EAZA Reptile Taxon Advisory Group

Best Practice Guidelines for the Crocodile Monitor (*Varanus salvadorii*)

1st Edition,
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EAZA Best Practice Guidelines disclaimer

Preamble

Right from the very beginning it has been the concern of EAZA and the EEPs to encourage and promote the highest possible standards for husbandry of zoo and aquarium animals. For this reason, quite early on, EAZA developed the "Minimum Standards for the Accommodation and Care of Animals in Zoos and Aquaria". These standards lay down general principles of animal keeping, to which the members of EAZA feel themselves committed. Above and beyond this, some countries have defined regulatory minimum standards for the keeping of individual species regarding the size and furnishings of enclosures etc., which, according to the opinion of authors, should definitely be fulfilled before allowing such animals to be kept within the area of the jurisdiction of those countries. These minimum standards are intended to determine the borderline of acceptable animal welfare. It is not permitted to fall short of these standards. How difficult it is to determine the standards, however, can be seen in the fact that minimum standards vary from country to country.

Above and beyond this, specialists of the EEPs and TAGs have undertaken the considerable task of laying down guidelines for keeping individual animal species. Whilst some aspects of husbandry reported in the guidelines will define minimum standards, in general, these guidelines are not to be understood as minimum requirements; they represent best practice. As such the EAZA Best Practice Guidelines for keeping animals intend rather to describe the desirable design of enclosures and prerequisites for animal keeping that are, according to the present state of knowledge, considered as being optimal for each species. They intend above all to indicate how enclosures should be designed and what conditions should be fulfilled for the optimal care of individual species.

Preface

In 2002, I received the first crocodile monitors at the zoo where I was working. I had recently joined the herpetology team as a part-time keeper, and I remember the feeling when I saw such a beast. A week before the arrival, we prepared the enclosure for the animal. We just made some minor changes to the former home of a water monitor (*Varanus salvator*), the indications were to change the substrate and that's pretty much that: at the end of the day *V. salvadorii* and *V. salvator* are pretty much the same, aren't they?

Of course, we couldn't be more wrong on how to manage the species at first, and it didn't take long to start seeing the first problems arising: obesity, skin abrasions, and blunted claws. The animals were, nonetheless, the stars of the reptile house, people looked at them with awe, especially as the animals begun trusting the keepers, and we started feeding them in front of the crowd. The husbandry improvements went from natural branches to a larger space. At the same time, we started learning about the first conflicts from females towards males, even after several years of peaceful coexistence: their social behavior became the greatest enigma to be solved.

Almost 20 years have passed since then and now, thanks to technology, connectivity, and experience, we have learnt a lot about these interesting species, from their complex social behavior to their remarkable arboreal capabilities.

This document has been written by 20 different experts from EAZA, AZA, and ZAA institutions, NGOs, and universities. We are bringing the most updated and comprehensive piece of knowledge for this species with a clear objective: improve the welfare standards of crocodile monitors to increase the breeding rate and lifespan in captivity. Let's do it!

This work is part of the dissertation of the editor for the Ethology and Conservation MSc at the Autonomous University of Madrid. Manuel Merchán is the academic supervisor.

I dedicate this work to my baby girl Claudia Reh-Encinas and my lovely wife Cecilia Encinas for being my inspiration and motivation ♡

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Cover photo: Crocodile monitor pair at Mandai Singapore Zoo. Photo: Borja Reh

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Introduction

Crocodile monitors are impressive canopy dwellers; these large lizards are an apex predator of the tropical forests of the island of New Guinea. Being highly active and energetic animals, they offer an interesting option for a tropical habitat in any zoological institution. Moreover, this charismatic animal is an excellent ambassador to highlight the rampant habitat destruction in their native forests, the threats posed by the illegal and unsustainable wildlife trade, and the need for further conservation efforts. However, crocodile monitors are considered difficult to manage and breed in captivity. Furthermore their lifespan in captivity is presumably shorter than their wild counterparts. Therefore only a few zoological institutions dare to include them in their collection plans. Over recent years, substantial efforts have been placed in improving the captive management of this species resulting in new research and breeding successes that indicate an overall improvement of the knowledge of this species.

These EAZA Best Practice Guidelines were developed with the objective of improving the evidence-based knowledge of this species and provide the most comprehensive and up-to-date information for Zoological Institutions to ensure their animals have access to the best care.

The aspirational aim of this guide is to provide an overview of the critical components that need to be considered when keeping a large arboreal tropical lizard, to guarantee positive welfare experiences and correct physical development. By doing so, we expect to increase the breeding rate and lifespan in captivity and thus reduce the need or desire to remove this species from the wild. Improved understanding and appreciation of this species in captivity will also allow zoos to play an increased role in supporting and informing ex situ conservation efforts for this species. Additionally, we aim to raise the profile of the species as a suitable candidate for tropical exhibits in zoos across the EAZA members.

Section 1: Biology and field data

Biology

1.1 Taxonomy

- Order: Squamata
- Family: Varanidae
- Genus: *Varanus*
- Subgenus: *Papusaurus*
- Species: *salvadorii* (Peters and Doria, 1878)
- Subspecies: There are no recognized subspecies (Auliya & Koch 2020)

- Common names: Crocodile monitor, Papuan monitor, Salvadori's monitor, Tree crocodile
- Local names: Artrellia (PNG), Biawak salvadorii, biawak Papua (Indonesia) Birmopuku (Irian Jaya, Papua), Crocodile monitor (PNG), Giant Monitor (PNG), Totoro (Irian Jaya, Papua), Wa'o (Irian Jaya, Papua), Wuo'o (Irian Jaya, Papua), Phot Mingras (Moile dialect, Papua), Soa Soa Bintang (Papuan dialect, Papua) (Auliya & Koch 2020; Bayless 2004; Pattiselanno 2007).
- Etymology: The species was named in honor of the Count Tommaso Salvadori (1835-1923), a renowned ornithologist.

1.2 Morphology

The first description of *Monitor salvadorii* was provided by Wilhelm Peters and Giacomo Doria from one individual collected by Dr Odoardo Beccari in Manokwari, Irian Jaya, Indonesia in 1875 (Figure 1) (Peters and Doria 1878).

