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Does the European wildcat (*Felis silvestris*) show a change in weight and body size with global warming?

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Abstract. The question whether the European wildcat, adapted to cooler climate than other small to medium sized felids, shows changes in body mass or size in response to climate change as indicated for other animals is addressed. The literature yielded body mass data of individual specimens covering the time span from about 1860 to 1960. Also the records of collections were accessed to record weight and body length. These mainly cover the time after 1950. Additionally, three cranial measures, gsl, cbl and zw were measured as indicators of size in the collections representing Germany and Slovakia. Museum records of weight from the last 60 years alone do not show a statistically significant change over time or mean annual temperature. But they do so for body length. The combined data from literature and collections from both regions show a statistically significant decrease in weight over time. As the samples from the literature and museum records represent different time periods, prior to and after 1950, it is difficult to decide if the literature data might be unrealistically high or if there was a real decrease in weight. The German and Slovakian samples differ statistically in the studied parameters, which complicates the picture. Overall the indications of changes in size of wildcats with time or mean annual temperature are not consistent in the studied regions and therefore difficult to assess. Even though there is ample material and substantial literature the collected specimens in the collections do mainly represent relatively short time periods and the available data on weight are also unevenly distributed in time. This supports the necessity to collect large series of specimens over time.

Key words: body mass, body length, skull length, skull width, mean annual temperature, Germany, Slovakia

Introduction

In general, body size and body mass are important features as they are linked to morphology, physiology, ecological performance (Schmidt-Nielsen 1984), as well as life history parameters such as survival and reproductive success (Peters 1983, Calder 1984, Gaillard et al. 1992) and evolution and extinction probabilities (Cardillo et al. 2005). Yom-Tov & Geffen (2011) state that food availability particularly during the growth period is a key determinant of body size. Food availability as well as the requirements of the considered species for its physiological maintenance are mainly determined by climate, temperature, precipitation, air pressure, but also humans through e.g. agriculture, wildlife management or other factors (Yom-Tov & Geffen 2011). Particularly for carnivores size is important as it mainly determines the size of prey species and prey diversity that can be used (Gittleman 1985). Also competition between species (Mukherjee & Groves 2007) and between sexes within a species play a role determining body size (Hendrick & Temeles 1989, Dayan & Simberloff 1996). In many mammals body size and mass are directly correlated to latitude following the Bergmann's rule (Rosenzweig 1968, Ashton et al. 2000, Ashton 2002, Meiri & Dayan 2003). However, Meiri et al. (2004) showed that fewer carnivores follow Bermgann's rule than previously assumed. Overall determination of body size in mammals is more complex (Smith & Lyons 2011).

Recently it had been suggested that size changes occur in several groups of mammals and birds but also some ectotherms in response to global warming (Gardner et al. 2011). The trends in different groups of mammals are heterogeneous in magnitude and direction and the authors suggest further studies of museum data and theoretical models "to predict the sensitivity of species to climate change" (Gardner et al. 2011). According to Sheridan & Bickford (2011), many species already show smaller size due to climate change and the authors discuss future research directions to better understand the trend. "Measurements of body mass and skeletal size have been shown to reflect changes in environmental conditions over time and space" (Rode et al. 2010). In one case, Smith et al. (1995) and Smith et al. (1998) showed changes of body size in a rodent species over 25000 years and relate it to climate change.

Changes in body size occurred in other time periods as well, so it has been shown that towards the end of the Pleistocene correlating with warming, mammoths (Vartanyan et al. 1993, Agenbroad et al. 1999, Guthrie 2004), horses (Forsten 1991, Guthrie 2003) and red deer (Lister 1989) decreased in size. There are other examples of size changes on islands (the island rule, Foster 1964): size reduction or dwarfing of large mammals on islands, for example the dwarfed elephants of the Mediterranean Islands (Palombo 2001, Davies & Lister 2001, Raia et al. 2003), or size increase to gigantism of smaller mammals (mainly rodents and leporids) like e.g. *Nuralagus rex* (Quinata et al. 2011).

There are also studies on size or weight changes in extant mammals on a shorter, non-geological time scale (about one century or more). For rodents, Pergams & Lawler (2009) indicated changes in several characters of diverse rodents within the last 100+ years and fast changes were also indicated in the sigmodontine murid *Peromyscus* (Pergams & Lacy 2008). Changes in skull morphology over time have been demonstrated in the skull of the Arctic wolf (like overall reduction in overall size, size of the teeth, widening of the cranium and shortening of the facial region within about 60 years, Clutton-Brock et al. 1994).

To address the question whether a change in size can be seen in another European carnivore species, the European wildcat *Felis silvestris* Schreber, 1777, was selected. It probably evolved during cooler periods of the late Pleistocene (Hemmer 1984, 1993). Within felids it can be considered adapted to cooler climate, as most other small to medium sized felids occur in the tropics, up to 11 species e.g. in India (Mukherjee & Groves 2007). The Central Asian wildcat (*F. s. ornata*) is regarded unable to cope with low temperatures (Heptner & Sludskii 1972).

Thus the European wildcat might be affected by global warming. This species has been of special interest in recent years as it is strongly protected in Europe since 1992 under the European Habitat Directive. The wild cat is a Palaearctic species with an originally wide range of distribution from the Iberian Peninsula to the Caucasus and Scotland (Piechocki 1990). For some time, particularly in the 18th and 19th century, it was the aim to eradicate carnivores dangerous to man, game and domestic animals in most of Europe (e.g. von Hoberg 1687). Particularly due to the resulting rarity of the wildcat a rich literature differing in aim and quality is available on the species (Stefen & Görner 2009).

