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# Laying the groundwork for reptile welfare assessment in zoos and private keeping: A literature-based proposal

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## Abstract

With the increasing number and diversity of reptile species kept in zoological facilities and households, their welfare in captivity warrants structured and consistent evaluation. However, focused research on reptile welfare remains limited within the broader field of animal welfare science. Recognising such a gap, this study adopts an evidence-informed approach to review existing literature and proposes two conceptual welfare assessment frameworks — one for zoo settings and another for private keeping. We first identify the intended audiences for each framework and discuss common challenges reptile caretakers may face when conducting welfare assessments in different contexts. The frameworks are grounded in established principles from the Five Domains model and the European Welfare Quality® protocol, incorporating both resource- and animal-based indicators under the domains of Environment, Nutrition, Physical Health, and Behaviour. The design rationale is also explained to support future refinement. Finally, these conceptual frameworks are intended as a foundation for the development and validation of adaptable tools, capable of guiding improved husbandry practices and resource allocation for better welfare outcomes across a broad range of reptile taxa.

## Introduction

In recent years, there has been an escalating popularity in keeping reptiles in captivity, especially in zoological facilities (Brereton & Brereton 2020) and in households as pets (Schuppli *et al.* 2014). While it is challenging to quantify the number of reptiles being kept in captivity in general due to poor record-keeping (Auliya *et al.* 2016; Green *et al.* 2020a), a 2018 analysis indicated that up to approximately 91% of zoological facilities worldwide house reptiles (Brereton & Brereton 2020), and in 2020, around 8 million reptiles were kept as pets in Europe (Toland *et al.* 2020). A trend toward greater species diversity is also evident, with predictions that zoos will increasingly maintain broader reptile collections (Brereton & Brereton 2020). Similarly, the pet trade has seen rising diversity, with an estimated 36% of reptile species involved in wildlife trade and increasing species representation from 2004 to 2018 (Marshall *et al.* 2020; Azevedo *et al.* 2022).

The considerable number and diversity of reptiles held in zoological collections and the pet industry not only underscore the importance of addressing their welfare, but also pose a substantial challenge for scientific research, as the breadth of species-specific needs exceed the current availability of scientific evidence. Furthermore, welfare considerations are grounded in the capacity for sentience (Mellor 2019) — an attribute increasingly supported in reptiles. A growing body of evidence indicates that reptiles possess the neuroanatomical structures commonly associated with the experience of pain and other affective states (Font *et al.* 2023), including nociceptors and opioid receptors (Mosley 2011). Beyond neuroanatomical evidence, studies have also demonstrated that reptiles are capable of experiencing affective states such as pain, stress, and pleasure (Burghardt 2013; Lambert *et al.* 2019; Learmonth 2020; Mellor 2019). While certain aspects remain under investigation, current knowledge provides a strong basis for recognising reptile sentience and the corresponding need to address their welfare in captivity.

Despite its importance, literature indicates that the needs of reptiles can be challenging to meet in captive settings (Grant *et al.* 2017; Warwick *et al.* 2017). Reptiles present unique challenges in captivity, as they are not domesticated and have not undergone genetic selection for traits that facilitate coexistence with humans (Frantz *et al.* 2020). Another challenge originates from their ectothermic nature (Azevedo *et al.* 2021). Reptiles rely heavily upon proper environmental conditions to maintain their optimal physiological and behavioural performances (Huey 1982; Taylor *et al.* 2021). With the variety of species held in captivity, all with their unique species-

specific requirements, it can be difficult for us to satisfy all these environmental needs. Unfortunately, many of these highly specific conditions are also difficult to replicate in captivity, which may jeopardise the welfare of affected species. Moreover, scientific evidence to inform appropriate care remains limited for many taxa (Böhm *et al.* 2016). Additionally, husbandry based upon folklore exists amongst the reptile-keeping community leading to many blindly accepting practices that are based upon anecdotal evidence (Arbuckle 2013).

Despite growing interest in improving reptile husbandry and management in captivity (Warwick 1990; Schaeffer *et al.* 1992; Murphy *et al.* 1994; Warwick *et al.* 2023), sufficient scientific research is currently lacking, and several aspects of relevant topics remain poorly understood (Burghardt 2013). Given the large number of reptiles at risk of experiencing suboptimal welfare due to gaps in scientific understanding, there is an urgent need not only to advance research in reptilian welfare, but also to translate emerging knowledge into effective practice. As such, this study seeks to address the need for a structured, evidence-informed approach to reptile welfare assessment in both zoos and private keeping. Throughout, we have taken a precautionary approach — aligned with the precautionary principle in cases of uncertain but plausible sentience (Birch 2017) — by favouring welfare-focused interpretations in areas where direct evidence is lacking (Toland *et al.* 2020). Accordingly, we propose a conceptual framework that integrates current knowledge and husbandry experience, and is intended to serve as a foundation for future development, refinement, and validation of species- or taxon-specific tools (Figure 1).

## Features of applicable assessments

Before introducing our proposed conceptual frameworks, we would first like to discuss the essential components of a reliable welfare assessment tool and how our version of assessment frameworks attempt to meet these criteria.

### *Target audiences*

Before developing any kind of guideline or assessment, it is crucial to first identify the target audiences since such information can help inform not only the scope and aims of the assessments but also the appropriate communication style and format (Eccles *et al.* 2012). The intended audiences for our assessments are zoo and aquarium staff for the zoo reptile welfare assessment, and reptile pet owners for the pet reptile welfare assessment. While the tools are designed to be accessible, they may be most effectively applied by individuals with some experience in animal care and husbandry.

### *Key features: Validity, reliability, and practicality*

Validity, reliability, and practicality are considered the three most vital features for these assessment tools (Jones *et al.* 2022). A practical welfare assessment tool should be evaluated on whether the result of the assessment reflects its purposes (validity), whether it can be conducted with consistency (reliability), and how it can be implemented without too much difficulty (practicality) (Yon *et al.* 2019). As this paper presents a conceptual framework rather than an empirically tested tool, we focus primarily on the framework's validity — its alignment with current welfare science and relevance to reptile needs — and reliability, meaning the clarity and structure of its components to support consistent interpretation. Ensuring these two characteristics are met at the conceptual stage lays the groundwork for future development into practical tools.