Further detailed descriptions of *Varanus salvadorii* can be found in the publications by Horn (2004) and Mertens (1942, 1962; 1950). According to the record books, *Varanus salvadorii* would be the longest lizard in the world, even more than the famous *Varanus komodoensis*. The record appears to be held by a specimen examined by Dr Michael Pope, a zoologist of Port Moresby, which measured 4,75m of total length (TL) (Wood 1972). Unfortunately, neither the lizard nor Dr Pope can be traced (Bennett 1995). Another specimen of 4,27m has been reported from the area of Kikori, Gulf Province, Papua New Guinea (MacKay, pers. comm.). However, these records may be overstated, as the TL recorded in captive individuals seldom exceed 2,5m (75-85cm SVL). In the literature, the longest specimen is ZFMK 47533, recorded at the Research Museum Alexander Koenig in Bonn, Germany, which measures 2,55 cm (Böhme and Ziegler 1997). The males are usually longer than the females, in at least 1,5:1 ratio respectively. Apparently, captive born adult females tend to be slightly smaller compared with their wild caught counterparts (Camina, pers. obs.). The males are heavier than the females as well, presenting a bulkier body and typically a more robust head. Data on crocodile monitor weight in captivity can be misleading; pictures in social media show animals above 10 Kg and some websites even claim the average weight of adults to be 20 Kg (Wojtasek 2013). We consider the healthy weight for adult reproductive males (~75cm SVL) to be between 5-6 Kg and around 2,5-3 Kg for adult females given their arboreal lifestyle as seen in the wild (Reh et al. 2021).

The main features of this monitor lizard are its blunt snout, which is not seen in other species of this genus, with the nostril slightly closer to the corner of snout than to the eyelid (De Rooij 1915), and the extremely long tail that takes up two thirds of the TL (Eidenmüller 2007). Depending on the individual/locality, the dorsal coloration in adults may vary between black to dark green-olive, with about five to seven irregular cross bands with large yellow spots, in between small spots, with juveniles being more distinctly patterned. These rows are also present along the entire length of the tail with irregular and indistinct yellow colour (Auliya and Koch 2020). Crocodile monitors of different localities seem to present slightly different color patterns (Figure 2). Although there are no publications supporting it, within the reptile market exists a nomenclature distinguishing between specimens originating from Sorong, Jayapura, and Merauke. The latter presents a characteristic yellowish snout, and a more brilliant colour pattern.

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14. Monitor Salvadorii, n. sp.

(*Tav.* II, *fig.* 1-2).

M. rostro elongato convexo, naribus obliquis anterioribus; squamis supraorbitalibus mediis irregularibus majoribus; occipitali distincto, squamis minoribus incluso; squamis colli corporisque undique carinatis elongatis; cauda longissima basi rotundata, reliqua triangulari, supra bi-, subtus multicarinata.

Niger, capite colloque flavo-punctato, corpore flavo punctato et maculato, cauda annulata, gastraeo flavo nigro marmorato.

Long. a rostro ad caud. bas. 0^{m}, 50; *capit.* 0^{m}, 11; *extr. ant.* 0^{m}, 19; *extr. post.* 0^{m}, 235; *caud.* 1^{m}, 15.

Hab. Dorei, Nova Guinea borealis (Coll. *Beccari*).

Questa forma assai rimarchevole è quasi un passaggio tra i sottogeneri *Hydrosaurus* ed *Odatria* perchè non ha la coda remiforme dei primi, nè grandemente verticillata delle seconde; nella nostra specie invece è rotondata alla base, quasi leggermente depressa e quindi diviene triangolare. Il capo ha il muso molto allungato e convesso, gli angoli rostrali sono rotondati, le narici sono allungate e poste presso il suo apice. Gli scudetti sopracefalici sono rimarchevoli per la loro grandezza specialmente quelli che si trovano innanzi al muso e nella regione interorbitale. Le regioni sopraorbitali sono coperte da scudetti più piccoli in mezzo ai quali ve ne sono alcuni irregolari più grandi degli altri. Lo scudetto nucale è ben distinto e circondato da altri più piccoli. Le squame della nuca sono come quelle del dorso, cioè rilevate da una carena longitudinale, e le anteriori sono più piccole delle posteriori. Le squame della gola innanzi alla *plica* hanno quasi la stessa forma di quelle del dorso, ma quelle del petto e del ventre sono molto più grandi, allungate, ristrette e fortemente carenate, come pure sono carenate quelle che ricoprono le estremità. Le squame della coda formano alla sua base dei piccoli anelli regolari, ma in seguito quelle inferiori diven-

Ann. del Mus. Civ. di St. Nat. Vol. XIII. (8 Ottobre 1878). 22

Figure 1. First description of crocodile monitor by Peters & Doria (1878) in Annali del Museo civico di storia naturale di Genova - Page 337. By Museo civico di storia naturale di Genova (Italy). . Holding Institution: Smithsonian Libraries. Sponsor: Biodiversity Heritage Library.

Figure 2. Crocodile monitors from different regions on New Guinea. Left Jayapura, and right Merauke. Photo: Harvey Lienardo - NLI Project Indonesia

1.3 Physiology

Very limited information is available on crocodile monitor physiology specifically. However, some studies provide insights of the physiological processes that could be considered general among monitor lizards. This field is obviously full of opportunities for future research in zoos.

1.3.1 Metabolism

Reptiles have significantly lower energy consumption than endothermic mammals and birds (Nagy 2005). However, monitor lizards have the highest metabolic rate for any squamate (Thompson and Withers 1997). Furthermore, within the Varanidae family, the arboreal species have a higher metabolic rate than the terrestrial ones (Thompson et al. 1995). It is also worth noting that widely foraging lizards have a higher field metabolic rate than ambush foraging lizards (Nagy 2005). It is unclear whether crocodile monitors are foraging or ambush predators. They have shown active foraging behavior in captivity (Reh pers. comm.). However, many experts seem to believe the opposite - that they ambush birds and bats in the forest canopy (Weijola pers. comm.).

