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# Relevance of body weight effects for the population development of common voles and its significance in regulatory risk assessment of pesticides in the European Union

Magnus Wang<sup>1</sup> , Markus Ebeling<sup>2</sup> and Jörg Hahne<sup>2\*</sup>

## Abstract

**Background:** The common vole (*Microtus arvalis*) is typically the wild mammal species driving regulatory pesticide risk assessment (RA) in Europe. The risk assessment endpoint for wild mammals is taken from the studies conducted mainly with rodents for the toxicological part of the dossier. Body weight effects in these studies are often driving the selection of the No Observed Adverse Effect Level (NOAEL) used for wildlife risk assessment. Thus, assessing body weight effects in voles very frequently constitutes a key scenario in the RA. Although many studies on ecology, reproductive biology, population genetics, and other aspects of common voles are available, the relevance of body weight for their survival and reproduction has not yet been specifically analysed. There is also little guidance on how to quantitatively deal with body weight effects in the regulatory risk assessment of pesticides.

**Results:** We evaluated the population relevance of body weight effects on voles by analysis of a dataset from a multi-annual study with repeated life-trapping and genotyping, and have correlated body weight with reproductive success, taking account of the seasonality of body weight. Body weight and growth were similar between reproducing and non-reproducing females. The number of confirmed offspring indicated no correlation with parental body weight. Reproductive success of the voles was mainly influenced by the date of birth, i.e., animals born in spring have a higher chance to reproduce. Body weight did not correlate with life span during most of the year, except for autumn. Animals weighing < 15 g in October did not survive winter.

**Conclusions:** These results demonstrate no detectable influence of common vole body weight on reproductive success and survival during most times of the year. The results of this study suggest that, additional to the hazard information from toxicity studies, ecological information on voles as a typical species of concern should be considered in the regulatory risk assessment of pesticides.

**Keywords:** Body weight, Reproduction, Survival, Common vole, Pesticide risk assessment

## Background

The European Food Safety Authority (EFSA) has developed detailed guidance on how to assess the risk of exposure to pesticides for wild mammals, and which risk assessment scenarios to consider to ensure that their use does not pose unacceptable risks [1]. In this risk assessment, the generic

focal species scenario “small herbivorous mammals” (represented by the common vole) is nearly always included. Due to the high feeding rates of common voles, and the high predicted residues on ground foliage eaten by the species, the common vole is typically the wild mammal species driving the pesticide RA in the European Union (EU) [2, 3].

In this regulatory RA, a no-effect level (NOAEL) is employed, which is based on effects observed in laboratory studies (typically the rat reproduction study, OECD Guideline 416 [4]) conducted for toxicological purposes.

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A typical effect observed in many of these reproduction studies is reduced body weight, which can be taken as the endpoint for the wild mammal RA, on the assumption that body weight correlates with reproduction and/or survival of the animals. However, the protection goal defined by EFSA [1] aims to ensure “no visible mortality and no long-term repercussions for abundance and diversity” for wild mammal populations. While abundance and diversity are directly linked to survival and reproduction, the key question regarding body weight is, therefore, whether and how much a lower body weight affects survival or reproduction under field conditions.

The common vole (*Microtus arvalis*) is one of the best studied small mammals in Europe, inhabiting agricultural landscapes [3, 5–7], but the relevance of body weight for their survival and reproduction has not been specifically analysed. For such purpose, field studies provide very useful information when body weights are taken and the fate of individuals can be followed. However, typical capture–mark–recapture studies only provide limited information on reproductive success of particular individuals. In the present analysis, data from a study conducted in outdoor enclosures were available [8] in which a large number of regularly trapped individuals were genotyped which enabled an assignment of offspring to parents. The study was originally conducted to assess the fitness costs or benefits of “dispersers”, and was here re-evaluated for potential body weight effects on reproductive success.

The analysis of body weight is, however, not straight forward, since body weight varies considerably within the