Traditionally weight is an important measure for mammals, usually recorded for each individual during the process of preparation or in taxidermy and usually kept in museum records. It is also important (next to skull size or trophy size) for the assessment of hunted specimens.

This study addresses the question whether a change in size measured by weight and body length occurred in the European wildcat *Felis silvestris silvestris* over the last century and with mean annual temperature. As weight is only one measure of size and data on body size are more limited than weight data, the greatest skull length, condylobasal length and zygomatic width of the skull were also used as size indicators. Particularly condylobasal length is a measure commonly used in biogeography studies for body size (e.g. Rausch 1963, Ralls & Harvey 1985, Meiri et al. 2004).

The rationale behind this study is based on a) the mentioned probable adaptation of the wildcat to cooler climate and therefore its susceptibility to climate change and b) that a probable increase in competition with free ranging domestic cats might drive the need for niche differentiation, which might result in size changes.

Material and Methods

Data from the literature

The available historic literature of the last centuries on the wildcat as searched in different databases and comparison of references given in each paper (Stefen & Görner 2009) was used as source for published weights of wildcats. The geographic regions considered were: Germany, France, Belgium, Switzerland, and Slovakia. When no indication of the individual age was given, it was assumed to be adult. In most cases the year or even exact date of death of the animal was given; if not, the year of publication is used (Supplementary material).

Museum records – weights

Additionally, the recorded weights for the wildcats mainly from the Harz region (partially published by Piechocki & Stiefel 1988) and Thuringia (most published by Krüger et al. 2009) in Germany and Slovakia (partially summarized by Sládek et al. 1971, Kratochvíl 1976) from museum records were taken into consideration when skulls were measured. Where analysis of skulls was possible (see below), cats with permanent dentition at least of an age of about seven months (Condé & Schauenberg 1969) were listed as "adults". The weights recorded in the museum collections were analyzed alone and later combined with the weights for individual wildcats from the historic literature.

Museum records – skull parameters

The greatest skull length (gsl), condylobasal length (cbl) and zygomatic width (zw) were measured with digital calipers to the nearest 0.01 mm. The measurements represent standard measures in mammalogy, and were taken as in Stefen & Heidecke (2011) and Stefen (2012a).

Material and/or museum records have been studied in the following institutions:

AAT, Arbeitsgruppe Artenschutz Thüringen (Species conservation group Thüringen), collection situated in Ranis, Thuringia, Germany; Institute of Vertebrate Biology, Academy of Sciences of the Czech Republic, Brno, Czech Republic; MHNG, Muséum d'Histoire Naturelle, Geneva, Switzerland; MTD, Senckenberg Naturhistorische Sammlungen Dresden, Museum für Tierkunde, Germany; NMB, Naturhistorisches Museum Basel, Switzerland; NMBE, Naturhistorisches Museum der Burgergemeinde Bern, Switzerland; NOK, Naturkundemuseum im Ottoneum, Kassel, Germany; SMB, Šariš Museum Bardejov, Natural Sciences, Slovakia; SMF, Senckenberg Forschungsinstitut und Naturmuseum Frankfurt, Germany; ZFMK, Zoologisches Forschungsmuseum Alexander König, Bonn, Germany; ZMB, Zoologisches Museum Berlin, Germany; and ZSM, Zoologische Staatsammlung München, Germany. Where possible, wildcats were determined on the basis of cranial volume measured with glass beads of 1 mm in diameter and a graded cylinder. Cranial volume ranges from 32.5-50 cm^3 in wildcats and from 20-35 cm^3 in domestic cats (Piechocki 1990). For cats with a cranial volume of 32-35 cm^3 the cranial index (= greatest total skull length: cranial volume) has to be calculated. A cranial index < 2.75 is indicative of wildcats while an index > 2.75 is indicative of domestic cats (Schauenberg 1969). Also records of intestine length were used: males (m): 120-170 cm, females (f): 110-150 cm in wildcats and m: 165-254 cm, f: 155-220 cm for domestic cats (Piechocki 1990) and intestine index for wildcats 2.13-3.16 (m), and 2.04-3.17 (f) and for domestic cats 3.27-4.84 (m and f) (Schauenberg 1977). Individuals that could not be clearly assigned were excluded.

Geographic and climate data

The locality data were taken from the museum records and the geographic parameters latitude, longitude and elevation above sea level were identified for the locations using (http://de.mygeoposition.com) to the closest as possible. The latitudinal range of the wildcats studied is 10.54°, from 43.02 to 53.56 N, the longitudinal range is 40.19°, from 4.46 to 44.65 E, and the altitude ranges from about 10 to 1000 m. As locality information in the analyzed literature varies substantially, they were only assigned to the regions.

The current climate change is evident in increasing temperatures (Luterbacher et al. 2004, IPCC 2013, Jones 2014) and extended growing season in Europe (e.g. Menzel & Fabian 1999). Global mean annual temperature data were taken from Hansen et al. (2001, http://data.giss.nasa.gov/gistemp/tabledata_v3/GLB.Ts.txt from 1880 to 2013). There is a strong positive correlation between the year and the mean annual temperature (Pearson correlation 0.777**, P = 0.000, N = 507).

