
Keywords: 8CH/camera-trapping/camera trap/domestic cat/Felis catus/Felis silvestris/Felis silvestris silvestris/hybrids/identification/monitoring/phenotype/picture/wildcat

Abstract: Information concerning cryptic species such as the European wildcat *Felis silvestris silvestris* is often difficult to assess. Relevant information about the presence of wildcats in Switzerland may have provided 681 cat pictures taken during lynx camera-trapping monitorings between 2007 and 2009 in the Jura Mountains of Switzerland. The applicability of these cat pictures required a correct identification of the cats as either wildcat or domestic cat *Felis silvestris catus* by phenotype characters. However, the accuracy of such characters is disputed. To assess the accuracy of experts identifying cats correctly on camera-trapping pictures, we created an expert survey containing 25 pictures of cats with known identity. Here we report that experts achieved low accuracy identifying wildcats, hybrids and domestic cats correctly on pictures by phenotype characters and that especially hybrids were poorly identified. Thus, the applicability of camera-trapping pictures is limited and other methods are needed.
Testing the applicability of pictures taken by camera-traps for monitoring the European wildcat *Felis silvestris silvestris* in the Jura Mountains of Switzerland

Master thesis of Anna Eichholzer

March 2010

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General introduction

The European wildcat *Felis silvestris silvestris* was formerly widely distributed in Europe (Piechocki, 1990; Sommer and Benecke, 2006). Severe declines due to habitat destructions and local extirpations resulted in a fragmented distribution with relict populations (Stahl and Artois, 1991). Several populations have now slowly recovered and even extended their range, such as the Harz population in Germany (Raimer, 2009). Other populations further declined, like the population in the Nature Reserve of Serra da Malcata in Portugal (Sarmento et al., 2009).

In Switzerland, the wildcat was originally found in the Jura Mountains from Geneva to Schaffhausen and inhabited also parts of the plateau, but scarcely the Alps (Schauenberg, 1970; Eiberle, 1972; Nussberger et al., 2007). Due to persecution in the 19th century, wildcats were restricted to the Jura Mountains and in the middle of the 20th century, wildcats were considered endangered if not virtually extinct (Baumann, 1949; Hediger, 1976). Between 1943 and 1968, there were no confirming observations of wildcats in Switzerland (Nussberger et al., 2007). Since 1962, due to the revision of the Swiss federal game law, the wildcat has been a protected species listed as vulnerable in the Red Lists of Switzerland (Duelli, 1994).

An increasing number of observations in the southern Jura Mountains in the 1990s (Dötterer and Bernhart, 1996; Lüps et al., 2002; Mermod and Liberek, 2002) and in recent years in the northern part of the mountain range (Nussberger et al., 2007; Weber et al., 2008) indicated a renaissance of the population.

The pattern of the assumed increase in the Jura Mountains is not understood. There is a possible correlation of the recovery of wildcat populations in central and western Europe with milder winters as a consequence of climatic warming (Nussberger et al., 2007). Other or additional explanations may be intensified immigration from the adjacent lowland populations in France, a recovery of a very small remnant or underestimated nucleus (Fernex, 2002) or reintroductions made in the 1970s (Nussberger et al., 2007).

To date the occurrences of wildcats in Switzerland are poorly documented. Relevant information may be provided through cat pictures taken during camera-trapping monitorings in the Jura Mountains of Switzerland. Camera-trapping has been used in the Swiss Alps by KORA (Coordinated research projects for the conservation and management of carnivores in Switzerland) since 1998 to non-invasively assess Eurasian lynx *Lynx lynx* population size and density in the framework of capture-recapture methodologies (Breitenmoser et al., 2007). Not only lynxes, but also many other species were photographed under the implementation of standardised methods. This included 681 cats, which were registered as “bycatches”.

The aim of my Master thesis was to analyze the applicability of cat pictures taken during camera-trapping monitorings between 2007 and 2009. In the first part of my Master thesis I investigated, if it was generally possible to correctly identify the cats on the pictures as either wildcat, domestic cat *Felis silvestris catus* or hybrid and also, if the quality of the camera-trapping pictures sufficed to recognise
wildcats and domestic cats specific traits. In the second part of my Master thesis, I used the camera-trapping pictures to assess, if the wildcats and the domestic cats were spatially or ecologically separated from each other.

The results of my study will help to set further conservation and management guidelines to preserve the wildcats in Switzerland.

References

Sommer, R. S., Benecke, N., 2006. Late Pleistocene and Holocene development of the felid fauna (Felidae) of Europe: a review. J. Zool. 269, 7-19.
The low accuracy of experts correctly identifying European wildcats *Felis silvestris silvestris* and domestic cats *Felis silvestris catus* on pictures

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Abstract

Information concerning cryptic species such as the European wildcat *Felis silvestris silvestris* is often difficult to assess. Relevant information about the presence of wildcats in Switzerland may have provided 681 cat pictures taken during lynx camera-trapping monitorings between 2007 and 2009 in the Jura Mountains of Switzerland. The applicability of these cat pictures required a correct identification of the cats as either wildcat or domestic cat *Felis silvestris catus* by phenotype characters. However, the accuracy of such characters is disputed. To assess the accuracy of experts identifying cats correctly on camera-trapping pictures, we created an expert survey containing 25 pictures of cats with known identity.

Here we report that experts achieved low accuracy identifying wildcats, hybrids and domestic cats correctly on pictures by phenotype characters and that especially hybrids were poorly identified. Thus, the applicability of camera-trapping pictures is limited and other methods are needed.

Keywords: *Felis silvestris silvestris*; cryptic species; camera-trapping; expert survey; Switzerland

Introduction

Management plans and arrangements are crucial for the conservation of threatened species. To set effective management guidelines, a lot of information about the species in concern is needed. This information is often difficult to assess, especially for cryptic species such as the European wildcat *Felis silvestris silvestris*.

The European wildcat shows a fragmented distribution in Europe due to severe declines and habitat destructions as well as local extirpations (Stahl and Artois, 1991). Since 1962, the wildcat has been a protected species listed as vulnerable in the Red Lists of Switzerland (Duelli, 1994).

To date, the occurrences of wildcats in Switzerland are scarcely documented, presumably because of its inconspicuous behaviour and due to it being easily confused with domestic cats *Felis silvestris catus*. Relevant information about the presence of wildcats in Switzerland may be provided through cat pictures taken during camera-trapping monitorings in the Jura Mountains of Switzerland between 2007 and 2009. Camera-trapping has been used in the Swiss Alps by KORA (Coordinated research projects for the conservation and management of carnivores in Switzerland) since 1998 to estimate Eurasian lynx *Lynx lynx* population size and density (Breitenmoser et al., 2007).
Not only lynxes but also many other species were photographed under the implementation of standardised methods. This included 681 cats, which were registered as “bycatches”. The applicability of these cat pictures required a correct identification of the cats as either wildcat or domestic cat by phenotype characters.

However, the accuracy of phenotype characters for the identification of wildcats and domestic cats is disputed. Krüger et al. (2009) proposed that the distinctness of the tail bands, the stripes on the nape and the stripes on the shoulder are the three most reliable characters for identification in the field. Other important characters are a blunt and short tail tip and one dorsal stripe which does not reach the tail rings (Piechocki, 1990; Rangi and Possenti, 1996; Spassov et al., 1997). In contrast, domestic cats have a more narrow tail (Piechocki, 1990; Sunquist and Sunquist, 2002).

However, other researchers stated that it is difficult to tell with certainty a genetically pure wildcat from a tabby looking domestic cat (Driscoll et al., 2007; Nussberger et al., 2007; Nussberger and Weber, 2007).

The aim of our study was to assess the accuracy of experts identifying cats correctly on camera-trapping pictures as well as to assess the applicability of camera-trapping pictures to answer wildcat specific questions. Therefore we created an expert survey containing pictures of cats with known identity.

We expected that the experts were able to tell a wildcat and a domestic cat apart and that their assessment of certainty would correlate with the accurate answers. However, we also expected that some pictures would trouble the experts either because they showed hybrids or because they were of too poor quality to recognise essential traits.

The camera-trapping pictures may contribute additional information about the occurrences of wildcats in Switzerland, which helps to set further conservation and management arrangements.