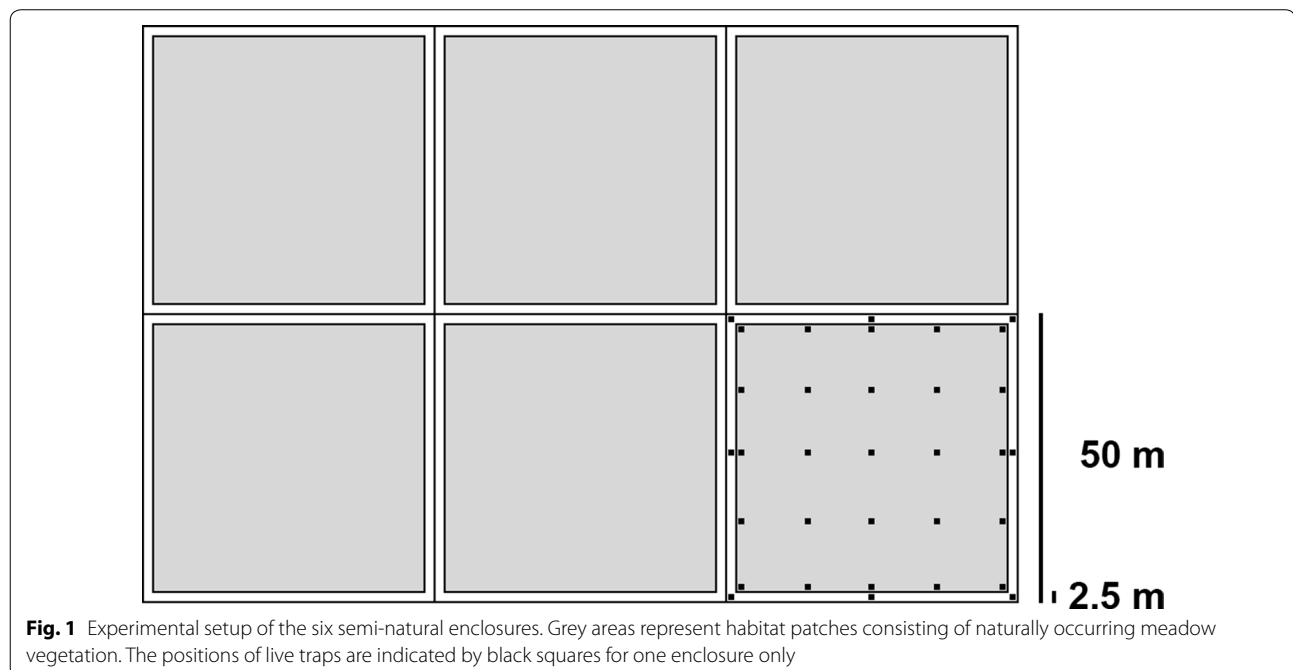
season [9, 10]. Hence, seasonality needed to be taken into account.

## Materials and methods

### Live trapping

Live trappings were conducted at the Remderoda field station (near Jena, Germany: 50°55'N, 11°35'E). The station comprises six 50 × 50 m outdoor enclosures that were separated from each other by metal plates, which inhibit the voles from passing between enclosures (Fig. 1). The enclosures were additionally surrounded by a 2-m-high fence which prevented ground predators from entering the station. Access of predatory birds was not restricted. Enclosures contained natural meadow vegetation (mainly consisting of *Calamagrostis* sp., *Festuca rubra*, *Cirsium arvense*, *Convolvulus arvensis*, and *Crepis biennis*) which was left untouched during the experiments. Each enclosure's habitat patch was covered with a grid of 25 Oos live traps (Oos, Germany) which were modified with an additional wooden box providing shelter from rain and insulation on hot or cold days [11]. The Oos live traps were spaced 10 m apart. Additionally, eight multiple-capture Ugglan live traps (Grahnab, Sweden) were distributed in the corners of each enclosure and in the middle in between enclosures.

Colonies of voles were started in each of the enclosures in 2004 and restocked each year to maintain a typical density and to avoid inbreeding. Voles were live-trapped bi-weekly and equipped with transponders from 2004 to 2006 to ensure individual recognition. The populations had maximum annual densities ranging between 121 and



**Fig. 1** Experimental setup of the six semi-natural enclosures. Grey areas represent habitat patches consisting of naturally occurring meadow vegetation. The positions of live traps are indicated by black squares for one enclosure only

232 N/ha (see [21]). At the time of transponder application, a tissue sample was taken and stored in 70% ethanol for genetic analysis. For each vole, the trapping location, sex, body-weight, and the reproductive state were recorded at each capture. For the latter, we distinguished between enlarged and non-visible testes in males, and between closed vagina, open vagina, pregnancy, and lactation in females. A vole was considered to be adult/mature as soon as testes were enlarged in males or as soon as a perforation of the females' vagina (open vagina) or any sign of pregnancy was observed (i.e., pregnant or lactating). Population densities were measured using minimum number alive (MNA) [12]. For further details on the trapping methodology, see Hahne [8].

### Genotyping

For genetic analysis, 13 microsatellite loci (MM1, MM8, CRB5, MAG25, MAG6, MAR113, MM2, MM6, Moe02, Mar049, MAR016, MAR 080, AVPRup [13–15], which have previously been shown to be sufficiently polymorphic for paternity analyses, were evaluated. Details of the genetic analysis and parentage assignment are provided in Hahne [8] (but note that in Hahne [8], only a subset of the data were analysed which was considered relevant for studying dispersal; while, in the present study all available data were used). A total of 1353 individuals caught between 2004 and 2006 were genotyped. From these some were excluded since their tag was lost or their identity could not be determined undoubtedly. Finally, genotypes from 1224 animals were used for further analysis.