As with other monitor lizard species, heart rate hysteresis is thought to occur in crocodile monitors whereby the heart rate increases during heating and decreases during cooling, and the associated changes in peripheral blood flow are thought to facilitate faster rates of heating and slower rates of cooling (Clark, Butler, and Frappell 2005; Seebacher and Grigg 2001). However, no studies have been carried out to confirm this claim in crocodile monitors.

Oxygen consumption, heart rate, ventilation, arterial pH and other physiological processes in varanids are more pronounced than in other reptiles, reflected in their specialized lung morphology and control of ventilation, and other physiological effects (Horn and Visser 1997). Hicks demonstrated the activity dependent flexible response of the pulmonary system in savannah monitors (*V. exanthematicus*) whereby hyperventilation was observed during active periods, and hypoventilation during digestion periods, in comparison with fasting rest values (Hicks, Wang, and Bennett 2000). These aerobic qualities are found in snakes and crocodiles as well, so it is expected to be general in monitor lizards. In this sense, crocodile monitors are considered to have the highest aerobic properties of reptiles (Horn 2004). However, once again we are missing specific studies on this species.

1.3.2 Blood physiology

Fontenot et al. describe physical, hematologic, and plasma biochemistry blood physiology on captive crocodile monitors using a small sample. The values are similar to other species. This study shows the effect of sex on the blood values: Males show higher values of chloride, while females show higher values of calcium, phosphorus, cholesterol, total protein, globulin, and uric acid which could be the result of estrogen-induced physiological changes observed in the normal breeding cycle of monitor lizards (except the higher uric acid). It also shows the seasonal variation in blood values highlighted by an elevated lactate dehydrogenase (LDH) value in winter (Fontenot, Lamberski and Pfaff 2004).

1.4 Longevity

Virtually nothing is known about crocodile monitors lifespan in the wild. There is some data about the longevity of captive specimens, but these data are tainted by the fact that most captive stock are wild-caught imported specimens and the age is therefore estimated upon arrival. Age estimation of physically small specimens is easier, while larger adult specimens are harder to determine and less accurate.

The oldest female crocodile monitor to have lived in an AZA institution was estimated to be a little over 21 years old at her death (Reeves 2019). She was an import that was estimated to be around 3 years old when she arrived at the Central Florida Zoo, where she lived for 18 years.

The oldest male crocodile monitor to have lived in an AZA institution was estimated to be a little over 25 years old at his death (Reeves 2019). He was an import that was estimated to be around 4 years old when he arrived at the Honolulu Zoo. He lived there for 21 years.

As husbandry and knowledge of captive requirements improves, there is no doubt amongst experts, that animals can exceed these ages. Overall, the captive population still tends to die at much younger ages. A large number of those younger animals die prematurely from egg binding, gout, or injuries from conspecifics. Improvements in the understanding of social interactions and nesting sites should fill major gaps in the husbandry knowledge available.

Field data

1.5 Conservation status/Zoogeography/Ecology

1.5.1 Distribution

Crocodile monitors are recorded from lowland and hill forests around most of the coast of New Guinea, and from Salawati Island off the western tip of the main island (Horn, Sweet, and Philipp 2007). They are found in open woodland habitat within the Trans-Fly region (Allison 2006). There are no confirmed records for the northeastern coast beyond Vanimo, though there are reports of kundu drums with crocodile monitor skin drumheads from the Torricelli and Prince Alexander ranges as far east as Wewak. However, the Tenkile Conservation Alliance (TCA) has recently reported captures of crocodile monitors in trail cameras in the Torricelli mountains far from their previously speculated distribution (Reh and Thomas 2021). Significantly, there are no records of any kind from the north coast eastward from the mouth of the Sepik River, despite decades of biological and anthropological research. The easternmost record on the southern coast is from the Kemp-Welch River east of Riga. The great majority of records are from below 200 m elevation. Recent camera trap findings by TCA, however, show crocodile monitors at a higher elevation than previously thought, with images of active animals at 1500 m and 18ºC of temperature (Reh and Thomas 2021). This finding supports a range extension to the Northern New Guinea montane rain forest ecoregion, at least in the Torricelli's. Crocodile monitors appear to avoid cleared areas and secondary forest and are eliminated by hunting around settlements. Fossil material assigned to *V. salvadorii* is known from northern Queensland, Australia (Molnar 2004).

Figure 3. A crocodile monitor captured by a trail camera in the Torricelli mountains at an elevation of 1300m. Photo: Tenkile Conservation Alliance (TCA).

Figure 4. A wild crocodile monitor at Wau, Abun, Tambrauw Regency, West Papua, Indonesia. Photo: Martin Mandák – Inaturalist

