

Research Article

Animal welfare implications of management strategies for invasive freshwater turtles

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Abstract

Invasive alien species are a recognised threat to biodiversity, ecosystem functions, and human well-being. Management efforts often prioritise ecological and economic outcomes, neglecting the implications of control methods on animal welfare. We investigated the perceived impacts on animal welfare of different lethal and non-lethal methods to control invasive slider turtles *Trachemys scripta* in Europe. We elicited the opinions of a group of 24 herpetologists, turtle caretakers, veterinarians and welfare experts, combining the Five Domains welfare framework with a formal structured elicitation approach. Experts generally agreed that welfare impacts in traps or transport would be mostly minor, but could increase with time of exposure, turtle densities and inadequate protocols. For captive containment post-capture, concerns included inadequate diets and habitats, disease and behavioural concerns, although the latter were particularly uncertain. For lethal methods, lethal injection and properly executed shooting were judged to cause no or mild suffering only. Self-expressed confidence in the elicited estimates was relatively high, but decreased for higher impact levels, longer timeframes and less-known welfare domains such as behavioural concerns. Future research would refine welfare assessment models, particularly for the evaluation of cumulative impacts across different methods and multiple affected individuals. However, in a field as multifaceted as animal welfare, some degree of expert interpretation will likely always be necessary to guide policy: structured expert elicitation can help formalise current knowledge and make those interpretations more transparent.



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Introduction

Invasive species are a primary threat to biodiversity, ecosystem functioning and human well-being (Roberts et al. 2013; Jones 2017; Chinchio et al. 2020). Invasive species can impact ecosystems through different mechanisms such as competition, predation, spread of disease or physical modification (Strayer et al. 2006). Against such threats, management of invasive species including removal from invaded ecosystems is an important tool to reduce impacts (Clout and Williams 2009). Whether and how such management is implemented depends on trade-offs between benefits for biodiversity and other considerations, such as management costs and, increasingly, welfare concerns for target and non-target species (Paquet and Darimont 2010; Crowley et al. 2017; Hampton et al. 2020; Sekar and Shiller 2020). Recently, Lynch et al. (2025) have advocated for animal welfare to be considered alongside other fundamental objectives in a structured decision making approach. In such an approach, the expected performance of alternative actions is explicitly evaluated against each objective independently, to allow formal, transparent trade-offs (Gregory et al. 2012; Lynch et al. 2025). However, these explicit evaluations remain rare for invasive species, particularly those of conservation concern.

A widely used method to evaluate animal welfare is the Five Domains framework (Beausoleil and Mellor 2015; Mellor 2017). In this framework, each Domain describes potential disruption to different components of welfare: nutritional concerns such as water or food deprivation (Domain 1), environmental challenges such as heat or absence of shelter (Domain 2), health concerns such as disease or injury (Domain 3), behavioural and/or social concerns such as restricted interactions (Domain 4) and mental concerns such as distress, anxiety or pain (Domain 5). Domains 1–4 represent the deviations from optimal conditions experienced by individuals; Domain 5 represents the overall consequence of such deviations. In the context of invasive species, Sharp and Saunders (2011) used the Five Domains framework to develop an assessment of the relative humane nature of vertebrate pest animal control methods, focusing on lethal removal methods (with only one Domain directly describing the suffering experienced before insensitivity). This framework has been used in the context of pest control, but rarely for species of limited economic relevance and especially for non-mammals (Beausoleil et al. 2022).

Amongst invasive species, the pond slider *Trachemys scripta* (with its three main subspecies, the red-eared slider *T. s. elegans*, the yellow-bellied slider *T. s. scripta* and the Cumberland slider *T. s. troostii*) has been included in the IUCN list of the 100 most invasive species (Lowe et al. 2000), in the EU list of relevant invasives (Brundu et al. 2022) and the list of invasive alien species in Switzerland (Wittenberg et al. 2006). Native to North America and popular in the pet trade, *T. scripta* may now be found worldwide (Ficetola et al. 2012). In Europe, where its trade is now banned (EU Regulation 1143/2014), it has become widespread throughout climatically favourable Mediterranean areas, with increasing evidence of successful establishment and reproduction even in cooler climates such as northern Italy, central Slovenia or southern Germany (Vamberger et al. 2012; Schradin 2020; Liuzzo et al. 2023). *T. scripta* can compete directly with native species such as the

European pond turtle *Emys orbicularis*, contribute to disease spread (Winter et al. 2025) and alter food webs at different trophic levels due to its omnivorous diet (McCann and Hastings 1997; Cadi and Joly 2003). For example, *T. scripta* may have an advantage when hunting tadpoles of native European amphibians, who exhibit reduced reaction to chemical cues of alien predators such as *T. scripta* (Polo-Cavia et al. 2009). Such concerns also apply to other emerging invasive freshwater turtles (Tietz et al. 2023).

In the face of such negative impacts, multiple management actions are being implemented or considered, both non-lethal methods such as trapping and captivity and lethal methods such as targeted shooting or lethal injection. However, such actions might have implications for the welfare of target *T. scripta*. Even in apparently harmless situations such as captive containment, *T. scripta* can have unique problems in case of inadequate husbandry, nutritional deficiencies resulting in cystic calculi (bladder stones) or irregular shell growth, respiratory and ear infections, abnormal shedding, algae on the shell, fractures or prolapses of organs because of lack of vitamin A (Rawski et al. 2018; Brooks 2024). Moreover, in captive conditions, close co-existence of a large number of individuals can lead to development and facilitated transmission of various infectious diseases, trauma or simply lack of space (McRobert 1999; Wappel and Schulte 2004; Rawski et al. 2018; Leineweber et al. 2025). In the European Union, a recent report assessed management methods for invasive species of high concern, including their humane implications through a qualitative simplification of the Sharp and Saunders approach (Smith et al. 2022). For *T. scripta*, several methods – including trapping, nest removal and lethal dispatch – were considered potentially suitable, but in need of further information.

In this study, we sought to begin filling this gap, providing both information on *T. scripta* management and general insights about the application of the Sharp and Saunders approach. We assessed the welfare of *T. scripta* individuals under different management approaches (trapping, containment and suppression) and at different stages (capture, transportation and captivity). Given the general scarcity of empirical evidence on turtle welfare, we used an expert elicitation approach to define the current knowledge and uncertainty, highlight areas of particular concern and suggest research priorities.

Materials and methods

In March 2024, we began our study by holding a one-day workshop with experts and managers in Italy (details below), to obtain preliminary indications about actions, expected welfare concerns and possible expert contributors. With this knowledge, we then proceeded in four steps: (1) preparing the framework and elicitation platform; (2) collating existing information and additional empirical data; (3) assembling the expert group; and (4) conducting the elicitation and analysing results.