### Analysis of body weight, reproductive success and survival

Reproductive success was evaluated based on the number of genetically confirmed offspring. On average 87.7% of genotyped individuals could be assigned to their mother and/or father. The recapture rate was >73.5% which means that in most cases, individuals were trapped more than once. To evaluate the relationship between body weight and reproductive success, any seasonal body weight changes needed to be accounted for. Seasonality of body weight changes was, therefore, also assessed.

### Statistics

Growth curves of voles were shown on the individual level, instead of using summarising statistics (mean and standard deviation), since this facilitates capture of the full variability of both speed of growth and body weight reached. Correlations between the number of produced offspring and other factors (number of months remaining until the end of the breeding season, body weight) were evaluated using Pearson's correlation coefficient. To compare the weight of animals with or without offspring, a non-parametric Mann–Whitney *U*-test was applied,

since body weight is not normally distributed. However, since body weight is practically always given reported as a mean value and standard deviation in both the ecological literature and in regulatory documents (e.g., EFSA [1]), we chose to follow this convention to facilitate between study comparisons, despite of non-normality of the data.

## Results

### Portion of breeding animals

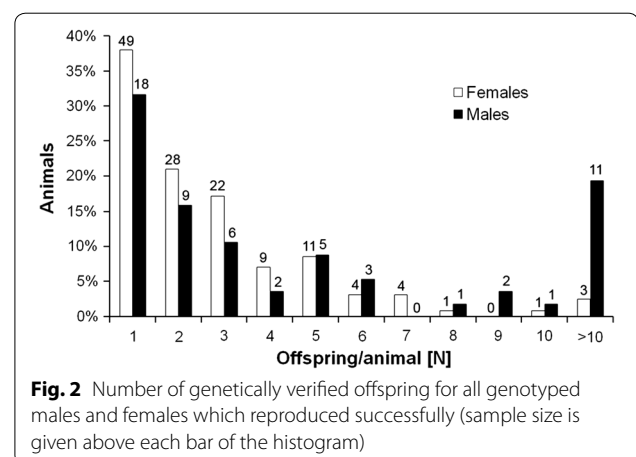
The analysis of breeding animals was based on data of all genotyped animals (note that in a previous analysis by Hahne [8], main emphasis was put on the sub-set of dispersers and their potential progeny). From all individually marked and genotyped females, only 18.1% had genetically identified offspring, i.e., about 80% of females presumably did not reproduce successfully. The maximum number of offspring per female was 13 (Fig. 2). Only 10.0% of genotyped males had verified offspring (max. number offspring per male: 32). Hence, most animals had no genetically detectable offspring.

