Is Limited Space the Final Frontier?
Maximizing Surface Area in Reptile Enclosures

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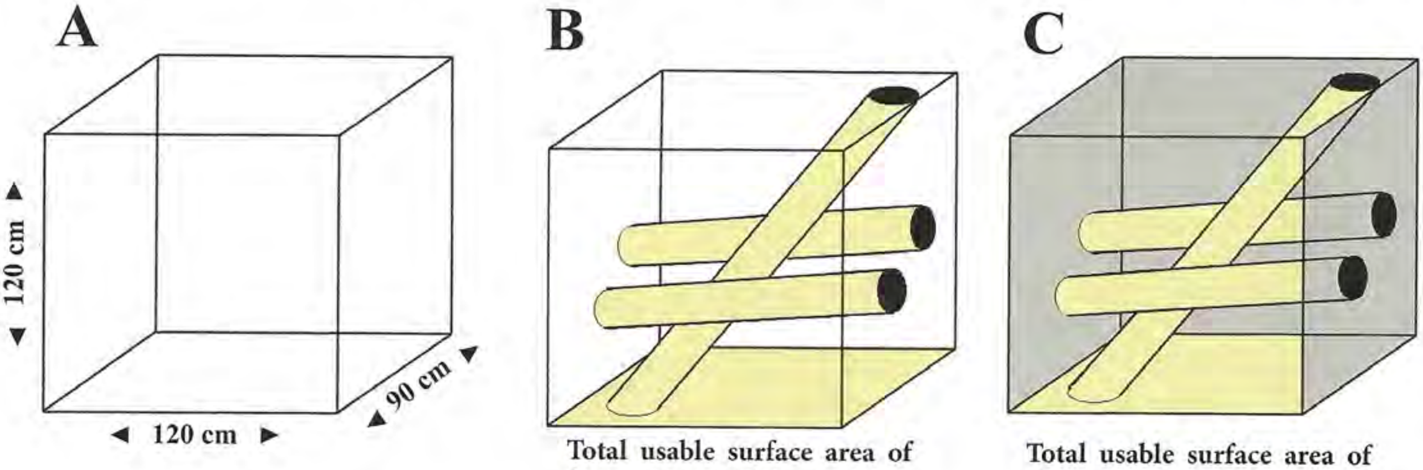
Meeting the ecological and physiological demands of reptiles in captivity has long presented challenges for reptile keepers, and it has taken zoos and private herpetoculturists many decades to develop basic understandings of the captive requirements of some species that allow for successful reproduction and long-term keeping success to occur. Addressing all aspects of reptilian biology can help reptile keepers develop more appropriate taxon-specific husbandry practices which enrich the lives of individuals and improve animal welfare.

As animal caretakers in zoos and related facilities, reptile keepers are responsible for providing and maintaining a range of conditions that best replicate those utilized by a species in nature (Arena and Warwick, 1995; Guilette et al., 1995; Lillywhite and Gatten, 1995; Petzold, 2008). This is a perpetual process, as keepers must regularly update, adapt, and revise husbandry practices as new information becomes available about a species' biology or captive management. Many aspects of a species' natural environment can be recreated in captivity; however, some biological parameters may be difficult or impossible to replicate in captivity due to various logistical constraints. Perhaps the most obvious example of this is space, as many reptile species maintain extensive home ranges in nature that would simply be too large to recreate or accommodate under current captive conditions.

Abundant field data is available on the spatial ecologies and home ranges of many reptile species, yet few zoological institutions have been able to incorporate these data into the design of reptile enclosures due to spatial limitations. It can also be difficult to accommodate complexity within spatially restricted enclosures, and limited variation in both physical and environmental factors can compromise animal welfare (Warwick, 1995). For example, diminutive enclosures can contribute to lethargy, injuries arising from triggered flight reactions, and health issues which present challenges for their management (Warwick, 1995; Warwick et al., 1995; Wright, 2005), and although available behavioral data is limited when compared to that of mammalian or avian captives, reptiles do exhibit several maladaptive stereotypic behaviors that can be linked to restrictive captive environments such as repeated interactions with transparent boundaries and regular exploratory and escape activities (Warwick, 1995). Further complicating matters, zoological facilities may be inclined to display multiple individuals of a species together within the same enclosure for public viewing purposes (including solitary species), even though the enclosure used to house the group is substantially smaller than the home range size of a single individual of the species. Housing multiple individuals together within confined spaces with limited physical complexity (i.e., refugia, visual barriers, etc.) can lead to the development of abnormal social and dominance hierarchies (e.g., Barker et al., 1979; Daltry, 1991; Petzold, 2008) which can increase stress levels and affect the health and wellbeing of captives.

