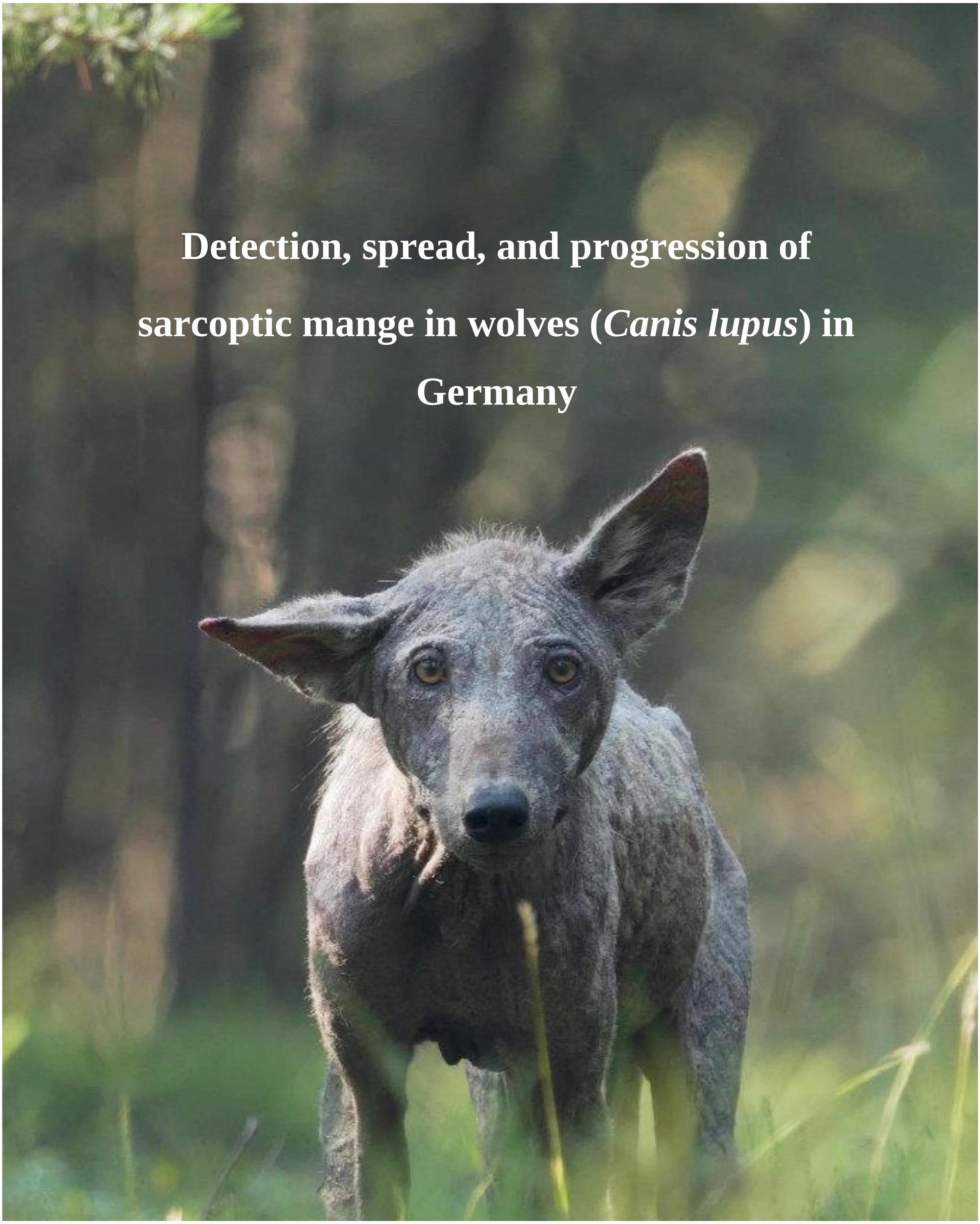
Detection, spread, and progression of sarcoptic mange in wolves (*Canis lupus*) in Germany



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Bachelor Thesis

Detection, spread, and progression of sarcoptic mange in wolves (*Canis lupus*) in Germany

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Image front page: Wolf with a severe mange infestation in the territory of the Dauban pack on 2020-07-19 (copyright: Tobias Bürger 2020)

Preface

We decided to write our bachelor thesis on mange in wolves because the topic is very close to our hearts and therefore, we were itching the last year to write this thesis. We are convinced that ways need to be found to allow humans and wildlife to live side by side without conflict. Gaining knowledge about mange in wolves and making it useful for different parties can, in our opinion, contribute to this peaceful coexistence. Therefore, after completion, we will also create a brochure that will be distributed to all federal states in Germany.

We would like to take this opportunity to thank our lecturers Ralf Mullers and Jeroen Breidenbach as well as our statistics lecturer Henry Kuipers, who always provided us with advice and support during the development of our bachelor thesis. We would also like to thank Claudia A. Szentiks and the IZW for providing us with data. Our very special thanks go to Gesa Kluth, Catriona Blum-Rérat, Sarah Schölzel and the LUPUS Institute, who gave us the opportunity to write such a bachelor thesis in the first place and who were always willing to support us in our work process. Furthermore, we thank the volunteers Tobias Bürger, Steffen Heiber, Stephan Kaasche, Andre Klingenberger, Sebastian Koerner, Reinhard Möckel, Andre Pfeiffer and Ralf Schreyer as well as the employees of the Biosphere Reserve Oberlausitzer Heide- und Teichlandschaft and the employees of the Bundesforstbetrieb Oberlausitz Franz von Plettenberg and Michel Lisk for their support and for making their pictures available. We would also like to thank friends and family who have supported us both content-wise and emotionally during the whole time.

Abstract

Understanding common wildlife diseases in managed wildlife populations can be crucial. In the case of wolves, sarcoptic mange is such a disease. The inexperience of some wolf managers with the disease and the lack of any guidelines for identifying and assessing the severity make it difficult to make a uniform assessment of the prevalence and intensity of mange across Germany. Furthermore, there is a lack of knowledge about the dynamics and progression of mange, making it difficult to conduct targeted public relations work to increase trust in wolf management and to prevent an increase in public rejection. Our goal was to generate guidelines on how to identify and classify a mange infection in wolves and to understand the spread of mange in wolf populations. Photos of dead mange-infested wolves from Germany were used to develop categories with different levels of mange infestation. Camera trap pictures from wolves from Saxony and Brandenburg from the monitoring years 2009/2010 to 2020/2021 were used to investigate the spread of mange within and between wolf packs. Two Binomial GLMMs were used to investigate the effect of average monthly rainfall and temperature on the spread of mange and to investigate whether the change of the territorial adults had an effect on the mange prevalence in the pack. For 19 identifiable wolves with mange, it was calculated how long it takes on average for a wolf to move from one Category to the next. For classification, the categories 0 = no mange, 1 = mild infestation (<10% bald), 2= moderate infestation (10-50% bald), 3 = severe infestation (>50% bald) and A = healing were developed. Furthermore, it has been shown that precipitation and temperature have a negative correlation with the probability of mange and that an animal that remains in Category 2 for a longer period of time is more likely to change to Category 3 than to heal. No effect on the infectedness of a pack due to the change of a territorial adult could be detected. The knowledge on how to identify and classify mange offers those responsible for wolf management the possibility to recognize a mange infestation more reliably and to assess its severity. In addition, better predictions can be made regarding the spread of mange and the course of an infected animal. Both can help management to make appropriate and fact-based decisions and thus minimize human-wildlife conflict.

Key words: sarcoptic mange, wolves, canids, skin diseases, wildlife diseases, classification, temperature, precipitation, pack structure, ectoparasite, mite

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1 Introduction

Wild species are returning to Western Europe and Germany, to areas where they had disappeared (CORLETT 2016; TROUWBORST 2010). There they encounter habitats dominated and modified by humans (MCKINNEY 2006; WATERS et al. 2016), which can lead to a variety of human-wildlife conflicts (HWC) (NYHUS 2016). Diseases that these animals bring with them when they return or that can be spread by them can create such conflict. A disease can cause behavioral changes in the animal creating potential or perceived danger to human health and life. Due to the increased contact between humans, domestic animals and wildlife, the increased possibility of transmission or the fear of it can also cause a conflict (NYHUS 2016; THULIN et al. 2015). Therefore, it is crucial for wildlife managers to recognize these potential HWC to apply adaptive management and mitigate potential conflicts.

The wolf (*Canis lupus*), as a large predator and keystone species, has had and continues to have a widespread impact on its range due to its cascading impacts on local ecosystems, contributing to a healthy and functioning ecosystem (BESCHTA & RIPPLE 2016; STAHLER et al. 2002; STAHLER et al. 2006; WEISS et al. 2007). The wolf was once widespread throughout the Northern Hemisphere, with few local exceptions (DBBW 2016), and was pushed to extinction by human actions across much of Europe (WENZEL 2017). Thanks to strict conservation measures, like the Fauna Habitat Directive (FFH Directive) (Bundesamt für Naturschutz 2019) the populations recovered after 1970. In Appendix A, a map with their current distribution can be found.

Since 2009 sarcoptic mange is present in German wolf populations (SCHLAUTMANN 2020). In monitoring year 2020/2021, at least 15% of the packs were demonstrably affected by mange. Sarcoptic mange, also called scabies in man and mange in animals (BORNSTEIN et al. 2001), is a skin disease caused by the burrowing mite *Sarcoptes scabiei* (OLEAGA et al. 2011). Canids and consequently also the wolf are infested with the mite *Sarcoptes scabiei var. canis* (PENCE & UECKERMANN 2002). Excretions, dead mites and their eggs trigger dermatitis, and hyperkeratosis, as a result of which infected animals suffer from hair loss and itching, giving the classic appearance of the disease (BAUMGÄRTNER & GRUBER 2020; PENCE & UECKERMANN 2002).

The FFH Directive obliges Member States to monitor the conservation status of protected species such as the wolf and to summarize it in a national report every 6 years (Bundesamt für Naturschutz 2022). How exactly conservation status is to be understood is not defined in the FFH Directive, but since diseases can have a considerable influence on the population dynamics of a species (LYLES & DOBSON 1993), it can be assumed that common diseases like mange in wolves should also be part of this report. The attitude of the local people can, in addition to the influence that a disease has on population dynamics, also have an influence on the (endangered) species (EBUA et al. 2011). A study by the Federal Agency for Nature Conservation (BfN) showed that a large part of the human population in Germany has a positive attitude towards the wolf. However, it also showed that this opinion was not very consolidated and the possibility existed that possible problems could turn the general mood towards the opposite (REINHARDT & KLUTH 2007). It has already been observed that wolves that were severely infested with mange, which have lost their fur due to the disease, change their behavioural patterns and tend to approach human settlements more often to seek sheltered places (JIMENEZ et al. 2010; SHELLY & GEHRING 2002). Thus, an animal in search of warmth may hide for example in a barn (LUPUS Institute, personal interview, Spreewitz, 2022-03-02, Appendix B.). Furthermore, it was observed by CROSS et al. (2016) that heavily infected wolves change their typical activity pattern and are mainly active during the day. This altered activity pattern could cause wolves and humans to encounter each other even more frequently. The sighting of heavily infested wolves especially in the vicinity of human settlements could result in greater fear and rejection of the wolf by local people, as many people (40-70%) still consider an encounter with a wolf as dangerous (KUTAL et al. 2018). There are repeated calls for management action to be taken as soon as a mangy wolf is sighted (LUPUS Institute, personal interview, Spreewitz, 2022-03-02, Appendix B.), even though there is no evidence to date that injured or sick wolves (except for rabies) pose a greater risk to humans (REINHARDT et al. 2020). In addition, the fear of transition of mange could worsen the image of the wolf. In England, it was shown that the attitude of the local human population towards a fox population deteriorated noticeably after mange had spread in this fox population, presumably due to fear of transmission of the mite to humans or pets (BAKER et al. 2004). It is conceivable that something comparable could result from a spread of mange in wolves. This highlights the need for further understanding on mange in wolves to prevent a deterioration of public opinion regarding the wolf.

To be able to collect and generate valuable data for the FFH Directive report over the conservation status regarding mange in wolves and to prevent the public image of the wolf from deteriorating due to mange, all responsible managers have to be able to recognize the disease to generate a uniform picture of the spread of mange and to be able to do targeted public relations work. As camera trap images are an important part of monitoring, they are one of the best sources of information on mange infections in wolves. However, there are currently no guidelines in Europe addressing mange in wolves (LUPUS Institute, personal interview, Spreewitz, 2022-03-02, Appendix B). Furthermore, many of those responsible in wolf management lack experience in recognizing the infection on camera trap pictures because the disease is not widespread yet. As mange in wolves will continue to spread in Germany (SCHLAUTMANN 2020) (Figure 1), it is quite likely that they will be confronted with the disease more often. Their lack of experience could cause them to overlook the first signs of an infestation or confuse mange with other diseases or the change of coat (LUPUS Institute, personal interview, Spreewitz, 2022-03-02, Appendix B). Even if it is possible to identify a mange infestation by means of a photo, the severity of the infestation may be misjudged. Consequently, it is possible that inexperienced wolf managers may misjudge a mange infestation generating a biased picture of mange in the German wolf population.

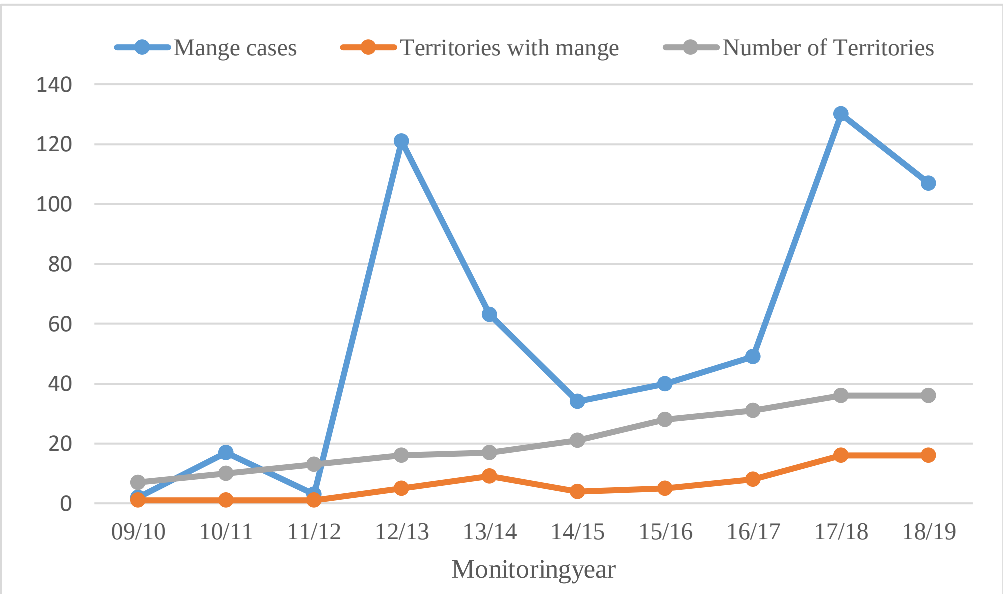

Figure 1: Mange cases, infected territories and number of territories per monitoring year, the blue line shows the number of mange cases, the orange line shows the number of infected territories and the grey line shows the number of territories in general (SCHLAUTMANN 2020)

One of the tasks of wolf management is to carry out public relations work and consequently to prevent unfounded fear of wolves and mange within the local population (LUPUS Institute, personal interview, Spreewitz, 2022-03-02, Appendix B). However, little is known about the way mange behaves in wolf populations. Information on this could help to make predictions and educate the local population more targeted. For example, the relationship between weather (rain and temperature) and mange is not yet fully understood. The noticeably increased number of cases in the monitoring years 2012/13 and 2017/18 (see Figure 1.) suggest that there was a factor favoring the spread of mange in these years (SCHLAUTMANN, 2020). One study indicated that relative humidity had a positive and temperatures a negative correlation with the survival of *Sarcoptes scabiei var. canis* (ARLIAN et al. 1989).

Sarcoptes mites are transmitted by direct contact or secondary contact via resting and scratching places (BAUER et al. 2012), so it is quite likely that members from the same pack can easily infest each other. A wolf pack usually consists of a breeding pair (also called parents) and their offspring (DBBW 2019). The offspring of a pack often leave their pack of origin to find a mate and reproduce. In doing so, the offspring may take up breeding positions that have become vacant in a neighboring pack or usurp one of the leaders of the other pack (MECH & BOITANI 2007). Consequently, this change in a territorial wolf may cause a spread of mange between packs. However, whether this spread of mange is actually related to the change of a territorial adult, or whether mange spreads between packs in some other way is not known.

There is a lack of sufficient information to be able to make predictions course of mange in a wolf. Thus, it is not possible for responsible authorities in wolf monitoring and management to predict the course of the infestation at the first signs of mange.

The goal of this research is to generate a classification system on how to identify and classify a mange infection in wolves based on a camera trap picture and to understand the spread of mange in wolf populations. To be able to better communicate the knowledge gained to those responsible, a brochure will be produced for these responsible for wolf monitoring and management after the completion of this paper. It is intended to clearly present the findings on mange classification, its spread and to summarize general information on the disease.

The following research question which this paper aims to address, arise from the problems and objectives identified in the previous section:

How can the course of mange in wolves be determined and predicted?

1. How to identify and categorize mange from camera trap and sighting images?
2. Which factors are associated with the spread of mange within and between wolfpacks and how?
3. To what extent is it possible to predict the course of mange based on the first determination of an infected individual?

2 Methodology

2.1 Research Type and Research Design

The main part of the thesis consisted of a descriptive study using qualitative methods, as the aim was to find a method how to identify and quantify visual signs of mange and predict the course of an infestation. Furthermore, there was statistical part, using quantitative methods to investigate whether there is a relation between mange distribution and factors such as sex and age of the animal or the weather. Only secondary data was used for the analysis, as there was already sufficient data for the planned study.