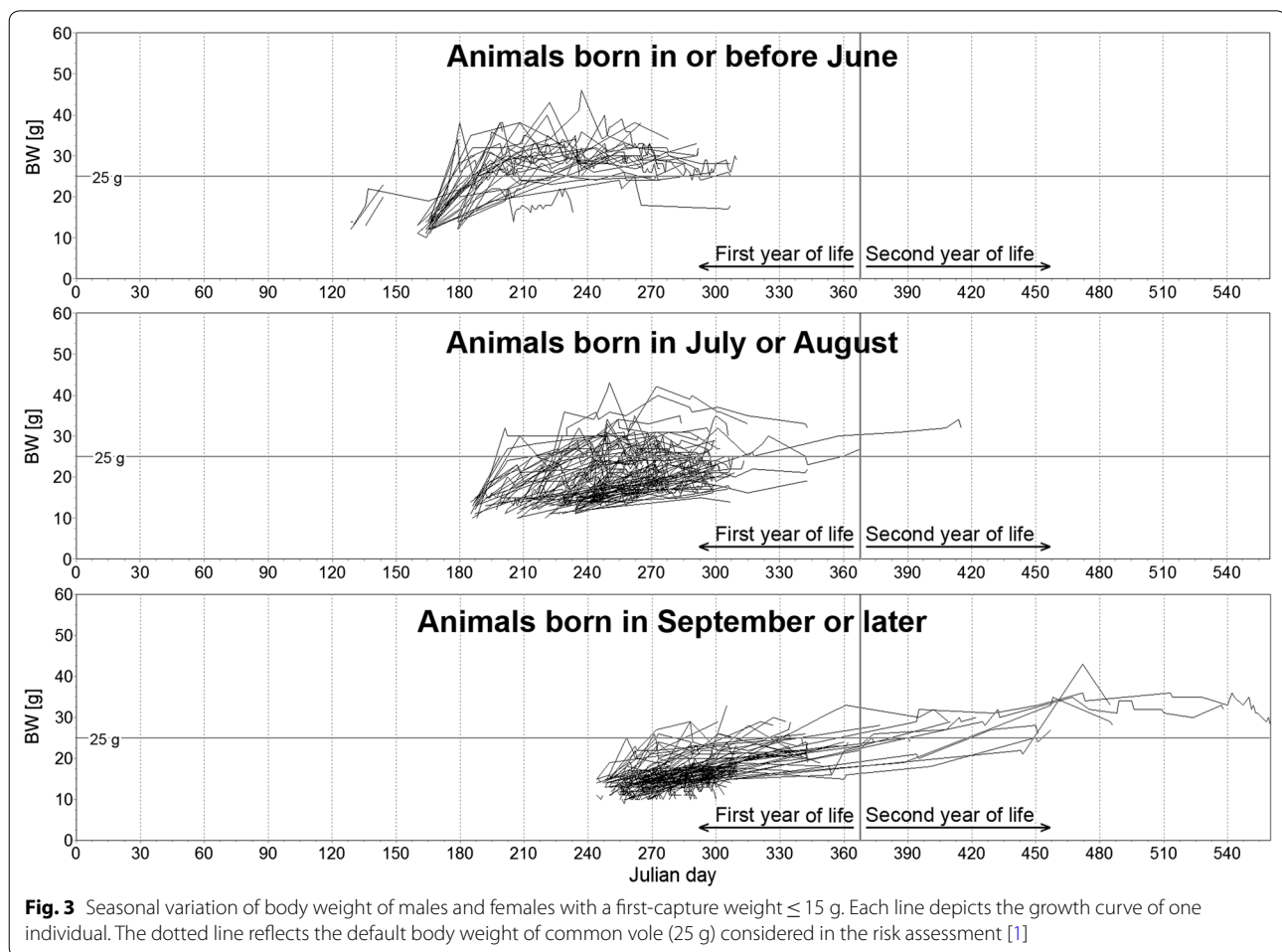
### Seasonality of growth and body weight

To evaluate the seasonality of growth, the body weight development of all animals which were juveniles at first capture (here defined as  $\leq 15$  g weight,  $n = 542$ ) was evaluated. Voles showed a very clear seasonal growth pattern, with rapid growth and high maximum body weight being reached in late spring and summer (Fig. 3). In autumn, voles grew more slowly and maintained a low body weight until the next season. Therefore, analyses of the relation of body weight and reproductive success have to take seasonality into account.

### Effect of body weight on reproductive success

To evaluate if body weight had an effect on the reproductive success, the seasonal growth curves for all females that were caught for at least 60 days (to ensure that females had





