



Research Article

An Examination of the Effects of Dam Age on Productivity to Make Recommendations for Captive Breeding of the Hazel Dormouse *Muscardinus avellanarius* (Linnaeus, 1758) (Rodentia: Gliridae) in the UK

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Abstract: The hazel dormouse *Muscardinus avellanarius* became extinct in half of its former range in the UK during the 20th century. A national studbook records all dormice held in captivity; more than 1500 individuals and 214 litters, from 1987 (when captive breeding began) to the end of 2021. These records provide a unique opportunity to study the captive reproduction of this relatively rare and elusive species and make recommendations for captive breeding. Studbook data were analysed, to examine the relationship between age of breeding female (dam) and various reproductive parameters. Maximum-recorded lifespan within the captive population is nine years and two months, compared with five years recorded in the wild in the UK. Maximum breeding age of captive dams is five years and they can produce up to three, and exceptionally four, successive litters in a season. Litter size ranged from 1-9 with four being the most frequent. There was a non-significant decline in both mean and maximum litter size with dam age, and significant variation in the number of young born between sequential litters. Significantly higher mortality rates of unweaned young occurred in those born to five-year-old dams. To maximise captive breeding potential, breeding should focus on using younger dams. More precise and detailed record keeping by breeders contributing to the studbook database would assist future analysis.

Key words: Litter size, studbook, reproduction, lifespan

Introduction

The hazel dormouse became extinct in at least 17 counties in the UK during the 20th century (PTES 2022a) due to habitat loss and fragmentation and changes to habitat management (BRIGHT & MORRIS 1996). Since 2000, the national population has declined by 51% (WEMBRIDGE et al. 2019) and the species is listed as vulnerable to extinction on the Great Britain Red List (MATHEWS & HARROWER 2020). It received full legal protection under Schedule 5 of the Wildlife and Countryside Act 1981 (as amended) and in 1992 English Nature (now Natural England)

launched a Species Recovery Programme with the aim of restoring dormice to areas of England from which they had been lost and where natural re-colonisation was unlikely. An objective of the 1995 UK Biodiversity Action Plan (UK STEERING GROUP 1995) is the re-establishment of self-sustaining populations in at least five counties from which the species has been lost. It also proposes supplementing dormouse populations in counties where they are widely scattered.

In 1995, the Common Dormouse Captive Breeders Group (CDCBG) was formed to facilitate and coordinate breeding of the hazel dormouse

for reintroduction. Members of the group include breeders (private individuals, zoos and other institutions), The People's Trust for Endangered Species (PTES), Natural England and two zoos providing pre-release quarantine and health screening facilities (The Zoological Society of London and Paignton Zoo). Thirty-one dormouse releases took place at 25 reintroduction sites in 13 counties between 1993 and 2021. Also in 1995, a national studbook was initiated by the Zoological Society of London to record all movements of dormice between wild and captive populations; all transfers between members of the CDCBG; and all births and deaths in captivity. Records are held in SPARKS (Single Population Analysis and Records Keeping System), a DOS-based programme used by zoos to record and analyse data on the status of captive populations held in multiple facilities. Some captive breeding began in 1987, before the group was formed, and so records dating back to 1987 were added retrospectively. Management of the studbook was transferred to Paignton Zoo in 1997, then to Wildwood Trust in 2010. Seven editions of the studbook were published between 2006 and 2021, the latter recording 1513 individual dormice and 214 litters (KYNASTON & BEMMENT 2022).

Breeding stock is sourced from underweight autumn litters found in nest boxes at National Dormouse Monitoring Programme (NDMP) sites, under licence from Natural England, or wild animals that are brought to rescue centres due to accidental disturbance, injury or cat predation. The number and genetic diversity of breeding stock is therefore limited and so the same individuals may be used for breeding for several successive years. In wild UK populations, commonly one, but sometimes two, litters per year are recorded per female (BRIGHT et al. 2006). In Lithuania, third litters have been recorded from at least five females (JUŠKAITIS 2014). Each captive dam may produce up to three, or rarely four, litters per year of one to nine young (KYNASTON & BEMMENT 2022). The maximum recorded lifespan of wild dormice is five years in the UK (BIRD et al. 2012, TROUT et al. 2017) and six years in Lithuania (JUŠKAITIS 1999), whereas in captivity dormice can outlive their wild lifespan (KYNASTON & BEMMENT 2022). Anecdotal observations by breeders suggest that older females may produce fewer or smaller litters, and survival of young may be reduced. However, this has not been systematically investigated before.