2.2 Research Population and Research Area

The wolf (*Canis lupus*), lives in family groups (packs) usually composed of a territorial female, a territorial male and their offspring of the previous two years, but the composition of packs can also be a variation of this basal setting as sometimes it can happen that there is a second breeding pair in the pack, which usually consists of a daughter of the pack and another male. These animals are then called territorial female/male 2. The offspring of the pack is divided into pups and yearlings, with pups younger than one year (their birthday is defined to be the 1st of May) and yearlings in their second year of life. In Central Europe pups are usually born in late April or early May. Each pack claims its own territory, which in Central Europe usually covers between 100 and 350 km^2 (DBBW 2019). Yearlings - and also pups in their first winter - usually leave their parents' territory and migrate to other areas to establish a pack themselves, which is why there is usually only one reproducing pair per pack. If females and males live together in one territory but have no offspring (yet) they are called a territorial pair. A single wolf that fails to find a mate and therefore claims a territory for at least 6 months is a territorial single wolf (DBBW 2019). Up to now the wolf population in Germany has increased to around 157 packs, as well as 27 territorial pairs and 19 territorial individuals in the monitoring year 2020/21 (01 May until 30 April 2021) (DBBW 2022 B) (Appendix A for map with current distribution).

The study population consisted of all wolves (about 40 packs) that occurred in the federal state of Saxony and parts of Brandenburg (west of the A13 and south of the A15) in monitoring years 2009/2010 until 2020/2021 (01 May 2009 until 30 April 2021). This number is without the cross-border packs Ruszow, Vysluni, Luzicke Hory, Ruhland and Annaburger Heide due to the lack of data. The states have a human population of 220 and 85 per km^2 respectively and both border Poland and Saxony borders to Czech Republic as well (RUDNICKA 2022). Large areas are used for agriculture (49% in Saxony, 44% in Brandenburg) (Land Brandenburg 2021; Statistisches Landesamt des Freistaates Sachsen 2021a). 13.4% of the land in Saxony is used for roads and urban areas (Statistisches Landesamt des Freistaates Sachsen 2021b), in Brandenburg 9.5%. Both states are slightly below the national average of 13.9% (Statistik Berlin Brandenburg 2020). Large parts of Brandenburg are potentially well suited as wolf habitat. In Saxony, especially the border areas to Poland and Brandenburg are suitable (see Appendix C). Data was taken from the monitoring years 2009/2010 until 2020/2021 as there were no indications of mange before this period and the data for the monitoring year 2021/22 was not complete (SCHLAUTMANN 2020) (LUPUS Institute, personal interview, Spreewitz, 2022-03-02, Appendix B). Furthermore, all mange infested wolves that were found dead in Germany from 2009 to 2021 (n = 48) were also part of the study population.

2.3 Data collection

Pictures from dead infested wolves

For the detection and classification of mange, photos of 48 dead wolves infected with mange were used, as a more reliable determination of a mange infection can be made after a necropsy and good resolution photos of the wolves from both sides. The tests to determine whether a wolf is infested with mange were carried out by the Leibniz Institute for Zoo and Wildlife Research (IZW), which is responsible for the necropsy of all wolves that were found dead in Germany. When a mange infestation is detected through necropsy, this is included in the diagnostic report. The severity of dermatitis and alopecia is usually classified as low, moderate and high in the report. In addition to the medical examination, full-body photographs were taken of both sides of each individual. Of all the wolves examined by the IZW, 9.4% had mange (SZENTIKS, personal communication, 2022).

Mange classification

All images of the dead wolves were reviewed and sorted for their usability with regard to the study (OKUBOYEJO et al. 2013). For example, wolves whose appearance were significantly altered by e.g., a traffic accident were removed. The categories were divided into several stages depending on the intensity of the infestation, using information from the literature and personal assessment. As in PENCE et al. (1983), the severity was determined by the percentage of the body surface that was affected and classified into three categories by means of the percentage of hairless spots on the animal's body (no mange scored as 0, 1–5% scored as 1, 6–50% scored as 2 and > 50% scored as 3) (PENCE et al. 1983). However, this was supplemented by documenting also the infested body part to achieve a more accurate categorisation with a lower error rate, as it is usually hardly possible to see the animal from all sides in camera trap pictures and thus to accurately estimate the percentage of infestation. Furthermore, the Category A (healing infestation) was added, because a study in eastern Germany has shown that wolves, unlike other canids (TU München 2020), usually cure of mange (SCHLAUTMANN 2020).

The suitability of the categories was evaluated by categorising camera trap images of infested wolves to check whether these are usable in the field (OKUBOYEJO et al. 2013). Calibration was done by using 11 volunteers who were mostly active in wolf monitoring and have different stages of experience with mange. One person had no experience with wolves and mange, two had experience with wolves but not with mange, two had experiences with mange but not with wolves and 6 had experience with both, in different stages of experience. They were tested independently. First, the categories developed (sketches and associated text) were presented to them (see appendix F). Once they had an overview of the categories, individual camera trap pictures of mange-infected wolves were presented to them. For that, 125 different camera trap images of mange-infected and healthy wolves (summer coat, winter coat and shedding) were used. Every volunteer got the same 125 photos to make the results comparable. The volunteers were then asked to assign these photos to the categories that thought best fit the infestation shown in the photo.

Data and pictures from living wolves

DBBW Database

To assess data and photos of infested wolves in the wild, data from the Federal Documentation and Consultation Centre on Wolves (DBBW) database was used, in which information about wolves that occur in Saxony and South-East Brandenburg such as age, pack membership, mange infestation and other is compiled. The data for the DBBW database is gathered by the LUPUS Institute by means of identifying faeces, urine and oestrus blood, tracks, camera trap pictures, sightings, game animal and livestock killings, wolves captured alive, dead wolves, etcetera. Each observation (indication) is logged and recorded in the database of the DBBW. The date, territory, contact details of the finder/reporter, location (coordinates and location description), and category-related relevant information (e.g., time, behaviour or description of the animal's appearance) are added to the indication. If an animal shows signs of mange, a check mark is placed in the "Mange Signs" -field. Finally, the individual indications are assessed by an experienced person according to their verifiability following the SCALP method because many indications were entered into the database by inexperienced volunteers and interns (Status and Conservation of the Alpine Lynx Population) (REINHARDT et al. 2015).

Based on genetic analyses of feces and camera trap images, the territories of wolves can be spatially segregated from each other. With the knowledge about the territories, the monitoring can therefore be adapted to the specific territory. About 2-4 camera traps are set up per territory by LUPUS Institute & volunteers, which are located at strategically favorable points in the territory (e.g., a crossing of forest paths where there is increased evidence of wolves through feces). The camera traps can be used flexibly in the territory and can always be set up where there is increased wolf activity. An assessment of age and sex of photographed wolves and an evaluation of whether an animal has mange or not can only be made by experienced persons (see Appendix D) (LUPUS Institute, personal interview, Spreewitz, 2022-03-02, Appendix B; REINHARDT et al. 2015).

Only the indications that include a photo (camera trap images and sightings) were used for this research as these are the only indications by which mange can be detected. All indications that were confirmed as wolves were used (SCALP categories C3b, C3c, k.B. or f (see Appendix D) were not used). In the database are compiled almost 21000 indications which come with a photo that very likely shows a wolf and are therefore usable for the report.

For all wolf indications that are stored in the DBBW database mange signs are recorded. There were almost 1000 in which the field "Räudeanzeichen" (mange signs) indicates a mange infestation. To correct for possible errors, the data was first cleaned and sorted so that it was possible to query the indication of mange uniformly. This had already been done up to the monitoring year 2018/2019 and only had to be done for years 2019/2020 and 2020/2021. The data set was searched for wolf indications in which no mark was set for mange indication, but in which, for example, words such as "mange" or "shaggy" were used in the description of the coat and which consequently indicate that the mark has been forgotten (SCHLAUTMANN 2020). For these searches, the following words were used, which consist of different spellings for mange or describe a coat structure typical of mange: "räude", "raeude" "reude", "räudig", "reudig", "nackt", "nackig", "gerupft", "raude", "zottelig", "struppig", "unbehaart", "kein Fell", "schütteres Fell". Since the database is in German, all queries were made in German. If any wolf indications with signs of mange were found it was checked whether the box “mange” was ticked. If not, the box was ticked in retrospect to aid searches in the database. If it is not clear whether the wolf has actually shown signs of mange, e.g., if the description of the coat only says sparse fur instead of mange, the photo (if available) was examined together with experts from LUPUS Institute and it was then decided whether the animal shows signs of mange.

Pictures of shedding wolves

Since wolves undergoing shedding often show a mange-like appearance (sparse uneven fur), camera trap pictures with shedding wolves were used in the analysis to detect possible visual differences between mange symptoms and fur change. For that purpose, camera trap images from shedding wolves the months of March to May were used as comparative data, as the wolves change their thicker, longer winter coat for a shorter summer coat (MECH & BOITANI 2007). Which photos actually depict shedding and were used for analysis was determined by experts from LUPUS Institute who already have 20 years of experience in evaluating wolves on camera trap images.

Pictures from genetically identified wolves

Due to the genetic analyses done by Senckenberg Gesellschaft für Naturforschung on feces, urine, blood, hair of-, living and muscles of dead animals, individuals are known with their genetic identity (HARMS et al. 2011). Each new genetic identity receives a specific number (genetic number), for example, GW701m or GW112f. The number is divided as follows: GW is the short form of **G**enetic **W**olf, thereafter it is an ongoing number of identities, the last letter stands for **f**emale or **m**ale. To determine the course of mange, only photos of animals that can be identified for example with their genetic number (see Appendix E) were used, as only with these individuals it is possible to follow the course of the respective infestation by means of camera trap pictures. Out of a total of 37 identifiable individuals, there were 19 animals that were infested with mange and had a observable course and of which in total 290 photos exist from their mange period (average = 16 pictures per individual, SD ± 11). Furthermore, the categories that were developed for sub-question 1 were used to develop a standardized classification of the camera trap pictures with them.

Literature research

Mange in wolves and other canids

Literature research was conducted about mange in canids to obtain first indications of typical development and external characteristics of the disease. For that, keywords like “mange”, “scabies”, “mange canids”, and “symptoms mange” were used. Moreover, medical articles and examinations of canids on diseases that manifest themselves on the skin were used to investigate how these differ from the external appearance of a mange infestation. These articles served as possible guides on how to describe and schematize visual symptoms. To find the articles, the first step was to search for all possible diseases and parasites that can manifest themselves on the skin in canids, using search terms such as “parasites canids”, "skin diseases canids", "diseases dogs list", "skin diseases dog", and "skin diseases wolf”. Diseases were sorted out which had a clearly different appearance than mange, which only occurred in cats, which did not occur in Europe and for which it is very unlikely that a wolf could be affected by them (e.g., drug intolerance, breed-specific diseases, rare hereditary diseases etc.). After that, individual diseases and parasites that resemble the appearance of mange were searched for by looking for their colloquial as well as their scientific name. All the characteristics that distinguish these mange-like diseases and other reasons for similar symptoms from an actual mange infection have been summarized in a flowchart. This should make it possible to exclude other causes for an atypical skin and coat appearance.

For the literature research, the search engines Google, Ecosia and Google Scholar were used and searched for using German and English keywords. In order to gather as many scientific sources as possible, further suitable sources were searched for by scanning literature lists of sources that were already being used. If one source referred to another, this was first checked and then cited as the original source in the study. If possible, two independent sources were compared for their content for each statement.

Weather stations

Relative humidity and temperature have an impact on the life expectancy of the mite (ARLIAN et al. 1989), so it is likely that weather conditions will have an impact on the spread of mange. To investigate this assumption, weather data from all weather stations within the main study area (n = 115) were used. Data on average temperature per month and year, and precipitation in l/m^2 were used, as these gave an indication of the conditions with which the mite had to deal. These data were obtained from the website www.wetterkontor.de, as it was possible to trace the average values per month and year back to 2009.

2.4 Data preparation and processing

Mange identification

In order to rule out other causes of a mange-like appearance and thereby develop guidelines for mange detection, images of and information on various diseases that can manifest themselves on the skin or coat of wolves or other canids were used. These were supplemented by pictures of wolves undergoing a change of coat. Subsequently, the shape, structure, color, body parts affected and, if applicable, development of each disease or coat change were used to detect features that are typical for these and can help to differentiate them from mange (KRASNOVA et al. 2015). In the following, it was worked out which characteristics (possibly in combination) are unique to mange and which characteristics definitely exclude a mange infestation. Characteristics were determined which may indicate mange, but which may also be caused by other factors.

DBBW Database

After the records were standardized, it was possible to search in the database for all protocols where the field “Räudeanzeichen” (mange signs) was ticked. This made the data records clearly recognizable and usable for analysis. In addition, if information on the age of the animals was missing, afterwards the indication was checked by LUPUS Institute and the information was added. The age of the animal at the time of this indications was determined based on pictures, genetic results or computed tomography results. Possible categories are "Altwolf" (animal older than two years), which also includes the "Territoriale Fähe" and the "Territorialer Rüde" (territorial female and male), "Jährling" (yearling, wolf in the second year of life) and "Welpe" (pup, wolf in the first year of life), as well as the categories "Jährling oder Welpe" and "Jährling oder Altwolf". Indication types relevant for the analysis were the camera trap images, all sightings, dead finds and logs of captured wolves recorded since 2009. That means all indications where the animal can be clearly seen and the infection symptoms, can be recognized.

After cleaning the database, a table was extracted from it which was also checked for further errors and corrected if necessary. Furthermore, the columns "mange individual" and "genetic individual" were added. Through the added column genetic individual, it was possible to identify the infected animals in even more detail, as in the case of genetic samples the genotype of the animal can be determined, whereby the parents and sometimes also the year of birth is known. Data was transferred from the main table to other tables for analyses.

Influence of weather

The mean values per month of 115 weather stations in the area were calculated for temperature and rainfall. The values of the weather stations per climate zone were summarized according to WINKLER et al. (1999) (I: humid-mild hilly area; II: dry and marginal areas; III: transitional area from hilly area to foothill areas up to the middle mountain areas of the low mountain ranges; IV: high mountain areas of the low mountain ranges (> 500 m)) (see Appendix G). This means that the averages produced may be different for packs from different areas. It was not possible to summarize per territory because of sufficient weather data being not available for each territory at the local level. Since none of these classifications could be found for Brandenburg, all data from the weather stations in Brandenburg are summarized (V). For the analysis, all records from the DBBW database were used. For each indication, the date of capture, if known the pack, the region (I, II, III, IV, V) and whether the wolf in the photo was infested with mange (1=yes, 0=no) were noted. Furthermore, for each indication, the average weather that had been prevalent in the region for the 30 days prior to the indication was calculated. 30 days were taken as the data was only available in average per month and the incubation time normally takes 6 to 30 days (NIEDRINGHAUS et al. 2019a). The mean weather was calculated with the following formula for precipitation and temperature:

$$\frac{x \times w_1 + y \times w_2}{30}$$

Here, w1 stands for the average temperature or the average precipitation of the first month in which the 30 days fall and w2 for the second month. X and y are the number of days respectively. So, if an indication was received on 28 March and the average temperature in March is 15 °C and the average temperature in February was 12 °C, the formula would look like this:

$$\frac{2\ days \times 12\ degrees + 28\ days \times 15\ degrees}{30} = 14.8\ degrees$$

<u>Spread of mange due to the change of territorial adults</u>

As pack members are spatially close to each other and physical contact can occur, it was conceivable that the mange mite can be transmitted (directly or indirectly) quickly from one pack member to the other (ALTIZER et al. 2003). If one or both territorial adults of a non-infested pack are replaced by one or two infested territorial adults, it was therefore conceivable that this change will also result in the infection of other pack members. To follow up on this assumption, a table was created in which it was shown per year and pack whether the territorial male or female had changed from previous year and if the pack had mange. A distinction was made between territory and pack, as not all animals that are detected in a territory automatically belong to the pack. If the new territorial male or female could be clearly identified from the indication with mange for the respective monitoring year, the pack was considered to be infested with mange in this year. The same applied to evidence of pups before 31 December of the respective monitoring year or to evidence of pups or yearlings running together with the pack. This method excluded the possibility that the animal was only roaming the territory and did not belong to the pack. If there were indications of mange in a territory where the individual could not be clearly assigned to the pack, this mange case was not assigned to the pack.

Course of mange

All images of identified individuals were first classified using the categories developed in sub-question 1 (0 = no mange, 1 = light infestation, 2 = medium infestation, 3 = heavy infestation and A = healing from mange). The course was summarized in a table for each individual to get a first impression of the data. The date of the first indication and the date of the last indication of a category was noted down per animal and the time span in days in between was calculated. Also, the number of indications in this period between the two dates was recorded. Furthermore, it was calculated how long the animal was in the respective category and how many days passed between the categories without an indication.

2.5 Statistics

Categories test

The Fleiss Kappa coefficient (DescTools version 0.99.45; SIGNORELL et al. 2021) was used to check how much the classifications of the test persons differ per photo. If the κ-coefficient would have been above 0.6 (strong to (almost) complete conformity) (LANDIS & KOCH 1977), the categories were considered suitable for the standardized classification of mange. If the value was lower (≤0.6), further analysis of the data was carried out to identify which photos had frequent discrepancies between the ratings and the comments that the test subjects had written about some of the photos were looked at. Whether the categories should only be used by certain test persons was investigated by using only the very uniformly rated photos, *i.e.*, photos that were classified in the same category by at least 8 of the 11 test persons. It was calculated how often the test persons rated these very similarly rated photos contrary to the general assessment. Subsequently, it was checked whether their experience had an influence on their number of deviations. Whether only certain photos should be used for categorization was checked by running the Kappa again, exclusively with photos that were of medium to good quality (no night shots and large motion blur).

Based on these results from the first category test, the categories were revised and tested again based on two test subjects with the Cohens Kappa (DescTools version 0.99.45; SIGNORELL et al. 2021). The test was repeated with only two subjects (with the authors of this paper) because the remaining study period was insufficient to conduct another comprehensive test. A different kappa was used due to the different number of test participants.