### *In zoological facilities*

To increase the practicability of welfare assessments in zoos and aquaria, the framework needs to be comprehensive enough to cover a wide range of species (Jones *et al.* 2022). However, a trade-off often exists between ensuring sufficient generality to accommodate multiple species and providing enough detail to capture species- or individual-specific welfare indicators. Another factor worth considering in the development of a welfare assessment tool is the recommendation on the frequency of implementation (Jones *et al.* 2022). While assessments intended to be repeated at shorter intervals are likely to be simple and quick to complete, tools designed to capture more detailed welfare changes may be more complex to apply. To address this, our zoo reptile welfare assessment framework includes

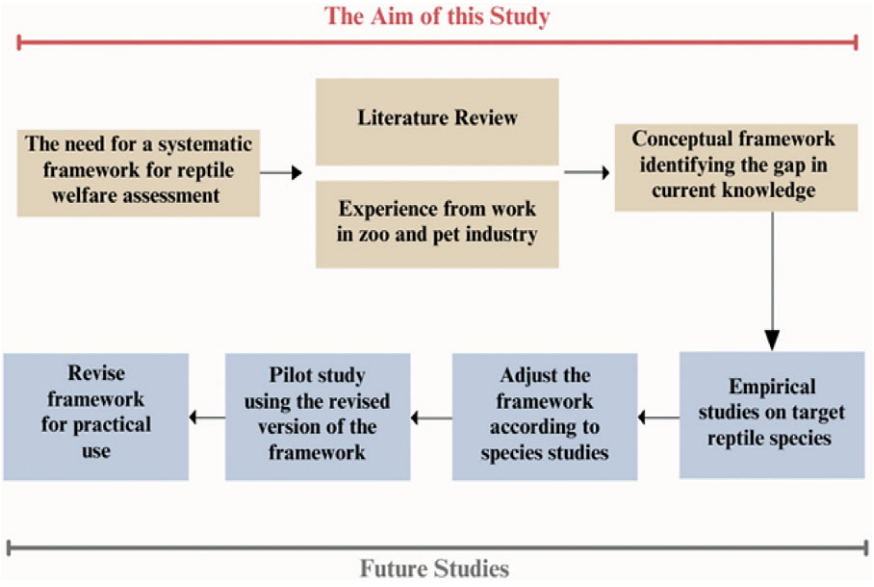


**Figure 1.** A flow chart summarising the structure and aims of the study. The upper part represents the work conducted in this study, including the rationale for and development of a conceptual framework for reptile welfare assessment, based on literature review and practical experience. The lower part identifies proposed directions for future research, including empirical validation, species/taxon-specific adjustments, pilot testing, and refinement for practical application.

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both three- and five-point scales, allowing flexibility in conducting either individual or group assessments. The option to conduct group assessments may help reduce the time required compared to evaluating each animal individually. Consequently, this approach could support more frequent welfare assessments than the commonly used annual schedule (DEFRA 2012). Though currently conceptual, the framework was developed with eventual application in mind, balancing detail with feasibility for zoo environments.

### *Addressing emotional attachments and bias in zoological facilities*

For a zoo reptile welfare assessment to be reliable, it must account for potential biases due to emotional attachments between animal keepers and the animals under their care, which can influence welfare assessment results (Jones *et al.* 2022). It is reasonable to assume that some keepers may attempt to avoid low welfare scores for their animals. To help mitigate potential bias, the zoo reptile welfare assessment proposed in this study incorporates both three- and five-point scales, primarily to enable group-level assessments. However, this approach also enhances scoring flexibility and reduces predictability as well as deliberately imposing challenges in false reporting with the intention of achieving high scores. Additionally, it is recommended that two or more raters conduct each round of assessment to increase the reliability of the results (Yon *et al.* 2019).

### *In households as companion animals*

While the target audience for the zoo welfare assessment comprises zoo professionals, the pet reptile welfare assessment framework is designed primarily for private owners, some of whom may be novice keepers. Although conceptual at this stage, the pet reptile welfare framework was designed with future practical application in mind. Given the current gap between welfare theory and reptile husbandry practices, particular attention was paid to accessibility for non-specialists, including simplified language and explanatory captions. This approach aims to support the eventual translation of the framework into a usable tool.

A 2021 study examining the number of species involved in imports, exports, and breeding in the US, which has the most diverse range of reptile species on the global market, recorded 1,445 species in live pet trades (Stringham *et al.* 2021). Another study indicated that more than 500 species were involved in the European pet market (Warwick *et al.* 2018). Given the extent of species diversity in the reptile pet industry, the framework must be sufficiently broad to accommodate future application across a wide range of taxa, much like the zoo version.

A study by Azevedo *et al.* (2022) provides valuable insights regarding reptile owners' attitudes toward their pets. Most participants described their reptiles as "family members" and cited motivations such as a "duty of care" and "companionship" for long-term ownership. Notably, many respondents acknowledged their pets' capacity to experience "pain and discomfort" as well as "stress and fear," suggesting a recognition of reptilian sentience (Azevedo *et al.* 2022). Based on these findings, the pet reptile welfare assessment framework employs a simplified three-point scale system to enhance user accessibility and promote consistent application. This format is intended to support honest self-reflection. While all assessors may be subject to bias, pet owners have little incentive to deliberately report inflated welfare scores, as doing so would not contribute to their animal's well-being. In contrast, institutional assessors, such as zoo staff may — consciously or unconsciously — be influenced by organisational pressures, including workload constraints or supervisory oversight, which can have implications for performance evaluations. Another reason for limiting the scoring system to a three-point scale is that the pet version of the assessment framework is intended for individual assessments, as most pet owners are unlikely to keep collections as large as those found in zoos.