Statistical analyses

Basic descriptive statistics including the analysis of outliers, Q-Q plot, a stem-leaf plot and histogram were

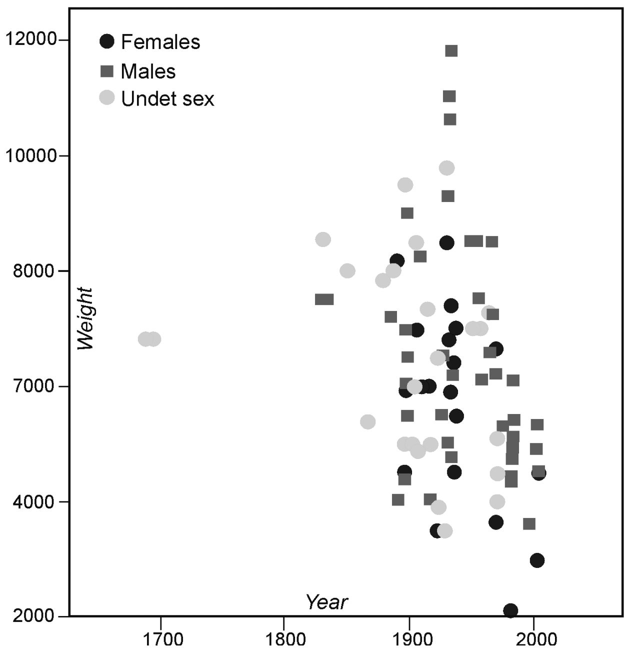

Fig. 1. Scatter diagram of weights to year of death or publication given for wildcats in the literature from Central Europe differentiated according to sex. Data as in Supplementary material.

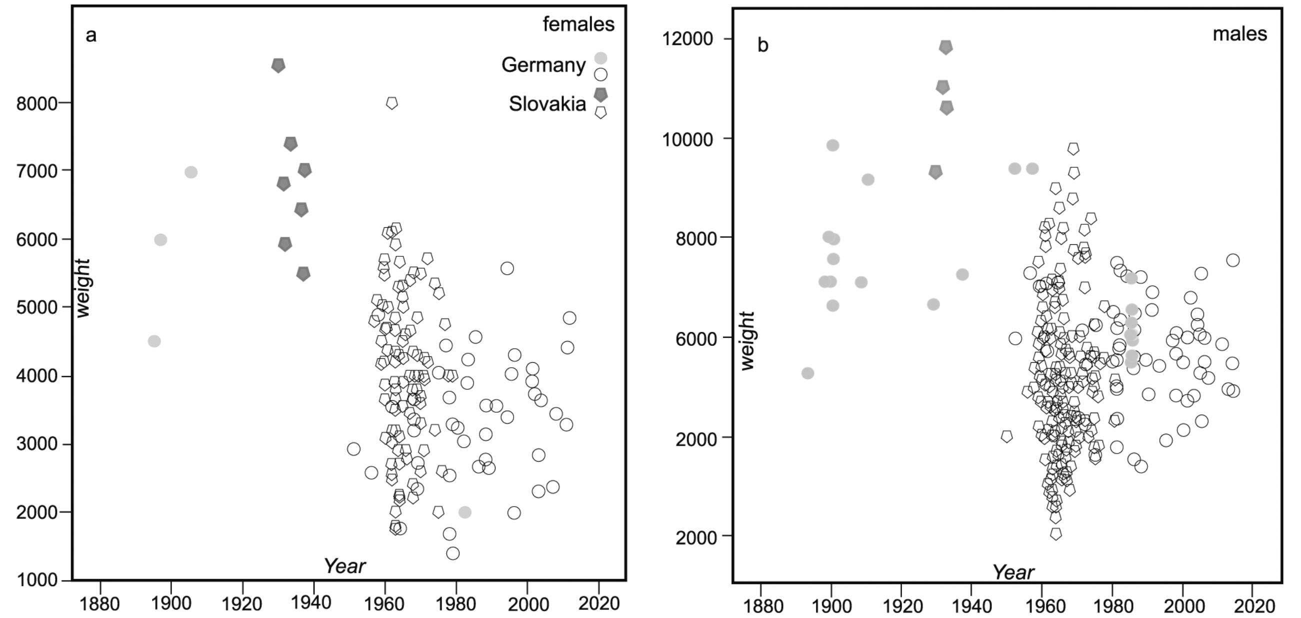

Fig. 2. Scatter diagrams of weights (g) to the year of death for wildcats from museum records and the literature from Germany and Slovakia. a) males, b) females. Open symbols indicate museum records; grey symbols indicate data from the literature. Weights up to 11.9 kg are considered.

performed for weight, cbl, gsl and zw and were used to see if the data fit a normal distribution and whether outliers exist. Statistical analyses include Pearson's correlations (bivariate) of weight (BM), body length (BL), gsl, cbl and zw to the year of death (or publication) and global mean annual temperature, as well as to the geographic variables latitude, longitude and altitude.

To test for statistically significant differences between samples, Student's t-tests on the 0.05 % significance level were performed. In cases where the variances were unequal, the Mann-Whitney U-test was used. The statistical analyses were performed using SPSS 14.