**Materials and Methods**

**Wildcat, hybrid and domestic cat pictures**

To assess the accuracy of experts identifying cats correctly on camera-trapping pictures, we created an expert survey containing 25 pictures of cats with known identity which were integrated in a sample of 137 pictures of cats with unknown identity.

The 25 pictures of cats with known identity included 10 pictures of wildcats, 10 pictures of domestic cats and 5 pictures of hybrids. The pictures of wildcats showed cats from well-established breeding populations as well as wild living individuals. The pictures of domestic cats showed wild living individuals taken during camera-trapping monitorings in Switzerland in the central and north-western Alps, where no wildcats occur. The pictures of hybrids showed wild living individuals taken in the northern part of Switzerland in the region of Baselland and Solothurn (Table 1).
The identity of the 25 cats on the pictures was either genetically confirmed or the cats originated from well-known populations.

The 137 pictures of cats with unknown identity were taken during three camera-trapping monitorings in the Jura Mountains of Switzerland between 2007 and 2009. They showed tabby looking cats with a wildcat phenotype as well as tabby looking cats with an explicit domestic cat phenotype.

All photos were taken at dawn or at night and were standardised using Adobe Photoshop 7.0 so that the cats were presented approximately the same size. Moreover, most pictures were taken with camera traps. Therefore the pictures were of equal quality and fitted well into the sample of 137 pictures of cats with unknown identity.

**Table 1.** Source of the 25 pictures of cats with known identity.

<table>
<thead>
<tr>
<th>Identity</th>
<th>Pictures</th>
<th>Region</th>
<th>Confirmation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic cat</td>
<td>10</td>
<td>Swiss Central West, Northwestern Alps</td>
<td>region without wildcats</td>
</tr>
<tr>
<td>Wildcat</td>
<td>5</td>
<td>Dählhölzli, Bern</td>
<td>breeding population</td>
</tr>
<tr>
<td>Wildcat</td>
<td>2</td>
<td>Baselland and Solothurn</td>
<td>genetically</td>
</tr>
<tr>
<td>Wildcat</td>
<td>2</td>
<td>Tierstation Bockengut, Horgen</td>
<td>breeding population</td>
</tr>
<tr>
<td>Wildcat</td>
<td>1</td>
<td>Jura français</td>
<td>region with known wildcats</td>
</tr>
<tr>
<td>Hybrid</td>
<td>5</td>
<td>Baselland and Solothurn</td>
<td>genetically</td>
</tr>
</tbody>
</table>

Two hybrids displayed a wildcat haplotype with simultaneously large domestic cat proportion according to microsatellites and three hybrids displayed a domestic cat haplotype with simultaneously large wildcat proportion according to microsatellites.

The two genetically confirmed wildcats from Baselland and Solothurn were analysed using microsatellites.

**Expert survey**

The 162 pictures of cats with known and unknown identity were presented to the experts in combination with a questionnaire consisting of three parts. Firstly, the respondents had to identify each cat picture either as: (1) wildcat, (2) domestic cat or (3) hybrid. Next, they were asked to indicate the degree of certainty of their choice with the options: (1) certain, (2) rather sure, (3) rather unsure and (4) uncertain. Then, they had to give reasons for their uncertainty with the option of multiple answers. The options were as follows: (1) picture is of too poor quality to evaluate, (2) essential traits are not visible, (3) do not feel confident enough to judge, (4) can not decide between wildcat and hybrid, (5) can not decide between hybrid and domestic cat and (6) can not decide between wildcat and domestic cat.

The prepared expert survey was uploaded on the online learning and training platform OLAT of the University of Zürich. 59 experts were invited to participate in the survey, including game wardens and hunters acting in the Jura Mountains of Switzerland, as well as researchers from Germany, Switzerland and France who are currently or were previously studying wildcats.

All statistical analyses were performed using the R statistical software V.2.10.0 (R Development Core Team 2009, Vienna, Austria).
Results

Of the 59 contacted experts, 7 experts refused to participate in the survey, 13 experts did not respond at all and two experts filled in the questionnaire together. Thus, 39 experts participated, leaving 38 evaluable questionnaires.

In identifying the 25 pictures of cats with known identity, there was a high discrepancy in the accuracy of the best and of the worst experts. The best experts identified 100% of the wildcats correctly and also 80% of the domestic cats, but identified none of the hybrids. On the contrary, the worst experts identified 40-60% of the hybrids correctly but only 0-20% of the wildcats and 10-20% of the domestic cats (Fig. 1). The accuracy of the experts correctly identifying the 25 pictures of cats with known identity ranged from 5 to 18 with a mean of 11.03 ± 3.47 (n = 25). The accuracy of the wildcats ranged from 1 to 10 with a mean of 3.66 ± 3.05 (n = 10), for the domestic cats, it ranged from 0 to 10 with a mean of 6.82 ± 2.57 (n = 10) and for the hybrids the range was from 0 to 3 with a mean of 0.87 ± 1.12 (n = 5) (Table 2).

Table 2. Accuracy rate of the N = 38 experts.

<table>
<thead>
<tr>
<th>Identity</th>
<th>Pictures</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic cat</td>
<td>10</td>
<td>6.82</td>
<td>0</td>
<td>10</td>
<td>± 2.57</td>
</tr>
<tr>
<td>Wildcat</td>
<td>10</td>
<td>3.66</td>
<td>1</td>
<td>10</td>
<td>± 3.05</td>
</tr>
<tr>
<td>Hybrid</td>
<td>5</td>
<td>0.87</td>
<td>0</td>
<td>3</td>
<td>± 1.12</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>11.34</td>
<td>5</td>
<td>18</td>
<td>± 3.47</td>
</tr>
</tbody>
</table>

Even though the experts had a low accuracy for identifying the cats correctly, they did not answer by chance. Otherwise, we would have expected that wildcats got appointed as frequently as hybrids and domestic cats, with a possibility of 33.33%. This is not the case as experts appointed 43.17% of the 25 cat pictures of known identity as domestic cats, 33.52% as wildcats and only 23.31% as hybrids (Table 3). The Pearson's chi-square test revealed a relation between expert opinion and identity of the cats ($X^2 = 266.279$, df = 4, $p < 0.010$).
Table 3. Identification of the 25 cat pictures by the experts.

<table>
<thead>
<tr>
<th>ID</th>
<th>Experts opinion</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wildcat</td>
<td>Hybrid</td>
<td>Domestic cat</td>
<td>Total ID</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>Wildcat</td>
<td>139</td>
<td>(39.04%)</td>
<td>111</td>
<td>(31.18%)</td>
<td>106</td>
</tr>
<tr>
<td>Hybrid</td>
<td>126</td>
<td>(68.85%)</td>
<td>33</td>
<td>(18.03%)</td>
<td>24</td>
</tr>
<tr>
<td>Domestic cat</td>
<td>37</td>
<td>(10.22%)</td>
<td>66</td>
<td>(18.23%)</td>
<td>259</td>
</tr>
<tr>
<td>Total E.</td>
<td>302</td>
<td>(33.52%)</td>
<td>210</td>
<td>(23.31%)</td>
<td>389</td>
</tr>
</tbody>
</table>

Percentages in brackets are relative to the row N under Total ID. 49 times the experts did not identify the cat on the picture. Therefore, the total N of 901 was composed of 38 experts multiplied by the 25 pictures minus 49.

Experts achieved higher accuracy correctly identifying the domestic cats than the wildcats (Wilcoxon matched-pairs signed-ranks test with continuity correction, $p < 0.01$). Hybrids were identified the worst and were mostly assigned to the wildcats (2-sample test for equality of proportions with continuity correction, $X^2 = 136.013$, df = 1, p-value < 0.01). Also, the 19 experts with the most correct answer, less frequently appointed hybrids than the 19 experts with the most incorrect answers (Wilcoxon matched-pairs signed-ranks test with continuity correction, $p = 0.003$) (Fig. 1).

![Accuracy rate of the N = 38 experts.](image)

Overall, the experts felt very sure with their decisions and chose significantly more often the option “sure” or “rather sure”, than “rather unsure” and “uncertain” (Wilcoxon matched-pairs signed-ranks test with continuity correction, $p = 0.010$). In particular, experts felt more secure identifying the domestic cats (Wilcoxon matched-pairs signed-ranks test with continuity correction, $p < 0.01$).
However, no correlation (Kendall's rank correlation tau, $p = 0.072$) was observed between the certainty of the experts and the accuracy of the experts correctly identifying the cat pictures (Fig. 2).