## Main structure of proposed framework

### *Common frameworks and protocols utilised in welfare assessments*

The Five Freedoms (freedom from hunger and thirst; freedom from discomfort; freedom from pain, injury, and disease; freedom from fear and distress; and freedom to express normal behaviour) proposed by Brambell (1965) have been the fundamental framework for assessing animal welfare (Wolfensohn *et al.* 2018) and the basis of most welfare-related legislation (Morton *et al.* 2020). Initially based on observations of farm animals (McCulloch 2013), it later became the main structure for the current European Welfare Quality® protocol, a large-scale welfare assessment project (Botreau *et al.* 2007; Veissier *et al.* 2011). However, a major deficiency of the traditional Five Freedoms approach is that it merely prevents the occurrence of negative welfare states without necessarily promoting the experience of positive welfare states (Jones *et al.* 2022). In response, Mellor (2017) proposed the Five Domains model to highlight the importance of positive experiences in enhancing welfare and expand the focus to both physiological and psychological attributes of an individual's well-being (Mellor 2017). Furthermore, as most reptiles kept in captivity are exotic species, many possess genetically encoded needs and evolutionary adaptations suited to the challenges of their natural environments. However, scientific evidence addressing critical welfare aspects for many reptile species remains limited. Acknowledging this gap, the three main concepts of welfare proposed by Fraser *et al.* (1997), encompassing physical health, mental states, and natural living, offer a robust conceptual foundation for guiding welfare assessment efforts across diverse taxa (McCulloch 2013). This comprehensive approach is particularly valuable when species-specific information is limited, as it supports a more holistic evaluation of welfare.

#### The Five Domains model

The Five Domains model consists of four physical domains: Nutrition, Environment, Health, and Behaviour, resulting in the fifth domain, Mental State, to assess an animal's physiological well-being and overall affective state (Mellor *et al.* 2020). The most up-to-date version of the model revised the fourth domain to Behavioural Interactions to highlight the importance of an individual's ability to cope with its surroundings, including the environment, other animals, and humans, via behavioural expressions (Mellor *et al.* 2020). Despite adoption by the World Association of Zoos and Aquaria (WAZA), Zoo and Aquarium Association of Australasia (ZAA), and Southeast Asian Zoos and Aquariums Association (SEAZA) as their welfare assessments and accreditations, there has been little peer-reviewed or published literature on these assessment tools (Jones *et al.* 2022). An example of adopting the Five Domains model in published studies is a zoo animal welfare risk assessment framework proposed by Sherwen *et al.* (2018). However, the risk assessment was intended to adopt an evidence-based approach to inform zoological institutions on resource allocation to improve animal welfare. It was largely confined to resource- or input-based

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assessments and lacked animal-based measures to monitor individual animal welfare, which the provision of resources does not necessarily translate into the prevention of poor welfare nor positive welfare (Sherwen *et al.* 2018). Nonetheless, a recent review on welfare assessment models highlights that the Five Domains model remains the most widely adopted for exotic pet species and holds strong potential to inform scientifically grounded welfare practices (Warwick *et al.* 2024).

### The European Welfare Quality® protocol

The European Welfare Quality® protocol includes four principles: good feeding, good housing, good health, and appropriate behaviour (Temple *et al.* 2012). This protocol focuses primarily on animal-based measures and emphasises using output-based assessments (Welfare Quality® Consortium 2009). The developers also added that input measurements that reliably reflect animal conditions may be used when it is impossible to fully implement animal-based measures (Welfare Quality® Consortium 2009). Another highlight of this assessment protocol is its emphasis on factors that are easy to identify and record (Blokhuis *et al.* 2010), reflecting the European Food Safety Authority's (EFSA) requirement for feasibility (EFSA Panel on Animal Health and Welfare [AHAW] (2012). Although the protocol was originally designed to assess farm animal welfare, this framework has become an important reference for later-developed assessment tools to monitor the welfare of some exotic species, such as WelFur, the farm foxes and minks welfare assessment project (Mononen *et al.* 2012), C-Well, the Cetacean Welfare Assessment tool (Clegg *et al.* 2015), and, with more validated behavioural indicators (Whittaker *et al.* 2021), a proposal for application on pygmy blue-tongue skinks (*Tiliqua adelaidensis*) (Benn *et al.* 2019).

### *The Proposed Framework: A Combination of the Five Domains model and The European Welfare Quality® protocol*

The main structure of the proposed reptile welfare assessment frameworks in this study is adapted from the four physical domains of the Five Domains model, widely applied to several zoo animal species (Sherwen *et al.* 2018). The Five Domains model highlights that the fifth psychological domain should be reflected by the four physical domains (Mellor *et al.* 2020). Consensus is also lacking from professionals as regards which behaviours or signs may indicate positive emotional states (Whittaker *et al.* 2021). We decided to omit the Mental State domain from frameworks in order for the assessment to be able to be carried out more objectively and to make it simpler for untrained specialists to provide reliable scores. Based on suggestions from a thorough review of zoo animal welfare assessments (Jones *et al.* 2022), these proposed conceptual frameworks utilise a combination of multiple measures to determine the welfare status of reptiles. Considering the European Welfare Quality® protocol, both resource-based and animal-focused factors were chosen to surpass the predominant focus on resource provision in previous applications (Sherwen *et al.* 2018) and correctly assess and monitor the welfare of the animals (for structure of the proposed zoo and pet reptile welfare assessment frameworks, see Table 1; for the visual representation of the framework and the complete assessment frameworks, see the Supplementary material).

In developing the proposed welfare assessment frameworks, we conducted a structured literature review to identify potential welfare indicators relevant to reptiles. This process included peer-reviewed studies, technical guidelines, and welfare models across a range of taxa. The full list of indicators and their sources is presented in Table S1 (Supplementary material), which includes the study type and the species or taxonomic group referenced.