Results

Literature data

The fairly rich literature on the European wildcat from Central Europe lists some weights for individual wildcats mainly in the late 19th century, starting around 1860 with one reference from 1831 (Lenz 1831). In total 113 records were found; three for juveniles, six of 14 kg and more, and three of 12 to 13.9 kg which were eliminated so that 101 records remained. The Q-Q plots and histograms with indicated normal distribution showed that weights beyond 12 kg were clear outliers and therefore they were eliminated

Table 1. Descriptive statistics for body length (BL from snout to tail in mm) and body mass (BM in g) from museum records only. Abbreviations: reg – region, Ger – Germany, Slov – Slovakia; sex: f – female, m – male; N – number of specimens; min – minimum; max – maximum; SE – standard error of mean; SD – standard deviation.

	reg	sex	N	range	min	max	mean	SE	SD	variance
BM	Ger	f	46	4205	1395	5600	3305.30	137.87	935.07	874363
BM	Ger	m	68	4547	1953	6500	4549.97	131.96	1088.21	
BM	Slov	f	99	6250	1750	8000	4007.47	117.37	1167.78	1363709
BM	Slov	m	193	7750	2050	9800	5219.82	108.30	1504.56	2263685
BM	all	f	146	6605	1395	8000	3786.74	94.38	1140.36	1300423
BM	all	m	269	7847	1953	9800	5030.07	87.31	1432.01	2050649
BL	Ger	f	31	320	450	770	539.74	10.42	58.02	3366
BL	Ger	m	42	277	393	670	581.62	7.99	51.80	2683
BL	Slov	f	94	288	402	690	549.89	4.511	43.739	1913
BL	Slov	m	187	370	490	860	596.87	3.723	50.911	2591
BL	all	f	126	368	402	770	547.71	4.24	47.59	2265
BL	all	m	237	467	393	860	593.74	3.29	50.63	2563

Table 2. Statistical significant Pearson correlations of body mass (BM) and body length (BL) for the different samples from museum records only (Germany, Slovakia, and all combined) separated for sex (f – females, m – males) differences to the year of death (Y) and mean annual temperature (aT) for all cases or only those from winter or autumn, seasons 1 and 4 (sea 1&4). Correlations are given as: correlation coefficient * − significant on the 0.05 level and ** significant on the 0.01 level, P – probability and N – number of cases, nc – no correlation.

Correlation	Germany f	Germany m	Slovakia f	Slovakia m	all f	all m
BM/Y	nc	nc	nc	nc	nc	–0.175** P = 0.004 N = 267
BM/aT	nc	nc	nc	nc	nc	–0.156* P = 0.001 N = 267
BL/Y	nc	–0.513** P = 0.001 N = 40	nc	+0.326** P = 0.000 N = 187	nc	nc
BL/aT	nc	–0.3738* P = 0.033 N = 40	nc	nc	nc	nc
BL/Y sea 1&4	nc	–0.516** P = 0.001 N = 40	nc	+0.326** P = 0.000 N = 187	–0.179* P = 0.046 N = 125	nc
BL/aT sea 1&4	nc	–0.372* P = 0.018 N = 40	nc	nc	nc	–0.137* P = 0.035 N = 235
BM/Y sea 1&4	nc	nc	nc	nc	nc	–0.175** P = 0.004 N = 267
BM/aT sea 1&4	nc	nc	nc	nc	nc	–0.156* P = 0.011 N = 267

Table 3. Differences in body mass (BM) and body length (BL) between the sample from Germany (Ger) and Slovakia (Slov) from museum records only separated for females (f) and males (m). Other abbreviations: df – degrees of freedom, N – number of specimens, P – probability, Student's t-test (TT), Mann-Whitney U-test (MWU).

		df	P	N Ger/N Slov	
BM	f	143	0.305	46/99	TT
BM	m		0.002	68/193	MWU
BL	f	123	0.082	31/94	TT
BL	m	227	0.082	42/187	TT

from the analyses. The stem-leaf plot even indicates weights above 9000 g as extremes. For Germany, the records come from different geographic regions and in time are concentrated in the late 19th century (e.g. Langkavel 1899) and first part of the 20th century. The earliest values are listed by Schauenberg (1970) for cats from Switzerland, one dating from 1688 and one from 1692, neither of which are included in further statistical analyses as the gap in time to the other data is large. Weights were mainly given for individuals from Germany and Slovakia and fewer for Switzerland, France, Belgium and the Netherlands (Fig. 1, Supplementary material).

Table 4. Pearson correlations of body mass (BM) and body length (BL) to year of death (Y) and mean annual temperature (aT) in the sample from Germany and Slovakia separated for females (f) and males (m) from literature data and museum records combined. Correlations are given as in Table 1.

Correlation	Germany f	Germany m	Slovakia f	Slovakia m	all f	all m
BM/Y	–0.304* P = 0.032 N = 50	–0.527** P = 0.000 N = 89	–0.499** P = 000 N = 106	–0.250** P = 0.000 N = 197	–0.439** P = 0.000 N = 167	–0.330** P = 0.000 N = 315
BM/aT	n	–0.483** P = 0.000 N = 88	n	n	–0.233** P = 0.003 N = 166	–0.222** P = 000 N = 310

