

## Survey of the Lynx distribution in the French Alps: 2000–2004 population status analysis

Pregled razširjenosti risa v Francoskih Alpah: analiza statusa populacije za obdobje 2000–2004

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**Abstract.** Within the SCALP framework, the status of the pan-alpine population of Eurasian Lynx is assessed every 5 years, based on the compilation of national reports and standardized classification of lynx presence signs according to data confidence levels (C1, C2, C3). From 2000 to 2004, the French national network of lynx experts collected N= 393 data, out of which 224 (compared to only 69 in 1995–1999) were considered as robust enough to evidence the presence of lynx (C1 = 1%; C2 = 42%; C3 = 57%) and were used for further analysis. A majority of the signs concerned the northern part of the Alps, however, in mostly two regions (Chartreuse/Epine : 34% of the signs; Maurienne: 21%). Other data were more scattered over space, from the Chablais region close to Switzerland down to the Haut-Verdon close to the Mercantour mountains. A negative trend was noticed from north to south in proportions of best quality signs (C1+C2), and a positive one in low quality ones – C3 – ( $\chi^2 = 3.56$ , 1 df,  $p = 0.06$ ), which could point at some methodological artefacts. Discarding C3 may however be too conservative a strategy to assess the species range and status. Using spatial recurrence and trend over time of all signs available (C1+C2+C3) could, therefore, provide the right balance between being *too much* versus *not enough* conservative. – When doing so, the area with lynx signs regularly detected sharply increased between 1996–1998 (100 km<sup>2</sup>), 1999–2001 (250 km<sup>2</sup>), and 2002–2004 (1195 km<sup>2</sup>). The latter area is still quite small regarding what is required for a viable large carnivore population. A simple demographic model suggested that even a quite moderate proportion of immigrants (e.g. dispersal inflow from neighbouring core areas – French Jura or Swiss Alps) could considerably decrease the theoretical demographic extinction risk of such a small population, but still depending upon adult survival rates, which also strongly influenced the extinction risk. The factors that may influence this sensitivity analysis (such as habitat connectivity and management of wooded corridors) should be evaluated within the Scalp framework.

**Keywords:** *Lynx lynx*, France, Alps, distribution, monitoring, population viability

## Introduction

Standardized monitoring over countries that share large carnivore populations is obviously the first step towards a common management of these species. Over Europe, such an international collaboration for population monitoring is now properly implemented only for the Eurasian lynx over the Alps within the SCALP framework (MOLINARI-JOBIN & al. 2003). The status reports about the national sub-units of this conceptual population build up a key-issue for assessing the overall status of the pan-alpine

“meta-population” (see *Hystrix*, vol. 12(2), 2001 for the 1995–1999 period), and regular meetings held under the auspices of SCALP yield valuable contributions (e.g. MOLINARI-JOBIN & al. 2005). The present paper provides the 2000–2004 French update, together with some simple demographic modelling to roughly enlighten the importance of dispersal and connectivity on the demographic viability of the ‘French’ alpine sub-population. Dispersal, indeed, is a key-parameter when considering fragmented and/or small populations (see e.g. SCHADT 2002; ZIMMERMANN 2004). Factors affecting the habitat continuity – e.g. roads and traffic volume, fencing – may, therefore, result in barrier effects to dispersal, and increased population extinction risk due to isolation (KLAR & al. 2006).

