**Risk factors influencing brumation success in captive tortoises in the United Kingdom**

Vicki Baldrey1, Louis Guzennec1,2, Joanna Hedley1

1Beaumont Sainsbury Animal Hospital, Royal Veterinary College, 4 Royal College Street, London, NW1 0TU.

2 Present address: 93 Sterndale Road, Flat second floor, London W14 0HX

Corresponding author: Vicki Baldrey, Beaumont Sainsbury Animal Hospital, Royal Veterinary College, 4 Royal College Street, London, NW1 0TU. [vbaldrey@rvc.ac.uk](mailto:vbaldrey@rvc.ac.uk)

**Abstract**

**Background** This survey of tortoise owners was performed to investigate the factors contributing to morbidity and mortality during and post brumation in captive *Testudo* species in the UK.

**Methods** Information regarding a total of 270 tortoises was included in the study, from 252 completed surveys. Binary logistic regression and multivariate modelling were used to evaluate the potential predictors associated with brumation mortality and those associated with post-brumation problems.

**Results** A 7.78% mortality rate was found, with 7.22% of surviving tortoises reported to have post-brumation health concerns. Brumation in a garden and an uncontrolled reduction of temperature prior to brumation were the main risk factors for morbidity and mortality in the study.

**Conclusions** Veterinarians should be aware of these risk factors to ensure they target husbandry and brumation advice to owners of tortoises to reduce these risks.

**Introduction**

Brumation in terrestrial chelonians is a state of inactivity and decreased metabolic rate triggered by lowering of the environmental temperature.1 It is part of the normal physiology for many temperate chelonians.2 The term ‘hibernation’ is used commonly by both owners and vets to refer to brumation in pet tortoises, however this term more correctly refers to the process undergone by endothermic animals. Throughout this paper, the term brumation will be used when referring to chelonians.

Of those tortoises commonly kept in the UK, the following undergo brumation in the wild during winter months: *Testudo marginata, T. Hermanni, T. horsfieldii* and some *T. graeca* subspecies. The duration of brumation in the wild varies between species, depending on their country and region of origin.3 There is little scientific evidence in the literature relating to brumation in wild or captive chelonians and most of the existing literature in wild animals relates to the desert tortoise (*Gopherus agassizii*).4-6

The function and necessity of brumation for captive chelonians is not fully understood and most information comes from anecdotal sources and personal experience.3 Brumation is thought to be advantageous by facilitating a reduction of metabolism during a time of the year with few resources. It is suggested that brumation can be an important trigger for reproduction in many temperate species1,7,8 and can utilize excess body reserves of fat and establish natural development of body weight and size.3

Brumation can however carry risks and brumation- related health problems are reported to be common in chelonians. One study looking at *T. graeca* and *T. hermanni* species imported into the UK showed a 23-29% annual mortality rate over the 4 year study period, with brumation and brumation-associated conditions responsible for 84.5% of those deaths in tortoises.9 In a more recent survey of 141 vets who had seen tortoises in the previous 12 months, 56% said post-brumation anorexia or weight loss was one of the most common problems they saw.10 According to the same survey, 45% of vets believed that the owner’s lack of understanding of brumation directly contributed to the development of this conditions.

Common methods of brumation in captivity include ‘natural’ or uncontrolled brumation, with the tortoise left to self-brumate in the garden. In the UK climate this can lead to excessively long brumation periods, with a risk of flooding, freezing or predator attack. Using an insulated box method has similar problems, as tortoises may be exposed to temperatures below freezing, leading to tissue damage, or to temperatures which are too high, leading to the tortoise rousing and utilising reserves.11 In recent years, the use of a fridge or a chiller has become a recommended brumation method due to the ability to closely control temperature and monitor the tortoise.3

The aim of this study was to evaluate brumation methods being used for pet tortoises in the UK and to identify potential risk factors for mortality and post-brumation morbidity.

**Materials and methods**

Between March and November 2019, tortoise owners were invited to complete a survey on their approach to brumating their tortoise. The study was limited to the Horsfield’s tortoise (*Testudo* (*Agrionemys*) *horsfieldii*), Hermann’s tortoise (*T. hermanni*) and Spur-thighed tortoise (*T. graeca*). Only owners who had already brumated their tortoise at least once were eligible to participate. If multiple tortoises were kept, owners were asked to answer the questions for each individual tortoise. If information was provided on multiple tortoises rather than individuals, these surveys were not included in the data analysis. The survey consisted of 26 questions including details of their tortoise’s signalment, preparation for brumation, brumation method and outcome. Owners were also given the opportunity to make additional comments about their brumation experiences.