While reptile-specific data were prioritised, the limited availability of empirical studies for many reptile species necessitated drawing upon research from other vertebrate taxa, such as mammals and birds, where welfare-relevant mechanisms are likely to be broadly conserved. We acknowledge that species-specific validation remains essential; however, cross-taxon insights offer a valuable foundation for initial framework development in under-studied taxa, such as reptiles.

## Structure and background of the proposed framework: Domains and factors considered

### *Environment*

In the proposed reptile welfare assessment frameworks, the Environment domain is further categorised into 15 factors, including: 'Thermal Gradient', 'Thermal Cool Zone and Hotspot', 'Humidity', 'UVA and UVB', 'Light Period', 'Light Intensity', 'Water Body, Substrate, Enclosure Design and Furnishing', 'Noise and Vibration', 'Functional Space', 'Refuge', 'Predation Risk', 'Enrichment', 'Air Quality and Ventilation', and 'Extra Space for Animals to be Housed with or Separated from Each Other'. Most factors in the Environment domain are resource-based measures, while a few may require animal-based observations to provide sufficient information for completing the assessment.

Reptiles are ectotherms, making temperature in the environment crucial for their well-being (Bowers 2012). Providing appropriate thermal cool zones and hotspots ensures the preferred optimum temperature zone (POTZ), reflecting the thermal range of a species' natural habitat, allowing the animals to function optimally and promoting their maximum immune responses (O'Malley 2008; Bowers 2012). From a welfare perspective, it is essential to offer reptiles opportunities to choose their preferred environmental temperature. Research on leopard geckos (*Eublepharis macularius*), for example, indicates that the animals engage significantly with thermal enrichment, suggesting that providing a thermal gradient is not only beneficial for their body function but also a stimulating experience (Bashaw *et al.* 2016).

Humidity is another critical environmental aspect. Inappropriate humidity can lead to shedding difficulties in reptiles kept in dry environments and cause skin blister disease in overly moist conditions (Girling 2013). High humidity levels in the environment can also lead to fungal infections in reptile respiratory systems (Schumacher 2003). Changes in humidity also affect how reptiles interact behaviourally with their living spaces. A study on whiptail lizards (*Aspidoscelis exsanguis*), for example, found that the animals utilised different microhabitats during dry and wet periods, with short-term rainfall being a better predictor for the lizards' daily microhabitat use than soil and air temperatures (Ryan *et al.* 2016). Appropriate humidity not only ensures the physical health of reptiles but also acts as enrichment to encourage the expression of natural behaviours.

The aspect of light, including ultraviolet light, photoperiod, and light intensity, is one of the most important environmental factors to consider when keeping a reptile since the lives of animals from this taxon are strongly influenced by changes in light and temperature (Baines *et al.* 2016). Firstly, regarding ultraviolet light, several species of reptiles are known to rely on UV-A light to aid their foraging behaviours and allow visual communications with other individuals (Fleishman *et al.* 1993; Honkavaara *et al.* 2002) while

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**Table 1.** The four domains, factors, and considerations during assessment of the proposed zoo and pet reptile welfare assessment tools

| Domain | Factor | Considerations during assessment |
|---|---|---|
| Environment | 1. Thermal Gradient | Range and steepness of the thermal gradient |
| | 2. Thermal Cool Zone and Hot Spots | Suitability of thermal cool zones and hot spots |
| | 3. Humidity | Daily and seasonal changes and range of humidity |
| | 4. UVA and UVB | Wavelength and intensity of UV light, range of UV change, check of UV index |
| | 5. Light Period | Provision and adjustment of light period |
| | 6. Light Intensity | Provision and adjustment of light intensity |
| | 7. Water Body | Maintenance of water quality, appropriate volume and variety of water body for soaking or swimming |
| | 8. Substrate, Enclosure Design and Furnishing | Suitability of the substrate and enclosure facilities, regular changes in the settings, cleanliness |
| | 9. Noise and Vibration | Levels of noise and vibration |
| | 10. Functional Space | Suitability for full body length stretching and all activity needs |
| | 11. Refuge | Size, number and location of refuges |
| | 12. Predation Risk | Possibility of predation |
| | 13. Enrichment | Planning, implement, and effectiveness of enrichment |
| | 14. Air Quality and Ventilation | Ventilation level and air pollutant removal efficiency in the space |
| | 15. Extra Space for Animals to be Housed with or Separated from Each Other | Availability of appropriate extra spaces |
| Nutrition | 1. Diet | Nutritional value, quantity, and changes to the make-up of the diet |
| | 2. Food Quality and Presentation | Freshness of food from its preparation to consumption |
| | 3. Frequency of Feeding | Feeding frequency, species-specific and seasonal adjustments of feeding |
| | 4. Provision of Food | Presentation and time of provision of the food |
| | 5. Drinking Source | Availability and cleanliness of drinking source |
| | 6. Encouragement of Natural Foraging Behaviour | Effort made in the attempt to promote species natural foraging behaviour |
| | 7. Food Intake | Interest in food, amount of food being consumed, and display of natural foraging behaviour |
| Physical Health | 1. Body Condition Score or Weight Monitoring | Individual body score, or change in the weight compared with the last time the individual's weight was taken |
| | 2. Condition of Scales (and Scutes) and Claws | Condition of scales (and scutes) and claws |
| | 3. Ecdysis and Skin Condition | Condition of ecdysis and shedding |
| | 4. Condition of Eye Region and Snout | Presence of sores, injuries and abnormalities |
| | 5. Defaecation and Excretion | Frequency and condition of defaecation and excretion |
| | 6. Skeletal (and Carapace) Structure | Presence of skeletal (and carapace) structure deformities |
| | 7. Diseases | Impact of disease and illness |
| | 8. Medical Treatment | The need for and/or the process of medical treatment |
| | 9. Preventive Medical Programmes, Regular Health Checks and Quarantine Measures | Execution and recording of preventive medical programmes, regular health checks, and quarantine measures |
| Behaviour | 1. Mobility | Ability to move with balance |
| | 2. Relaxed Alertness | Presence of signs of relaxed alertness |
| | 3. Activity Level | Presence of hyperactivity and/or hypoactivity |
| | 4. Interaction with Transparent Boundaries (ITB) | Signs and frequency of ITB |
| | 5. Sign of Stress and Abnormal Behaviour | Signs and frequency of stress and abnormal behaviours |
| | 6. Excessive Aggression | Signs and frequency of excessive aggressions |
| | 7. Social Interaction | Expression of social interaction and impact to other animals |
| | 8. Training | Plans, evaluations, and readjustments of desensitisation and trainings for medical and enrichment purposes |
| | 9. Exploratory Behaviour and Interaction with the Environment | Presence and frequency of exploratory behaviours and relaxed species-specific natural behaviours |