An obvious remedy to this issue of limited space and the health and husbandry-related issues associated with it would be to design and construct larger enclosures

Fig. 1: Rendering the three interior walls of an enclosure usable by affixing a climbable material to them can increase the usable surface area by more than 200%.



Total usable surface area of floor and perching: 16,200 cm^2.

Total usable surface area of floor, perching, and three interior walls: 52,200 cm^2.

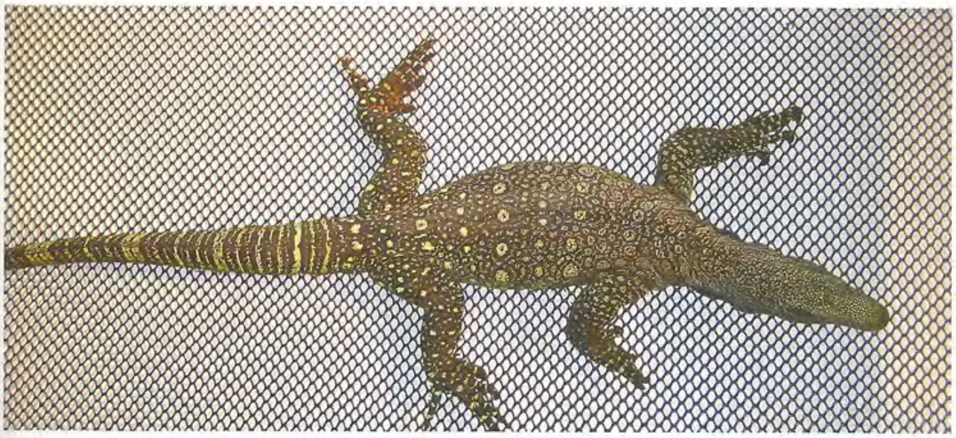


Fig. 2 (above, top): Wood or PVC garden lattice can be mounted to enclosure walls to increase surface area for climbing (Solomon Island spiny monitor, *Varanus spinulosus* pictured).

Fig. 3: (above, bottom) A two meter long crocodile monitor *Varanus salvadorii* climbs the HDPE aquaculture netting mounted to the rear wall of its terrarium. Photograph courtesy of Samuel S. Sweet, University of California, Santa Barbara.

Table 1. Comparison of surface areas when enclosure walls are rendered climbable. Excludes perching.

Enclosure Dimensions (L x W x H) cm	Ground Surface Area (cm2)	Surface Area of the Walls (cm2)	Total Surface Area (cm2)	Increase in Usable Surface Area
60 x 60 x 60	3,600	10,800	14,400	300%
60 x 60 x 90	3,600	16,200	19,800	450%
90 x 90 x 90	8,100	24,300	32,400	300%
90 x 90 x 120	8,100	32,400	40,500	400%
120 x 120 x 120	14,400	43,200	57,600	300%
120 x 120 x 180	14,400	64,800	79,200	450%
180 x 120 x 180	21,600	75,600	97,200	350%
240 x 120 x 240	28,800	115,200	144,000	400%
240 x 240 x 240	57,600	172,800	230400	300%

which also offer greater variation in physical and environmental conditions. However, this option may not be available to most zoological institutions due to tight operating budgets and/or a lack of available space and infrastructure to expand upon. While certainly not an equivalent substitute for larger enclosures, modifying existing enclosures to maximize the quantity and quality of usable surface area available within them represents an immediate, and perhaps more feasible technique in which reptile keepers can facilitate a greater range of mobility and activity among captives.

WHAT IS SPACE?

The concept of "space" in animal husbandry may take on different connotations depending on the species or taxonomic group in question. For example, while the total volume of an enclosure may be an appropriate determinant of space when designing enclosures for flighted birds, fishes, or other aquatic or flying animals that are able to utilize the full extent of their three dimensional environments, it would be a poor measurement for large terrestrial mammals and other species that are restricted in their movements to the ground and/or vertical surfaces. In the context of herpetological husbandry, volume may be an acceptable measure of space for some taxa such as aquatic turtles and crocodilians, but not for terrestrial turtles, lizards, and snakes. Possible exceptions to this generalization are flying dragons (*Draco* sp.) and other gliding reptiles (e.g., gliding geckos *Ptychozoon sp.*; gliding snakes *Chrysopelea sp.*) which use open spaces between trees for transport in nature. Despite widespread understanding of the general habits and spatial use of most reptile groups (i.e., aquatic, arboreal, terrestrial, etc.), volume is often perceived as the most appropriate measure of space for all reptile enclosures, even though voluminous open space may be of little to no use or benefit to many of these animals.