## Methods

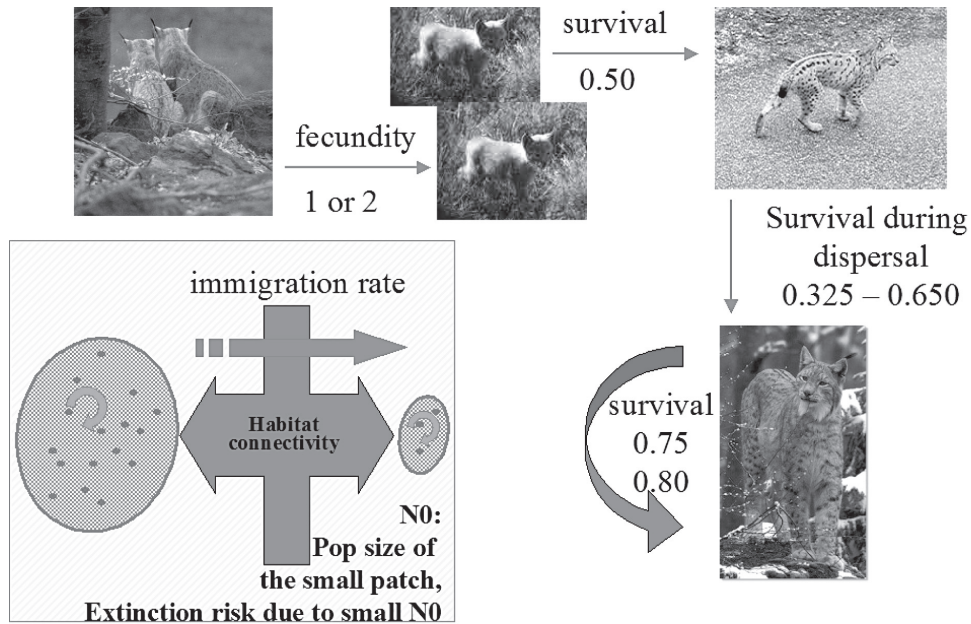
### *Lynx monitoring in France*

The lynx monitoring in France is based on an extensive field work by a national network of about 850 lynx-experts who have been specially trained to collect possible presence signs (scats, tracks, visual observations, wild and domestic preys). All the data are validated by a single national expert (Office National de la Chasse & de la Faune Sauvage) using a standardized grid of criteria that basically relies on the degree of convergence between technical characteristics within each presence sign (see VANDEL & STAHL 2005, for a detailed description). Such a centralized process ensures that any field data is analysed in the same way, wherever it comes from and whoever collected it. The presence signs, once validated, are converted into C1, C2, C3 categories to fit to the SCALP requirements: C1 are hard facts such as captures, dead lynx, photos; C2 are data directly collected by lynx-experts and further confirmed by the national expert; C3 are data indirectly collected by lynx-experts from the general public and confirmed by the national expert. Biologists in charge of evaluating the lynx status usually devote most consideration to direct data first (C1+C2).

Regarding range estimates, point data (i.e. defined by X, Y coordinates) were transformed following VANDEL & STAHL (2005)’s method: each data was attributed a spatial buffer of 81 km<sup>2</sup> grid area of theoretical lynx presence, made of nine 3 x 3 km elementary squares, centred on the given X,Y coordinates. The sum of the squares was the estimated overall range. When overlapping maps from different yearly periods, the elementary squares that were regularly “lynx-positive” made up the regularly occupied area, a conservative estimate of lynx distribution (since areas newly or irregularly detected were discarded).

### *Demographic modelling*

Because the French alpine population may be considered as small relative to other alpine ones (VON ARX & al. 2004) and may be demographically connected to those from the Jura Mountains and Swiss Alps, its long term viability may depend on immigration from these areas. Using Monte Carlo runs within the ULM package (LEGENDRE & CLOBERT 1995), a simple female-based model (with 3 age classes: kitten, sub-adult, adult; see the life cycle and structure of the model, Annex 1) with demographic stochasticity on vital rates was used to compute relative population viability analyses (PVA) according to the proportion of additional input from immigration. Mean survival and fecundity rates were from the literature (SCHADT 2002), and the influence of dispersal on the population extinction risk was modelled, step-by-step, by adding a given proportion of immigrant sub-adults to the initial population size. Because the colonizing process within the French Alps is still active over a very large un-colonized area, dispersal of local sub-adults out of the Alps was set to zero – i.e. *immigration to* but no *emigration from* the French Alps. Because the dispersal success may depend on habitat fragmentation, an additional barrier mortality was incorporated into the model, simulating either strong connectivity (i.e. weak additional mortality of  $1/3$ ) or weak connectivity (i.e. large additional mortality of  $1/2$ ). The extinction risk was estimated by the proportion of trajectories that went under a minimum of 1 individual within 1000 trajectories simulated over 100 years.



