First estimation of Eurasian lynx (*Lynx lynx*) abundance and density using digital cameras and capture–recapture techniques in a German national park

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Abstract

*First estimation of Eurasian lynx (*Lynx lynx*) abundance and density using digital cameras and capture–recapture techniques in a German national park.*— Eurasian lynx are individually identifiable by their unique coat markings, making them ideal candidates for capture–recapture (CMR) surveys. We evaluated the use of digital photography to estimate Eurasian lynx population abundance and density within the Bavarian Forest National Park. From November 2008 to January 2009 we placed 24 camera trap sites, each with two cameras facing each other (on well–used walking tracks). The units were placed based on a systematic grid of 2.7 km. We captured five independent and three juvenile lynx and calculated abundance estimates using Program Mark. We also compared density estimates based on the MMDM method (Mean Maximum Distance Moved) from telemetry data (½$MMDM_{GPS}$) and from camera trapping data (½$MMDM_{CAM}$). We estimated that in an effectively sampled area of 664 km^2 the Eurasian lynx density was 0.9 individuals/100 km^2 with ½$MMDM_{CAM}$. The Eurasian lynx density calculated with ½$MMDM_{GPS}$ was 0.4 individuals/100 km^2 in an effectively sampled area of 1,381 km^2. Our results suggest that long–term photographic CMR sampling on a large scale may be a useful tool to monitor population trends of Eurasian lynx in accordance with the Fauna–Flora–Habitat Directive of the European Union.

Key words: *Lynx lynx*, Camera trap, Capture–recapture, Abundance, Half MMDM, Actual MMDM, Density.

Resumen

*Primera estima de la abundancia y de la densidad del lince euroasiático (*Lynx lynx*) utilizando cámaras digitales y técnicas de captura–recaptura en un parque nacional alemán.*— Al lince euroasiático se le puede identificar individualmente mediante las marcas de su pelaje, que son únicas, lo que le convierte en un candidato ideal para los estudios de captura–recaptura (CMR). Hemos evaluado el uso de la fotografía digital para estimar la abundancia y la densidad de la población del lince euroasiático en el Parque Nacional Forestal Bávaro. Desde noviembre del 2008 a enero del 2009 establecimos 24 lugares de trampeo, cada uno de ellos provisto de dos cámaras encaradas entre sí, en lugares de paso frecuentados. Colocamos las unidades basándonos en una cuadrícula sistemática de 2,7 km. Capturamos cinco linces independientes y tres jóvenes, y calculamos las estimas de abundancia utilizando el programa Mark. También comparamos las estimas de densidad mediante el método MMDM (distancia media máxima recorrida) de datos telemétricos (½$MMDM_{GPS}$) y de datos de las cámaras trampa (½$MMDM_{CAM}$). Hallamos que en un área muestreada eficazmente de 664 km^2 la densidad del lince euroasiático era de 0,9 individuos/100 km^2 mediante ½$MMDM_{CAM}$. La densidad del lince euroasiático calculada mediante el método ½$MMDM_{GPS}$ fue de 0,4 individuos/100 km^2 en una zona muestreada eficazmente de 1.381 km^2. Nuestros resultados sugieren que un muestreo fotográfico CMR a largo plazo y a gran escala puede ser una herramienta muy útil para monitorizar las tendencias poblacionales del lince euroasiático, según la Directiva de Hábitat, Flora y Fauna de la Unión Europea.

Palabras clave: *Lynx lynx*, Cámara trampa, Captura–recaptura, Abundancia, Media MMDM, MMDM real, Densidad.

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Introduction

How can we count a cryptic camouflaged species, with home range sizes up to 700 km^2, in a low range mountain area? The Eurasian lynx is a secretive and elusive species that is difficult to monitor, but to implement management plans, wildlife managers need to know the size of wildlife populations. To date, monitoring of Eurasian lynx in Germany has been limited to chance observations and occasional telemetry studies, but these methods are unsuitable to obtain accurate abundance and density estimates. The individual coat markings and the behaviour of the Eurasian lynx make it an ideal candidate for systematic monitoring using remote photography and statistical capture–recapture methods (Cooch & White, 2006). In recent years, the use of camera traps has been implemented to estimate abundances of individually recognisable species such as felids. *e.g.,* with tigers (Karanth & Nichols, 1998), ocelots *Leopardus pardalis* (Trolle & Kéry, 2003), jaguars *Panthera onca* (Silver et al., 2004), Iberian lynx *Lynx pardinus* (Gil–Sánchez et al., 2011) and bobcats *Lynx rufus* (Larrucea et al., 2007). The challenge of camera trap monitoring is to maximize the number of target species captures by assuring that every individual has the chance to be detected. This means that every potential home range should include camera trapping sites. For species like the Eurasian lynx, which presumably occur in low densities, site selection is critical to obtain a sufficient number of pictures. Therefore, in addition to a suitable site it is crucial to find a reliable camera trap that can deliver high quality pictures that will allow individual recognition.