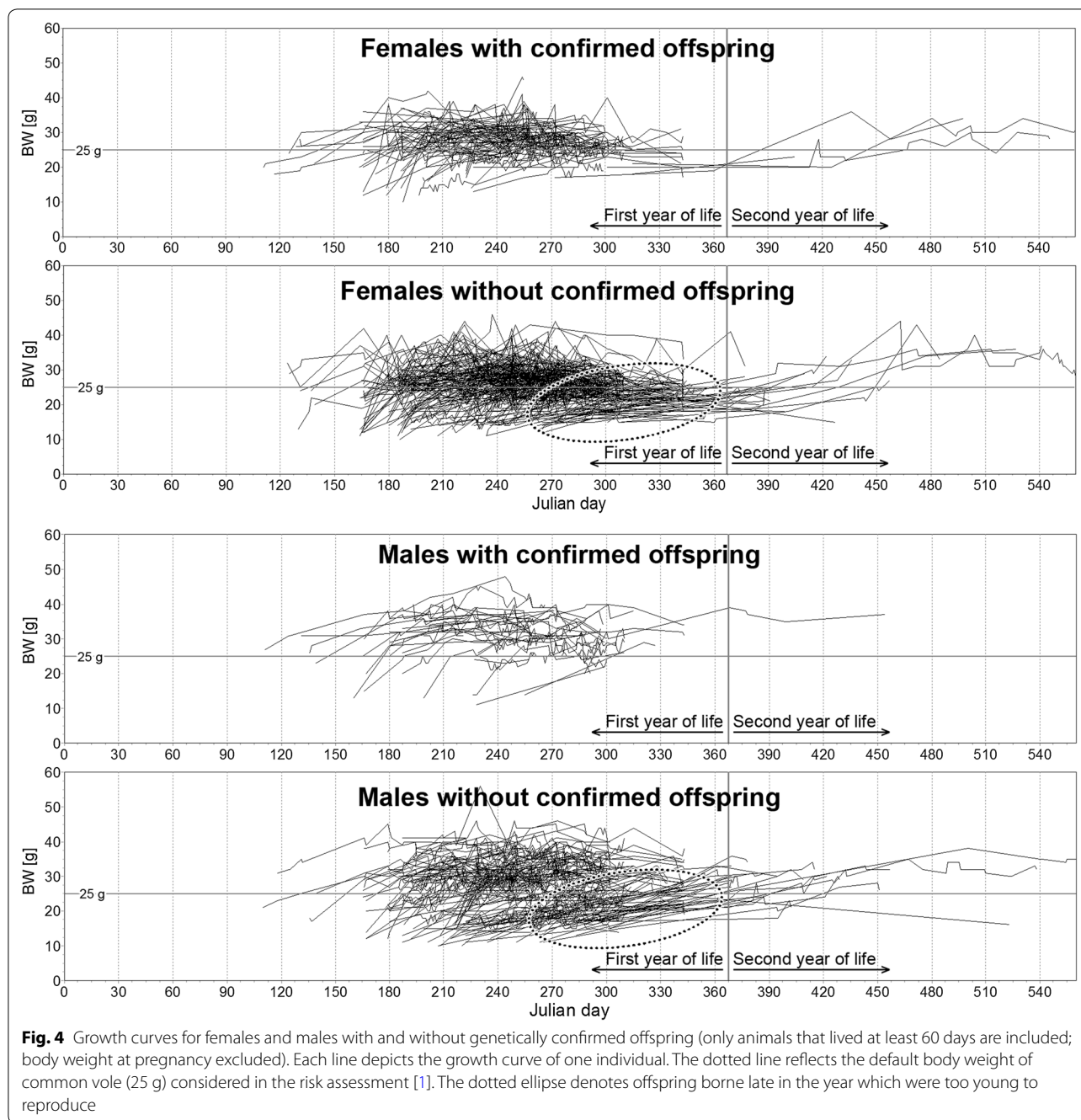
reached adult age) were compared for females with and without confirmed offspring. Weights of pregnant females were excluded. Growth curves of females with and without offspring were practically identical (Fig. 4), but due to a much larger number of non-reproducing females, their range of body weights was wider. The same was true for males, i.e., growth curves for reproducing and non-reproducing males were practically identical. Notably, non-reproducing females included a proportion of animals that were born late in the year and hence did not become mature within the first year. Consequently, these animals have a low body weight (see dotted ellipse in Fig. 4).

Also, when comparing body weight of females with and without confirmed offspring for different seasons (Fig. 5), reproductive success did not correlate with body weight. Correlations of female body weight and the number of offspring, conducted for each month, were not significant (Table 1). The main factor affecting the number of produced offspring was the month of first capture of females (Fig. 6). The number of offspring produced correlated significantly with the months

remaining until the end of the breeding season (Pearson  $R$ : 0.999,  $p < 0.001$ ,  $R^2$ : 0.998). Females born earlier were able to reproduce for a longer period.

Although body weights of individuals born early in the season were also larger, the body weight was not the cause for a larger number of offspring, since the comparison of body weight month by month (see above and Table 1) showed that body weight did not correlate with the number of offspring when seasonality is accounted for.

To exclude bias by young animals that were not able to reproduce within the study period, body weights were also analysed only for those animals which were born before July (i.e., only animals that lived at least for 60 days, and for females, body weight during pregnancy was excluded). Females with confirmed offspring reached practically the same maximum weights (mean: 31.6 g, SD: 3.3 g,  $n$ : 23) as females without confirmed offspring (mean: 31.2 g, SD: 4.5 g,  $n$ : 36). This difference was not significant (Mann–Whitney  $U$ -test:  $p = 0.8643$ ). For males, there was only a small difference between males



with and without confirmed offspring. Males with offspring reached on average 36.9 g (SD: 4.3,  $n$ : 14), while males without offspring reached on average 34.4 g (SD: 4.7,  $n$ : 25). However, this difference was also not significant (Mann–Whitney  $U$ -test: 0.1432).