Influence weather

It was expected that the average precipitation has a positive and the average temperature a negative effect on the number of mange infections (ARLIAN et al. 1989). This was tested statistically by means of a Binomial Generalized Linear Mixed Model (glmmTMB version 0.2.3; BROOKS et al. 2017). Consequently, it was tested whether the probability of mange being present was related to weather data (LAVALLEY 2008; SHANUBHOGUE & GORE 1987). The dependent variable was whether there were signs of mange on the indication. The independent variables were average temperature of the 30 days prior to the indication and rainfall. Pack to which the animal belongs, year and the location where the photo was taken were included as random factors. A conceptual model of this can be found Appendix H.

Changing territorial adults

A Binomial Generalized Linear Mixed Model (glmmTMB version 0.2.3; BROOKS et al. 2017) was performed to test whether there is a correlation between a change of the territorial female or male and the occurrence of mange within the pack. Whether there was a change in the territorial female or male were the independent variables. "Mange" was the dependent variable and pack and monitoring year were the random factors. A conceptual model of this can be found in Appendix H.

Development of mange

Descriptive statistics were used to gain insight into the course of the infection. For this purpose, a crosstab was created that summarizes how long individuals were in one category on average before moving to the next. To do this, the time it takes for an animal to move from one category to another was calculated by taking half the time from one indication to the other. Thus, if 30 days had passed between a Category 1 indication and a Category 2 indication, it was assumed that the animal has had the transition between the Categories in about the middle of the time. In addition to the average, the standard deviation and the number of individuals included in the calculation were also given in order to assess the validity of the results. Furthermore, it was calculated what percentage of the wolves reach which category. A conceptual model of this can be found in Appendix H.

3 Results

3.1 Mange detection

Common clinical signs of mange include erythema, pruritus, seborrhea, hyperkeratosis and alopecia (BORNSTEIN et al. 1995; AUJLA et al. 2000). Furthermore, there are at least two unique manifestations of mange: "common" mange, characterized by alopecia with relatively small numbers of mites, and "crusted mange," which results in hyperkeratosis and serocellular crusts and is associated with a high number of mites (PENCE AND UECKERMANN, 2002; FRASER et al. 2018). Based on camera trap images, diseases with similar symptoms can be mistaken for mange disease. The flow chart (Figure 2) can be used to distinguish between mange-like symptoms due to a mange infestation or by other diseases, injuries or shedding. A detailed description and photos of these other causes can be found in Appendix I. Information used for this flow chart was mainly found in the handbook "Skin Diseases of the Dog and Cat" (NUTTALL et al. 2009). In total, over 120 different diseases were examined in more detail. Six of them were integrated into the flow chart, as they were most likely to be mistaken for mange and where it is most likely that a wolf could become infected with them. The flowchart starts at the top question "Does the animal have bold patches?". If you can answer a question with yes, you follow the green arrow. If the answer is no, follow the red arrow. Other diseases, injuries, or shedding that are at the ends of some paths are colored in light orange. All symptoms that indicate mange lead to the dark orange mange field.

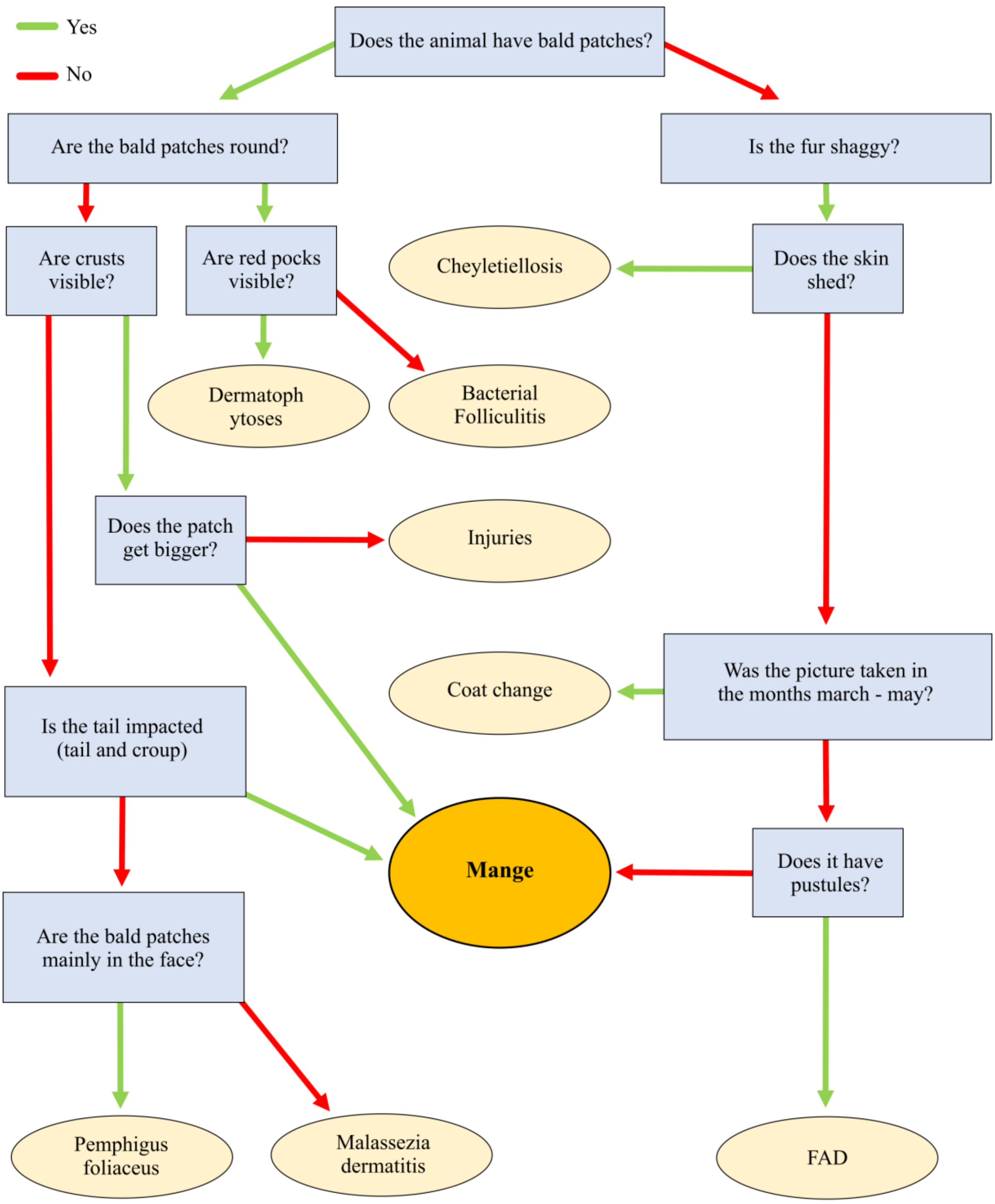

Figure 2: Flowchart for the visual identification of mange. The flowchart should only be used if mange infestation is suspected. A detailed description of the diseases, as well as pictures, can be found in Appendix I.

3.2 Mange categories

For each category, full-body outlines from one side of wolves were depicted, showing which body parts were likely affected in each category and how. Four different colors were used: White areas indicate that no infestation is visually apparent, orange areas indicate altered coat structure and density, red areas represent bald patches, yellow areas symbolize regrowing fur. The sketches represent a typical look at a Category 1, 2, 3 or A mange infestation, but it may be that other areas are affected than those shown in the drawings. A total of 48 infected dead wolves were dissected, of which 6 could not be used because the spread of the infestation could no longer be detected due to advanced decomposition or extensive injuries caused by traffic accidents. For the animals used, an average of 94 photos per wolf was available. For the definition of terms and for a better understanding of the following chapters, Figure 3 shows a wolf with the corresponding designations of its body parts. The chosen terms are based on common terms from the dog world.

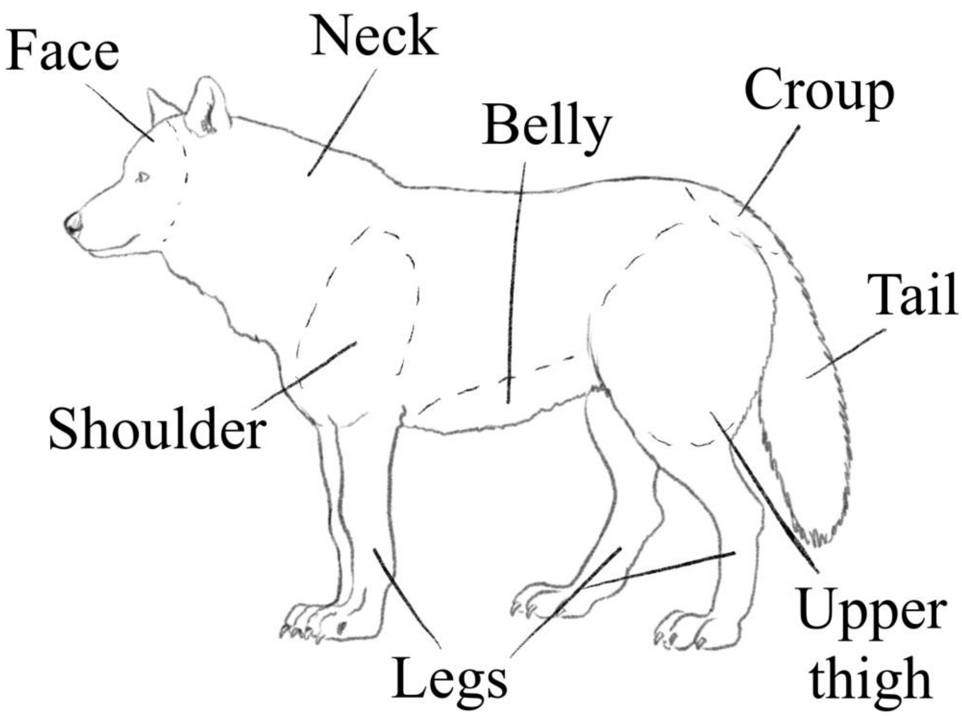

Figure 3: Body parts of the wolf

Of the 42 animals used, 13 were classified as low mange infestation (31% of the animals), as less than 10% of their bodies were bald (mean 4.9%, SD ± 2.2%). 10 of the animals (23.8%) had medium infestation. They had several hairless patches covering a total of 10 to 50% of the body. 16 of the 42 animals (38.1%) were more than 50% bald, which is why they were classified as heavily infested. 3 of the wolves (7.1%) were already healing from the disease. For the sake of completeness, Category 0 was developed for animals that do not have mange, in order to completely cover the course of a mange infestation.

Category 0, no infestation

A Category 0 wolf shows no recognizable mange symptoms. It usually has a uniformly long and dense coat. It is neither shaggy nor thinned out and there are no bald patches (see Figure 4 and Figure 5). However, due to coat changes, injuries and diseases other than mange, mange-like symptoms may still occur in some cases. How these symptoms can be distinguished from an actual mange infestation was discussed in chapter 3.1.

Figure 4: healthy wolf with a summer coat, female yearling of the Daubitz pack on 2019-07-01 in Lusatia Germany (Bundesforstbetrieb Lausitz 2019)

Figure 5: Healthy wolf with a winter coat in the territory of the Milkel pack on 2018-12-01 in Lusatia Germany (RALF M. SCHREYER, Staatsbetrieb Sachsenforst - Biosphärenreservatsverwaltung 2018)

Category 1, light infestation

13 of the 42 wolves were categorized as lightly infested. On average, 70% (±36.8%) of their body showed signs of mange, 4.9% (±2.2%) of their body surface was bald. The first recognizable signs of a light mange infestation can be seen especially on the croup (7 out of 13) and the face (13 out of 13). 3 of the 13 animals from Category 1 had hairless patches on the tail, sometimes with a ring of hair remaining in the middle of the tail. In addition to the bald spot on the tail, a slightly blotchy face can often be seen in better visual conditions, which is also an indication of an incipient infestation (see Figure 6). This change in the face could be seen in all the animals examined. Furthermore, in some wolves a changed structure in the coat could be seen (9 out of 13). The coat may appear shaggy and thinned out (see Figure 7). Especially in young pups it often can be seen that the body is still completely covered with hair, but the skin is clearly visible under the coat.

Figure 6: Wolf with signs of mange on the croup and on the face in the territory of the Großräschen pack on 2019-08-29 in Lusatia Germany (LUPUS 2019)

Figure 7: Wolf with shaggy and thinned out coat, a pup of the Milkel pack on 2010-1205 in Lusatia Germany (ANDRE KLINGENBERGER 2010)

The two sketches in Figure 8 show the range in which an infestation of Category 1 is to be classified. On the left side there is only a small patch of baldness on the croup and a blotchy face, whereas on the right side the entire coat is shaggy or thinned out and there are already bald patches on the croup, on the tail and on the back of the thigh.

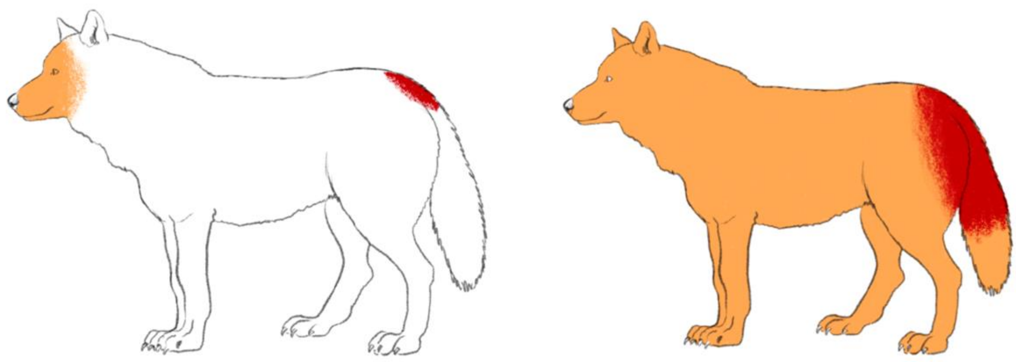

Figure 8: Category 1 of a mange infestation. White areas indicate that no infestation is visually apparent. Orange areas indicate altered coat structure and density. Red areas represent bald patches.

Category 2, moderate infestation

A moderate infestation, was detected in 10 of the 42 cases and assigned to Category 2. In this case, clearly larger bald, scabbed and sometimes bloody areas were seen. The bald areas cover a total of over 10% and under 50% of the wolf body. On average, 32.3% (±8.8%) of their body was bald. The side was often affected (10 out of 10), but bald patches could also appear on other parts of the body, such as the legs (7 out of 10), upper tight (7 out of 10), back (4 out of 10) or chest (3 out of 10). In all the wolves examined for that category the tip of the tail remained slightly hairy. In this category, the rest of the coat, apart from the bald patches, may look inconspicuous or may be shaggy and thinned out (7 out of 10). An example of a Category 2 wolf can be seen in Figure 9 and Figure 10.

Figure 9: An example of a Category 2 wolf, it has a bald area on the left side of its body as well as a thinned-out tail, the wolf was phototrapped in the territory of the Milkel pack on 2012-03-29 in Lusatia Germany (ANDRE KLINGENBERGER 2012)

Figure 10: Another example of Category 2 with several bald patches spread over the body, the territorial female of the Dauban pack GW114f also called Frieda (FT9) in the territory of the Dauban pack on 2020-11-12 in Lusatia Germany (TOBIAS BÜRGER 2020)

The two sketches in Figure 11 again visually represent the category 2 just described.

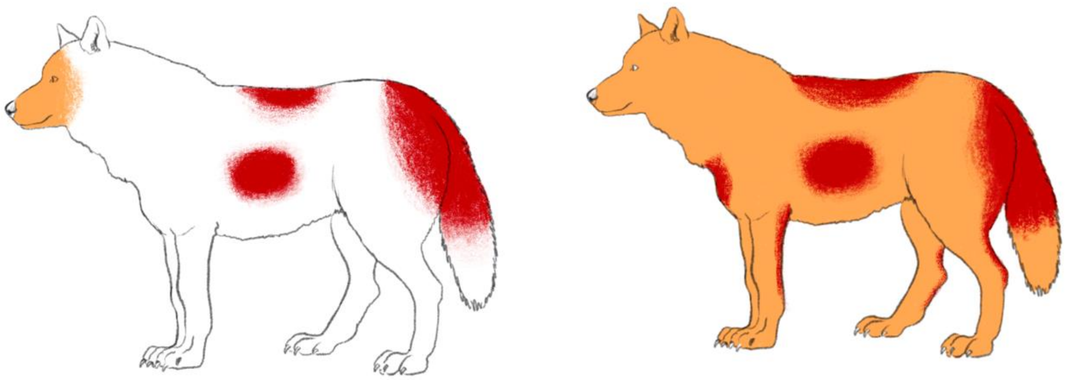

Figure 11: Category 2 of a mange infestation. White areas indicate that no infestation is visually apparent. Orange areas indicate altered coat structure and density. Red areas represent bald patches.

Category 3, heavy infestation

Category 3 includes all severe cases of mange. 16 of the 42 cases were assigned to this category. In this stage, the entire body is affected and most of the body (over 50%) is hairless. On average, 85.6% (±13.9%) of their body was bald. If some parts of the body still remained hairy, the coat was shaggy in all cases. Often it was the face (between the ears and in the front part of the face) (9 out of 16), legs (5 out of 16) and paws (13 out of 16), that were not completely hairless. In some the belly (3 out of 16), the neck (6 out of 16) and the tail (3 out of 16) remained hairy. Exemplary pictures can be found in Figure

12 and Figure 13. In Figure 13 you can clearly see the darker pigmentation of the skin as a reaction to the sun's rays (2 out of 16). The infestation is clearly visible and the risk of confusion or overlooking the infestation is very low.

Figure 12: An example of a Category 3 wolf, the wolf is nearly completely naked, the animal was photo trapped on an ecoduct in the territory of the Chransdorf pack on 2019-10-14 in Lusatia Germany (REINHARD MÖCKEL 2019)

Figure 13: Another wolf in category 3, here it can be seen, that the face is naked too. In completely naked animals, the skin may appear darker, the animal was photographed on 2020-07-19 in the territory of the Dauban pack in Lusatia Germany (TOBIAS BÜRGER 2020)

Figure 14 once again sketches the typical characteristics of a Category 3 infestation just discussed.