![Fig. 2. Relation between the accuracy and the certainty of the experts. There was no correlation between the accuracy and the certainty of the experts (Kendall's rank correlation tau, $p = 0.072$). The y-axis displays a degree of certainty of the experts. A value above 0 means that the expert felt certain and a value below 0 means the reverse.](image)

**Discussion**

Here we demonstrated that altogether, experts had low accuracy identifying wildcats, hybrids and domestic cats correctly on pictures. However, there was a high discrepancy between the accuracy of the best experts and the accuracy of the worst experts. These findings support the statements from several researchers that the distinction between wildcats and domestic cats by phenotype characters alone is difficult and questions the applicability of proposed distinguishing phenotype characters. Hybrids especially were poorly identified and were mostly assigned to the wildcats. This confirmed several observations concerning the difficulties identifying hybrids on morphological grounds alone (Rhymer and Simberloff, 1996; Nussberger et al., 2007; Nussberger and Weber, 2007; Krüger et al., 2009). It also led one to assume that the hybrids had a phenotype more similar to the wildcats than to the domestic cats.

Experts also made numerous mistakes identifying wildcats and domestic cats correctly and assigned almost every third wildcat wrongly to the domestic cats and every 10th domestic cat wrongly to the wildcats.

However, poor quality of camera-trapping pictures where not all essential traits were visible could have resulted in the low accuracy of experts identifying the 25 pictures correctly.

Perhaps also the experts had low accuracy rates, because the identity of the 25 cats were not as clear as first suspected. Most of the cats on the 25 pictures were genetically confirmed, but the genetic
methods are not conclusive and therefore the identity of the cats on the 25 pictures may have been contradictory.

The weak applicability of phenotype characters questions the current policies concerning cats such as the regulation that allows experts including game wardens and hunters to shoot domestic cats in the forests and in remote areas of Switzerland (Federal Law on Hunting and on the Protection of Mammals and Birds Living in the Wild). This regulation is intractable, since every third shot domestic cat could indeed be a wildcat. On the other hand, beside habitat destruction, deforestation and forest fragmentation, hybridisation with domestic cats is regarded as a major threat to the wildcats (Stahl and Artois, 1991; Duelli, 1994; Pierpaoli et al., 2003; Biro et al., 2003; Germain et al., 2008; Oliveira et al., 2008; Krüger et al., 2009; Sarmento et al., 2009). In many areas of Europe including Switzerland, hybridisation has been documented (Pierpaoli et al., 2003; Biro et al., 2005; Lecis et al., 2006; Nussberger et al., 2007; Randi, 2008; Germain et al., 2008; Oliveira et al., 2008; Hertwig et al., 2009). Thus, this regulation could additionally protect the wildcats in Switzerland from hybridisation, because it minimises the density of domestic cats in the forests. But our data suggested that hybrids will possibly not be shot by hunters and game wardens if observed away from residential areas because they were mostly identified as wildcats. Therefore, further mating of hybrids with wildcats would be possible which leads to introgression. Because it is still unknown if there is a viable wildcat population in the Jura Mountains of Switzerland, a reduction of individual numbers could have serious impacts on the preservation of wildcats. Since wildcats are protected species, this regulation is questionable and we suggest that only domestic cats with an explicit domestic cat phenotype should allowed to be shot.

The questionnaire also revealed that the experts generally felt very certain identifying the cat pictures. However, the accuracy of the experts did not correlate with the certainty, what also reflects the difficulties concerning the distinction between wildcats and domestic cats by phenotype characters. Our study also showed that the experts who are familiar with the Jura population and the experts who are not familiar with the Jura population displayed different accuracy rates correctly identifying the 25 cat pictures. Therefore, we assumed that there is variability in pelage markings between regions, possibly due to differences in the rates of hybridisation and introgression (Hertwig et al., 2009), and we suggest it would be advisable to define phenotype characters for each region separately. Hence, the proposed phenotype characters may be applicable for distinguishing between wildcats and domestic cats on pictures when all traits are clearly visible and when they are applied in the right region.

In conclusion, even though camera-trapping has successfully monitored other cat species such as the lynx, the identification of wildcats, hybrids and domestic cats on camera-trapping pictures will remain challenging and the applicability of camera-trapping pictures is limited. Therefore, other methods for the classification are needed. The most commonly used reliable method uses morphological characters like intestine length and cranial volume which enable wildcats and domestic cats to be distinguished with certainty (Schauenberg, 1969; Schauenberg, 1977; Krüger et al., 2009). Unfortunately, these are
post mortem characters and are not applicable in the field. Another method used to identify wildcats, hybrids and domestic cats is genetic analysis. However, the genetic research is not conclusive and genetic classification is also limited because mtDNA does not discriminate between different degrees of hybridisation (Nussberger and Weber, 2007). Therefore, it is important to find a reliable method for the distinction of wildcats and domestic cats in the field to assess more information about the occurrences of the species. Current policies must be reconsidered as our data showed that the possibility of mistakenly shooting protected wildcats is high. If further information concerning the wildcats in Switzerland is provided, it is possible to set conservation and management plans to preserve the wildcats from hybridisation. The harmful effects of hybridisation have threatened the genetic integrity of many populations and species and it is especially problematic for rare species that come into contact with other species that are more abundant (Rhymer and Simberloff, 1996). Genetic mixing through introductions has already threatened endangered mammalians such as the grey and red wolves, the European polecat, the Simien jackals or the Scottish red deer (Wayne, 1992; Gotelli et al., 1994; Abernethy, 1994; Davison et al., 1999). The expansion in the wild of feral animals should be carefully observed to avoid loss of genetic diversity. More information is needed to set management policies, conservation and management arrangements for the preservation of threatened species.

Acknowledgements

We would like to thank all the experts who participated in the survey. We are also grateful to Darius Weber, Patrice Raydelet and Marianne Hartmann who kindly provided cat pictures. Also many thanks to the Tierpark Dählhölzli in Bern who let us install a camera trap in the wildcat enclosure. Special thanks to the KORA team for providing cat photographs from camera-trapping monitorings.

References


Spatial and ecological overlap of European wildcats *Felis silvestris silvestris* and domestic cats *Felis silvestris catus* in the Jura Mountains of Switzerland

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Abstract

The European wildcat *Felis silvestris silvestris* shows a fragmented distribution in Europe. Hybridisation with domestic cats *Felis silvestris catus* is regarded as major threat. Since in regions, where wildcats are sympatric with domestic cats were nevertheless genetically distinct wildcat populations identifiable, it is presumed that they were separated either spatially, ecologically or through differences in behavioural patterns.

In Switzerland, no such studies exist and even the occurrences of wildcats are poorly documented. I have used 681 cat pictures taken during lynx camera-trapping monitorings between 2007 and 2009 in the Jura Mountains of Switzerland to assess occurrences of wildcats. I investigated, if there was a spatial separation existent between the wildcats and the domestic cats. Secondly, with an Ecological-Niche Factor Analysis (ENFA) and the Lloyd’s asymmetric overlap index I investigated, if the wildcats and the domestic cats were separated in niche.

My data revealed that domestic cats occurred everywhere where wildcats occurred in the Jura Mountains of Switzerland and also that the niche of the wildcats was almost totally encompassed by the niche of the domestic cats.

Because population boundaries can have far-reaching management implications, it is important that further studies focus on behaviour patterns. Only if more information concerning wildcats and domestic cats are provided, conservation and management guidelines can be developed to preserve the wildcats in Switzerland.

**Keywords:** *Felis silvestris silvestris*; spatial segregation; Ecological-Niche Factor Analysis; discriminant analysis; Switzerland

Introduction

The European wildcat *Felis silvestris silvestris* shows a fragmented distribution in Europe due to severe declines and habitat destructions as well as local extirpations (Stahl and Artois, 1991). Since 1962, the wildcat has been a protected species listed as vulnerable in the Red Lists of Switzerland (Duelli, 1994).