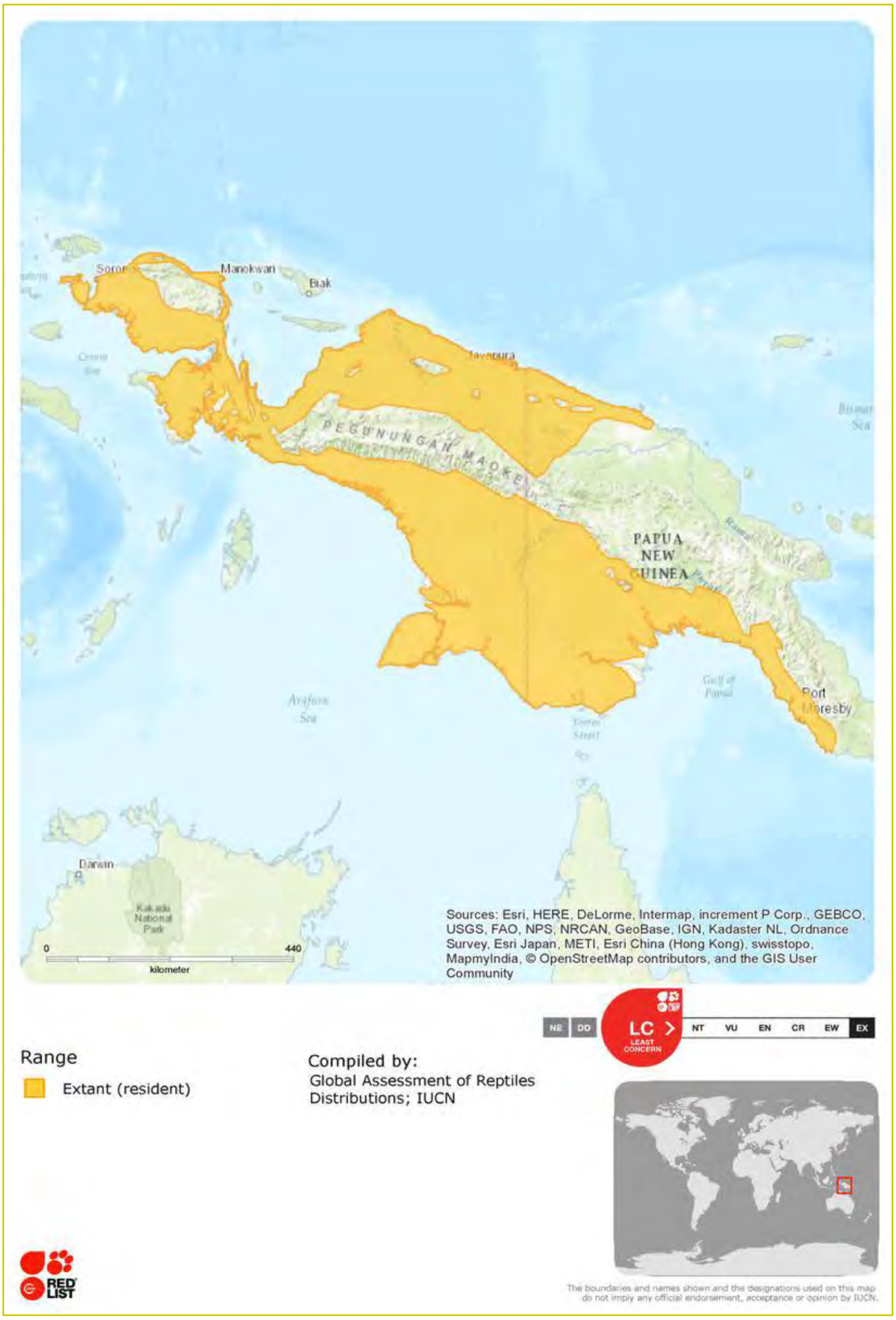


Figure 5. Crocodile monitor distribution map. The IUCN Red List of Threatened Species – published in 2016.

1.5.2 Habitat

This species inhabits a range of habitats including rainforest vegetation such as mixed alluvial and mixed hill forest types, as well as lowland and riparian forests. It appears to be restricted to intact undisturbed primary forests and strictly avoids contact with humans (Horn et al. 2007; Shea et al. 2016; Pattiselanno 2007). They are also found in open woodland habitat within the Trans-Fly region (Allison 2006). They are good swimmers and individuals have been observed in forests along rivers (Marshall and Beehler 2011). New elevation findings up to 1500 m ASL indicate the species inhabits the Northern New Guinea montane rain forests ecoregion, at least in the Torricelli Mountain Range (Reh and Thomas 2021).

1.5.2.1 Vegetation type

Crocodile monitors have been observed in primary rainforest of the Arfak Nature Park at 650 meters ASL where the following tree species were described: pacific teak trees (*Intsia* spp.), matoa trees (*Pometia* spp.), fig trees (*Ficus* spp.), pulai trees (*Alstonia* spp.), Java almond trees (*Canarium* spp.), Malay apple trees (*Syzygium* spp.), Klinki trees (*Araucaria* spp.), and Papua nutmeg trees (*Myristica* spp.) (Pattiselanno 2007). Cann reported capturing an animal in a sago palm (*Metroxylon sagu*) (Cann 1974; Horn 2004).

Figure 6. Crocodile monitor climbing a tree at the Varirata National Park, East PNG. Photo: Markus Lilje – Inaturalist

Crocodile monitors have been seen in the Sepik-Ramu forest system, formed by lowland rain forests dominated by Pacific teak trees (*Intsia* spp.) with local concentrations of *Agathis labillardierei*, especially in the Torricelli mountains and south of the Sepik river. Other species found in the region are the usual lowland species such as *Pometia* spp., *Terminalia* spp., *Palaquium* spp., *Eugenia* spp., and *Planchonella* spp. (FAO 2000).

1.5.3 Climate

New Guinea has a monsoonal climate with high temperatures and humidity throughout the year (Climate change development authority, Government of PNG 2020). There are only slight seasonal temperature variations although temperatures vary significantly according to altitude (Figure 7). Climatic conditions vary greatly from one area to another owing to the mountainous topography and the two major prevailing air streams (Prentice and Hope 2006). However, daytime temperatures below 2000 m height generally exceed 22 °C regardless of season. Each variation in elevation creates new ecological zones (Encyclopedia Britannica 2021). Crocodile monitors are widely distributed in the island of New Guinea except from Highlands Mountain range. This distribution includes different ecoregions including lowland rainforests, trans fly savanna and grasslands, mangroves, freshwater swamp forests, and montane rain forests (according to recent findings) (Figure 8).

