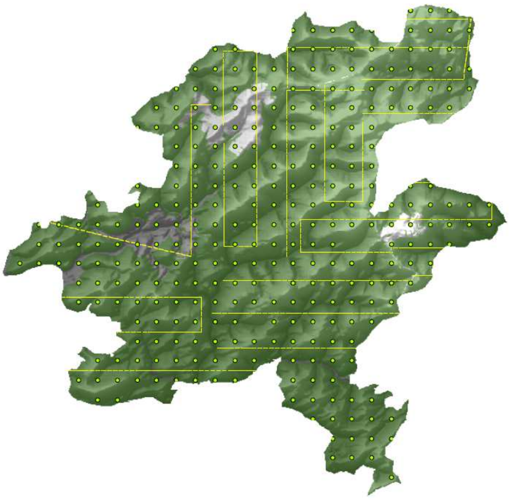
# RESULTS AND EVALUATION OF DIFFERENT METHODS OF FAECAL PELLET GROUP COUNTS TO ESTIMATE RED DEER (*CERVUS ELAPHUS*) WINTER DISTRIBUTION IN THE PALATINATE FOREST



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von

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# Zusammenfassung

Im grenzüberschreitenden Biosphärengebiet „*Pfälzerwald-Nordvogesen*“ wurde im Jahre 2005 ein 111 km² großes Wildforschungsgebiet (WFG) eingerichtet, in dem u. a. die Wechselwirkungen zwischen Rotwild (*Cervus elaphus*) und seiner Umwelt untersucht werden. Das Gebiet ist zu 93% bewaldet und liegt 17 km südlich von Kaiserslautern im dünn besiedelten Pfälzerwald. In den Jahren von 1999 bis 2008 wurden jährlich durchschnittlich 0,9 Stück Rotwild pro 100 ha erlegt. Im Rahmen des Schalenwildmonitorings der für das WFG zuständigen *Forschungsanstalt für Waldökologie und Forstwirtschaft Rheinland Pfalz* (FAWF) wurden seit 2007 jeweils im Frühjahr vier Losungskartierungen zur Ermittlung der Winterverteilung von *C. elaphus* durchgeführt. Verschiedene Linientransektmethoden wurden dabei angewendet. Diese Arbeit untersucht die Winterverteilung 2009 und 2010 und stellt einen Vergleich mit den Ergebnissen der Kartierung aus den beiden vorangegangen Jahren her. Eine Evaluation der angewandten Methoden bezüglich der Kosten- und Zeiteffizienz wird als weiterer Aspekt durchgeführt.

Die Untersuchung der räumlichen Verteilungsmuster des Rotwilds unter Anwendung einer Kernel Density Estimation und einer Quadrat Count Analyse ergibt für die im Jahre 2007 beginnende Zeitreihe übereinstimmende Schwerpunkte im Norden und Osten des Studiengebietes. Ein Methodenwechsel von rasterbasierten ‘strip-transects’ mit 50 m Länge zu langen Linientransekten, welche das Gebiet durchziehen, lässt einen weiteren Schwerpunkt des winterlichen Rotwildvorkommens in den zentralen Bereichen des Gebietes erkennen. Dieser wurde durch die vorherige Methode nicht abgebildet. Zusätzlich könnte sich der neue Schwerpunkt, der sich in einer ca. 2400 ha großen Kernzone des Biosphärengebietes befindet, noch ursächlich einer Habitatverbesserung durch erhöhten Holzeinschlag und verringerte Jagdintensität in den letzten Jahren verstärkt haben.

Unter Effizienzgesichtspunkten erweisen sich die langen Linientransekte sowohl in der Generierung einer hohen Stichprobenzahl als auch hinsichtlich des betriebenen Zeit- und Kostenaufwands den ‘strip-transects’ als überlegen. In den Jahren 2009 und 2010 konnten mit langen Linientransekten 378 bzw. 420 Losungshaufen kartiert werden (3,3/3,9 pro km²). Die Finderate bei den ‘strip-transects’ 2007 und 2008 betrug demgegenüber nur 131 bzw. 150 Losungshaufen (1,2/1,4 pro km²). Pro Manntag wurden die Finderaten durch den Methodenwechsel von ‘strip-transects’ zu langen Linientransekten von 4,09 auf 26,25 bzw. 29,08 angehoben. Die höhere Effizienz der langen Linientransekte spiegelt sich auch in geringeren Fahrtkosten wider. 2010 wurden pro km² abgedeckter Fläche 2,4 km gefahren, 2007 (‘strip-transects’) 15,6 km.

**Schlagwörter**: Rotwild, Losungskartierung, *Cervus elaphus*, Pfälzerwald, Winterverteilung, Evaluation, Transekte

# Abstract

Between 2007 and 2010 faecal pellet group (FPG) counts based on strip and long line transects were conducted annually in a wildlife research area (WFG) implemented within the framework of the transfrontier biosphere reserve "Vosges du Nord - Pfälzerwald". This area is located 17 km south of Kaiserslautern amidst the sparsely inhabited Palatinate Forest. The WFG covers an area of approximately 110 km² and consists mainly of forest (93%). Between 1999 and 2008 a mean of 0.9 red deer were harvested per 100 ha per year in this area. The main goal of ungulate monitoring carried out by the Research Institute for Forest Ecology and Forestry of Rhineland-Palatinate (FAWF) is to gain information about *Cervus elaphus* winter distribution, population density and browsing and bark peeling impact on forest stands. In this thesis red deer spatial winter distributions of 2009 and 2010 are analysed via Kernel Density Estimation and Quadrat Count Analysis. Furthermore these results will be compared with results from prior studies. Since different methods were tested in the four surveys an evaluation of all approaches in terms of time and cost-efficiency is done.

Spatial hotspots in the north and east of the research area identified in pellet counts in spring 2007 and 2008 could be confirmed by outcomes of surveys from spring 2009 and 2010. Additionally, a prior undetected second centre of distribution was identified in central parts of the study area. On the one hand former survey methods very likely did not identify this hotspot. On the other hand it is located in a core zone of the biosphere reserve. Increased logging and less hunting activity could have intensified deer attracting effects of this area.

Long line transects used recently approved as a more time and cost-efficient alternative compared with raster based strip transects of surveys 2007 and 2008. Detection rates per person-day increased from 4.05 in surveys with 'strip-transects' to 26.25 and 29.08 in surveys with long line transects. With the shift from 'strip-transects' to long line transects, overall sample size increased from 131 and 150 FPG's to 378 and 420 respectively. Detection rates per km² increased from 1.2 and 1.4 in 2007 and 2008 to 3.3 and 3.9 in 2009 and 2010. The higher sample size was generated in a narrower time span, less prone to bias due to changes in pellet detection probability. The efficiency of the long line transects is furthermore reflected in less travel costs. In 2007, 15.6 km were driven to sample a represented area of one square kilometre, in 2010 this value could be reduced to 2.4 km per km².

**Keywords:** Faecal Pellet Group Count, Strip & Line Transect, Red Deer, *Cervus Elaphus*, Palatinate Forest, Winter Distribution, Evaluation

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# List of Abbreviations

| | |
|---|---|
| ATKIS | Amtliches Topographisch-Kartographisches Informationssystem |
| m a.s.l. | Meters Above Sea Level |
| CMR | Capture-Mark-Recapture |
| FAR | Faecal Accumulation Rate |
| FAWF | Forschungsanstalt für Waldökologie und Forstwirtschaft (Research Institute for Forest Ecology and Forestry of Rhineland-Palatinate) |
| FPG | Faecal Pellet Group |
| FSC | Faecal Standing Crop |
| IT | Intermediate Transects |
| KDE | Kernel Density Estimation |
| MAB | Man and the Biosphere |
| VTMR | Variance-To-Mean-Ratio |
| WFG | Wildforschungsgebiet (Wildlife Research Area) |

# 1 Introduction

In the year 1992 an area of 179.000 ha of the "Palatinate Forest" was accepted by UNESCO's programme on Man and the Biosphere (MAB) as biosphere reserve. Since 1998 this area is part of the transfrontier biosphere reserve "Vosges du Nord – Pfälzerwald". The establishment of biosphere reserves follows different objectives including monitoring and research. Goal III of the Seville strategy (UNESCO 1996) is the basis for ungulate monitoring implemented by the Research Institute for Forest Ecology and Forestry of Rhineland-Palatinate (FAWF) within a 10.000 ha wildlife research area in the centre of the forest (FAWF DEPARTMENT OF WILDLIFE ECOLOGY 2005 and HOHMANN & HUCKSCHLAG 2010). Their monitoring of red deer (*Cervus elaphus*) involves coverage of population structure, density and distribution as well as evaluation of bark peeling and browsing of trees and hunting activities.

For estimating *C. elaphus* winter distribution four faecal pellet group (FPG) count surveys testing different line or strip transect methods were conducted within the framework of ungulate monitoring from 2007 to 2010. Exact data on ungulate abundance is important for wildlife management. It allows temporal and spatial interpretation of wildlife behaviour and their interaction with environment. One major aspect of red deer management in the FAWF wildlife research area is the impact of (prospective) unmanaged population in a core zone of the biosphere reserve concerning tree damages at the surrounding forest stands.

New methods developed in recent years and refinements of established census techniques caused a large variety of approaches wildlife managers can select from. With increasing numbers of different methods to monitor wild ungulates, the question arises which approach suits best for each selected site.[1] Lately, many authors discussed this question on the topic of trade-offs between accuracy and time- and cost-efficiency (CAMPBELL *et al.* 2004, DANIELS 2006, FRANCO *et al.* 2007 and GAIDET-DRAPIER *et al.* 2006).

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[1] For a first overview of common techniques and further reading see KRAUSMANN 2002.

The main goal of this thesis is to analyse the spatial winter distributions of red deer in the wildlife research area in 2009 and 2010 on the basis of data collected from line transect surveys prior to this paper. The results of 2009 and 2010 will be compared with the distributions of 2007 and 2008 analyzed by BEVANDA 2008 and SIMON & OSTERHELD 2007. Furthermore, the author analyses the different methods tested in the four surveys in terms of information content and time- and cost-efficiency. Given that the selected method of population census is a compromise between accuracy and efficiency (KRAUSMANN 2002) a 'best-practise' method for the present area will be proposed in the conclusion.

Regarding the spatial winter distribution of *C. elaphus*, likely effects of attracting deer within the established biosphere core zone are analysed (chapter 5.2 and 5.3) and discussed (chapter 6.2 and 6.3). Long line transects are used recently on the assumption that they imply better overall efficiency. Chapters 6.5 and 7.2 deal with analysis and discussion of the efficiency of the four transect methods tested.

## 1.1 Dung count methods

Indirect detection of wild ungulate abundance on the basis of faecal pellets is used since 1940 when it was first established in the United States (BENNETT *et al.* 1940). Dung counts are prevalent especially in woodland habitats, where direct counts are difficult, (ACEVEDO *et al.* 2008). According to LEOPOLD *et al.* (1984) pellet group count data can be used to describe relative habitat use since they indicate occupancy. The outcome of this is the possibility to derive winter distributions from dropping counts. Beside those findings on the spatial distribution of wildlife, several statistical models to estimate population densities using pellet group counts exist. The feasibility of pellet counts as an indirect method of population estimation is questionable. SMART *et al.* (2004) figured out that density estimations on the basis of FPG were only precise at high deer densities (~ 30 deer/km²). They are also highly dependent on a precise estimation of site-specific dung persistence and defecation rates. Spatial and seasonal variation in decomposition is regulated by many factors such as ground vegetation, insolation, rainfall, temperature and coprophagous beetle activity. This variation is a source of errors and minimises accuracy. Also, defecation rates change individually (age, sex) and with different food supplies (HEMAMI & DOLMAN 2005, BAILEY & PUTMAN 1981, PUTMAN 1984 and BORKOWSKI 2004).