Captive breeding requires resources such as staff and volunteer time, enclosure space, breeding stock and funding for food, husbandry and veteri-

nary care. These resources are limited and captive breeding efforts need to be focussed on producing the most effective and successful results. Therefore, we investigated whether older dams may produce smaller or fewer litters. If so, we would recommend retiring older dams and focussing resources on younger, more productive females to improve efficiency.

Materials and Methods

Captive breeding

Captive dormice are paired for breeding in late spring, with one male and one female housed together in each outdoor enclosure at several captive breeding facilities in Southern England. Some pairs are overwintered together from the previous year. Young dormice are not paired for breeding until they have overwintered at least once and so are in their second year. Wooden nest boxes are provided for resting and breeding. During the breeding season (May to October) the nest boxes are regularly checked and any young found are counted, weighed and sexed. The weight and development stage of the young are used to estimate their date of birth (BRIGHT et al. 2006) and to distinguish order of birth of litters where more than one litter is present. These data are entered into the SPARKS database.

Dams are mostly wild-born animals, brought into the breeding programme to increase genetic diversity. The age of the dam, if known, is recorded in the studbook. Young of the year can usually be distinguished from adults by weight, pelage colour (CHANIN & GUBERT 2012) and tail hairiness (TROUT et al. 2017). Once they have overwintered, they are classified as adults but the actual age cannot be determined by a visual inspection. Therefore, the age of adults arriving from the wild is mostly recorded as 'unknown'. Each captive individual, whether born in captivity or brought in from the wild for breeding, is allocated a studbook number and adults are marked with a passive integrated transponder (PIT) for identification. Their birth date, parentage, birth location and death date are recorded in SPARKS.

Data Extraction

There are a number of reports, available to download in SPARKS, which perform some data analysis. However, for most of the investigations here, these were not used as it was not possible to filter out unsuitable data such as wild born litters or dams of estimated age. Instead, in most cases, the raw data were exported from SPARKS and inappropriate records removed manually before analysis.

The SPARKS report ‘Reproductive Parameters’ was used to export litter data for 214 litters born between 1988 and December 2021 into an Excel spreadsheet. This dataset was used for all the following analyses, unless other reports are specified. Underweight autumn young, brought in from the wild along with their dam, are recorded on the studbook as ‘litters’ and so were excluded from the analysis. The database allocates a default birth date of 1st January 1900 to any individual whose birth date is entered as ‘unknown’. These were manually removed from the dataset initially but their minimum ages were later estimated for some additional analyses as detailed below.

Lifespan

A ‘Studbook Report’ restricted to the event type ‘Death’ was extracted from the SPARKS database. A SPARKS ‘Age Report’ could not be used as it would include animals of estimated age. Lifespan in captivity was examined for dormice of known birth year. In addition, the minimum age was calculated for animals of unknown birth year by adding one year (the minimum age of an adult) to the number of winter hibernations survived in captivity.

Comparison with wild populations

The PTES collects dormouse breeding data using the NDMP. Volunteers, checking dormouse nest boxes on a monthly basis, record age class and litter size at sites throughout England and Wales (PTES 2022b). NDMP data for wild litters, found between 1988 and 2021 at 670 monitoring sites (each monitored for between one and 34 years), was used to plot litter size against number of litters. ‘Pink’ age class litters (newborn) were excluded as these are rarely counted accurately by volunteers, leading to a default value of one allocated for any unknown litter size entered on the NDMP database. ‘Eyes open’ age class litters were also excluded as they included litters of ten (n=4) and twelve (n=2), which exceeds the maximum recorded litter size for this species. Therefore, they were likely to be a result of multiple litters in a single nest box or a crèche formed of litters from more than one dam (BRIGHT et al. 2006, JUŠKAITIS 2014). In addition, young in this age group might suffer higher mortality as they are active outside the nest box, meaning the number counted at this age may not be a true reflection of the litter size at birth. BÜCHNER et al. (2003) observed a reduction in litter size between newborn and nearly independent (eyes open) young, with postnatal mortality proven in some cases. Therefore, only ‘grey, eyes closed’ age class litters were used for analysis.