Annex 1: Life cycle and structure of the demographic lynx model

The model is run in the framework of demographic stochasticity on survival rates, to simulate the chance extinctions due to small numbers of individuals. Both the immigration and survival of sub adults while dispersing between sub populations are modulated. Transition probabilities between age classes are fecundity and survival rates from the literature. Two level of habitat connectivity between populations are simulated: a weak connectivity associated to a large cost of dispersal (i.e. a strong additional mortality rate of 50%); a strong connectivity associated to a low cost of dispersal (i.e. a weak additional mortality rate.

## Results

### Lynx distribution

During the 2000–2004 period,  $N = 393$  data have been collected, out of which 55% have been finally validated and used for further analysis. Despite this large number of data discarded, a sharp increase in the number of validated data is observed for the last pentad (Table 1). Although C3 are still in a majority, robust data about the lynx presence (i.e. C1+C2), are obviously increasing too. Most of the presence signs were, however, still concentrated over some very limited areas in the northern French Alps (Fig. 1), such as the Chartreuse / Epine massif, the Maurienne valley, and the Bauges massif (respectively  $n = 72$ ,  $n = 45$ , and  $n = 20$ , i.e. 34%, 21%, and 9% of all signs of presence). North to Anancy and south to Grenoble, the data were more or less scattered over space, from the Chablais region down to the Haut-Verdon. Location of data (north to Grenoble vs. south to Grenoble) and data type (C1+C2 vs. C3) were not independent (Table 2,  $\chi^2 = 3.56$ , 1 df,  $p = 0.06$ ): there was a negative trend from north to south in proportions of C1+C2, and, conversely, a positive one in C3.

Table 1: Numbers of lynx presence data, according to SCALP categories, validated over the French Alps.

Categories	1990–94	1995–99	2000–04	Total
C1	2	0	3	7
C2	5	7	92	103
C3	24	62	128	214
Total	31	69	224	324

Regarding range estimates, the area regularly occupied (using C1+C2+C3) increased from 100 km<sup>2</sup> in 1996–1998, to 250 km<sup>2</sup> in 1999–2001, and up to 1195 km<sup>2</sup> in 2002–2004. When adding areas newly detected, for which no one knows whether they will finally contribute to the regular area of the species, the total estimate amounted to 4444 km<sup>2</sup>. Because the latter value is based on large numbers of C3 detected for the very first time in new areas, one would better consider the lower range estimate (1195 km<sup>2</sup>), computed only from those C1+C2+C3 that were recurrent over time.

Table 2: Unbalanced numbers of lynx presence data, according to SCALP categories (C1+C2 versus C3), and to geographical location.

Categories	North to Grenoble	South to Grenoble
C1+C2	80 (46%)	16 (31%)
C3	93 (54%)	35 (69%)
Total	173	51

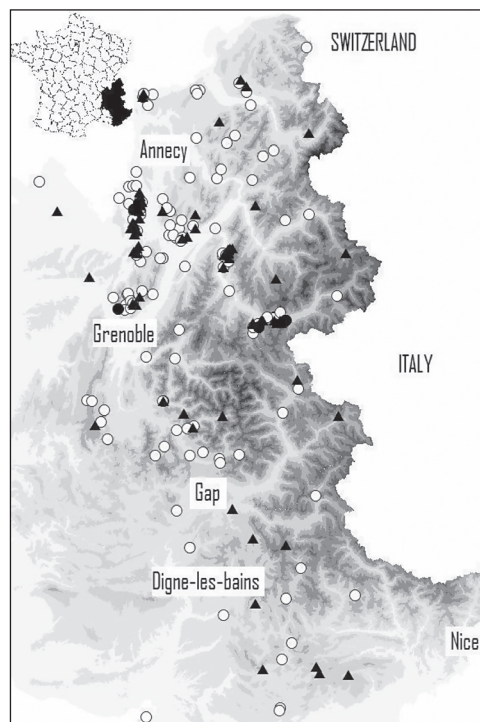


Fig. 1: Distribution of validated lynx signs (●= C1, ▲= C2, ○= C3) collected from 2000 to 2004 in the French Alps; shaded areas represent altitudinal patterns (the darker, the higher).