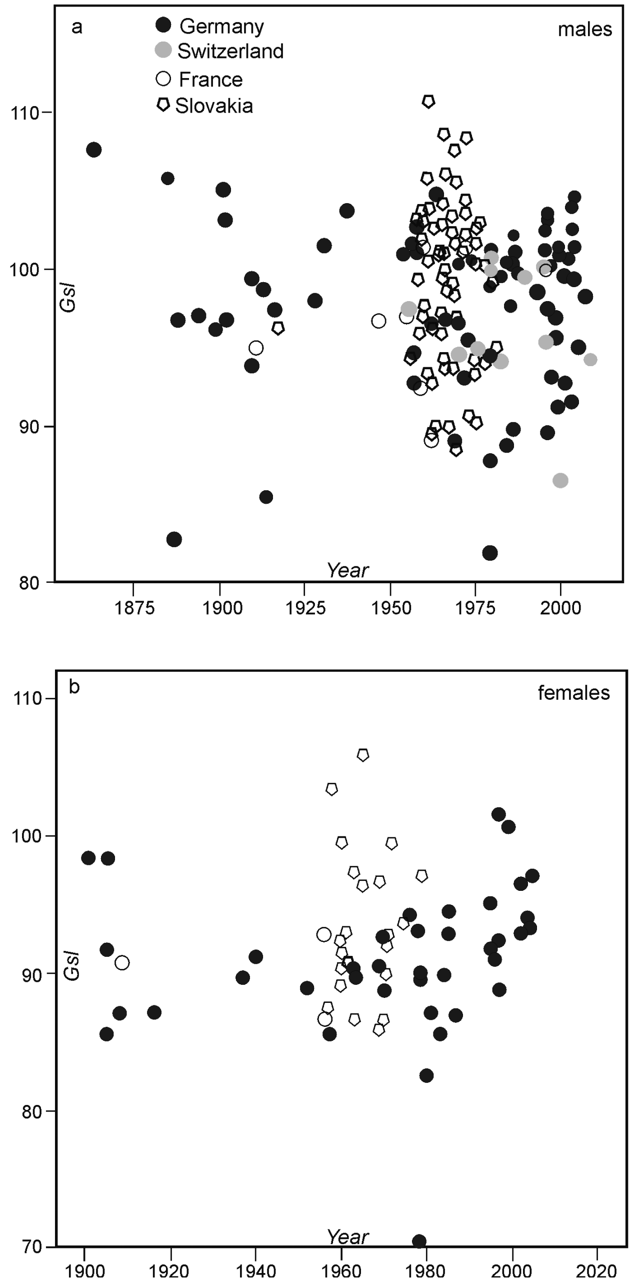

Fig. 3. Scatter diagrams of the greatest skull length (gsl in mm) for wildcats from Germany and Slovakia; a) females, b) males.

Museum records – weight and body length

The weights of wildcats in the studied museum records do not exceed 10 kg (Table 1). Only museum records from all regions indicate a statistical significant decrease of weight to year of death and mean annual temperature in males, whereas the separated regional groups do not show that. These, however, show a significant correlation of BL to both parameters. This picture is about equal if only the animals found death in autumn and winter were considered (Table 2). The samples from Slovakia and Germany differ in BM; in BL only in males (Table 3).

Table 5. Differences in body mass (BM) and body length (BL) between the sample from Germany (Ger) and Slovakia (Slov) and from the museum records (mrec) and literature data (lit) from the literature and museum records separated for females (f) and males (m). Other abbreviations: gr – group, df – degrees of freedom, N – number of specimens, P – probability, Student's t-test (TT), Mann-Whitney U-test (MWU).

	sex	gr1/gr2	df		N gr1/gr2	
BM	f	Ger/Slov	154	0.001	50/106	TT
BM	m	Ger/Slov	287	0.069	92/197	TT
BM	f	mrec/lit		0.000	145/22	WMU
BM	m	mrec/lit		0.000	269/49	WMU

Table 6. Differences in skull measurements gsl – total skull length, cbl – condylobasal length and zw – zygomatic width between the samples from Germany and Slovakia separated for females (f) and males (m). Other abbreviations: df – degrees of freedom, N – number of specimens, P – probability, Student's t-test (TT), Mann-Whitney U-test (MWU).

	sex	df	P	test
gsl	f	39	0.008	TT
	m	91	0.170	TT
cbl	f	41	0.001	TT
	m	90	0.033	TT
zw	f	40	0.029	TT
	m		0.019	MWU

Museum records and literature data

Together, literature data and museum records indicate a significant size decrease of wildcats over time and with mean annual temperature in both sexes (Table 4). As the literature yielded only few data on body length, these were not evaluated.

Tests indicate that the two samples of wildcats from Germany and Slovakia differ significantly in weight in females but not in males (Table 5). The two weights > 11 kg are for individuals of undetermined sex and therefore do not influence this correlation.

Museum specimens – skull measurements

No statistically significant correlation of gsl, cbl or zw to the year of death or mean annual temperature was found for both sexes in the German or Slovakian sample alone, but for all females. The Student t-test revealed that gsl, cbl and zw are significantly different between Germany and Slovakia (Table 6).