Owners were contacted by advertising the study through tortoise interest groups and online forums, in addition to promoting the survey in a paper format at the British Chelonian Group conference in March 2019. This study was ethically reviewed by Social Science Research Ethical Review Board at the Royal Veterinary College and ethical approval was granted under the reference number (URN SR2019-0190).

Data were analysed using commercially available software (SPSS® Statistics, Version 26) and a *p* value of < 0.05 was taken to indicate statistical significance. Tortoises were divided into two groups: those that had survived brumation and those that did not survive. Out of the surviving group, tortoises were then subdivided into two further groups: those with post-brumation problems (any signs of ill health including taking more than 1 week to start eating) and those with no post-brumation problems. A χ2 test or Fisher’s Exact test was used to compare mortality or post-brumation problem between groups. Binary logistic regression was implemented to evaluate the potential predictors associated with brumation mortality and those associated with post-brumation problems. Predictors with p < 0.25 were then entered into a multivariable logistic regression model and manual backward elimination method was used to obtain the final model. Odds ratio (OR) and its 95% confidence intervals (CIs) were calculated. Incomplete questionnaires were included in data analysis (as long as the species and brumation outcome were completed) which accounts for the differences in numbers of tortoises analysed for each risk factor.

**Results**

A total of 287 owners completed surveys detailing 341 tortoises: 271 surveys were completed online and 16 were on paper. Of these, 35 surveys were excluded on account of being completed incorrectly, detailing tortoises that had never been brumated, a non-target species or not providing the key information on species and brumation outcome. The 252 remaining surveys provided information on 270 tortoises, comprising 53 *T. horsfieldii*, 132 *T. hermanni* and 85 *T. graeca*. These consisted of 129 males, 110 females and 31 of unknown sex and ranged in age from 1 year to 100 years old. In total, 249 tortoises had survived brumation and 21 individuals (7.78%) had not survived. There were no statistically significant associations between survival post-brumation and species, age, sex or previous medical history (Table 1).

*Pre-brumation preparation*

The majority (95.6%) of owners changed their tortoise’s management in preparation for brumation (Fig 1). A statistically significant association was found between a controlled pre-brumation temperature reduction and survival, with the odds ratio of not surviving being 2.55 times higher (95% CI 1.02-6.35) if temperature reduction was not controlled. There were no statistically significant associations between survival post-brumation and any of the other management changes performed pre-brumation (Table 1).

*Brumation methods*

The majority (64.7%) of tortoises were brumated in a fridge / chiller compared to only 27% brumated in a box and 8.3% brumated in the garden. A statistically significant association was found between survival post-brumation and the brumation technique. Tortoises brumated in the garden were 6.05 times (95% CI 1.77-20.72) more likely not to survive brumation than those brumated in a fridge / chiller. A statistically significant association was also found between survival post-brumation and regular temperature monitoring during brumation. Tortoises that were brumated with no temperature monitoring performed were 3.29 (95% CI 1.31-8.28) times more likely not to survive brumation than those that had temperature monitoring performed. There were no statistically significant associations between survival post-brumation and whether the tortoise was regularly weighed during brumation or not (*p* = 0.051). Six tortoises were brumated for less than one month and all of these survived brumation, although overall there was no statistically significant association between survival post-brumation and brumation length (*p* = 0.54).

Brumation problems were reported in 56 tortoises (20.7%) with the most common problem being warm hibernaculum temperatures (*n* = 17) (Fig 2). Carrying out a multivariable model with all the variables in Table 1 where *p* < 0.1 (pre-brumation temperature drop, hibernaculum temperature monitoring, brumation method and brumation weighing) resulted in only brumation method remaining in the final model as an independent predictor of mortality.

*Post-brumation*

Of the 249 tortoises who had survived brumation, 18 tortoises (7.22%) were reported to have post-brumation problems, either not eating within a week or being identified by owners as showing other signs of ill health. Eleven tortoises (4.41%) were taken for a post-brumation vet check, although this only included one of the tortoises reported as having post-brumation problems. All tortoises with post-brumation problems survived.

A statistically significant association was found between presence of post-brumation problems and brumation technique, with those brumated in the garden being 4.89 (95% CI 1.13-21.15) times more likely to have post-brumation problems, compared to those brumated using the fridge / chiller method. A statistically significant association was also found between survival post-brumation and regular temperature monitoring during brumation. Tortoises that were brumated with no temperature monitoring performed were 3.11 (95% CI 1.14-8.54) times more likely to have post-brumation problems than those that had temperature monitoring performed.