Defecation rates not only influence density estimations from pellet group counts. They also affect the decision whether indirect detection via pellet group count is feasible at all. The high defecation rates of red deer approve this method as feasible. Besides some old and obviously underestimating rates, many authors refer to defecation rates of 19 pellet groups per day stated by TOTTEWITZ *et al.* (1998). Recently BAUCH *et al.* (2007) figured out that defecation rates vary from 12 (winter/spring) to 19 (summer/autumn) FPG's per day. Detection probability is based on observer abilities, litter- or snow coverage. According to THEUERKAUF *et al.* (2008) the best period to assess winter habitat use through pellet group counts is the period after snowmelt.

To minimise bias in density estimates, the red deer population density estimation strategy in the wildlife research area was changed to a modified capture-mark-recapture (CMR) approach using non-invasive genetic sampling via faeces similar to the method tested on wild boar (*Sus scrofa*) in the same area (EBERT *et al.* 2009). FPG counts in the WFG are used to analyse *C. elaphus* spatial winter distribution, but not to estimate population density.

Pellet group count data investigations are divided into two alternative methods. Faecal accumulation rate (FAR) needs a clearance of the sample spots in a first run, mostly in autumn. The second count measures the daily accumulated rate of droppings since clearing. Faecal standing crop (FSC) is done with only one run in spring. Overall density is measured and in consideration of decomposition rates the duration since pellet drop is estimated (CAMPBELL *et al.* and ACEVEDO *et al.*) Accumulation and duration rates are only necessary to estimate population density and thus not gathered in the WFG.

# 2 Study area

The different surveys on *Cervus elaphus* abundance were conducted in an area of wildlife research in the Palatinate Forest ('Wildforschungsgebiet', WFG). This research area was established in 2005 and includes the largest core zone situated in the German part of the transfrontier biosphere reserve ("Quellgebiet der Wieslauter", approx. 2.400 ha).[2] The WFG contributes 9.000 ha to the 62.800 ha of red deer area of the Palatinate Forest. The study area is located 17 km south of Kaiserslautern and covers an area of 11.132 ha. Altitudes range from 220 to 611 m a.s.l. It mainly consists of forest (93 %, 10.300 ha). The dominant tree species are *Fagus sylvatica* (33%), *Pinus sylvestris* (30%), *Quercus spec*. (16%), *Picea abies* (10%) and *Pseudotsuga menziesii* (8%) (FORSTEINRICHTUNG 2009 and HOHMANN & HUCKSCHLAG).

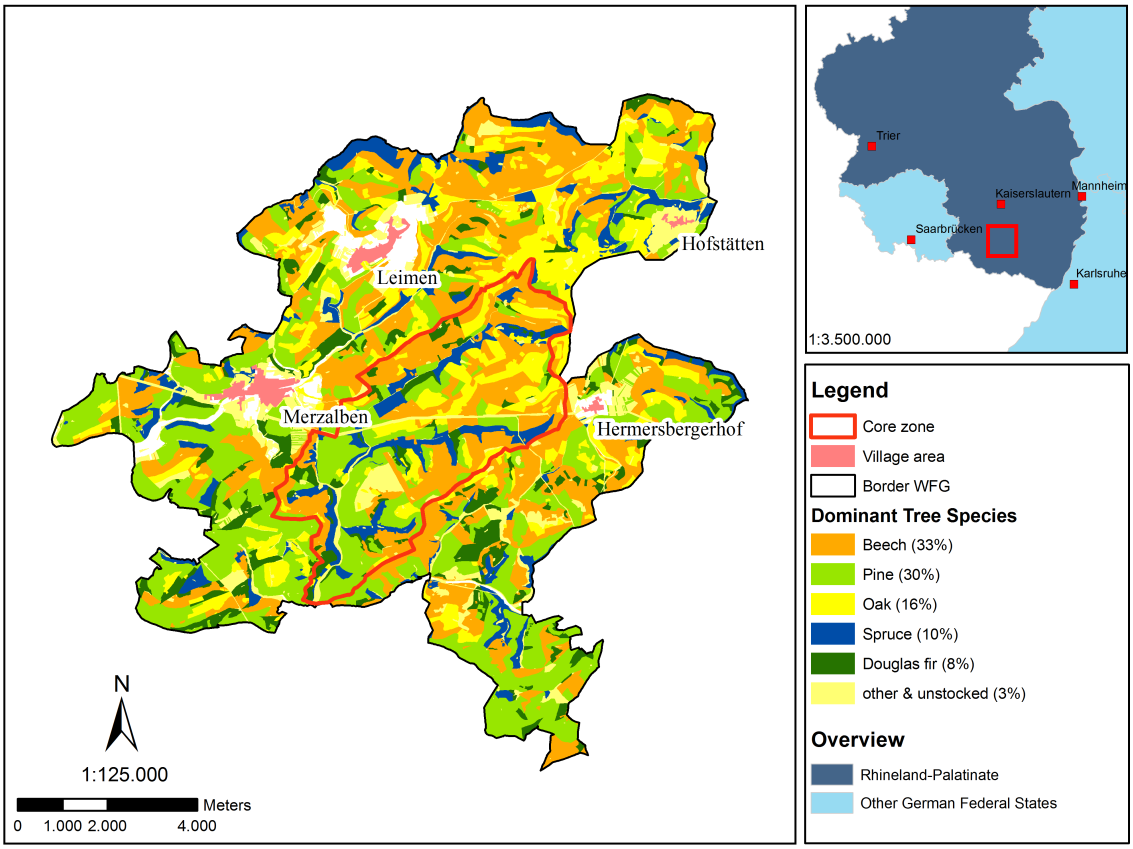


Figure 1: Map of the approx. 11.100 ha large wildlife research area „Palatinate Forest" and distribution of forest stands together with its geographic location in Rhineland-Palatinate. Note the central position of the biosphere core area "Quellgebiet der Wieslauter". (Source of data: FORSTEINRICHTUNG 2009 and ATKIS).

2 "Headwater of Wieslauter".

The southern extremity of the study area is separated by the federal road B 10. Between 1999 and 2008 a mean of 0.9 red deer (SD = 0.22) were harvested per 100 ha per year. Roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*) occur area-wide. Hunting bags of 2.7 (wild boar) and 2.3 (roe deer) per 100 ha and year are stated for the research area in the period from 1999/00 to 2005/06 (REIS 2006). A topographic map of the research area is presented in the appendix (fig. 10, p. 33).

# 3 Survey designs

## 3.1 2007

The survey 2007 was proceeded following the pellet count technique according to TOTTEWITZ *et al.* The 312 sample plots - each sized 100 m² - were evenly distributed over the area. The raster grid was 600 x 600 m, leading to a represented area of 39 ha per plot (fig. 2). Plots were installed as strip-transects with a length of 50 m and 2 m of detection width. The plots were cleared of pellets in autumn 2006 (FAR technique) and resampled collecting the pellets deposited there since clearance in spring 2007 (period of 38 days from March 7, 2007 to April 13, 2007). The search intensity was high (assistants moved slower than walking speed), a double observer method was chosen.

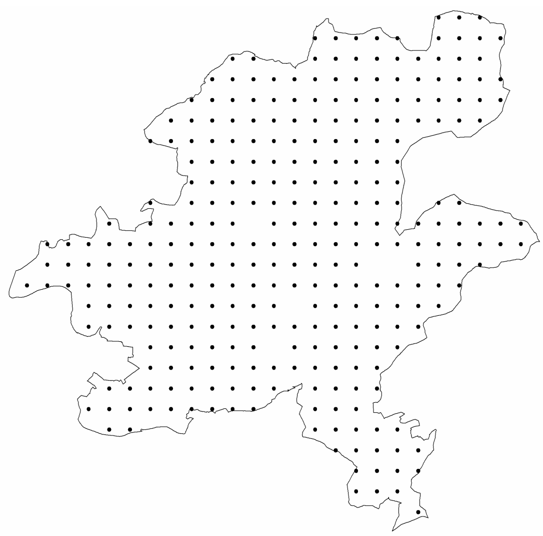

Figure 2: Survey design 2007. Map of the 302 sample locations. At each 'plot' a strip transect of 50 m length and 2 m width is sampled. (10 out of 312 planned sample plots were not realised due to logging activities and location in villages).

## 3.2 2008

The 2008 study design was enhanced with intermediate transects (IT) connecting the sample plots installed in 2007 (fig. 3), acknowledging the fact that the distance between plots had to be covered either way. This resulted in an inhomogeneous pattern of line transects (fig. 4). Search intensity on the 234 intermediate transects was lower (assistants moved in walking speed), the search width was the same compared to the 50 m plots (table 1).


Figure 3: Enhancement of 50 m strip transects located at sample plots based on a raster grid with connecting intermediate transects (IT) in 2008. Length of IT is depending on range between two sample plots (mean 609 m). Detection width is even (2 m).

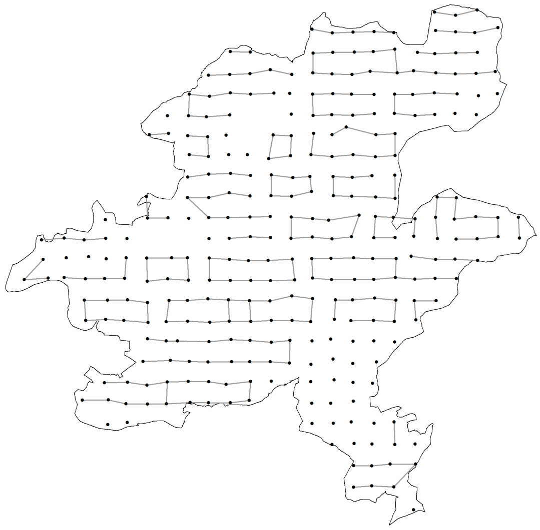

Figure 4: Survey design 2008. Map shows the 306 sample plots and all 234 realised intermediate transects (IT) connecting sample plots. Sampling was done using strip transects of 50 m length and 2 width at sample plots and also on 2 m width at intermediate transects. Length of connecting transects varied from 333 to 922 m. Six out of 312 planned sample plots were not realised due to logging activities and location in villages.

| Intermediate Transects (IT) | |
|---|---|
| count (N) | 234 |
| min. length | 333m |
| max. length | 922m |
| ∑ length | 142.5km |
| mean length | 609m |
| SD | 72m |

Table 1: Total numbers and length statistics of intermediate transects enhancing the raster based sample plots.

Again, the plots were cleared from pellets in autumn (FAR technique). No clearing was done on the intermediate transects (FSC technique). The sampling itself in spring was done in a period of 56 days from March 4, 2008 to April 28, 2008. The survey in 2008 is a combination of intensively searched 50 m strip transects and longer line transects with a less intense sampling.

