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Review

A Review of the Physiological Mechanisms Used to Combat Limited Water Availability in Reptiles, Mammals, Birds, and Beetles Living in a Desert Environment

Lauren Strabley[1]*, Michelle Abalos[1], Christina Reisner[1], Natasha Bozir[1], Miryam Rodriguez[1], and Dennis Kolosov[1]

[1] Department of Biological Sciences, California State University San Marcos
* Correspondence: strab001@csusm.edu

Abstract: Desert environments can be particularly harsh and unforgiving to their inhabitants which make it an ideal setting to study mechanisms of osmoregulation in different organisms. In this paper, we will be examining four different types of organisms that live in deserts around the world, comparing and contrasting their methods of osmoregulation. The South African Springhare (*Pedetes capensis*) concentrates its urine and dries out its feces in order to conserve water while the Gila Monster (*Heloderma suspectum)* reabsorbs water from its bladder to rehydrate itself in times of drought. The Namib Desert Beetle (*Onymacris unguicularis*) collects atmospheric moisture and uses metabolic water to stay hydrated, whereas the Turkey Vulture (*Cathartes aura*) concentrates urine and eliminates excess nitrogen to avoid poisoning its blood. Each of these organisms has a unique method of survival, showcasing the different mechanisms desert animals adapt in order to survive these harsh dry environments.

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Desert animals have found many ways to combat the lack of water available to them in their environment, and many different mechanisms have been used to conserve water in these harsh conditions. In this paper we will examine the osmoregulation strategies of Turkey Vultures, South African Springhares, Gila Monsters, and Namib Desert Beetles. Desert animals have various different methods of conserving water, and we will be comparing and contrasting these different strategies in this paper. Deserts are environments without easily accessible water, and many animals that live there have found ways to compensate for the lack of water. These animals will often have a lower water intake, but higher water conservation in their bodies in order to avoid having to take in more water[1]. We compared the challenges these organisms face, and their responses to the water and salt imbalance, using multiple research papers (Table 1). While the goal is the same these different animals have evolved different methods of conserving water, and have mastered the ability to survive in these harsh conditions, and we will be discussing these differences and similarities in depth.

While there are various strategies for these animals to conserve fluids, there is a common mechanism that some of them use. One common method of conserving fluids is to decrease food intake, and search for food less frequently. The South African Springhare is a large, burrowing rodent with an herbivorous diet and nocturnal lifestyle. As an inhabitant in the semi-arid to arid southern and eastern Africa, springhares are able to acclimate to low levels of water in various ways. According to one study, when water-deprived for 168 hours, springhares underwent selective feeding and a reduced food consumption[2]. In doing so, they produced very dry feces and in turn reduced the amount of water loss via excretion. Another response to water deprivation was the concentration of their urine; urine volume decreased from 73.5 ml/day to the lowest volume of 12.5 ml/day, which was the minimum necessary for excretion[2] (Figure 1).

Mammals are not the only type of organism to exhibit this sort of behavior, which suggests that many different organisms might use this method of water conservation. The

Gila Monster, also known as *Heloderma suspectum*, is a venomous lizard that lives in the Sonoran Desert that yearly experiences increased plasma osmolality in the months between April and July due to water scarcity[3]. Gila Monsters forage infrequently during dry seasons in an effort to conserve water and can rapidly rehydrate themselves and refill their urinary bladder volume during heavy rainfall by drinking a large amount of water from puddles[3,4]. There is a distinct difference between these two animals though, as the Gila Monster exhibits an ingenious way of storing water. In the months when food and water are unavailable in its desert environment, the Gila Monster uses its urinary bladder as a fluid reserve[4]. It can use this stored water to keep itself from dehydrating in harsh droughts, and this increase in water storage in the bladder also leads to decreased osmolality in the blood[4] (Figure 2).

Table 1. A summary of osmoregulatory imbalances, and the mechanisms used to combat them.

Species	Imbalance	Mechanisms	Source
Gila Monster (*Heloderma suspectum)*	Water Deprivation and Dehydration	Absorbed water from urinary bladder into blood circulation, increased plasma osmolality	Davis et al., 2007
Namib Desert Beetle (*Onymacris unguicularis*)	Water Deprivation	Fog basking and metabolic water production	Naidu, 2008
South African Springhare (*Pedetes capensis*)	Water Deprivation	Concentrating urine, producing dry feces, maintaining plasma volume	Peinke and Brown, 1999
Turkey Vulture (*Cathartes aura*)	Water Deprivation and Nitrogen accumulation	Concentrating urine and excreting excess nitrogen as urate	McNabb et al., 1980