Beside habitat destruction, deforestation and forest fragmentation, hybridisation with domestic cats *Felis silvestris catus* is regarded as a major threat to the wildcats (Stahl and Artois, 1991; Duelli, 1994; Pierpaoli et al., 2003; Biro et al., 2003; Germain et al., 2008; Oliveira et al., 2008; Krüger et al., 2009; Sarmento et al., 2009). In many areas of Europe including Switzerland, hybridisation has been documented (Pierpaoli et al., 2003; Biro et al., 2005; Lecis et al., 2006; Nussberger et al., 2007; Randi,
hybridisation only occurred occasionally (as e.g. Italy, eastern Germany), wildcats in other areas (e.g. western Germany, Hungary) were extensively hybridised (Pierpaoli et al., 2003; Randi, 2008; Hertwig et al., 2009).

In regions, where wildcats are sympatric with domestic cats were nevertheless still genetically distinct populations of wildcats identifiable, as for instance in France (O’Brien et al., 2009). This finding suggested that even though wildcats and domestic cats were co-occurring and potentially hybridising, they were separated somehow. Separation may occur as a consequence of differences in habitat use (Klar et al., 2008) or through differences in behavioural patterns (Biro et al., 2003; Germain et al., 2008).

In Switzerland, no such studies exist and even the occurrences of wildcats are poorly documented. The aim of my study was to investigate, if there is a phenotypically recognisable wildcat population left in the Jura Mountains of Switzerland. Secondly I wanted to know, if there is a separation between the wildcat population and the domestic cat population either through space use or through habitat preferences.

Information about the presence of wildcats and domestic cats in Switzerland were available by cat pictures taken during Eurasian lynx *Lynx lynx* camera-trapping monitorings in the Jura Mountains of Switzerland. Camera-trapping has been used in the Swiss Alps by KORA (Coordinated research projects for the conservation and management of carnivores in Switzerland) since 1998 to estimate lynx population size and density (Breitenmoser et al., 2007).

During three lynx camera-trapping monitorings between 2007 and 2009, not only lynxes but also many other species were photographed under the implementation of standardised methods. This included 681 cats, which were registered as “bycatches”. After experts analysed the 681 pictures of cats and confirmed their identity (see Part 1), I used these pictures to first investigate, if the wildcats and the domestic cats could be separated in space. Further, I performed an Ecological-Niche Factor Analysis (ENFA) to investigate, if the wildcats and the domestic cats displayed diverse habitat preferences.

The results of my study help to set further conservation and management guidelines for the wildcats in Switzerland; because populations are natural focal units for conservation and management and population boundaries can have far-reaching management implications (Waples and Gaggiotti, 2006).

**Materials and Methods**

**Study area**

The study area consisted of three lynx camera-trapping monitoring regions in the Jura Mountains of Switzerland. The regions encompassing a total of 2295 km² were situated between 47° 22’ N, 7° 52’ E as the northeastern corner and 46° 25’ N, 6° 7’ E as the south-western corner (Fig. 1 and Fig. 2).
Felid species (Karanth et al., 2004; Jackson et al., 2006). Lynx also have distinctive individual coat

Forests cover about 40-50% of the area and are dominated mainly by beech species. They included parts of the cantons of Bern, Jura, Neuenburg, Solothurn, Waadt, Baselland and Aargau and were encircled by the Vallée de Delémont in the north-west, Hägendorf in the north-east, the Val de Travers, the border to France and the Vallée de Joux in the west, by lakes of Neuenburg and Biel and the Montagne de Boudry in the east, the plateau in the south-east and the Col de la Givrine in the south-west.

The Jura Mountains are a secondary limestone mountain chain under an oceanic climate regime (yearly precipitation 1000-2000 mm) with altitude reaching up to 1.718 m a.s.l. in Crêt de la Neige. The landscape is a mosaic of forests and pastures, the latter accounting for about 15-18% of the area. Forests cover about 40-50% of the area and are dominated mainly by beech *Fagus sylvatica*. Mixed deciduous forests are found along the slopes and coniferous forests on the ridges (Blant, 2001).

**Camera-trapping**

Camera-trapping is nowadays a common tool to assess abundance and density of naturally marked felid species (Karanth et al., 2004; Jackson et al., 2006). Lynx also have distinctive individual coat markings (Laass, 1999; Thüler, 2002) and this characteristic is used to identify individuals on
photographs and build their history of capture (Laass, 1999; Zimmermann et al., 2006; Fattebert and Zimmermann, 2007).

Between 2007 and 2009, three lynx camera-trapping monitorings took place in the Jura Mountains of Switzerland (Table 1).

**Table 1. Number of wildcat and domestic cat pictures provided by the camera-trapping monitorings.**

<table>
<thead>
<tr>
<th>Camera-trapping monitorings</th>
<th>northern Jura</th>
<th>central Jura</th>
<th>southern Jura</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sites</td>
<td>56</td>
<td>57</td>
<td>57</td>
<td>170</td>
</tr>
<tr>
<td>Pic. o</td>
<td>403</td>
<td>107</td>
<td>2</td>
<td>512</td>
</tr>
<tr>
<td>Pic. n</td>
<td>379</td>
<td>96</td>
<td>1</td>
<td>471</td>
</tr>
<tr>
<td>Obvious domestic cats</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tabby cats</td>
<td>136</td>
<td>28</td>
<td>5</td>
<td>169</td>
</tr>
<tr>
<td>Total</td>
<td>539</td>
<td>135</td>
<td>7</td>
<td>681</td>
</tr>
<tr>
<td></td>
<td>487</td>
<td>118</td>
<td>5</td>
<td>610</td>
</tr>
</tbody>
</table>

Under Pic. o are the total number of pictures listed. Under Pic. n are the number of pictures after excluding those of insufficient quality listed.

During the three camera-trapping monitorings, a total of 170 sites were equipped with camera-traps. Every site was sampled using two camera-traps, a “mother camera” and a “slave camera” facing each other, the latter getting activated by the flash of the “mother” camera. Therefore, both flanks of the lynx got pictured which enabled certain individual identification (Zimmermann et al., 2004).

The camera-traps were positioned along easily accessible passages which lynxes regularly use during their movements such as forest tracks, hiking trails and deer passes. Each camera-trapping monitoring lasted for 60 days.

The camera-traps got controlled every 5 to 6 days to change the batteries and films and maintenance work.

Beside lynx, 169 tabby looking cats and 512 obvious domestic cats were photographed (Table 1).

**Wildcat and domestic cat data**

After scanning all cat pictures of the three camera-trapping monitorings, I allocated the photographs taken by the “slave” camera to the appropriate complement of the “mother” camera by comparing data and time. In cases, where two photographs from two different sides of an individual existed, I only considered the one with the higher quality. Thereafter, 681 pictures of obvious domestic cats and assumed wildcats reminded. In further analysis, I excluded pictures of insufficient quality. Thus, 610 cat pictures reminded (Table 1).
Fig. 2. Distribution map of the wildcats and the domestic cats in Sample 2. The red dots stand for sites where the wildcats were pictured, the blue squares stand for sites where the domestic cats were pictured. The small grey squares display all camera-trapping sites. The black stars describe the sites, where cat pictures reminded unidentified. The yellow patches stand for settlements.

After a first morphological separation of these cat pictures, in which all black, white or ginger coloured cats or cats wearing a collar were counted as obvious domestic cats, 139 photographs of possible wildcats reminded. In obvious cases, where the same cat was photographed more than ones within the same minute, I only considered one photograph.

Table 2. Identification of the 137 cat pictures by the nine best experts.

<table>
<thead>
<tr>
<th>ID</th>
<th>Experts opinion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wildcat</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Wildcat</td>
<td>72</td>
</tr>
<tr>
<td>Hybrid</td>
<td>39</td>
</tr>
<tr>
<td>Domestic cat</td>
<td>15</td>
</tr>
<tr>
<td>Total E.</td>
<td>126</td>
</tr>
</tbody>
</table>

Percentages in brackets are relative to the row N under Total ID. 4 times the experts did not identify the cat on the picture. Therefore, the total N of 221 was composed of 9 experts multiplied by the 25 pictures minus 4.
In total, 137 pictures of tabby looking cats from the camera-trapping monitorings and 25 pictures of cats with known identity were included in an expert survey (see Part 1).