Discussion

General aspects of weight

Generally the variation in weight and size is great, may vary with sex, feeding status and thus season and sexual status (in males when they fight for females

Table 7. Pearson correlations of the skull measurements gsl – total skull length, cbl – condylobasal length and zw – zygomatic width and body mass (BM) and body length (BL) from museum records to the geographic parpameters lat – latitude, long – longitude and asl – height above sea level in the samples from Germany and Slovakia, and all separated for females (f) and males (m). Correlations are given as in Table 1.

sex	Germany f	Germany m	Slovakia f	Slovakia m	all f	all m
BM/lat	nc	nc	nc	nc	–0.283** P = 0.001 N = 139	–0.163* P = 0.010 N = 247
BM/long	nc	nc	nc	nc	+0.262** P = 0.002 N = 139	+0.168** P = 0.008 N = 247
BM/asl	nc	nc	nc	nc	nc	nc
BL/lat	nc	nc	nc	nc	nc	nc
BL/long	nc	nc	nc	nc	nc	nc
BL/asl	nc	nc	nc	nc	nc	nc
cbl/lat	nc	nc	nc	nc	–0.513** P = 0.000 N = 43	nc
cbl/long	nc	nc	nc	nc	+0.410** P = 0.006 N = 43	nc
cbl/asl	nc	nc	nc	nc	nc	nc
gsl/lat	nc	nc	nc	nc	–0.391* P = 0.011 N = 41	nc
gsl/long	nc	nc	nc	nc	+0.319* P = 0.042 N = 41	nc
gsl/asl	nc	nc	nc	nc	nc	nc
zw/lat	nc	nc	nc	nc	–0.322* P = 0.037 N = 42	nc
zw/long	nc	nc	nc	nc	nc	+0.247* P = 0.017 N = 92
zw/asl	nc	nc	nc	nc	nc	nc

or space) and reproduction or lactating in females, age, illness etc. Size and weight also change with ontogeny and age and vary substantially with feeding status associated with the seasons (Piechocki 1986). For several Carnivora and felid species including the European wildcat sexual dimorphism in size and weight is known (e.g. Petrov 1992). Therefore, it is difficult to use data of specimens of unknown sex or pooled data for females, males and unsexed individuals. For this reason, several data could not be included in the analysis here as there are a fair amount of unsexed individuals in the literature data (Fig. 1).

Any given weight is considered somewhat imprecise as it varies with freshness and time the cadaver spent in frost, integrity of the specimen (relevant sometimes in road casualties), and last but not least accuracy of equipment. Weights given in historic hunting literature may also be imprecise because they are scaled differently, or because the scale was not well maintained. Precision could also be influenced by the hope to reach record sizes, or individuals having been broken open, though the latter is usually not relevant for wildcats as it is only common for game used for human consumption. Also conversion problems between metric units might change weight data slightly. Most given values appear rounded to 500 grams.

Evolutionary changes in size and weight changes are probably driven by ecological and physiological factors by as yet fairly unknown mechanisms (Smith & Lyons 2011). Some have been associated with climate change (Gardner et al. 2011), but also other causes have been discussed (Rosvold et al. 2014).

Weights from literature data and museum

Most weights given in the consulted historic hunting literature fall within the weight range retrieved from museum records, up to 10 kg at most for males, but nine values were ≥ 11 kg. The higher weights given are 11.50 kg for an unsexed individual from Germany (Lehnen 1956), 12 and 14 kg for individuals in France (Condé & Schauenberg 1971) and 10 to 12.4 kg for males in Slovakia (Lindemann 1953, Supplementary material). A few individual weights of 14 to 18 kg exceed even these values and were published by Zurian (1955, cited by Lindemann 1955) and copied and reiterated by others like van den Brink (1957). These values have been discussed and criticized as unrealistic by Sládek et al. (1971) and Condé & Schauenberg (1971). The circumstances of Zurian's (1955) publication and whether he actually dealt with wildcats cannot be checked any more. There is only one other record that states 14 kg for a French wildcat (Philipon 1930), cited in Condé & Schauenberg (1971), Supplementary material.

The other "large" weights of 10 to 12 kg can be discussed, and might be unrealistically enlarged. But in this range might well be rare but realistic exceptions for wildcats, as the records come from different regions and sources (Supplementary material) and as few records for domestic cats (two individuals of 18 kg and even 21.3 kg and a cat breed reaching about 11 kg; not scientifically proven) indicate. Modern domestic cats might be "stuffed" more than any wildcat would be. Kratochvíl (1966) regards 15 kg as the absolute upper limit of possible weights for wildcats.

Change of weight with time

Weight for wildcats does only show a significant change with time and annual mean temperature in males from all regions in the museum records, but this is over a period of about 60 years only (Fig. 2). As most of the Slovakian individuals which are significantly heavier than the German ones, predate the latter the regional difference could bias this result. Also the German sample might be more affected by hybridization (see below) which again might influence this result, so that the correlation to year of death results from one or both of these two points. For body length the museum records indicate a significant decrease over time and with temperature in males in Germany and with year in Slovakian males (Table 2) which indicates at least some change.

When weights from the literature are added more samples show a significant correlation to the year of death. The extraordinarily high weights exceeding 12 kg were not included in this analysis. One explanation for the apparently higher weights in former times might be that the weights given in the historic hunting literature were taken with less care than the museum records. Also, only extremely large wildcats might have been considered worthy of publication. But at some times wildcats were so rare that each one might have been considered worth a note. The records in the literature date from an earlier time period, mainly prior to 1950 (Fig. 1). Thus, the combination of museum records and literature data might indicate that wildcats reached larger weights prior to 1940 or 1950, the time of the beginning of the current population growth (Haltenorth 1940, Röben 1974). This increase of the population might have included a higher degree of hybridization, minimizing the body mass of wildcats as domestic cats are generally slightly smaller and of less weight.

But genetic studies indicate a generally low level of hybridization in the wildcat population of eastern Germany (Hertwig et al. 2009). For Slovakia the history of the size of the wildcat population is less well known and therefore it is difficult to speculate about hybridization.