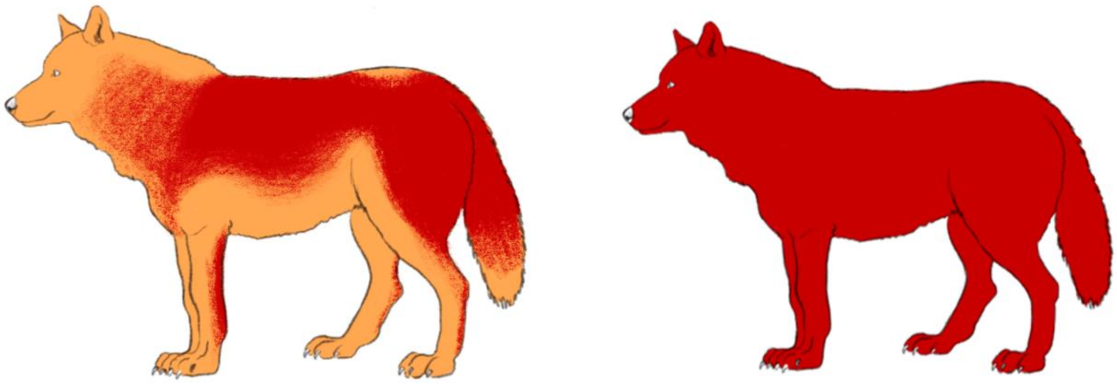

Figure 14: Category 3 of a mange infestation. Orange areas indicate altered coat structure and density. Red areas represent bald patches.

Category A, Healing

3 out of the 42 wolves were in Category A (Healing). Category A can occur after any of categories 1 to 3, although the healing process may be difficult to detect visually after a light mange infestation. The clearest sign of the beginning of healing is the regrowth of fur on the formerly bald areas. This is usually much finer and shorter than the normal coat and resembles a very short summer coat. To illustrate the difference, the summer coat of a healthy wolf (right side) and a wolf that has healed (left side) are compared in Figure 15. All three wolves appeared to have been previously in Category 3, as regrowing fur covered at least 50% of the body surface. Figure 16 shows another example of Category A. In this one, the healing process has just begun and it can be confused with Category 3.

Figure 15: Comparison between a wolf from Category A (left) and a healthy wolf with a summer coat (right) both photo trapped on the same location in the territory of the Daubitz pack in Lusatia Germany, the wolf on the left is known as the individual "right eye blind" (Bundesforstbetrieb Lausitz 2019)

Figure 16: An example of Category A that can be confused with Category 3, the fur on the hind part of the body is growing back, at the front part of the body the old fur is visible, the individual is the territorial female of the Dauban pack GW114f also called Frieda (FT9) photographed in the territory of the Dauban pack on 2021-02-28 in Lusatia Germany (TOBIAS BÜRGER 2021)

As shown in the sketches in Figure 17, it may be that the entire body is affected or only some areas. This depends on how severe the previous infestation was and how large the bald areas were.

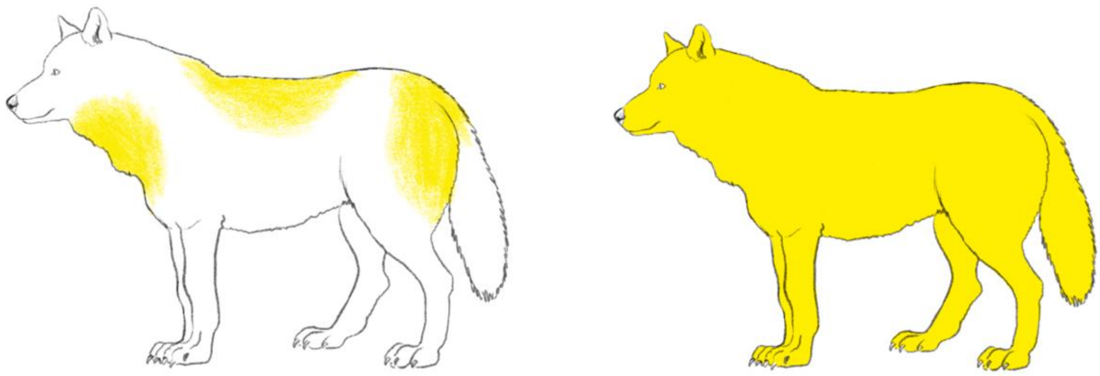

Figure 17: Category A of a mange infestation. White areas indicate that no infestation is visually apparent and yellow areas symbolize regrowing fur.

3.3 Category-test

Of the 125 test images, 14 were placed in the same category by all 11 test participants. For 20 images, one person selected a different category, and for 15 images, all but two test subjects placed the image in the same category. These 49 images, which were rated fairly similar, were taken as a basis for determining which subjects frequently deviated from the general rating. This was done to determine whether categorization depended on factors such as subjects' experience with mange or wolves. The mean number of deviations per person was 5.1 (SD ± 3.6) out of the 125 pictures. The person without any previous experience had the most deviations. She deviated from the general categorization in 11 of the 49 images.

One person stated that she had a different image of healing mange and therefore had difficulties with the evaluations based on the categories. She had 10 deviations in total. Another person with 9 deviations overestimated the percentage mange covering the body than the others in each deviation. Five of the eleven test subjects had a maximum of three deviations. The person with the most experience in wolves and mange had not a single deviation in the 49 cases. Furthermore, it was also checked how often the test persons were uncertain and fluctuated between two categories. An indication was considered uncertain if, for example, Category 2 - 3 was given or a comment was made in which the person indicated that it could also be a different category. One person did not make any uncertain statements, the highest number of uncertain statements of a person was 27. The number of uncertain statements is not obviously related to the experience of the person (how many years they worked in wolf monitoring and research). In a total of 68 images, at least one person was uncertain in his or her evaluation. The maximum number of uncertain statements per image was 4, but this was only the case for one image. This was an image (no. 113) of medium quality, which was rated C3a (see Appendix D). One test person had both high deviations (7) and many uncertain ratings (27).

A Fleiss Kappa was run to see if out of 11 different test subjects, when rating 125 camera trap images, they put them into the same categories. There was a medium agreement, κ = 0.429 (95%CI, 0.416 to 0.441). When photos with poor image quality (blurred or poor lighting conditions) were excluded from the analysis, the Kappa improved slightly, κ = 0.455 (95%CI, 0.442 to 0.469). The same was for the removal of C3a photos, κ = 0.433 (95%CI, 0.419 to 0.446). By excluding 3 test subjects with the most deviations of the nearly identically evaluated pictures, the kappa improved to $\kappa = 0.488$ (95%CI, 0.471 to 0.506). When all, the 3 subjects, the bad photos and the C3a images were excluded, a higher kappa was achieved, $\kappa = 0.521$ (95%CI, 0.501 to 0.541). In no scenario could the set minimum value of $\kappa > 0.6$ be achieved.

The categories were defined and described in more detail (compare Mange categories and Appendix F). For example, the percentage of the body that is bald for each category was specified to leave less room for subjective assessments. Category A pictures were also added to make the difference between a healthy wolf or a wolf with active mange and a wolf that is still healing clearer. After the categories were improved, the same test was repeated again. This time with only two test persons and the Cohens Kappa was clearly above the 0.6 ($\kappa = 0.760$, 95%CI, 0.671 to 0.848). This result indicates that the improved version is sufficient.

3.4 Influence of the weather

One GLMM was used to investigate whether weather (temperature and precipitation) had an influence on the probability that a wolf indication (camera trap or sighting) was with mange. The results show that the probability of having an indication with mange decreased by 9% ($\chi^2 = 126.37$, df = 1, $P < 0.001$) when the temperature rose by one degree. Since rain was not normally distributed, this variable was modified using the square root function. When it rains the square root of one liter per m^2 more, the odds of an indication with mange decreased by 12% ($\chi^2 = 15.97$, df = 1, $P < 0.001$).

Figure 18 shows the just described effect of rain and temperature on the probability of mange again.

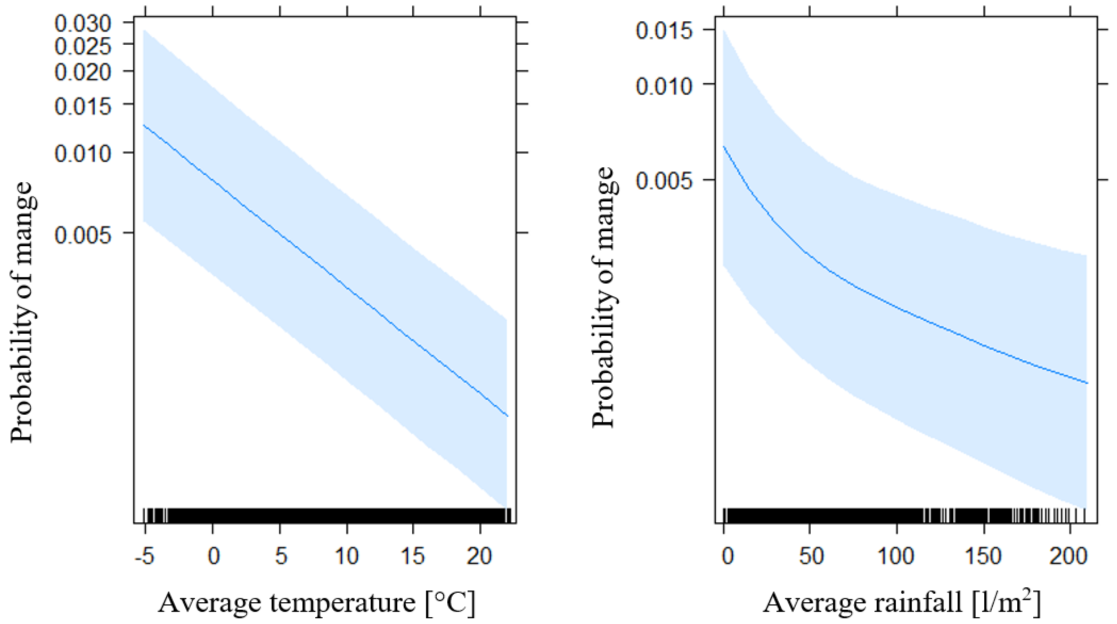

Figure 18: The graphs show the effect of temperature in °C (left) and rainfall in l per m^2 (right) on the probability that at least one wolf is mangy on a camera trap or a picture of a wolf sighting. The results were obtained using data from Saxony and parts of Brandenburg (west of the A13 and south of the A15) from the monitoring year 2009/2010 till 2020/2021 (01 May 2009 until 30 April 2021).

3.5 Territorial adults

The binomial GLMM showed no correlation between the change of the female (χ^2 = 0.118, P = 0.732) or the male (χ^2 = 0.041, P = 0.840) and the probability of mange in the pack. Also, when the data for territory were used instead of the pack, no correlation was found (female χ^2 = 1.433, P = 0.231; male χ^2 = 0.031, P = 0.860). Due to the data situation, no other analyses could be carried out regarding infestation within and between packs depending on position in the pack, age or sex of the animal and that like.

3.6 Course of mange

To describe the course of mange, the photos of 19 recognizable individuals that were infected with mange once or several times were examined. On average, 16 photos (SD ± 11) per wolf covering a period of 270 days (SD ± 194) were evaluated. From 16 of the animals there were photos from Category 0, 15 from Category 1, 9 from Category 2 and 8 from Category 3. In 12 animals a healing process could be observed. 7 of the examined animals had mange several times or had a relapse (were already in Category A and were then sorted into Category 1 - 3 again). In the case of 15 animals, the course of mange could not be observed until the completely healed and healthy stage after infection. In the case of 3 of the 15 animals, it was the case, because of them being infested with mange beyond the study period. In the case of 6 animals, there was still evidence of their survival after the last photo-trap images (through genetic samples on urine, feces or game and livestock killings). 3 animals had no further evidence after the last mange photos. 3 animals died shortly after the last mange indication. The detailed course per animal can be found in Appendix J.

The transition time from one to the other category is summarized in Table 1. Each square shows how long the individuals took on average in days from one category (left column) to the next (first row). In addition, the standard deviation (SD) of this mean value and the number of animals on which the values are based (N) are shown.

Table 1: Mean transition time in days from one mange category (left column) to the other (first row). The categories are 0 = no mange, 1 = light infestation, 2 = medium infestation, 3 = heavy infestation, A = healing.

from \ to	**0**	**1**	**2**	**3**	**A**
0		Mean 64.3 SD 69 N 9	Mean 65 SD 59.8 N3	Mean 18 N 1	Mean 99 N1
1	Mean 62 N 1		Mean 51.3 SD 35 N 8	Mean 51.8 SD 8.3 N2	Mean 52.2 SD 16.4 N 3
2	Mean 162.3 SD 48.8 N 2	Mean 83 N 1		Mean 65.4 SD 43.7 N 4	Mean 28.9 SD 20.8 N 4
3	Mean 122 SD 80.5 N 2	-	-		Mean 47 SD 48.7 N 6
A	Mean 74.8 SD 22.9 N 3	-	-	Mean 70.8 SD 30.8 N 2	

Many of these progressions are based on only one or two observations from individuals (8 out of 20). However, for the "classical" progressions from 0 to 1 to 2 to 3 to A, from 0 to 1 to 2 to A, or from 0 to 1 to A there are relatively many observations per category (5.3 on average). Looking only at these progressions (green), individuals took a particularly long time to heal (74.8 days). The second longest process was from Category 2 to Category 3 (65.4 days). However, when the animals changed to Category A after Category 2, they were in Category 2 for a distinctly shorter time (28.9 days).

4 Discussion

The aim of this study to generate a guideline on how to identify and classify mange and to get an insight into which factors influence the spread within and between packs was partially reached. In order to better identify mange on camera trap images, a flowchart was developed using typical features of mange and other causes of altered hair and skin appearance as well as the affected body parts. The resulting flowchart can help to distinguish mange from other diseases and causes with similar symptoms and thus to identify mange with a higher certainty. Categories have been developed to enable those involved in wolf management to classify the severity of a mange infestation. These categories were: 0 = no infestation, 1 = mild infestation (<10% of the body is bald), 2 = medium infestation (10- 50% bald), 3 = heavy infestation (>50% bald) and A = healing infestation. The change of territorial adults had no effect on the presence of mange in the respective wolf pack. Also, when it rains more or the temperatures rise, mange is less likely to be seen on wolves in the camera trap images. Of the individuals studied over a longer period of time (on average 270 days) to gain insight into the progression of mange disease, the animals that were in Category 2 for a short period of time were more likely to heal than to fall into Category 3. So, if an animal remains in Category 2 for a longer period of time, it can be assumed that the animal will also reach Category 3 and thus have a more severe course of mange.

4.1 Mange classification and identification

Identification

Mange in wolves can be identified via camera trap pictures using typical features of the disease such as the shape, color and type of skin and coat changes as well as the affected body parts. In general, it can be said that definitive proof of mange can only be provided by a medical examination. However, according to OLEAGA et al. (2011), who studied the dynamics of mange in Iberian wolves (*C. lupus signatus*) using camera trap images, photographs of dead wolves, and medical examinations of dead wolves, showed that camera traps have proven useful in detecting animals with mange. It is also unrealistic and impractical to make management decisions based solely on information obtained from pathological examinations. Nevertheless, the results of the necropsy should not be left out as they can provide management relevant information. Camera traps are still an efficient and non-invasive tool in wildlife monitoring (TROLLIET et al. 2014) and we expect that our flowchart can additionally help to correctly identify mange on camera trap images with higher certainty due to its clear handling and the use of the best available information. Especially in the case of a severe course of disease, the risk of confusion with other diseases is virtually excluded in our experience.

The flowchart contains the question "Does the patch get bigger?". This implies that one has to follow the wolf over a longer period of time to be able to answer the question. Consequently, this part of the flowchart is not useful for evaluating a single photo. However, this question helps to distinguish scars and injuries from mange infection. As wolves with scars are often easier to identify as individuals, it is better possible to track them and consequently know whether it is a scar or not. Fresh wounds on the other hand do not always stay for long time since wolves heal even severe wounds very well (REINHARDT et al. 2020). However, fresh wounds especially skin abrasions may be more difficult to distinguish from mange, as they can closely resemble mange.

For the differentiation from other diseases, only diseases of domestic dogs were taken as orientation, as no scientific publications and medical websites on other skin diseases in wolves and how they manifest themselves could be found. It is therefore not possible to guarantee with certainty that wolves can also fall ill with the diseases mentioned. However, since wolves and dogs are very closely related to each other (GANSLOẞER & KITCHENHAM 2019) and only diseases were considered that are likely to be present also in wolves in Germany (diseases that occur in Europe and no diseases caused by drug intolerance or that are breed specific or rare hereditary diseases), the probability is assumed to be high. Another disadvantage of only finding information on dogs is that it is not known whether the diseases behave differently in wolves. For example, mange in dogs starts on the ears, thorax, abdomen and hocks (BOVSUN 2019). In wolves, mange starts at the tail, the croup and the face. This could be due to a different physiology (coat and skin structure) or a different way of life and behavior (ILIJN 1941; MARSHALL-PESCINI et al. 2017; WETZELS et al. 2021). Furthermore, the method of using dog diseases as a basis may lead to overlooking diseases that are exclusive to wolves and are not found in domestic dogs. Consequently, the resulting flowchart cannot claim to be complete or to identify mange beyond doubt. More studies on skin diseases in wolves and how they manifest themselves would be helpful to be able to make even more substantiated statements.

Classification

By analyzing photos of infected dead wolves, it was possible to develop categories based on coat structure, percentage of bald body area, as well as affected body parts. These categories were: 0 = no infestation, 1 = mild infestation (<10% of the body is bald), 2 = medium infestation (10- 50% bald), 3 = heavy infestation (>50% bald) and A = healing infestation.