### Population dynamics modelling

Demographic parameters were derived from Schadt (2002). Survival rates were set at 0.50 (kits), 0.65 (sub-adults), 0.75–0.80 (adults); fecundity was 1 for the first attempt to breed, and 2 for older females. When using such values within a simple matrix-based deterministic model, the yearly population growth rate was  $\lambda = 1.02 - 1.07$  (i.e. 2 to 7% increase/year);  $\lambda$  was more sensitive to changes in adult survival rates (elasticity: 0.66) than to changes in any other vital rate (e.g. overall fecundity : 0.17): a 10% increase in adult survival would yield a  $10 \times 0.66 = 6.6\%$  increase in  $\lambda$ , whereas a similar 10% increase in fecundity would yield only a  $10 \times 0.17 = 1.7\%$  increase in  $\lambda$ . Within the stochastic framework (Monte Carlo runs), the extinction risks were, therefore, modelled according to changing adult survival rates (0.75 or 0.80); the dispersal success between source and target populations was modulated too, using additional mortality rates of  $1/3$  or  $1/2$  as a simulation of differences in habitat connectivity due to e.g. fragmentation of wooded corridors [i.e. survival while dispersing within a patch: 0.65; survival while dispersing between patches:  $0.65 \times (1 - 0.33) = 0.50$  or  $0.65 \times (1 - 0.50) = 0.325$  according to high vs. low habitat connectivity].

A rough and conservative estimate of lynx numbers in the French Alps may be obtained using an average winter density of 1 adult/100 km<sup>2</sup> together with 0.5 young/100 km<sup>2</sup> (HALLER & BREITENMOSER 1986; BREITENMOSER-WÜRSTEN & al. 2001) over the estimated range (1195 km<sup>2</sup>). Assuming a balanced sex-ratio, half of the resulting value was used as an initial population size (i.e. 9 females) in Monte Carlo runs to simulate extinction of population trajectories.

The extinction risk decreased sharply with increasing immigration rates, and reducing the level of theoretical mortality while dispersing from higher to lower values improved population persistence too (Figure 2A). This pattern was most pronounced when adult survival rate was lower: once this rate amounted 0.80, the extinction risk was moderate even with no input from immigration (Figure 2B). The influence of immigration on extinction risk logically depended on survival rates (of sub-adults and adults), but some kind of similar ‘threshold effect’ was observed with a 5–10% immigration rate.