## 3.3 2009 & 2010

The surveys conducted in 2009 and 2010 were different from the former data collection. Long line transects were established, without any distinction concerning the sampling intensity (assistants moved in walking speed on the whole transect). The search intensity is therefore comparable with those on the intermediate transects, just as the search width (2 m). If pellets were detected, adaptive cluster sampling was performed in a small but unspecified radius. For practical reasons, some parts of the transects lie outside the WFG whereas other parts have not been covered (in 2009 tests of long line transects were focused on hot spot areas and thus did not cover the western part). The maximum distance of approximately 1.200 m between two transects was deduced from home range estimations of red deer in the northern Vosges (HAMANN *et al*. 1997) where daily home range centre size varies from 76 to 200 ha. A circular area of approximately 150 ha has a radius of 700 m. This radius was also used as a buffer to select the represented area. In 2009 the survey involved thirteen transects, in 2010 three additional transects were established (fig. 5). Table 2 shows the length of the different transects and the sampling period. The clearance of transects at the beginning of the winter was not perpetuated in 2009 and 2010. The collection technique therefore shifts to FSC, although the effects may be the same due to high decomposition rates until late autumn in the Palatinate Forest (U. HOHMANN, pers. communication).

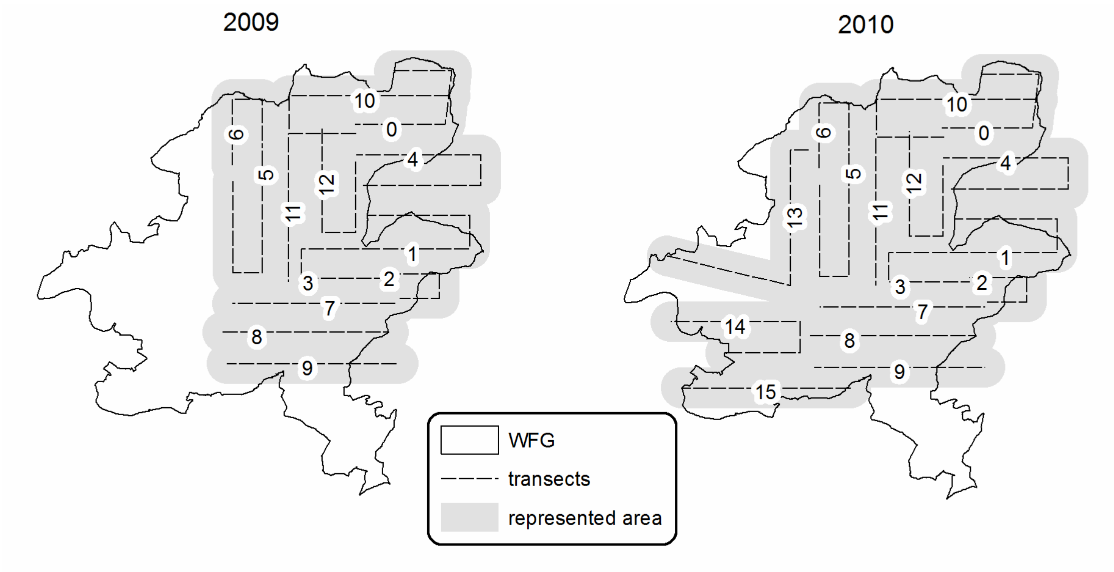


Figure 5: Locations of long line transects in 2009 (13 transects, ∑ 87.7 km ) and 2010 (16 transects, ∑ 111.5 km). The represented area is deduced from home range centre estimations in the northern Vosges.

| **Transect No.** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length (km) | 6.99 | 8.33 | 4.21 | 6.08 | 9.50 | 8.51 | 4.99 | 5.74 | 5.76 | 5.94 | 6.81 | 7.51 | 7.26 | 9.70 | 8.16 | 5.89 |
| Extent 2009 | Each transect was sampled on 9 consecutive working days from March 23rd to April 3rd 2009 (total length of the 13 realised transects: 88.7 km) | | | | | | | | | | | | | | | |
| Extent 2010 | Each transect was sampled on 10 consecutive working days from March 15th to March 26th 2010 (total length of the 16 realised transects: 111.5 km) | | | | | | | | | | | | | | | |

Table 2: Summary of long line transects used in 2009 and 2010 survey design to sample red deer faecal pellet groups. Due to bad weather conditions on one day sampling was performed only on 9 days in 2009.

Consecutive sampling of the same transects in 2009 and 2010 was done to generate recaptures for the population estimation via genetic CMR approach. Analyses of this thesis only deal with data from the first day in most cases since they describe winter distribution and ensure comparability within the different survey designs.

# 4 Methodology

## 4.1 Spatial data

To analyse the spatial patterns of *Cervus elaphus* winter distribution, the collected data of 2009 and 2010 had to be transformed into spatial data. All locations with pellet detections were thus implemented in ArcGIS. In 2009 and 2010 all field assistants carried GPS Loggers (Mobile Action, IgotU GT-120, http://www.i-gotu.com), tracking their position in short intervals. The recorded tracks (.gpx files) were converted into shapefiles with ArcGIS.[3] The resulting point feature class then allowed the allocation of the pellet detections noted in the (analogical) transect-logs with the GPS observations via timestamps. Missing observations due to technical troubles were estimated with the help of mean walking speed deduced from existing observations from ensuing days (29 out of 420 positions in 2010).

Insufficient data for the 1st day (due to malfunctions of some devices) necessitated the use of data from subsequent survey days on three out of twelve transects in 2009. Table 3 shows which days were used to substitute missing data. The difference results from the range between faecal pellet groups (FPG) detected on the first day (the day that should have been used if GPS data was sufficient) and FPG's found on the day actually used in the analysis. It describes bias concerning the number of detections, but spatial bias (dispersion of the points on the transect) cannot be acquired.

| **Transect** | **Sampling day used** | **FPG 1st day/day used** | **Difference** |
|---|---|---|---|
| 3 | 5th | 45/42 | -3 |
| 7 | 4th | 24/55 | 31 |
| 10 | 3rd | 64/30 | -34 |

Table 3: Survey days used to substitute insufficient data for the 1st day in 2009. Difference is the range between faecal pellet groups (FPG) detected on the 1st day of the survey and FPG's found on the day actually used in the analysis .

3 Shapefile = Spatial data format containing geometry and attributes of point, line or area features.

The author of this thesis, who participated in the sampling in 2010 while completing an internship, created and managed all spatial data from 2009 and 2010 and performed all further analyses (chapter 4.2 et seq.). The spatial data of the 50 m plots from the 2007 and 2008 surveys could be drawn from shapefiles and results of prior studies (BEVANDA and SIMON & OSTERHELD) in the majority of cases. Only the positions of pellet detections on the intermediate transects in 2008 had to be estimated by the author from survey data, giving the count of pellet groups on subsets of the transect.[4] Therefore, the intermediate transects were scaled into 12 even sized segments of approximately 50m length.[5] Pellet detections on subsets of the intermediate transects were noted in a table. At each subset with pellet detections, new point features were created in ArcGIS. The count of FPG's found on subsets is given to these points as an attribute. According to this procedure spatial accuracy of pellet detection on intermediate transects is ± 50 m and therefore comparable with detection accuracy on the 50 m strip transects at sample plots.

As a result, marked spatial point patterns arise from the four surveys.[6] In 2007 and 2008 one single location in the shapefile may represent several pellet detections (∑ FPG's per location = mark) on 50 m transects (or 50 m subsets of the intermediate transect). In 2009 and 2010 one single location represents exactly the position of the detection of any FPG. Points may be marked if more than one group was found at the tracked location.

## 4.2 Spatial analysis I: Kernel Density Estimation

To analyse the intensity of red deer distribution a Kernel Density Estimation (KDE) with program `R` was performed. The shapefiles were converted using the package `maptools`. The fixed KDE was done with the `spatstat` extension.

Kernel Density Estimation shows isopleths of intensity of utility distribution (WORTON 1989 and HEMSON *et al.* 2005).[7] The mean influence of points at intersections of a

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4 Survey data in Excel tables from analyses of BEVANDA 2008.

5 Depending on the length of the intermediate transects.

6 Extra information attached to the points are called marks. In this case mark variable is *continous* (attribute is pellet groups per location).

7 "'Intensity' is the average density of points (expected number of points per unit area)." (see BADDELAY 2008: p. 8).

superimposed grid is calculated. KDE is widely used for home range estimations with data from telemetry. There is no objective method to choose the bandwidth or smoothing factor *h*, the width of the 3D-kernel surrounding each data point (POWELL 2000). In home range estimations, 'least squares cross validations' for determining *h* are common.

Because indirect detections have been used in this thesis to gain information about spatial distribution of several animals, smoothing factors similar to the radius of home range centres (see chapter 3.3) are chosen. One pellet detection represents an area similar to one home range centre. An automatic edge correction was applied to minimise edge effect bias. Same colours of the isopleths show same predicted intensities of pellet detections. Thus, high intensities of pellet detections show hotspots of *C. elaphus* winter distribution.

**KDE illustration**

The plotted output of Kernel Density Estimation is shown as a colour-coded image. Colours orange and yellow are related to areas with high intensities of red deer winter distribution. Areas with lower intensities tend to blue. The intensity estimation was clipped to the WFG extent, i.e. detections lying outside of the WFG (possible only on long line transects) were not taken into account. The black line represents the border of the WFG.

Blue areas do not necessarily mean absence of red deer. If a higher smoothing factor was chosen, all areas with surrounding pellet detections would clearly be different from areas without detections. Otherwise a wider kernel (> *h*) would mean smoothing out details in higher intensities (WORTON). To be able to figure out where single detections were made, all locations with FPG findings are additionally plotted as black dots.

To compare the effect of marked point patterns (see chapter 5.1) KDE's with binary data were plotted first (fig. 6). Figure 7 shows the smoothed KDE with marks. The size of the circles increases with the number of pellet detections at the location (only metric KDE's). Smoothing factors (*sigma* in `R` language) chosen are 700 for binary kernels and 950 for metric kernels. The underlying `R-Code` is presented in the appendix (A.1, pp. 29-30).

## 4.3 Spatial analysis II: Quadrat Count Analysis

To balance the inequality in transect design between the four years, a Quadrat Count Analysis was done using ArcGIS. A fishnet with 73 quadrats was created and clipped to WFG extent. If not reduced by clipping, one square has an area of approximately 225 ha (~ 1.500 x 1.500 m). Subsequently the transect lengths and pellet detections for each quadrat and each year were calculated. Mean number of detections per 100 m transect length calculated for each square level differences between transect lengths among any study design.

**Qudrat Count Analysis illustration**

Quadrats without any containing transect (-subset) in a specific year are displayed in red colours (»NA«). Thereby these missing values can be distinguished from quadrats without pellet detections (quadrats containing transect sections but no pellet detections remain white). Graduated colours refer to the mean number of FPG detections on 100 m transect subsets in the respective areas.

**Distribution of patterns resulting from Quadrat Count Analysis**

SPSS is used to do a One-Sample Kolmogorov-Smirnov procedure to test the null hypothesis that the results from the quadrat patterns come from a Poisson distribution.[8] Instead of mean values per 100 m, mean values per km were used as the 1-Sample K-S Test can only be performed with integers. A variance ($s^2$) to mean ($m$) ratio (VTMR) generated from the data of the Quadrat Count Analysis is used to describe the dispersion of the data points. A Poisson distribution of detected pellet groups would have a VTMR equal to 1. Deviation from the Poisson distribution indicates clustered or clumped objects (VTMR > 1) or uniform and regular dispersion (VTMR < 1) (SKEHAN & FRIEDMAN 1984 and ELLIOTT 2002).

## 4.4 Evaluation of efficiency

To compare the efficiency of the different methods used in 2007 and 2008 respectively, time estimation was mainly done analysing time registrations. FPG count data, transect lengths and represented areas were calculated using ArcGIS or taken from reports. For 2009 and 2010 the considered data was extracted from ArcGIS or Access databases, containing all information from the transect logs.