In a study of morphological change over time in rodents material collected before and after 1950 was compared (Pergams & Lawler 2009), which corresponds to the time line between literature data and museum records available for wildcats. The time period from which museum records and specimens are available might be too short to pick up the signal in weight change. However, Rode et al. (2010) indicated changes in skull width and body length of female polar bears over the shorter time period from 1982 to 2006 under conditions of declining sea ice. The change in ecological conditions can be assumed to be more extreme in the arctic regions than in Central Europe, causing stronger morphological responses. The wildcat, even the form *F. s. silvestris* has a large geographic range and thus might be adapted to different climate regimes (from more atlantic in the Rhine area and more continental in Slovakia).

Other potential causes for changes in weight and size

The focus of this study is to address the question whether wildcats changed in weight and size with global warming. But looking at size and temperature alone is of course an oversimplification of the probably very complex issue of size changes with time. Atmospheric CO_2 is considered one of the five major greenhouse gases mainly responsible for anthropogenic climate change (Hofmann et al. 2006). „The mean global atmospheric CO_2 concentration has increased from 280 ppm in the 1700s to 380 ppm in 2005, at a progressively faster rate each decade …“ (Raupach et al. 2007, see also IPPC 2007). To study effects of increased CO_2 level on mammals would be an issue by itself.

The size of mammals is affected – amongst other factors – by food availability mainly during the period of growth (Yom-Tov & Geffen 2011), and therefore, the prey species of wildcats have to be considered here briefly. Changes in prey abundance and diversity or increased seasonal changes in their population dynamics might influence the growth and size of wildcats. They use a number of prey species including insectivores, rodents, lagomorphs, birds, insects and occasional carrion; mammals form the dominant food (e.g. Sládek 1973a, b, Meinig 2002, Stefen 2012b). The species is considered a facultative specialist as it prefers rabbits when available (Moleón & Gil-Sánchez 2003). In Central Europe rodents and in particular *Microtus arvalis* forms their main prey. Over the last century the landscape and land use changed substantially. The availability of small mammals might be influenced and changed by land use. Particularly agriculture, representing the dominant land use in Western Europe, changed markedly beginning with the 1940s. Mainly increasing intensity and use of more machines lead to increased plot size, less hedgerows or margins with other vegetation, less crop diversity, increased use of fertilizer, herbicides, fungicides, and rodenticides (as e.g. summarized for England by Robinson & Sutherland 2002). Earlier changes occurred in the middle of the 18th century when the tradition of cultivating three crops in regular sequence slowly changed, and potatoes, beet and peas were increasingly used and started to alter soil chemistry (Witticke 2014). Parallel to the changes in the 20th century the populations of many organisms living on agricultural land decreased (Robinson & Sutherland 2002). Also the crops themselves were “engineered” for better performance, changed in quality and growth performance. Additionally in Central Europe increasingly canola and maize are cultivated and form large monocultures. Some studies address the differences in mammal communities between intensely and less intensely used landscapes (e.g. de la Peña et al. 2003, Michel et al. 2006, Heroldová et al. 2007, Fischer et al. 2011). The most intensely used area showed the lowest diversity of small mammals and the bank vole (*Clethrionomys glareolus*) was characteristic for this area (Michel et al. 2006). The decrease of hare (*Lepus europaeus*) has been attributed to changes caused by agricultural intensification (Smith et al. 2005) and also for the dramatic decrease of the common hamster (*Cricetus cricetus*) often changes in agricultural practice are considered as cause (e.g. La Haye et al. 2014). According to historic literature the common hamster was also part of the wildcat’s diet and a change in prey species with the decreased availability of some prey species for the wildcat has been hypothesized (Stefen 2012b). It can be assumed that the overall abundance of small mammals in fields decreased over the last century due to rodenticides, but an exact assessment or even less a correlation to the changes in size of the wildcat (or other predators) is impossible.

However, agricultural land is not the main habitat of wildcats, they mainly use woodlands and open grasslands, the edges apparently are important and their preferred habitat has been described as mosaic landscape (at least at the Iberian peninsula Lozano et al. 2003). Mountainous woodlands have been the refugium of wildcats during its persecution and therefore they might have been influenced by changes in woodland or forest management or use and resulting changes in small mammal communities. Even though forest appear stable to most humans, they are dynamic structures in time through natural processes and human activity. What the early Holocene woodlands actually looked like is difficult to assess and is discussed. Relevant for the brief considerations here are aspects of changes of forest management of the last centuries. In the middle of the 18th century the forests of Central Europe were strongly overused: traditional use as wood pasture, the collection of forest litter and firewood but also the need of wood for rafting of timber, metallurgical processes, heating, building etc. increased the demand of wood. Hunting and the collection of wild berries also occurred in woods and forests. The natural rejuvenation of beech and silver fir was impossible. At the end of the 18th century at least Thuringia (Germany) did not have continuous closed woodlands any more (Witticke 2015). In the beginning of the 19th century the fast growing species pine and spruce were used for reforestation. These species were originally intended to form the transition to allow rejuvenation of beech and fir but turned out to become the main aim of forest management (Witticke 2014, 2015). This brief sketch indicates the long term dynamics in forests and all species using this habitat had to adapt; this includes the wildcat. Whether and how these changes affected small mammal diversity and abundance can only be speculated. Probably there always has been and still is some food for the wildcat also in forests particularly *Apodemus sylvaticus* and

Clethrionomys glareolus (Kulicke 1960, Bäumler 1977).