To show the relationship between the individuals' genes and a mange infestation in wolves, categories were created in the study of PENCE et al. (1983) to show the severity of the progression. These categories were: Category 0 no mange, Category 1 less than 5% of the body affected, Category 2 6-50% affected, Category 3 more than 50% affected. In this study there is no Category A for healing. In contrast to the categories developed in the present study, only hair loss and lesions were used as mange symptoms for classification in the study of DECANDIA et al. (2021). However, since the shaggy fur is also an infestation symptom and therefore the body of a wolf with a light infestation can be 100% affected, it was decided to develop a different classification. Our Category 1 went up to <10% and Category A (Healing) was also added. Furthermore, we described that shaggy fur and blotches on the face can also indicate a mange infestation and that bald patches do not necessarily have to be visible. The advantage of our categories is that wolves that are only shaggy and have a blotchy face can also be identified and classified as mangy. The same applies to categories 2 and 3, the shaggy fur also increases the percentage of affected body, the newly developed categories offer a more detailed classification and thus a better overview of the infestation of an individual. Furthermore, it was considered in our classification that the animals can heal an infestation. Wolves in this stage could hardly be classified with DECANDIA et al. (2021), as they are no longer completely bald, but also do not have a healthy coat. Since they are still negatively affected by the not yet completely intact coat and possibly also by the strains of the cured mange disease, but their immune system no longer has to fight against the parasite and the itching is also gone, it would not make sense to classify the animals in one of the categories from 0 to 3. Consequently, the added Category A is necessary.

When we created the categories, we noticed that pups seem to react differently to mange as they were usually just shaggy (much more than adults) and did usually not show bold patches. Which could also be observed in a study from FUCHS (2014). In his study a total of 198 serum samples collected over 15 years from 141 captured Scandinavian wolves were tested for antibodies against S. scabiei. He found that none of the 56 tested pups were seropositive (antibodies against S. scabiei) and none of the animals showed symptoms. Among the adults on the other hand, 20 were seropositive, of which seven showed symptoms. Therefore, 13 adults without mange symptoms still had antibodies to the mites and it is therefore surprising that none of the pups were seropositive. FUCHS (2014) suspects three reasons for the absence of seropositive pups, a high mortality before the winter in which the animals were caught, less exposure of pups to mange or that the test used was not sensitive enough (FUCHS 2014).

For this study we first collected 125 images of mangy and non-mangy animals, then developed the categories, and subsequently used the 125 images to validate the categories to exclude any bias in pictures used. The most important advantage of this method is the pictures were selected that occur in everyday monitoring. Some of the pictures included were of lower quality, as there are many such pictures in everyday monitoring and the applicability of the categories could thus also be tested with such pictures. The test to evaluate the usability of our categories was developed before the development of the categories so the distribution of the categories (probably) corresponds to the distribution of mange in nature. The development of the test before the development of the categories can also be seen as a disadvantage, as some categories may have been tested too little while others have been tested too much.

Since the Fleiss Kappa showed that different test persons categorized photos of wolves too differently (<0.6) (LANDIS & KOCH 1977), the photos were examined again more closely with regard to their quality and the respective rating. The results showed that especially pictures with a high degree of motion blur and photos in which the wolf is in a shadowy area led to very different ratings, which was also confirmed by the feedback of the test persons. That lower quality images were more often classified differently by the test persons, is likely because in such photos sometimes it is not possible to see the coat structure and which parts of the body are not covered with hair. Consequently, the categories cannot be used for every photo that shows a wolf with mange to classify the severity of the infestation with certainty. It has to be judged individually by the person who assesses the infestation in the photos whether the quality of the photo is good enough to classify the mange infestation.

The test persons had difficulties in recognizing whether a wolf is in Category A and has therefore overcome its mange infection. Only individual pictures could be evaluated during the test and not the course of the disease of an individual animal, it can be assumed that these difficulties will occur less in practice, under the assumption that in practice more pictures will be available from that individual wolf. If one knows how the infection behaved, *i.e.* which parts were affected and how the wolf looked in general, it is probably easier to determine an improvement. From the feedback and the evaluation of the results, it could also be concluded that there was a risk of confusion with the change of coat. People who have more years of experience with wolves tend less often to confuse shedding and mange. This suggests that only people who are authorized to assess camera trap images according to the SCALP criteria (to assess how certain the wolf indication is, see Appendix D) and consequently already have a lot of experience with wolves on camera trap images should take over the classification of mange cases. One test person stated that she had a different view of mange. According to her opinion, mange begins to heal when there are no more sores or scabs. It could be argued that this reasoning makes sense on a medical level (PAULUSSEN et al. 2013), as the skin is healthy again. In developing the categories, we have found that it is not possible to be sure that there are no sores or scabs on a naked animal, so we have decided that Category A only starts from the moment the animal gets new fur. Even then, there may still be healing sores or scabby patches on the body. After careful consideration, we have decided not to adjust Category A, but to leave it at the given definition, as the definition makes it easier to categorize a mange case, especially for less experienced people.

Assessing a mange infestation based on camera trap images will probably not always result in every evaluator rating all camera trap images the same, even with the mange categories we have developed. Especially in case of poor quality of the photo or wolves that are on the border between two categories, different classifications could occur. However, the second review of the adjusted categories showed that they are now more valid, as the Kappa improved from 0.429 to 0.760. The result of the second kappa, however, is comparatively less valid, as only we, the creators of the categories, were the test subjects and the test was repeated. Due to the fact that the study period was very limited and the volunteers that did the first test were very restricted in terms of their time using us as test subject was the only possibility to review the improved categories. Since the Kappa is considerably higher than the 0.6 achieved, it can still be assumed that the suitability of the categories for classifying mange has improved markedly. Applying Cohen's Kappa only to our responses from the first round of testing, before the categories were improved, yields a value of 0.556. Although this is slightly higher than the Kappa that includes all 11 test persons, it would still not have been sufficient. The improvement towards 0.760 suggests that the categories have become more valid. We are therefore convinced that the categories provide a good guideline for assessment. Especially for wolf managers with little experience with mange it can be helpful to estimate the actual severity.

Only photos of wolves from Germany were used for the creation of the categories. Accordingly, it is possible that mange may behave differently elsewhere in Europe or the world because of different habitat and climatic conditions (LAFFERTY 2009) or because of genetical differences between the populations (DECANDIA et al. 2021). Therefore, to make the categories generally valid, they should be tested for wolves from other populations.

In a study by MUNEZA et al. (2019), camera trap images and photogrammetry techniques were used to assess the severity of skin disease in wildlife. They concluded that "camera traps presented an informative platform for examinations of skin disease ecology" (MUNEZA et al. 2019, P.1), as they are non-invasive and can be used for a wide variety of species. They also stated that this method could be used to make statements about temporal and/or spatial variations of the disease based on identifiable animals and that it can be used in combination with focal animal to analyze the effects of severity on the animal (MUNEZA et al. 2019). We believe that camera traps can make a valuable contribution in understanding some wildlife diseases and our classification could be used to learn even more about mange in wolves. We also think that our approach of dividing a skin disease into different degrees of severity using percentages of affected body surface area and affected body parts could be applied to other species as well. For the management of various animal species, it may be necessary to understand and classify skin diseases more precisely, as such diseases could, for example, weaken the animal population, which could be a problem especially for endangered species (HOSSAIN et al. 2011; JACOBS et al. 2009; MUBEMBA et al. 2020).

4.2 Factors associated with mange infestation

Weather

The probability of mange decreases when temperatures or precipitation increase. The effect of the weather on the probability of an indication with mange is statistically quite high but since only a small proportion of the photos show mange (4.3% of the indications used in the analysis), the overall effect is small. Therefore, weather data can only be used to predict the course of mange spread to a certain extent.

As already described in the previous chapter, only photos of wolves from Germany were used and therefore it is possible that mange may behave differently elsewhere in Europe or the world because of different habitat and climatic conditions (LAFFERTY 2009). In the study of FUCHS (2014) in Scandinavia a north-south difference was also found concerning the probability of catching a seropositive wolf (antibodies against S. scabiei); the chance to catch a seropositive wolf was higher in the south. A climatic difference of north and south was not mentioned in the study of FUCHS (2014), thus his discovered north-south difference could also be related to the influence of temperature and precipitation.

The result that precipitation and the probability of mange have a negative correlation contradicts previous findings. FAZAL et al. (2014) found that after heavy rainfalls in the previous months the prevalence of the mite was highest in dogs. Another study from ARLIAN et al. (1989) stated that precipitation is positively correlated with the life expectancy of the mange mite. It is possible that our results may have been influenced by the fact that wolves with moderate or severe mange are less protected against environmental influences due to bald patches. A study by CROSS et al. (2016) showed that these consequences of mange can lead to high heat loss, especially in colder temperatures and when wind is present. So it may be that mangy wolves tend to retreat more in rainy weather for self-protection and thus are less visible on camera traps, creating a bias as less infested individuals can be counted. Furthermore, our results could be due to the fact that rainfall data from large areas were combined for the analysis and thus local effects may have been lost. Repeating the study on a smaller scale could therefore be beneficial and produce different results as it would include the small-scale differences of weather.

The negative correlation between temperature and mange could also be attributed to the fact that mange is more easily detectable in winter than in summer because of the long winter coat. This could create a bias that just makes it appear that more mange cases occur in colder months than in the warmer summer months. Mange mite survives longer at lower temperatures (ARLIAN et al. 1989), so it is quite conceivable that there is a negative relationship between temperature and the likelihood of indications with mange. Also, ALMBERG et al. (2015) found that the number of mange cases was significantly more frequent in winter and decreased in summer, which further supports our findings.

The study of NIEDRINGHAUS et al. (2019b) also supports the results obtained that at higher temperature, mange is less likely to spread, as the results of this study show higher mortality of mites without host with increasing temperature (4° C, 18° C, 30° C). However, the results of this study also show that at temperatures of 0° C, the mortality of mites without host is the highest. Our study tested down to average temperatures as low as minus 5° C, and the results show a linear decrease in the probability of mange evidence with increasing temperatures. Thus, with the knowledge that mites have increased mortality outside of their host at cold temperatures, a decrease in the probability of mange evidence at lower temperatures is actually to be expected. It is also possible to see this decrease in mange evidence at average temperatures colder than those tested. Accordingly, the results could be different for countries with colder average temperatures than those in Germany.

<u>Change territorial adults</u>

It was not possible to find out how mange spreads within and between packs, as the change of a leader had no significant effect on whether or not mange was present in the pack. Consequently, transmission between packs may not primarily occur through direct contact, *i.e.* when a mangy animal from pack A takes over the territorial position in the healthy pack B, but through indirect contact, for example when territories overlap. These assumptions refer, remarkably, only to the territorial adults of a pack, since they were the only ones that could be tested. To what extent other individuals of the pack have an influence was not verified, but in general it is equally possible that any other animal of the pack has an influence on the spread of mange during the dispersal process of pups and yearlings or also territorial fights between the packs.

Studies from Spain have shown that yearlings had the lowest probability of being infected with mange compared to adults and pups (ALMBERG et al. 2015; OLEAGA et al. 2011).

Consequently, these animals are relatively unlikely to be spreaders of mange. Transmission by other canids such as foxes could instead have an impact. As all canids can be infested with Sarcoptes scabiei var. canis, all other canids like racoon dogs (*Nyctereutes procyonoides*), golden jackal (*Canis aureus*) and red fox (*Vulpes vulpes*) can spread the mange to wolves as well (Bornstein et al. 2001). A study by OLEAGA et al. (2011) found that the number of mange cases in wolves correlates strongly with the number of mange cases in foxes one year earlier, which indicates that the red fox is a likely origin of mange in wolves (OLEAGA et al. 2011). These results contribute to the assumption of FUCHS (2014) that a wolf-to-wolf transmission is less probable to cause a spread of mange. Including the factor "mange in other canids" in an analysis of mange spread in wolves could therefore be helpful for a better understanding of the dynamics of this disease in the ecosystem. The fact that no correlation could be found between the change of an adult and the likelihood of an infected pack could also be because it is not always possible to determine with certainty in which year the new animal actually took over the pack and therefore no exact data are available. That the change of the leader has an effect on the infection rate of the pack can therefore not be ruled out.

A pack was only marked as infected if the infected animal that was in the territory could be assigned to the respective pack, which can create a bias leading to packs being wrongly classified as healthy. However, this method had the advantage that a healthy pack was not wrongly marked as infected when a foreign mangy animal was running around in the territory. To minimize the error resulting from packs being wrongly classified as healthy, it was tested for both, territory and pack if the change of a territorial adult has an influence on the spread of mange. No effect could be demonstrated in this regard either.

<u>Other factors</u>

Looking at the monitoring years 2012/2013 and 2017/2018 in which SCHLAUTMANN (2020) found noticeably high numbers of mange indications, no abnormalities could be found with respect to the annual average temperature or the average precipitation in Saxony and Brandenburg (WetterKontor n.d.). It is therefore conceivable that these high mange numbers were caused by other factors. Since mange is a complex issue and numerous factors may influence the dynamics of the disease, more research is needed to better understand the way mange spreads. Further research could investigate the spread of mange among other canids in relation to the spread of mange in wolves as *sarcoptic* *mange var. canis* can infest all canids and therefore could be spread between different species (PENCE & UECKERMANN 2002). The study of OLEAGA et al. (2011), carried out in Iberia, has already shown that mange in foxes has a large effect on the spread of mange in wolves. Whether the same is true for the German population and whether there is also an interaction with other canids might be important to know, if indeed there is such a strong correlation as in OLEAGA et al. (2011).

Furthermore, several other factors could have an impact on the dynamics of mange like other diseases, stress, genes, age, and position of the animal in the pack on mange susceptibility or transmission probability as well as the habitat the wolves live in (DECANDIA et al. 2021; FUCHS 2014). In the study of FUCHS (2014) for example, females had a lower probability than males of getting mange, the sex difference decreased with increasing pack size as well as density dependency and latitude. FUCHS (2014) further suggests low probability of wolf-to-wolf transmission as in every case he collected a seropositive sample he collected a seronegative sample in the same pack as well as the observed recoveries from seropositive wolves. These factors could also have an influence on the spread of mange in the German population. These numerous possibilities illustrate how complex the topic is and that much research is still needed in this area to get a comprehensive overview. Nevertheless, we think that we have already been able to provide a little insight with our results and hope that our work will serve as an incentive for further research.

4.3 Mange progress

An animal that changes from Category 2 to 3 stays considerably longer in Category 2 (65.4 days) than an animal that changes from 2 to A (28.9 days). For example, if an animal is known to have been in Category 2 for a very long time and to be near human settlements, the first step could be to intensify monitoring at that time and subsequently issue a press release to inform and reassure the public (REINHARDT et al. 2020). Animals were in Category A the longest, which is probably because it takes some time for their fur to grow back. It is also conceivable that the duration of Category A depends on how severely the animals were previously infected, but the data is not sufficient to verify this.

Sometimes there were large gaps between the individual indications and relatively few indications in relation to the observation period (on average one indication per 16 days).

Because of that, it is possible that categories through which the animal has passed have not been observed and included in the data. Assigning half of the time between the last indication of the previous category and the first indication of the following category to one category and the other half to the other could furthermore distort the data and produce an inaccurate picture. However, no other convincing method of dealing with these data gaps could be found, as little is known about the time course of mange in wolves.

The large standard deviations that arise suggest that either the duration per category strongly varies individually from animal to animal, or that the number of indications is not sufficient to get a good insight. Consequently, it is difficult to make general statements about an average mange course based on the available data. Because an analysis like this was never done before for wolves, this study nevertheless provides a good first overview about how mange behaves on wolves. As more data of mangy wolves are collected with growing wolf numbers with passing time, it is conceivable that in a few years many more individuals will be known whose progress can be observed. However, the problem of incomplete data due to the animals not being photographed for a long period is likely to persist. When the dataset is large enough it would be interesting to look at the differences in the course of mange related to sex and age. FUCHS (2014) has already shown that females are less susceptible to infestation, the difference between male and female decreases with increasing pack size. Consequently, it can be assumed that they could also show differences in their mange progression.

During our study, we noticed that mange sometimes looked different in pups. They were particularly shaggy and already had very thin fur in Category 1. Some studies have already shown that young animals show clinical symptoms more frequently than adult wolves (NIEDRINGHAUS et al. 2019a). Since we could not follow any pups in their progression, it would be interesting to observe whether they might be more susceptible to severe mange progression or whether their mortality rate from mange is significantly higher compared to adults.

Another aspect that we noticed when analyzing the course is that two out of three animals that had a relapse from A back to Category 3 disappeared or died due to natural causes. Our data are not sufficient to make valid statements in this regard, but it might be interesting to take a closer look at the reasons and consequences of relapse for the individuals.

Considering that no other study could be found dealing with the course of mange, our study is of high value, especially for wolf monitoring and management. With the results generated, an assessment of the severity of the course is better possible and can give people in wolf management a little insight into the course of mange in a wolf. A continuation of the study in a few years would significantly improve the overview provided so far, but until then one can work well with the generated results.

5 Conclusion

The EU member states are obliged to report the conservation status of the species protected by the FFH Directive to the EU every 6 years in a report, which requires, among other things, understanding and insight into common diseases. In the case of wolves sarcoptic mange is such a disease. Inexperience of some wolf managers with the disease in the wolf population and the lack of any guidelines for identification and assessment of severity make it difficult to make german-wide uniform assessments of mange prevalence and intensity. Public attitudes towards a species can have a decisive effect on its conservation. In wolves, severe mange infestation can cause the wolves to approach human settlements and become primarily diurnal, which could lead to more frequent encounters between wolves and humans probably worsening their image. Our goal was to generate guidelines on how to identify and classify a mange infection in wolves based on a camera trap picture and to understand the spread of mange in wolf populations. Categories were developed to uniformly determine the severity of infestation. These categories are divided into Category 0 - no infestation, Category 1 - light infestation, Category 2 - moderate infestation, Category 3 - heavy infestation, and Category A - healing. However, they should only be used by experienced persons (who are also allowed to SCALP camera trap pictures) and for images of sufficient quality to ensure a reliable classification. Which images are good enough for classification has to be assessed individually by the wolf manager that is evaluating the picture. In addition, a flowchart was developed to exclude other mange-like diseases. The analysis to investigate the influence of a change of parents did not show any results. Temperature and precipitation both have a negative effect on the probability of a mange infestation. It has been shown that animals that stay longer in Category 2 tend to fall into Category 3 rather than heal. However, no definitive statement can be made regarding the classical course of mange due to the small study population. Given that no pups were included in the study of the course of mange as they usually are not clearly identifiable as individuals no conclusions can be made about the progression of mange in pups.