There was no discrepancy between the certainty of the experts identifying the 137 cat pictures with unknown identity and the certainty of the experts identifying the 25 cat pictures with known identity (2-sample test for equality of proportions with continuity correction, $X^2 = 0.753$, df = 1, p-value = 0.385). Therefore, I assumed that the 137 cat pictures with unknown identity were identified at least as good as the pictures of cats with known identity.

The nine best experts made in mean the smallest mistakes identifying the wildcats and the domestic cats on the 25 pictures of cats with unknown identity (Fig. 3). They achieved an accuracy rate identifying wildcats and domestic cats correctly of either 90%, 80% or 70% and only assigned 14.61% of the wildcats wrongly to the domestic cats and 16.85% of the domestic cats wrongly to the wildcats (Table 2). Therefore, I only considered the opinions of the nine best experts for identifying the 137 cats with unknown identity as either wildcat, domestic cat or hybrid.

![Fig. 3. Mistakes in % of the experts identifying the wildcats and the domestic cats correctly on the pictures. The mistake of all 38 experts assigning the wildcats and the domestic cats wrongly was in mean 20.00%, the mistake of the 29 best experts was in mean 21.74%, the mistake of the 20 best experts was in mean 22.81%, the mistake of the 9 best experts was in mean 15.73% and the mistake of the 5 best experts was in mean 16.00%.](image)

The ranking of the experts was based on the accuracy rate identifying wildcats and domestic cats only, because of the general low accuracy rate identifying hybrids (see Part 1).

In regard to the opinions of the nine best experts, I allocated the 137 cat pictures of unknown identity into two Samples. Sample 1 was more restrictive according to the assignment of a cat into either wildcat or domestic cat, whereas Sample 2 was less restrictive (Table 3).

In Sample 1, cats were only accepted as “wildcats”, if all experts agreed on the cat’s identity, and similarly for the domestic cats. However, the domestic cats also included the 471 obvious domestic cat
pictures, which were not part of the expert survey. All cat pictures, which did not meet these requirements reminded “unidentified”.

In Sample 2, cats were only accepted as “wildcats”, if all experts agreed that it was a wildcat or a hybrid but certainly not a domestic cat, and similarly for the domestic cats. However, the domestic cats also included the 471 obvious domestic cat pictures, which were not part of the expert survey. All cat pictures, which did not meet these requirements reminded “unidentified”.

These two Samples were used for further investigations. All analyses were performed using the R statistical software V.2.10.0 (R Development Core Team 2009, Vienna, Austria).

Table 3. Number of wildcats and domestic cats after the identification by experts.

<table>
<thead>
<tr>
<th></th>
<th>Camera-trapping monitorings</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>northern Jura</td>
<td>central Jura</td>
<td>southern Jura</td>
<td>Total</td>
</tr>
<tr>
<td><strong>Sample 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ID</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wildcats</td>
<td>29</td>
<td>14</td>
<td>3</td>
<td>46</td>
</tr>
<tr>
<td>Domestic cats</td>
<td>21+374</td>
<td>1+96</td>
<td>0+1</td>
<td>22+471</td>
</tr>
<tr>
<td>unidentified</td>
<td>63</td>
<td>7</td>
<td>1</td>
<td>71</td>
</tr>
<tr>
<td>Total</td>
<td>113+374</td>
<td>22+96</td>
<td>4+1</td>
<td>139+471</td>
</tr>
<tr>
<td><strong>sites</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of sites</td>
<td>56</td>
<td>57</td>
<td>57</td>
<td>170</td>
</tr>
<tr>
<td>Sites with no cats</td>
<td>20</td>
<td>36</td>
<td>55</td>
<td>111</td>
</tr>
<tr>
<td>Sites with wildcats</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Sites with domestic cats</td>
<td>26</td>
<td>14</td>
<td>1</td>
<td>41</td>
</tr>
<tr>
<td>Sites with both cats</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td><strong>Sample 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ID</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wildcats</td>
<td>42</td>
<td>16</td>
<td>4</td>
<td>62</td>
</tr>
<tr>
<td>Domestic cats</td>
<td>33+374</td>
<td>1+96</td>
<td>0+1</td>
<td>34+471</td>
</tr>
<tr>
<td>unidentified</td>
<td>38</td>
<td>5</td>
<td>0</td>
<td>43</td>
</tr>
<tr>
<td>Total</td>
<td>113+374</td>
<td>22+96</td>
<td>4+1</td>
<td>139+471</td>
</tr>
<tr>
<td><strong>sites</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of sites</td>
<td>56</td>
<td>57</td>
<td>57</td>
<td>170</td>
</tr>
<tr>
<td>Sites with no cats</td>
<td>20</td>
<td>36</td>
<td>55</td>
<td>111</td>
</tr>
<tr>
<td>Sites with wildcats</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Sites with domestic cats</td>
<td>22</td>
<td>13</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>Sites with both cats</td>
<td>11</td>
<td>4</td>
<td>1</td>
<td>16</td>
</tr>
</tbody>
</table>

The numbers added on refer to the obvious domestic cat pictures which were not included in the expert survey.
Spatial segregation

I tested spatial segregation between the wildcats and the domestic cats within Sample 1 and Sample 2 using a nearest-neighbour contingency table and performed a 2x2 chi-square test of independence, as proposed by Pielou (1961). On sites with only wildcats, the nearest-neighbours were presumed to be wildcats, on sites with only domestic cats, the nearest-neighbours were presumed to be domestic cats and on sites with wildcats and domestic cats, the nearest-neighbours were either wildcats or domestic cats (Table 4).

Segregation occurs, if species in a population are found more frequently near co-specifics and less frequently near other species than expected if the species are unsegregated. If the observed difference from expectation is significant at the probability level chosen, the conclusion follows that the two species may be regarded as partly segregated from each other. Contrariwise, if the observed frequencies do not significantly depart from expectation, the two species are not spatially segregated from each other (Pielou, 1961).

Table 4. Nearest neighbour contingency tables.

<table>
<thead>
<tr>
<th>Label of point</th>
<th>Nearest neighbour</th>
<th>Wildcat</th>
<th>Domestic cat</th>
<th>Total density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>Sample 1</td>
<td>Wildcat</td>
<td>8</td>
<td>(44)</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Domestic cat</td>
<td>10</td>
<td>(20)</td>
<td>41</td>
</tr>
<tr>
<td>Sample 2</td>
<td>Wildcat</td>
<td>8</td>
<td>(33)</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Domestic cat</td>
<td>16</td>
<td>(31)</td>
<td>35</td>
</tr>
</tbody>
</table>

Percentages in brackets are relative to total density. The 2x2 chi-square test of Sample 1 revealed no segregation in space use ($X^2 = 3.066, df = 1, p-value = 0.080$). The 2x2 chi-square test of Sample 2 revealed also no segregation in space use ($X^2 = 0.009, df = 1, p-value = 0.924$).

Landscape data

The study area was modelled as a raster map (1 ha per cell) based on the Swiss Coordinate System. Thereof, 167 cells contained camera-trapping sites.

For types of descriptive Eco-geographical Variables (EGVs) were integrated into the model: 1. Topographic variables, including altitude, slope and aspect. 2. Anthropogenic variables, including distance to single buildings and paved roads. 3. Habitat variables, including distance to bushy forest, groves, croplands, meadows and non-productive vegetation and 4. Hydrological data like distance to watercourses (Table 5). The distances between the focal cells and the closest cells with presence of the concerned variables were calculated in ArcView GIS 3.3 (ESRI) with the module “calculate distance”.

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The distributions of the EGVs were normalised by the Box-Cox algorithm (Sokal and Rohlf, 1994). The species maps consisted of presence data of wildcats and domestic cats according to Sample 1 and Sample 2.

Table 5. Source of the 11 ecogeographical variables used in the Ecological-Niche Factor Analysis (ENFA).