The wildcat can tolerate human activities in forests as observations of the use of anthropogenic structures indicate (Vogt 1985). Wildcats have been recorded close to and in villages in Germany particularly in very cold winters when food was scarce (Piechocki 1990), but also in Russia (Heptner & Sludkii 1972), Scotland (Scott et al. 1993) and France (Artois 1985). This indicates that probably the increase of urbanization and inhabited landscape might not have a great influence on wildcats. The associated increase of traffic on roads (and rail) increased the casualties among wildcats and other mammals but does not influence weight.

Thus, considering these factors which might influence long-term changes in the wildcats weight and size is very speculative and in detail beyond the scope of this study. And there might be many more factors remaining unconsidered.

Cranial measurements as indications of size and change with time

The skull measurements only indicate significant changes with time in all females (not shown). As several specimens from the late 19th and early 20th century are not sexed, the time span from which material is available is restricted (Fig. 1).

The skull parameters differed significantly between the German and Slovakian wildcat sample.

In other studies it had been shown that cranial volume in particular is larger in the wildcats from the Carpathians than in the sample from the Harz region (Krüger et al. 2009, Platz et al. 2011, Stefen & Heidecke 2011). Other variables compared appeared in similar range in both populations Stefen & Heidecke (2011). This might indicate a higher degree of hybridization in the Harz region compared to Slovakia, but is not subject of further discussion here.

Correlation to geographic parameters

For *Felis silvestris* (including all forms or subspecies that are usually distinguished: *F. s. lybica*, *F. s. silvestris* and *F. s. ornata* from Europe, Asia and Africa) Meiri et al. (2004) found a positive significant correlation of cbl and latitude. Yamaguchi et al. (2004) indicated similarities and differences between the wildcats from Europe and Asia and revealed different recent evolutionary histories of distribution expansions. Therefore, looking for latitudinal correlation in *F. silvestris* from all continents together does not seem to be representative of the distinguished wildcat forms. Here only *F. s. silvestris* from parts of continental Europe indicated a correlation of cbl to latitude for females only. The negative correlation to latitude is diverging from Bergmann's rule as has been shown for other carnivores as well (Meiri et al. 2004). Why a correlation is only found in females is not clear.

Two constraints might influence the result as they might have lead to skewed samples not representing the populations well: wildcats in Germany were "collected" as individuals found dead as they were under protection at the time of collection, whereas in Slovakia they were shot. The animals found dead might represent weaker, smaller individuals than those shot at random. More data collection should go on to reveal long term trends with probably ongoing changes in temperature and resulting changes of faunal composition and increased human activity in some areas. Another factor that might be considered in studies with detailed collection of relevant data is how competition to domestic cats or other predators in areas with low abundance of small mammals influences the body size of wildcats.

Overall the available data on body weight and body length to test whether the wildcat decreased in weight and size over the last century and with changes in mean annual temperature are unsatisfying. All weight data together indicate that the wildcats decreased in body mass over the last century, but not so within the last 60 years. As the samples from the literature and museum records represent different time periods, prior to and after about 1950, it is difficult to decide whether the literature data might be unrealistically high, or there was a real decrease in weight. The decrease in body length in the museum records could support the latter, but the lack of a decrease in body weight cannot be explained. And the geographic differences indicated by the correlations to latitude and longitude and in the comparisons of the samples further complicate the picture.

Maybe a weight change occurred prior to about 1950. The cranial measurements as proxies of size of material from about 1900 to 2010 with a clear focus on the second half of the 20th century (Fig. 3) do not indicate a clear change over this time period in the samples. A multivariate analysis to test for differences in German wildcats with time was difficult due to the small sample sizes of well sexed individuals (Stefen 2012a). But slight differences are indicated, and for Scotland, changes in skull morphology in wildcats relative to domestic cats were found (French et al. 1988).

Conclusions for collections in the future

Even though there is a substantial amount of literature on the European wildcat from more than a century, it is difficult to get records of weights of individual specimens well spread over a century or more. Besides the difficulties with the recorded weights in general as outlined, there is also the problem that only few regions of the species distribution are represented. The same also holds for the fair amount of museum specimens. They are concentrated from few regions and time periods. The regional concentration is certainly due to the extirpation of wildcats in many regions at the beginning of the 21st century and the collection of material in only a few refuge areas. There is also the problem that many specimens, e.g. some of those mentioned in the literature, were preserved by individuals or, if they were donated to a collection, might not have survived problems of two World Wars and different restructuring of collections or museums. Additionally, not all data for all museum specimens are (still) available; in several cases sex, weight and body measurements are unfortunately lacking today.

Overall, this suggests that it is still important to collect apparently trivial weight and body measurement data on more specimens of all species, particularly rare ones, to document them well (ideally with the individual together, but at least identifiably as individual) at relevant, publicly accessible, and hopefully in future still persisting collections. It is important to keep them in reference books, labels and/or in digital form, so that they can be used today and in future research. Publication only in reports that are not publicly available is not sufficient; in case of an internet database, future accessibility to other researchers and maintenance must be guaranteed. Otherwise lots of questions that arise now with climate change will later face the same problem of unsuitable sample or data sets.

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Supplementary online materials

Table of weights for wildcats compiled from the literature. Author, year – the publication of the weight; year – the year of the death of the animal or if not available the year of publication; sex: f – female, m – male, ? – unknown; source – the source publication if the original was not accessed (Excel file; URL: http://www.ivb.cz/folia/download/stefen_c_supplementary_material_table.xls).