A related factor affecting the design, layout, and function of reptile enclosures is the misconception that "terrestrial" species are strictly terrestrial and will not climb or benefit from having the option to do so. Most lizards, even species with reduced or absent limbs possess some ability to climb even if they are not truly arboreal in habit, and many will readily utilize vertical climbing space in captivity. Landscapes in nature are rarely flat, and many terrestrial reptiles will regularly climb objects and landforms of various heights to forage, survey their environment, or communicate with conspecifics. Thus, enclosure heights of one, two, or even three meters could hardly be considered "arboreal", and are well within the acceptable ranges for many terrestrial reptile species when adequately designed to offer the ability to climb. Vertical surfaces are also important for many arboreal species such as monitor lizards of the *Varanus prasinus* complex which copulate while clinging vertically to the sides of trees (e.g., Mendyk, 2006), as well as other lizard species that utilize vertically-oriented habitats (i.e., tree trunks) such as *Draco* sp., forest dragons *Gonocephalus* sp., helmeted iguanas *Corytaphanes* sp., and frilled lizards *Chlamydosaurus kingii*. Enclosures which maximize climbing space can also facilitate a greater range of natural behaviors that would otherwise not be possible in strictly terrestrial captive environments, as well as offer greater opportunities for thermoregulation given the vertical temperature gradients within enclosures.

INCREASING USABLE SURFACE AREA

The interior walls of reptile enclosures are often overlooked in terms of their utility, and as a result, are rarely used to the benefit of their inhabitants. This can be observed by visiting reptile houses in many North American zoos, where exhibits on public display often feature bare concrete or fiberglass walls. Increasing the usable surface area within such enclosures by rendering the walls climbable represents a simple, inexpensive, and effective way of increasing space for captives. This approach, widely practiced in European reptile collections for several decades, has recently begun to catch on and gain popularity among North American herpetoculturists.

To what extent can the usable surface area of existing enclosures be expanded upon? Consider the following hypothetical lizard enclosure measuring 120 x 90 x 120 cm (length x width x height) (Fig. 1a). Assuming that this enclosure is furnished with tree limbs for perching (horizontal and diagonally oriented), offering a combined surface area of 5,400 cm^2 themselves, the total usable surface area of the enclosure when factoring in floor space (10,800 cm^2), is 16,200 cm^2 (Fig. 1b). By simply affixing a climbable material to the three interior walls of the enclosure, the total usable surface area of the enclosure is increased by 222% from 16,200 cm^2 to 52,200 cm^2 (Fig. 1c). Similar increases are shown for additional enclosures of varying dimensions in Table 1.

A variety of materials can, and have been used to render the walls of reptile enclosures climbable, but the appropriateness and utility of each will depend on the specific application (i.e., on public display vs. off-exhibit) and species in question, as some materials and their textures may be more appropriate for some taxa than others. For example, while prefabricated cork tiles and cork sheeting (often sold in rolls for floor underlayment) provide a climbable surface suitable for many clawed lizard species, they would be of no use to snakes or legless lizards since they do not offer the three dimensional surface texture needed by these animals for gripping and climbing. Instead, textured, hollow, or perforated materials such as virgin cork bark, cork tubes and garden lattice may be more appropriate for snakes, and can also be used with a variety of lizard species (Fig. 2). Additional materials that can be used in a similar light include virgin cork bark slabs, burlap, shade cloth, large sections of tree bark, and split tree trunks (i.e., the excess trimmed from trunks as they are milled lengthways into lumber). For heavily-bodied species such as large iguanid and varanid lizards, extruded high-density polyethylene (HDPE) aquaculture netting can be used as a strong wall covering to provide additional climbing surfaces (Fig. 3).