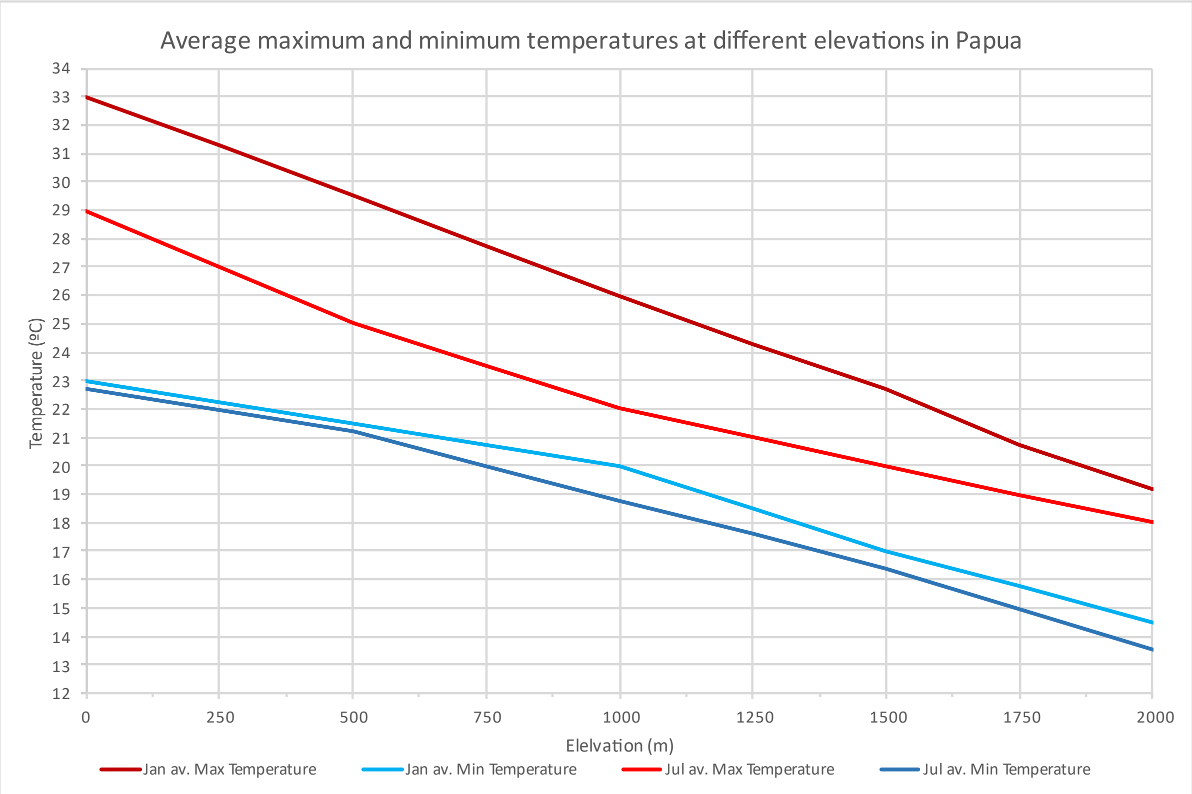


Figure 7. Average maximum and minimum temperatures for January and July for surface stations at different elevation on the Mt Jaya transect. Adapted from Prentice and Hope (2006).

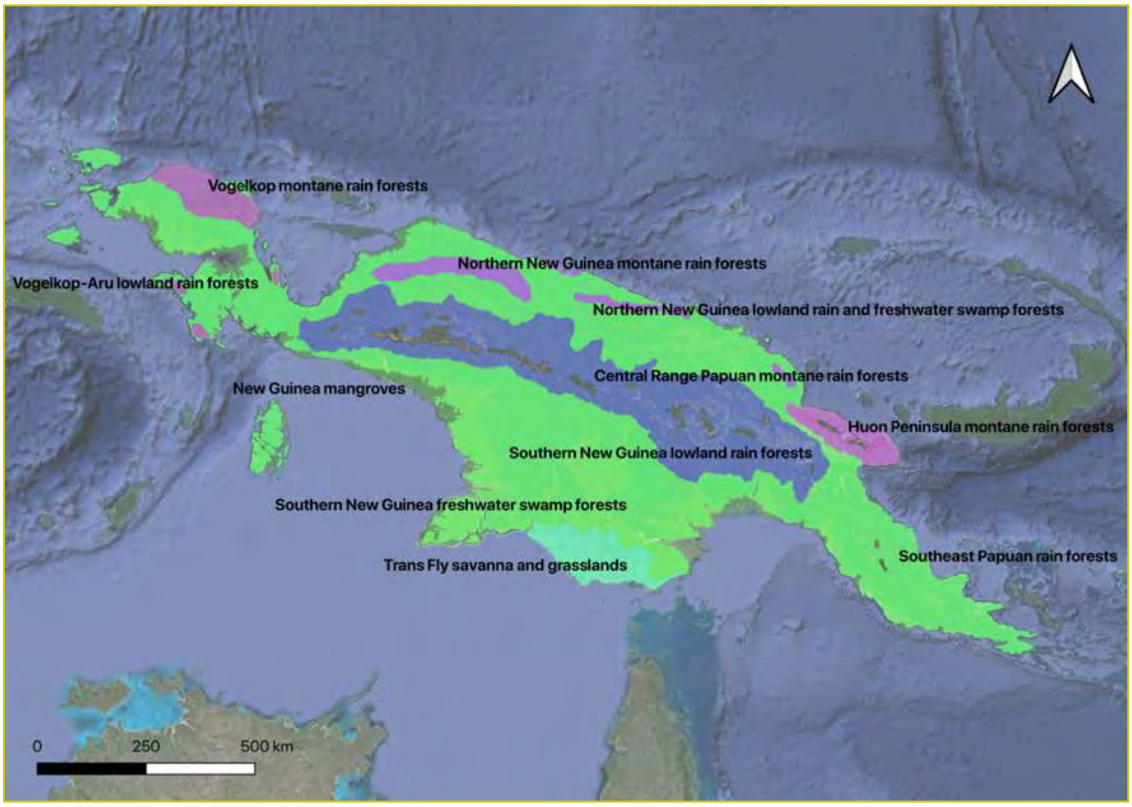


Figure 8. Ecoregions of New Guinea. Crocodile monitors occupy the lowland rain forests (except the Southeastern part of the island), savanna and grasslands, mangroves, and some parts of the montane rain forests. (Map data ©2015 Google).

Temperature variations and seasonality differences exist within the species distribution range. Below are climographs from different locations within the distribution of the crocodile monitor (Harris et al. 2020; Horn et al. 2007; Shea et al. 2016; Zepner et al. 2021). Note the slight variations caused by the northwest monsoon from December to March (Torricelli and Jayapura), a southeast monsoon from May to October, and the dryer season in the south in summer.