<table>
<thead>
<tr>
<th>Official database</th>
<th>Topic</th>
<th>Source</th>
<th>Derived EGV</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHM</td>
<td>topography</td>
<td>OFT</td>
<td>altitude, aspect, slope</td>
</tr>
<tr>
<td>NOAS92</td>
<td>habitat variables</td>
<td>OFS</td>
<td>distance to bushy forests, groves, croplands, meadows, non-productive vegetation</td>
</tr>
<tr>
<td>GWN</td>
<td>hydrography</td>
<td>OFS</td>
<td>distance to watercourses</td>
</tr>
<tr>
<td>Vector 25</td>
<td>anthropogenic variables</td>
<td>OFT</td>
<td>distance to single buildings and paved roads</td>
</tr>
<tr>
<td>Camera-trapping</td>
<td>wildcat data</td>
<td>KORA</td>
<td>presence data</td>
</tr>
<tr>
<td>Camera-trapping</td>
<td>domestic cat data</td>
<td>KORA</td>
<td>presence data</td>
</tr>
</tbody>
</table>

OFT, Swiss Office of Topography; OFS, Swiss Office of Statistics.

ENFA

Sample 1 and 2 provided presence data only and therefore, an Ecological-Niche Factor Analysis (ENFA) was used to describe the habitats of wildcats and domestic cats in my study (Hirzel et al., 2002).

The ENFA computes suitability functions by comparing the species distribution in the EGV space with that of a whole set of cells. ENFA summarises the overall information under the form of two types of indices. The first index is termed ‘marginality’ and the second and subsequent factors are termed ‘specialisation’. Specialisation is a measure of a species’ tolerance. Marginality and specialisation are uncorrelated factors with the major information contained within the first factors (Hirzel et al., 2002). A global marginality factor close to 1 means that the species lives in a very particular habitat relative to the reference set. The procedure of ENFA has been described in detail by Hirzel et al. (2002).

I computed two different ENFAs. In the first analysis, I compared the species distribution of Sample 1 in the EGV space with that of the 167 cells containing camera-trapping sites. In the second analysis, I compared the species distribution of Sample 2 in the EGV space with that of the 167 cells containing camera-trapping sites.

All procedures are implemented in the software BIOMAPPER 3.2 (Hirzel et al., 2005).

Niche differentiation

With the performance of a discriminant analysis, I compared the ecological niches of the wildcats and the domestic cats. This multivariate analysis uses the space defined by the EGVs and both species’ distributions simultaneously (Legendre and Legendre, 1998). The computed discriminant factor maximises the interspecific variance and minimises the intraspecific variance. This factor allowed
further investigation of the relationship between the two niches and could be used to compute indices describing the niches’ breadth and overlap. To measure niche breadth of the two species, I used the Hurlbert’s index ($B'$). It varies between 0 (corresponding to a specialised species) and 1 (corresponding to a generalist species) (Hurlbert, 1978). The overlapping of the species niches was evaluated with Lloyd’s asymmetric overlap index ($Z$). $Z_{x(y)}$ is the part of the niche of x, which is also shared by y. Therefore it is the overlapping of the niche of y on the niche of x (Hurlbert, 1978).

All these procedures are implemented in the software BIOMAPPER 3.2 (Hirzel et al., 2005).

**Results**

During the lynx camera-trapping monitorings between 2007 and 2009, a total of 681 cats were photographed. After excluding pictures of insufficient quality, 610 pictures to be analysed reminded. Thereof, 487 cats got photographed in the northern Jura Mountains, 118 cats got photographed in the central Jura Mountains and 5 cats got photographed in the southern Jura Mountains. Totally, 139 pictures showed tabby looking cats and 471 pictures showed obvious domestic cats (Table 1). Within the more restrictive Sample 1, the nine best experts assigned 46 cats to the wildcats, 22 cats to the domestic cats and 71 cats reminded unidentified. Together with the 471 obvious domestic cats, which were not included in the expert survey, a total of 493 cats were regarded as domestic cats. Within the less restrictive Sample 2, the best nine experts assigned 62 cats to the wildcats, 34 cats to the domestic cats and 43 cats reminded unidentified. Together with the 471 obvious domestic cats, which were not included in the expert survey, a total of 505 cats were regarded as domestic cats (Table 3).

In the northern Jura Mountains, at 20 out of 56 sites no cats were photographed, in the central Jura Mountains at 36 out of 57 sites no cats were photographed and in the southern Jura Mountains at 55 out of 57 sites no cats were photographed (Table 3). Within Sample 1 and Sample 2, at 8 sites only wildcats were photographed. In Sample 1, at 41 sites only domestic cats were pictured and in Sample 2, at 35 sites only domestic cats were pictured. Wildcats and domestic cats were mainly photographed in the northern and central part of the Jura Mountains (Fig. 1 and Fig. 2). In the southern part of the Jura Mountains, cats were photographed at only two sites.

The cells containing camera-trapping sites were located in average on an elevation of 964 m a.s.l. with an aspect of $21^\circ$. The cells containing camera-trapping sites were also situated in mean 992 m away from single buildings, 1161 m away from watercourses, 304 m away from paved roads, 766 m away from bushy forests, 459 m away from groves, 548 m away from cropland, 391 m away from meadows and 3294 m away from non-productive vegetation.

Wildcats and domestic cats in Sample 1 and Sample 2 showed a big overlap in spatial use. The 2x2 chi-square test of the nearest-neighbour contingency table of Sample 1 revealed no segregation in
space use ($X^2 = 3.066, \text{df} = 1, \text{p-value} = 0.078$) and the results for Sample 2 turned out to be even more clearly ($X^2 = 0.009, \text{df} = 1, \text{p-value} = 0.924$).

The comparison of the species distribution of Sample 1 in the EGV space with that of the cells from the camera-trapping sites displayed a global marginality value of 0.527 for the wildcats. This indicated that they had no tendency to live in a very particular habitat type compared to the available conditions at the cells containing camera-trapping sites. But in comparison with the global marginality of 0.475 for the domestic cats, the wildcats were pictured in less average conditions than the domestic cats compared to the available conditions at the cells containing camera-trapping sites. A tolerance of 0.464 for the wildcats suggested a certain acceptance towards departure from the optimal habitat at the cells containing camera-trapping sites. In contrast, the domestic cats displayed a tolerance of 0.789 what indicated that the domestic cats were even less choosy on their living environment. The first 5 ecological factors explained 94.80% of the total variance that means 100% of the marginality and 94.80% of specialisation. The relatively high value of 28.16% marginality for the wildcats explained that they had a more restricted range as the domestic cats which had a marginality value of only 18.17%.

The wildcats were photographed mainly closer to watercourses and on sites situated on lower altitudes in relation to the available conditions at the cells containing camera-trapping sites. In addition, the wildcats were pictured further away from non-productive vegetation, meadows and from paved roads. Also the wildcats were pictured on steeper sites. The wildcats seemed to have a narrower range than available at the cells containing camera-trapping sites for the distance to bushy forests, the distance to croplands and the elevation (high value of the first specialisation factor for these EGVs) (Table 6).

**Table 6.** Correlation between the ENFA factors and the ecogeographical variables for the wildcats of Sample 1.

<table>
<thead>
<tr>
<th>EGV</th>
<th>Marginality</th>
<th>Spec. 1</th>
<th>Spec. 2</th>
<th>Spec. 3</th>
<th>Spec. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28.16%</td>
<td>31.56%</td>
<td>13.48%</td>
<td>8.83%</td>
<td>7.59%</td>
</tr>
<tr>
<td>Aspect</td>
<td>---</td>
<td>***</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Distance to single buildings</td>
<td>+</td>
<td>0</td>
<td>*****</td>
<td>**</td>
<td>*****</td>
</tr>
<tr>
<td>Distance to watercourses</td>
<td>--</td>
<td>***</td>
<td>**</td>
<td>0</td>
<td>***</td>
</tr>
<tr>
<td>Distance to paved roads</td>
<td>+++</td>
<td>*</td>
<td>**</td>
<td>0</td>
<td>**</td>
</tr>
<tr>
<td>Altitude</td>
<td>----</td>
<td>*****</td>
<td>**</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>Slopes</td>
<td>++++</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>***</td>
</tr>
<tr>
<td>Distance to bushy forests</td>
<td>0</td>
<td>*****</td>
<td>*****</td>
<td>**</td>
<td>0</td>
</tr>
<tr>
<td>Distance to groves</td>
<td>+</td>
<td>**</td>
<td>*****</td>
<td>*****</td>
<td>*</td>
</tr>
<tr>
<td>Distance to cropland</td>
<td>0</td>
<td>****</td>
<td>**</td>
<td>********</td>
<td>***</td>
</tr>
<tr>
<td>Distance to meadows</td>
<td>+++</td>
<td>**</td>
<td>**</td>
<td>0</td>
<td>*</td>
</tr>
<tr>
<td>Distance to non-productive vegetation</td>
<td>+++++</td>
<td>*</td>
<td>*</td>
<td>0</td>
<td>***</td>
</tr>
</tbody>
</table>