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UV-B light has been found to be crucial for the production of vitamin $D_3$ which is related to the performance of calcium metabolism and bone growth (Bowers 2012; Baines *et al.* 2016). Although it was once assumed that ultraviolet light was less important to nocturnal and crepuscular species since they could obtain enough of the vitamin via their diet (Girling 2013), not only has this assumption been overthrown (Finke & Oonincx 2023) but also studies and field observations confirmed that many of these species do expose themselves to some amount of ultraviolet light, either incidentally or deliberately (Brattstrom 1952; Baines *et al.* 2016; Baines 2017). Although the optimal UV requirements for many reptile species remain largely unknown, it is suggested to provide reptiles gradients for UV light to allow animals to behaviourally regulate their physiological status (Mancera & Phillips 2023). While there is currently little literature pointing out the direct effects of photoperiod and light intensity on the welfare of captive reptiles, some studies revealed that light-and-dark cycles could act as important cues for the performance of survival-related behaviours, such as thermoregulatory behaviours (Sievert & Hutchison 1989). This indicated that the provision of appropriate light period has the potential for allowing the expression of natural behaviours from the animals. On the flip side, the unusual light intensities and spectral properties have been reported to disturb the physiology, behaviours, and infradian rhythm of reptiles (Perry *et al.* 2008).

Other basic considerations for the Environment domain include hygiene, reflected by the 'Water Body', 'Substrate, Enclosure Design and Furnishing', and 'Air Quality and Ventilation' factors.

From a behavioural standpoint, positive animal welfare involves not only minimising negative states, but also fostering opportunities for animals to engage in rewarding activities, build functional skills, and experience overall psychological well-being (Rault *et al.* 2025). Thus, 'Water Body', 'Substrate, Enclosure Design and Furnishing', 'Functional Space', 'Refuge', and 'Enrichment' are all the environmental factors that address the inputs that provide the animals opportunities to express a more diverse range of natural and species-specific behaviours (Mendyk & Augustine 2023). Among these five factors, 'Functional Space' and 'Enrichment' deserve some extra mentions. Since there have been abundant studies indicating that both the quantity and quality of space have implications on the welfare of a variety of species (Little & Sommer 2002; Winckler 2019; Hoehfurtner *et al.* 2021), these two environmental factors address the two critical characteristics of an animal's living space. Lack of functional space, either vertically or horizontally, may contribute to poor physical health of animals since limited space allowance can restrict animals' opportunities to exercise and interact with their environments (Littlewood *et al.* 2023). Among reptiles, snakes, in particular, are susceptible to the risk of being housed in enclosures without sufficient space to exercise or express natural behaviours since many of them have been found to be kept in spaces that do not allow them to fully stretch their body (Warwick *et al.* 2019). Despite it being a challenge to provide enclosures that allow snakes to stretch out due to their generally longitudinal body sizes, a comprehensive review by Warwick *et al.* (2021) highlighted the importance of functional space to snake welfare, such as the performance of normal locomotion, the reduction of stress-related behaviours, injuries and diseases, and the satisfaction of species-specific behavioural needs. Regarding the quality of living space, the implementation of enrichment is used as an indicator for the evaluation of space quality as it has been widely recognised as a crucial element to improve welfare in animal husbandry (Hutchins & Smith 2003; Barber 2009; Howard & Freeman 2022). Some examples of enrichment for reptiles include novel food presentations, olfactory stimuli, and provision of objects for animals to manipulate (Case *et al.* 2005; Almli & Burghardt 2006; Londoño *et al.* 2018; Hoehfurtner *et al.* 2021). To evaluate the 'Enrichment' factor, it is recommended to refer to the SPIDER framework, which suggests six major steps, 'Setting goals', 'Planning', 'Implementation', 'Documentation', 'Evaluation' and 'Re-adjustment', to ensure appropriate implementation of an enrichment plan (Mellen and Sevenich MacPhee 2001).

'Noise and Vibration' are included to caution against potential environmental disturbances to reptiles, as most reptiles possess ear structures to sense pressure waves in the air (Saunders & Johnstone 1972), and snakes retain acute vibration sensitivity (Christensen *et al.* 2012). Ensuring comfort from noise and vibration disturbances is essential for reptile welfare.

The factor 'Predation Risk' is added in the assessment to avoid inflicting potential fear and suffering on those animals sharing the same living space. The field of animal welfare science has been mainly concerned with the subjective feeling of an animal (Dawkins 2017) and one of the initial foci is to avoid or prevent the cause of suffering or pain on animals (Dawkins 1990; Wemelsfelder *et al.* 2001; Bateson 2004; Fraser 2008). Minimising perceived predation risk can be supported by providing multiple shelters, avoiding cohabitation of animals that show significant size differences, and considering the influence of chemical or visual cues between individuals (Mendyk & Augustine 2023). Additionally, 'Extra Space for Animals to be Housed with or Separated from Each Other' is considered for management purposes and to address the social needs of reptiles, recognising that housing preferences are highly context-dependent (Kappel *et al.* 2017).