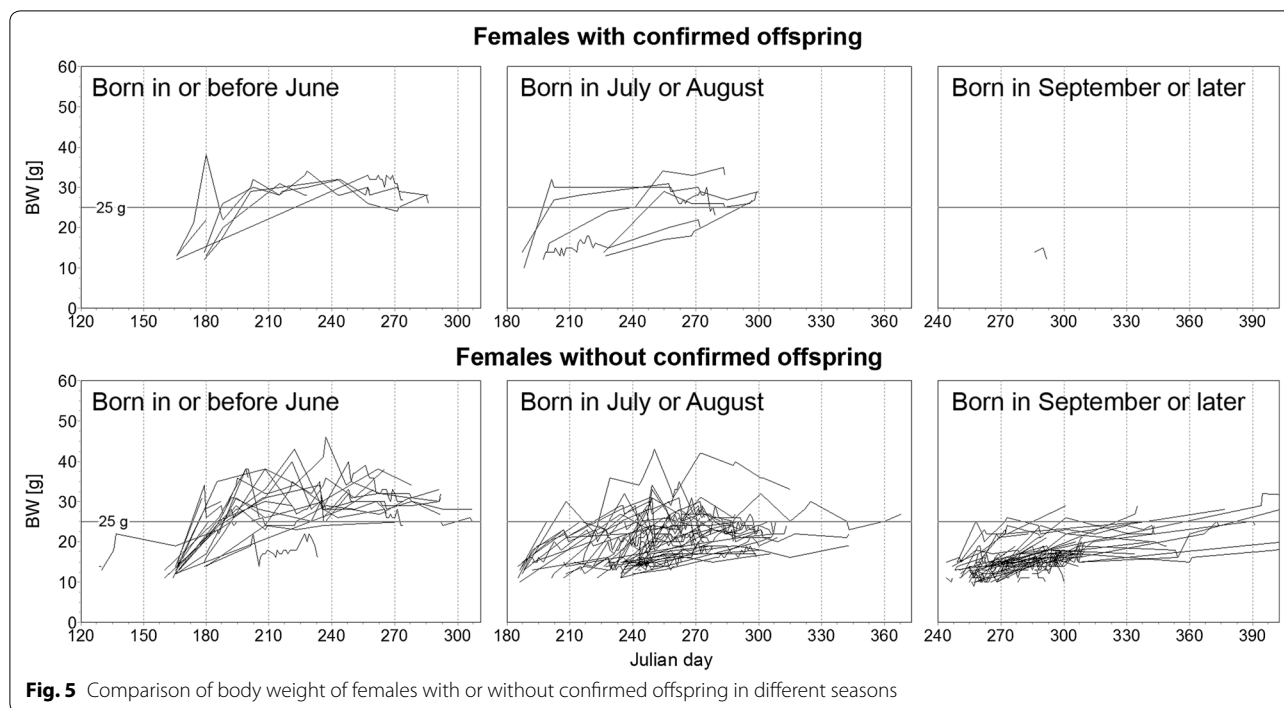
**Life span and body weight**

An analysis of life span (males and females) and body weight conducted for each month indicated no influence of body weight on life span for any month of the year in

which animals were born, except for October. Of all animals caught the first time in October with a weight of less than 15 g ( $n$  = 233), only one survived the following winter (Additional file 1: Figures S1–S6). Of all heavier animals, 19.3% survived until the next year.

**Discussion**

In toxicology studies such as the rat reproduction study [4], in which animals are exposed to treated diet for several months, effects on body weight are frequently

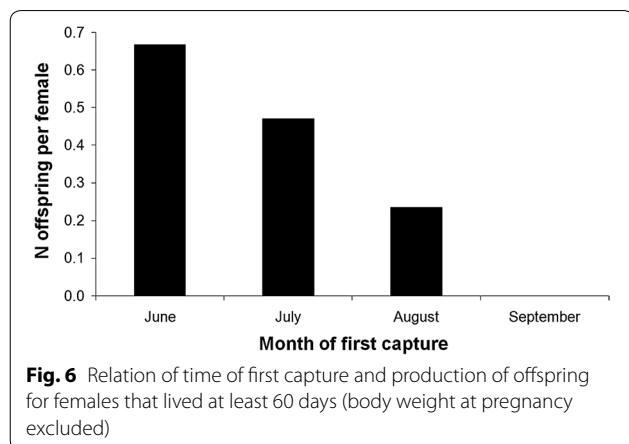


**Fig. 5** Comparison of body weight of females with or without confirmed offspring in different seasons

**Table 1** Relation of time of first capture, mean body weight at the month of capture (body weight at pregnancy excluded) and production of offspring for females that were caught as juveniles (weight ≤ 15 g) and lived at least 60 days

First-capture month	Mean body weight in month (g)	Remaining reproductive months	Offspring per female per lifetime	Pearson <i>R</i>	<i>p</i> value	<i>R</i> <sup>2</sup>
June	14.8 (13.1–16.9)	3	0.667 (0.067–1.667)	−0.039	0.890	0.002
July	16.3 (14.7–18.0)	2	0.471 (0.059–1.059)	0.191	0.462	0.037
August	15.4 (14.1–17.0)	1	0.235 (0.000–0.647)	−0.166	0.524	0.028
September	15.8 (14.0–18.0)	0	0.000 (0.000–0.000)	–	–	–

90% confidence intervals (bias corrected accelerated bootstrap confidence intervals, BCa) are provided in brackets



**Fig. 6** Relation of time of first capture and production of offspring for females that lived at least 60 days (body weight at pregnancy excluded)

observed (most often in form of retarded growth, rather than actual body weight loss). Since the results from these studies are used for the wild mammal risk assessment of pesticides, the question arises to what extent effects on body weight may affect populations of free ranging animals exposed to pesticides under field conditions.

