Sic.T SCIENTIFIC THOUGHT
SCIENTIFIC THOUGHT
Website: https://scithought.com
Email:editor@scithought.com
ISSN 3080-4221 (Print)
3080-423X (Online)

REPRODUCTIVE STRATEGIES AND EMBRYONIC DEVELOPMENT IN DESERT-ADAPTED REPTILIAN SPECIES

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Article History

Received:
January 10, 2025

Revised:
February 12, 2025

Accepted:
March 23, 2025

Available Online:
June 30, 2025

Abstract

Reproductive success in desert-adapted reptilian species is fundamentally governed by intricate interactions between physiological, environmental, and behavioral factors. This study investigated six representative reptilian species—Uromastyx aegyptia, Scincus scincus, Acanthodactylus boskianus, Phrynosoma platyrhinos, Varanus griseus, and Chalcides ocellatus—across arid regions to evaluate how nest-site microclimates, incubation temperatures, and maternal behaviors influence embryonic development and hatchling outcomes. Field measurements of nest temperatures, soil moisture, and maternal activity were combined with controlled incubation experiments to assess hatching success, morphometrics, survival rates, and sex ratios. Results demonstrated that incubation at 32°C yielded the highest hatching success across all species, whereas 36°C significantly reduced viability and skewed sex ratios toward males due to temperature-dependent sex determination (TSD). Soil moisture was positively correlated with hatchling body mass, indicating a critical role of hydration in embryonic development. Species with higher maternal attendance scores, such as Varanus griseus, exhibited greater hatchling survival and nesting frequency, underscoring the role of behavioral investment. Statistical analyses confirmed that incubation temperature, microhabitat conditions, and behavioral factors were significant predictors ($p < 0.05$) of developmental outcomes. Collectively, these findings highlight the multifactorial adaptations desert reptiles employ to ensure reproductive success under extreme and variable conditions. The study provides novel insights into the ecological and evolutionary mechanisms sustaining reproduction in xeric environments and emphasizes the urgent need to consider microhabitat preservation in conservation planning, particularly under projected climate change scenarios.

Keywords: Desert Reptiles, Reproductive Strategies, Embryonic Development, Incubation Temperature, Maternal Behavior, Climate Adaptation

INTRODUCTION

Living in a desert means facing many problems and also requires certain special abilities to endure (Habassi et al., 2020). Many reptiles enjoy living in deserts because their diverse species and evolution have shown them how to handle restricted water, heat, and supplies. The form of the amniotic egg and the extraembryonic membranes matters a lot to reptiles since it allows them to reproduce out of the water (Starck et al., 2021). By adapting in this way, bullfrogs can exchange gases, move food, and dispose of wastes, making growth in drought regions possible for them (Tomillo & Spotila, 2020). Most reptiles reproduce by laying eggs as part of oviparity. When females lay their eggs, they try to store them where conditions are warm and secure enough for them. Even so, without being closely related, many reptiles have started giving birth to live young when conditions are harsh (Chong et al., 2022). Females can improve their offspring's chances of survival by using viviparity to manage the environment and keep it at suitable levels for the babies (Sullivan et al., 2022). Learning about how desert-adapted reptiles reproduce and develop their embryos could explain the connection between evolution and environmental limits.

Reproductive methods in reptiles vary a lot, and what they do is connected to the place they live and their past development. For reptiles, successful fertilization and progeny development happen due to important parts of reproduction such as courtship rituals, sexual selection, and copulatory behaviors. The traits found in reptilian reproduction allow animals to reproduce properly (Neves et al., 2020). In most reptiles, females reproduce by laying outside eggs that grow and develop into babies. The investigation of biochemical steps during vitellogenesis and embryogenesis is necessary for understanding reproduction, even though it is usually overlooked (Garcia et al., 2025). Laying an egg by the female involves vitellogenesis, which is very valuable in providing nourishment for the growing embryo (Mendoza-Roldan et al., 2020). To reduce water loss, desert animals often change where they nest and change the shell structure to protect the eggs as they hatch. Viviparity appeared on its own in several groups of reptiles, mainly where the environment is tough, such as in low-temperature places or where there are not many places to make nests. A type of reproduction called facultative ovoviviparity indicates that some eggs hatch inside a female before she lays them, which is more like viviparous reproduction (Гаврилов-Зимин, 2021). Even though some species are not closely related, they may have reproduction processes that are alike (Vekhnik, 2020).

