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Putting the evidence into evidence-based husbandry: A scoping review of empirical approaches to improving captive reptile welfare

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A R T I C L E I N F O

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A B S T R A C T

Non-avian reptiles are commonly kept in captivity, including zoos, aquariums, farms, laboratories, classrooms, rehabilitation centres, and homes. With this wide range of captive conditions and potential diversity of species housed, it is crucial to ensure that these animals are housed appropriately. Lack of data from wild populations for many species limits the foundation of husbandry practice parameters. In the absence of field data, facilities should use data from related species as well as research in applied settings to inform decisions on captive animals. Together these constitute evidence-based husbandry. A systematic scoping review was performed to examine publications that evaluated modifications in the maintenance of captive reptiles with the aim to improve welfare. Scopus, PubMed, Web of Science and Zoological Record databases were searched for publications that implemented at least one modification applied to a reptile in a captive setting and where at least one welfare-based metric was used to assess the impact of the change. A total of 72 papers were identified, consisting of 75 studies that met the inclusion criteria. Data extracted from each paper included the setting type, taxon, modification type, welfare measures, and the overall outcomes. The most common taxonomic order studied were Squamata. Housing modifications were the most common type of intervention, with the majority adding or altering furnishings to the enclosure. Behavioural metrics were the most frequently used measure of impact. Overall, studies often concluded either neutral/ambiguous or positive effects of the modifications. With the high prevalence of neutral outcomes, more research is needed to further determine optimal husbandry and welfare strategies. Additionally, with only 72 identified papers there is greater need for more published research focused on evidence-based husbandry practices for captive reptile species, and greater focus on some taxa is urgently needed.

1. Introduction

Animal welfare is a prominent issue, and many institutions housing captive animals are making strides and advancements in improving the welfare of animals in their care. Animal welfare can be defined as the overall evaluation of the wellbeing of an individual, utilising empirical animal-based measures (Fraser, 2008; Hemsworth et al., 2015; Hewson, 2003; Reimert et al., 2023). Therefore, when constructing environments and husbandry protocols for captive animals, decisions need to be made on sufficient empirical evidence (Mendyk and Augustine, 2023). Additionally, care needs to be taken to ensure that comparisons are scientifically sound. Controlled or semi-controlled conditions can point to clear relationships between independent and observable dependent variables (Rose and Riley, 2021; Williams et al., 2023; Wolfensohn et al., 2018). Systematic empirical study should be the basis for establishing husbandry guidelines and recommendations where parameters from wild populations cannot be obtained or cannot be sufficiently replicated in captive settings (Melfi, 2009). Furthermore, evidence-based husbandry has a wide range of applications, particularly for species whose wild counterparts are extinct or species whereby collecting data is met with problems.

Since an early paper showing how the simple addition of objects to a turtle's barren enclosure had a beneficial effect on reducing self-injurious behaviour was published (Burghardt, et al., 1996), studies on enhancing captive reptile have multiplied rapidly. Although a recent edited volume covered numerous aspects of captive non-avian reptile

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health and welfare (Warwick, et al., 2023; Mendyk and Warwick, 2023), unfortunately most species lack sufficient biological and environmental parameters to inform husbandry decisions (Binding et al., 2020; Gardner et al., 2007; Mason and Parker, 2010; McGarigal and Cushman, 2002; Mendyk and Warwick, 2023; Tingley et al., 2016). Reptiles are kept in a variety of settings within captivity; crocodiles, turtles, and snakes can be kept within intensive farming production (for production of meat, leather, and venom), wildlife rehabilitations centres, zoological organisations, aquariums and within the pet trade (Bush et al., 2014; Hewitt and Small, 2021; Orós et al., 2016; Powell et al., 2006; Sparrow et al., 2024). Within the UK, turtles and snakes are among the top 10 most popular pets, with both being present in 2.9 % of households and although not within the top 10, lizards are also common pets within the U.K and worldwide (UK Pet Food, 2024). The reptile pet trend has shown steady increase over the past few decades, and the trend is expected to continue upward (Bush et al., 2014; Valdez, 2021; Warwick, 2014). Despite these trends and due to limited research, many husbandry protocols and advice regarding reptile care are based on anecdotal observations and assumptions, which are often referred to as "folklore husbandry" (Arbuckle, 2010, 2013; Azevedo et al., 2021; Jessop et al., 2023; Melfi, 2009; Mendyk and Augustine, 2023; Mendyk and Warwick, 2023). As all animals in captivity are in a state of *controlled deprivation* (Burghardt, 1996; Mendyk and Augustine, 2023) in the sense that many aspects of their natural environments are curtailed, this raises questions as to whether it is even possible for reptile keepers to provide their animals with a "life worth living" since there is such minimal evidence to inform husbandry (Burghardt, 2013; Mellor, et al., 2020; Warwick et al., 2018; Warwick and Steedman, 2021). Therefore, it is imperative to understand what aspects of husbandry have been empirically investigated to further support evidence-based husbandry.

1.1. Objectives

This scoping review aimed to identify published research carried out to improve welfare for captive reptiles. The focus was on research utilising sound scientific methodologies potentially providing evidence and context needed to inform "best practice" guidelines. The setting for identified studies could be in any long-term captive situation. Any species could be the target and statistical evidence provided in comparing interventions or experimental treatments to a control. This compilation of publications should inform future research and identify those aspects of husbandry that are supported by empirical evidence.

2. Materials and methods

2.1. Protocol and registrations

This scoping review followed the guidelines set out for PRISMA-ScR guidelines (Tricco et al., 2018). Furthermore, this review followed similar scoping review formats conducted by Rust et al. (2024) and Turner et al. (2025). This review did deviate from the original protocol as the authors (S.LH., E.J.F. and A.W.) made a collective decision during the screening stage to remove health and nutritional modifications from the search of the databases, as these were originally included (Tricco et al., 2018). The removal of health-based modifications was decided due to the often specific nature of metrics utilised, these would frequently involve specific diagnostic testing and so would not have applications to general welfare assessments for captive animals. The removal of permanent nutritional modifications was decided since many of these involved the feeding of live prey and this is subject to differing legislative guidance across the globe, together with that fact that many outcomes measured related to a health outcome, digestibility. It is crucial to acknowledge that health is a major component of overall wellbeing, however for the purposes of this review it was decided to exclude medical and pharmacological interventions.

2.2. Search strategy

Four databases; PubMed, Scopus, Web of Science and Zoological Record were utilised to search key terms: these keywords were generated from prior knowledge of the topic along with consultations with the university liaison librarian. The search terms are provided in supplementary materials 1 which followed the PICO format; reptile, captive environment, modification and measure. The search was conducted on the 3rd of March 2025 and included all publications from database inception up to 3rd of March 2025. Due to the influx of relevant literature, a further search was conducted on the 6th of September 2025.

2.3. Inclusion and exclusion criteria

For the purposes of this scoping review, quantitative primary research studies that investigated reptile species were selected. These could include any individual from the orders of: Testudines, Crocodilian, Squamata or Rhynchocephalia. As this review focuses on non-avian reptiles, birds were excluded. Furthermore, the subjects studied had to be in a captive environment, including: 1) Companion animal [home]; 2) Zoological organisation; 3) Farm; or 4) Laboratory. Only papers including captive animals were considered, with a captive state defined by those kept in captivity for at least six-months prior to the study or from birth if the subjects were $<$ 6 months old. Additionally, if the subjects were released into the wild and welfare measures taken post-release these were excluded.

For sources to be eligible for inclusion they had to be published in a peer-reviewed journal, and thus books and book chapters and grey literature (e.g. newsletters, unpublished theses) were excluded. The target papers were those studies designed to test methods aimed at improving welfare through experimental interventions resulting in quantitative (numerical) results utilising at least one animal-based welfare measure. For the purposes of this review veterinary medical interventions were not included.

Papers were excluded if they were a review, a survey, if they lacked quantitative data, or if there was no English translation available of the full text. Although we acknowledge this as a limitation, given current consideration with increasing international contributions to the scholarly record, this was not something we were able to accomplish in this review. However, our impression is that not many empirical studies fitting our criteria exist in other languages, given the short history of the field.

2.4. Article selection

Once search criteria were inputted into the respective databases, sources were downloaded and imported into Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia; www.covidence.org). Covidence software removed most duplicates, however, some were removed manually. Two reviewers (S.L.H. & B.C.R.) independently screened titles and abstracts. Any conflicts at this stage were discussed between the two reviewers and a consensus made. The two reviewers then evaluated the full text and independently assessed whether the article was eligible for extraction. For any exclusions, a reason was selected. Any conflicts at this stage were decided by a third reviewer (E.J.F.).