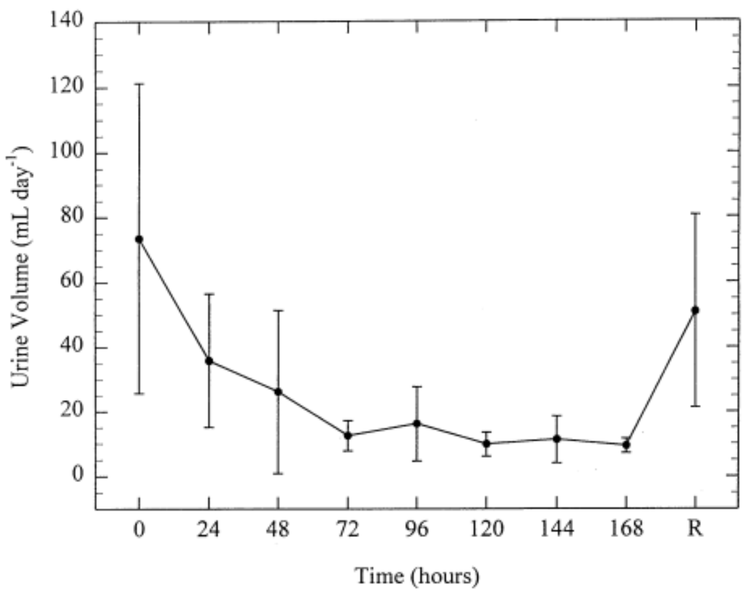

Figure 1. The figure above shows the average urine production (±1SD) of springhares throughout 168 hours of water deprivation. Average urine volume overall decreased throughout the 7 days despite a slight increase at 96 hours. The dropping urine concentration reflects the springhares' efforts to conserve water and limit water loss. R signifies 24 hours of rehydration, in which urine volume rapidly increased in response to water gained[2].

For falconiformes to survive in their environments, they utilize a renal mechanism of concentrating their urine to excrete excess nitrogen and conserve water in environments that have water scarcity. Turkey Vultures (*Cathartes aura*) have developed an adaptation of excreting highly concentrated urate and a decrease in urea after consuming a meal. Since vultures live in habitats where water isn't readily available and they consume prominently carnivorous diets, they have developed an evolutionary advantage of initiating a rapid response adaptation to quickly concentrate and emit nitrogen as urate after eating a protein rich meal. The pear shaped kidney of a Turkey Vulture has multiple lobes and the collecting ducts line the outer portion of the lobes to accumulate wastes from the nephrons. The collection of minimally concentrated fluid from multiple lobes in the kidney transport urine into the cloaca; here, the uric acid enters the intestine by reverse peristalsis where it is further concentrated before exiting with feces[5]. This very low rate of water loss in conjunction with nitrogen excretion is highly efficient, and can be compared to the function of mammalian kidneys[5]. This mechanism allows birds of this species to conserve water and excrete excess nitrogen to maintain physiological balance with their environment.

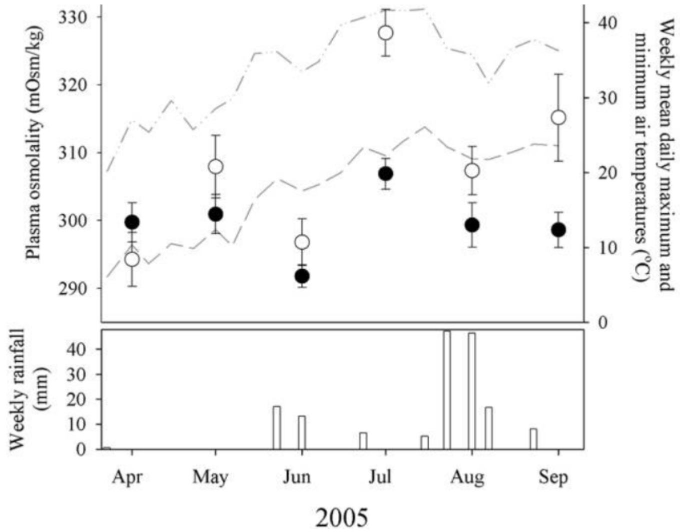

Figure 2. Seasonal comparison in plasma osmolality of water-supplemented (*filled circles)* and control (*open circles*) *Heloderma suspectum* during their active season in the Sonoran Desert according to weekly rainfall in 2005[4].