Finally, we would like to emphasise the importance of considering all factors, especially those in the 'Environment' domain, from the perspective of the species in question since various needs in reptiles are highly dependent upon their ecological traits.

### *Nutrition*

The 'Nutrition' domain has seven factors which contribute to it: 'Diet'; 'Food Quality and Presentation'; 'Frequency of Feeding'; 'Provision of Food'; 'Drinking Source'; 'Encouragement of Natural Foraging Behaviour'; and 'Food Intake'. Similar to the previously mentioned 'Environment' domain, this domain is also mainly based on resource-based criteria, with the factor 'Food Intake' being the sole item directly associated with the output of an animal.

Some basic elements in the 'Nutrition' domain included 'Diet', 'Food Quality and Presentation' and 'Frequency of Feeding' which cover the nutritional value and hygiene of the food being presented to reptiles since these factors directly affect the physical health, one of the major components contributing to welfare (Dawkins 2008). We also would like to highlight the importance of considering food-associated stimuli, such as scent, movement, or presentation method, which may significantly influence feeding responses and welfare outcomes (Maslanka *et al.* 2023).

The factors 'Provision of Food', 'Drinking Source', and 'Encouragement of Natural Foraging Behaviour' not only address the species-specific requirements for food processing and water ingestion, but also consider whether positive welfare is supported through the promotion of natural foraging behaviours. Given the varying interpretations of "natural behaviour" in the literature, and ongoing debate regarding whether such behaviours reliably indicate positive welfare, we adopt a definition that captures both functional and affective dimensions: natural behaviour refers to behaviour that animals have a tendency to perform, when given the opportunity under natural conditions, because it is positively motivated and promotes biological

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functioning in the environment in which the species evolved (Bracke & Hopster 2006). As welfare concerns the fulfilment of animals' needs, including behavioural motivations, this definition helps link observable behaviour to internal states. While the expression of natural behaviour alone may not confirm positive welfare, it can serve as a valuable indicator when supported by additional evidence. For example, professionals at Taipei Zoo started hanging foliage from high above, instead of presenting food on the ground, to stimulate a more natural feeding scenario for their Aldabra giant tortoises (*Aldabrachelys gigantea*) once they found out that the animals' leg muscles were not able to properly support the animals' own bodyweights. The result of this trial and error turned out to be a successful attempt at improving the muscle and overall physical status of the tortoises (EAZA 2019). Regarding unconventional drinking habits, several lizard and snake species are known to 'drink' from moisture, rainfall or water droplets, instead of drinking from a body of water, which are factors to be considered (Henschel & Seely 2008; McGeough 2016; Phadnis *et al.* 2019).

During the development of the 'Nutrition' domain, the provision of live vertebrate prey was considered but not included in the proposed framework. Although the exact manner in which this practice impacts the overall welfare of the reptile under assessment remains a topic for debate, it raises ethical questions concerning the treatment of prey animals. While ongoing discussions exist regarding which species are sentient, there is broad recognition that vertebrates are generally regarded as capable of experiencing subjective states (Duncan 2006). This perspective is reflected in the trend among many modern zoos and aquaria to reduce or eliminate the use of live vertebrate prey in feeding practices, citing welfare considerations (Cooper & Williams 2014). However, as this issue relates more closely to ethical decision-making than to the scientific assessment of the welfare status of the target animal, it was excluded from the scope of the proposed framework.

### Physical Health

To emphasise the physical aspect of the 'Health' domain, we chose the name 'Physical Health' to fulfil this purpose. This domain contains nine factors that are 'Body Condition Score or Weight Monitoring', 'Condition of Scales (and Scutes) and Claws', 'Ecdysis and Skin Condition', 'Condition of Eye Region and Snout', 'Defaecation and Excretion', 'Skeletal (and Carapace) Structure', 'Diseases', 'Medical Treatment', and 'Preventive Medical Programmes, Regular Health Checks and Quarantine Measures' for the zoo version and 'Quarantine and Medical Resources' in the pet version of the assessment. Most factors in this domain are regarded as animal-based assessments.

Body condition score (BCS) is a widely used subjective method for visual evaluation of an individual's body condition and fat reserves on a five-point scale (Rawski & Józefiak 2014; Vieira *et al.* 2015; Gimmel *et al.* 2021). Although obesity is a serious health threat caused by inappropriate husbandry or nutrition (Mans & Braun 2014), there are only some evidence-based scoring systems for a number of reptile species (Gimmel *et al.* 2021). Additionally, with shells covering most of their bodies, it can be challenging to accurately assess chelonian body conditions based on visual inspections (Rawski & Józefiak 2014). Traditional weight monitoring and tracking is therefore acceptable when evidence-based body condition scoring is not allowed.

Factors 'Condition of Scales (and Scutes) and Claws', 'Ecdysis and Skin Condition', 'Condition of Eye Region and Snout' and 'Defaecation and Excretion' are all basic indicators to evaluate an individual's physical health status based upon visual appearances. For instance, malnutrition, poor hydration, or inappropriate environmental conditions are known to cause difficulty in shedding or dysecdysis in reptiles and, as such, can be a sign of poor health (Green *et al.* 2020b).

Although we are aware that some of the abnormalities reported in the factor 'Skeletal (and Carapace) Structure' may be congenital, others are likely to be related to metabolic bone disease (MBD) that is typically caused by inadequate husbandry practices (Hoby *et al.* 2010). Clinical signs of MBD include both functional and morphological changes in bone structures that may be a result of a combination of multiple factors like the imbalance in the dietary calcium (Ca) and phosphorus (P) ratio, a lack of Ca and vitamin D intake, or deficiency of UV-B light exposure (Hoby *et al.* 2010). In many cases, the tails or limbs of diagnosed individuals are either deformed or fractured and, in more severe instances, MBD can lead to muscle twitching, paralysis and even death which are all serious threats to the animals' well-being (Zotti *et al.* 2004).