The determined data imply pellet detection counts, transect lengths, represented area, travel costs and person-days. Means calculated from these data safeguard comparability of the different approaches.

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8 Poisson distribution is regarded as the appropriate ‘null’ model assuming complete spatial randomness (CSR) for point patterns (BADDELAY).

# 5 Results

## 5.1 Spatial data

The creation of spatial data results in four shapefiles containing geographic sample locations and number of pellet groups at each location. Table 4 shows a summary of the surveys from 2007 to 2010 generated from these shapefiles.

| | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| Points (N)[1] | 63 | 383 | 307 | 263 |
| Min FPG | 1 | 1 | 1 | 1 |
| Max FPG[2] | 15 | 25 | 4 | 11 |
| ∑ FPG | 130 | 748 | 344 | 420 |
| Mean | 2.06 | 1.96 | 1.12 | 1.60 |
| SD | 2.15 | 2.06 | 0.42 | 1.39 |
| Variance | 4.64 | 4.23 | 0.18 | 1.97 |

Table 4: Summary of key statistics from four faecal pellet group (FPG) counts on transects in the wildlife research area “Palatinate Forest” from 2007 to 2010.[1] Number of locations with pellet group detections (point features), [2] Highest number of FPG’s found at one location. Note: Locations in 2007 and 2008 represent 50 m transect subsets leading to higher max. FPG numbers.

## 5.2 Kernel Density Estimation

All years show high intensities in the north-eastern parts of the WFG (fig. 6 & 7).[9] A smaller hotspot of distribution is located in the east in 2007 and 2008. Low intensities in the central parts in 2007 are followed by higher intensities in the following years.

Considering the binary plots only (fig. 6) a small eastern-central hotspot becomes apparent at the plots 2007 and 2008 without the intermediate transects (IT). Additional FPG detections on the IT indicate an obvious second centre of red deer distribution in the central parts (2008 binary with IT). The KDE’s of 2009 and 2010 also show a second hot spot area of *C. elaphus* winter distribution. A small shift southwards of the central hotspot compared to 2008 is recognisable.

The smoothed KDE’s with metric data resulting from marked point patterns show similar tendencies (fig. 7). The first focus is located even more precisely in the north-eastern edge of the WFG. Further peaks are located in more central parts since 2008 (with IT).

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[9] Intensity here is equivalent to core areas or hotspots of distribution

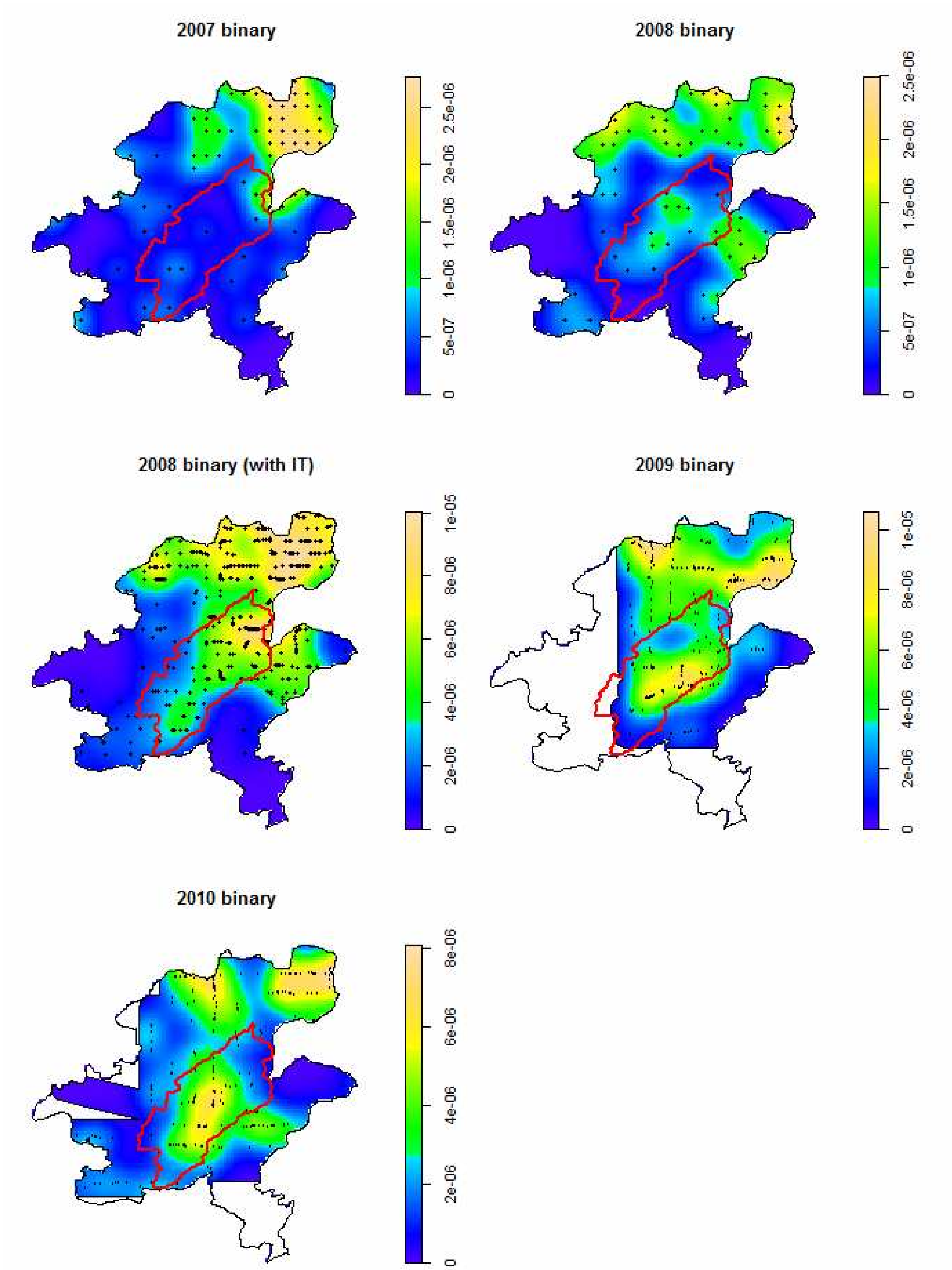


Figure 6: Each figure shows the specific Kernel Density Estimation computed with program R. These KDE's were done with binary data ('presence-absence' of pellet detections). The red line is the border of the biosphere reserve core zone "Quellgebiet der Wieslauter", the black line is the border of the wildlife research area (WFG). '+IT' = with Intermediate Transects. Areas inside the WFG remaining white are not represented by the study design (see chapter 3.3 and fig. 5). Hotspots of *C. elaphus* winter distribution are displayed in colours orange and yellow.

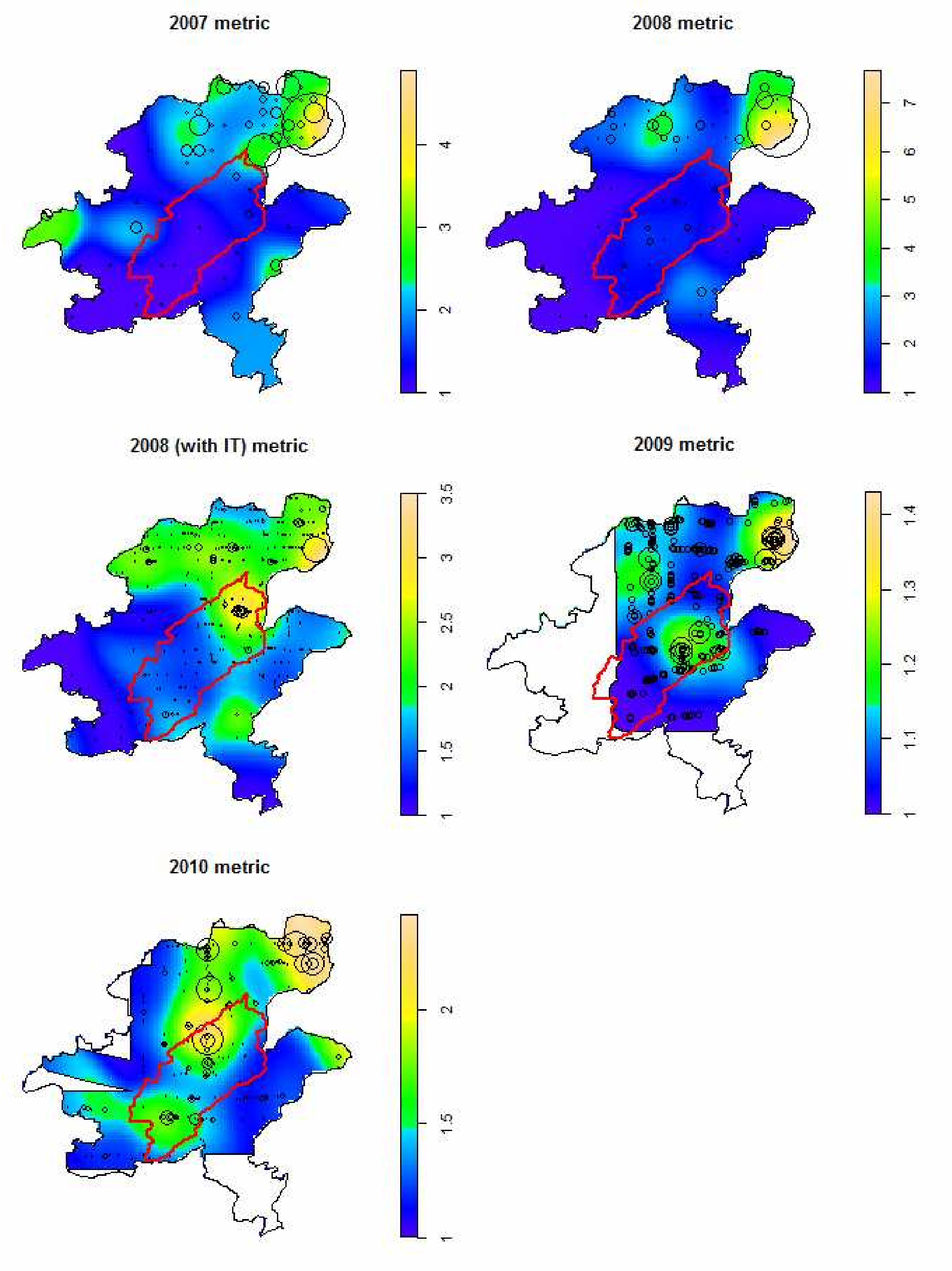


Figure 7: Metric KDE's resulting from marked point patterns with number of pellet detections per location for each study design. Circles increase with number of FPG's found. Red border indicates biosphere reserve core zone "Quellgebiet der Wieslauter". The black line is the border of the wildlife research area (WFG). Areas inside the WFG remaining white are not represented by the specific study design (see chapter 3.3 and fig. 5). Hotspots of *C. elaphus* winter distribution are displayed in colours orange and yellow.

## 5.3 Quadrat Count Analysis

Concerning the spatial winter distribution of red deer in the WFG, the results from the Quadrat Count Analysis are similar to those of the Kernel Density Estimations. Each year shows high detection rates in the northern parts. A minor centre of distribution is recognisable in the east in 2007 and 2008. As noticed before at the KDE's the central parts gain higher values in surveys with long line transects (2009 and 2010). Some squares in the centre of the WFG show similar values compared to the peaks in north-east (fig. 8).