The results of this study may play a small part in helping mange to be better recognized and assessed by responsible wolf managers who still have little experience with this disease. They can use the flowchart and the categories developed to become more familiar with the disease to identify mange on pictures with a higher certainty and to classify the severity of a mange infection. This can reduce the risk of not recognizing or misclassifying mange, allowing them to make more informed management decisions. Also, a minor insight could be given, which external factors have an effect on the spread of mange. Knowing that more mange cases are to be expected in colder temperatures and with little precipitation can help those responsible for wolf management to plan ahead and assess in which weather conditions more monitoring may be needed. Information on the progression of mange can help to prepare in time for necessary measures such as more intensive monitoring and increased public relations. An estimation of how mange will develop in an individual is also useful to make the population more aware of the issue and possibly reduce their fear of the diseased animal. However, mange is still a very complex subject depending on many factors, some questions have been answered in this research, but there are still enough unknown whose research would be necessary to gain a complete picture of this complex disease in the future.

6 Recommendations

Usage of the results in Management:

1. The created flowchart can be used as an assistant tool to identify mange on camera trap pictures with the fact in mind that it is based on dog diseases.

2. The created classification of severity should be done by a person who already has experience with wolves in photo-trap images.

3. Based on the test results of the categories test, it was concluded that not every picture is suitable for assessing the severity of the mange infestation. Whether an image is suitable must be decided individually from photo to photo, depending on the image quality and the visibility of the wolf.

4. Based on the results of the weather analysis, it can be said that with colder temperatures, more mange cases are to be expected, which is why wolf managers could prepare for this, for example, through increased monitoring.

5. Whether more rain actually means less mange could not be clarified due to the inconsistency of our results with other studies, which is why this information cannot be included in management-relevant decisions.

6. The longer a wolf is in Category 2, the more likely it is that it will enter Category 3, which is why monitoring should be possible intensified for wolves that are in Category 2 for a long time.

From this study, the following aspects emerge that would be useful and interesting to explore in the future:

1. Repeat the study of whether the amount of rain has an effect on the spread of mange on a smaller scale as for this study combined data of large areas where used and thus local effects may have been lost. Furthermore, it would be interesting to take a deeper look into the topic with regard to climate change and the resulting effects on the local weather.

2. Investigate the interaction of mange spread in wolves and other canids as in this study no data was available on mange in other canids and therefor the influence of other canids

on the spread of mange in the German wolf population could not be included in the analyses. As the influence of other canids was quite high in other wolf populations, it is assumed that it is also a determining factor in the German population.

3. Investigate whether individual differences in animals (other diseases, stress, genes, age, and position of the animal in the pack) have an effect on mange susceptibility or transmission probability. Since an effect of individual characteristics was found in other populations, it can be assumed that the same applies to the German population and that knowledge about this can help to gain a more detailed insight into the dynamics of mange in Germany.

4. Influence of fall back from healing to Category 3 on mortality rate of mangy wolves in connection with other disorders such as injuries and other diseases the animal may be suffering from. In our study it was found that two out of three wolves who had such a fall back died or disappeared thereafter. Since the study population here was very small, this number is not particularly meaningful, so it is extremely interesting to take a closer look at the influence of such a fallback.

5. Repeat the analysis on course of mange in a few years with a larger data set in order to get more insight on the individual differences and a more general overview about the course of mange in wolves.

6. More studies on skin diseases in wolves and how they manifest themselves would be needed to be able to make more substantiated statements regarding the differentiation of mange. Compared to the other diseases addressed in this thesis, mange is relatively well studied for the wolf, but much less is known about the effects of the other diseases on the population and also about possible human wildlife conflicts.

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Appendix

Appendix A, Map of the current distribution of the wolf in Germany

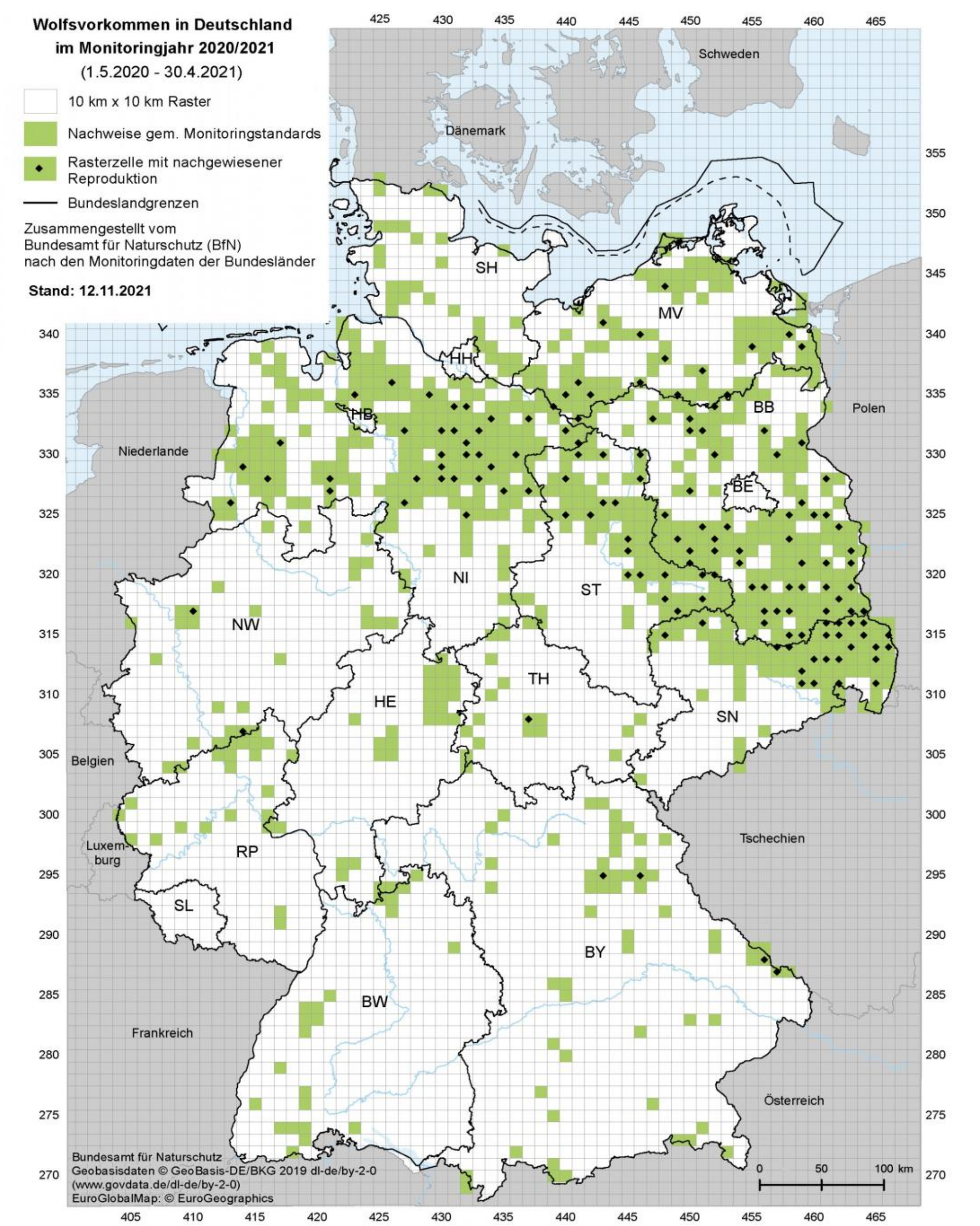


Figure 19: Map of occupied grid cells. The grid cells are green, when a wolf indication (at least one C1 or three C2) was registered there. The black dots show where reproduction was verified (DBBW 2022).

Appendix B, Introduction interview LUPUS Institute 2022-03-02

Most relevant notes:

- More mange in the packs in the last two years.
- Neither for Germany nor in Europe guidelines for handling and recognition of mange, until last year no categories for the course. Study from America that used categories as a method
- ➔ Categories insufficient because they are too imprecise
- In other federal states hardly any experience with mange, uncertainty about how to deal with it, therefore handout for the federal states
- Can easily be mistaken for shedding
- Mange can be more easily detected in winter, possibly a source of error
- What other diseases can have these symptoms? Mange is always written in the case of coat and skin problems
- Mangy wolf "Felix" in northern Saxony-Anhalt and Brandenburg, transmitter data in Sachsen-Anhalt, many FF pictures
- Ask your vet if mange can be cured even in a mild stage.
- Examples of mange progression
- When determining pack composition often confusion how fast is the change from fur to naked fur?
- Assessing mange according to SCALP criteria
- What topics in the brochure?
- Categorization good
- Reclassify later? If a wolf later has C1 mange, reclassify all C3 cases?
- Spotted fur on face? Separate category?
- SCALP for pack and not individual
- How long stage A-B-C? Progress study
- Influence of parents on mange in the pack
- Does the IZW also test for mites when no symptoms are present?
- Density dependence mapped
- Camera trap images of foxes from LUPUS
- No "problem animals" they are looking for warmth
- Listing of animals close to settlements
- Parents` mange in summer -> influence on pups?
- Density- self-regulation Discussion
- At a certain stage no longer detectable?
- When is mange detection 100% certain?
- Behavior and appearance
- Mange sites and their influence?
- DBBW mating and packs
- Do not forget the process report
- DBBW database -> table packs -> mating
- Evidence of mange, skin scraping at Rolf's capture did not show mites, was there evidence at death? According to logic only confirmed hint. Ask IZW how often

mites are detectable and how she evaluates the mange cases, does she test for mites in each case?

- Categories based on clear evidence, so photo can also be clear evidence
- Watch videos, behavior, to what extent is scratching related to mange?
- Possibly check the 10 years before the first infestation in Milkel for mangy foxes, it is noticeable that it took 10 years
- Check density dependence Use maps? As an argument for wolf self-regulation
- Did disappeared parents have mange before and are mangy animals therefore exploited more often?
- Impression: if pups are infected particularly early, they have a particularly severe course of disease
- What have been the cases so far? How did the federal states deal with it? What has happened?

Appendix C, Map showing the assessment of the suitability of areas in Germany as wolf habitat.

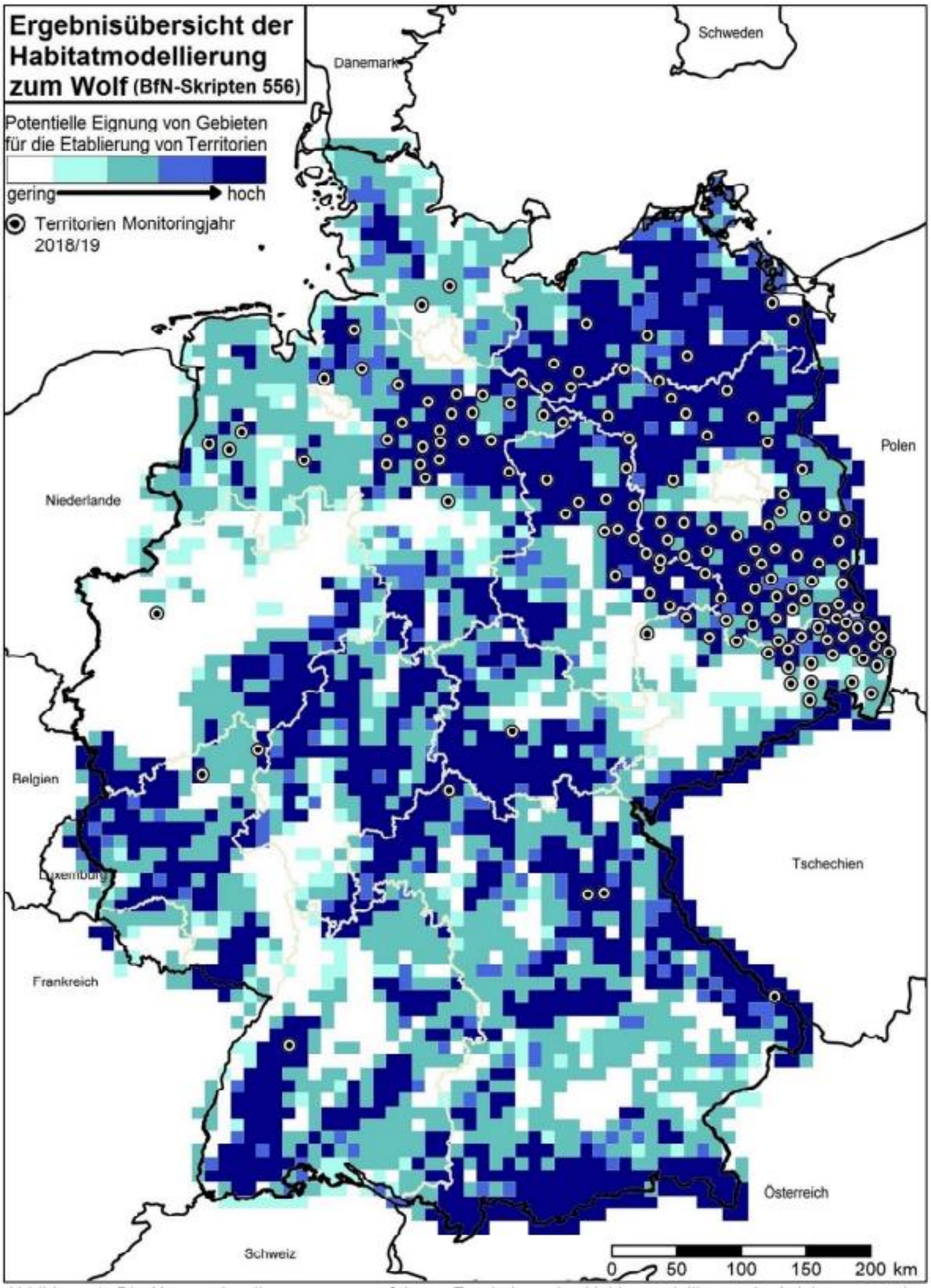


Figure 20: The map shows which areas in Germany are particularly suitable for the establishment of wolf territories. The darker, the more suitable. The circles show the territories from the monitoring year 2018/2019. (KRAMER-SCHADT et al. 2020)

Appendix D, Final assessment and interpretation of wolf indications

In the Standards for the Monitoring of Large Carnivores in Germany (KACZENSKY et al. 2009), hereinafter referred to as "Monitoring Standards", the categorization of data was determined on the basis of their verifiability. This categorization was based on the SCALP criteria, which were developed within the framework of the project "Status and Conservation of the Alpine Lynx Population" (SCALP) for transnational lynx monitoring in the Alps. These SCALP criteria were further developed for wolf and bear and adapted to the conditions in Germany. The letter C stands for category, the numbers 1 - 3 indicate the verifiability of the evidence.

C1: Clear evidence = hard facts that clearly confirm the presence of a large carnivore (live capture, dead find, genetic evidence, photo, telemetry location).

C2: Confirmed evidence = evidence verified by an experienced person (e.g., track or crack), where a large carnivore could be confirmed as the causative agent. The experienced person can confirm the indication himself in the field or on the basis of documentation from a third person.

C3: Unconfirmed evidence = All evidence where a large carnivore could neither be confirmed nor ruled out by an experienced person due to the lack of "evidence". This includes all visual observations without photo documentation, also by experienced persons. Furthermore, all evidence that is too old and/or unclear or incompletely documented, *i.e.*, for which too little information is available to provide a clear picture (e.g., in the case of tracks) or which is insufficient for confirmation for other reasons; also, all evidence that could not be verified.

At the LUPUS Institute for Wolf Monitoring and Research, this category is further subdivided into C3a, C3b and C3c. C3a means probably wolf, C3b wolf or another animal and C3c rather no wolf.

False (f): False report = information where a large carnivore could be excluded as the causative agent.

No assessment possible (K.B.) = evidence where the characteristics that could indicate the causative agent can no longer be examined.

As wolf indications can easily be confused with those of dogs, a final assessment of the indications by experienced persons is necessary. These persons should have years of experience in recognizing and evaluating wolf indications. An indication does not only have to technically show all the characteristics that speak for a wolf indication. The overall impression and the experience of the evaluating person are ultimately decisive. A well-documented track at a laced trot that has wolf-typical dimensions does not automatically become a confirmed indication. If the experienced person evaluating this track gets doubts whether it is really a wolf track due to the shape or position of the paws, the course of the track or the behavior of the animal, then he will evaluate it as C3 (unconfirmed indication) or false (wolf excluded).

Differentiation between two neighboring territories:

- Reproduction was confirmed in both territories at the same time OR
- Reproduction was confirmed within a distance of at least 10km from each other at the same time OR
- Two activity centers (accumulation of tracks / looses) are confirmed at the same time at a distance of at least 10 km from each other OR
- At least one of the territories is known via telemetry

Appendix E, Table of individuals

The following table consists of the individuals with known genetic identity or who have clear recognition features and which are therefore clearly determinable. The clearly identifiable wolves from the last two years of the research period will be added soon.