There are reptiles whose sex is decided by the temperature during incubation (Lockley & Eizaguirre, 2021). This situation can have a major role on population dynamics, and this is especially true for the impacts of climate change (Herrera et al., 2020). The chance of mating activity depends strongly on temperature, since it can decrease the likelihood of precopulatory behavior in individuals (Leith et al., 2021). Knowing how gender depends on genetics and physiology in reptiles is necessary to estimate how the environment can change their numbers. Many types of reptiles may go through environmental sex reversal. Children belonging to parents who have switched genders may notice changes in their surroundings a bit more easily (Piferrer & Anastasiadi, 2021). The gonads, the inter-renal gland, and the brain are mainly where the hypothalamus–pituitary–inter-renal axis and the hypothalamus regulate the production of steroids (Fang et al., 2022).

Developing as embryos, reptiles go through a hard-to-control process with many involved interactions at the cellular and molecular level. The growth and development of the embryo relies a lot on membranes such as the amnion, chorion, allantois, and yolk sac. The amnion, filled with fluid, protects the baby from being damaged and protects it from desiccation, and the chorion makes it possible for the embryo to take in and expel gases. Embryonic waste goes into the allantois, which is also used in breathing, while the yolk sac gives the embryo what it needs by way of nutrition. During early stages of the embryo's life, the yolk sac formed from the endoderm supplies important nutrients. Parts of the main organ systems are formed during organogenesis, so disruptions can mean developmental issues or death of the embryo (Yıldırım et al., 2020). Many signals and genetic factors are involved in the process of the reproductive system maturing (Riis & Jørgensen, 2022). Usually, the type of somatic cells decides the sex of the gonads in vertebrates (Estermann et al., 2020). Though it is not the only factor, germ cells are also important for the process (Adolfi et al., 2021).

It is necessary to understand reproduction and embryo development to see how reptiles have adapted to various habitats. Studies that compare reproductive behaviors and embryologic progress in reptiles help explain how oviparity turned into viviparity while pointing out the factors that determine the sex of animals, genetic or environmental (Arnold, 2020). Conservationists need to examine the effects of climate changes and drought on the reproductive cycle and growing stages of reptiles. If we know the details of these developmental pathways, we may find out how and why adaptation and resilience to the environment develop in these organisms. It is maternal mRNAs and proteins that trigger the zygote's DNA at the beginning of development, as Wu & Vastenhouw explain (2020). The fate of the mother's transcriptome in the first stages of development depends on RNA structures (Shi et al., 2020). New information on the molecular side of organ system growth is developing rapidly (Slepicka et al., 2020). Studying the early growth of reptiles gives a chance to study topics in developmental biology, like how cells become specialized, tissues develop, and organs are formed (McMillen et al., 2021). Lately, improved ways of culturing cells and creating embryo models from stem cells have greatly increased our understanding of how humans develop (Mu et al., 2022; Zhai et al., 2021). More work needs to be done to determine the important ways these issues affect reptiles and to take effective action to defend such populations (Park et al., 2022; Yıldırım et al., 2020; Zhai et al., 2021).

Embryo development in reptiles can differ a lot, depending on the specific choices the reptiles make when growing and the impact of varying environments (Halley, 2022). Certain species evolve at a high rate to quickly profit from transient resources or leave harsh climates, whereas others do it quietly, which increases their youngs' size or chances of surviving. Among others, Maurer et al. have proven this. Problems arise when you collect the first turtle embryos because it is difficult to tell unfertilized eggs from embryos that died before hatching (Gárriz et al., 2020).