Another striking aspect is the reduction of absent values in years or rather designs with long line transects (table 5). This factor has to be considered in the evaluation of the different methods.

| **Squares with:** | **2007** | **2008** | **2008 (IT)** | **2009** | **2010** |
|---|---|---|---|---|---|
| zero detections | 33 | 28 | 16 | 3 | 12 |
| detections | 33 | 38 | 50 | 34 | 41 |
| NA | 7 | 7 | 7 | 36 | 20 |
| % zero values[1] | 50% | 42% | 24% | 8% | 21% |

Table 5: Summary showing number and percentage of squares containing transect segments but no pellet group detection (zero detections). Squares without any containing transects are »NA«. [1] »NA« values are left out in calculation to show effect of chosen method regarding possibility of non-detection.

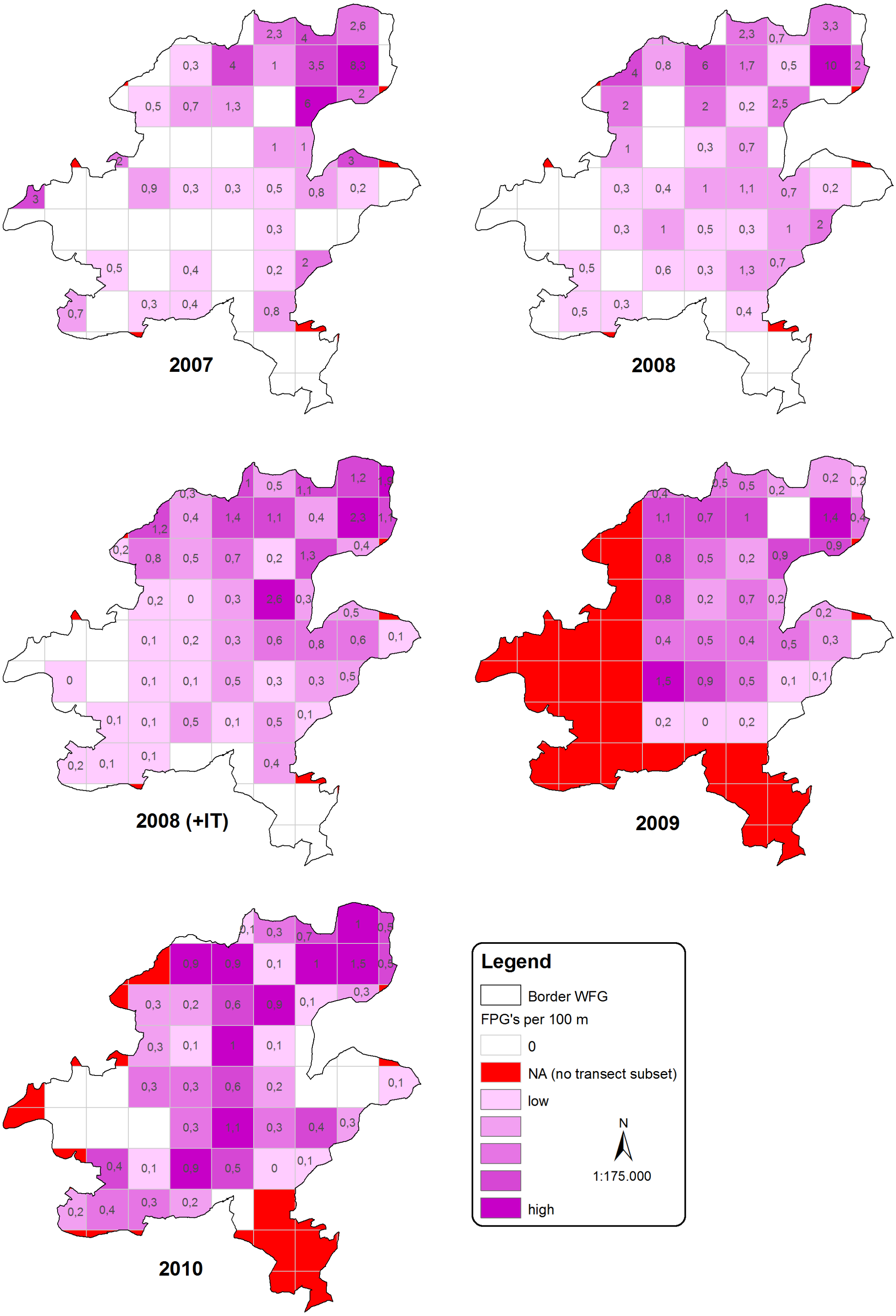


Figure 8: Maps show the results from Quadrat Count Analysis. Each map represents one survey design showing the mean numbers of faecal pellet group detections per 100 m transect length. Graduated colours indicate whether the number of detections in each specific square is low or high in the respective year. Squares without any containing transect (-subset) are regarded as absent values (»NA«).

Table 6 shows the key statistics of the Quadrat Count Analysis (the whole matrix is presented in the appendix, A.2, pp. 31-32).

| | **2007** | **2008** | **2008(+IT)** | **2009** | **2010** |
|---|---|---|---|---|---|
| N (∑ of detections per 100 m) | 55.86 | 56.35 | 28.54 | 17.56 | 18.29 |
| Mean detections per 100 m | 0.85 | 0.85 | 0.43 | 0.47 | 0.35 |
| median | 0.11 | 0.33 | 0.23 | 0.41 | 0.27 |
| SD | 1.52 | 1.64 | 0.55 | 0.38 | 0.36 |
| Var | 2.30 | 2.70 | 0.30 | 0.15 | 0.13 |
| VTMR | 2.72 | 3.17 | 0.70 | 0.31 | 0.37 |
| Dispersion (following VTMR) | clustered | clustered | uniform | uniform | uniform |
| CV | 1.79 | 1.93 | 1.27 | 0.81 | 1.03 |

Table 6: Key statistics from quadrat count analysis of different transect methods of pellet group counts. *SD* = standard deviation, *VTMR* = variance-to-mean-ratio, *CV* = coefficient of variation. *VTMR* of *1* means random (Poisson), > *1* = clustered, < *1* = uniform.

## 5.4 Distribution

The results from the One-Sample-Kolmogorov-Smirnov Test show significance below α 0.05 for all survey designs and therefore the patterns are not Poisson (i.e. the distribution is not random).

| **One-Sample Kolmogorov-Smirnov Test** | | | | | | |
|---|---|---|---|---|---|---|
| | | QA[1]2007 | QA2008 | QA2008IT[2] | QA2009 | QA2010 |
| N (Missing values excluded) | | 66 | 66 | 66 | 37 | 53 |
| Poisson Parameter[a,,b] | Mean | 8.42 | 8.53 | 4.30 | 4.76 | 3.47 |
| Most Extreme Differences | Absolute | .559 | .501 | .353 | .259 | .257 |
| | Positive | .559 | .501 | .353 | .259 | .257 |
| | Negative | -.184 | -.160 | -.154 | -.136 | -.160 |
| Kolmogorov-Smirnov Z | | 4.543 | 4.069 | 2.864 | 1.574 | 1.873 |
| Asymp. Sig. (2-tailed) | | .000 | .000 | .000 | .014 | .002 |

a. Test distribution is Poisson.

b. Calculated from data.

Table 7: Output of 1-Sample K-S Test computed with SPSS to test spatial patterns resulting from quadrat count analysis of line transect methods to sample faecal pellet groups.[1] *QA* =quadrat count analysis, [2] *IT* = with intermediate transects.

The VTMR suggests that the distribution in 2007 and 2008 (without IT) is clustered. With additional intermediate transects the VTMR indicates a slightly uniform distribution, while the patterns from 2009 and 2010 are clearly uniform (table 6).

## 5.5 Efficiency

### 5.5.1 Detection rates

| | Transects realised | ∑ Length (km) | ∑ FPG[1] | FPG/km | Area (km²)[2] | FPG/km² | Sampling days[3] | Person-days[4] | Length p.PD. (km)[5] | Detections p.PD.[6] |
|---|---|---|---|---|---|---|---|---|---|---|
| **2007 (50m strip transects)** | 302 | 15.1 | 131 | **8.7** | 108.7 | 1.2 | 16 | 32***** | 0.47 | 4.09 |
| **2008 (only 50m strip transects)** | 306 | 15.3 | 150 | **9.8** | 110.2 | 1.4 | 28 | | | |
| **2008 (only intermediate tr.)** | 234 | 142.5 | **601** | 4.2 | 129.2 | **4.7** | 21 | | | |
| **2008 (total)** | (306/234) | 157.8 | **751** | 4.8 | 110.2 | **6.8** | 28 | 43***** | 3.67 | 17.47 |
| **2009 (long line transects)** | 13 | 87.7 | **378** | 4.3 | 96.5 | **3.9** | 1 | **13** | 6.75 | **29.08** |
| **2010 (long line (transects)** | 16 | 111.5 | **420** | 3.8 | 126.1 | **3.3** | 1 | **16** | 6.97 | **26.25** |

Table 8: Summary of evaluation of different pellet group count methods. [1]faecal pellet groups detected, [2]area represented by survey design, [3]days needed to sample all transects, [4]person-days needed (~ 7.5 h assumed as one person-day), [5]transect length sampled per person-day, [6]detections per person-day, * a double observer method used at the whole survey 2007 and partly 2008 leads to (almost) doubled person-days.

The first notable fact is the increase of the sample size (∑ FPG) with a shift to long line transects (table 8). FPG counts of 131 and 150 samples respectively found on the raster-based 50 m plots are less than one-third compared with 601, 378 and 420 samples found on long line transects. Although the intensive search on the 50 m plots produces detection rates (per km) twice as much as the search behaviour on the line transects, they cannot match up with the detection rate per person and day achieved in 2009 and 2010. The efficiency concerning detection rates per person-day is four times higher in 2008 with additional intermediate transects (4 compared to 17) and even more than six times higher with long line transects (4 compared to 26 and 29). That means that even if only one observer would have sampled equivalent numbers of FPG's in the same time in 2007, detections per person-day on long line transects would still be three times higher.

Higher rates in findings per person-day in 2009 compared to 2010 suggest higher overall detection rates. Those two years are easy to compare.[10] A focus on the 13 transects that were sampled in 2009 as well as 2010 reveals FPG counts to be nearly the same in the beginning and lasts on high levels until the 6th day of the surveys. The difference of approximately 700 overall detections (2741 compared with 2017) is mainly a result of decreasing detections on the last days of survey in 2010. Also, the total number of 2741 detections in 2009 was done with 19 runs less (table 9 and fig. 9).

| Day | 2009 | 2010 |
|---|---|---|
| 1 | 372* | 379 |
| 2 | 397 | 393 |
| 3 | NA** | 213 |
| 4 | 339 | 194 |
| 5 | 369 | 255 |
| 6 | 309 | 304 |
| 7 | 206 | 86 |
| 8 | 370 | 70 |
| 9 | 187 | 80 |
| 10 | 192 | 43 |
| ∑ | 2741 | 2017 |
| ∑ transects realised | 110*** | 129 |
| FPG's per transect | 24.9 | 15.6 |

Table 9: Number of pellet group detections (FPG's) on consecutive sampling days on 13 similar transects sampled 2009 as well as 2010. * Difference of -6 (372) compared with results in table 8 (378) due to the fact that transect no. 2 was sampled for the first time on day 5 of survey 2009, ** bad weather conditions did not allow for sampling on 3rd day of survey 2009, *** absence of one whole sampling day and seven further individual transect runs not realised on different days.