The Eurasian lynx population of the Bavarian and Bohemian Forest was newly founded in the 1980s following lynx releases in the area that is now the Šumava National Park, Czech Republik (Bufka & Cerveny, 1996). Sources of information concerning the progress of the population mainly came from unconfirmed references (Wölfl et al., 2001). In 1996 the Czech National Park Šumava set up the first telemetry projects, and in 2000 German telemetry projects were launched to support this initiative and thirteen Eurasian lynx were collared (Heurich & Wölfl, 2002; Bufka & Cerveny, 1996).

Radio–telemetry delivers high–quality data, but it is invasive and costly (Gil–Sánchez et al., 2011). It mainly captures movement and behaviour although other information can be obtained, such as, kill rates for carnivores. Although there has been evidence of reproduction in the study area, it was seldom possible to capture dispersal or life histories of any animals other than the collared animals. Information regarding Eurasian lynx numbers, required by the lynx monitoring plan of the state of Bavaria, was still lacking (StMUGV, 2008). Abundance and density estimates of Eurasian lynx are required as a key factor to understand life histories and demography for decision–making in conservation (*e.g.,* Fauna–Flora–Habitat directive) and politics (Hetherington & Gorman, 2007; Andrén et al., 2006). Digital camera traps offer a non–invasive, less costly method to evaluate the status of the Eurasian lynx population. Camera traps could allow us to monitor lynx demography by following individual life histories and assessing survival, recruitment and even dispersal. With this objective, we set up the first camera trap monitoring in a German National Park to test whether it is possible to generate abundance and density estimates in the putative core area of the Eurasian lynx population in the Bavarian Forest.

Study area

The Bohemian Forest and the Inner Bavarian Forest form one of the largest connected woodlands in Central Europe: The Greater Bohemian Forest Ecosystem is the largest, strictly protected, contiguous forest expanse in Central Europe. Entire tracts of forest are the property of the Bavarian state or the Czech Republic. The region is characterized by a low density of human habitation compared to other parts of Europe. In the core areas, this density it is less than 30 inhabitants/km^2, with approximately 70 inhabitants/km^2 at the margins. Vast parts of this expanse are protected areas, such as the German Bavarian Forest National Park (with 242 km^2) and the Czech Šumava National Park (with 690 km^2) (Heurich & Wölfl, 2002), both surrounded by landscape protected areas. We conducted research in the IUCN Category II Bavarian Forest National Park with more than 98% forest cover (Elling et al., 1987). This area is located in the centre of this complex, extending along the Czech border. Forestry had been the dominating form of land use until the National Park was founded in 1970. Altitudes range from 650 m to a maximum of 1,420 m. The climate of the Bavarian Forest National Park is characterized by Atlantic and continental influences. The total annual precipitation is between 1,200 and 1,800 mm depending on altitude. Up to 50% of this amount falls as snow and the snow heights in the highest parts can reach up to 3 m (Bässler et al., 2008). Annual mean air temperature varies from 3.8°C in the high montane zones to 5.8°C in the valley sites (Noack, 1979; Bässler, 2004). The lowest temperature during the camera trapping session was reached in January with –12.4°C. There was snow from 22th of November until 10th of April and the snow level was highest in February with 111 cm at 945 m above sea level (weather station Waldhäuser). The National Park is a popular tourist site in summer and winter. There are 215 km of bike routes, 351 km of hiking trails 75 km being official winter hiking trails —and 85 km of cross–country skiing routes in use.

Material and methods

Camera traps

The technique of individual recognition is based on the unique coat pattern of every Eurasian lynx (Karanth & Nichols, 1998; Karanth, 1995; Thüler, 2002; Garrote et al., 2011; Gil–Sánchez et al., 2010; Gil–Sánchez et al., 2011; Larrucea et al., 2007). For the accurate comparisons of individuals high quality pictures of both sides of the flanks are needed, including the inner surfaces of the fore and hind legs (Silver et al.,

Table 1. Names, sex and transmission dates for seven individuals of Eurasian lynx (*Lynx lynx*) radio–tracked in the study area between 2008 and 2012. The transmission of 'Milan' covered two camera trapping sessions; the other individuals were radio–tracked during one camera trapping session: S. Sex (M. Male; F. Female); D. Transmission duration (in days): O. Ongoing.