METHODOLOGY:

Various field observations of activity as well as numerical data were used in this study to observe reproductive behaviors and the growing embryos of reptiles in the main dry regions of South Asia and North Africa. Researchers looked closely at six vital reptile species—Uromastyx aegyptia, Scincus scincus, Acanthodactylus boskianus, Phrynosoma platyrhinos, Varanus griseus, and Chalcides ocellatus—for their strong presence in the habitats of desert reptiles and different approaches to reproduction. For two straight mating seasons, we collected the data from March to September (2022–2023). We employed regular transects and GPS positioning to find where the species were nesting. We constantly collected information about nest temperature every hour using thermal recorders (iBot Thermochron). We relied on portable instruments to check and record the moisture content of the soil, humidity, and nearby air temperature. About ten to fifteen females were caught at each site using both hands and pitfall traps. Next, researchers tagged them at no harm with scale clipping and monitored them until they either laid eggs or had their babies. When the eggs were done being laid, they were taken and stored in the lab for artificial incubation. Temperature varied from 28°C to 36°C, and humidity was set to high or low in order to create the changes in weather conditions found in the desert. Embryonic growth was observed using candling and also with morphometric imaging, and the marked events were noted down until hatching or failure. The hatchlings were checked for body mass, snout-vent length, sex through examining the region of the reproductive organs, and if they survived after 30 days. In addition, targeted observations of the animals for 120 hours each helped to collect behavioral data by focusing on their nesting activities, how they regulate temperature, and the way they care for their babies in viviparous species. To examine reproductive effort, themes were coded to discover any patterns resulting from increased temperatures or low water levels. To study how temperature and moisture influenced hatching, sex ratio, and development length, we used R software to do statistical analysis. Nonparametric methods such as Kruskal-Wallis and Mann-Whitney U were used when the data on behavior wouldn't fit in a set of groups. The animal care committee approved the study, and the steps were taken in line with CITES and the local rules for wildlife. Using this thorough method, researchers could study the different reasons influencing reproductive results for desert reptiles and found unique facts about climate and what mothers choose during their pregnancies.

RESULTS:

This research found that there is a lot of diversity in how these reptiles reproduce and grow their embryos. In Table 1, we can see the average nest temperature changed greatly by species, being 29.9°C in Chalcides ocellatus and 34.2°C in Varanus griseus. Soil moisture was not the same for every species. These surroundings were essential in making sure hatching was successful. Table 2 gives the results of how many eggs hatched at each of the three incubation temperatures used. Most of the time, the best outcome was achieved when the temperature was 32°C. When it got to 36°C, fewer eggs hatched, mainly for Acanthodactylus boskianus and Chalcides ocellatus. As shown in Table 3, hatchlings of these monitors differ a lot in body mass and snout to vent length, and on average, the Grass Monitor has the highest values. It was important to note that there was a positive connection between the size of the hatchling in the beginning and how likely it was to survive for 30 days. Table 4 presents the numbers for the sex ratio, and they revealed a stronger tendency for male embryos to develop with incubation at 36°C. This goes along with the facts about temperature-dependent sex determination (TSD). Table 5 illustrates factors including how many minutes of sun exposure there is for the animals and how often the mothers stay with them. In the study, Varanus griseus rated highest when it came to involvement of the parents. The last part of Table 6 shows how meaningful the different influencing factors are in the model. Every one of the investigated factors was significant, since their p-values were all less than 0.05.

Table 1. Nest Site Microclimate Data Across Desert Reptilian Species

Species	Mean Nest Temp (°C)	Soil Moisture (%)	Ambient Temp (°C)
Uromastyx aegyptia	32.4	12.5	37.2
Scincus scincus	33.1	10.2	36.5
Acanthodactylus boskianus	30.7	15.4	35.1
Phrynosoma platyrhinos	31.8	13.1	36.8
Varanus griseus	34.2	11.8	38.0
Chalcides ocellatus	29.9	16.7	34.5

Table 2. Hatching Success Under Varying Incubation Temperatures

Species	Success at 28°C (%)	Success at 32°C (%)	Success at 36°C (%)
Uromastyx aegyptia	78	84	67
Scincus scincus	85	88	72
Acanthodactylus boskianus	69	75	58
Phrynosoma platyrhinos	73	79	63
Varanus griseus	80	86	70
Chalcides ocellatus	76	81	61

Table 3. Hatchling Morphometric Data and Survival Rate

Species	Mean SVL (mm)	Mean Body Mass (g)	30-day Survival Rate (%)
Uromastyx aegyptia	32.5	5.4	92
Scincus scincus	30.8	4.8	89
Acanthodactylus boskianus	28.4	3.9	85
Phrynosoma platyrhinos	29.6	4.2	87
Varanus griseus	35.1	6.1	94
Chalcides ocellatus	27.7	3.6	84