Captive bred litters were plotted for comparison. Again, a litter outside the known size range (recorded as 14) was discounted, as it was likely to be two litters combined. All age classes of young were included in the analysis because captive litters are always counted, mortality rates are low and the remains of dead young are easily found in the nest box or enclosure. Pearson correlation was performed to compare wild and captive bred litters.

Dam age

To aid analysis, dam ages were grouped into age classes based on the number of winter hibernations passed since birth. For example, a dam born in August 2010 was recorded as age class one when she produced a litter in June 2011. Females of unknown age were manually removed from this report before analysis. Correlations between dam age and number of litters born and litter size were measured using Pearson correlation coefficient.

Sequential litters

All litters were allocated a sequence number from one to four, based on the date order in which they were born to a specific dam within the same year, one being the first litter of the season. Spearman’s rank correlation was computed to assess the relationship between dam age and both mean and maximum litter size of sequential litters. An ANOVA test was conducted to examine variation between sequential litters.

Mortality

The SPARKS ‘Reproductive Parameters’ report, exported in Excel, includes a survival category for each individual born; ‘died before 30 days’, ‘died after 30 days’ or ‘viable’ (living at the time of data analysis or when last recorded, for example, on the date of release into the wild). A chi-squared test was performed to compare mortality of young before 30 days of age (unweaned) with dam age, both using known age dams and to increase the size of the dataset, including dams of minimum known age. Minimum known age was calculated as for lifespan.

Results

A maximum lifespan of 9 years and 2 months was recorded in captivity for a wild-born hand-raised female, studbook number 1034. Thirty captive individuals of known age outlived the UK maximum-recorded lifespan of 5 years in the wild (Fig. 1). When the dataset was expanded to include the minimum age of animals with an unknown birth date, this increased the sample size to 44 individuals.

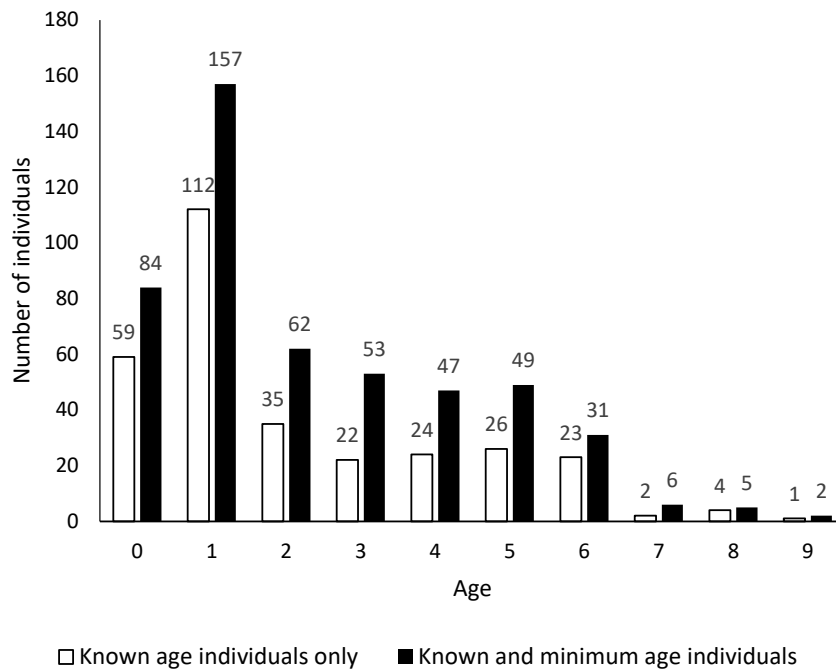


Fig. 1. Age at death of dormice in captivity comparing known age individuals with both known age and minimum age individuals combined. Minimum age is calculated by assigning an age of one year to adult dormice of unknown age on admission to the captive breeding programme from the wild.