Table 2: Clearly identifiable individuals

Pack	**Genetic number**	**Origin**	**Position in the pack**	**Name**
Biehain	GW021m	Wymiarki (Poland)	Territorial male	
Biehain	GW558f	Biehain	Pup	
Cunewalde	GW1234m	Cunewalde	Pup	
Daubitz	GW381m	Wymiarki (Poland)	Territorial male	
Großräschen	GW528m	Altengrabow	Territorial male	
Hornow	GW315m	Nochten	Territorial male	
Knappenrode II	GW691m	unbekannt	Territorial male	
Kollm	GW212m	Nochten	Pup	
Kollm	GW379f	Dauban	Territorial female	
Kollm	GW677m	Kollm	Pup	
Kollm	GW917m	Kollm	Pup	
Milkel	GW025m	Nochten	Territorial male	MT4 („Rolf“)
Milkel	GW042m	Polen	Territorial male	
Milkel	GW075f	Milkel	Pup	
Milkel	GW173f	Milkel	Adult	
Milkel	GW211m	Nochten	Pup	
Milkel	GW365f	Milkel	Yearling	
Niesky	GW031f	Daubitz	Territorial female	FT8 („Greta“)
Nochten	GW038m	Nochten	Territorial male	
Nochten	GW106m	Krepnica (Poland)	Territorial male	
Nochten	GW278f	Nochten	Pup	
Nochten	GW648f	Dauban	Adult	
Nochten	GW701m	Wymiarki (Poland)	Territorial male	
Rosenthal	GW112f	Milkel	Territorial female	FT7 („Marie“)
Rosenthal	GW176f	Dauban	Adult	
Rosenthal	GW294m	Polen	Territorial male	
Seese	GW386m	Dauban	Territorial male	
Welzow	GW070m	Seenland	Territorial male	
Welzow	GW139f	Welzow	Territorial female	
Dauban	GW1520f	Dauban	Territorial female 2	
Dauban	GW1158m	Daubitz	Territorial male 2	
Dauban	GW114f	Dauban	Territorial female	FT9 („Frieda“)

Dauban	GW399m	Nochten	Territorial male	
Neustadt	GW401f	Milkel	Territorial female	
Welzow	GW1010m	Spitzbergen-Jüterborg	Territorial male	
Milkel	GW081m	Seenland	Territorial male	
Daubitz	Not clearly identifiable	Daubitz	Yearling	„reAuge blind“

Appendix F, Test for the categories and od description of them

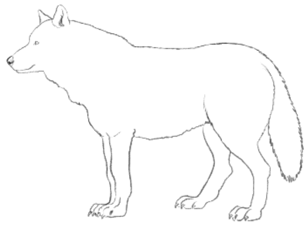
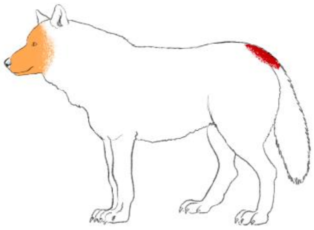
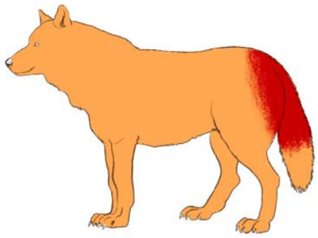
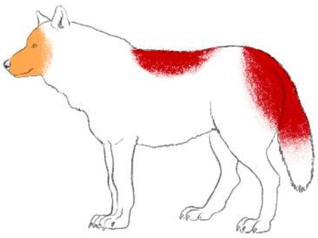
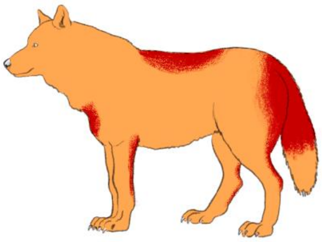
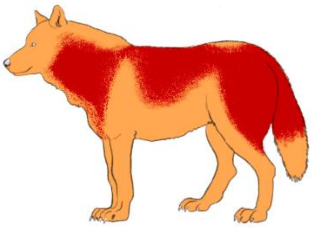
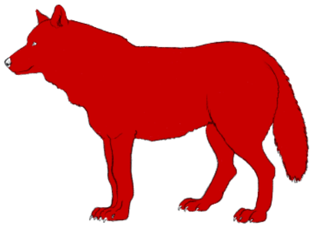
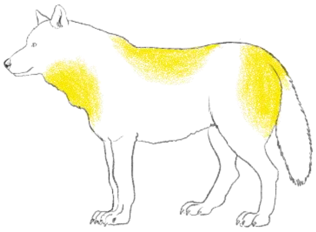
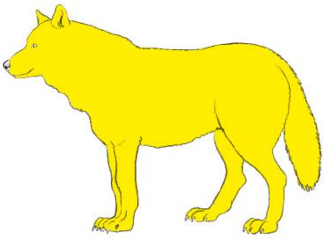
In the following test, 125 pictures are to be evaluated according to the newly developed mange categories. The categories are divided into "Category 0" no mange, "Category 1" light infestation, "Category 2" medium infestation, "Category 3" heavy infestation and "Category A" healing. On the last page of the test are the sketches of the categories and their definitions.

Have fun :)

Table 3 :Table for results of the individual tests of the categories

Picture number	Mange category	Notes
1		
2		
3		
...		
125		

Table 4: Summary of the mange categories

Category 0		
Category 1		
Category 2		
Category 3		
Category A		

Category 0, no infestation

A Category 0 wolf shows no recognizable predation symptoms. It usually has a uniformly long and dense coat. It is neither shaggy nor thinned out and there are no bald patches. However, due to coat changes, injuries and diseases other than mange, mange-like symptoms may still occur in some cases.

Figure 21: healthy wolf with a summer coat (left) (Bundesforstbetrieb Lausitz 2019) female yearling in the territory of the Daubitz pack and wolf with a winter coat (right) in the territory of the Milkel pack both in Lusatia Germany (RALF M. SCHREYER, Staatsbetrieb Sachsenforst - Biosphärenreservatsverwaltung 2018)

Category 1, light infestation

The first recognizable signs of an incipient mange infestation can be seen mainly on the croup and the face. Especially the former is a clear feature on camera trap pictures even in poor visibility conditions. There you can see that a piece of the coat seems to be missing. Sometimes it can also happen that a kind of hair ring remains in the middle of the tail and several areas are bald. In addition to the bald spot on the tail, a slightly blotchy face can often be seen in better visibility, which is also a very clear indication of an incipient infestation. Furthermore, some wolves already show a changed structure in their coat. The coat may appear shaggy and thinned out. Especially in young pups, it often happens that the body is still completely hairy, but the skin is clearly visible under the coat.

The two sketches show the range in which an infestation of Category 1 can be classified. On the left side there is only a small patch of baldness on the croup and a blotchy face, whereas on the right side the entire coat is shaggy or thinned out and there are already bald patches on the croup, the tail and the back of the thigh.

Figure 22: Wolf with signs of mange on the tail (left) a pup in the territory of the Niesky pack on 2015-02-08 (LUPUS 2015) and Wolf with shaggy and thinned out coat (right) a pup in the Milkel pack in the territory of Milkel on 2010-12-05 in Lusatia Germany (ANDRE KLINGENBERGER 2010)

Category 2, medium infestation

A medium infestation, which is classified in Category 2, is already much more pronounced and better recognizable than an infestation in Category 1. In this case, clearly larger bald, scabbed and sometimes bloody areas can be seen, which, however, do not yet affect the majority of the body. The back is often affected, but larger bald patches can also appear on other parts of the body, such as the legs, chest or neck. Generally, the tip of the tail in Category 2 still remains slightly hairy. In this category, too, the rest of the coat, apart from the bald patches, may look inconspicuous or be shaggy and thinned out.

Figure 23: An example of a Category 2 wolf, it has a bald area on the left side of its body as well as a thinned-out tail, in the territory of the Milkel pack on 2012-03-29 in Lusatia Germany (ANDRE KLINGENBERGER 2012)

Category 3, severe infestation

Category 3 includes all very severe mange infestations. In this stage, the entire body is affected and most of the body (over 50%) is hairless. If some parts of the body are still hairy, this coat is usually shaggy. Often it is the neck, face (between the ears and in the front part of the face), shoulders and belly, as well as parts of the legs and paws that are not yet completely hairless. In very young pups, the belly is hardly hairy even when healthy, so this must be taken into account in the assessment. The infestation is clearly visible and the risk of confusion or overlooking the infestation is very low.

Figure 24: An example of a Category 3 wolf, the wolf is nearly completely naked in the territory of the Großräschen pack on 2020-04-20 in Lusatia Germany (LUPUS 2020)

Category A, Healing

Category A (Healing) may occur after any of categories 1 to 3, although the healing process may be difficult to detect visually after a light mange infestation. The most obvious sign that healing has begun is the regrowth of fur on the formerly bald areas. This is usually much finer and shorter than the normal coat and resembles a very short summer coat. When the mange heals, it can be that the entire body is affected or only some areas. This depends on how severe the previous infestation was and how large the bald areas were.

Figure 25: Comparison between a wolf from Category A (left) and a healthy wolf with a summer coat (right) both photo trapped on the same location in the territory of the Daubitz pack in Lusatia Germany, the wolf on the left is known as the individual “right eye blind” (Bundesforstbetrieb Lausitz 2019)

Coat change

Wolves change their coat in spring as well as in autumn. Especially the change from the thick winter coat to the much shorter summer coat can easily be mistaken for mange, as the animals appear very shaggy at this time. A first indication for a change of coat is therefore the season. If a wolf is only shaggy in the months of March to May, it is most likely a change of coat and not mange. Another indication is the appearance and condition of the coat. In the case of mange, the hairs fall out without new hairs growing directly, so the skin shines through in the case of a mange infestation. When the coat changes, however, the skin should not be visible under the coat, as the short summer coat grows back directly there. Mangy wolves can sometimes be very thin or emaciated. Especially the pups look emaciated very quickly in case of a severe infestation. However, many are well nourished despite mange infestation and appear generally fit.

Figure 26: Wolf that changes its coat, territorial male of the Milkel pack in the territory of Milkel on 2019-04-18 in Lusatia Germany (RALF M. SCHREYER, Staatsbetrieb Sachsenforst - Biosphärenreservatsverwaltung 2019)

Appendix G, Map of the Climate zones in Saxony

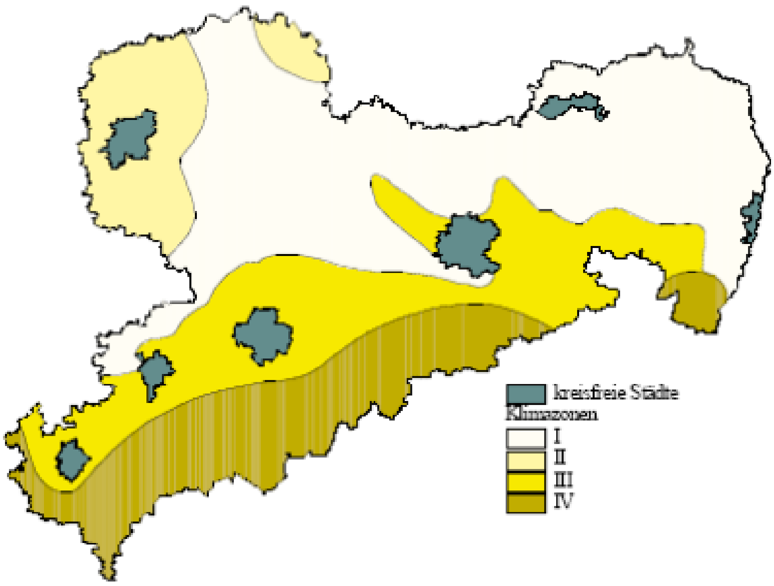


Figure 27**:** Climate zones in Saxony (WINKLER et al. 1999)

Appendix H, Conceptual model

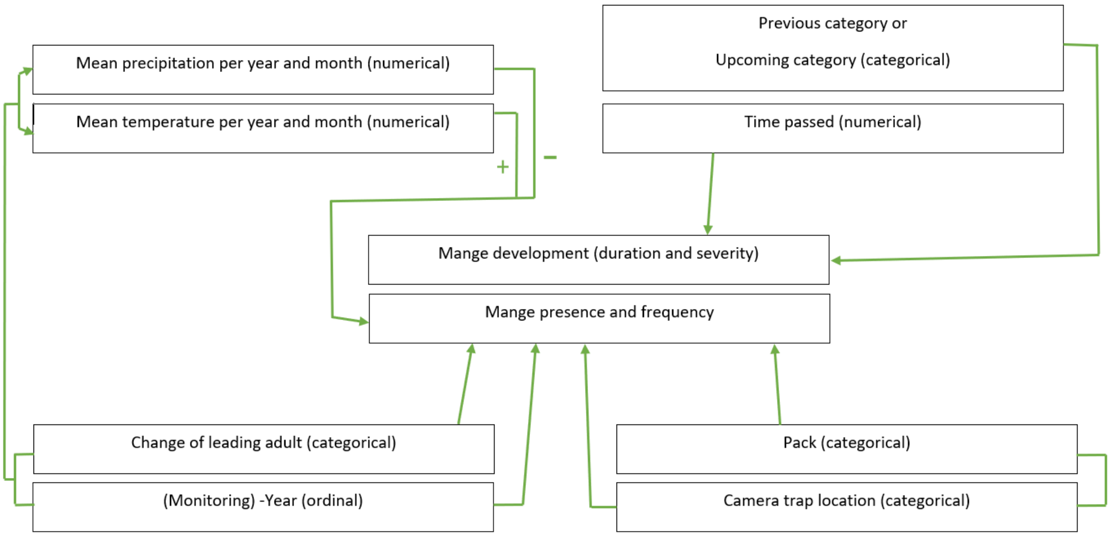


Figure 28: Conceptual model for the statistical test carried out in this research

Appendix I, More detailed description of other diseases, changes of coat and injuries as a supplement for the flowchart to identify mange.

Coat change

Wolves change their coat in spring as well as in autumn. Especially the change from the thick winter coat to the much shorter summer coat (in March until May, MECH & BOITANI 2007) can appear very shaggy at this time as the hair does not fall out evenly (see Figure 29, left side). A first indication for a change of coat is therefore the season; if a wolf is shaggy only in the months March until May (MECH & BOITANI 2007), it is most likely a change of coat and not mange. Another indication is the appearance and condition of the coat. In the case of mange, the skin under the coat is not visible, as the short summer coat is already under the longer hair of winter coat (see Figure 29, left side) (FOSTER & WALTER n.d.). It can take a few weeks until the change is complete. The start of the change can vary due to weather conditions. In October the winter fur grows back. This is a more even process and does not occur in patches. The wolf regularly does not look shaggy at any time (LUPUS Institute, personal interview, Spreewitz, 2022-03-02, Appendix B.).

Figure 29: Wolf that changes its coat (left) territorial male of the Milkel pack in the territory of Milkel on 2019-04-18 in Lusatia Germany (RALF M. SCHREYER, Staatsbetrieb Sachsenforst – Biosphärenreservatsverwaltung 2019) and wolf with a mange infestation (right) it has a bald area on the left side of its body as well as a thinned-out tail, in the territory of the Milkel pack on 2012-03-29 in Lusatia Germany (ANDRE KLINGENBERGER 2012)

Injuries

Injuries can also be mistaken for mange. Thus, fresh bloody injuries such as abrasions or scars can be mistaken for mange infestation. If the skin is injured too deeply, e.g., in a traffic accident, this can lead to hair no longer growing in the affected area after scarring (JUNG et al. 2013). In general, all parts of the body can be affected by injuries and scars. They can be distinguished from mange by the lack of accompanying symptoms such as shaggy coat. In addition, scars usually last a lifetime, so if an animal has the same bald spot even after a long time without the rest of the coat changing, it is most likely a scar.

Comparable diseases

In the following, possible alternative diseases for mange-like symptoms, such as an altered coat structure, as well as bald patches and an altered skin appearance are discussed and ways of differentiating mange are presented. A lot of information could be found especially on diseases in dogs, which is why the handbook "Skin Diseases of the Dog and Cat" (NUTTALL et al. 2009) gave a helpful guide to find possible mange-like diseases.

Dermatophytoses

A Dermatophytoses is a fungal infection that affects the coat, skin or claws of dogs. The infestation is easily transmissible both directly and indirectly; usually adult and healthy dogs can heal the infection well. Symptoms are mainly itchy, bald patches and scaly areas with brittle hair. Often several areas are affected by the hair loss at the same time. Sometimes red pocks are visible on the skin (see Figure 30, left side). Typical parts of the body that are affected are the feet, the tail, the face and the tips of the ears. When dermatophytosis affects the coat, it leads to folliculitis, an inflammation of the hair follicles (see Figure 30, mid) (CURTIS et al. 2021; MERCHANT 2020; WARD n.d.). The fungal infection can be distinguished from a mange infection by the fact that it usually causes round patches of hair loss (see Figure 30, left side). In addition, as the infestation spreads, the coat already grows back in the middle (MARSELLA 2021; WARD n.d.).

Figure 30: Dermatophytoses in Dogs (ROSANNA MARSELLA 2021)

Furthermore, infestation of the claws and pads can occur, causing the claws to become brittle and the skin to become inflamed and covered with pustules (WARD n.d.). Figure 31 clearly shows such an infestation. As the feet are usually hardly affected by a mange infestation, such a heavy infestation can also be an indication that it is a fungal infection and not a mange infestation.

Figure 31: Dermatophytoses on a dog’s paw (ROSANNA MARSALLA 2021)

Malassezia dermatitis

Malassezia dermatitis is an opportunistic infection and is caused by saprobic fungi (BAJWA 2017), which are also present in the skin flora of a healthy dog and other mammals (CAFARCHIA et al. 2005). When skin conditions change (e.g., increased oil production) or the immune system is weakened, this can lead to increased growth of the fungus, resulting in infection. Malassezia dermatitis is one of the most common skin diseases in dogs. It is not transmissible to conspecifics and often recurs without treatment. The following parts of the body can be affected by an infestation: muzzle, ear, interdental spaces, nail fold, ventral neck area (underside), mid-thigh, perianal region (area around the anus) and intertriginous areas (including armpit, groin region). Typical symptoms include severe itching, hair loss with reddened skin, leathery skin lesions, hyperpigmentation (darkly pigmented skin), scaly, waxy or greasy eczema (yellow or slate grey), dark brown nail bed discolouration or claw bed inflammation (BAJWA 2017; HUNTER n.d.). How the disease manifests itself on the skin is shown in Figure 32.

Figure 32: Malassezia dermatitis in dogs (SAVD 2022)

Malassezia dermatitis can be distinguished from mange mainly by the frequently affected body parts. For example, the tail is usually not affected, which would be very untypical for a mange infestation. Also, the feet are less frequently affected by mange, in contrast to fungal infestation.