2.5. Extraction

Extraction was carried out in Microsoft Excel by one reviewer (S.L.H.). A sample of resulting outputs were then verified for accuracy by a second reviewer (B.C.R.). Data extracted from articles were as follows: authors, title, year. journal title, country of facility, setting type, order, family, species, intervention type, intervention subtype, welfare measure category, subcategory and outcome. Where possible, drop-down boxes were set up to minimise errors that could be made between

Table 1
Definitions utilised for extraction of data from studies.

Article:			A publication. For data synthesis article count was used for year, setting type and journal.
Study:			A study was defined as separate modifications that occurred at different times. For instance, multiple modifications could occur at one time, and this would be included as one study. Additionally, if the same modification occurred at different times this would also qualify as one study with repeats.
Research Setting:			
	Farm		Any research conducted within a setting which focusses on the sale of an animal derived products (normally crocodile farm or snake venom farm).
	Laboratory		Studies conducted within an institution or academic setting with a primary purpose of research.
	Zoos or Aquariums		Study conducted within a setting that allows the admittance of visitors or public, usually a zoological park or aquarium for the purposes outlined by Spooner et al. (2023).
	Wildlife Refuge		Research conducted within a sanctuary park or rehabilitation centre focussing on conservation of a population and wildlife health.
	Companion		Research conducted within the private keeping sector. This can be within homes, veterinary practices or pet shops.
Intervention type and Sub types:			
	Housing		Any intervention which altered the physical environment of the enclosure. This change was long term (more than 2 weeks) to permanent.
		Furnishing	The structural aspects of the enclosure are changed or added, this can include climbing branches or hides.
		Humidity	The amount of water vapour present in an enclosure is altered either artificially or naturally.
		Lighting	The lighting conditions, whether it is type of lighting, duration of lighting on times or intensity is changed.
		Size	Individuals are housed in different sized enclosures either increasing or decreasing in area size.
		Substrate	The ground covering is altered.
		Temperature	The temperature ranges are intentionally altered.
		Water	Aspects of water are altered such as quality and amount available (aquatic species such as turtles and crocodiles).
	Human Interaction		Any intervention that altered the protocols around the management of the animal.
		Human Direct	Any implementation that altered human impact, the human would need to physically be in contact with the animal, for example, handling procedures.
		Human Indirect	Any other intervention that altered human involvement such as cleaning enclosures.
	Conspecific Change		Any intervention that altered the social grouping of animals.
		Conspecific Direct	Intervention allowed individuals to physically share the same space with no barriers and be in physical contact with each other, for example comparing single housed to pair housed.
		Conspecific Indirect	Intervention that altered conspecific contact which they were not able or restricted from physical contact, for example implementing visual barriers to reduce aggression.
	Environmental Enrichment		A temporary modification that aims to increase species specific behaviour and promote positive welfare. If one device encapsulated multiple types of enrichment, then description from the original paper was selected. For example, a puzzle feeder with food was described by the authors of that paper as cognitive then cognitive would be selected.
		Cognitive	Also referred in literature as occupational enrichment which utilises problem-solving puzzles or exercise opportunities.
		Food	Temporary changes to diet, novel additions or altering presentation of food.
		Sensory	Enrichment that aims to stimulate the individuals' senses either visual, auditory, olfactory or tactile.
		Social	A form of enrichment that provides opportunities to interact with other animals or conspecifics.
		Structural	Modification that alters the physical environment by increasing complexity. This must be a temporary addition and removed within 2 weeks.
Welfare Metrics:			
	Behavioural		The observable responses an animal has within an environment; e.g. locomotion and enclosure usage.
	Physiological		An animals' internal biological responses; e.g. corticosterone and Vitamin D3 concentrations.
	Physical		The external morphological presentation of the animal; e.g. weight and body score conditioning.
Outcome			Each study could have multiple outcomes but only one of each type (as listed below) could be recorded. Outcome was determined based on both the publication authors results that their interpretation of said results.
		Positive	A statistically significant increase in positively valenced measures as defined by the study authors, such as increased activity or decreases in negatively valenced measures such as a reduction in corticosterone or abnormal behaviours.
		Neutral	Data which lacked statistical significance.
		Negative	A statistically significant decrease in positively valenced measures as defined by the study authors such as a decrease in active behaviours or increases in negatively valenced measures such as time spent out of sight or glucocorticoid concentrations.

reviewers. Where disagreements occurred a third reviewer (E.J.F.) made the final decision. As data sought by this review included the scope of the research to identify gaps, a risk of bias analyses were not performed (Tricco et al., 2018).

2.6. Data synthesis

Data extracted were split into categories and subcategories as

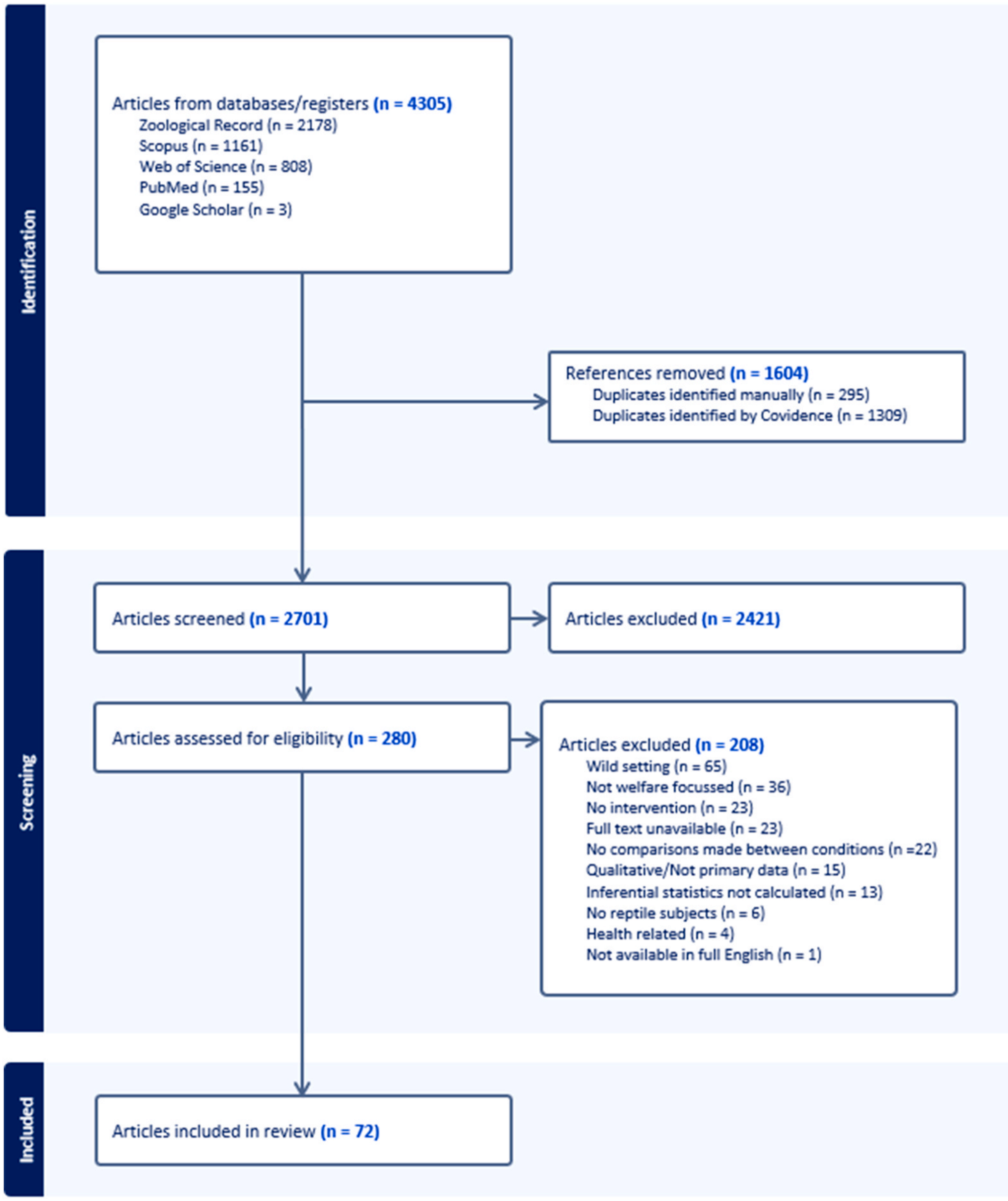

Fig. 1. PRISMA flowchart detailing the number of papers identified following screening and review process.

highlighted in Table 1. Authors (S.L.H, E.J.F. and A.W.) collaborated on category and subcategory choices and definitions. Published works were categorised as both (a) papers and (b) studies. Each published article equated to one paper. However, multiple studies could exist within any one publication, which included two or more interventions measured at different times. Papers or studies were then used to examine the percentage of occurrence for any category of interest. For instance, publications per year were counted in terms of total papers, whereas taxonomic representation were examined in terms of total studies (see Results below). Graphical representations of data were then created to visualise results, with Microsoft Excel© and GraphPad Prism© software.