*Tabla 1. Nombre, sexo y datos de transmisión de siete individuos de lince euroasiático (*Lynx lynx*) a los que se hizo un radio–seguimiento en el área de estudio entre 2008 y 2012. La transmisión de "Milan" se solapó con dos sesiones de cámara trampa; los demás individuos estaban siendo seguidos durante una sola sesión de cámara trampa: S. Sexo (M. Macho; F. Hembra); D. Duración de la transmisión (en días): O. En curso.*

		Transmission		
Individual	S	On	Off	D
Milan	M	12 XI 2008	13 II 2010	458
Matilda	F	17 III 2010	01 III 2011	349
Kubicka	F	17 III 2010	07 II 2011	327
Ctirad	M	15 I 2011	14 III 2012	424
Tessa	F	27 II 2011	10 III 2012	377
Matilda	F	02 III 2011	O	O
Kika	M	22 III 2011	O	O

2004). An initial trial of six camera models identified a passive infrared–triggered camera trap with white flash as the best in regard to image quality for use in the field (Cuddeback Capture Green Bay, Wisconsin, USA – Weingarth et al., in press). Due to the white flash the exposure time is shortened, resulting in sharp and fixed images with a very fine image definition. Consequently, the coat patterns of the Eurasian lynx can be distinguished without deforming the spots (Laass, 1999). The fast trigger speed of 0.3 sec is essential for use on trails if the animal is to be pictured in the centre of the image. The cameras ran for 24 h during the session and the delay between two pictures was set at a minimum of 30 sec.

Telemetry

The Eurasian lynx project of the Bavarian Forest National Park and Šumava National Park started in 2005, with a focus on the predator–prey relationships of Eurasian lynx and roe deer, and Eurasian lynx population trends in a low mountain area.

Eurasian lynx are captured in wooden, two–door boxtraps (2.5 × 1 × 1 m), which are set up along forest roads and hiking paths used by the animals as trails. The traps are monitored continually with an electric transmitter that sends a message by SMS. Sedation is achieved by shooting through a closable opening in the trap with a blowpipe and Hellabrunner mixture (Heurich, 2011). The Eurasian lynx were equipped with GPS–GSM collars (Vectronic Aerospace, Berlin, Germany). The collars were programmed for two daily fixings at 12:00 am and 12:00 p.m. Table 1 shows the dataset of Eurasian lynx that were have been equipped with collars during the 60–day period of the camera trapping session (26.11–24.01) over the years.

We used telemetry data from previous years of the camera trapping study, to have a sufficient number of animals (N = 7) for the analysis. This was possible, because we assumed a constant Eurasian lynx density from snow tracking data.

Study design

Systematic distribution

The distribution of the traps was designed to ensure that every individual in the study area had the chance of being detected (Karanth & Nichols, 1998). Therefore, a camera trapping site was set up in every second grid cell with an edge length of 2.7 × 2.7 km for a systematic distribution according to Laass (1999). This resulted in four to five camera trapping sites within an average female home range (Karanth & Nichols, 2002). Two opposing cameras were installed parallel to each other and 70 cm above the ground (withers of Eurasian lynx) to record both flanks (Silver et al., 2004). We installed 48 cameras, on 24 sites for the first intensive camera trapping session in the Bavarian Forest National Park in November 2008 (fig. 1). Each opposing pair of cameras was installed at a distance of 4.5 to 10 m and turned slightly away from each other to avoid interaction of the flashes and overexposure of the image. The camera traps were installed in wooden covers as a shelter against physical damage. The height of the camera was adjusted to the snow height by shifting it up and down a wooden pole. The minimum convex polygon (MCP; fig. 1) of all camera trapping sites formed a study area of 275 km^2.

Site selection and control routine

For the site selection we displayed the telemetry data of two former collared Eurasian lynx, added the systematic snow tracking data since 1997, accidental lynx observations (tracks, kills, vocalisations, visual observations) and lynx prey sites since 2005 in a geographic information system (ArcGIS 9.3). Due to analysis of prey selection in the National Park Bavarian Forest, we assume that roe deer *Capreolus capreolus* is the most important prey species in the area as it is elsewhere in Central Europe (Okarma et al., 1997; Molinari–Jobin et al., 2007). Therefore, telemetry data of 64 roe deer collared in the study area were also included. Additionally, local and international experts selected trap locations based on their experience and topographical aspects. For example, rocky areas are preferred by Eurasian lynx for day resting sites and