Welfare assessment framework

We sought to investigate the welfare implications of different stages of management: trapping (encompassing the period from the moment a turtle was trapped until its removal from the trap), transportation (beginning with the turtle being

placed in a transport container and ending upon its removal) and end-point management, encompassing either lethal dispatch or long-term captivity. Based on the existing EU report (Smith et al. 2022), common practices and preliminary discussions with managers, we chose the following actions for assessment: (1) capture using fyke/minnow traps; (2) capture using basking traps; (3) transportation from point of capture to processing site; (4) containment in semi-natural enclosures (hereafter referred to as Captivity 1); (5) containment in intensively managed enclosures (hereafter referred to as Captivity 2), as well as lethal dispatch via (6) shooting by rifle; (7) lethal injection; and (8) freezing of eggs. For a complete definition, see Table 1. Note that, although we separated the assessment for clarity, these actions are not mutually exclusive: for example, individuals might be caught in traps, then transported to a captivity centre or to a veterinarian for euthanasia. We further assessed how welfare impacts of each action would change the longer the action lasted in time, for example, when individuals remain in traps for multiple days or when captive conditions are experienced for many years. Each action was thus assessed against four to six time intervals, ranging from seconds to minutes after application of lethal methods, to years and decades for containment in captivity (Table 1). For each of the action/time combinations, we assessed the level of welfare impact on a five-step constructed scale (No impact, Mild, Moderate, Severe and Extreme; Sharp and Saunders (2011)). Each level was defined for each of the five Domains by applying minor modifications to the definitions in Sharp and Saunders (2011). For lethal methods, rather than separate Domains, we evaluated a single impact of suffering before death, with the same five levels described above. For all definitions, see Suppl. material 1.

Expert elicitation

Group selection

To obtain welfare scores for the framework described above, we followed a modified Delphi process with an anonymous online survey followed by discussion rounds. Starting in December 2024, we selected 27 experts from Italy, Switzerland and Germany with experience in management of *T. scripta*, knowledge of turtles and/or reptiles as biologists or caretakers or expertise in animal welfare. We set up the questionnaire on www.umfrageonline.ch and provided it in German, English and Italian. Answers were completely anonymised including no record of IP addresses. Experts were allowed, but not required, to indicate their field of expertise and country of work.

Survey

The survey itself consisted of a series of questions about the impacts on the five Domains for each non-lethal action and about Domain 5 only (general suffering) for each lethal action. In each part, experts were asked to score the impact of the respective actions on the respective Domain. Based on data collected and general management practices for invasive *T. scripta*, the presented durations were between 12 hours and 48 hours for fyke traps, between 24 hours and seven days for basking traps, between three hours and 24 hours for transportation and between one year and ≥ 10 years for captivity scenarios. Similarly, for the lethal

Table 1. Summary definitions of management actions for invasive *T. scripta* and respective timeframes. For full definitions, see Suppl. material 1.

Actions	Timeframes	Details
Fyke/minnow trap	12 h, 24 h, 36 h, 48 h	Fyke or minnow traps, commonly used to capture invasive <i>T. scripta</i> , have funnel-shaped entrances and include both submerged and floating sections. Turtles may remain trapped for varying durations, but traps are generally not left unchecked for more than two days.
Basking trap	24 h, 48 h, 72 h, 7 d	Basking traps, consisting of a floating frame with a basking platform leading into a net below, capture turtles as they retreat from thermoregulating. Turtles may remain trapped for varying durations, but traps are generally not left unchecked for more than seven days.
Transportation	3 h, 6 h, 12 h, 18 h, 24 h	When they are not dispatched <i>in situ</i> , turtles are kept in covered transport boxes (0.4–0.8 m ² base, up to 10 individuals). The time turtles spend inside such a box may vary depending on the specific management plan.
Captivity 1	1 y, 5 y, 10 y, > 10 y	This scenario reflects a low management, fenced natural or semi-natural area where captured turtles are released after quarantine. Turtles are free to reproduce. There is no additional feeding, water quality control or habitat manipulation.
Captivity 2	1 y, 5 y, 10 y, > 10 y	This scenario reflects a highly managed captivity centre, matching recommendations for the correct husbandry in captive stations in Italy, produced within the LIFEASAP project and endorsed by the Italian Institute for Environmental Protection and Research (Alonzi et al. 2018).
Shooting	0 s, < 30 s, < 1 m, < 5 m, < 30 m, > 30 m	Turtles are shot with a 0.222 calibre rifle. Depending on the hit, turtles may die instantaneously or remain alive for a certain time before dying or losing consciousness.
Lethal injection	0 s, < 30 s, < 1 m, < 5 m, < 30 m, > 30 m	A veterinarian administers (1) sedative and (2) deep anaesthetic (e.g. a lethal dose of pentobarbital) to stop heart and brain functions. Timeframes refer to the interval between the start of the procedure and loss of consciousness.
Egg freezing	< 30 s, < 1 m, < 5 m, < 30 m, > 30 m	Eggs removed from wild nests are frozen at –18 °C. Where the age of the embryo cannot be determined, in late-stage embryos, neural pathways may already have begun to form.

dispatch methods, experts were asked to score the expected level of suffering for durations ranging from immediate to > 30 minutes between the beginning of the treatment and loss of consciousness or death. In addition, we assessed expert confidence after each question by asking for an indication of their certainty between 0% (no confidence) and 100% (absolute confidence). The complete survey can be found in Suppl. material 3.

Background information

To provide experts with a common knowledge base, we collated published information, newly-collected empirical data reflecting welfare Domains 1–4 (nutrition, environment, health and behaviour) across trapping, transport and captivity, as well as interviews with managers and caretakers. We collected empirical data about management by joining existing field programmes in Hungary (trapping and captivity) and Switzerland (shooting). Data collection methods included temperature logging, camera footage, visual inspections, and photographic documentation of injuries, behaviour and enclosure conditions. For lethal methods—shooting, lethal injection and egg freezing—we gathered data on equipment and necropsies of carcasses, guidelines for euthanasia and information on embryonic development and pain perception from published studies. The data are summarised in Table 2 and described in full details in Suppl. material 2. This information was provided as free, non-mandatory reading within the survey questionnaire.

Elicitation

Out of 27 experts invited, 24 completed a first round of the survey, after which we held multiple online discussion rounds in English, German and Italian, where we showed visual summaries of the results, clarified linguistic uncertainty in the

Table 2. Summary of background information on management of invasive *T. scripta* provided to experts. Captivity 1 refers to containment in semi-natural enclosures; Captivity 2 refers to containment in intensively managed enclosures. For full details on data collection, see Suppl. material 2.