Already EFSA [16] noted that there were “no quantitative experimental data to define the level of body weight change that is associated with impaired mating performance or parental care”. However, no more guidance was then given in the relevant EFSA guidance [1] on how to quantitatively interpret body weight effects observed in the laboratory or how to translate these to field conditions for risk assessment.

The generic focal species scenario “small herbivorous mammals”; i.e., Common voles, often drives the initial steps of pesticide RA in the EU [2, 3]. To date, the relevance of body weight on free ranging common voles has never been studied with regard to pesticides, although body weight is typically measured during capture–mark–recapture field effect studies.

The present evaluation is based on a unique dataset from a live trapping study conducted over 3 years and from genotyping of more than a thousand individual voles. Since animals were kept in outdoor enclosures from which they could not move away, the likelihood of trapping them was high. Therefore, information on their life span is considered robust. Since not all animals could be genotyped due to practical reasons, it is possible that some offspring were not detected. However, since a relatively large number of 1255 individuals were genotyped, the data can be considered adequate to address the objective (Additional files 2, 3, 4, 5).

A first remarkable result of the present analysis was that about 80% of all females and about 90% of all males had no genetically confirmed offspring. Hence, a considerable proportion of the population did not reproduce or did not reproduce successfully, while relatively few animals produced most offspring (females and males produced up to 13 and 32 pups, respectively).

This means that even under the optimal conditions of this study (grassland habitat, ground predators excluded, population density was in a normal range), the availability of home ranges was a limiting factor for the population. In turn, 80% and 90% of non-reproducing females and males, respectively, provided a considerable ‘reproductive reserve’, which could start to reproduce when becoming resident, or when reproducing animals disappeared (e.g., by emigration, predation or agricultural practice). This population resilience is not only relevant for pesticide risk assessment but also explains why common vole populations recover very quickly after rodenticide application [17]. Although voles have short lifespans (during the breeding season most animals live only about a month), they exhibit a high reproductive output and often disperse from their natal areas [18–21].

Body weight effects, as observed in toxicological studies, could potential impact reproductive success of voles, for example during the “breeding phases” defined by EFSA [1]: “Establish breeding site”, “pairing” and “mating”. For example, smaller female voles may potentially have a lower reproductive success due to competition over breeding territories.

However, females of small mammal species in agricultural fields are not very selective regarding mates [22, 23], and males, which have larger home ranges encompassing a number of female home ranges, are only loosely

connected with females and thus mate with a large number of females (i.e., polygynous mating system with multiple paternity [24, 25]). Multiple paternity or polyandry is seen as a common female strategy to increase genetic diversity of offspring or to avoid infanticide. Multiple paternities within a litter have been described in common voles [23, 25], several other small mammals [22, 26–28] and animals in general [29, 30]. Thus, the actual mating system of common voles is in fact very resilient to effects on individuals and this may also explain that differences in adult body weight of factor 2 or more were not associated in our study with measurable differences in reproductive success, a key element of the regulatory protection goal.

The focus of the present evaluation was to determine to what extent body weight had an effect on reproduction and survival, to inform the risk assessment or management of small mammals.

However, since common vole body weight showed a typical seasonal trend as previously reported [9, 10, 31], seasonality needed to be taken into account. The main factor influencing reproductive success (measured as the number of genetically confirmed offspring) was the month of birth. Females born early in the season had more offspring than females born later in the season. Body weights were generally higher early in the season (before population density reaches its peak) than in late summer or later. Hence, one might suspect that body weight is related to a higher number of offspring. However, this is not the case, because when seasonality was accounted for by comparing the number of confirmed offspring and female bodyweight month by month, it was found that larger body weight did not relate to more offspring. That is, for each month, there was no correlation between body weight and the number of confirmed offspring. Overall, this means that seasonally changing body weight does not seem to affect reproductive success, but that the single most influential factor affecting it is the time of birth (or in other words, the time animals have for reproduction). Also, when comparing the body weights of successfully reproducing females (i.e., those with confirmed offspring) and unsuccessfully reproducing females (i.e., those without confirmed offspring), no influence of body weight was found.

In contrast, regarding life span, an effect of body weight was found in young animals born late in the year: when comparing life span and body weight month by month (again to take account of seasonality), it was found that of all animals caught the first time in autumn (October), only those with a body weight of at least 15 g survived until the next year. However, survival of animals caught the first time in October was generally low (only 13% survived until the next year). But a low winter survival of

animals born late in the season probably does not affect populations much, since only about 15% of all ‘first captures’ were caught in October or later.