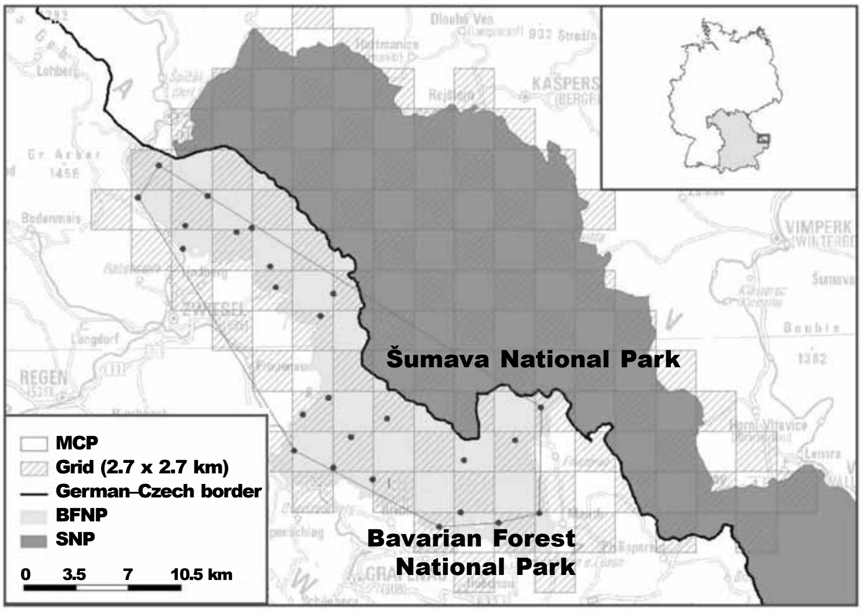

Fig. 1. Map of the Bavarian Forest National Park (BFNP) and Šumava National Park (SNP) showing the grid (2.7 × 2.7 km) used to position the 24 camera trapping sites (•). The study area was defined as the minimum convex polygon (MCP) of the camera trapping sites.

Fig. 1. Mapa del Parque Nacional Forestal Bávaro y Parque Nacional Šumava, mostrando la cuadrícula (2,7 x 2,7 km) utilizada para situar el emplazamiento de las 24 cámaras trampa (•). El área de estudio se definió como el polígono convexo mínimo (MCP) de los emplazamientos de las cámaras.

chances are high that lynx use trails along ridges. To determine the exact site we relied on expert advice and locations that had a high density of data. Practical considerations, however, limited site selection. Sites above 1,200 m were excluded because of costly maintenance (low infrastructure, high snow levels) during the snow season. This is justified by the telemetry data of Eurasian lynx and roe deer in the study area, which shows low usage of the high elevations in winter. For the site selection, topography and vegetation structures were also taken into consideration as possible Eurasian lynx marking spots, tree cover and potential daily resting sites (Matjuschkin, 1978). Locations that lend themselves as easy passes, such as tree trunks over rivers or ridges leading to marking spots (Karanth & Nichols, 1998), can be of advantage.

We controlled the camera trapping sites once a week so as to solve any technical failures, to adapt the camera positions to changing snow conditions, to check the alkaline batteries (variation in temperatures between +10°C in the sun until –15°C at night), and to assure no loss of pictures. A trap night was defined as effective if at least one camera at the site was able to produce images. The term 'potential trap night' means that the cameras were theoretically able to produce photos. If potential trap nights are not effective, influences such as snow in front of the lenses, defective flashes or low batteries prevented both cameras to detect objects.

Time of operation

For this first camera trapping monitoring, we chose a session length of 60 days, (Karanth & Nichols, 1998, 2000; Guil et al., 2010). The length of one trapping occasion was set to five days (Zimmermann et al., 2008), *i.e.,* several captures of the same individual at one particular camera trap site during five days are counted as a single capture event. The monitoring was carried out during the winter season because of positive experiences in Switzerland with less human disturbance in winter time. Additionally, between November and March, male Eurasian lynx have to cover long distances to find females and induce ovulation with their visits and defend their territories against other males during pre–mating season (Breitenmoser et al., 2006; Zimmermann et al., 2004). Due to snow tracking (Heurich et al., 2003) we know that Eurasian lynx in the Bavarian Forest National Park often frequent established routes, probably because it is the easiest way to move from A to B (Zimmermann et al., 2004). We assumed that touristic used winter hiking trails and snow hiking trails would offer an adequate chance to detect Eurasian lynx on the trail.