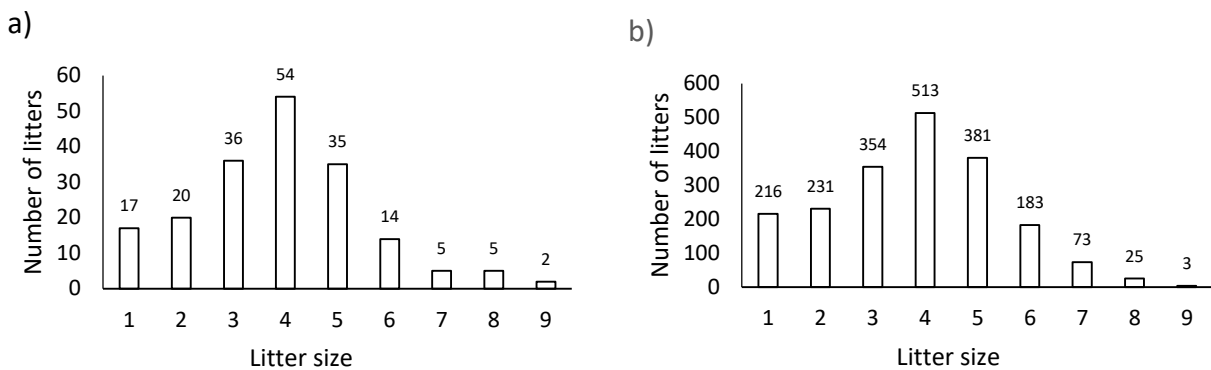


Fig. 2. Litter size range and frequency in a) un-weaned young in UK captive population (1988-2021) and b) ‘grey, eyes closed’ young in UK wild populations (NDMP data, 1988–2021).

Litter size in both captive (Fig. 2a) and wild (Fig. 2b) populations ranged from one to nine, with four being most frequent. There is a strong positive correlation between these two populations ($r=0.99$, $p<0.001$, $n=9$).

The number of litters born in captivity significantly declined with dam age (Fig. 3) ($r=.98$, $p<0.001$, $n=188$). Only 3.6% of dams produced litters at age five. Of the dams that successfully produced at least one litter in a year, the mean number of litters per dam per year in each age class ranged from 1.20 (age class 5) to 1.52 (age class 2) but there was no significant correlation with dam age ($r=.50$, $p=.386$, $n=5$).

There was a marginally significant decline in mean litter size with increasing dam age class ($r=-.15$, $p=.040$, $n=188$) (Fig. 4) and a non-significant trend of decreasing maximum litter size with increasing dam age class ($r=-.88$, $p=.051$, $n=5$).

Of the captive dams that bred successfully, most (62.9%) only ever produced one successive litter per year; 28.9% produced up to two, 6.2% up to 3 and only 2.1% had four in any one year. There is significant variation in numbers of young born between sequential litters ($F=7.266$ (3,190), $p<.001$), with a distinct decline in age class 4 (Fig. 5). However, the overall trend is unclear ($r_s = -0.4$, p (2-tailed) = 0.6) although this may be due to low statistical power.

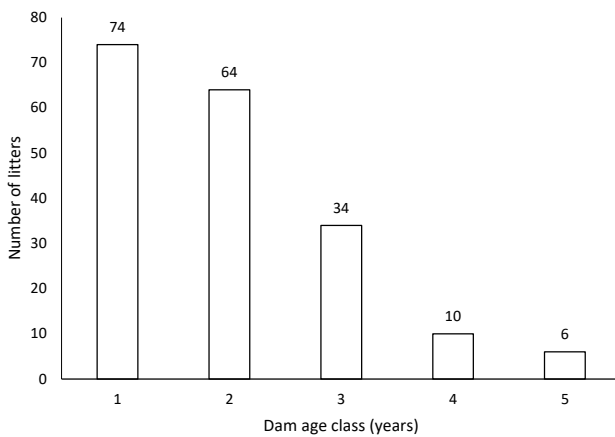


Fig. 3. Change in number of litters born in captivity with increasing dam age.