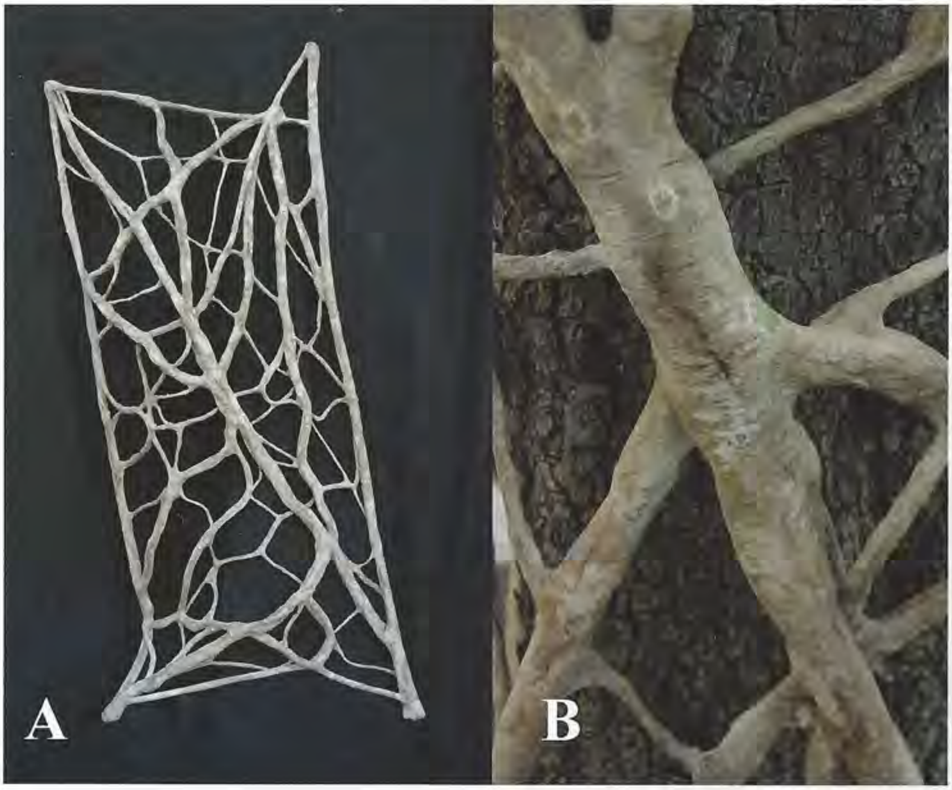
The usable surface area of an enclosure can be further increased when virgin cork flats and tubes, or double-sided wooden panels covered with climbable material (i.e., cork tiles or sheeting) are mounted to walls that have already been covered with flat, climbable wall coverings such as cork tiles or cork sheeting. This "double-layer" provides additional climbing space on top of and behind the coverings, and can also be used to create tight-fitting crevices for refuge (Fig. 4). Mounting these double-sided panels and cork flats to the walls with hinges can also allow for easy keeper access to specimens in hiding.

Most of these materials are easily cut to size, and can be mounted to existing wood, concrete, composite, or fiberglass walls and structures in a myriad of ways with little difficulty. Additionally, most are easy to clean and disinfect with mild bleach solutions or other disinfectants, and do not present any serious risks or concerns for harmful microbial growth. Many of these wall coverings, especially cork materials and HDPE aquaculture netting, may be beneficial to the claws of lizards, by helping maintain proper length, curvature, and sharpness through normal wear and tear.

In situations where aesthetics are important, particularly in exhibits on public display, materials such as cork sheeting, aquaculture netting, and burlap

Fig. 4: Virgin cork flats mounted on top of cork sheeting can provide additional climbing space and also create tight-fitting crevices for refuge (Spotted tree monitor, *Varanus similis* pictured).

Fig. 5: Flexible "StranglerFig Climbers™" (Zoological Fabrication, Inc., Sacramento, CA 95820; http://zoofab.com) can be mounted flat to enclosure walls (A) or wrapped around pillars, structural columns, and trees to increase climbable surface area and offer a more naturalistic jungle tree appearance (B).



may not be acceptable. As an alternative, several composite materials have specifically been developed for use in the zoo and aquarium field that can be used to render walls climbable while also adding a naturalistic appearance to exhibits. For example, non-toxic sculptable epoxies (Polygem, Inc., West Chicago, IL 60186; http://polygem.com) are safe and easy to use for creating naturalistic, climbable landforms such as rocks, cliffs, trees, roots, and vines. These materials have a broad range of applications which extend beyond naturalistic fabrication, and can be valuable for zoological facilities to keep on hand for episodic repairs or modifications to exhibits and various other projects. Similarly, some exhibit fabrication companies have developed flexible wall-mounting products specifically for the purpose of increasing vertical climbing space within enclosures while also offering the naturalistic appearance of jungle trees and vines (Fig. 5).

OUTLOOK

Utilizing the interior walls of reptile enclosures represents a simple and relatively inexpensive way in which zoos and related institutions can increase the amount of surface area available to lizards and snakes. As demonstrated in this article, modifications to bare walls can increase usable surface area more than threefold (Table 1), with additional alterations and additions yielding even further climbing space. Such increases can facilitate greater activity levels and promote a broader range of natural behaviors, and materials added to the walls can also increase variation in the physical environment, creating visual barriers and refuge sites which can reduce stress levels caused by conspecifics within the same enclosure.

As many zoological facilities may be unable to fund or accommodate new exhibit construction or renovation projects, keepers must look to alternative means of improving existing reptile enclosures to better suit the biological needs of their inhabitants. Such improvements need not be elaborate, costly, or require the expertise of architects, exhibit designers or fabricators, and even the simplest innovations can reap huge rewards in terms of improved animal welfare and keeping success. Since herpetological husbandry is a constantly evolving discipline that can always be improved and expanded upon, zoos and related facilities are strongly urged to look beyond the limitations of space and operating budgets to develop and experiment with innovative solutions to the husbandry-related challenges they face.

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