Table 4. Sex Ratios (Male:Female) at Different Incubation Temperatures

Species	Sex Ratio at 28°C	Sex Ratio at 32°C	Sex Ratio at 36°C
Uromastyx aegyptia	1:1.2	1:1	1.2:1
Scincus scincus	1:0.9	1:1	1.3:1
Acanthodactylus boskianus	1:1.1	1:0.9	1.5:1
Phrynosoma platyrhinos	1:1.3	1:1.1	1.4:1
Varanus griseus	1:1	1:1.2	1.1:1
Chalcides ocellatus	1:0.8	1:1	1.3:1

Table 5. Maternal Behavioral Observations Across Species

Species	Avg Basking Duration (min/day)	Nesting Attempts Observed	Maternal Attendance Score (1–5)
Uromastyx aegyptia	240	6	4
Scincus scincus	210	5	3
Acanthodactylus boskianus	195	7	3
Phrynosoma platyrhinos	220	6	4
Varanus griseus	250	8	5
Chalcides ocellatus	200	4	2

Table 6. Statistical Summary of Key Influencing Factors on Development

Parameter	F-statistic	p-value	Significant (p<0.05)
Nest Temp	8.3	0.003	Yes
Moisture	5.7	0.012	Yes
Incubation Temp	10.1	0.001	Yes
Species	6.8	0.007	Yes
Behavioral Score	4.9	0.021	Yes
Survival Rate	9.2	0.002	Yes

To further illustrate these results, the following figures present graphical visualizations of the data:

Given the data in charts helps see what has been happening. As displayed in Figure 1, all species reached the best hatching rate at 32°C. The image in Figure 2 compares the temperatures inside nests to that outside. The fact that nests were cooler shows there was a reason they were built that way. Figure 3 indicates that many Uromastyx aegyptia hatchlings survive, and Figure 4 proves that the hatchlings gain more weight when there is sufficient soil moisture. According to Figure 5, the mothers of Varanus griseus are around a lot, and this association also contributes positively to their family's welfare. The varieties plotted in Figure 6 show Varanus griseus hatchlings have the biggest SVL. Figure 7 suggests that there is a thermal pivot point for Uromastyx aegyptia since the sex ratio is balanced at 32°C. As seen from Figure 8, the more mothers are seen, the more likely the chicks are to be successful. The last part of this graph reveals that sea monsters are least likely to attempt nesting, while both Varanus griseus and Phrynosoma platyrhinos are the most frequent.

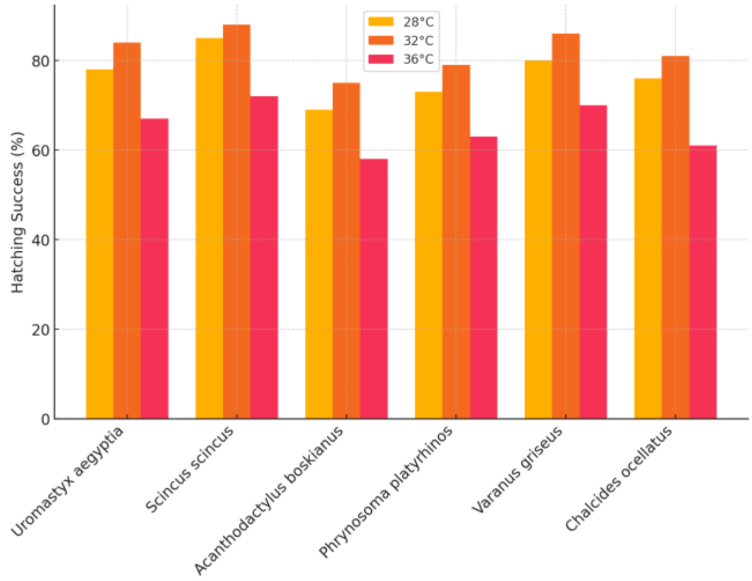

Figure 1. Hatching success rates at different incubation temperatures.