Action	Data collected in the field	Data collected from partners	Data collected from literature
Fyke trap	Temperature data Spatial properties of used traps Number of turtles found in one trap Sizes and weights of turtles found in traps	–	–
Basking trap	Temperature data Spatial properties of used traps Number of turtles found in one trap Sizes and weights of turtles found in traps	–	–
Transport	Temperature data Spatial properties of boxes Food and water availability Sizes and weights of turtles Pictures from before and after transport Video footage recorded during transport	–	–
Captivity 1	Pond size and basking opportunities Marks/Injuries and algae infestation Pictures of marks/injuries	Feeding/health check schedule Husbandry practices Comments and observations by caretakers	Common problems in aquatic turtles
Captivity 2	–	–	Common problems in aquatic turtles
Shooting	Picture of shot turtle	Calibres used	–
Lethal injection	–	Chemicals used	Usual effect and mechanism of the drug
Freezing of eggs	–	–	Information on neural development and capability of pain procession

survey questions and facilitated sharing of reasoning and information. Experts were free to choose how many discussions they wanted to join. Experts were not required to breach the anonymity of their answers at any time in the process. We then asked all experts to complete the survey once again, changing their scores if they wished, based on the discussions (for all of which we provided translated summaries). In total, 19 out of 24 experts who had filled in the online survey participated in at least one discussion and in the second round of elicitation. We removed four estimates by three experts that were inconsistent with impact level definitions, i.e. where experts had associated immediate loss of consciousness for shooting and injection with impact levels greater than “No impact”. We retained all other final scores for subsequent analyses.

Aggregation and analysis

For each Domain, we summarised expert estimates and confidence visually and obtained summary statistics of the frequency of selection of different impact levels. We repeated the analysis both for the raw elicited score and by weighting the scores by the self-expressed confidence of each expert, following the method described by Vernet et al. (2024); after results indicated no differences between weighted and unweighted scores, we used unweighted scores throughout (see Suppl. material 1). We also summarised scores separately between the self-attributed professional

categories of experts, either (1) reptile experts and caretakers or (2) veterinarians and welfare experts (no experts indicated they identified as both categories). Further, we used generalised linear models to assess the correlation between impact levels and timeframe (continuation ratio model in R package GLMMadaptive) and between confidence and either impact level or timeframe (generalized linear mixed model with a beta error distribution in package glmmTMB). We repeated all models for impact levels and confidence with and without a term indicating professional categories. For all models, we included a random effect at the level of individual experts. For beta regressions, we transformed stated confidences of 0 or 100 by adding/subtracting 0.001% to ensure values were bounded in the (0,1) interval, assuming that true confidence is unlikely to be exactly 0% or 100%. Finally, we estimated the overall probability across experts that a given action/timeframe would result in impacts greater than Moderate. We implemented a multinomial-Dirichlet regression in a Bayesian framework in JAGS. We obtained 15,000 posterior samples for each probability after a 20,000 burn-in and assessed convergence using the Gelman-Rubin statistic. All data and code for analysis are available in Suppl. material 5.

Results

Welfare impacts

For trapping, welfare impacts increased in time across all Domains for both trap actions (fyke and basking traps), with slightly more experts expecting Moderate or Severe impacts in the environmental and social/behavioural Domains (Domains 2, 4; Suppl. material 1: figs S1–S4). For Domain 5, most experts considered fyke and basking traps to have No or Mild impacts for the first 24 hours; after 24 hours, opinions split between those who thought impacts would remain constant and those who expected impacts up to Moderate and Severe for fyke and basking traps, respectively (Fig. 1).

For transportation, impacts for timeframes of up to six hours were mostly considered None to Mild for Domain 1, None to Moderate for Domains 2–3, None to Severe for Domain 4 and None to Moderate for Domain 5 (Fig. 1). For transportation at 12 and 24 hours, impacts became higher on average and expert opinions became more divided, with some envisaging Severe or Extreme impacts on Domain 5 (Fig. 1), especially reflecting higher impacts on Domains 2–4 (Suppl. material 1: figs S1–S4).

For semi-natural captivity (Captivity 1), concerns were similar across all Domains (Fig. 1, Suppl. material 1: figs S1–S4). For Domain 5, impacts were considered None to Moderate during the first year; over longer timeframes, opinions again became more divided and spanned all possible impact levels, with 5/13 experts considering Severe or Extreme impacts for durations of ≥ 10 years (Fig. 1). Overall, this scenario had the greatest spread of opinions across experts. Conversely, for the intensively managed captive scenario (Captivity 2), expert judgements for Domain 5 were predominantly of No or Mild impact, with 3/15 indicating Moderate impacts (Fig. 1). These judgements remained essentially constant over timeframes (Fig. 1) and across Domains 1–4, with a slightly higher chance of Moderate impacts for Domain 4 (Suppl. material 1: figs S1–S4).

For lethal methods, all experts agreed that shooting would cause no suffering if loss of consciousness was immediate, opinions were divided for 30 seconds