The percentages indicate the amount of specialisation accounted for by the factor. The plus signs under the marginality factor mean that the species was found in locations with higher values than the average cell. The minus signs mean the reverse. The greater the number of signs, the higher the correlation; 0 indicates a very weak correlation. Any number > 0 of the star signs under the specialisation factors mean the species was found occupying a narrower range of values than available. The greater the number of signs, the narrower the range; 0 indicates a very low specialisation.
For the domestic cats of Sample 1, 88.80% of the total variance was explained by the first 6 ecological factors. The domestic cats were pictured on sites with lower altitudes, closer to croplands, watercourses, single buildings, groves and meadows in relation to the available conditions at the cells containing camera-trapping sites. In addition, the domestic cats were pictured further away from non-productive vegetation, paved roads and bushy forests. Also, the domestic cats were pictured at a narrower range than available for meadows, bushy forests, watercourses and croplands (Table 7).

Table 7. Correlation between the ENFA factors and the ecogeographical variables for the domestic cats of Sample 1.

<table>
<thead>
<tr>
<th>EGV</th>
<th>Marginality</th>
<th>Spec. 1</th>
<th>Spec. 2</th>
<th>Spec.3</th>
<th>Spec.4</th>
<th>Spec.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect</td>
<td>---</td>
<td>0</td>
<td>**</td>
<td>****</td>
<td>0</td>
<td>***</td>
</tr>
<tr>
<td>Distance to single buildings</td>
<td>---</td>
<td>0</td>
<td>0</td>
<td>****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>Distance to watercourses</td>
<td>---</td>
<td>****</td>
<td>***</td>
<td>**</td>
<td>****</td>
<td>***</td>
</tr>
<tr>
<td>Distance to paved roads</td>
<td>+</td>
<td>*</td>
<td>********</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Altitude</td>
<td>----------</td>
<td>*</td>
<td></td>
<td>*******</td>
<td>0</td>
<td>***</td>
</tr>
<tr>
<td>Slopes</td>
<td>++</td>
<td>*</td>
<td>****</td>
<td>****</td>
<td>***</td>
<td>*</td>
</tr>
<tr>
<td>Distance to bushy forests</td>
<td>+</td>
<td>****</td>
<td>***</td>
<td>*</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>Distance to groves</td>
<td>-</td>
<td>0</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*******</td>
</tr>
<tr>
<td>Distance to cropland</td>
<td>----</td>
<td>***</td>
<td>*</td>
<td>*******</td>
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<td></td>
</tr>
<tr>
<td>Distance to meadows</td>
<td>-</td>
<td>********</td>
<td>*</td>
<td>0</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Distance to non-productive vegetation</td>
<td>+++++</td>
<td>*</td>
<td>0</td>
<td>0</td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>

The percentages indicate the amount of specialisation accounted for by the factor. The plus signs under the marginality factor mean that the species was found in locations with higher values than the average cell. The minus signs mean the reverse. The greater the number of signs, the higher the correlation; 0 indicates a very weak correlation. Any number > 0 of the star signs under the specialisation factors mean the species was found occupying a narrower range of values than available. The greater the number of signs, the narrower the range; 0 indicates a very low specialisation.

The ENFA of the less restrictive Sample 2, in which I compared the distribution of the cats of Sample 2 in the EGV space with that of the 167 cells containing camera-trapping sites displayed similar values as the ENFA of Sample 1. Because the number of sites where domestic cats were pictured reminded the same in Sample 1 as in Sample 2, the ENFA of Sample 2 displayed the same values for domestic cats as the ENFA of Sample 1 (Table 7). The only differences concerned the wildcats. A new tolerance of 0.745 for the wildcats indicated that they were as the domestic cats less choosy on their living environment. The first 5 ecological factors explained 88.10% of the total variance that means 100% of the marginality and 88.10% of specialisation. The relatively high marginality value of 28.16% for the wildcats in Sample 1, was in Sample 2 replaced by a marginality value of only 8.19% what indicated that the wildcats in Sample 2 live in very average conditions compared to the available conditions at the cells containing camera-trapping sites. In Sample 2, the wildcats were photographed mainly closer to watercourses, closer to buildings and closer to croplands in relation to the available conditions at the cells containing camera-trapping sites. Additionally, the wildcats seemed to be at sites situated on lower altitudes. They were also pictured further away from non-productive vegetation, paved roads and meadows. Furthermore, the wildcats were pictured on steeper sites compared to the available
conditions at the cells containing camera-trapping sites. They also seemed to have a narrower range than available for the distance to croplands, the distance to bushy forests and the distance to buildings (high value of the first specialisation factor for these EGVs) (Table 8).

Table 8. Correlation between the ENFA factors and the ecogeographical variables for the wildcats of Sample 2.

<table>
<thead>
<tr>
<th>EGV</th>
<th>Marginality</th>
<th>Spec. 1</th>
<th>Spec. 2</th>
<th>Spec. 3</th>
<th>Spec. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect</td>
<td>8.19%</td>
<td>27.65%</td>
<td>19.04%</td>
<td>12.19%</td>
<td>9.19%</td>
</tr>
<tr>
<td>Distance to buildings</td>
<td>--</td>
<td>**</td>
<td>*</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td>Distance to watercourses</td>
<td>***</td>
<td>*****</td>
<td>*****</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Distance to paved roads</td>
<td>+++</td>
<td>*</td>
<td>0</td>
<td>****</td>
<td>*</td>
</tr>
<tr>
<td>Altitude</td>
<td>------</td>
<td>*</td>
<td>*****</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td>Slopes</td>
<td>+++++</td>
<td>*</td>
<td>*</td>
<td>****</td>
<td>0</td>
</tr>
<tr>
<td>Distance to bushy forests</td>
<td>0</td>
<td>****</td>
<td>*</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td>Distance to groves</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>****</td>
<td>***</td>
</tr>
<tr>
<td>Distance to cropland</td>
<td>-</td>
<td>*******</td>
<td>*******</td>
<td>****</td>
<td>***</td>
</tr>
<tr>
<td>Distance to meadows</td>
<td>+</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>***</td>
</tr>
<tr>
<td>Distance to non-productive vegetation</td>
<td>++++</td>
<td>0</td>
<td>0</td>
<td>**</td>
<td>0</td>
</tr>
</tbody>
</table>

The percentages indicate the amount of specialisation accounted for by the factor. The plus signs under the marginality factor mean that the species was found in locations with higher values than the average cell. The minus signs mean the reverse. The greater the number of signs, the higher the correlation; 0 indicates a very weak correlation. Any number > 0 of the star signs under the specialisation factors mean the species was found occupying a narrower range of values than available. The greater the number of signs, the narrower the range; 0 indicates a very low specialisation.

The analysis of niche differentiation between the wildcats and the domestic cats in Sample 1 showed that the niche of the wildcats and the niche of the domestic cats could not be separated (Fig. 4).
Also the computed discriminant axis for Sample 2 could not separate the two species (Fig. 5). The Hurlbert’s niche breadth index $B'$ in Sample 1 indicated that the niche of the wildcats ($B' = 0.274$) was much smaller than the niche of the domestic cats ($B' = 0.695$). The Lloyd’s asymmetric overlap of the niche of the domestic cats on the niche of the wildcats was 3.667, whereas the reciprocal overlap was only 1.320. These findings suggested that the niche of the wildcats was almost totally encompassed by the niche of the domestic cats.

The Hurlbert’s niche breadth index $B'$ in Sample 2 showed that the two niches are more similar in size than in Sample 1. The niche of the wildcats ($B' = 0.468$) was only little smaller than the niche of the domestic cats ($B' = 0.681$). The Lloyd’s asymmetric overlap of the niche of the domestic cats on the niche of the wildcats in Sample 2 was 3.667, whereas the reciprocal overlap was 1.760. Again, the niche of the wildcats was almost totally encompassed by the niche of the domestic cats.

