6 weeks (at first and last treatment) with the population-specific suspension at a dose of 2.0 ml per animal. Animals were ear tagged with one tag after the first vaccination and with a second tag after the second vaccination.

Fig. 8 Claws from Fig. 7 after resection

Results

Capture success

In total, 275 free-ranging animals were caught in the three study areas (Table 2), 100 of them in net traps, and 175 in different types of kraals. No deaths or severe injuries of animals occurred during catching and handling procedures. Four cases of accidents happened to catchers, which were hit by rams' horns in the catching funnels.

A disadvantage of the kraal trapping system is that it can be used with success only in late autumn and in winter when mouflons are attracted to the fodder cribs filled with high-quality hay and apple draff enriched with oats as a lure. Unfortunately, the trapping lattices were often occupied by roe deer or wild boars, which were attracted by the lure too. Disadvantages of the net cage system are that it can only be operated by manpower and that caught mouflons must be promptly removed from the net cage.

Prevalence of foot rot in the studied populations

Among the studied mouflon populations, the 'Hinterland' population was the most affected with the highest prevalence of animals showing clinical symptoms and requiring

Table 2 Data from three populations

Population	Hinterland	Vogelsberg	Donnersberg	Total
Prevalence (%)[a]	90	50	60	–
Caught animals	100	55	120	275
Individuals	90	55	105	250
Treated animals	80	35	45	161
Vaccinated (1×/2×)	67[b]/33	55/55	105/104	227/192
Loss of foot horn (shoeing out)	9	1	None	10
Topical treatment without success	12	None	1	13
Lost probands[c] (during study period)	app. 40	8	17	65
Re-infected	50	None	None	50
Still alive (end of study)	40	45	84	169

[a] Prevalence of root rot according to field observations
[b] First-caught animals escaped during the time of sampling and production of vaccine
[c] Escaped after storm, died from new foot rot infections, shot and died from *Clostridium perfringens* type D infections

treatment and with the highest prevalence of shoed-out (see Fig. 10 and Table 2), lost and re-infected animals. In this population, no regular treatment or vaccination dates could be met. Even re-capture within the quarantine corral often was not possible because of technical problems. The 'Vogelsberg' and 'Donnersberg' populations were managed with better success. Eighty-two percent and 80%, respectively, of the treated and/or vaccinated animals survived and could be observed for up to 2 years after the end of the study without clinical signs of re-infection (Table 2). The differences in survival rate between the 'Hinterland' and 'Donnersberg' populations ($p<0.00001$) and between the Hinterland and Vogelsberg populations ($p=0.00002$) were significant, whereas the survival success of the 'Vogelsberg' and 'Donnersberg' populations ($p=0.08$) did not differ significantly. Differences in the necessity of treatment between the populations follow a similar scheme of significances ($p<0.00001$, $p=0.0006$ and $p=0.02$, respectively).

Loss of hoof shoes (shoeing out) occurred in the 'Hinterland' population affecting 9 of 90 animals (10%) and 1 of 55 (1.8%) in the 'Vogelsberg' population. In this study, a new tender horn capsule was built up before the old shoe loosened. Four affected animals could be observed with re-infections after some months.

Fig. 10 Loss of horn capsules at the front legs of a lamb

Treatment success

Of the 250 captured animals, 165 needed treatment as described above. In 13 animals, treatment was unsatisfying because a second treatment and a control were not possible. All regularly treated animals got well and showed no clinical signs after the complete treatment procedure. During the whole stay (4–6 weeks) in the field corral under high pathogen pressure, none of the treated animals showed a remission in disease status (Table 2).

The trimming of the horn shoes following the trimming scheme shown in Fig. 8 proved essential for avoiding the growing of hoof horn into unphysiological shapes. The length ratio of toe to heel (bulb) has to be in the range of 1.5–2:1. Lower ratios or cutting of a warp into the horn of toe tip results in the growth of half-moon-shaped horn shoes.

Vaccination

Of the 250 captured animals, 192 were vaccinated at least two times. In the Hinterland population, only 33 out of 67 animals could be vaccinated for a second time. At Donnersberg, only one ram could not be kept in the corral because of his very aggressive behaviour. He was shot 2 years after the first vaccination because he showed lameness and claw alterations.

After the first vaccination, all animals at Donnersberg and Vogelsberg were fenced for several weeks in the corral until re-vaccination. None of the treated and vaccinated animals displayed remission as described above, and none of the untreated and vaccinated animals contracted foot rot

Fig. 11 Caught diseased group in poor body condition before first treatment

during the time in the quarantine corral. The vaccine was well tolerated; only small subcutaneous reactive nodes could be seen for approximately 2 weeks.