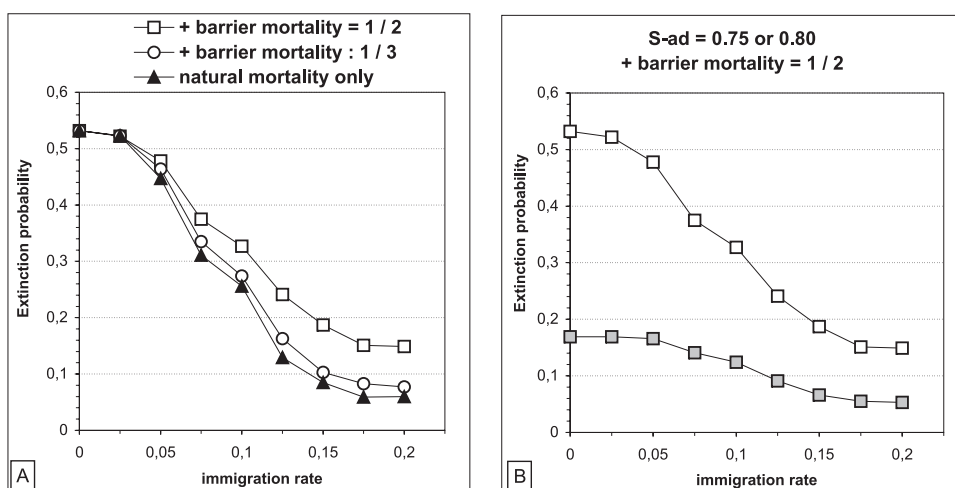


Fig. 2: Extinction risk (y-axis) as a function of increasing (0 to 20%) immigration rates (x-axis); survival of dispersing sub-adults is modulated (A- barrier effect) together with that of philopatric adults [B- □: S-ad = 0.80; ■: S-ad = 0.75].

## Discussion

During the 2000–2004 period, the strong increase in numbers of lynx signs collected is likely to reflect both a higher sampling rate (quite a large number of new lynx-field experts have been additionally trained to collect possible lynx signs), and an actual north-to-south colonizing process of the lynx. In spite of this active colonizing process, the *detected* distribution area of the species is still composite: north to Grenoble, the range is more or less continuous and documented by quite robust data (C1+C2), whereas, southward to this latitude, only islets of presence that are mostly C3-based have been detected so far. Because the lynx expert network is implemented now in the whole possible distribution area of the species, the latter trend (more and more C3 south to the core area) could illustrate sampling artefacts (C3 being more likely in those newly- or even non-colonized areas). This might therefore suggest that the lynx status over the French Alps be first assessed in a conservative way, i.e. using preferably C1+C2 data only. However, within C3s collected at time  $t$ , those that were actual artefacts are unlikely to be spatially recurrent later on, whereas those that were not artefacts are likely to be next confirmed either as C3s, C2s, or even C1s. The spatial recurrence of all data available (C1+C2+C3) could, therefore, be used as a complementary approach to assess the lynx status.

The spatial patchiness in the distribution of lynx signs may reflect a low efficiency of the expert network to record these data under the alpine environmental conditions. The relationship between the locations of lynx signs of presence and the surrounding eco-variables (altitude, steepness, percentage of wood, distance to roads or cities) have been modelled using the ENFA method (HIRZEL & al. 2002; BASILLE 2004). The resulting map displayed a very patchy distribution of areas where lynx signs would likely be detected (Figure 3), and a methodological bias due to habitat accessibility was suspected (e.g. a negative relation was noted between signs of occurrence and increasing distance to roads). Contrary to the academic and biological findings in ZIMMERMANN (2004), our map reflects only the sub-sample of the potential distribution area for which the expert network could detect lynx signs of presence. The next issue is to improve the detection rate of such signs, based on e.g. an extensive use of remote camera traps or hair snares (see ZIMMERMANN & al. 2006, MARBOUTIN & al. 2005). Despite the possible under estimation of the range occupied, lynx presence signs are however found over larger and larger areas; the species is now well established and regularly detected in several mountainous geographic entities (see Table 2 in VANDEL & STAHL 2005 for a detailed review). Compared to the previous SCALP-update (1995–1999, STAHL & VANDEL 2001), numbers of detected signs and corresponding areas are, from north to south: i) stable north to Annecy (Chablais, Chamonix, Glières-Aravis, Vuache-Salève); ii) stable (Belledune-Oisan-Taillefer) or increasing (Bauges, Maurienne, Chartreuse-Epine) between latitudes of Annecy and Grenoble; iii) stable but scarce and scattered (Dévoluy-Beauchêne, Valbonnais-Valgaudemard, Briançon-Queyras) between latitudes of Grenoble and Gap; iv) still to be confirmed (Monges, Embrunais-Ubaye, Haut-Var, Haut-Verdon-Canjuers) south to Gap (Fig. 1). Such a patchy distribution of lynx signs results in a small proportion of the total area being regularly occupied: in 2002–2004, the overall range detected was about 4500 km<sup>2</sup> out of which only 1200 km<sup>2</sup> with regular presence. The corresponding population size (roughly estimated to less than 20 animals) can obviously not be considered a long term viable unit, from the demographic or genetic point of view.