The last animal we will discuss is the Namib Desert beetle (*Onymacris unguicularis*). This beetle has developed adaptations to facilitate water capture by fog-basking to withstand the extreme environmental conditions of the Namib Desert, this adaptation is believed to be the result of low water availability in the dunes, allowing this insect to survive in the desert by preventing desiccation. A previous study found that after a 10-day dehydration period at 27°C, *O. unguicularis* had a total weight loss of 28.9mg which is a 14.9% weight loss from its initial body weight[6]. Of the 28.9mg lost after day 10, 20.5mg were found to be lipids indicating that the weight loss during dehydration was not due to water loss but instead caused by oxidation of lipids[6] (Figure 3). After having access to water for 1 hour the Namib Desert beetle gained 6.2% of its initial body weight during the rehydration period; however, this was insufficient to raise the beetle's body weight back to normal[6]. Based on the results gathered from that study it was estimated that the 20.5mg of lipids lost during dehydration produced 21.9 mg of oxidation water after metabolizing[6]. These results suggest that the Namib Desert beetle has a mechanism that allows it to metabolize lipids during periods of dehydration to obtain water when availability is low. The study also reported a 37% decrease in haemolymph volume after the 10-day dehydration period; however, hemolymph volume did not increase significantly after 1 hour of rehydration and this is thought to be because the water consumed is being used for the synthesis of lipids[6].

These animals are each fighting the same battle, attempting to increase their water intake while minimizing water loss, and expelling wastes. Mammals like the Springhare concentrate their urine, much like the Turkey vulture which also produces extremely concentrated urine in order to conserve water. Gila monsters use their bladder as a water reserve and can change the concentration of their blood, Namib Desert Beetles allow water to collect on their bodies from the morning dew to increase their water intake. The Springhares and the Namib Desert Beetles both utilize the burning of lipids in their bodies in order to create a bit of metabolic water, and avoid using up the water reserves they have. These adaptations are highly varied, but they do have some similarity, and they all have a common goal of conserving water in environments where there may not be much freely available water[1]. These animals display a large range of adaptations and abilities that allow them to survive and even thrive in their individual niches.

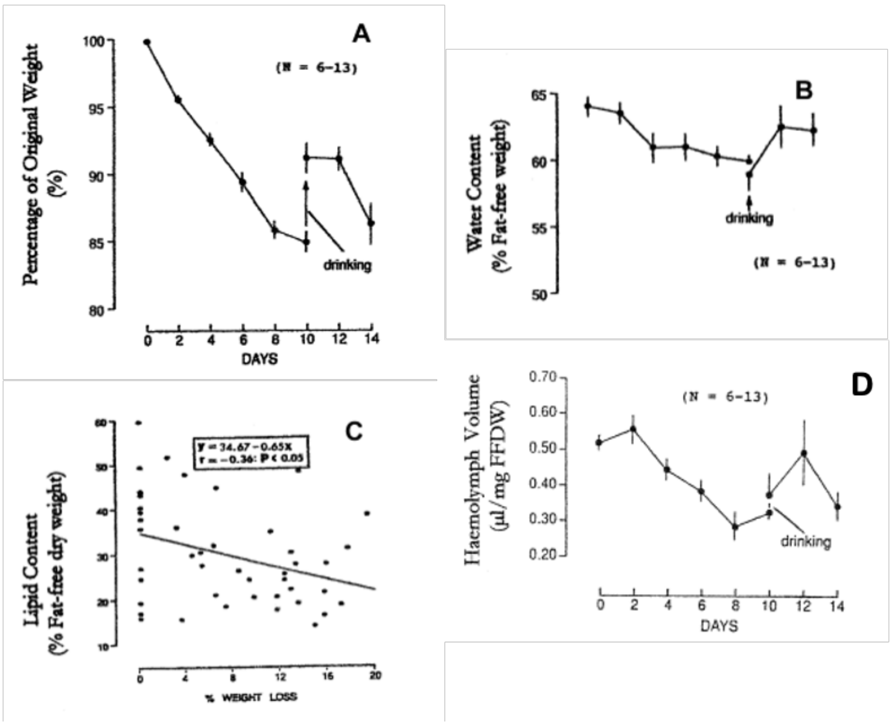

Figure 3. A) Percent of total weight loss in the Namib Desert beetle *(O. unguicularis)* during dehydration and rehydration. Approximately 92% of the total body weight was regained on day 10, 1 hour after drinking water. **B)** Water content of *O. unguicularis* during dehydration and rehydration shown in percentages. Water content dropped significantly at day 10 of dehydration but did not increase significantly after a 96-hour rehydration period. **C)** Percent lipid content plotted against percent weight loss showing a significant negative correlation in the Namib Desert beetle. **D)** Haemolymph volume in *O. unguicularis* expressed as µl/mg FFDW during dehydration and rehydration period. Hemolymph volume decreased significantly on day 10 of dehydration; however, the increase in volume was only significant after 48 hours of rehydration[6].

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