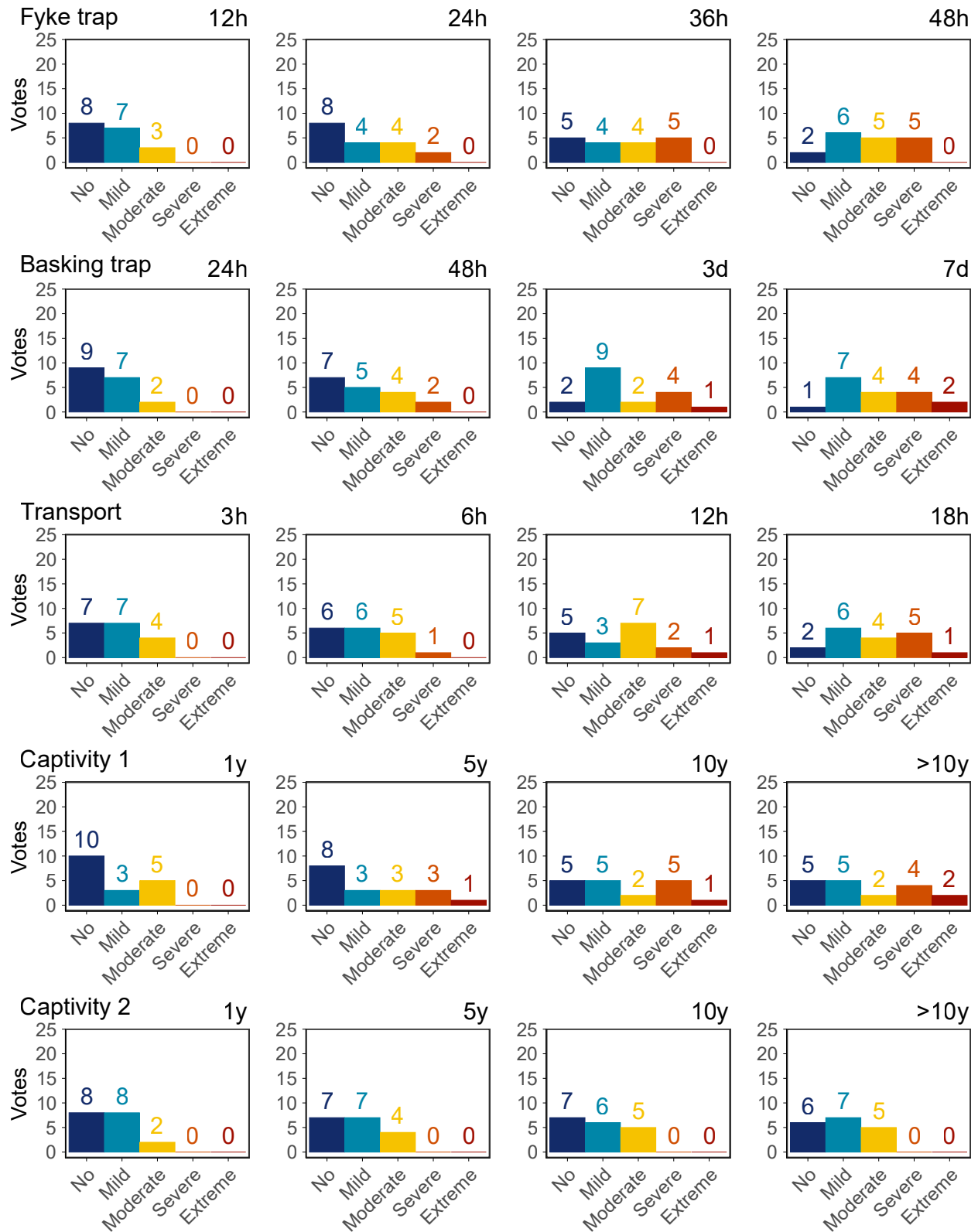


Figure 1. Elicited judgments for non-lethal actions regarding welfare Domain 5 for invasive *T. scripta*, aggregated by action and timeframe. Numbers on each bar indicate number of votes/experts. For the full assessment across Domains 1–4, see Suppl. material 1: figs S1–S4.

(Mild and Severe being the most voted levels) and most experts considered impacts to be Extreme for > 5 minutes (Fig. 2). For lethal injection, impacts were mostly considered None to Mild for immediate irreversible unconsciousness or

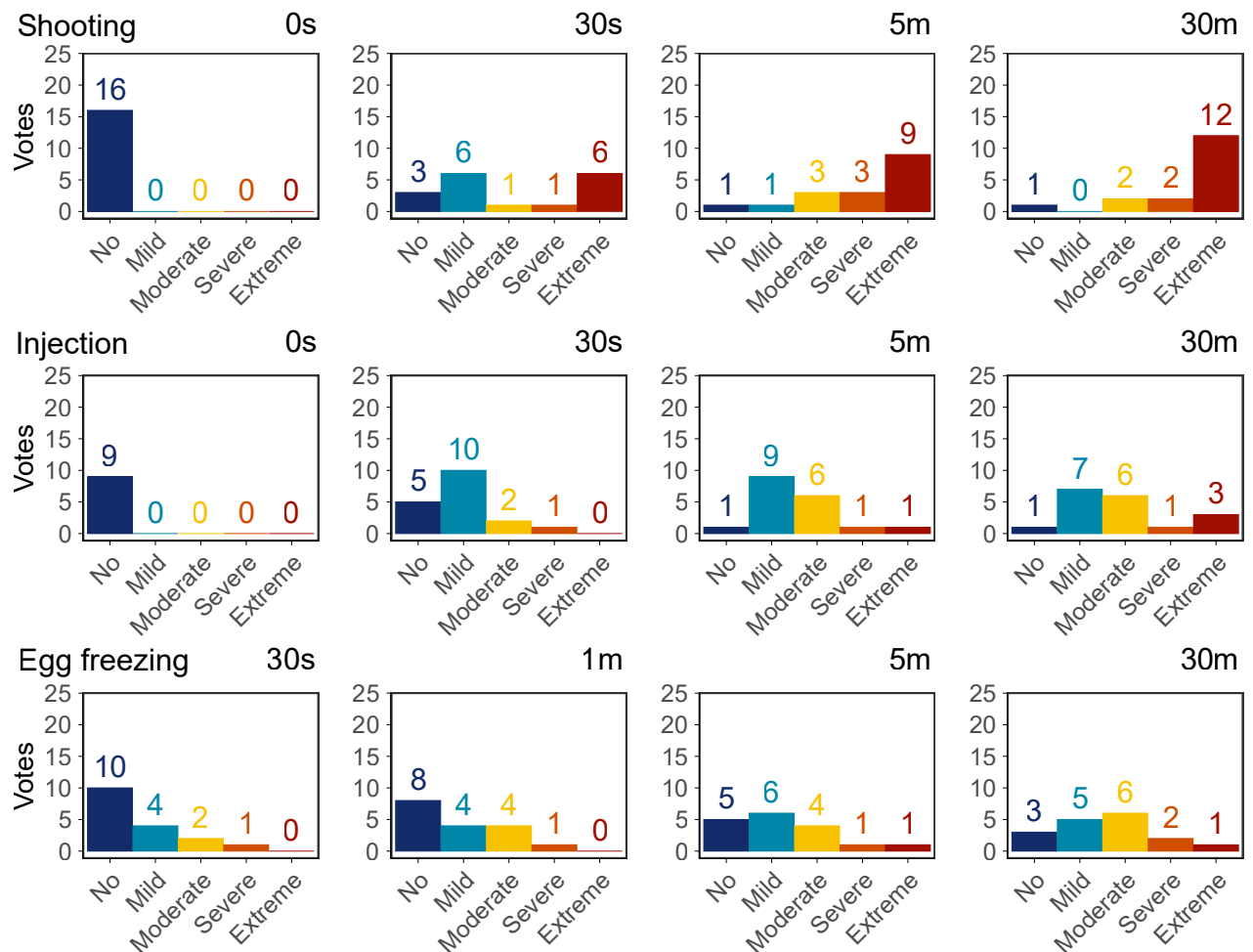


Figure 2. Elicited judgments for non-lethal actions (suffering) for invasive *T. scripta*, aggregated by action and time until loss of consciousness/death. Numbers on each bar indicate number of votes/experts. Note: votes across and within actions do not sum to the same number, because some votes were deliberately not expressed by experts or were removed where inconsistent with definitions (see Materials and methods).