No statistically significant associations were shown between post-brumation problems and signalment, previous medical history, any of the pre-brumation measures or other brumation factors (Table 2). Carrying out a multivariable model with all the variables in Table 2 where *p* < 0.1 (hibernaculum temperature monitoring and brumation technique) resulted in only garden brumation remaining in the final model as an independent predictor of post-brumation problems.

**Discussion**

Brumation problems were reported in this survey including both mortality and post-brumation morbidity, but prevalence of problems was lower than in other surveys.9,10 This may be due to selection bias, as the owners filling in the survey were members of tortoise interest groups and internet forums, so may be better informed on current husbandry recommendations. This is supported by the fact that the majority of owners did make some pre-brumation preparations for their tortoise and self/ garden brumation was uncommon. The previous owner survey was carried out in the 1980s,9 when self/ garden brumation was the usual method and tortoise husbandry practices very different from today.

That species and age didn’t affect brumation outcome is interesting, as Horsfield’s tortoises naturally have a longer brumation period than other *Testudo* species with brumation periods of 9 months being reported in one study.12 The generally accepted length for brumation of captive *Testudo* species is 10-12 weeks, with up to 14 weeks recommended for *Testudo horsfieldii*.3 Six tortoises in our study were brumated for less than one month and all these survived brumation, although overall there was no statistically significant association between survival post-brumation and brumation length. Evidence base for the age at which tortoises should be brumated is lacking, however in the wild hatchlings and juveniles will undergo brumation from their first year as ambient temperatures decrease.13 It is generally accepted that in a captive environment, juveniles should be allowed a short period of brumation3 and this has been suggested to be carried out in preference to overwintering, to control growth rates.11

Brumation preparation did affect outcome and a statistically significant association was found between a controlled pre-brumation temperature reduction and survival. In the wild, tortoises will be exposed to a slow decline of temperature, shorter day length and a decrease in food availability which is associated with a decrease in metabolism and activity which prepares the animal for brumation. An uncontrolled temperature reduction will remove this period of preparation for brumation, where food intake reduces to allow the GI tract to empty of ingesta which may otherwise ferment during the brumation period.3

Brumation method also affected outcome. The majority (64.7%) of tortoises were brumated in a fridge or chiller. Tortoises brumated in the garden were 6.05 times more likely not to survive brumation than those brumated in a fridge or chiller, consistent with the literature citing risk of freezing, flooding and predation with uncontrolled garden brumation.3

Brumation problems were reported in 56 tortoises (20.7%) with the most common problem being warm hibernaculum temperatures. Tortoises that were brumated with no temperature monitoring performed were 3.29 times more likely not to survive brumation than those that had temperature monitoring performed. Cause of death of these individuals was not documented so it is hard to speculate, but this finding is consistent with the literature advising a brumation temperature of 5-8oC.3 Higher temperatures, for example room temperature, will cause a protracted state of catabolism with subsequent metabolic catastrophe.13 There were no statistically significant associations between survival post-brumation and whether the tortoise was regularly weighed during brumation or not. Significant weight loss is widely cited as a reason to terminate brumation early2,3,11,13 so it is surprising this factor was not of higher significance.

7.22% of tortoises surviving brumation were reported to have post-brumation problems, either not eating within a week or being identified by owners as showing other signs of ill health. Eleven tortoises (4.41%) were taken for a post-brumation vet check, although this only included one of the tortoises reported as having post-brumation problems. A statistically significant association was found between presence of post-brumation problems and brumation technique, with garden brumation an independent predictor of post-brumation problems. This is consistent with the risks of self/ garden brumation already discussed, and the additional risk that with self-brumation, the owner may not recognise the tortoise is no longer hibernating.14

The survey looked only at owner perception of ill health and not any veterinary data. Given that tortoises may mask clinical signs of disease until illness is advanced, it is possible that post brumation morbidity was underestimated in the study. Further analysis of veterinary data combined with more extensive owner surveys would be helpful to characterise brumation associated risk factors in more detail.

**Conclusion**

This study provides information to increase our understanding of brumation techniques and outcomes for captive tortoises in the UK. Brumation is a considerable risk for tortoises, with 7.78% mortality in the study population and 7.22% of surviving tortoises reported to have post-brumation health concerns. Brumation in a garden and an uncontrolled reduction of temperature prior to brumation were the main risk factors for morbidity and mortality in the study.

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Data available on request from the authors

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