In order to detect whether a reptile is disturbed by diseases or experiencing chronic stress under prolonged medical treatments, 'Diseases' and 'Medical Treatment' are designed to be rated by the duration of such experience to assess the animal's welfare.

The final factors in the 'Physical Health' domain of the zoo and pet reptile welfare assessment frameworks, 'Preventive Medical Programmes, Regular Health Checks and Quarantine Measures' and 'Quarantine and Medical Resources', respectively, are included to evaluate whether the organisation or person keeping reptiles have access to adequate medical resources to safeguard the physical health of their animals. While many zoos and aquaria have established their own medical programmes or health-related standard operating procedure (SOP) for their animals, it is worrying that many private owners do not consult any veterinary professionals when their animals are subject to health problems, potentially due to difficulties in finding a specialised veterinarian or the high cost of medical treatments, despite the importance of veterinary care (Pasmans *et al.* 2017). Thus, we decided to add this factor into this domain, not only to ensure that appropriate veterinary resources are in place for zoos but also to remind pet reptile owners to proactively seek out available medical resources.

To sum up, reptile keepers can regularly monitor the physical health of their animals with basic animal observations. If anything does not seem right during the inspections, they should have the resource or access to provide their animals with proper veterinary care.

### Behaviour

Since some cases of animals interacting with their environments have already been covered in the 'Environment' domain, the title 'Behaviour' is used for this domain, instead of the recently proposed 'Behavioural Interactions' (Mellor *et al.* 2020). Nonetheless, an individual's interaction with other animals, including humans, was considered during the development of this domain. The proposed 'Behaviour' domain included a total of nine factors which are 'Mobility', 'Relaxed Alertness', 'Activity Level', 'Interaction with Transparent Boundaries (ITB)', 'Sign of Stress and Abnormal Behaviour', 'Excessive Aggression', 'Social Interaction', 'Training' in the zoo version of the assessment and 'Desensitisation' in the pet version, and 'Exploratory Behaviour and Interaction with the Environment'. Aside from the factors 'Training' and 'Desensitisation', the majority of factors in the 'Behaviour' domain are animal-based assessments.

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Most definitions of the behavioural factors in the proposed assessment are based on Warwick *et al.* (2013). The behaviours are selected based mainly on how easily they can be observed and how readily they can be applied to a wide range of species from the taxon. In particular, identifying abnormal behaviours requires an understanding of what constitutes normal behavioural patterns for reptiles. These may include, but are not limited to: maintenance behaviours (e.g. feeding, thermoregulation), distance-reducing behaviours (e.g. aggregation, courtship and mating, parental care), and agonistic behaviours (e.g. territoriality, anti-predator responses) (Gillingham & Clark 2023). Understanding these typical behavioural categories provides a basis for recognising deviations that may signal stress or compromised welfare.

With the current recognition in social behaviours in reptiles, such as play behaviours demonstrated by crocodilians (Burghardt 2015; Dinets 2015), and social learning in the non-social red-footed tortoises (*Geochelone carbonaria*) (Wilkinson *et al.* 2010), social behaviours are therefore included as positive welfare indicators. Despite a lack of clear evidence indicating whether reptiles prefer to have interactions with another individual or not, having a companion is expected to encourage the expression of a more diverse range of behaviours which is now widely regarded as an indicator of positive welfare (Miller *et al.* 2020). It is also important to acknowledge that categorising reptiles as inherently asocial can be problematic (Doody 2023). As in other taxa, the outcomes of social interaction vary depending on species, context, and individual compatibility. Focusing primarily on negative outcomes, as many studies have done, may obscure the potential for beneficial social experiences that remain underexplored. That said, we strongly emphasise that social housing should only be considered when species biology, individual compatibility, and husbandry conditions have been thoroughly evaluated. For certain species or contexts, social housing may pose significant risks, such as stress, aggression, or injury, particularly when incompatible cage-mates are housed together (Hayes & Jennings 1998). Therefore, we encourage social interaction only where it does not compromise the welfare of any individual and aligns with the species' natural history.

Since there are studies showing that animal training can help reduce animal's fear of humans (Ward & Melfi 2013) and increase voluntary husbandry and veterinary care of the animals (Fernandez & Martin 2021), the 'Training' factor in the zoo version of the assessment and 'Desensitisation' in the pet version are included to address the potential stress caused by handling or daily husbandry procedures which, as mentioned previously, non-domesticated animals are susceptible to. While there may be doubts regarding the effectiveness of training on reptilian species, it has been demonstrated that a wide range of reptile species can indeed be trained (Deane 2017) and therefore are potentially able to have a similarly positive experience of training as animals from other taxa.

The final factor categorised in the 'Behaviour' domain is 'Exploratory behaviour and Interaction with the Environment'. Since the historical focus on negative indicators has resulted in minimum husbandry standards for captive animals (Melfi 2009), the current trend in the field of study has gradually turned to the search for positive welfare criteria to promote positive welfare, instead of merely avoiding negative experience. Exploratory behaviour can be defined as an animal familiarising itself with its surroundings, including the environment, resources that are vital to its survival and other elements that provide additional information regarding the individual's situation (Wood-Gush & Vestergaard 1989). According to this definition, the expression of exploratory behaviours can indicate that an animal is having a stimulating experience interacting with its surroundings and thus experiencing positive welfare. The lack of interest in exploring its surroundings, on the other hand, may suggest that an animal is experiencing stress and anxiety, leading to negative welfare states (Moszuti *et al.* 2017). Furthermore, the inclusion of species-specific behaviour addresses the 'naturalness' element in Fraser's proposed welfare concepts (Fraser *et al.* 1997). While the performance of natural behaviour itself does not necessarily equate to the experience of positive welfare for the performer, from an ecological perspective, an animal may be evolved to perform some behaviours and therefore have certain needs to express species-specific natural behaviours. Thus, it is recommended that raters consider whether a natural behaviour is associated with the animal's health or reflects a strong motivation to perform it, in order to make more informed decisions regarding its welfare relevance (Dawkins 2003).