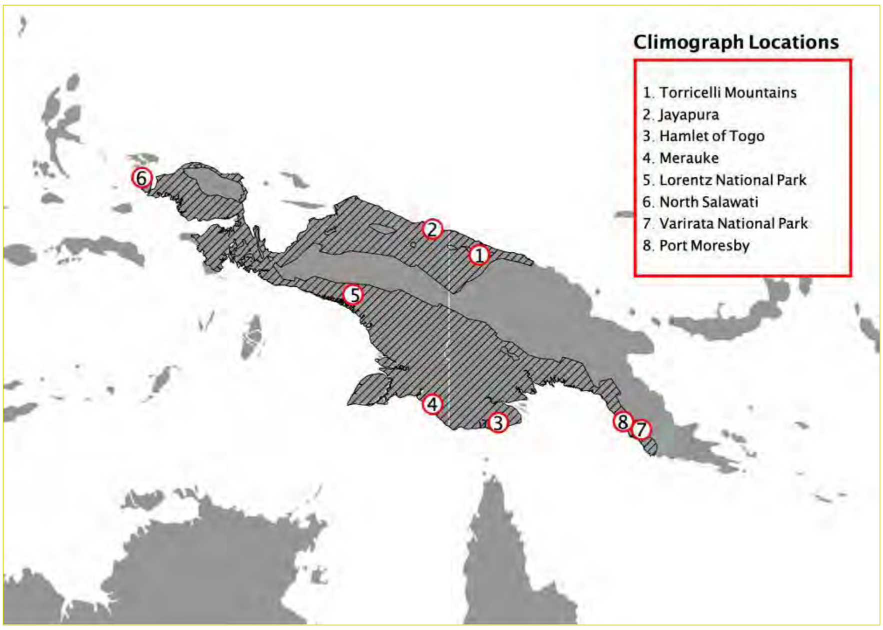
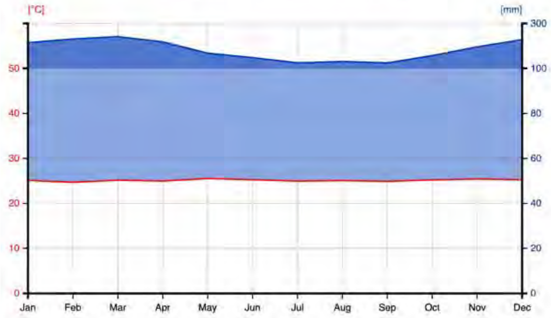


Figure 9. Climographs of different locations within the crocodile monitor distribution.

Torricelli mountains, Papua New Guinea

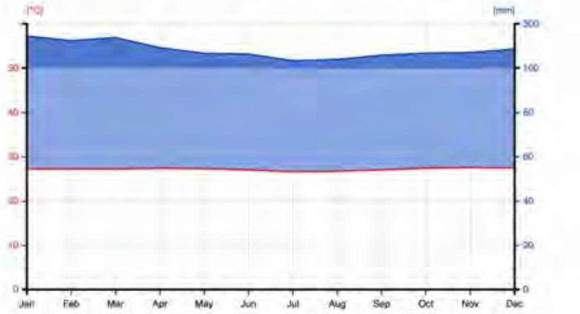
3.405S, 142.21E | Elevation: 1013 m | Climate Class: Af | Years: 1986-2017



Temperature Mean: 25.1 °C Precipitation Sum: 2178.8 mm

Jayapura, Papua, Indonesia

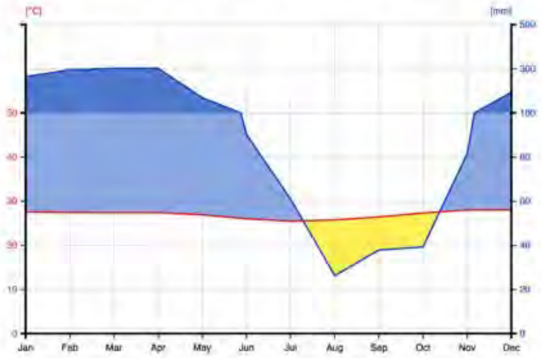
2.555S, 140.672E | Elevation: 338 m | Climate Class: Af | Years: 1956-2019



Temperature Mean: 27.2 °C Precipitation Sum: 2186.3 mm

Hamlet of Togo, Western Province, Papua New Guinea

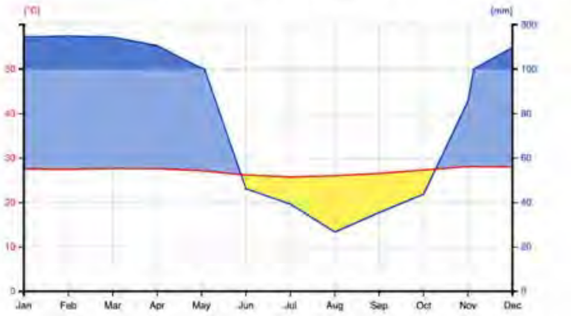
9.212S, 142.726E | Elevation: 13 m | Climate Class: Am | Years: 1956-2019



Temperature Mean: 27 °C Precipitation Sum: 1862.6 mm

Merauke, Papua, Indonesia

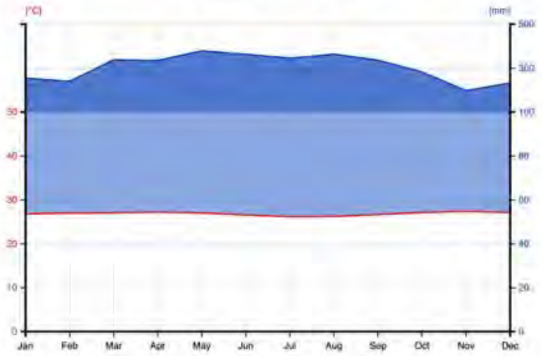
8.467S, 140.446E | Elevation: 9 m | Climate Class: A | Years: 1956-2019



Temperature Mean: 27.1 °C Precipitation Sum: 1519.9 mm

Lorentz National Park, Papua

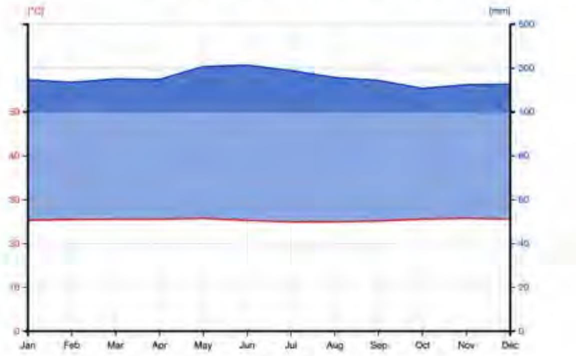
4.897S, 137.717E | Elevation: 25 m | Climate Class: Af | Years: 1956-2019