3. Results

3.1. Extraction results

Fig. 1 outlines the PRISMA flowchart throughout the screening process. Initially, a total of 4305 articles were identified. Following the removal of duplicates, 2701 papers were identified utilising the search criteria. During abstract screening, 2421 were excluded from full text review as these were completely irrelevant from the question and exclusion criteria outlined. For the full text review, a total of 280 articles were identified as being eligible for extraction. A total of 208 papers were excluded for reasons noted in the flowchart (Fig. 1). The result was 72 papers extracted. Only two papers contained more than one study, these were Chiszar et al. (1980) which contained three studies and Rose et al. (2014) which contained two. This resulted in 75 studies conducted across the 72 articles. A full list of extracted papers can be found in Tables 2a-2e.

3.2. Publication demographics

Fig. 2 illustrates the publication count per year. Both the count and cumulative frequency are illustrated. The first paper was published in 1980 followed by a substantial gap between that and the second article, which was published in 1993. A slow increase in the contribution to this topic of research can be seen until 2021, which produced the highest number of publications ($n = 12$, 19.35 %). Although ten papers have

Table 2a
A table detailing all the extracted data from publications conducted within Laboratory settings (* indicates articles that contained more than one study and therefore data extracted is repeated to reflect study). Note: Sub-category abbreviations include Housing (Ho), Enrichment (En), Human Interaction (HI) and Conspecific (Co).

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
Almli and Burghardt, (2006)	Environmental enrichment alters the behavioral profile of ratsnakes (*Elaphe*)	Squamata	Colubridae	*Elaphe obsolete quadrivittata* *Elaphe obsolete obsoleta*	Housing	Ho: Furnishing	Physical Behaviour	Mass Length Ethogram Cog Test
Bashaw et al., (2016)	Does enrichment improve reptile welfare? Leopard geckos (*Eublepharis macularius*) respond to five types of environmental enrichment	Squamata	Eublepharidae	*Eublepharis macularius*	Enrichment	En: Food En: Sensory En: Structural En: Cognitive	Behaviour	Ethogram Behavioural Diversity
Bradwell and Hackett, (2013)	The Effects of Ultraviolet (UV) Light Exposure on Physiology And Behaviour of Captive Corn Snakes (*Elaphe guttata*)	Squamata	Colubridae	*Pantherophis guttatus*	Housing	Ho: Lighting	Physical	Mass Length
Chiszar et al., (1980) *	**Investigatory behavior in snakes, II: Cage cleaning and the induction of defecation in snakes**	**Squamata**	**Colubridae** **Boidae** **Viperidae** **Viperidae**	***Thamnophis sirtalis*** ***Pantherophis guttatus*** ***Bogertophis subocularis*** ***Lampropeltis triangulum*** ***Pituophis melanoleucus*** ***Drymobius margaritiferus*** ***Corallus hortulana*** ***MalayoPython reticulatus*** ***Crotalus viridis*** ***Crotalus viridis*** ***Crotalus durissus*** ***Crotalus durissus***	**Human Interaction** **Human Interaction** **Human Interaction** **Enrichment**	**HI: Indirect** **HI: Indirect** **HI: Indirect** **En: Social**	**Behaviour** **Behaviour** **Behaviour**	**Ethogram** **Ethogram** **Ethogram**
Ciocan et al., (2018)	Increasing photoperiod enhances growth in captive hatchling *Caiman latirostris*	Crocodilia	Alligatoridae	*Caiman latirostris*	Housing	Ho: Lighting	Physical Physiological	Mass Length CORT/GM
Crisante et al., (2025)	Does environmental enrichment impact the behaviour and welfare of bearded dragons (*Pogona vitticeps*)?	Squamata	Agamidae	*Pogona vitticeps*	Housing	Ho: Furnishing Ho: Substrate	Behaviour	Ethogram Cog Test
Damas-Moreira et al., (2025)	Tokay geckos adjust their behaviour based on handler familiarity but according to context	Squamata	Gekkonidae	*Gekko gecko*	Human Interaction	HI: Direct	Behaviour	Ethogram
Dantur et al., (2022)	The effect of environmental enrichment on *Salvator merinanae* under captivity conditions	Squamata	Teiidae	*Salvator merianae*	Enrichment	En: Food En: Cognitive En: Structural En: Sensory	Behaviour	Ethogram
Denommé et al., (2025)	Influence of enclosure design on the behaviour and welfare of *Pogona vitticeps*	Squamata	Agamidae	*Pogona vitticeps*	Housing Human Interaction	Ho: Furnishing Ho: Substrate HI: Indirect	Behaviour Physiological	Ethogram Enclosure Use Haematology
Garner et al., (2021)	Tokay geckos (Gekkonidae: *Gekko gecko*) preferentially use substrates that elicit maximal adhesive performance	Squamata	Gekkonidae	*Gekko gekko*	Housing	Ho: Furnishing	Behaviour	Ethogram Enclosure Use
Gramanzini et al., (2013)	Assessment of dual-energy x-ray absorptiometry for use in evaluating the effects of dietary and environmental management on	Testudines	Testudinidae	*Testudo hermanni*	Housing	Ho: Lighting	Physical	Mass Body Condition Scoring

(continued on next page)

Table 2a (*continued*)

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
	hermann's tortoises (*Testudo hermanni*)							
Hernandez-Bocardo et al., (2019)	Optimizing the Design of Artificial Shelters for the Pygmy Alligator Lizard (*Gerrhonotus parvus*) in Captivity	Squamata	Anguidae	*Gerrhonotus parvus*	Housing	Ho: Furnishing	Behaviour	Enclosure Use
Hoehfurtner et al. (2021a)	Does the provision of environmental enrichment affect the behaviour and welfare of captive snakes?	Squamata	Colubridae	*Pantherophis guttatus*	Housing	Ho: Furnishing	Behaviour Physical	Mass Cog Test Ethogram
Hoehfurtner et al. (2021b)	Does enclosure size influence the behaviour & welfare of captive snakes (*Pantherophis guttatus*)?	Squamata	Colubridae	*Pantherophis guttatus*	Housing	Ho: Size	Behaviour Physical	Mass Cog Test Ethogram
Hollandt et al. (2021)	Animal-appropriate housing of ball pythons (*Python regius*)—Behavior-based evaluation of two types of housing systems	Squamata	Pythonidae	*Python regius*	Housing	Ho: Furnishing Ho: Size Ho: Lighting	Behaviour	Ethogram
McRobert (1999)	Housing Density and Growth in Juvenile Red-Eared Turtles	Testudines	Emydidae	*Trachemys scripta elegans*	Conspecific	Co: Direct	Physical	Mass Length
Milner et al., (2004)	Effects of husbandry manipulations on respiratory rates in captive bearded dragons	Squamata	Agamidae	*Pogona vitticeps*	Human Interaction	HI: Direct	Physiological Behaviour	Resp rate Ethogram Body Temp
Nagabaskaran et al., (2021)	Environmental enrichment impacts discrimination between familiar and unfamiliar human odours in snakes (*Pantherophis guttata*)	Squamata	Colubridae	*Pantherophis guttata*	Housing	Ho: Furnishing	Behaviour	Cog Test
Nagabaskaran et al., (2022)	Western Hognose Snakes (*Heterodon nasicus*) Prefer Environmental Enrichment	Squamata	Colubridae	*Heterodon nasicus*	Housing	Ho: Furnishing	Behaviour	Enclosure Use Cog Test
Nagabaskaran et al., (2025)	Environmental Enrichment Increases Brain Volume in Snakes	Squamata	Colubridae	*Heterodon nasicus*	Housing	Ho: Furnishings	Physical	Internal Morphometric
(Ortega et al., 2023)	Captive breeding of Crocodylus intermedius under different stocking densities	Crocodilia	Crocodylidae	*Crocodylus intermedius*	Conspecific	Co: Direct	Physical	Mass Length Body Conditioning Scoring
Rickman et al., (2025)	The impact of enriched housing on the behaviour and welfare of captive leopard geckos (*Eublepharis macularis*)	Squamata	Eublepharidae	*Eublepharis macularius*	Housing	Ho: Furnishing	Behaviour	Ethogram Cog Test Enclosure Use
Rose et al., (2014)*	**Using student-centred research to evidence-base exhibition of reptiles and amphibian: three species-specific case studies**	**Squamata** **Squamata**	**Iguanidae** **Colubridae**	***Sauromalus*** ***Pantherophis guttata***	**Housing** **Housing**	**Ho: Furnishing** **Ho: Furnishing** **Ho: Size**	**Behaviour** **Behaviour**	**Ethogram** **Enclosure Use** **Ethogram** **Enclosure Use**
Rosier and Langkilde, (2011)	Does environmental enrichment really matter? A case study using the eastern fence lizard, Sceloporus undulatus	Squamata	Phrynosomatidae	*Sceloporus undulatus*	Housing	Ho: Furnishing	Behaviour Physical Physiological	CORT/GM Ethogram Mass Length
Stockley et al., (2020)	How to handle your dragon: Does handling duration affect the behaviour of bearded dragons (*Pogona vitticeps*)?	Squamata	Agamidae	*Pogona vitticeps*	Human Interaction	HI: Direct	Behaviour	Cog Test
(Szabo, 2024)	Changes in enclosure use and basking behaviour associated with pair housing in Tokay geckos (*Gekko gecko*)	Squamata	Gekkonidae	*Gekko gecko*	Conspecific	Co: Direct	Behaviour	Enclosure Use Ethogram
Tetzlaff et al., (2022)	You can go your own way: No evidence for social behavior based on kinship	Testudines	Emydidae	*Terrapene carolina*	Conspecific	Co: Direct	Behaviour	Enclosure Use Cog Test