30 seconds, whereas for longer durations votes encompassed all levels, with Mild and Moderate the most voted levels (Fig. 2). For egg freezing, votes were also more widely spread, with most opinions ranging between No and Mild impacts for ≤ 5 minutes and between Mild and Moderate for 30 minutes, with only one or two votes for Extreme impacts at all durations (Fig. 2; note immediate unconsciousness was not an option for freezing).

The continuation ratio and Bayesian multinomial-Dirichlet model suggested that, across all experts and Domains, the expected probability of more severe impacts increased with the time intervals of each specific action (Fig. 3). This increase was generally a near-linear relationship, with more or less steep increases: for example, Captivity 2 remained overall unlikely to result in Moderate impacts, whereas shooting impacts increased steeply with time (Fig. 3). Finally, when we evaluated expected impacts separately by the experts' professional background, we found generally limited differences (Fig. 4). Veterinarians tended to express slightly higher impact levels for all actions, with the exception of shooting where average impact levels were similar; opinions of veterinarians were generally less polarised than those of turtle experts and caretakers (Fig. 4). However, the continuation ratio model suggested the effect of professional background on impact levels was not statistically significant (model coefficient mean $\pm$ SD = -0.453 ± 0.356 , z -score = -1.273 , $p = 0.203$).

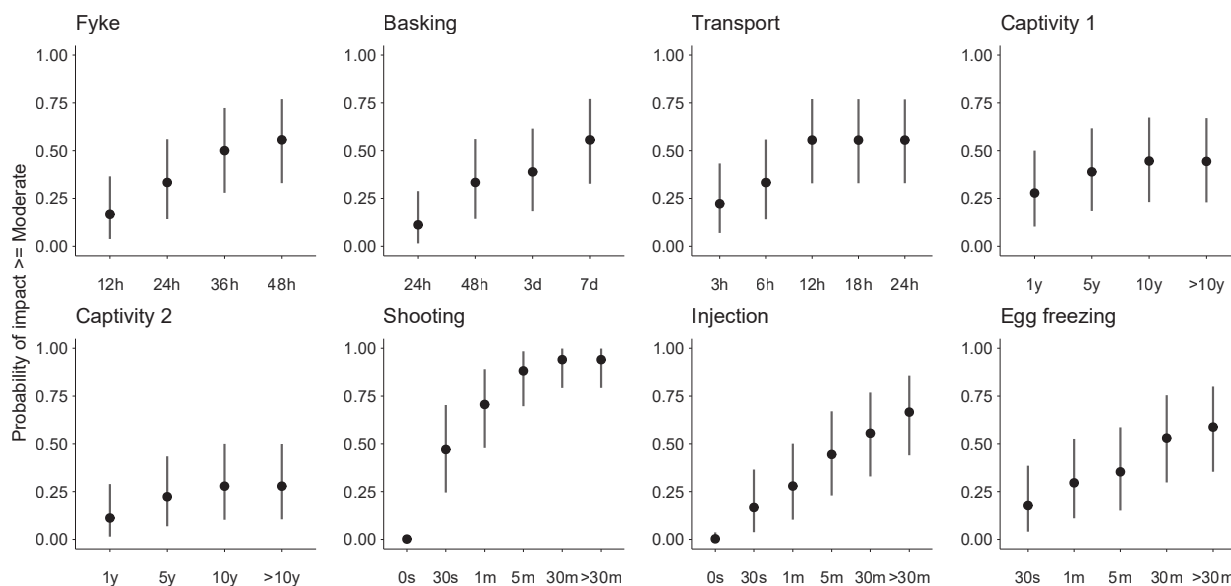


Figure 3. Estimated probabilities of an action having welfare impacts on invasive *T. scripta* equal to or greater than Moderate. Points and bars indicate mean and 95% credible intervals, respectively, estimated across all Domains and experts using the Bayesian multinomial-Dirichlet model.

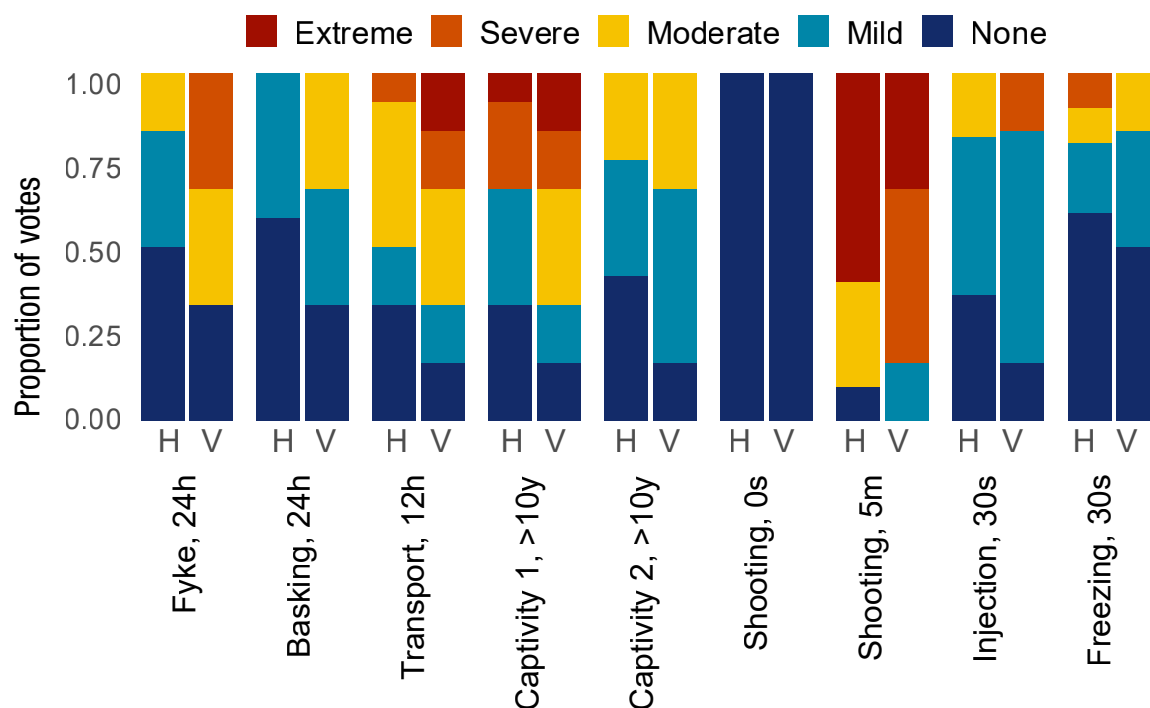


Figure 4. Proportion of welfare impact judgements for invasive *T. scripta*, grouped by the professional background of experts. For each action, the two bars indicate the judgements expressed by veterinarians and welfare experts (V) and reptile experts and caretakers (H). Judgements shown are not weighted by uncertainty (see Suppl. material 1: fig. S5). The subset of actions and timeframes shown reflects common practice for trapping, transport, long-term captivity, lethal injection and egg freezing and two possible scenarios for shooting.