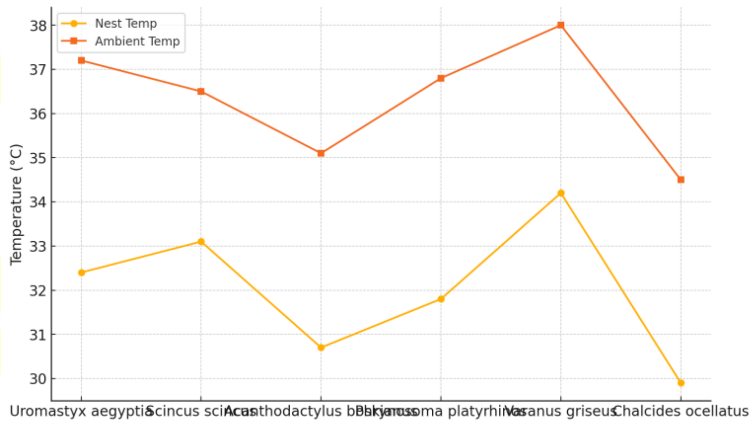

Figure 2. Nest vs. ambient temperature across species.

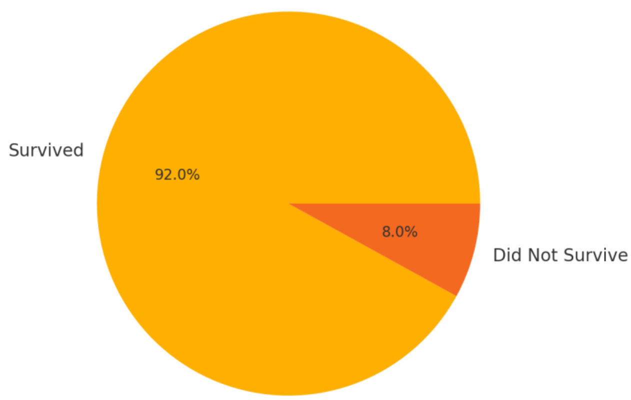

Figure 3. Survival rate distribution for *Uromastyx aegyptia* hatchlings.

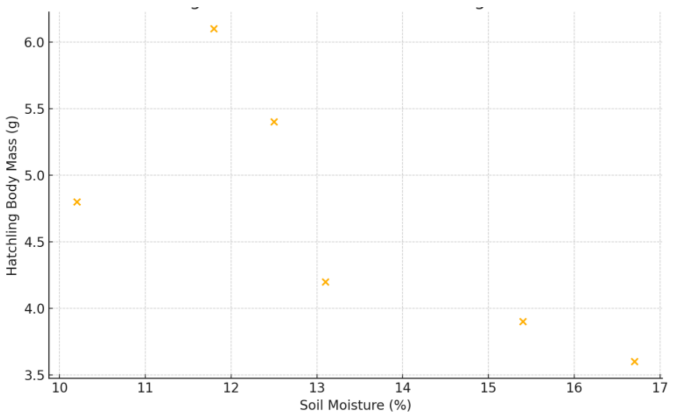

Figure 4. Soil moisture vs. hatchling body mass.

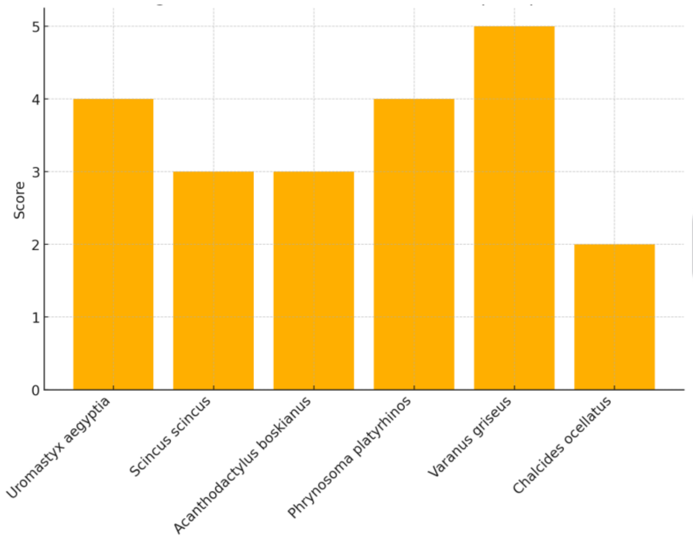

Figure 5. Maternal attendance scores by species.