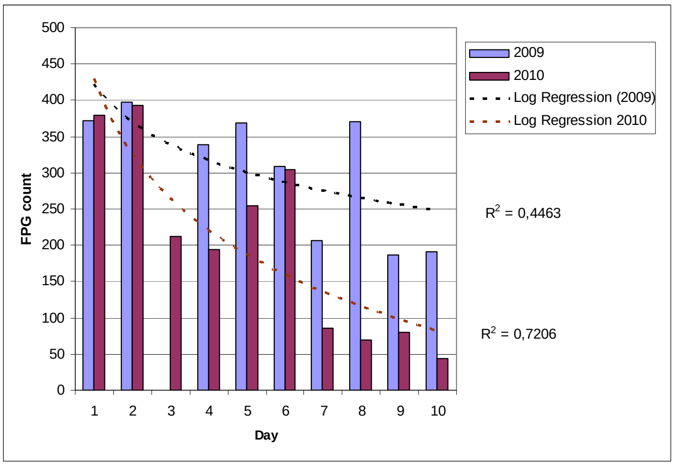


Figure 9: Histogram showing the FPG counts on each day of surveys 2009 and 2010 (transects 0 – 12). A logarithmic trendline and corresponding R² values are added.

[10] Note: The following results regard data from consecutive sampling days on the same transect. This was done only in 2009 and 2010. Data from consecutive sampling days was not taken into consideration of estimation of *C. elaphus* winter distribution and overall evaluation of efficiency within the four different methods used. It may help analysing differences in detection rates between surveys 2009 and 2010.

### 5.5.2 Travel costs

Estimation of travel costs cannot be computed for every year. Sufficient data were available for 2007 and 2010. In 2010, 300 km travelled by cars on the first day of long line transects are opposed to 1.700 km travelled in 2007. Since coverage of the area was different, travel effort was calculated to sample an area of one square kilometre represented by the specific study design. In 2007, 15.6 km were driven to sample one square kilometre, in 2010 this value could be reduced to 2.4 km per $km^2$.

# 6 Discussion

## 6.1 Spatial distribution

The recent shift of red deer winter distribution into the central parts oft he WFG as indicated by the KDE’s and the Quadrat Count Analysis can be interpreted in several ways. One reason might be the use of an inappropriate method to investigate red deer abundance in 2007 (and partly 2008). In other words, red deer were present in the central parts but not detected. This is supported by a number of sightings of live deer in these parts by foresters in the winters of 2006/07 and 2007/08 (HOHMANN & HUCKSCHLAG). In the spring 2007 survey only 100 m² were searched representing 39 ha. If by chance no droppings were found on the 50 m strip it produced a false »absent value«. Long line transects simply increased the length and density the area was searched on (i.e. $\overline{X}$ of 230 m at 50 m plots compared to $\overline{X}$ > 1.800 m at long line transects per quadrat count square). Areas with less frequent distribution of red deer become apparent, mistakenly assumed absence becomes less probable.

As an additional explanation a real shift of the intensity of *C. elaphus* presence might have occurred throughout the years. Thereupon absent values in 2007 and 2008 would not be the result of pure chance. The ‘Quellgebiet der Wieslauter’, core-zone of the biosphere reserve, spans over the newly discovered focus of distribution (figure 6 & 7). Circumstances were not constant in the core-zone during the last four years. Within the framework of the ungulate monitoring concept of the WFG all hunting activities should have been continued until 2012 with the same effort. Actually, a creeping decrease can be stated (D. HUCKSCHLAG, pers. communication). Furthermore, increased attraction to red deer because of decreased disturbance from hunting can even be augmented by logging activities in the core zone. Extraction of species inadequate to the site (Spruce and Douglas fir) serve as habitat improvement. The mere presence of chainsaw noise is deemed to be attracting deer. Tree logging creates open spaces with arriving ground vegetation as food supply. Also, crown material lying on the ground after harvesting is grazed by red deer.

## 6.2 Evaluation

### 6.2.1 Sample size and efficiency

One major concern about the study design is to have a time and cost-efficient method generating adequate accuracy and sample size.

Higher values of dropping counts per distance on the 50 m plots in the surveys 2007 and 2008 seem to result from higher search intensities. Observer speed was less than on longer transects 2009 and 2010. Consequently, the mean number of findings per distance on the intermediate transects 2008 decreased as well. Higher means of detection in the quadrat count analysis in 2007 and 2008 (without IT) are therefore implications of higher search intensity on the 50 m plots (i.e. squares with values 6, 8, and 10) (fig. 8).

According to this, higher search speed might cause oversights of pellet groups. This may be the reason for the steady detection rate on the first days of long line transect surveys (table 9). Another explanation for almost unvarying detection numbers between the first survey days might be attributed to assistants' slight departure from the transect line of the previous day: The long line transects were not marked, navigation was done via compass and map. Both interpretations would mean a decrease of detections at the end of the survey. Pellets overlooked in first instance are sampled in the consecutive days and field assistants more constantly use the same transect line. This scheme can be stated for 2010, but not for 2009. Either more new droppings were deposited in 2009 or field assistants further departed from the transect line. The plus of 700 overall detections in 2009 compared to 2010 cannot result from more pellets effectively existing, as detection rates on the first day are very much the same. In further investigations, comparing the daily GPS tracklogs might give a hint to which extent field assistants deviate from the intended transect line and thereby influence detection rates.

For estimating winter distribution and evaluation of efficiency the author had to concentrate on the first sampling of a transect or plot in spring. Nonobservance of pellets due to higher search speed in 2008 (on intermediate transects), 2009 and 2010 has to be assumed constantly over the transect distance. The identification of red deer distribution hotspots is still feasible with overlooked pellets since the ratio remains the same. Additionally, overall detections increased with less time needed although some pellets probably remained undetected. Since one major goal of the long line transects was to increase sample size, one may approve to the certainty of overlooking FPG’s.

Besides the increase of sample size and higher detection rates per person and working day, the long line transects imply several further advantages. The short overall sampling period minimises bias in detection probability by reason of changing circumstances such as soil vegetation, swirling of the litter compressed by snow, different decomposition rates and beetle activity. As an additional benefit of short sampling periods a reduction of travel costs can be identified. On the other hand, even if the sampling date is chosen properly, remaining snow coverage on transect subsets may be a problem with narrow time slots. In 2010 the field assistants were to designate areas that were still covered by snow on the first day. Thus approx. 5 km of 111 km (4.5 %) total transect length showed snow coverage. Deposited pellets lying beneath the snow could not be detected on these parts.

| | |
|---|---|
| Transect length 2010 | 111.4 km |
| Transect length 2009 | 87.6 km |
| Snow-coverage 2010 | 5.059 m |
| % snow covered (extent 2010) | 4.5 % |
| % snow covered (extent 2009) | 5.8 % |

Table 10: Percentage of transect length with snow-coverage in 2010.

The narrow time frame of the long line transects means that many assistants are used. Some inexperienced observers are recruited as additional field staff. Admittedly this minimises costs but bears the risk of observer bias. Species-specific distinction of faecal pellets can influence the sample size and winter distribution estimation, but not the population density estimation via genetic CMR. Nevertheless, indicated hotspots of *C. elaphus* distribution should be correct even if some pellets were not sampled right. In 2010 a second look at the sampled pellets indicated 17 out of 437 pellets found on the first day as mistakenly roe deer (*Capreolus capreolus*) or wild boar (*Sus scrofa*) pellets.

### 6.2.2 Coverage of area

A smaller coverage of the area is accompanied with the long line transects. The distance between two transects is greater than between two plots and some areas of the study region are omitted completely. Greater distances between transects do not seem to influence winter distribution estimation via KDE or quadrat count analysis. Areas not covered by any transects in the survey 2010 might have to be completed with new transects. The shift from narrow raster based plots to transects with greater distances in between is a secondary factor making the long line transects more efficient.

# 7 Conclusion

With small population densities the suitability of the chosen method for FPG counts via line transects is of great importance and has to be selected carefully. Beside the issue of efficiency the most critical point is the danger of underestimation of wildlife distribution and density due to overlooking pellets. Small population densities bear the risk not to detect FPG's as indirect proof of actual occurrence of wildlife. If the study design is based on short transect plots, the possibility to miss or detect droppings by chance increases. As a consequence of the coincidence factor, misinterpretations may lead to wrong decisions in wildlife management. Additional data (such as sightings reported by hunters, camera-traps, spotlight counts, thermal-infrared sensing etc.) may give a hint whether areas with few or even zero pellet detections are artefacts due to an inappropriate method chosen.

The present study suggests that long line transects minimise a potential bias and incorrect assumptions of spatial distribution patterns. Especially in areas with small populations they can be considered an accurate, time- and cost-efficient alternative to procedures that follow TOTTEWITZ *et al.*[11]

Long line transects are not restricted to small populations but rather approve as very time and cost efficient in general. If the method to estimate population density is not depending on detection of every single pellet group, the effort to sample droppings can be minimised with simultaneously increasing sample size by using long line transects. Restrictions that have to be taken into account are a sufficient number of both technical devices and (experienced or trained) field assistants available for a short period of time. As GPS trackers are not expensive assistants should better carry two devices in order to make sure that the effort to get exact positions of the detected pellets is not ruined by malfunctions.

Further investigations might be useful to determine whether pellet detection probability on long line transects is the same at each subset. Observer accuracy on long steep slopes of several 100 meters, for instance, might vary on long line transects compared to a smaller strip transect of just 50 m in difficult terrain.

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[11] A first preliminary estimation of the red deer population in the WFG from 2010 resulted in 424 animals (confidence interval 379 – 488) for the research area. This corresponds to a density of 3.53 animals (3.16 – 4.06) per 100 ha (C. EBERT, pers. communication).