(*continued on next page*)

Table 2a (*continued*)

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
	or familiarity in captive juvenile box turtles							
Tetzlaff et al., (2018)	Captive-reared juvenile box turtles innately prefer naturalistic habitat: Implications for translocation	Testudines	Emydidae	*Terrapene carolina*	Housing	Ho: Furnishing	Behaviour	Cog Test
Turton et al., (1997)	Relationship of blood corticosterone, immunoglobulin and haematolological values in young crocodiles (*Crocodylus porosus*) to water temperature, clutch of origin and body weight	Crocodilia	Crocodylidae	*Crocodylus porosus*	Housing	Ho: Temperature	Physiological Physical	CORT/GM Haematology Length Mass
Wiesner and Iben, (2003)	Influence of environmental humidity and dietary protein on pyramidal growth of carapaces in African spurred tortoises (*Geochelone sulcata*)	Testudines	Testudinidae	*Centrochelys sulcata*	Housing	Ho: Humidity	Physical	Body Condition Scoring
Zieliński (2023)	The Effect of Enrichment on Leopard Geckos (*Eublepharis macularius*) Housed in Two Different Maintenance Systems (Rack vs Terrarium)	Squamata	Eublepharidae	*Eublepharis macularius*	Housing Enrichment	Ho: Furnishing Ho: Size Ho: Substrate En: Structural En: Food En: Cognitive	Behaviour	Ethogram

been included in the extraction for 2025 these have not been included in Fig. 2 as they are not representative for a complete year.

The majority of publications were conducted in the United States (30.56 %), the United Kingdom (26.39 %), and Australia (9.72 %). Argentina and Canada provided the setting for 4.17 % of articles each, with Brazil, Cape Verde, Germany and South Africa represented 2.78 % each. All other countries (Austria, Brazil, China, Italy, Japan, Mexico, New Zealand, Poland, Switzerland, Thailand and Venezuela) only had one publication (1.39 %).

Fig. 3 illustrates the setting type across the 72 articles. Laboratory settings were utilised the most frequently; 43.06 % of articles, followed by Zoos and Aquariums (40.28 %), Farms (9.72 %), Wildlife Refuges (5.56 %) and finally, within the private keeping industry (1.39 %).

3.3. Taxa breakdown

Fig. 4 demonstrates the range of species featured within the 75 studies (see 2.6 for paper/study distinction). Squamata were the most represented across studies (61.45 %), when distinguished between snakes and lizards, snakes were the most represented (31.33 %), however, proportions were similar, with lizards represented 30.12 % across identified studies. These were followed by Testudines (22.89 %), Crocodilians (14.46 %) and finally, Rhynchocephalia (1.20 %). Colubridae were the most commonly utilised family (14.46 %) and Crocodylidae were the second most common family (10.84 %). The next frequently utilised families were Testudinidae (8.43 %) and Emydidae (7.23 %), both of which are within the Testudines Order. Agamidae and Viperidae were utilised within 6.02 % of studies. Cheloniidae, Varanidae and Pythonidae were each reported within 4.82 % of studies. Alligatoridae, Eublepharidae, Gekkonidae and Boidae were represented across 3.61 % of studies each. Elapidae were represented in 2.41 % of studies. Most studies utilised multiple species across different families therefore the total occurrence of families ($n = 83$) were higher than the total count of studies ($n = 75$).

3.4. Modification types

Fig. 5 demonstrates the different types of modifications implemented across all studies. This is also cross referenced to setting type. The most frequently investigated intervention type was housing, which contributed to 46.51 % of modifications. All settings contributed to a housing modification, with Laboratory settings investigated the most (25.58 %), followed by Zoos and Aquariums (15.12 %). Farms and Wildlife Refuges contributed to 2.33 % of studies and finally the Companion industry contributed to 1.16 %. The impacts of human interactions have been explored in 17.44 % of studies. The setting type for this modification varied, with Laboratories and Zoos being involved in 8.14 % of studies each. Wildlife Refuges then contributed to 2.33 % of studies. Finally, Farms and the Companion animal industry were the setting for one study each (1.16 %). Impacts of enrichment were investigated in 17.44 %. Enrichment studies were only conducted in two settings: Zoos and Aquariums (12.79 %) and Laboratories (4.65 %). Changes to social dynamics were implemented for 15.12 % of studies. The distribution for setting type was skewed towards Farms and Laboratories (4.65 % each). Zoos contributed to 3.49 % of studies and Wildlife refuges were utilised in 2.33 %.

As a modification type could be split into subtypes and multiple subtypes could be applied in any one study the total count for subtype ($n = 121$) is greater than the modification count ($n = 86$). Table 3 lists all the subtypes of modifications across the 75 studies.

Within housing modifications, furnishings were the most prevalent subtype investigated across studies (19.01 %). Following this, lighting conditions and substrates were altered and impacts measured 7.44 % of studies each. Changes to sizes of enclosures were then modified across 5.79 %. Alterations to temperature were reported in 3.31 %. Finally, changes to humidity and water quality were investigated the least frequently (2.48 % and 1.65 % respectively). It is also important to highlight that for many studies multiple interventions were implemented at any one time.

Table 2b
A table detailing all the extracted data from publications conducted within Zoological settings. Note: Sub-category abbreviations include Housing (Ho), Enrichment (En), Human Interaction (HI) and Conspecific (Co).

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
Augustine et al., (2022)	Investigating Welfare Metrics for Snakes at the Saint Louis Zoo	Squamata	Viperidae	*MontiVipera wagneri*	Human Interaction	HI: Indirect	Behaviour Physiological	Ethogram Corticosterone
Bannister et al., (2021)	Can colored object enrichment reduce the escape behavior of captive freshwater turtles?	Testudines	Emydidae	*Pseudemys concinna* *Pseudemys peninsularis* *Trachemys scripta scripta* *Trachemys scripta elegans* *Trachemys scripta troostii*	Enrichment	En: Sensory En: Food	Behaviour	Ethogram Behavioural Diversity
Brien et al., (2016)	Effect of housing density on growth, agonistic behaviour, and activity in hatchling saltwater crocodiles (*Crocodylus porosus*)	Crocodilia	Crocodylidae	*Crocodylus porosus*	Conspecific	Co: Direct	Physical Behaviour	Ethogram Enclosure Use Mass Length
Cardiff, (1996)	Assessing environmental enrichment for juvenile Jamaican boas *Epicrates subflavus* Stejneger, 1901	Squamata	Boidae	*Chilabothrus subflavus*	Housing	Ho: Furnishing	Behaviour	Ethogram Enclosure Use
Dickinson and Fa, (1997)	Ultraviolet Light and Heat Source Selection in Captive Spiny-Tailed Iguanas (*Oplurus cuvieri*)	Squamata	Opluridae	*Oplurus cuvieri*	Housing	Ho: Lighting Ho: Temperature	Behaviour	Enclosure Use
Ferguson et al., (2021)	Is the natural UV zone important for successful captive propagation of the Panther Chameleon (*Furcifer pardalis*); are different UVB irradiance exposures that generate a similar dose equally successful?	Squamata	Chamaeleonidae	*Furcifer pardalis*	Housing	Ho: Lighting	Physiological Physical	Mass Length Survival D3 conc.
Fieschi-Méric et al., (2022)	An Improvement in Enclosure Design Can Positively Impact Welfare, Reduce Aggressiveness and Stabilise Hierarchy in Captive Galapagos Giant Tortoises	Testudines	Testudinidae	*Chelonoidis niger*	Housing	Ho: Size Ho: Furnishing Ho: Humidity Ho: Temperature	Behaviour	Ethogram
Freeland et al., (2020)	Documenting aggression, dominance and the impacts of visitor interaction on galápagos tortoises (*Chelonoidis nigra*) in a zoo setting	Testudines	Testudinidae	*Chelonoidis niger*	Human Interaction	HI: Direct	Behaviour Physical	Ethogram Body Condition Scoring
Januszczak et al., (2016)	Is behavioural enrichment always a success? Comparing food presentation strategies in an insectivorous lizard (*Plica plica*)	Squamata	Tropiduridae	*Plica plica*	Enrichment	En: Food	Behaviour	Ethogram Behavioural Diversity Enclosure Usage
Kane et al., (2024)	Effects of prey-based and non-prey-based scent enrichment on two zoo-housed monitor lizards	Squamata	Varanidae	*Varanus macraei* *Varanus cumingi*	Enrichment	En: Sensory	Behaviour	Ethogram
Kane et al., (2023)	Effects of different heat and light sources on the behaviour of captive reptiles	Testudines Squamata	Geoemydidae Varanidae Elapidae	*Geoclemys hamiltonii* *Varanus macraei* *Oxyuranus microlepidotus*	Housing	Ho: Lighting	Behaviour	Ethogram Enclosure Use Behavioural Diversity
Kawazu et al., (2022)	Rock Installation Reduces Aggressive Behavior in Captive Hawksbill Turtles	Testudines	Cheloniidae	*Eretmochelys imbricata*	Housing Conspecific	Ho: Furnishing Co: Direct	Behaviour Physiological	Ethogram CORT/GM
Kreger and Mench, (1993)	Physiological and behavioral effects of handling and restraint in the ball python (*Python regius*) and the blue-tongued skink (*Tiliqua scincoides*)	Squamata	Pythonidae Scincidae	*Python regius* *Tiliqua scincoides*	Human Interaction	HI: Direct	Behaviour Physiological	CORT/GM Leukacyte number Ethogram