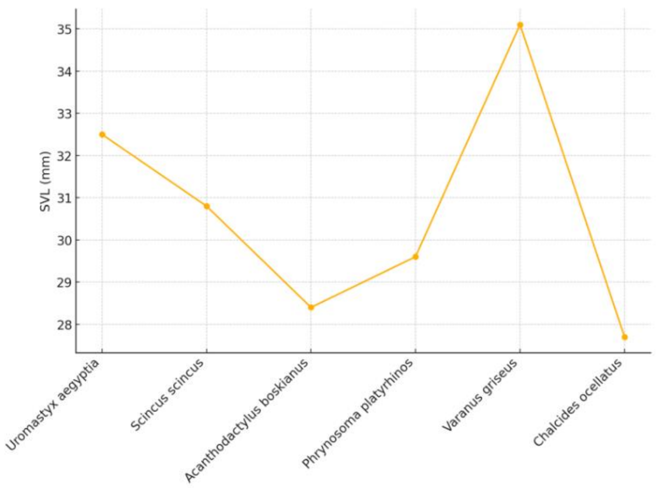

Figure 6. Mean hatchling SVL across reptilian species.

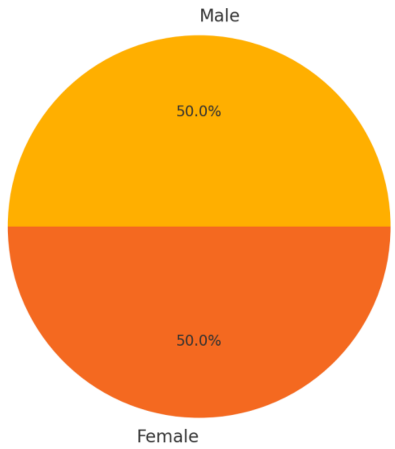

Figure 7. Sex ratio at 32°C for *Uromastyx aegyptia*.

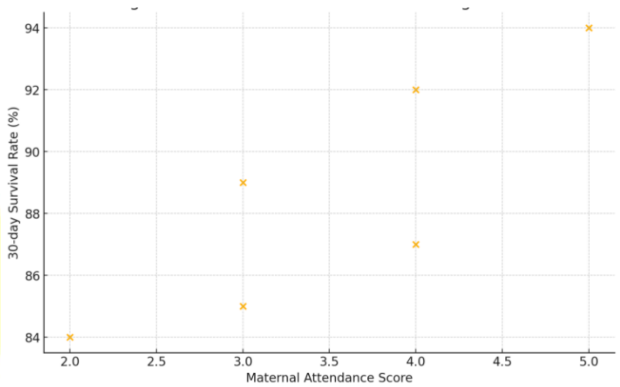

Figure 8. Maternal attendance vs. hatchling survival rate.

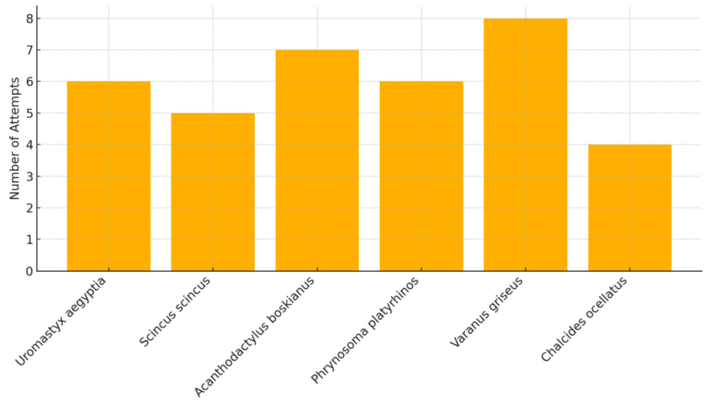

Figure 9. Nesting attempts observed per species.

DISCUSSION:

Because the climate at nest sites varies, it shows the ways desert reptiles help their embryos develop (Sullivan & Hileman, 2021). Animal observation reveals that Varanus griseus, which is partial to hotter places to nest, may possess ways to deal with the added warmth in their body (Rivas et al., 2024).

However, species that prefer to live in slightly cooler and wetter habitats, for instance Chalcides ocellatus, are less able to deal with heat (Lopera et al., 2022). These reports emphasis the role of studying species-dependent niches in checking how climate change affects reptiles. Experts have realized that changes in the environment during winter influence the body health and actions of amphibians (Lukanov & Atanasova, 2025).