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# A Appendices

## A.1 R-Code

```
library(maptools)
library(spatstat)
#2007
    L07 <- readShapeSpatial("D:/R/Losung_2007.shp")
    y <- as(L07, "SpatialPoints")
    z <- as(y, "ppp")
    Grenze <- readShapeSpatial("D:/R/GrenzeWFG.shp")
    WFG <- as(Grenze, "SpatialPolygons")
    WFG <- as.owin(WFG)
    Kart07 <- z[WFG]
#binary:
    den07 <- density(Kart07, sigma = 700, edge=TRUE)
#marked point pattern
    m <- L07$ANZAHL
    marks(z) <- m
    Kart07m <- z[WFG]
    Y07 <- Kart07m
#2008withouIT
    L08 <- readShapeSpatial("D:/R/Losung_2008.shp")
    y <- as(L08, "SpatialPoints")
    z <- as(y, "ppp")
    Kart08 <- z[WFG]
#binary
    den08 <- density(Kart08, sigma = 700, edge=TRUE)
#marked point pattern
    Grenze <- readShapeSpatial("D:/R/GrenzeWFG.shp")
    WFG <- as(Grenze, "SpatialPolygons")
    WFG08 <- as.owin(WFG)
    m <- L08$Anzahl
    marks(z) <- m
    Kart08m <- z[WFG08]
    Y08 <- Kart08m
#2008withIT
    L08ZT <- readShapeSpatial("D:/R/Losung_2008mitZT.shp")
    y <- as(L08ZT, "SpatialPoints")
    z <- as(y, "ppp")
    Grenze <- readShapeSpatial("D:/R/GrenzeWFG.shp")
    WFG <- as(Grenze, "SpatialPolygons")
    WFG <- as.owin(WFG)
    Kart08ZT <- z[WFG]
#binary
    den08ZT <- density(Kart08ZT, sigma = 700, edge=TRUE)
#marked point pattern
    Grenze <- readShapeSpatial("D:/R/GrenzeWFG.shp")
    WFG <- as(Grenze, "SpatialPolygons")
    WFG08ZT <- as.owin(WFG)
    m <- L08ZT$Anzahl
    marks(z) <- m
    Kart08mZT <- z[WFG08ZT]
    Y08ZT <- Kart08mZT
#2009
    L09 <- readShapeSpatial("D:/R/Losung_2009neu.shp")
    y <- as(L09, "SpatialPoints")
    z <- as(y, "ppp")
    Grenze <- readShapeSpatial("D:/R/GrenzeWFG.shp")
    WFG <- as(Grenze, "SpatialPolygons")
    WFG <- as.owin(WFG)
    Kart09 <- z[WFG]
    #binary
    den09 <- density(Kart09, sigma = 700, edge=TRUE)
#marked
    Grenze <- readShapeSpatial("D:/R/GrenzeWFG.shp")
    WFG <- as(Grenze, "SpatialPolygons")
    WFG09 <- as.owin(WFG)
    m <- L09$Anzahl
    marks(z) <- m
    Kart09m <- z[WFG09]
    Y09 <- Kart09m
#2010
    L10 <- readShapeSpatial("D:/R/Losung_2010neu.shp")
```

```
    y <- as(L10, "SpatialPoints")
    z <- as(y, "ppp")
    Grenze <- readShapeSpatial("D:/R/GrenzeWFG.shp")
    WFG <- as(Grenze, "SpatialPolygons")
    WFG <- as.owin(WFG)
    Kart10 <- z[WFG]
#binary
    den10 <- density(Kart10, sigma = 700, edge=TRUE)
#marked
    Grenze <- readShapeSpatial("D:/R/GrenzeWFG.shp")
    WFG <- as(Grenze, "SpatialPolygons")
    WFG10 <- as.owin(WFG)
    m <- L10$Anzahl
    marks(z) <- m
    Kart10m <- z[WFG10]
    Y10 <- Kart10m
#core zone "headwater of wieslauter"
    core <- readShapeSpatial("D:/R/kernzone.shp")
    core <- as(core, "SpatialPolygons")
    core <- as.owin(core)
#areas not represented 2009 & 2010
    notcovered09 <- readShapeSpatial("D:/extent2009.shp")
    WFG09 <- as(notcovered09, "SpatialPolygons")
    WFG09 <- as.owin(WFG09)
    notcovered10 <- readShapeSpatial("D:/extent2010.shp")
    WFG10 <- as(notcovered10, "SpatialPolygons")
    WFG10 <- as.owin(WFG10)
#output binary KDE
    par(mfrow=c(2,3))
        plot(den07, axes=FALSE, main="2007 binary")
        plot(Kart07, add = TRUE, cex=0.3, pch = 3, col = 1)
        plot(WFG, add=TRUE, lwd=1.5)
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
        plot(den08, axes=FALSE, main="2008 binary")
        plot(Kart08, add = TRUE, cex=0.3, pch = 3, col = 1)
        plot(WFG, add=TRUE, lwd=1.5)
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
        plot(den08ZT, axes=FALSE, main="2008 binary (with IT)")
        plot(Kart08ZT, add = TRUE, cex=0.3, pch = 3, col = 1)
        plot(WFG,add=TRUE, lwd=1.5)
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
        plot(den09, axes=FALSE, main="2009 binary")
        plot(Kart09, add = TRUE, cex=0.3, pch = 3, col = 1)
        plot(WFG09, add=TRUE, col="white")
        plot(WFG, add=TRUE, lwd=1.5)
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
        plot(den10, axes=FALSE, main="2010 binary")
        plot(Kart10, add = TRUE, cex=0.3, pch = 3, col = 1)
        plot(WFG10, add=TRUE, col="white")
        plot(WFG, add=TRUE, lwd=1.5)
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
    par(mfrow=c(1,1))
#ouput metric KDE
    par(mfrow=c(2,3))
        plot(smooth.ppp(Y07, sigma=950, edge=TRUE),main="2007 metric")
        plot(Y07, add = TRUE)
        plot(WFG, add=TRUE, lwd=1.5)
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
        plot(smooth.ppp(Y08, sigma=950, edge=TRUE),main="2008 metric")
        plot(Y08, add = TRUE)
        plot(WFG, add=TRUE, lwd=1.5)
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
        plot(smooth.ppp(Y08ZT, sigma=950, edge=TRUE),main="2008 (with IT) metric")
        plot(Y08ZT, add = TRUE)
        plot(WFG, add=TRUE, lwd=1.5)
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
        plot(smooth.ppp(Y09, sigma=950, edge=TRUE),main="2009 metric")
        plot(Y09, add = TRUE)
        plot(WFG, add=TRUE, lwd=1.5)
        plot(WFG09, add=TRUE, col="white")
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
        plot(smooth.ppp(Y10, sigma=950, edge=TRUE),main="2010 metric")
        plot(Y10, add = TRUE)
        plot(WFG, add=TRUE, lwd=1.5)
        plot(WFG10, add=TRUE, col="white")
        plot(core, add=TRUE, border=2, lwd=2, lty=1)
    par(mfrow=c(1,1))
```

## A.2 Results from Quadrat Count Analysis with ArcGIS

| Quadrat No. | FPG p. 100 m 2007 | FPG p. 100 m 2008 | FPG p. 100 m 2008 (+IT) | FPG p. 100 m 2009 | FPG p. 100 m 2010 | Σ FPG 2007 | Σ FPG 2008 | Σ FPG 2008 (+IT) | Σ FPG 2009 | Σ FPG 2010 | Length 2007 (m) | Length 08 (m) | Length 08 (+IT) (m) | Length 09 (m) | Length 10 (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 791 | 0 | 0 |
| 2 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 1145 | 0 | 0 |
| 3 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 0 | 50 | 50 | 50 | 0 | 0 |
| 4 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 0 | 50 | 50 | 50 | 0 | 0 |
| 5 | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 0 | 50 | 50 | 50 | 0 | 0 |
| 7 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 0 | 400 | 400 | 1086 | 0 | 0 |
| 8 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 0 | 250 | 250 | 2394 | 0 | 0 |
| 9 | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0.7 | 0.0 | 0.2 | NA | 0.2 | 1 | 0 | 2 | 0 | 2 | 150 | 150 | 1224 | 0 | 1087 |
| 11 | 0.0 | 0.5 | 0.1 | NA | 0.4 | 0 | 1 | 3 | 0 | 6 | 200 | 200 | 3316 | 0 | 1547 |
| 12 | 0.3 | 0.3 | 0.1 | NA | 0.3 | 1 | 1 | 6 | 0 | 5 | 300 | 300 | 4038 | 0 | 1547 |
| 13 | 0.5 | 0.0 | 0.0 | NA | 0.2 | 1 | 0 | 0 | 2 | 3 | 200 | 250 | 2640 | 0 | 1547 |
| 14 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 0 | 0 | 0 | 1 | 0 | 150 | 100 | 100 | 0 | 4 |
| 15 | 0.8 | 0.4 | 0.4 | NA | NA | 2 | 1 | 1 | 0 | 0 | 250 | 250 | 250 | 0 | 0 |
| 16 | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 4 | 100 | 150 | 1016 | 0 | 0 |
| 18 | 0.5 | 0.5 | 0.1 | NA | 0.4 | 1 | 1 | 3 | 0 | 5 | 200 | 200 | 2565 | 0 | 1124 |
| 19 | 0.0 | 0.0 | 0.1 | NA | 0.1 | 0 | 0 | 4 | 0 | 2 | 450 | 450 | 5201 | 0 | 2451 |
| 20 | 0.6 | 0.4 | 0.5 | 0.2 | 0.9 | 2 | 2 | 25 | 4 | 21 | 350 | 450 | 5356 | 2470 | 2470 |
| 21 | 0.0 | 0.3 | 0.1 | 0.0 | 0.5 | 0 | 1 | 4 | 1 | 15 | 400 | 300 | 3343 | 3094 | 3094 |
| 22 | 0.2 | 1.3 | 0.5 | 0.2 | 0.0 | 1 | 6 | 6 | 5 | 1 | 450 | 450 | 1294 | 3089 | 3089 |
| 23 | 2.0 | 0.7 | 0.1 | 0.0 | 0.1 | 3 | 1 | 1 | 0 | 1 | 150 | 150 | 876 | 1355 | 1355 |
| 24 | 0.0 | 0.0 | 0.0 | NA | NA | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 1388 | 0 | 0 |
| 25 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 0 | 0 | 1 | 0 | 0 | 250 | 250 | 2921 | 0 | 1282 |
| 26 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 0 | 0 | 0 | 0 | 0 | 200 | 200 | 3432 | 0 | 1547 |
| 27 | 0.0 | 0.3 | 0.1 | NA | 0.0 | 0 | 1 | 6 | 0 | 0 | 300 | 300 | 4042 | 0 | 2533 |
| 28 | 0.0 | 1.0 | 0.1 | 1.5 | 0.3 | 0 | 3 | 6 | 15 | 3 | 300 | 300 | 4357 | 972 | 972 |
| 29 | 0.0 | 0.7 | 0.5 | 0.9 | 1.1 | 0 | 1 | 18 | 18 | 22 | 200 | 150 | 3776 | 1957 | 1957 |
| 30 | 0.3 | 0.3 | 0.2 | 0.5 | 0.3 | 1 | 1 | 9 | 17 | 10 | 300 | 350 | 3619 | 3094 | 3094 |
| 31 | 0.0 | 1.0 | 0.3 | 0.1 | 0.4 | 0 | 2 | 14 | 2 | 12 | 200 | 200 | 4100 | 2687 | 2687 |
| 32 | 0.0 | 2.0 | 0.5 | 0.1 | 0.3 | 0 | 3 | 5 | 1 | 2 | 150 | 150 | 1081 | 749 | 749 |
| 33 | 3.0 | 0.0 | 0.0 | NA | 0.0 | 3 | 0 | 0 | 0 | 0 | 100 | 100 | 591 | 0 | 70 |
| 34 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 0 | 0 | 0 | 0 | 0 | 350 | 350 | 1724 | 0 | 1593 |
| 35 | 0.0 | 0.0 | 0.0 | NA | 0.0 | 0 | 0 | 0 | 0 | 0 | 200 | 250 | 1758 | 0 | 1591 |
| 36 | 1.1 | 0.2 | 0.1 | NA | 0.3 | 4 | 1 | 3 | 0 | 6 | 350 | 450 | 2318 | 0 | 1836 |
| 37 | 0.2 | 0.5 | 0.2 | 0.4 | 0.3 | 1 | 2 | 8 | 10 | 7 | 450 | 400 | 4676 | 2356 | 2356 |
| 38 | 0.3 | 1.0 | 0.3 | 0.5 | 0.6 | 1 | 3 | 13 | 19 | 26 | 300 | 300 | 4172 | 4043 | 4043 |
| 39 | 0.4 | 1.3 | 0.6 | 0.4 | 0.2 | 2 | 5 | 30 | 10 | 6 | 450 | 400 | 5222 | 2506 | 2506 |
| 40 | 0.7 | 0.8 | 0.8 | 0.5 | 0.0 | 2 | 2 | 24 | 11 | 0 | 300 | 250 | 3145 | 2189 | 2189 |
| 41 | 0.2 | 0.2 | 0.6 | 0.3 | 0.0 | 1 | 1 | 26 | 9 | 0 | 450 | 450 | 4332 | 2706 | 2706 |
| 42 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0 | 0 | 2 | 0 | 2 | 200 | 200 | 2219 | 1604 | 1604 |
| 43 | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 2.0 | 0.0 | 0.0 | NA | NA | 1 | 0 | 0 | 0 | 0 | 50 | 50 | 218 | 0 | 0 |