(*continued on next page*)

Table 2b (*continued*)

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
Krishnan et al., (2022)	The effect of varied enrichment types on snake behavior	Squamata	Colubridae Pythonidae Boidae	*Lampropeltis getula Orthriophis taeniurus Pantherophis guttats Pituophis catenifer sayi Lampropeltis triangulum Euprepiophis mandarinus Heterodon nasicus Python regius Gongylophis colubrinus Lichanura trivirgata*	Enrichment	En: Sensory En: Structural	Behaviour	Ethogram
Leeds et al., (2022)	Out of Sight, Out of Mind or Just Something in the Way? Visual Barriers Do Not Reduce Intraspecific Agonism in an All-Male Group of Nile Crocodiles (*Crocodylus niloticus*)	Crocodilia	Crocodylidae	*Crocodylus niloticus*	Conspecific	Co: Indirect	Behaviour	Ethogram Enclosure Usa
Lynch et al., (2025)	The effects of light and novel enrichment on Eastern indigo snake (*Drymarchon couperi*) behavior and physiology	Squamata	Colubridae	*Drymarchon couperi*	Housing Enrichment	Ho: Lighting En: Structural En: Sensory En: Cognitive	Behaviour Physiological Physical	Ethogram Enclosure Use Cog Test CORT/GM Body Condition Scoring Mass Length
Mehrkam and Dorey, (2014)	Is preference a predictor of enrichment efficacy in Galapagos tortoises (*Chelonodis nigra*)?	Testudines	Testudinidae	*Chelonoidis niger*	Enrichment Human Interaction	En: Social En: Structural Hu: Direct	Behaviour	Ethogram Cog Test Enclosure Use
O'Brien et al., (2024)	Moving Toward Evidence-Based Care: Measuring Preferences in Zoo-Housed Aquatic Turtles Using 24 h Remote Monitoring	Testudines	Emydidae	*Emydoidea blandingii Glyptemys insculpta Clemmys guttata*	Housing	Ho: Substrate	Behaviour	Enclosure Use
Pereira et al., (2024)	Inclusive Enrichment for Dragons: Behavioral Responses of Amputee and Non-Amputee Individuals of Bearded Dragons Pogona vitticeps to Different Food Enrichment Items	Squamata	Agamidae	*Pogona vitticeps*	Enrichment	En: Food	Behaviour	Ethogram
Powell et al., (2025)	Effects of Substrate Provision and Associated Cleaning Practices on Welfare Indicators in Eastern Long-Nosed Vipers (*Vipera ammodytes meridionalis*) During Growth and Development	Squamata	Viperidae	*Vipera ammodytes meridionalis*	Housing Human Interaction	Ho: Substrate Ho: Humidity HI: Indirect	Physical Physiological Behaviour	Mass Length Body Condition Scoring Haematology CORT/GM Ethogram
Scheun et al., (2021)	Hot and bothered: alterations in faecal glucocorticoid metabolite concentrations of the sungazer lizard, *Smaug giganteus*, in response to an increase in environmental temperature	Squamata	Cordylidae	*Smaug giganteus*	Housing	Ho: Temperature	Physiological	CORT/GM
Snyder and Barrett, (2023)	Postoccupancy evaluation of staff, visitors, and three species of animals in a zoo setting	Squamata	Varanidae	*Varanus komodoensis*	Housing	Ho: Size Ho: Furnishing	Behaviour	Ethogram Enclosure Use
Spain et al., (2023)	Social Structure and Habitat design affect the impact of a	Crocodilia	Alligatoridae	*Alligator mississippiensis*	Enrichment	En: Food	Behaviour	Ethogram Enclosure Use

(*continued on next page*)

Table 2b (*continued*)

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
	novel feeding enrichment for alligators							
Therrien et al., (2007)	Experimental evaluation of environmental enrichment of sea turtles	Testudines	Cheloniidae	*Caretta caretta* *Chelonia mydas*	Enrichment	En: Food En: Structural En: Sensory En: Cognitive	Behaviour	Ethogram
Thomson et al., (2021)	Interest in coloured objects and behavioural budgets of individual captive freshwater turtles	Testudines	Emydidae	*Pseudemys concinna* *Pseudemys peninsularis* *Trachemys scripta*	Enrichment	En: Sensory	Behaviour	Ethogram
Turner et al., (2022)	Behavioural Impact of Captive Management Changes in Three Species of Testudinidae	Testudines	Testudinidae	*Astrochelys radiata* *Stigmochelys pardalis* *Aldabrachelys gigantea*	Housing Human Interaction	Ho: Size Ho: Furnishing Ho: Substrate HI: Direct	Behaviour	Ethogram Behavioural Diversity
van Heerbeek et al., (2022)	Using a novel ethogram of tuatara behaviour to evaluate the impact of interaction with zoo visitors	Rhynchocephalia	Sphenodontidae	*Sphenodon punctatus*	Human Interaction	HI: Direct	Behaviour	Ethogram
(Waterman et al., 2021)	Evaluating Environmental Enrichment Methods in Three Zoo-Housed Varanidae Lizard Species	Squamata	Varanidae	*Varanus komodoensis* *Varanus prasinus* *Varanus salvadorii*	Enrichment	En: Food En: Structural En: Sensory	Behaviour	Ethogram
Wierzal et al., (2025)	Hide-and-seek: Examining hide preferences and behavior patterns of reptiles through 24-hour monitoring	Squamata	Pythonidae Viperidae Helodermatidae	*Python sebae* *Crotalus unicolor* *Bitis gabonica* *Heloderma exasperatum*	Housing	Ho: Furnishing	Behaviour	Cog Test Enclosure Use

3.5. *Measures utilised*

Fig. 6 illustrates the distribution of measures utilised within the 75 studies. It is important to note that many studies utilised more than one type of metric (e.g. ethogram and enclosure use).

Behavioural metrics were the most prevalent and represented 55.90 % of measures used. Within this ethograms were the most popular measure (30.43 %), followed by enclosure usage (14.29 %). Cognitive testing was reported across 8.70 % of studies and finally behavioural diversityindices were calculated in 2.48 % of studies.

Physical metrics were employed in 28.57 % of studies. Bodyweights were compared in 11.18 % studies and body lengths measured in 9.32 % studies. Body condition scores were utilised in 5.59 % of studies and survival/longevity type measures employed in 1.86 %. Finally, an internal morphometric measure was utilised in 0.62 % ($n = 1$) of studies.

Physiological metrics were utilised in 15.53 % of studies. The most frequently utilised measure were corticosterone/glucocorticoid measure (8.07 %), followed by haematology markers (3.73 %) and respiration rate (1.86 %). All other physiological metrics were utilised one occasion (0.62 %) each.