Temperature Mean: 26.9 °C Precipitation Sum: 3664.2 mm

North Salawati, West Papua, Indonesia

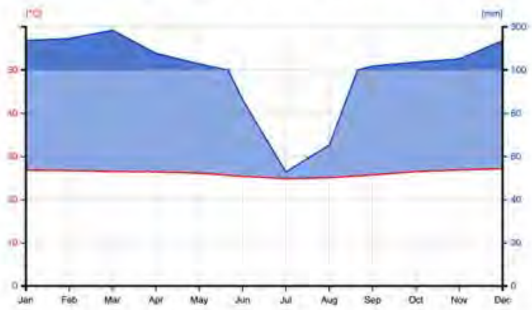
0.944S, 130.829E | Elevation: 217 m | Climate Class: Af | Years: 1956-2019



Temperature Mean: 25.4 °C Precipitation Sum: 3056.3 mm

Varirata National Park, Papua New Guinea

9.434S, 147.373E | Elevation: 741 m | Climate Class: Am | Years: 1956-2019



Temperature Mean: 26.2 °C Precipitation Sum: 1915.4 mm

Port Moresby, Papua New Guinea

9.43S, 147.22E | Elevation: 42 m | Climate Class: A | Years: 1875-2007

Temperature Mean: 26.9 °C Precipitation Sum: 1058.1 mm

1.5.4 Population

There are no hard data on the population biology of crocodile monitors, and they are probably extirpated wherever hunting for bushmeat is pursued. Basic considerations (large size and high metabolic rate) and the general observation that small mammals and birds are present only in low densities in lowland forests across New Guinea suggest that crocodile monitor population densities are also low. The current population trend is unknown (Shea et al. 2016).

1.5.5 Threats

The main threats for the species are habitat loss and human use for meat consumption and the international pet trade (Shea et al. 2016).

1.5.5.1 Habitat loss

Logging is an important source of income in New Guinea and also a sector in which unlawful activities are common (Mousseau and Bracale 2018; Mousseau and Lau 2016). Logging is affecting primary forests exponentially over the past decades and the trend is increasing (Letsoin et al. 2020; Miettinen, Shi and Liew 2011; PNG Data Portal 2021). Logging concessions in Papua are targeting key tree species linked to crocodile monitors including dawan and teak trees. Furthermore, alteration of microclimate on the logging sites is expected (Murdjoko et al. 2016).

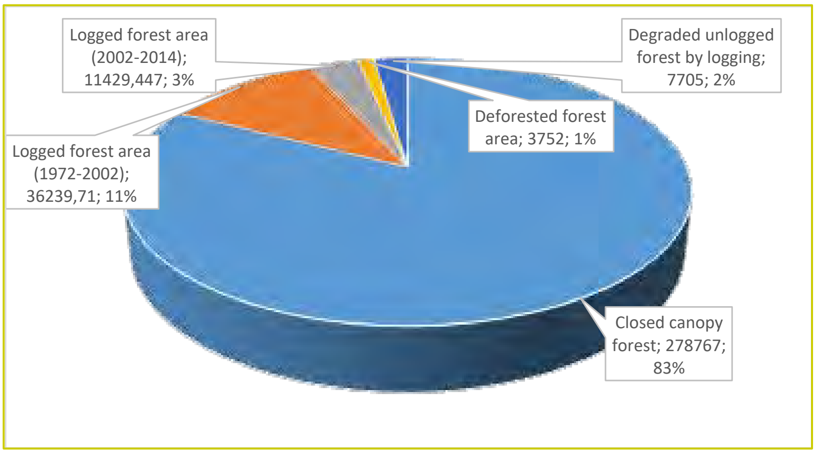


Figure 10. Forest Cover change in Papua New Guinea between 1972-2014. PNG Data Portal.

The main driver of habitat loss is in New Guinea is the recent operation of large palm oil companies that are clearing massive areas of forest for this intensive monoculture. The archipelago is experiencing one of the fastest rates of deforestation in the world (Amindoni and Henschke 2020; Curtis et al. 2018). Habitat loss is an increasing concern for the conservation of crocodile monitors. However, the impact of this threat has not been studied.

Figure 11. The rainforest in Papua is threatened by deforestation for palm oil plantations. Photo: Mighty Earth.