<u>Pelodera (Rhabditis) strongyloides</u>

Pelodera strongyloides is caused by a nematode that is found in decaying organic material. In rare cases, the larvae of the worm can penetrate the skin of various mammalian species, such as dogs, via lying areas and cause dermatitis. Clinical symptoms occur mainly on the skin areas that come into direct contact with the soil and decaying organic material when lying down. At these sites, hair loss, reddening of the skin, crusting and inflammation, as well as itching develop (GERHOLD 2020; SAARI & NIKANDER 2006). A light infestation can be seen in Figure 33.

Figure 33: Pelodera (Rhabditis) strongyloides in dogs (S. A. SAARI & S. E. NIKANDER 2006)

This infestation can be distinguished from mange mainly by the affected areas. Pelodera strongyloides affects the extremities, abdomen and thorax as well as the perineum (GERHOLD 2020). These parts of the body may also show symptoms of mange infestation, but are usually not primarily affected. Furthermore, Pelodera strongyloides rarely occurs (GERHOLD 2020; SAARI & NIKANDER 2006), which is why the occurrence of symptoms in wolves is probably rather caused by a mange infestation.

<u>Flea saliva allergy dermatitis (FAD)</u>

Flea saliva allergy dermatitis (FAD) is an immunological disease caused by the injection of antigens from a flea bite. Symptoms are primarily seen on the hind back, croup, hind thigh and inner thigh and are mainly manifested by pustules. In addition, reddening of the skin, bald patches, crusts and hyperpigmentation (darkening of the skin) may occur (DRYDEN & BLAKEMORE 1989; DRYDEN 2021; HENSEL et al. 2015). The manifestation of FAD in dogs is shown in Figure 34.

Figure 34: Flea Allergy Dermatitis in Dogs (MICHAEL DRYDEN 2021; Frontline 2019)

Symptomatically, FAD resembles a mange infestation and the affected areas are also the same. In temperate climates, the disease occurs seasonally (most frequently in late summer; less frequently in winter) (JAMESON et al. 1995; TAVASSOLI et al. 2010), which is why the season in which an infested wolf is sighted can already be an indication of how likely FAD is. Furthermore, FAD only makes the fur thinner and more translucent and pustules form. In the case of a mange infestation, pustules do not form and bald patches occur, especially in more severe cases.

Bacterial Folliculitis

Similar to filamentous fungus, folliculitis can also be caused by bacteria. Bacterial folliculitis is one of the most common skin diseases among canids (CURTIS et al. 2021). Common symptoms include pustules, itching, redness, swelling, crusting and circular hair loss that occur multifocally (in several areas at once). A very typical symptom of bacterial skin inflammation is epidermal collarettes (scaly crusts). The trunk, abdomen and axillae are particularly affected (BESTEIROS 2019; BLOOM 2014; CURTIS et al. 2021; HILLIER et al. 2014). Figure 35 shows the symptoms described, with the pustules on the left and a typical epidermal collarette on the right.

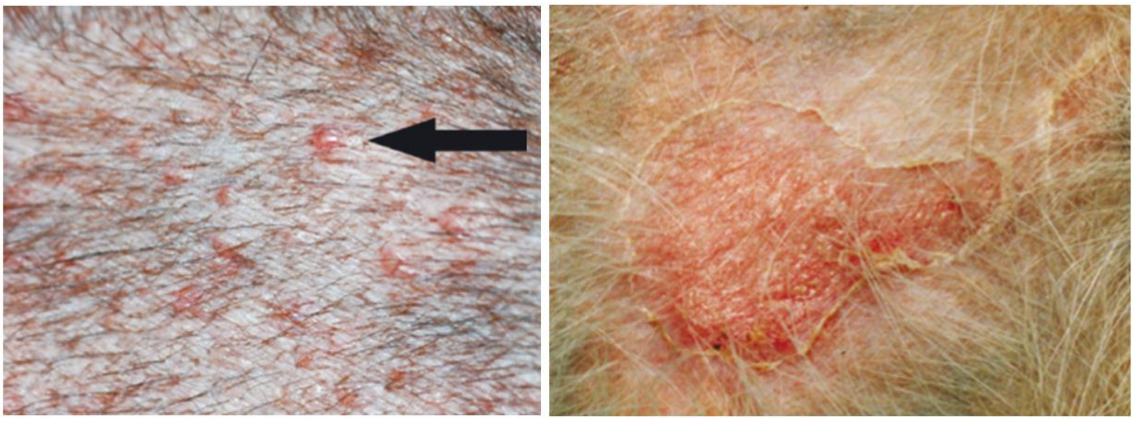


Figure 35: Bacterial folliculitis in dogs (A. HILLIER et al. 2014)

In particular, circular patches of hair loss and epidermal colarettes may indicate that it is a bacterial folliculitis and not a mange infestation. However, bacterial folliculitis can also be caused by mite infestation (BESTEIROS 2019; BLOOM 2014), which is why it cannot be ruled out that bacterial folliculitis is a secondary disease following mange infestation.

<u>Cheyletiellosis</u>

Cheyletiellosis is caused by the Cheyletiella mite, which is widespread worldwide and affects dogs (Cheyletiella yasguri), cats and humans, among others. Infestation is often characterised by the formation of large, diffuse skin scales. Sometimes there is also itching, as well as local hair loss and inflammation. The scales mainly affect the back. Infected animals are very contagious through direct contact (BRONSWIJK & DE KREEK 1976; LÖWENSTEIN 2016; REYNOLDS 2017). Different severities are shown in Figure 36, ranging from less severe to very severe.

Figure 36: Cheyletiellosis in dogs (Happy Dog Naturals 2020)

In particular, severe cheyletiellosis may be mistaken for mild mange, as it can make the coat look shaggy and sick. However, as an incipient or mild mange infestation is mainly concentrated around the croup and cheyletiellosis appears on the back (REYNOLDS 2017), the affected area is a good indication to distinguish between the two diseases.

<u>Pemphigus foliaceus</u>

Pemphigus foliaceus is the most common autoimmune skin disease in dogs. Through this disease, the immune system attacks the connections between skin cells, causing hair loss, scabs and ulcers. It mainly affects the skin on the face, head, ears and paws. However, the symptoms can spread further over time (ALMELA & CHAN 2021; HUNTER & BARNETTE n.d.). Figure 37 shows the symptoms described.

Figure 37: Pemphigus Foliaceus in Dogs (RAMÓN M. ALMELA & TIM CHAN 2021)

The symptoms are similar to those of mange, but the affected region gives an indication of which disease it is. In a mange infestation, the face is also affected, but much less intensively than in pemphigus foliaceus. Mostly it is only spotted and only in case of a very severe mange infestation further symptoms appear, such as loss of fur and sores in this region. In the autoimmune disease, however, the symptoms on the head are much stronger and the rest of the body is rather unaffected except for the paw pads.

Appendix J, Tables for the mange course per individual

Table 5: Mange course GW031f

Date from - until	Category	Duration in days	Number of indications
13.07.2017	0		
Days without an indication: 0			
14.07.2017 – 21.09.2017	1	70	13

Table 6: Mange course GW038m

Date from - until	Category	Duration in days	Number of indications
22.05.2013 - 23.05.2013	1	2	2
Days without an indication: 18			
11.06.2013 - 12.06.2013	2	2	2
Days without an indication: 7			
20.06.2013 – 05.07.2013	3	16	11
Days without an indication: 2			
08.07.2013 – 28.09.2013	A	83	17
Days without an indication: 36			
04.11.2013 – 07.03.2014	0	124	13
Days without an indication: 11			
19.03.2014 - 21.03.2014	2	3	4
Days without an indication: 48			
10.05.2014	3	1	1
Days without an indication: 33			
14.06.2014	0		
10.04.2017	2	1	1
Days without an indication: 21			
02.05.2017	A	1	1
13.01.2018	Dead (traffic accident)		

Table 7: Mange course GW070m

Date from - until	Category	Duration in days	Number of indications
07.12.2012	0		
Days without an indication: 1			
09.12.2012 – 30.12.2012	1	22	2
Days without an indication: 18			
18.01.2013 – 03.02.2013	2	17	7
Days without an indication: 17			
21.02.2013 – 25.02.2013	A	5	2

Table 8: Mange course GW081m

Date from - until	Category	Duration in days	Number of indications
21.01.2012 – 12.03.2012	1	52	2
Days without an indication: 3			
16.03.2012 – 17.03.2012	2	2	2
Days without an indication: 11			
29.03.2012 – 16.04.2012	A	31	9
Days without an indication: 19			
06.05.2012	0		

Table 9: Mange course GW1010m

Date from - until	Category	Duration in days	Number of indications
07.12.2019	0		
Days without an indication: 78			
23.02.2020 – 26.02.2020	2	4	5
Days without an indication: 336			
27.01.2021	0		

Table 10: Mange course GW106m

Date from - until	**Category**	**Duration in days**	**Number of indications**
04.07.2013 – 07.10.2013	A	4	9
Days without an indication: 11			
19.10.2013	3	1	1
Days without an indication: 74			
02.01.2014	A	1	1
Days without an indication: 77			
21.03.2014	0		
20.09.2014	dead (unknown)		

Table 11: Mange course GW112f

Date from - until	**Category**	**Duration in days**	**Number of indications**
26.01.2017	1	1	1
Days without an indication: 110			
17.05.2017 – 28.06.2017	A	43	12

Table 12: Mange course GW114f

Date from - until	**Category**	**Duration in days**	**Number of indications**
22.02.2020	0		
Days without an indication: 6			
29.02.2020 - 04.12.2020	1	280	6
Days without an indication: 25			
30.12.2020 - 06.01.2021	3	8	3
Days without an indication: 7			
14.01.2021 – 02.04.2021	A	79	11

Table 13: Mange course GW158m

Date from - until	**Category**	**Duration in days**	**Number of indications**
09.10.2019 – 02.11.2019	1	25	4
Days without an indication: 74			
16.01.2020 – 23.03.2020	0	69	7
Days without an indication: 71			
03.06.2020	1	1	1
Days without an indication: 47			
21.07.2020 – 25.07.2020	3	6	7

Table 14: Mange course GW139f

Date from - until	**Category**	**Duration in days**	**Number of indications**
24.10.2012 – 07.12.2012	1	45	
Days without an indication: 1			
09.12.2012 – 22.01.2013	2	45	

Table 15: Mange course GW1520f

Date from - until	**Category**	**Duration in days**	**Number of indications**
07.12.2020	0		
Days without an indication: 63			
09.02.2021 – 13.05.2021	1	94	2
Found dead after investigation period on 05.11.2021 (traffic accident) her course of mange was not investigated after may 2021			

Table 16: Mange course GW173f

Date from - until	Category	Duration in days	Number of indications
12.08.2014	0		
Days without an indication: 87			
08.11.2014	1	1	1
Days without an indication: 1			
10.11.2014 – 06.02.2015	2	89	4
Days without an indication: 66			
14.04.2015 – 21.07.2015	3	99	12
Days without an indication: 41			
01.09.2015 – 19.11.2015	A	80	4
Days without an indication: 2			
22.11.2015 – 20.12.2015	3	29	5
Days without an indication: 54			
13.02.2016	dead (natural)		

Table 17: Mange course GW315m

Date from - until	Category	Duration in days	Number of indications
18.02.2014	0		
Days without an indication: 40			
31.03.2014	1	1	1
Days without an indication: 19			
20.04.2014	A (only pictures of death for this category, traffic accident)		

Table 18: Mange course GW379f

Date from - until	Category	Duration in days	Number of indications
18.05.2018	3	1	1
Days without an indication: 7			
26.05.2018	A	1	1

Table 19: Mange course GW381m

Date from - until	Category	Duration in days	Number of indications
26.05.2016 – 04.06.2016	1	10	3
-			
13.06.2018 – 19.06.2018	1	7	7
Days without an indication: 126			
24.10.2018 – 20.11.2018	A	28	3
Days without an indication: 7			
28.11.2018	0		

Table 20: Mange course GW399m

Date from - until	Category	Duration in days	Number of indications
24.12.2019	0		
Days without an indication: 13			
07.01.2020 – 26.02.2020	2	51	12
Days without an indication: 112			
18.06.2020	0		
Found strongly weakened, euthanized on 12.12.2021			

Table 21: Mange course GW401f

Date from - until	**Category**	**Duration in days**	**Number of indications**
14.01.2020	0		
Days without an indication: 37			
20.02.2020 – 23.02.2020	1	4	3
Days without an indication: 69			
02.05.2020 – 25.05.2020	2	24	2
Days without an indication: 4			
29.05.2020 – 19.07.2020	A	53	6

Table 22: Mange course GW528m

Date from - until	**Category**	**Duration in days**	**Number of indications**
26.02.2018	0	1	1
Days without an indication: 34			
02.04.2018 – 10.05.2018	3	39	3
Days without an indication: 293			
28.02.2019	0	1	1
Days without an indication: 15			
16.03.2019	1	1	1
Days without an indication: 44			
30.04.2019	2	1	1
Days without an indication: 120			
29.08.2019	1	1	1
Days without an indication: 151			
28.01.2020 - 08.02.2020	2	12	2
Days without an indication: 9			
18.02.2020 - 12.03.2020	3	24	3

Table 23: Mange course right eye blind

Date from - until	Category	Duration in days	Number of indications
16.10.2018	0		
Days without an indication: 196			
30.04.2019 – 03.05.2019	A	5	4
Days without an indication: 0			
04.05.2019 – 07.05.2019	3	4	4
Days without an indication: 72			
18.07.2019 – 29.10.2019	A	103	5

Appendix K, Glossary

The definitions of the technical terms used in the report are given below. These definitions were mostly created by LUPUS and supplemented by definitions of words used for the first time in this report.

General terms about wolves:

Adult wolf: wolf older than two years.

Yearling: Wolf in its second year of life.

Pup: Wolf in its first year of life. Since wolf pups are usually born at the beginning of May, the transition from pup to yearling occurs on 01 May.

Resident single wolf (territorial single wolf): lone wolf confirmed for at least six months in an area with C1 or C2 data.

Territorial pair: male and female wolves that mark their territory together but have no offspring (yet). Accordingly, **territorial male** and **territorial female**.

Wolf family (wolf pack): a group of more than two wolves living in one territory.

Reproductive wolf family: consists of at least one adult wolf with confirmed reproduction = wolf pack.

Territory: area claimed by a wolf pack and demarcated from other territories by markings (scat and urine).

Monitoring & Management:

Wolf monitoring: The aim of wolf monitoring is to obtain comprehensive information on wolves. Systematic recording enables statements to be made on the occurrence of wolves, the size and distribution of their populations and their development. Common measures are the setting up of camera traps, excursions to search for looses, tracks and urine. In addition, sightings from the public are recorded, dead wolves are documented, and in some cases wolves are captured and transmitted in order to obtain further information from the telemetry data. More information on wolf monitoring can be found in the monitoring standards "Monitoring of wolf, lynx and bear in Germany" by Ilka Reinhardt, Petra Kaczensky, Felix Knauer, Georg Rauer, Gesa Kluth, Sybille Wölfl, Ditmar Huckschlag and Ulrich Wotschikowsky (2015).

Wolf management: The task of wolf management is to minimise conflicts arising from the return of the wolf to Germany. The individual federal states are responsible for this. Wolf management is divided into different areas of responsibility: collecting basic data on the distribution and areas of conflict, conducting public relations work, organising the protection of livestock, monitoring the wolf population.

FT / MT: The wolves fitted with a collar transmitter are given a consecutive number, which starts with FT (f = female, t = telemetry) for the females and MT (m = male, t = telemetry) for the males.

Monitoring year: 01 May - 30 April. The period covers a biological "wolf year", from the birth of the pups to the end of their first year of life.

<u>Thesis relevant words:</u>

Sarcoptic mange / scabies: Skin disease caused by the burrowing mite Sarcoptes scabiei var. canis. Symptoms are dermatitis, hyperkeratosis and alopecia.

Relevant evidence: Evidence relevant to the preparation of this work from the categories of camera trap image, sighting, capture and dead find where mange can be clearly identified.

Research period: period from 2009-05-01 to 2021-04-30 (monitoring year 2009/10 to 2020/21) during which the mange indications were analyzed.

Area of occurrence: the area actually occupied by the species. It is described by the occupied grid cells of the EU grid of 10 x 10 km size. A grid cell is considered occupied if C1 is detected. If there is no C1 evidence, at least three independent C2 indications are required for the wolf species. Cells for which only C3 or less than 3 independent C2 indications are available are not considered occupied.

LUPUS Institute: The LUPUS German Institute for Wolf Monitoring and Research is responsible for the monitoring of all wolf packs in Saxony and for the packs in Brandenburg located west of the A13 and south of the A15. Client of this work. Originator of data from database.

Database: DBBW database in which all references to wolves are recorded in protocols.

Shedding: Wolves change between summer and winter fur, which makes a considerable difference in appearance. +The appearance during the coat change can easily be mistaken for mange symptoms. Due to the different thickness of the coat, mange is also easier to recognize in winter than in summer.

IZW: Leibnitz Institute for Zoo and Wildlife Research. The institute is responsible for the pathology of all wolves found dead in Germany. Second client of this work. Originator of the data on dead wolves.

Mange maps: Spatial distribution of mange in the LUPUS area of responsibility. Depending on the mange infestation, the territories are not colored at all (no mange), diagonally (territory has mange) or chequered (pack has mange). A distinction is made between territory and pack, as not all animals that are in a territory automatically belong to the pack. If the male or the female can be clearly identified from the mange indications for the respective monitoring year, the pack is considered to be infested with mange in this year. The same applies to evidence of pups before 31 December of the respective monitoring year or to evidence of pups or yearlings running together with the pack. This excludes the possibility that the animal is only roaming the territory and does not belong to the pack. If there is evidence of mange in a territory where the individual cannot be clearly assigned to the pack, the territory is marked accordingly.

Limitation of pathology data: Some carcasses are so badly deformed due to a traffic accident or decomposition that the identifying features for mange are no longer recognizable. Therefore, only those records are used in which the injuries of the cause of death can be clearly distinguished from the mange characteristics (e.g. blood on the skin, which clearly comes from a fresh deep injury, scabbing underneath is nevertheless clearly recognizable as a mange characteristic).

Affidavit

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Hoyerswerda, July 24, 2022

Carolin Schlautmann and Anna Stubbe