From a theoretical basic modelling, the influence of demographic stochasticity on extinction risk could be buffered first with increasing adult survival rates, and with moderate immigration rates (5–10%). Immigration also means that the local dynamics *within* the source population are very important too. Population simulations are projections rather than exact predictions, because they rely on the quality of both model structure and demographic data. They should mostly be used, as a result, to evaluate relative outputs of different scenarios. In the present case, reducing for example the theoretical mortality induced by the barrier effect from  $\frac{1}{2}$  to  $\frac{1}{3}$ , when dispersal rate is 0.15, would induce a 50% relative decrease in extinction risk (from 0.2 to 0.1). Such results should only be regarded relative values, as they are partly conditional on the structure of the model and parameters' values. Increasingly powerful but complicated models are available (e.g. Schadt & al. 2002, Wiegand et al.

2004), so the trade-off is now between richness of model structure and availability of field estimates for their parameters. Above all, the present results should be analysed as an illustration that factors affecting dispersal patterns may be key-ones, but conditional on patterns in adult survival rates. When these vital rates are to fluctuate over time/space (e.g. due to diseases, or man-induced mortality) the buffering influence of immigration on extinction risks should not be neglected. Some emphasis should also be put on the study of dispersal patterns since recent results have shown this phenomenon is area-specific (ZIMMERMANN & al. 2005). Factors that may improve the dispersal success, such as habitat connectivity and management, based on the conservation of e.g. wooded corridors, should therefore be evaluated as a possible key-issue for lynx conservation (ZIMMERMANN 2004, KLAR & al. 2006). The SCALP approach perfectly fits into that framework since it makes use of trans-boundary monitoring of populations and management of key-factors as a basis for defining what could be a robust conservation biology strategy.

### Acknowledgements

The authors are indebted to the lynx experts from the national network for providing the field data; many thanks to A. Molinari-Jobin, SCALP coordinator, for having created the pan-alpine scientific network and for fruitful discussions about related concepts. The authors are indebted to A. Molinari-Jobin, P. Molinari & M. Wölfel for comments on a first draft. Many thanks to F. Zimmermann for advices regarding ENFA application.

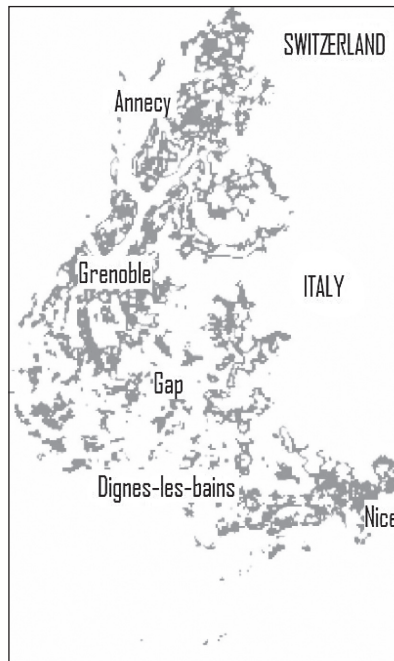


Fig. 3: ENFA-based modelling of the potential distribution of detected lynx presence signs. The grey areas are those with higher detection likelihood, i.e. those where the lynx-experts network would likely collect presence signs given the presence of the species AND the environmental conditions (slope, altitude, wooded area, distance to roads).