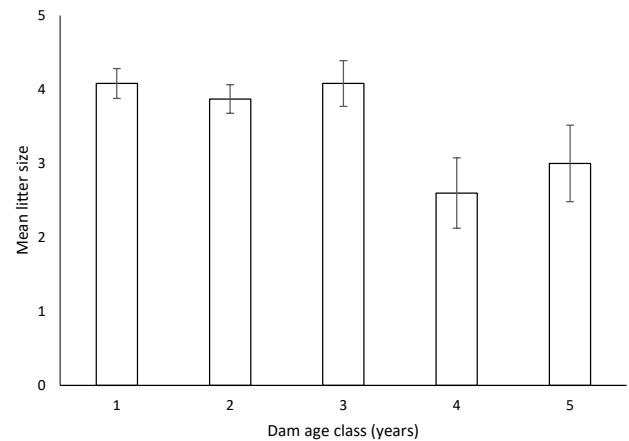


Fig. 4. Relationship between mean litter size (+/- standard error) and age of captive dam.

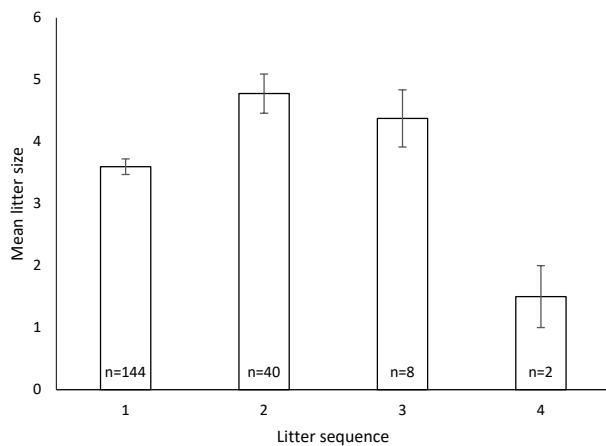


Fig. 5. Mean litter size of sequential litters in a year (+/- standard error).

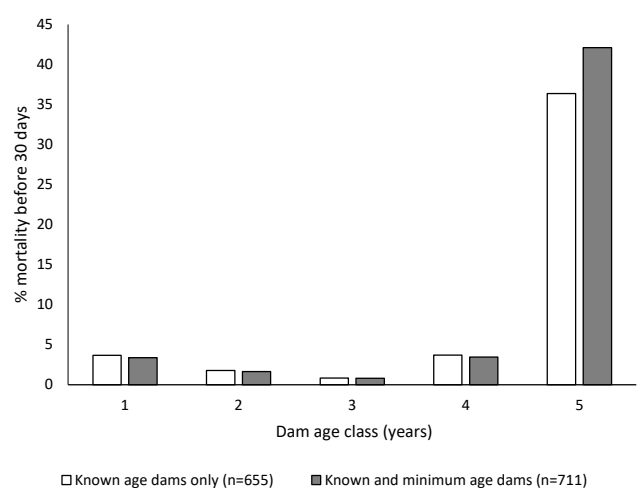


Fig. 6. Mortality of unweaned (under 30 days of age) captive born young by dam age.

There is a suggestion of a decline in maximum litter size with litter sequence but it is not quite significant, again possibly due to low statistical power given the small number of sequences ($r = -.934$, $p = .066$, $n = 4$).

There is a highly significant increase in mortality of young before 30 days of age in five-year-old dams of known age ($\chi^2(4, n=655) = 44.99$, $p < .001$) and also when minimum age dams are included ($\chi^2(4, n=711) = 92.08$, $p < .001$) (Fig. 6).

Discussion

The results of this study show that age of captive dams has a significant effect on their reproductive output. Captive hazel dormice can outlive wild dormice by at least four years, but breeding has not been recorded in captive dams older than five years.