Expert confidence

Across all elicited values, mean expert confidence was 80.17%. Mean confidence for non-lethal methods (all four Domains combined) was higher than for lethal methods (suffering) with 81.31% and 72.36%, respectively. Mean confidence was

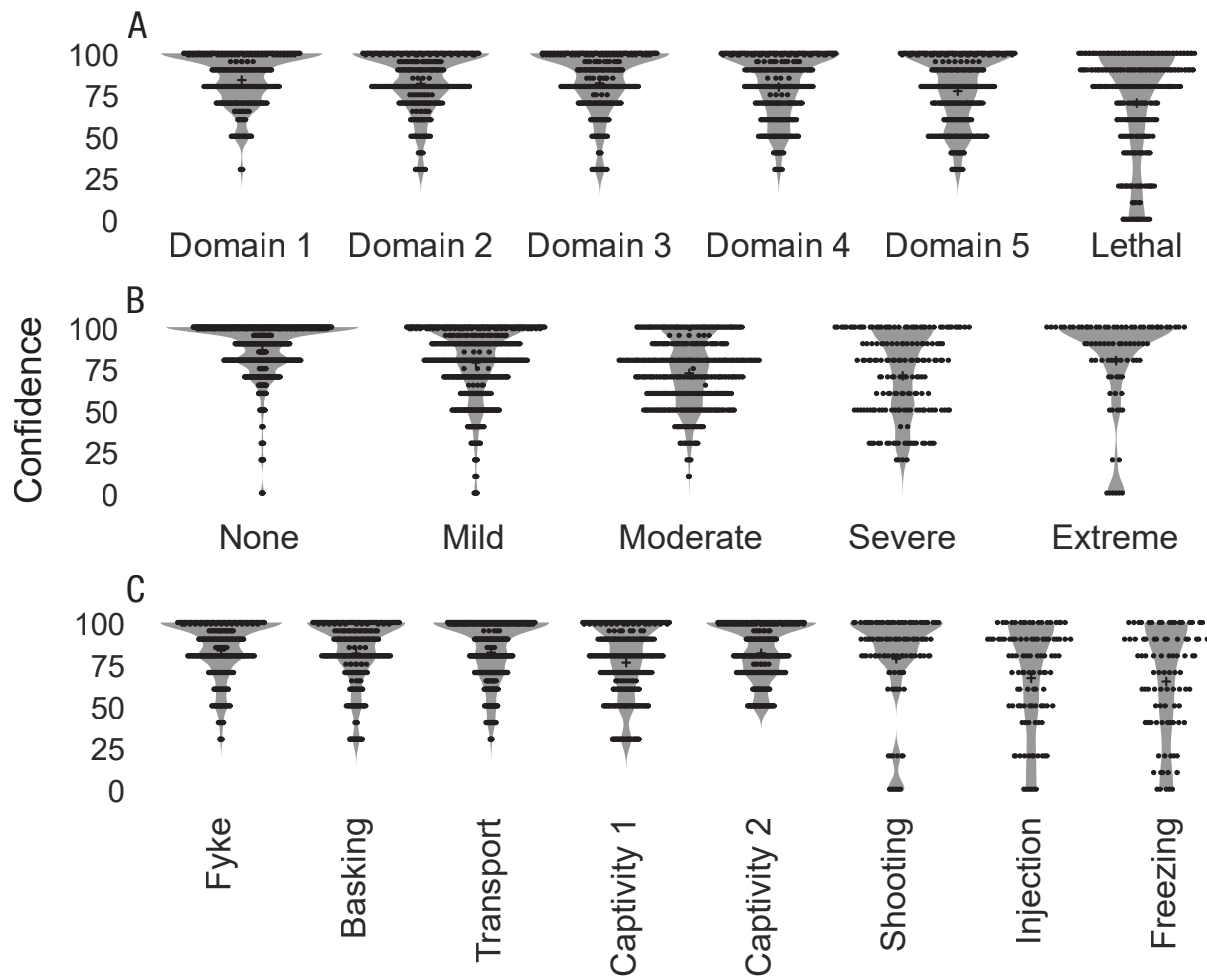


Figure 5. Self-expressed expert confidence in elicited judgements for welfare of invasive *T. scripta*. Scores are aggregated by: **A.** Welfare Domain; **B.** Impact level; **C.** Management action. Within each violin, a dot represents an expert vote (one per action per Domain; NB only one Domain for lethal actions). Points are jittered horizontally for clarity; the underlying grey violins reflect the overall distribution for a given category.

highest for transport (83.1%) and lowest for egg freezing (63.4%). Across Domains (all non-lethal methods combined for each of the Domains 1–4 and all lethal ones combined for suffering), confidence was highest for Domain 1, nutritional concerns (82.8%) and lowest for Domain 4, social/behavioural concerns (79.6%) and for suffering linked to lethal actions (72.4%) (Fig. 5). GLMMs suggested confidence significantly decreased as impact levels increased (Suppl. material 1: table S2); however, impacts also tended to become more severe for longer timeframes (Suppl. material 1: table S3). After controlling for impact, confidence decreased significantly only in the longest timeframes for each action (Suppl. material 1: table S2). Finally, across all values, veterinarians and welfare experts expressed slightly lower confidence than turtle experts, but this effect was not statistically significant (mean $\pm$ SD: 81.6 $\pm$ 21.6 for turtle experts and 75.3 $\pm$ 18.6 for veterinarians and welfare experts; beta regression coefficient mean $\pm$ SD = -0.460 $\pm$ 0.521, z-score = -0.883, p = 0.377).

Expert discussions

Here, we summarise comments and opinions mentioned during expert discussions, grouped by action. The detailed minutes of each of the six discussions can be found in Suppl. material 4. Note that, although we use factual text for

conciseness, the statements below remain the opinion of experts (all or a majority thereof, unless otherwise stated): for example, where we present a concise statement that “mesh size and aggressive individuals add to injury risks”, the full text implied is “experts generally agreed that mesh size and aggressive individuals are highly likely to add to injury risks”.

Trapping

Experts highlighted generally limited welfare concerns for fyke and basking traps. The aspects considered most critical were environmental influences such as restricted space, behavioural restrictions such as the inability to escape uncomfortable situations and the risk of injury. Fyke traps may occasionally provide food via bycatch, while basking traps rarely do. Seasonal factors (e.g. post-hibernation, reproduction) and trap placement were seen as crucial in determining ultimate impacts, especially to prevent overheating. Basking traps may buffer conditions better if densities remain low, but higher densities in either trap increase risks of stress, aggression and injury, particularly for egg-laying females. Mesh size and aggressive individuals add to injury risks. Short-term behavioural unease stems from limited shelter, basking or nesting opportunities. Regular checks (≤ 24 h for fyke, ≤ 3 days for basking) were deemed essential by all experts.