## References

- BASILLE, M. 2004: Le Lynx, l'ENFA, et le SIG. Msc. report, Univ. Lyon C. Bernard.
- BREITENMOSE-WÜRSTEN, Ch., F. ZIMMERMANN, A. RYSER, S. CAPT, J. LAASS, A. SIEGENTHALER & U. BREITENMOSE 2001: Untersuchungen zur Luchspopulation in den Nordwestalpen der Schweiz 1997–2000. KORA-Bericht 9: 1–88.
- HALLER, H. & U. BREITENMOSE 1986: Zur Raumorganisation der in den Schweizer Alpen wiederangesiedelten Population des Luchses (*Lynx lynx*). Z. Säugetierkunde 51: 289–311.
- HIRZEL, A., J. HAUSSE, D. CHESSSEL & N. PERRIN 2002: Ecological-niche factor analysis: how to compute habitat suitability maps without absence data? Ecology 83: 2027–2036.
- KLAR, N., M. HERMANN & S. KRAMER-SCHADT 2006: Effects of roads on a founder population of lynx in the biosphere reserve "Pfälzerwald-Vosges du Nord". Naturschutz und Landschaftsplanung 38: 330–337.
- LEGENDE, S. & J. CLOBERT 1995: ULM, a software for conservation and evolutionary biologists. J. Appl. Stat. 22: 817–834.
- MOLINARI-JOBIN, A., P. MOLINARI, C. BREITENMOSE-WÜRSTEN, M. WOELFL, C. STANISA, M. FASEL, P. STAHL, J.M. VANDEL, L. ROTELLI, P. KACZENSKY, T. HUBER, M. ADAMIC, I. KOREN & U. BREITENMOSE 2003: Pan-Alpine Conservation Strategy for the Lynx. Nature and environment 130, Council of Europe Publishing, 20 pp.
- MARBOUTIN, E., A. LAURENT, C. REGAZZI, F. LÉGER, P. MOISSON, M. LAMBRECH, L. BALESTRA, J.P. HENRI, M. BASILLE, L. TOUZAIN & D. MICHALLET 2005: Tests de nouvelles méthodes pour le suivi des populations de Lynx en France: le piégeage photographique en coulées et les pièges à poils. Oncfs Rapport Scientifique 2004: 18–21.
- MOLINARI-JOBIN, A. 2005: Proceedings of the 2nd conference on the Status and Conservation of the Alpine Lynx Population, 7th to 9th May 2003, Amden Switzerland. Environmental encounters 58: 1–105.
- SCHADT, S. 2002: Scenarios assessing the viability of a lynx population in Germany. Ph-D thesis, Univ. Munich, 116p.
- SCHADT, S., REVILLA E., WIEGAND T., KNAUER F., KACZENSKI P. & BREITENMOSE U. 2002: Assessing the suitability of central European landscapes for the reintroduction of Eurasian lynx. Journal of Applied Ecology 39: 189–203.
- VANDEL J.M. & P. STAHL 2005: Distribution trend of the Eurasian lynx (*Lynx lynx*) populations in France. Mammalia 69 (2): 145–158.
- VON ARX M., C. BREITENMOSE-WÜRSTEN, F. ZIMMERMANN & U. BREITENMOSE 2004: Status and conservation of the Eurasian Lynx (*Lynx lynx*) in Europe in 2001. KORA report Nr. 19.
- WIEGAND T., REVILLA E. & KNAUER F. 2004: Dealing with uncertainty in spatially explicit population models. Biodiversity and Conservation 13: 53–78.
- ZIMMERMANN, F. 2004: Conservation of the Eurasian lynx (*Lynx lynx*) in a fragmented landscape – habitat models, dispersal, and potential distribution. Ph-D thesis, Univ. Lausanne, 179p.
- ZIMMERMANN, F., C. BREITENMOSE-WÜRSTEN & U. BREITENMOSE 2005: Natal dispersal of Eurasian Lynx (*Lynx lynx*) in Switzerland. Journal of Zoology, London 267: 381–395.
- ZIMMERMANN, F., A. MOLINARI-JOBIN, P. MOLINARI, A. SIEGENTHALER & U. BREITENMOSE 2006: Bericht zum Luchs-Monitoring mittels Fotofallen in den Nordwestalpen und der Zentralschweiz West im Winter 2005/06. KORA –Berichte.