Visual identification

Like other felids (Trolle & Kéry, 2003, Karanth & Nichols, 1998), Eurasian lynx can be identified by their individual fur patterns, which they maintain their whole lifetime

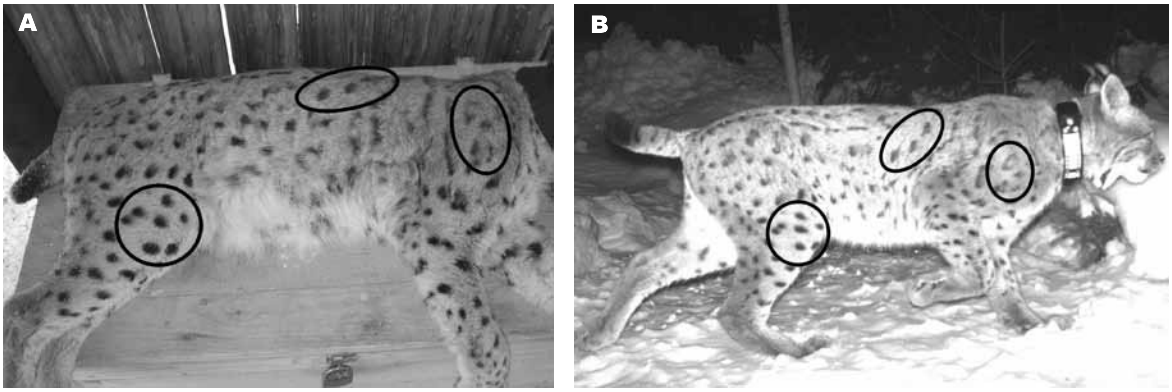

Fig. 2. Coat pattern of Eurasian lynx (*Lynx lynx*) used in the recognition of individual animals: A. A male lynx during sedation; B. The same individual on a camera trap image. For visual identification we compared three patches of the coat pattern (red ovals) to be discernible and congruent (Laass, 1999).

*Fig. 2. Patrones de manchas del pelaje de un lince euroasiático (*Lynx lynx*) utilizados para el reconocimiento de los animales individuales: A. Un lince macho sedado; B. El mismo individuo en una imagen de la cámara trampa. Para la identificación visual comparamos tres zonas del dibujo del pelaje (óvalos rojos) para que el reconocimiento fuera discernible y congruente (Laass, 1999).*

(Guil et al., 2010). Therefore, we compared three different regions of the body, particularly the flanks or the inner legs (fig. 2; Laass, 1999).

Sexual determination is only possible if a female is photographed with kittens or by detection of the nether regions (Guil et al., 2010). Age of the individuals cannot usually be determined exactly. Therefore, we defined three categories for the status of each photographed individual: The first category was 'independent' Eurasian lynx; this included adult and resident lynx identified through capture for GPS–collaring, animals that were documented for at least two years in the area, and lynx with cubs on camera trapping pictures. The 'independent' category would also include animals which were definitely over one–year old (subadults), when evidence was present in forms of camera trapping pictures taken in juvenile status one year ago (*i.e.*, year of birth is known; Rexstad & Burnham, 1991). The second category describes 'juveniles', which are still dependent on the mother. We defined the first 'lynx–year' from May 1 to April 30 of the following year when individuals start to disperse (Zimmermann et al., 2005). The third category, Eurasian lynx of 'unknown status', encompasses all remaining individuals without proof of independence or residency.

Statistical analysis

We tested the assumption of a closed population using CloseTest (Stanley & Burnham, 2004). A closed population means that there is no emigration, immigration, natality or mortality of individuals during the session duration. The captures and recaptures of Eurasian lynx were described by a binary matrix. Following Karanth & Nichols (1998), we defined five days to be one trapping occasion. We used closed population models in Mark (White & Burnham, 1999) for the abundance estimates. The model selection in Program Mark proposes the most appropriate model for the data.

Table 2. Results of the model selection in Mark. The model indices mean constant capture probability (o); capture probabilities vary by individual (h); capture probabilities vary by behavioral response to capture (b) and capture probabilities vary with time (t). Selected model has the maximum value.

Tabla 2. Resultados de la selección de modelo en Mark. Los subíndices del modelo significan: probabilidad de captura constante (o); las probabilidades de captura varían según el individuo (h); las probabilidades de captura varían según la respuesta conductual a la captura (b); y las probabilidades de captura varían con el tiempo (t). El modelo seleccionado es el de valor máximo.