3.6. *Welfare effect*

Fig. 7 demonstrates the welfare outcomes of the 75 studies. Any one study could have multiple welfare effects, which were defined as a statistically significant effect observed combined with the author interpretation of the effect (see Table 1). Neutral effects were observed in 88.00 % of studies, positive impacts found in 76.00 % and 26.67 % of studies reported negative effects.

4. Discussion

Reptiles are kept within a variety of different settings under human-care, but it is crucial that these husbandry practices be investigated, as reptiles are heavily reliant on their environments for normal physiological and biological processes (Gibbons et al., 2000; Jacob et al., 2024). Temperature, humidity, and environmental space and structure may be more critical, especially diurnal and seasonal variation, then for most mammals, birds, and aquatic species. Similarly, squamate reptiles often rely on chemoreception and other sensory modalities far more, and in different ways, than birds and mammals. It is all too easy to use uncritical anthropomorphism in assessing their needs (Warwick, et al., 2023). Many of the current protocols for reptiles in captivity utilise “folklore husbandry” which are often based on trial and error, anecdotal evidence or keeper intuition (Arbuckle, 2010, 2013; Azevedo et al., 2021; Jessop et al., 2023; Melfi, 2009; Mendyk and Augustine, 2023; Mendyk and Warwick, 2023). Although decisions made in this way may, especially in the hands of insightful and experienced caregivers, be useful and largely valid, there is still the risk that best practice guidelines (where they exist) are not supported by publicly available evidence (Warwick and Steedman, 2021). This review highlights the specific findings from 75 studies across 72 papers, including, the taxa studied, intervention type, welfare metrics utilised and overall outcomes. Reptile welfare publications have steadily increased, particularly within the last few years, with the majority of studies occurring in laboratories, involving Squamates, and utilising housing manipulations. Below, we detail some of the relevant findings and implications of those results.

4.1. *Setting and taxa*

Among the species studied Squamates were represented in over half

Table 2c
A table detailing all the extracted data from publications conducted within Farm settings. Note: Sub-category abbreviations include Housing (Ho), Enrichment (En), Human Interaction (HI) and Conspecific (Co).

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
Beale et al., (2025)	Use of fecal microbiome to understand the impact of housing conditions on metabolic stress responses in farmed saltwater crocodiles (*Crocodylus porosus*)	Crocodilia	Crocodylidae	*Crocodylus porosus*	Conspecific	Co: Direct	Physiological	Metabolites CORT/GM
Campbell et al., (2024)	Behaviours of farmed saltwater crocodiles (*Crocodylus porosus*) housed individually or in groups	Crocodilia	Crocodylidae	*Crocodylus porosus*	Conspecific	Co: Direct	Behaviour Physical	Cog Test Mass Ethogram Body Conditioning Scoring Enclosure Use
Isberg and Shilton, (2013)	Stress in farmed saltwater crocodiles (*Crocodylus porosus*): No difference between individually- and communally-housed animals	Crocodilia	Crocodylidae	*Crocodylus porosus*	Conspecific	Co: Direct	Physiological Physical	CORT/GM Length
Mendes et al., (2019)	Factors that can influence the survival rates of Coral snakes (*Micrurus corallinus*) for antivenom production	Squamata	Elapidae	*Micrurus corallinus*	Housing	Ho: Substrate	Physical	Survival
Olsson and Phalen, (2013)	Comparison of biochemical stress indicators in juvenile captive Esturine crocodiles (*Crocodylus porosus*) following physical restraint or chemical restraint by Midazolam injection	Crocodilia	Crocodylidae	*Crocodylus porosus*	Human Interaction	HI: Direct	Physiological Behaviour	Haematology Ethogram Resp rate
Siroski et al., (2012)	Ultraviolet Radiation on Innate Immunity and Growth of Broad-Snouted Caiman (*Caiman latirostris*): Implications for Facilities Design	Crocodilia	Alligatoridae	*Caiman latirostris*	Housing	Ho: Lighting	Physical Physiological	Length Haematology
Webb et al., (2021)	Effects of stocking density on growth and skin quality of grower Nile Crocodiles (*Crocodylus niloticus*)	Crocodilia	Crocodylidae	*Crocodylus niloticus*	Conspecific	Co: Direct	Physical	Body Conditioning Scoring Length Mass

Table 2d
A table detailing all the extracted data from publications conducted within Wildlife Refuges and rehabilitation centre settings. Note: Sub-category abbreviations include Housing (Ho), Enrichment (En), Human Interaction (HI) and Conspecific (Co).

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
Hua et al., (2017)	The Effects of Water Depth and Substrate Conditions on Changes in Body Weight and Health Status of Captive Big-headed Turtles *(Platysternon megacephalum*) during Hibernation	Testudines	Platysternidae	*Platysternon megacephalum*	Housing	Ho: Water Ho: Substrate	Physical	Mass Body Condition Scoring
Ruby et al., (1994)	Behavioral responses and time allocation differences in desert tortoises exposed to environmental stress in semi-natural enclosures	Testudines	Testudinidae	*Gopherus agassizii*	Housing	Ho: Water	Behaviour	Ethogram Enclosure Use
Usategui-Martin et al. (2021)	Assessment of captive rearing conditions on loggerhead hatchlings: Effect of handling frequency and stocking density	Testudines	Cheloniidae	*Caretta caretta*	Human Interaction Conspecific	HI: Direct Co: Direct	Physiological Physical	Length Mass Survival CORT/GM
Usategui-Martin A et al. (2024)	Husbandry Protocols for Juvenile Loggerhead Sea Turtles (*Caretta caretta*) Based on Stress Response to Stocking Density and Dry-Dock Time	Testudines	Cheloniidae	*Caretta caretta*	Conspecific Human Interaction	Co: Direct HI: Direct	Behaviour Physiological	CORT/GM Respiratory rate Ethogram

Table 2e
A table detailing all the extracted data from publications conducted within the Companion animal industry (pet shops). Note: Sub-category abbreviations include Housing (Ho), Enrichment (En), Human Interaction (HI) and Conspecific (Co).

Ref	Title	Order	Family	Species	Modification	Sub-category	Measure Category	Measure Types
Huo et al., (2025)	Effects of enrichment and handling on the behavior of captive corn snakes (Pantherophis guttatus)	Squamata	Colubridae	*Pantherophis guttatus*	Housing Human Interaction	Ho: Furnishings HI: Direct	Behaviour	Ethogram

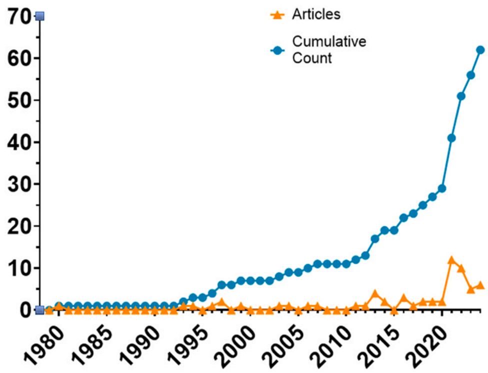

Fig. 2. A line graph showing the count of publications per year (in orange) and the cumulative frequency (in blue) up until the end of 2024. Ten papers were published in 2025 but not included in this graph.

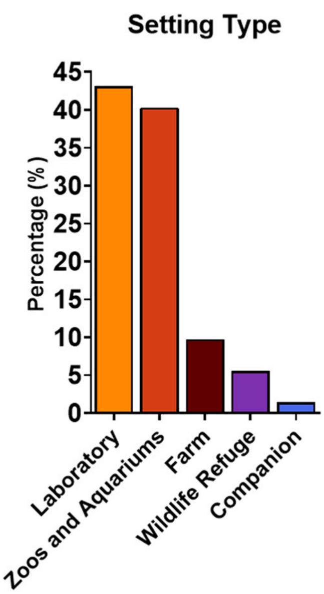

Fig. 3. A bar graph illustrating the occurrence of setting types used for all 72 publications.

of the studies. This potentially is a reflection of their prevalence within captivity, particularly within zoos, private keeping and in farms. Despite the focus within current literature for Squamates, research regarding their husbandry remains overall limited. Additionally, it is important to consider that Squamates represent approximately 96.3 % of known reptile species (Pincheira-Donoso et al., 2013). Although, this may not be a reflection of species richness within captivity, it is important to consider the somewhat high proportion of Testudines identified in this study. This could be due to public preferences which often put tortoises and lizards above other taxa, like snakes (Carr, 2016a, 2016b). Additionally, there is an economic interest regarding crocodile and large snake farming and so there is a need for research on welfare and husbandry methods within these settings also, because of regulation and public interest (Adan, 2000; Carr, 2016a, 2016b; Hewitt and Small, 2021; Thorbjarnarson, 1999). Laboratories were the most utilised setting, potentially due to the level of control researchers can exert over their subjects, reducing the risk of study confounds. However, it should not be understated the importance of conducting these experiments within applied settings. Additionally, this review identified only one study conducted within the pet industry (Huo et al., 2025). There have been some health-based studies conducted using pet subjects, but none of these specifically met the inclusion criteria for this review (Amaral et al., 2021). Considering the substantial population of pet reptiles worldwide, it is imperative that future research on animal welfare is conducted within these contexts, with particular emphasis on general husbandry practices, to ensure that care protocols are informed by rigorous empirical evidence. There are reptile breeders who are doing some valuable, as well as some suspect hybridization and colour morph selection. There has been evidence to show that the selective breeding of certain phenotypic traits in some species such as ball pythons are associated with “wobble disorder” which is indictive of impaired cognitive function and so genetics and poor breeding selection appears to impact welfare (Rose and Williams, 2014; Schrenk et al., 2022). Due to the popularity of private reptile keeping and the potential inbreeding to increase certain traits it is crucial to explore this area. Additionally, some owners could be incorporating valuable work into improving their reptile’s welfare, but these may not be empirically studied.