Transportation

Concerns focused on temperature, density and hydration. Turtles tolerate short-term food deprivation, but optimal temperatures (20–24 °C) and humidity are important. Overcrowding and mixing sizes increase risks of stress, injury and pathogen spread. Experts recommended compartmentalised boxes or cotton bags, which help maintain moisture. While some behavioural restrictions are unavoidable, their impacts were generally seen as minor if durations remain short and handling is appropriate.

Captivity

In semi-natural ponds (Captivity scenario 1), experts considered conditions to be mostly driven by densities given the available habitat and resources. High densities can increase disease risks, worsen water quality and drive competition, thereby increasing aggression. Well-structured habitats and controlled densities are likely to mitigate impacts, although some experts still raised concerns over long-term health, given the likely lack of veterinary checks. Conversely, intensive, high-standard captive conditions (Captivity scenario 2) were partly viewed more favourably due to veterinary oversight and controlled conditions. On the other hand, concerns included possible dietary deficiencies, restricted behaviour and inadequate availability of microhabitats suitable for brumation. Indeed, inadequate diet composition has been linked to health issues like otitis in *T. scripta* (Leineweber et al. 2025) and pyramidal growth syndrome in tortoises (Bauer et al. 2019). Reproductive management was highlighted as a particularly important area: sterilisation was generally considered preferable to castration to preserve natural behaviour, although castration might also reduce aggression in males; females that still lay eggs require nesting opportunities to avoid stress and health problems.

Lethal methods

Discussions of lethal control methods focused on minimising suffering. Shooting was generally considered highly acceptable if performed by trained professionals with high-calibre weapons, as recommended by the American Veterinary Medical Association (Underwood and Anthony 2020), though poorly-executed shots risk severe suffering. For lethal injection, sedation before administering lethal drugs (e.g. pentobarbital) was seen as essential although still at the veterinarian's discretion, because the AVMA Guidelines for the Euthanasia of Animals allow the administration of sodium pentobarbital alone as an injectable agent for euthanasia of reptiles (Underwood and Anthony 2020). More generally, experts emphasised that reptiles present unique challenges due to their variable metabolic rates which can alter the efficacy of sedatives and lethal agents; cold or stressed animals metabolise drugs poorly, complicating the process. Finally, experts agreed with current guidelines that freezing should not be used for adults (Smith et al. 2022), but considered that egg freezing had relatively low impact, pointing to physiological data suggesting that, in tropical species less tolerant to cold, nerve conduction is likely to be blocked by cooler temperatures (Lillywhite et al. 2017). However, most experts agreed that such effects remain highly uncertain for late-stage turtle embryos.

Expert confidence

Confidence was relatively high overall and was generally higher for shorter timeframes and lower impact levels. Experts agreed that this trend likely reflected a lack of experience with longer durations: for example, fyke traps are typically checked every 12 or 24 hours and rarely left unchecked for 36 or 48 hours. When comparing Domains, experts mentioned greater uncertainty concerning behavioural and social concerns (Domain 4) attributing this to the variable personalities of individual turtles and the general difficulty of predicting behaviour and social interactions for a non-mammal species. Nonetheless, the lack of knowledge and confidence concerning Domain 4 was only partly reflected by the confidence indicated by the experts during the survey.

Discussion

We used structured expert elicitation within the Five Domains framework to assess the welfare implications of common management strategies for invasive *Trachemys scripta*, encompassing trapping, transport, captivity and lethal control methods. Our results suggest broad agreement that welfare impacts are low under best practice settings and generally increase with duration of exposure, but they also highlight uncertainty and noise for longer-term and behaviour-related impacts. In the following sections, we discuss the results, suggest avenues for management-relevant research and reflect on insights from our methodology.

Management recommendations and information needs

Under current information, experts generally agreed on several best practices, matching existing guidelines (e.g. Alonzi et al. (2018)). For trapping, these include checking traps regularly (24 hours for fyke, 72 hours for basking, shortened during periods of

high activity), placing traps to avoid heat or allow cooler areas and shade and choosing materials to minimise injury and entanglement. For transportation, experts agreed that duration should be minimised, environmental conditions maintained within an ideal range (20–24 °C), individuals be compartmentalised and space restricted to minimise movement and injury and provision of food should be avoided to minimise risk of contamination. Captive facilities should carefully limit densities and provide well-structured sites with diverse microhabitats, basking opportunities, shelter, food sources for a balanced diet and digging and nesting opportunities, including when individuals are sterilised and sexes separated. Shooting interventions should be performed by skilled professionals only, considering the safety of humans and other animals. Finally, protocols for lethal injection should consider the ectothermic physiology of turtles when developing protocols: increased ambient temperatures help counteract the deceleration of metabolic rates. Before injecting lethal agents, it is essential to apply anaesthetics and verify they have set in, for example, by testing corneal reflex.

For short timeframes and despite the lack of specific empirical evidence, our expert panel generally agreed that most standard management methods should have limited impacts on *T. scripta* welfare. For longer timeframes, expert uncertainty likely reflects the knowledge gap for reptile welfare and indeed general biology (Doody et al. 2013; Kabelik and Hofmann 2018; Szabo et al. 2021). Uncertainty was greatest for the behavioural and social Domains, likely because the affective states of non-mammalian species are difficult to assess even for experienced handlers (Schnellbacher et al. 2012; Benn et al. 2019; Whittaker et al. 2021). The history of welfare science itself reflects an economic, cultural and regulatory focus on farm and laboratory mammals (Benn et al. 2019).

Future research could combine controlled experiments with standardised welfare indicators across all management stages. For trapping and transport, studies could compare trap or box designs, stocking densities, checking intervals and environmental conditions, while measuring injuries, mortality, hydration and body condition. Long-term captivity remains particularly uncertain because welfare depends on enclosure design, husbandry, veterinary care and reproductive management; comparative studies could assess effects on health, aggression and reproduction (McRobert 1999; Bauer et al. 2019; Fieschi-Méric et al. 2022).

Behavioural welfare assessments would benefit from reliable indicators of positive and negative states. Normal feeding, exploration and alertness may indicate positive welfare, whereas persistent interaction with transparent boundaries, hyperactivity or abnormal inactivity may signal chronic stress (Benn et al. 2019; Cronin and Ross 2019; Miller et al. 2020). Video monitoring, accelerometers, GPS, RFID and infrared thermography could help quantify activity, space use, thermoregulation and early signs of disease (Whitham and Miller 2016; Beaulieu and Masilkova 2024). During trapping, blood lactate and pH can indicate submergence stress (Stoot et al. 2013), while corticosterone or faecal metabolites can quantify handling and transport stress (Cash et al. 1997; Palme 2012; Benn et al. 2019). Behavioural impairment indices, based on reflex tests, may further help predict condition and mortality (Stoot et al. 2013). In captivity, these approaches could be complemented by body condition scoring and clinical indicators such as oculo-nasal discharge (Benn et al. 2019; Whittaker et al. 2021), using best-practice conditions (e.g. “Captivity 2” in our study) as reference baselines.