Model	M_o	M_h	M_b	M_{bh}	M_t	M_{th}	M_{tb}	M_{tbh}
Criterion	0.95	1.00	0.71	0.79	0.00	0.37	0.75	0.69

To estimate density we applied mean maximum distance moved (MMDM) measures as a buffer around the study area in order to obtain the effective sampled area. Originally, MMDM was based on camera trap data (hereafter $MMDM_{CAM}$) which is dependent on the camera trap design. $MMDM_{CAM}$ cannot be greater than the largest distance between two camera trapping sites. If the individual movement pattern of the species in concern includes larger distances, this might lead to overestimation of density. MMDM based on telemetry data (called 'actual' MMDM by Soisalo & Cavalcanti, 2006; hereafter ½$MMDM_{GPS}$) might be a better option (Karanth, 1995; Soisalo & Cavalcanti, 2006), because the realisation of GPS locations is not confined to the study area. Here, we compare two measures, the ½$MMDM_{CAM}$, which has often been used for rare felids (Karanth et al., 2002; Karanth et al., 2004), and the ½$MMDM_{GPS}$.

Results

Capture success and camera efficiency

We found 1,414 out of 1,440 potential trap nights on 24 sites with 48 cameras over 60 days to be effective (98.2%). Two cameras were stolen but they were immediately replaced during the camera trapping session. We obtained 26 images of Eurasian lynx corresponding to a trapping rate of 1.8 lynx images/100 trap nights. During the camera trapping session we took photos of five independent individuals (two males and three females) and three juvenile individuals (sex unknown). Ten out of 24 sites were frequented by Eurasian lynx (41.6%). The family relations between the detected Eurasian lynx kittens and their mothers were obvious due to very small time intervals (< 5 min) between the detections on sites within the mothers´ home ranges. Following the same logic, subsequent images of juveniles without their mother were counted as a recapture of their mother (Zimmermann et al., 2004). We had eleven captures in total and four independent Eurasian lynx were recaptured, a female with a maximum of three recaptures. The amount of failed photos was < 5%.

Abundance estimation

The Close Test resulted in significance level of p = 0.05764, which means demographic closure is assured during the session. The minimal count within 60 days was five independent individuals which were the basis of our calculation. The model selection of program Mark selected the M_h model as the most appropriate (table 2).

The mean value of 12 trapping occasions was six (CI: 6–15). The average capture probability is *p* = 0.1528 (Otis et al., 1978), with standard error 1.7440.

Density estimations

Four independent Eurasian lynx frequented at least two camera trapping sites. The maximum distances moved ranged from 3.67 km (female) to 11.38 km (male). The ½$MMDM_{CAM}$ of 4.28 km (N = 4) resulted in an area effectively sampled of 664 km^2 (MCP study area: 275 km^2).

Based on our abundance estimate of six independent individuals, this corresponds to a density of 0.9 independent individuals per 100 km^2. From the GPS data of seven Eurasian lynx radio–tracked within the period of the camera trapping session (60 days) in the study area (table 1), we obtained eight maximum distances moved (table 3; the transmission duration of 'Milan' covered two camera trapping sessions) and a ½$MMDM_{GPS}$ of 10.12 km for the buffer radius (fig. 3). The effective sampled area is 1,381 km^2, giving an estimate of 0.4 lynx individuals/100 km^2.

Table 3. The maximum distances moved (MDM, in km) by collared animals from 2008 to 2012.

Tabla 3. Máximas distancias recorridas (MDM, en km) por los animales provistos de collar de 2008 a 2012.

Lynx individual	Season	MDM
Milan	2008/2009	37.36
Milan	2009/2010	33.95
Kubicka	2010/2011	11.91
Matilda	2010/2011	12.95
Kika	2011/2012	23.73
Matilda	2011/2012	13.14
Ctirad	2011/2012	18.19
Tessa	2011/2012	10.60

Discussion

Camera model and study design

The Cuddeback Capture™ worked reliably during the whole winter session, with minimum temperatures of –12°C. The excellent picture quality with white flash enabled us to identify every individual on the images. The amount of failed images was very low (> 5%) in relation to the large amount of high quality images and compared to earlier felid projects that had percentages from 32% to 75% (Jackson et al., 2005).

Effective trap–nights

More than 98% of potential trap nights during the session of 60 days were effective. This value lies in the upper range of comparable camera trapping effectivity of 84.2% (Jura North, winter of 2006/2007) and 97.9% in Switzerland (Northwestern Swiss Alps, winter 2009/2010; Zimmermann et al., 2011). The combination