## Design rationale and intended use

### *Rater background and scoring methodology*

Regarding the suggested background of raters, the zoo reptile welfare assessment framework is conceptually intended to be carried out by a diverse group of professionals, ideally including: (1) the animal keeper responsible for daily care; (2) a veterinary professional familiar with the animal(s); (3) the curator or manager overseeing the species; (4) a taxonomic expert not directly involved in care; and (5) a welfare specialist with experience in assessment logic. This suggestion is based mainly on another welfare assessment tool currently in use which was developed by Lincoln Park Zoo (O'Brien & Cronin 2023), with added emphasis on veterinary and welfare expertise to enhance accuracy and depth. While such interdisciplinary teams may not be feasible in the context of private keeping, we recommend that private reptile owners seek guidance from qualified professionals, such as veterinarians with reptile expertise or behavioural consultants, when attempting to assess or improve their animals' welfare.

Another feature of the proposed assessment frameworks is the inclusion of a '0' rating option, which allows raters to indicate when they do not feel confident assigning a score for a given factor due to insufficient information or uncertainty. This option does not represent a welfare judgment but instead acknowledges knowledge gaps or ambiguity. It promotes flexibility, particularly when applying the framework to diverse reptile species. In a future applied context, the frequency or distribution of '0' scores may also help identify areas where the framework requires refinement or where additional training or species-specific guidance may be needed. Importantly, a low final score resulting from the accumulation of '0' ratings should not be interpreted as an indication of poor welfare, but rather as a reflection of limited assessability under current conditions.

As the proposed zoo reptile welfare assessment framework allows for both individual and group-level evaluations, it is advisable to collect basic contextual information — such as sex, age, housing type, and natural activity patterns of the species — prior to assessment. These factors can significantly influence welfare outcomes (Jones *et al.* 2022). The same consideration applies to the pet version of the framework.

### *Instruction and interpretation of results*

The main aim of the instructions regarding the performance of both assessments is to clarify and define some of common, descriptive

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words used in the frameworks. We discovered that a number of species-general welfare assessments currently in use in zoos and aquaria, include adjectives such as 'most', 'a few', 'short-term', 'long-term' and 'etc' which may cause confusion for raters that originate from a variety of different backgrounds. Therefore, the words used to describe the quantity, frequency, time duration and severity of different conditions are defined to increase the objectiveness of the result and avoid potential taxonomic bias.

As animal welfare is a dynamic state, the proposed frameworks encourage repeated evaluations of an animal's welfare over time. To support this, we have included suggested interpretations for different score ranges within each domain and the overall assessment, which may be provisionally understood as indicating 'No Welfare Concerns Detected', 'Little Welfare Concern,' 'Unacceptable Welfare Status,' or 'Quality of Life (QoL) Threatening'. Although a detailed discussion on quality of life is beyond the scope of this review, the concept has been subject to growing attention in animal welfare science, particularly in relation to determining whether an individual's life is considered worth living (Green & Mellor 2011). These preliminary interpretation categories are intended to prompt further thinking regarding how assessment results could eventually guide decisions regarding appropriate actions, responsible parties, and the timing or frequency of interventions. In zoological contexts, they may also assist in resource allocation, while for pet owners, they could help highlight effective practices and areas that may require further attention.

### *Limitations*

Given that the proposed assessment frameworks are intended as the structure for an applicable assessment tool across a wide range of reptile species, some inherent limitations should be acknowledged. The frameworks are yet to undergo field validation, and further empirical testing is required to evaluate their practicality, reliability, and adaptability to species-specific contexts. Furthermore, as many aspects of reptile welfare remain under-researched, components of the framework are intentionally flexible to allow for future refinement as new scientific evidence emerges. Finally, the consistency of the assessment results also depends substantially on the assessor's familiarity with the biology and husbandry needs of the species in question.

With respect to the focus of this study, the proposed zoo reptile welfare assessment framework is limited to the four physical domains of the Five Domains model and the reflection of inputs and outputs that relate directly to the assessed individual's welfare status, such as the nutrition provided or the behaviours the animal expressed. Other aspects that may contribute to enhancing zoo reptile welfare, like management, biosecurity measures, animal transportation protocols etc, are not included in the proposed tool. Another approach that may be cause for concern is the justification for allowing group welfare assessments. Since there has been a consensus in the field that animal welfare shall focus on individual animals (Richter & Hintze 2019), group welfare assessments will need to calculate the subjective experience of every individual in such a group, and this may not be feasible in practical terms. Furthermore, the question of whether this calculated sum of group welfare status can be compared with or truly reflect the welfare of the individual animal warrants further discussion (Winckler 2019). Despite this unconcluded discussion in the field of animal welfare science, welfare assessments conducted at group level are more feasible in many captive settings, especially those housing animals in great quantities, where individual animals cannot be properly identified and tracked, thereby allowing the assessment tool to be more practical.

## Animal welfare implications and conclusion

Since the establishment of animal welfare science, there has been a disproportionate amount of research and literature dedicated to improving the welfare of mammals and farm animals (Hill & Broom 2009; Jones *et al.* 2022). However, with increasing numbers of reptiles kept in captivity and growing recognition of their sentience, there is a clear need for more structured welfare approaches for this highly diverse group.

This study proposes conceptual welfare assessment frameworks for zoo and pet reptiles, drawing from the Five Domains model and the European Welfare Quality® protocol. The frameworks aim to structure existing knowledge in a way that supports future development of adaptable tools. Practical considerations, target users, and interpretive approaches are also discussed to bridge current gaps between theory and practice.

Although not intended for immediate implementation, these frameworks have the potential to support more consistent welfare monitoring, encourage reflection on husbandry practices, and promote better resource allocation. They may also help identify species-specific knowledge gaps and stimulate further research and discussion around reptile welfare. In a wider context, our approach could offer a starting point for considering the welfare of other less-studied groups.

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