Amongst lethal methods, shooting was considered consistent with animal welfare guidelines under ideal conditions, but there was uncertainty regarding shot

placement, duration of consciousness and assessment of insensibility (Underwood and Anthony 2020). Research could include post-mortem assessments and field studies quantifying first-shot success, escape and delayed mortality (Hampton et al. 2015; Hampton et al. 2016; Stokke et al. 2018). For lethal injection, experimental studies comparing temperatures, sedatives and administration routes could improve understanding of time to unconsciousness (Schnellbacher et al. 2012; Benn et al. 2019). For egg freezing, early-stage embryos were generally considered unlikely to experience substantial suffering, in line with, for example, bird embryo guidelines (Underwood and Anthony 2020); developmental and electrophysiological studies would further clarify when embryos may become capable of nociception, which remains poorly understood in reptiles (Lillywhite et al. 2017).

Ultimately, however, policy needs to be developed and applied without unrealistic expectations of perfect knowledge, particularly in as multifaceted an area as animal welfare. Not all the possible avenues of research we have listed above would be feasible or even equally informative. Best practices in trapping, transportation and lethal injection are likely to have minimum welfare impacts, so further research might add little. The value of new information is maximum where uncertainty is greatest, where new knowledge can significantly change decisions and where learning can be quick and effective (Canessa et al. 2015). In this sense, our results suggest high value of investigating the welfare impacts of shooting, a cheap, likely effective action where uncertainty about shot placement and effectiveness could rapidly be reduced. Semi-natural containment, a cheaper alternative to intensively managed captivity, was also surrounded by uncertainty; here, longitudinal studies of individual welfare might take several years, but this lag could be reduced by cross-comparison of different facilities and conditions.

Expert elicitation for welfare assessments

Beyond the case of *T. scripta*, our study offers broader insights into the use of expert elicitation for welfare assessment in conservation contexts. The most important concept is that formal elicitation does not necessarily seek consensus, which might hide linguistic uncertainty and groupthink (Morgan 2014; Wintle et al. 2022). Rather, by allowing individual, anonymous estimates in a feedback/revision cycle, it aims to explicitly capture uncertainty both within and amongst experts (Hemming et al. 2018). The discrepancies and variability in expert confidence observed in our study are, thus, not a limitation of formal elicitation, but a key outcome. Such noise can be a source of poor decision-making, particularly when uncertainty is not made explicit and single experts are consulted (Kahneman et al. 2021; Ewen et al. 2026).

A key challenge was the standardisation of scenarios. Experts without management experience often lacked a complete understanding of field conditions, while those with experience tended to filter all scenarios through their own perspectives. Similarly, experts found it difficult to clearly separate welfare Domains in their judgements. We considered whether Domain 5 should be treated as a quantitative aggregation or elicited independently, ultimately opting for the latter to allow experts to weigh trade-offs across Domains according to their judgement. Such issues require careful planning of both group composition and of elicitation questions, to capture diverse backgrounds and experiences while ensuring answers are comparable. This sharing and standardisation were greatly helped by conducting multiple rounds of elicitation, feedback and discussions as recommended by the Delphi protocol. However, some linguistic uncertainty persisted; for example, although immediate

loss of consciousness was clearly associated with “No impact”, at least two experts estimated mild, moderate and even extreme impacts for shooting and lethal injection at 0 s. Although these misunderstandings had limited effects on our overall results, they highlight both the importance of discussion and clarification and the risk of running informal elicitation that do not allow evaluation of noise.

We combined individual surveys with group discussions, in line with established elicitation practice, but conducted all steps online, except for a smaller preliminary in-person workshop prior to the elicitation. The online approach facilitated the inclusion of a larger and more diverse group, enabled discussions in experts’ preferred languages and allowed careful documentation and translation of contributions. However, it also suffered from the inherent limitations of online interaction, including technical difficulties and reduced interpersonal exchange.

Possibly our most significant modification of the original framework by Sharp and Saunders (2011) was the explicit separation of timescales. We reasoned that impacts might increase with duration, but at different rates across Domains (e.g. dehydration versus space restriction). Experts were, therefore, asked to score impacts at distinct time intervals. This approach made it easier for experts to standardise scenarios and formulate context-specific recommendations, but also introduced challenges: timeframes ranged from seconds for lethal methods to decades for captivity, complicating relative comparisons. Further, welfare can change over time in two ways; by the cumulative effect of ongoing suffering (for instance, prolonged confinement in small cages) and by the progression of certain conditions that become more severe with time (such as food deprivation leading to starvation). We chose our approach to allow comparison and keep the elicitation manageable; other efforts might attempt to disentangle the two components if this is considered relevant for management decisions.

Finally, our assessment focused on individual welfare, while real management decisions will likely also need to consider the overall number of animals affected, the combination of interventions and their relative importance and intensity (for example, trapping followed by transportation and lethal injection). To keep our problem tractable, we also ignored welfare impacts of management on other, non-target species, for example, because of bycatch in traps, that will be likely to feature in management planning. These additional sources of complexity will introduce further trade-offs that can best be addressed in a formal decision-analytic framework, as recommended by Lynch et al. (2025).

The main caveat of our work is that it still reflects expert opinion rather than empirical evidence and it should be interpreted as such. Its value lies in identifying current knowledge boundaries, highlighting consensus and uncertainty and establishing a baseline to guide future research and debate. Ultimately, because of the multifaceted nature of welfare, assessments will always involve some degree of human judgement, but formal elicitation offers a structured means to reduce bias and make those judgements more transparent and reproducible.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.

No AI tools were used in the preparation of this manuscript.

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Author contributions

Lisa Moser and Stefano Canessa conceived the research, facilitated discussions and carried out analyses; Lisa Moser, Stefano Canessa, Bethany Smith and Caio Kenup developed the framework; Lisa Moser prepared the questionnaire and collated all data; Lisa Moser, Stefano Canessa and Bethany

Smith wrote the original manuscript; all co-authors gave critical input and approved the final manuscript.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

Supplementary material 1

Additional methods and results

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Supplementary material 2

Background information for experts

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Data type: pdf

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Supplementary material 3

Complete expert elicitation questionnaire

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Supplementary material 4

Detailed minutes of expert discussions

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Supplementary material 5

Data and R code for analysis

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