4.2. *Modifications*

As many aspects contribute to an animals’ physical captive environment it is crucial to identify which areas have had focus within literature so gaps can be highlighted and evidence provided to contribute to best practice guidelines. Additionally, the reliance reptiles have on their environment cannot be understated, therefore exploring the modifications to a captive reptile’s environment is critical. Burghardt (1996) coined the term “controlled deprivation” to recognise that captivity lacks many aspects of a natural environment that animals would have access to and particularly highlights this for reptiles. This review demonstrated that most studies investigated housing modifications with furnishings being the most frequently investigated subtype. Lighting and temperature were far less commonly studied, despite the importance of both on normal physiological processes for reptiles. For the purposes of this review a distinction was made when a modification involved structural changes within the exhibit. Permanent furnishings were classed within “housing” while furnishings provided on a short-term basis were classed within “enrichment”. It is important to note that many studies which utilised “environmental enrichment” within their titles such as Cardiff (1996), Hoehfurtner et al. (2021) and Nagabaskaran et al. (2021) utilised long-term to permanent changes in structural furnishing within the enclosure, therefore, for the purposes of this review they were classed within housing. The subject of environmental enrichment has been a focus of reptile research within the past two decades. Particularly, work by Almli and Burghardt (2006) exhibited promising results and cognitive differences between individuals housed within an enriched enclosure versus unenriched enclosures, additionally a narrative review conducted by Burghardt (2013) was a potential catalyst within this space. Furthermore, environmental enrichment has had increasing attention over the past 50 years across taxa and with more highlights being placed on underrepresented species such as Reptiles this could provide explanation as to the higher prevalence of furnishing changes and what was separately classed as enrichment within this review (Chan et al., 2025; Clark, 2017; de Azevedo et al., 2007; Kusumaningsih and Rosiana, 2023).

4.3. *Welfare outcomes*

Collating information regarding experiments conducted on modifications is critical to inform best practice guidelines but it is also imperative to understand how these changes can impact welfare, particularly with under researched taxa, such as Reptiles. There are fundamental issues when assessing welfare, particularly with reptiles, although abnormal behaviours for reptiles is well documented and somewhat understood, other behaviours such as “active” is more contested over how this is valenced (Jessop et al., 2023). Due to the difficulty of valencing metrics authors will often compare changes in metrics to negatively valenced metrics despite an increased focus in literature on identifying and utilising positively valenced measures when assessing

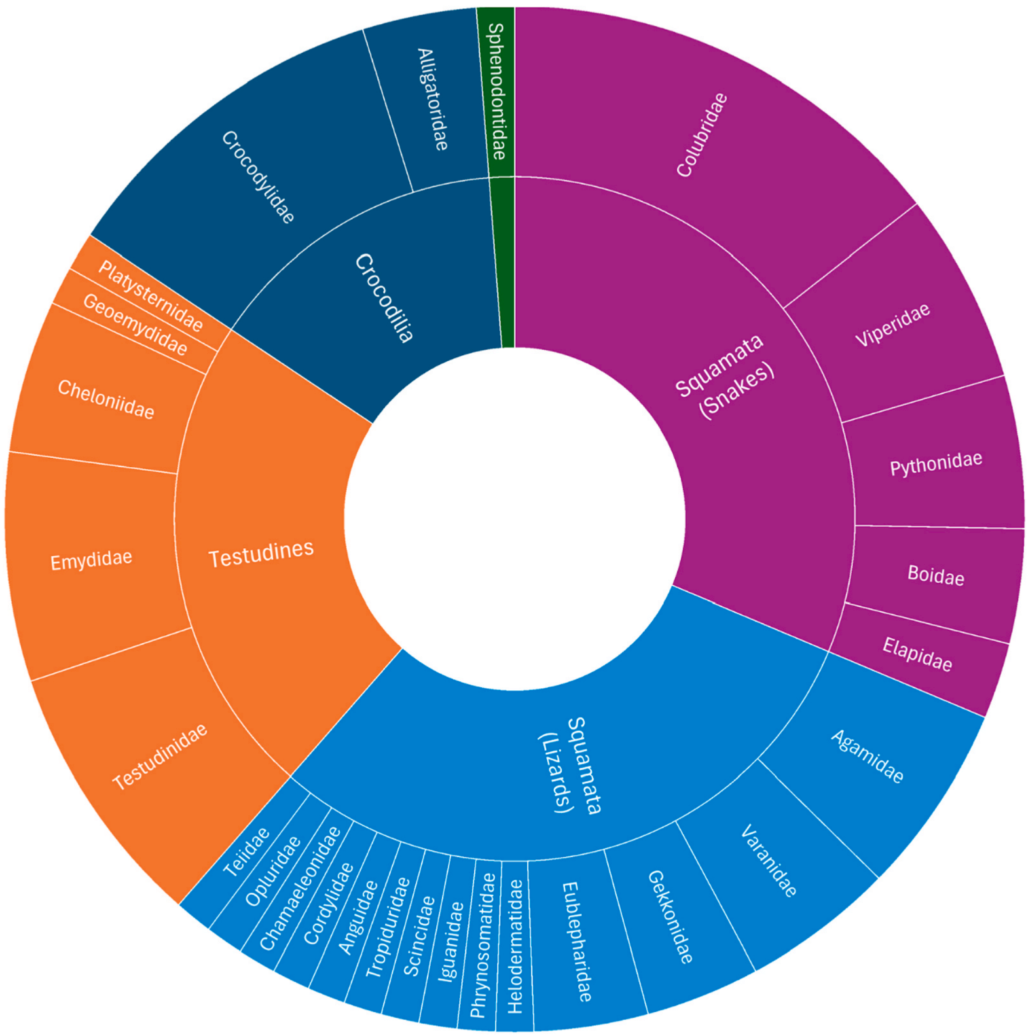

Fig. 4. A sunburst diagram of the 27 families utilised across 83 occurrences in the 75 studies. Taxa included is grouped by Order and then Family. For specific species information refer Table 2a-e.

welfare (Mellor et al., 2020). Therefore, there is a need to validate and explore metrics indicative of positive affect, as those metrics appropriate for mammals may not be applicable for reptiles.

Behavioural measures were the most utilised metrics. Similarly, other literature had also identified this trend of utilising behavioural metrics for animal welfare research (Fernandez and McWhorter, 2023; Fernandez and Martin, 2023). Behavioural metrics are vital when assessing welfare as they are the most immediate expression of emotional state, physical and physiological metrics have issues when interpreting affective state. Observing behaviour alone can be useful, however as a solitary method it can only provide a snapshot of the animals' possible affective state (Jones et al., 2021; Warwick, 2023; Watters et al., 2021). Additionally, the measuring of behaviour is often time intensive and so may not be utilised as frequently outside of research (Whittaker et al., 2021). Furthermore, context is crucial, if an animal is observed performing a repetitive abnormal behaviour such as pacing, it could be evidence of poor welfare. However, if the animal has a regular schedule and they are about to be fed that the same behaviour may be considered anticipatory which is often interpreted as a positive indicator (Clegg et al., 2018; Krebs et al., 2017; Spruijt et al., 2001). A potential issue to consider, particularly for reptiles, is that in nature, it is often disadvantageous to expressly show the affective state through behaviour, for instance, animals may try to mask or hide injury or illness to reduce predation (Weary et al., 2006). Additionally, interpreting behaviour of reptiles has many issues, few positively valenced metrics are known. Warwick (2023) identifies potential behavioural stress signs that could be observed in reptiles; however, an understanding of the animals' natural history needs to be known as abnormal behaviour for an inland taipan would be vastly different to that of a Gaboon viper.