**Discussion**

The best nine experts achieved an accuracy rate identifying wildcats and domestic cats correctly on pictures of either 90%, 80% or 70%. However, the identification of the camera-trapping pictures troubled even them and several cat pictures reminded unidentified. The main reason for the uncertainty of the experts in Sample 1 and Sample 2 were the facts that not all essential traits were visible and that the quality of the camera-trapping pictures was too poor to evaluate. Nevertheless, the experts identified 46 cats as wildcats and 22 cats as domestic cats in Sample 1, and 62 cats as wildcats and 34 cats as domestic cats in Sample 2.

My data revealed that there is a phenotypically recognisable wildcat population existing in the Jura Mountains of Switzerland. The wildcats and the domestic cats in Sample 1 and Sample 2 got mainly pictured in the northern part of the Jura Mountains (Fig. 1 and Fig. 2). The particularly small number

![Fig. 5. Niche characteristics of the wildcats and the domestic cats in Sample 2 in relation to global distribution of all cells of the camera-trapping along the discriminant factor.](image-url)
of cat pictures taken in the southern part of the Jura Mountains during camera-trapping monitoring in 2008/2009 may be the result of the strong winter in which there was a thick snow cover. Mermod and Liberek (2002) proposed that wildcats move to areas free of snow situated at lower altitudes when a thick snow cover is present and move back immediately after the snow melt. Therefore it is possible that we have missed the cats in the southern part of the Jura Mountains since the camera-trapping sites were in average situated on an elevation of 964 m a.s.l.. The next camera-trapping monitoring in this area might provide more information concerning wildcat and domestic cat occurrences.

My analysis showed that there was no spatial segregation between wildcats and domestic cats in the Jura Mountains of Switzerland. Sample 2 and even the more restrictive Sample 1 revealed no spatial segregation. Since the camera-traps were situated assumingly at the edge of the niche of domestic cats and no segregation could be detected, I concluded that domestic cats occur everywhere where wildcats occur, but the contrary could not be concluded.

Also the Lloyd’s asymmetric overlap index (Z) revealed that the niche of the wildcats was almost totally encompassed by the niche of the domestic cats. Therefore, the wildcats and the domestic cats in my Samples did not separate in niche use.

Since the camera-trapping sites were localised in favour to picture lynx, they may not have displayed the optimal habitat of wildcats. Likewise, the described niche of the domestic cats in my Samples did not display the niche of domestic cats in the Jura Mountains. It is expected that the niche of domestic cats is much bigger since they also frequently occur everywhere in Switzerland and also within human settlements. Therefore all niche measurements and habitat preferences of the wildcats and the domestic cats in my study were just comparable with each other and did not describe the optimal habitat of the species. Nevertheless, I assumed that the camera-trapping sites were localised rather in favour of the wildcats than the domestic cats that is to say in forests and away from human settlements (Klar et al., 2008).

The only differences between the niche of the wildcats and the niche of the domestic cats in Sample 1 concerned the distance to single buildings, whereas the domestic cats were pictured closer to single buildings and the wildcats further away. The data also revealed that the wildcats were pictured on higher altitudes and on steeper grounds than the domestic cats. Interestingly, the wildcats were pictured further away from meadows than the domestic cats, even though wildcats are said to be associated to close distance to meadows (Klar et al., 2008). In Sample 2, these differences were not anymore identifiable. This finding suggested that either the wildcats are not associated to a critical distance to single houses as predicted by Klar et al. (2008) or that the assumed wildcats in Sample 2 are indeed contradictory.

In conclusion, wildcats and domestic cats in the Jura Mountains of Switzerland are co-occurring and potentially hybridising. Since hybridisation with domestic cats is regarded as major threat to the wildcats it is important to assess, if there is still a genetically distinct wildcat population left in the Jura Mountains of Switzerland and also to assess the degree of hybridisation and introgression. Given that
separation did not occur as a consequence of differences in space and habitat use, they may be separated through differences in behavioural patterns such as no spatio-temporal sharing (Biro et al., 2003; Germain et al., 2008). Because population boundaries can have far-reaching management implications (Waples and Gaggiotti, 2006) it is important that further studies focus on behaviour patterns. Only if more information concerning wildcats and domestic cats are provided, further conservation and management guidelines can be developed to preserve the wildcats in Switzerland.

Acknowledgements

First I would like to thank all experts who participated in the survey. Many thanks also to the KORA team for providing the camera-trapping pictures. I am also grateful to Fridolin Zimmermann for helping me a lot and Urs Breitenmoser and Lukas Keller for intellectual assistance.

References


Thüler, K., 2002. Spatial and Temporal Distribution of Coat Patterns of Eurasian lynx (Lynx lynx) in two reintroduced Populations in Switzerland. KORA-Bericht 13, 1-35.


Schweiz 2005. KORA-Bericht 35, 1-64.
Appendix A

The questionnaire which was integrated in the expert survey is presented in Table A1.

**Table A1. Questionnaire of the expert survey.**

Ist diese Katze ihrer Meinung nach eine Hauskatze, ein Hybride oder eine Wildkatze? Selon votre avis ce chat est-il un chat domestique, un hybride ou un chat forestier? Is this cat in your opinion a domestic cat, a hybrid or a wildcat?

- Wildkatze/chat forestier/wildcat
- Hybride/hybride/hybrid
- Hauskatze/chat domestique/domestic cat

**Gewissheit/certitude/certainty**

Bitte geben Sie mir einen Wert für die Sicherheit Ihres Entscheides an. Je vous prie d’indiquer le degré de certitude de votre choix. Please indicate how sure you are with your choice.

- sicher/sûr/sure
- eher sicher/plutôt sûr/rather sure
- eher unsicher/plutôt incertain/rather unsure
- unsicher/incertain/unsure

**falls unsicher/si incertain/if unsure**

Falls eher sicher bis unsicher, bitte nennen Sie Gründe/si vous n’êtes pas sûr de votre choix, veuillez indiquer s.v.p. les raisons/ if rather sure to unsure, please give reasons (Mehrfachnennungen möglich/plurieres réponses possibles/multiple answers are permitted)

- Bild für eine Beurteilung zu schlecht/l’image est trop mauvaise pour juger/the picture is too poor to evaluate
- wesentliche Merkmale sind nicht sichtbar/certaines caracteristiques essentielles ne sont pas visibles/essential traits are not visible

- trau mir eine Beurteilung nicht zu/je ne me considère pas apte au jugement/I am not confident enough to judge
- zweifle zwischen Wildkatze und Hybride/j’hésite entre chat forestier et hybride/can not decide between wildcat and hybrid
- zweifle zwischen Hybride und Hauskatze/j’hésite entre hybride et chat domestique/can not decide between hybrid and domestic cat
- zweifle zwischen Wildkatze und Hauskatze/j’hésite entre chat forestier et chat domestique/can not decide between wildcat and domestic cat
Appendix B

Figures B1 – B3 display the 25 pictures of cats with known identity, which were part of the survey.

**Fig. B1.** The 10 wildcat pictures which were part of the expert survey.
Fig. B2. The 10 domestic cat pictures which were part of the expert survey.
Fig. B3. The 5 hybrid pictures which were part of the expert survey.
Appendix C

Figure C1 and C2 display the reasons for the uncertainty of the experts in Sample 1 and Sample 2.

**Fig. C1.** Reasons for the uncertainty of the experts for the 71 unidentified pictures in Sample 1. The y-axis shows the number of nominations by the experts. The x-axis describes reasons for the uncertainty of the experts whereas 1 = the picture is too poor to evaluate, 2 = essential traits are not visible, 3 = I am not confident enough to judge, 4 = can not decide between wildcat and hybrid, 5 = can not decide between hybrid and domestic cat, 6 = can not decide between wildcat and domestic cat.

**Fig. C2.** Reasons for the uncertainty of the experts for the 43 unidentified pictures in Sample 2. The y-axis shows the number of nomination by the experts. The x-axis describes reasons for the uncertainty of the experts whereas 1 = the picture is too poor to evaluate, 2 = essential traits are not visible, 3 = I am not confident enough to judge, 4 = can not decide between wildcat and hybrid, 5 = can not decide between hybrid and domestic cat, 6 = can not decide between wildcat and domestic cat.