Before October, body weight and survival did not correlate. In this context, it is interesting to see that body weight is generally highest in late spring and summer [this study, 9, 10] when survival is typically lowest [32]. These results are in line with findings in bank voles by Koskela [33] who studied the impact of litter size manipulation in outdoor enclosures in Finland. An artificial increase of litter size related to a lower body weight at weaning and a reduction of litter size resulted in larger weaning weights. While litter size manipulation had no effect on winter survival, survival of pups during lactation was reduced for enlarged litters. However, a higher female weaning weight related to a slightly higher winter survival, independent of litter size manipulation (survival of male offspring was not analysed). Adult female weight did not, however, explain the probability of surviving over winter.

## Conclusion

In conclusion, under field conditions, reproductive success seems to be influenced mainly by factors other than body weight, the main factor being the month of birth which determines for how long newborn animals have a chance to reproduce. Thus, body weight effects at the end of the season would be more of concern for the regulatory RA than for spring and summer exposures.

The present study is the first one to elucidate the relevance of body weight on reproductive success and survival in common voles. In the past, the relation of body weight and reproductive success or survival has received little attention in common voles or any other small mammal, although body weight is usually measured in capture mark–recapture studies. The seasonal increase of body weight in late spring and summer has been described by Schön [9] and Jacob [10], but since the studies did not focus on body weight effects and since animals were not genotyped, the relation of body weight and reproductive success or survival was not specifically analysed. In wood mouse, Flowerdew [34] studied the effect of supplementary feeding and observed an increase of mean body weight in the experimental area with supplementary feeding, compared to a control area. However, the population in the experimental area increased less than the one in the control area. Flowerdew [34] concluded that “factors other than food supply affect wood mouse populations, especially in summer”. This indicates that also in other species, body weight may not be the most relevant factor determining reproductive success or survival under field conditions. In another study on wood mice, based

on genetic analyses, Musolf [22] found that for males, increased body weight increased reproductive success; whereas for females, reproductive success depended on the time spent in the enclosure. Since the wood mouse females were seen to mate indiscriminately without preference for higher male body weight, the higher reproductive success was attributed to possible advantages of larger males in sperm competition in mixed paternity litters. In our study with common voles, no significant differences were found between the body weights of males with or without confirmed offspring. For the common vole females, the time available for reproduction was the only clear factor determining reproductive success.

With regard to the RA of agrochemicals, the results from this study indicate that changes in body weight may be typical under the conditions of current toxicological test designs (in which animals cannot choose between a treated and an untreated diet), but they may not be the most relevant factors under field conditions. Direct effects of toxicity which affect reproduction or survival are, therefore, more relevant for estimating risk and potential effects. Also the season when animals may be exposed is an important consideration. If body weight is reduced due to exposure to a toxicant, the risk at the population level may be very different depending on when animals are exposed. In spring or summer, a reduction of body weight may not have any adverse effect and other effects (e.g., a reduction of litter size) may be much more important; whereas in autumn, a reduction in body weight may be more relevant for offspring but direct effects on reproduction may be less relevant since most breeding has ended. These results stress the need to include ecological information in the RA to ensure that the nature of the risk and the factors which determine it are well understood.

## Supplementary information

**Supplementary information** accompanies this paper at <https://doi.org/10.1186/s12302-019-0240-y>.

**Additional file 1: Figures S1–S6.** Life span vs. body weight of animals.

**Additional file 2.** Genotyped animals.

**Additional file 3.** Allocated fathers.

**Additional file 4.** Allocated mothers.

**Additional file 5.** Trapping raw data.

## Abbreviations

bw: body weight; d: day; E: east; EFSA: European Food Safety Authority; EU: European Union; MNA: minimum number alive; N: north; *n*: sample size; NOAEL: No Observed Adverse Effect Level; OECD: Organisation for the Economic Co-operation and Development; ppm: parts per million; *R*: correlation coefficient (Pearson); *R*<sup>2</sup>: coefficient of determination; RA: risk assessment; SD: standard deviation.



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**Authors' contributions**

Data were kindly provided by JH. MW analysed the data and drafted most parts of the manuscript. JH and ME contributed remaining parts of the manuscript and provided information on the regulatory background. All authors read and approved the final manuscript.

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**Availability of data and materials**

The data are available in additional files.

**Ethics approval and consent to participate**

Not applicable. The present evaluation is an analysis of previously collected data [8].

**Consent for publication**

Not applicable.

**Competing interests**

ME and JH are employed by Bayer AG, a manufacturer of plant protection products. MW works as consultant for Bayer and other clients.

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