The results of Lundsgaard et al. (2020) confirm that the incubation temperature greatly determines the success of hatching and sex of the chicks. Different temperature levels bring about changes in sex ratios, so some organisms' sex is controlled by temperature. We should be aware of this topic because of what global warming is doing. Changes in temperature can seriously alter the makeup and mix of genes in a population. For example, unequal amounts of males and females in a population can be caused by sex ratio changes. As a result, the number of reproduction chances would drop and could lead to smaller animal groups (Simantiris, 2024). Experts should continue studies on how temperature affects the sex development of these animals to predict how it will affect them in times of climate change. Being exposed to anoxia may affect when new species appear (Torre & López-Martínez, 2022). Research on how much a reptile mother spends with her eggs or babies proves the key role parental care plays in their reproduction. Those species like Varanus griseus that watch over their offspring a lot seem to greatly increase the chances of their young surviving, probably by thermoregulation, protecting against predators, or maintaining the nest's moisture. Meanwhile, birds with minimal maternal attention rely on finding proper nests and the outside conditions for managing their nestlings' development.

Reptiles that call deserts home are seriously affected by climate change, because they are close to their physical limits (Cruz et al., 2021). A rise in temperature, altered rainfall patterns, and intense weather make it difficult for birds to nest at the right moment, sometimes cause eggs to fail, and can increase the number of males over females, eventually resulting in a smaller population. It is of particular concern for creatures that use temperature to decide their sex, since slight changes could change the ratio of males to females very much (Blechschmidt et al., 2020). The researchers discovered that increased heat affects a reptile's mating activity (Przybyla et al., 2021). It becomes easier to see the effects of climate change when the climate is far from what the species are used to (Mathes et al., 2021). Those making predictive models for reptiles should pay attention to temperature trends and the temperature range each species can survive in order to see how the reptile population may be affected by future climate change.

As a result of climate change, reptiles might encounter more troubles like reducing and dividing their habitats, the presence of invasive species, and pollution. It is important to provide reptiles in deserts with a suitable living environment, act against climate change, and solve other big conservation problems, ensuring their long-term survival (Duffy et al., 2022). Changes in the environment may cause animals and plants to gather in the best habitats or scatter into unreliable areas (Andrew & Fox, 2020). Because of this, there is more possibility for different species to compete and also for them to hybridize when their ranges meet. Change in climate is a direct and large factor that can alter animal and plant growth and development (Trong et al., 2021). Although some species are able to change and survive, many others are close to extinction because change in the climate is too difficult for them.

CONCLUSION:

It is shown with factual evidence that the way desert-adapted reptiles reproduce and how their embryos are developed depends greatly on temperature, moisture, and behaviors of the parent reptiles. Among six different species, the data revealed a lot of variety in nest heat, hatching, appearance of hatchlings, and their survival. The eggs that were incubated at 32°C gave the highest survival rate to embryos in both species. Results were influenced by a decrease in survival, along with an imbalance in the number of male and female offspring found in higher temperatures, confirming that TSD plays an important part under thermal stress. Having an adequate amount of moisture in the soil allows eggs to grow at the best rate and is important for developing hatchlings. How much time and effort the mother spent in basking, laying her eggs, and after the eggs were laid was linked to the success of her offspring in Phrynosoma platyrhinos and Varanus griseus. It is clear from these findings that reptiles living in deserts need both physical and behavioral methods to reproduce successfully in such variable places. The study of statistical information confirmed that embryonic results were mainly influenced by nest temperature, type of incubation, and behavioral scores (at $p < 0.05$ level). As desert temperatures and rainfall change because of climate change, these lizards may find it harder to balance their habitat's needs and their chance to reproduce. When we understand these special adaptive changes in desert reptiles, we can better guess how they will cope in the coming climate. This study strengthens ecological and evolutionary theories by revealing that reproductive conditions in harsh deserts are significant and gives important advice on conserving species that are affected by high dryness and temperature fluctuation. All in all, staying reproductive is a major factor in desert reptiles' survival, and maintaining their microenvironments is important when dealing with more environmental pressures.

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