| Quadrat No. | FPG p. 100 m 2007 | FPG p. 100 m 2008 | FPG p. 100 m 2008 (+IT) | FPG p. 100 m 2009 | FPG p. 100 m 2010 | Σ FPG 2007 | Σ FPG 2008 | Σ FPG 2008 (+IT) | Σ FPG 2009 | Σ FPG 2010 | Length 2007 (m) | Length 08 (m) | Length 08 (+IT) (m) | Length 09 (m) | Length 10 (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | 0.0 | 1.0 | 0.2 | NA | 0.3 | 0 | 2 | 5 | 0 | 4 | 200 | 200 | 2631 | 0 | 1516 |
| 46 | 0.0 | 0.0 | 0.0 | 0.8 | 0.1 | 0 | 0 | 1 | 12 | 1 | 200 | 300 | 2205 | 1516 | 1516 |
| 47 | 0.0 | 0.5 | 0.3 | 0.2 | 1.0 | 0 | 1 | 12 | 6 | 30 | 300 | 200 | 3569 | 3032 | 3032 |
| 48 | 1.0 | 0.7 | 2.6 | 0.7 | 0.1 | 3 | 2 | 84 | 10 | 1 | 300 | 300 | 3275 | 1516 | 1516 |
| 49 | 1.0 | 0.0 | 0.3 | 0.2 | 0.0 | 1 | 0 | 4 | 3 | 0 | 100 | 100 | 1295 | 1532 | 1532 |
| 50 | 3.0 | 0.0 | 0.5 | 0.2 | 0.0 | 3 | 0 | 7 | 1 | 0 | 100 | 100 | 1546 | 434 | 434 |
| 51 | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | 0.0 | 0.0 | 0.2 | NA | NA | 0 | 0 | 1 | 0 | 0 | 50 | 50 | 506 | 0 | 0 |
| 53 | 0.5 | 2.0 | 0.8 | NA | 0.3 | 2 | 8 | 27 | 0 | 5 | 400 | 400 | 3296 | 0 | 1883 |
| 54 | 1.6 | 0.0 | 0.4 | 0.8 | 0.2 | 4 | 0 | 5 | 8 | 2 | 250 | 550 | 1345 | 946 | 1141 |
| 55 | 1.1 | 2.3 | 0.7 | 0.5 | 0.6 | 4 | 7 | 28 | 14 | 17 | 350 | 300 | 3842 | 3025 | 3025 |
| 56 | 0.0 | 0.2 | 0.2 | 0.2 | 0.9 | 0 | 1 | 10 | 3 | 13 | 450 | 450 | 4866 | 1516 | 1516 |
| 57 | 6.0 | 2.5 | 1.3 | 0.9 | 0.1 | 12 | 5 | 41 | 22 | 3 | 200 | 200 | 3065 | 2401 | 2401 |
| 58 | 2.0 | 0.0 | 0.4 | 0.9 | 0.3 | 3 | 0 | 1 | 13 | 4 | 150 | 150 | 284 | 1488 | 1488 |
| 59 | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | NA | NA | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | 0.0 | 4.0 | 1.2 | NA | NA | 0 | 6 | 20 | 0 | 0 | 150 | 150 | 1688 | 0 | 0 |
| 62 | 0.4 | 0.7 | 0.4 | 1.1 | 0.9 | 1 | 2 | 12 | 16 | 13 | 250 | 300 | 3413 | 1516 | 1516 |
| 63 | 3.2 | 7.5 | 1.4 | 0.7 | 0.9 | 8 | 15 | 35 | 25 | 32 | 250 | 200 | 2463 | 3513 | 3513 |
| 64 | 1.0 | 1.7 | 1.1 | 1.0 | 0.1 | 3 | 5 | 38 | 21 | 2 | 300 | 300 | 3314 | 2142 | 2142 |
| 65 | 3.5 | 0.5 | 0.4 | 0.0 | 1.0 | 7 | 1 | 16 | 0 | 16 | 200 | 200 | 3692 | 1615 | 1615 |
| 66 | 8.3 | 10.0 | 2.3 | 1.4 | 1.5 | 25 | 30 | 61 | 22 | 23 | 300 | 300 | 2635 | 1547 | 1547 |
| 67 | 0.0 | 2.0 | 1.1 | 0.4 | 0.5 | 0 | 2 | 5 | 4 | 5 | 100 | 100 | 446 | 1019 | 1019 |
| 68 | 0.0 | 1.0 | 0.3 | 0.4 | 0.0 | 0 | 1 | 2 | 4 | 0 | 100 | 100 | 687 | 970 | 970 |
| 69 | 0.0 | 0.0 | 1.0 | 0.5 | 0.1 | 0 | 0 | 9 | 4 | 1 | 100 | 100 | 877 | 779 | 779 |
| 70 | 2.3 | 2.3 | 0.5 | 0.5 | 0.3 | 7 | 7 | 18 | 7 | 5 | 300 | 300 | 3400 | 1547 | 1547 |
| 71 | 4.0 | 0.7 | 1.1 | 0.2 | 0.7 | 6 | 1 | 19 | 3 | 11 | 150 | 150 | 1734 | 1547 | 1547 |
| 72 | 2.9 | 3.0 | 1.2 | 0.2 | 1.0 | 13 | 15 | 54 | 6 | 30 | 450 | 500 | 4536 | 3086 | 3086 |
| 73 | 0.0 | 0.0 | 1.9 | 0.2 | 0.5 | 0 | 0 | 9 | 3 | 10 | 50 | 50 | 480 | 1899 | 1899 |
| Σ | 55.9 | 56.3 | 28.5 | 17.6 | 18.3 | 130 | 150 | 744 | 332 | 389 | 15.300 | 15.650 | 156.966 | 73.457 | 96.810 |
| Mean | 0.8 | 0.9 | 0.4 | 0.5 | 0.3 | 1.8 | 2.1 | 10.2 | 4.5 | 5.3 | 210 | 214 | 2.150 | 1.006 | 1.326 |
| Median | 0.1 | 0.3 | 0.2 | 0.4 | 0.3 | 0.0 | 1.0 | 4.0 | 0.0 | 2.0 | 200 | 200 | 2.205 | 434 | 1.516 |
| SD | 1.5 | 1.6 | 0.6 | 0.4 | 0.4 | 3.8 | 4.4 | 15.6 | 6.7 | 8.1 | 133 | 141 | 1.605 | 1.168 | 1.084 |
| VAR | 2.3 | 2.7 | 0.3 | 0.1 | 0.1 | | | | | | | | | | |
| VTMR | 2.7 | 3.2 | 0.7 | 0.3 | 0.4 | | | | | | | | | | |
| CV | 1.8 | 1.9 | 1.3 | 0.8 | 1.0 | | | | | | | | | | |

Table 11: Results of Quadrat Count Analysis performed with ArcGIS. FPG = Faecal Pellet Group, IT = Intermediate Transect, SD = Standard Deviation, VAR = Variance, VTMR = Variance-To-Mean-Ratio, CV = Coefficient of Variation.

## A.3 Topographic map of the study area

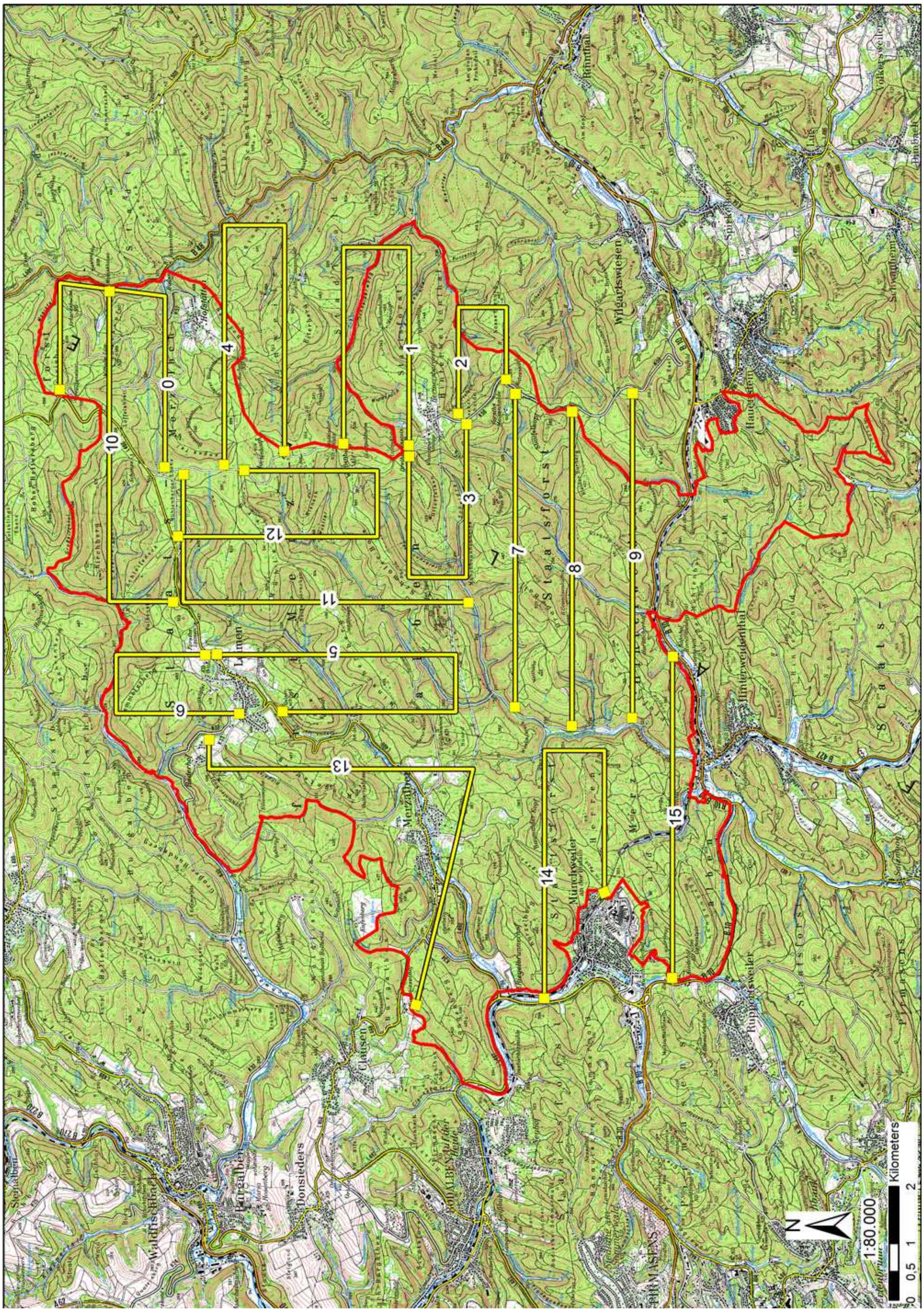


Figure 10: Topographic map of the study area. The red line is the border of the wildlife research area Rhineland-Palatinate (WFG, approx. 11.300 ha). Transects are displayed as yellow lines.

# Erklärung

Hiermit erkläre ich, dass ich die vorliegende Bachelor-Arbeit selbständig angefertigt habe. Es wurden nur die in der Arbeit ausdrücklich benannten Quellen und Hilfsmittel benutzt. Wörtlich oder sinngemäß übernommenes Gedankengut habe ich als solches kenntlich gemacht.

Ort, Datum

Unterschrift