In April 1987, the Laubach population consisted of 44 animals. In the summer, a dramatic foot rot endemic befell the population, and only eight animals survived until October. No vaccination and treatment were performed, and thus it took 15 years until the former population size of 40 animals was reached again. Today, foot rot disease has changed into a chronic form with some animals showing clinical symptoms, while others are without symptoms.

Discussion

The attitude towards the non-native species mouflon in Germany is ambivalent (Piegert and Uloth 2000; Bubenik 1984; Nöllenheidt 1978); however, there exist several well-established populations. Effective treatment of foot rot in this species requires cooperation of all stakeholders involved (Grenfell et al. 2001) including sheep owners, shepherds, hunters, landowners, veterinary authorities, wildlife managers and wildlife veterinarians. These groups must agree on a core set of objectives (Grauheding 2005), and the hunters as leaseholders can require prohibition of pasturing of certain parts of their hunting area. The latter method is also recommended for separating Bighorn sheep (*Ovis canadensis*) populations from domestic sheep carrying threatening infections (Jessup et al. 1995). Often, animal care considerations and animal welfare legislation provide the only legal basis for performing treatment of mouflon against foot rot.

The present study demonstrated distinct differences of treatment demands and survival success between affected mouflon populations. Differences in survival success between the Hinterland population and the other two treated populations were significant. These differences probably do not depend on disease-related or population factors such as more resistant foot rot agents or a higher number of mouflons with an insufficient immune status. Rather, in the Hinterland population, catching and keeping the animals were comparatively ineffective resulting in a lower proportion of the population receiving two vaccinations. This indicates that an effective system of capturing and treatment is crucial for an effective control of foot rot in free-ranging mouflons. Furthermore, mouflon hunters have to suspend their hunting activities during the treatment period to avoid the inadvertent shooting of treated and vaccinated animals.

Fig. 12 Same group as shown in Fig. 11 4 weeks after first treatment in the quarantine corral

Medical treatment of wild animal treatment is debated as much as is the existence of mouflon in the Central Europe (Angulo and Cooke 2002). Vaccination and medication are part of the management of diseases interacting between man or domestic animals and wildlife worldwide (Dobson and Grenfell 1995). In the case of foot rot, diseased domestic sheep carry the pathogens into mouflon habitats. Alterations of the physiological shape of horn shoes in diseased mouflons, e.g. overgrown walls, are irreversible (Volmer and Hecht 2006). Thus, there is no chance of spontaneous healing. The treatment used in this study has been proven successful. All animals treated according to the treatment scheme developed physiologically shaped horn shoes. The control of the healing progress during the treatment period was done by studying the individual courses of some clinical parameters in the blood serum. The activity of alkaline phosphatase and white blood cells counts are established parameters for the estimation of the animals' clinical status during foot rot infections (Volmer and Hecht 2006). The analysis of blood samples from newly caught and fenced animals should be therefore routinely performed. The body condition of the caught animals was evaluated at the beginning of the treatment and re-assessed during the stay in the corrals by aspection and palpation of the muscles and fat deposits especially in the *Musculus longissimus dorsi* region. Figures 11 and 12 show the differences in body condition of the same diseased group of mouflons directly after catching and 4 weeks later. The body condition after treatment and vaccination had improved considerably, although the animals received only hay as an additional food supplementing the natural vegetation in the field corral.

Vaccination

The vaccination performed as part of the study is regarded as a success because none of the animals that were vaccinated two times contracted a new infection with clinical signs during the observation period of 2 years. Even inside the highly contaminated quarantine field corral, none of the vaccinated animals became infected or re-infected. Population-specific vaccination must therefore be regarded as an effective prophylactic and therapeutic treatment against foot rot supporting the measure in diseased and treated animals as was previously reported for domestic sheep (Bostedt and Dedié 1996). Vaccination was apparently effective in breaking the cycle of infection, clinical disease, spreading of pathogens and re-infection within the populations. One drawback of this field study, in common with vaccination programmes in wild mammals worldwide (DeVos and Scheepers 1996; Roelke-Parker and Glass 1992; Hastings et al. 1991), is the lack of an untreated control group. Clear benefits of vaccination cannot be demonstrated unless such a control group is available for comparison. In our case, the course of disease in the Laubach population may be regarded as an example of what happens if nothing is done.

Conclusions

Attempts to manage foot rot disease in wild mouflon populations are expensive, and the success of these measures depends on several factors as described above. Today, foot rot disease is endemic in many populations of mouflons with some animals showing clinical symptoms, while others are without. Selective shooting of animals showing clinical signs is strongly recommended. In our view, only two options exist, either implementing an expensive control programme following the treatment schedule presented above or the selective shooting of all animals with clinical signs.

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