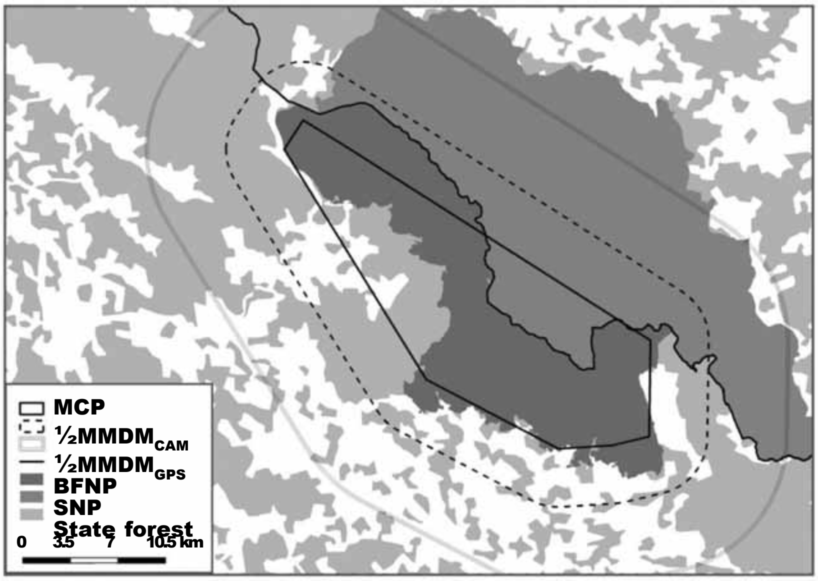

Fig. 3. Map showing the study area (black solid line) and two estimates for the effective study area obtained with a buffer radius of ½MMDM$_{CAM}$ (black dashed line) and ½MMDM$_{GPS}$ (grey solid line).

Fig. 3. Mapa que muestra el area de estudio (línea continua negra) y dos estimas del área de estudio efectiva, obtenidos con un radio–buffer de ½MMDM$_{CAM}$ (línea discontínua negra) y ½MMDM$_{GPS}$ (línea continua gris).

of high quality images and low camera failure technically minimizes the risk of missing individuals. Based on the grid of 2.7 × 2.7 km, we covered the whole area systematically, so we can assume that every individual present in the study area had the chance of being detected. This is also suggested by the finding that all individuals equipped with a radio–tracking collar that were present in the area in 2008/2009 were detected.

Camera traps on 41.6% of the 24 sites successfully detected individuals of Eurasian lynx, compared to 24% in the Jura (winter of 2007/2008; Zimmermann et al., 2007) and 65% in the Northwestern Swiss Alps (winter of 2007/2008; Zimmermann et al., 2008) using the same study design. These values reflect the fact that the mountainous topography of the Bavarian Forest National Park and the Jura offer less forced trails compared to an alpine topography in the Swiss Alps with its larger and steeper slopes.

Recognition of age on camera trapping pictures

In contrast to Guil et al. (2010), who studied Iberian lynx (*Lynx pardinus),* we are not convinced that the age of Eurasian lynx can be distinguished visually due to the body size, beard and brush size, or facial characteristics. We think this depends heavily on the season, as for example, a cub photographed in November can still be distinguished due to smaller body size. But this is difficult to achieve with a single individual taken in March. A former year kittens' body size at that time of the year is almost as big as a full–grown individual. In consequence we defined three categories which are strictly evidence–based. Due to continued camera trapping we will also be able to recognize individuals on a more detailed basis (*e.g.* year of birth or sex) in consecutive years.

Abundance estimate

A camera trapping session during the pre–mating season of Eurasian lynx, when especially males show enhanced activity and visits of individuals from outside the study area are most likely (Breitenmoser & Breitenmoser–Würsten, 2008), cautions against the assumption of a demographically closed population. Nevertheless, the Close Test (Stanley & Burnham, 2004) did not reject the assumption of population closure within 60 days from November to January. The rapid detection of all individuals within 25 days (corresponding to five trapping occasions; fig. 4) and the subsequent recapture of all individuals also suggest that we detected only regularly moving individuals. The software package Mark selected the M_h as the most appropriate model. This is a common finding in felids, which present large heterogeneity of individual capture probabilities (Kelly & Holub, 2008) due to their individual heterogeneity in capture probability. Future studies should determine the optimal length a session should be for the Eurasian lynx and which period of the year is most suitable for the camera trapping regarding the closure assumption, man power effort, and trap night efficiency. Whether the amount of Eurasian lynx captures during the late spring, summer and autumn season is sufficient for valuable estimates is questionable. The detection of the five independent individuals within the first five trapping occasions (fig. 4) and the additional finding that we detected all collared animals present in the study area favours our assumption that we detected most of the individuals present in the study area. On the other hand, the abundance estimate of six individuals within the area seemed to be close to reality, taking unconfirmed sightings and expert–confirmed prey sites into consideration. Likewise, the telemetry data also suggest free space for exactly one more Eurasian lynx home range within the study area. However, the minimum count of five independent Eurasian lynx as the basis for the abundance estimate, the large confidence interval of six to 15 and the low number of recaptures, led us to the conclusion that the study area needs to be enlarged.