Biological functioning can highlight attempts to cope that may not always present as a behavioural response, instead measures such as immunological defences and stress responses can be used (Hemsworth et al., 2015; Gangloff and Greenberg, 2023). Reference values to compare when using physiological measures are often difficult to obtain, with physiological metrics requiring specialist skill, specific equipment, cost incursions, and can involve a certain level of stress to the animal to collect samples (e.g. blood samples) (Benn et al., 2019; Gangloff and Greenberg, 2023; Silvestre, 2014). Additionally, stress hormones and other welfare markers will fluctuate over a year, between seasons and at different life stages (Lane, 2006; Mormède et al., 2007; Ralph and Tilbrook, 2016). Having good reference values and an understanding of natural history is crucial when utilising physiological metrics.

Physical measures can indicate where physiological functioning is unsuccessful in attempting to cope by showing a deterioration in body condition, growth or longevity (Hemsworth et al., 2015). However, it is important to consider that events, such as breeding season can naturally have a great impact on physical health but would not impact the animal's overall welfare. Additionally, impacts caused by modifications may take a long time to reflect onto the physical morphometrics of that animal. However, there are some examples of where stress can present

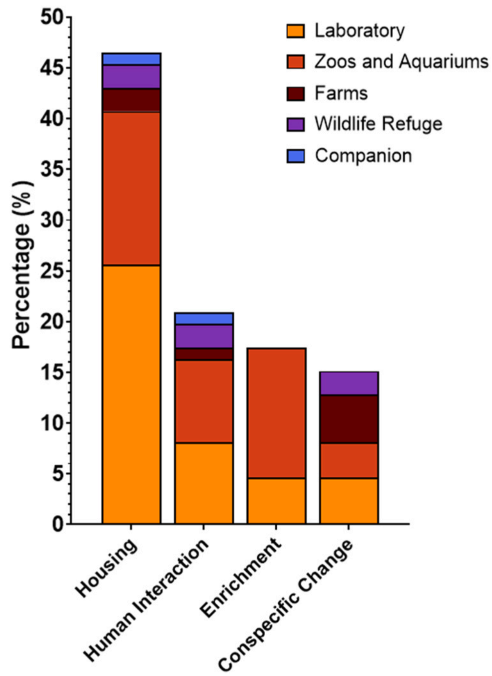

Fig. 5. Bar graph highlighting the different types of modifications, nested with the distribution of setting type utilised. The percentage occurrence for intervention types represented across the 75 studies.

Table 3
Summary of the count of the subtypes for the different modification utilised across the 75 studies.

Modification Type	Sub Type	Percentage (%)
Housing		
	Furnishing	19.01
	Lighting	7.44
	Substrate	7.44
	Size	5.79
	Temperature	3.31
	Humidity	2.48
	Water	1.65
Enrichment		
	Sensory	7.44
	Food	7.44
	Structural	6.61
	Cognitive	4.13
	Social	1.65
Human Interaction		
	Human Direct	9.92
	Human Indirect	4.96
Conspecific Change		
	Conspecific Direct	9.92
	Conspecific Indirect	0.83

relatively quickly physically, specifically some lizards will exhibit a colour change when stressed, such as green anoles "*Anolis carolinensis*" and common lizard "*Zootoca vivipara*" (Greenberg, 2002; Meylan et al.2007). Colour changes can also occur seasonally and be an aspect of communication for other reptiles (Gangloff and Greenberg, 2023). Although, no studies within this review measured colour changes this could highlight a need to explore this specific metric in closer detail when measuring welfare within captive settings.

It has been suggested that triangulation of welfare measures, utilising a range of measures should be performed to validate welfare assessment, with the "gold standard" considered as use of the trifecta of behavioural, physiological and physical parameters (Hosey, 2005; Jones et al., 2021; Veasey, 2017). Utilising a single type of measure does not allow for a complete view of that animal in terms of welfare to be assessed. Inclusion of newer measures, such as Qualitative Behaviour Assessments (QBA) could benefit future reptile welfare assessments (Wemelsfelder et al., 2009; Whittaker et al., 2021).

This review identified three studies that utilised behavioural, physiological and physical measures (Lynch et al., 2025; Powell et al., 2025; Rosier and Langkilde, 2011). For the majority of studies, impacts of the changes were neutral in relation to net welfare benefit. It should be highlighted that determining the valence of welfare metrics is challenging and often disputed. Context of the animal's situation needs careful consideration. Some measures that are often negatively valenced, such as glucocorticoid concentrations may not always reflect a negative state (MacDougall-Shackleton et al., 2019). For instance, increases in glucocorticoid concentrations can indicate arousal or stress, as it is indicative of activation of the hypothalamo-pituitary-adrenal (HPA) axis and depending on target tissue can increase or decrease fitness, this can cause issues when valencing to assess welfare (Ralph and Tilbrook, 2016).

4.4. Limitations

Many of the papers identified implemented more than one intervention, which can lead to difficulties when extrapolating results since it was unclear which modification had a more profound outcome. It is important to consider that although this review does highlight gaps in research and focusses on evidence-based husbandry modifications information from wild counterparts can be utilised to inform husbandry protocols, Warwick et al., (2023) provides specific information regarding different species spanning captive and wild settings.

Publications with a stated focus on welfare were investigated for the purposes of this review, with our main interest being in common measures used in welfare science. Therefore, nutrition and health were not included but are of course a vital contributor to animal welfare state (Fraser, 2008; Hemsworth et al., 2015; Hewson, 2003; Mellor et al., 2020; Reimert et al., 2023). Maslanka et al. (2023) provides information on nutritional considerations for different species. Additionally, due to the specificity of the inclusion/exclusion criteria there are many studies that have value and should be utilised when exploring non-avian reptile welfare, but they may not have fulfilled the criteria for this review. For instance, there is a growing body of literature discussing the importance of play and social behaviour on the welfare of reptiles (Brando and Burghardt, 2019; Burghardt et al., 1996; Burghardt, 2015; Gibson, 2020 Krause et al., 1999;). Additionally, the use of training for reptile care is also increasing with positive results found in reducing stress when target training was implemented (Augustine and Baumer, 2012; Gaalema and Benboe, 2008; Gutnick et al., 2020; Jackson et al., 2005; Weiss and Wilson, 2003; Williams et al., 2022). However, some studies exploring social behaviour and training did not meet the criteria due to having a more cognitive purpose rather than welfare or for some of the training studies didn't statistically compare with a control. It should not be understated that these are still crucial to welfare and improving husbandry practices.

5. Conclusions

Reptiles are commonly kept within a range of captive settings, yet decisions that inform how enclosures are set up, and protocols in place for care are often based on "folklore husbandry". A significant research gap exists in relation to modifications to housing and husbandry to improve welfare. This gap relates to number of studies conducted, and there are inherent challenges in understanding valences of indicators with positive indicators being far less prevalent. Laboratories were the most used setting which highlights a need for more research to be conducted within other settings which cannot exert the same level of control as impacts may differ. Additionally, this review highlighted only one publication used reptiles within the pet industry despite the large pet population. Most modifications assessed involved altering of the

Fig. 6. Sunburst diagram of 161 measures used across all 75 studies (most studies utilised multiple measures).

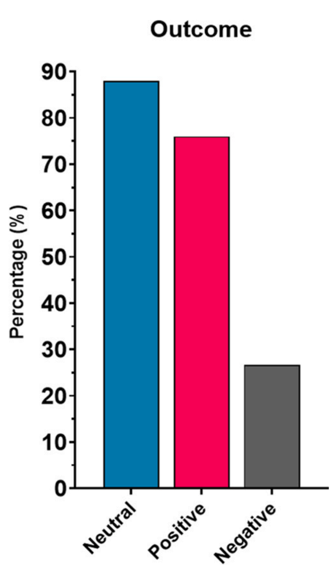

Fig. 7. Bar chart showing the percentage of outcomes across 75 studies. Note that many studies reported multiple types of outcomes (143 outcomes).

animals' physical housing with more emphasis placed on furnishing. This highlights a need for more research in other areas of the animals' physical environment. Despite reptiles being highly reliant on their environment there is a gap exploring environmental parameters such as light, temperature and humidity in relation to affect (as opposed to health). To effectively develop best practice guidelines that utilise evidence-based husbandry more research is required on targeted species, different aspects of the animals' physical environment and general welfare assessment.

CRediT authorship contribution statement

Eduardo J. Fernandez: Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization. **Bridget Cooper-Rogers:** Writing – review & editing, Validation, Data curation. **Gordon M. Burghardt:** Writing – review & editing, Supervision. **Hanson Sara Louise:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Whittaker Alexandra L:** Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization.

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Declaration of Competing Interest

The authors declare that there are no known competing financial interest or relationships that could have appeared to influence the work reported in this review.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2025.106831.

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