However, the decline in total number of litters recorded in the database with increasing age (Fig. 3) can partly be accounted for by fewer animals living to age five in captivity as well as due to older females being retired from the breeding programme when their mate dies or a new bloodline is available. The studbook does not record failed attempts to breed and it is recommended that a system is set up to record these in future.

Range and frequency of litter size is not affected by captivity (Fig. 2). Captive dormice produce up to 3, and rarely 4, litters per year, whereas a maximum of 3 litters has been recorded in the wild, and more commonly two. This difference is likely to be due to the high availability of food all year round in captivity, extending the breeding season at both ends. However, sometimes, captive

males are removed, after the first or second litter is born, to reduce the over-representation of particular bloodlines within the animals available for release and so not all females are given the opportunity to produce multiple litters. There is significant variation in numbers of young born in sequential litters, although the trend is not clear (Fig. 5). The graph indicates a possible increase between the first and second litters, then a distinct decline in age class 4. JUŠKAITIS (1997) recorded a higher number of young in second than first litters of the year in Lithuania, but in Germany there was no difference, although the sample size was small (BÜCHNER et al. 2003). Litter size in some mammal species can be influenced by morphological and environmental variables (BATTISTELLA et al. 2019). Wild dormice lose an average of 33% of their body weight during hibernation (JUŠKAITIS 2001). Therefore, females may be of a lower weight early in the breeding season and an increase in weight may be delayed due to climatic factors leading to a higher percentage of time spent in torpor (JUŠKAITIS 2014). NAIM et al. (2011) found a positive correlation between adult female body weight and litter size in both a natural and a re-introduced population of dormice in the wild in the UK. The decline at the 4th litter could be accounted for by depletion of the female's resources after three consecutive pregnancies and lactations. It is recommended that this analysis is repeated in future when there is a larger dataset available.

There is a decline in mean litter size with increasing dam age class (Fig. 4) and a general trend to decreasing maximum litter size with increasing dam age class. This concurs with a decline in litter size with maternal age observed in cavies (TRILLMICH et al. 2019) and a negative correlation between number of offspring per season and lifespan recorded in mammals (TUOMI 1980). However, in a wild hazel dormouse population in Lithuania, an increase in litter size from one- to two-year-old females was found followed by a decline in three- to four-year-old females (JUŠKAITIS 2014). Litters from females known to be five years of age were not recorded in the wild.

There is also a highly significant increase in mortality of young before 30 days in litters born to five-year-old dams (Fig. 6). This concurs with MORELLO et al. (2020) who found that advanced dam age and small litter size were associated with increased probability of pre-weaning pup death in laboratory mice.

The results reported here are dependent on the accuracy of data held in the studbook. A litter of 17 was excluded from the dataset as it was as-

sumed to have been multiple litters from the same breeding pair. This may have been incorrectly recorded as one litter by a breeder who checked the nest boxes infrequently and found two litters that had both reached juvenile age. Conversely, a litter not entered in chronological order may be split into separate litters by the software. Some litters, apparently born within the same month, were also discounted as this did not fit with the known gestation period. In addition, a change in method of recording adults of unknown ages from 2017 onwards was discovered, leading to estimated dam birth dates being used in the analysis. However, this only affected seven litters from four females that were included in the dataset. Therefore, accuracy of data entry is paramount. It is recommended that a standardised data entry protocol is adopted and information that is more detailed is entered when new individuals enter the breeding programme from the wild. Breeders should also monitor litters more closely and improve the clarity and consistency of records in future to aid analysis.

The captive breeding programme has limited resources. Breeders mainly pay for food and enclosures themselves with infrequent funding from grants. Daily husbandry and monitoring of breeding are time consuming. The retirement of older dams, that produce few small litters or fail to breed altogether, would free up enclosure space and time. These animals could be a benefit to educational establishments. The national dormouse studbook is an extensive resource and further data analysis, investigating other parameters, would be beneficial. Tools now exist to migrate older zoo management software, such as SPARKS, into a more modern database such as Species360 ZIMS (Zoological Information Management Software). Potential benefits for ease of data management and extraction should be considered.

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