Density estimations

Density estimation needs to take into account that individual home ranges might include areas outside the study area. The ½MMDM$_{CAM}$ method is widely used to estimate density for felids (Karanth & Nichols, 1998). The density estimate with the ½MMDM$_{CAM}$ resulted in 0.9 individuals/100 km^2, corresponding to a density estimate from the Central Swiss Alps of 0.85 independent individuals/100 km^2 (Zimmermann et al., 2004). As expected, our density estimate based on ½MMDM$_{GPS}$ (0.4 individuals/100 km^2) was lower than that based on ½MMDM$_{CAM}$, suggesting that the maximum distances moved by Eurasian lynx can be greater than the array of camera trapping sites, especially considering the elongate shape of the study area (fig. 1). These results are in congruence with those of Soisalo & Cavalcanti (2006) that deriving ½MMDM$_{GPS}$ from radio–tracking data leads to less biased densities.

Eurasian lynx population sizes are influenced by various factors; Hetherington & Gorman (2007) emphasized the strong relationship between Eurasian lynx density and ungulate biomass. Based on hunting statistics we assume a low roe deer density in the Bavarian Forest National Park, and consider that this would not be able to sustain higher long–term densities of Eurasian lynx. In Białowieza Primeval Forest (Poland and Belarus) high prey densities result in higher Eurasian lynx densities with 3 independent individuals/100 km^2 (Jedrzejewski et al., 1996).

Due to the elongated shape of the study area and the low sample size (N = 4), the ½MMDM$_{CAM}$ is a less accurate measure than the ½MMDM$_{GPS}$ (based on N = 8), suggesting that a future enlargement of the study should aim at creating a more compact shape. Then, with increasing number of recaptures at more than one camera trap site, the density estimates become more robust.

Successful camera trapping studies rely on well–trained and experienced staff (Sharma & Jhala, 2010) but, compared to radio–tracking studies, they are more cost–efficient and non–invasive (Gil–Sánchez et al., 2011). While the main goal of telemetry studies is to analyze the spatial and temporal behavior of the target species, the priority of systematic camera trapping is to estimate the abundance and density of the population.

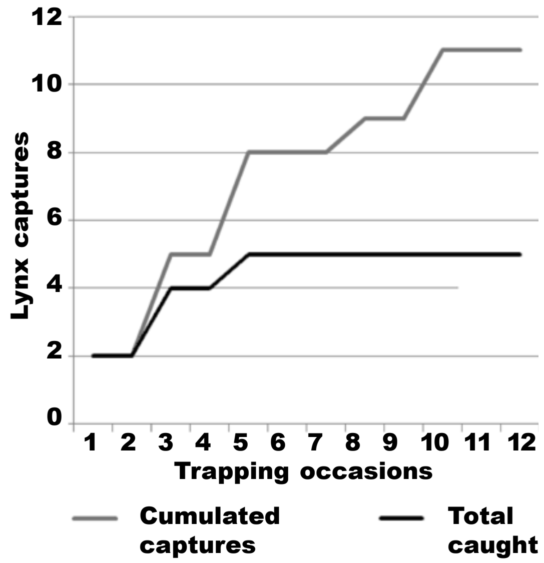

Fig. 4. Capture history of the independent Eurasian lynx. Juveniles were counted as recapture of their respective mother (Zimmermann et al., 2004). All individuals were detected within the first five trapping occasions.

Fig. 4. Historial de capturas de linces euroasiáticos independientes. Los juveniles se contabilizaron como recapturas de sus respectivas madres (Zimmermann et al., 2004). Todos los individuos se detectaron durante los cinco primeros trampeos.

Comparing different methods used to calculate carnivore densities, Balme et al. (2009) found that camera trapping produces accurate but less precise estimates than telemetry data. Here we have shown that the two techniques function best when used to complement each other: The mark–recapture design relies on camera trapping, but additional information, *e.g.*, the calculation of ½MMDM$_{GPS}$ comes from telemetry data.

The Eurasian lynx is listed in the Habitats Directive of the European Union in Annex II IV, which requires surveillance of the conservation status of this species by the authorities. Our results suggest camera trapping as an adequate monitoring tool for this purpose and we intend to implement long–term camera trap monitoring, as drafted in the Eurasian lynx management plan of Bavaria/Germany (StMUGV, 2008). If used properly, 'camera trap surveys represent the best balance of rigor and cost–effectiveness for estimating abundance and density of cryptic carnivore species that can be identified individually' (Balme et al., 2009).

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