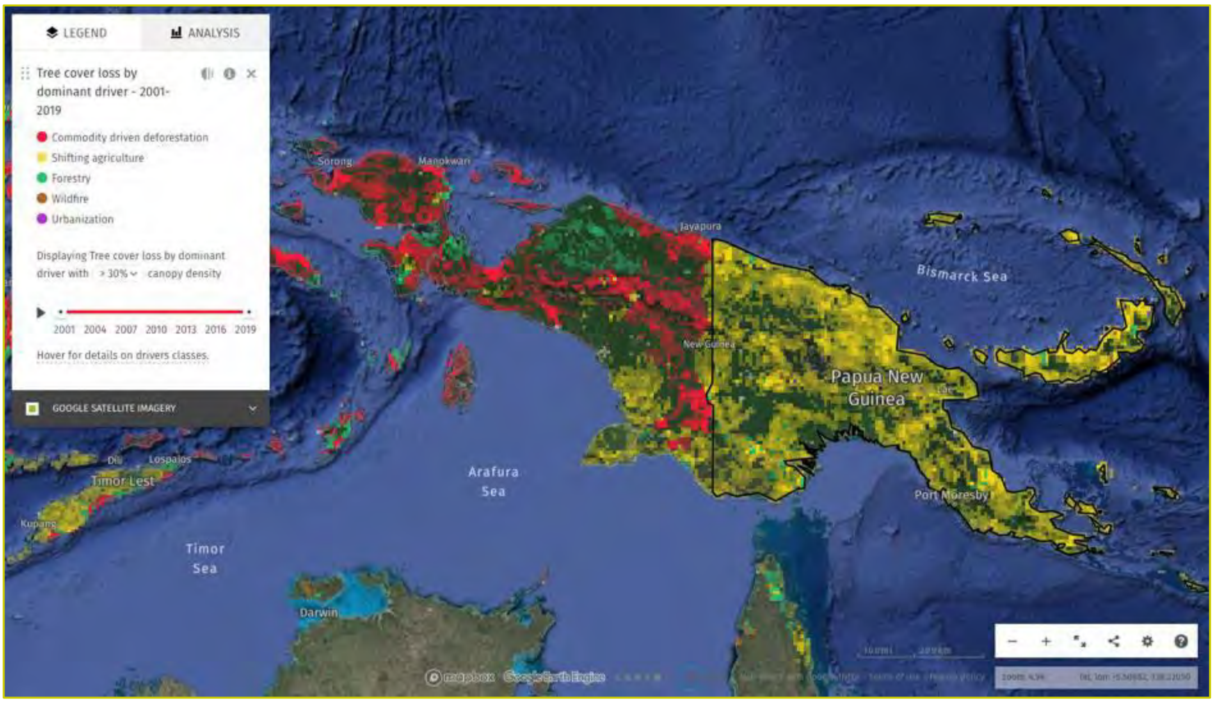


Figure 12. Dominant drivers of tree cover loss in New Guinea from 2001-2019. Commodity-driven deforestation: Large-scale deforestation linked primarily to commercial agricultural expansion. Shifting agriculture: Temporary loss or permanent deforestation due to small- and medium-scale agriculture. Forestry: Temporary loss from plantation and natural forest harvesting, with some deforestation of primary forests. Wildfire: Temporary loss, does not include fire clearing for agriculture. Urbanization: Deforestation for expansion of urban centers (Curtis et al. 2018).

Figure 13. The images above show forest clearing along the Digul River near Banamepe, Indonesia. The area was cleared between 2011 and 2016. The data used in the earlier image (left) by the Thematic Mapper (TM) on Landsat 5 in 2002; the later image (right) by the Operational Land Imager (OLI) on Landsat 8 in 2019 (Earth Observatory).

1.5.5.2 Human use

Crocodile monitors are actively hunted by local villagers for their skins (used for making drums) and for meat (Allison 2006). Although this species has a large geographic range in New Guinea, it tends to be uncommon and is highly sought after by the pet trade (Allison 2006). Indonesia, as one of two range States, allows a harvest of 300 live crocodile monitors for commercial trade annually, with 286 of these designated for international trade (as of 2021). This quota is based on data generated from non-detriment findings (NDFs) that would ensure offtake is sustainable and does not have a negative impact on wild populations. However, there are no accurate population estimates and it is likely the quota is based on levels of demand. There is plenty of evidence that the quotas set for harvest and export of wildlife from Indonesia are ignored and abused. Illegal trade in monitor lizards, including crocodile monitors, is relatively common and widespread, with animals being trafficked to Europe, North America and elsewhere to supply the demand for exotic pets (Figure 15). More research is needed to better quantify this trade and to inform policy measures, and to catalyse enforcement and conservation efforts.

Figure 14. Kundu drums, hollowed out with monitor lizard skin from the 1900-1950s. Photo: National Gallery of Victoria, Melbourne.

1.5.5.3 Invasive species

Invasive cane toads (*Rhinella marina*) have established in the northern, central, and south-eastern regions of PNG, as well as on many of the surrounding offshore islands. It is unclear whether these poisonous toads can cause problems to crocodile monitors or even if they will attempt to predate on them (Pettit et al. 2021). However, studies in Australia, have documented the potential impacts of cane toads on a suite of native taxa, including monitor lizards (Burnett 1997; Doody et al. 2009; van Winkel and Lane 2012).

1.5.5.4 Climate change

According to the World Bank Climate Change Knowledge Portal, Papua New Guinea is ranked as the tenth most vulnerable country in the world to the risk of climate change (Climate change development authority, Government of PNG 2020; World Bank 2011). Global warming in New Guinea will cause more frequent and severe El Niño and La Niña events (Prentice and Hope 2006). Furthermore, the latest El Niño event has been one of the strongest since data is collected in the 1950s (Kuleshov et al. 2019)

1.5.6 Conservation status

The conservation status of the crocodile monitor is poorly understood, and it remains among the least known of the varanids (Bennett et al. 1998; Horn et al. 2007; Reh et al. 2021). Knowledge of its geographic distribution over its range remains incomplete and threats to its survival are not well known (Reh et al. 2021). The IUCN Red List of Threatened Species assess this species as Least Concern and does not note any major threats to the conservation of the species (Shea et al. 2016). However, Crocodile Monitors are traded internationally as pets (Pernetta 2009) and although PNG does not permit commercial trade, this species is nonetheless captured and traded under an annual harvest and trade quota system in Indonesia. Crocodile monitors are listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and thus international trade is regulated. The EU, however, has suspended trade in wild-caught crocodile monitors from Indonesia since 1999 (Species+ 2021).

Figure 15. Seized adult crocodile monitor at the Munich airport (Germany), February 2011. Photo: Mark Auliya

1.6 Diet and feeding behavior

The population trend might be decreasing due to the combination of lowland forest loss and the potentially increasing demand by the pet trade. Meanwhile, the lack of population data in the wild remains the biggest uncertainty to understand their real conservation status.

There are no conservation projects targeting this animal specifically, however they are found in protected areas around the island of New Guinea.

1.6 Diet and feeding behavior

There is uncertainty around the feeding ecology of wild crocodile monitors. No research has been done on stomach content thus far, and we only have vague reports from local villagers and some unclear data. The existing information on the prey hunted by crocodile monitors include deer, pigs, dogs and even humans (Horn 2004), although the reports of large prey might have been exaggerated or based on carrion consumption. Other records indicate preference for smaller species such as small mammals, birds and their eggs, and even insects (De Lisle 1996; Pattiselanno 2007). Pattiselanno (2007) reported that crocodile monitors are observed in the cowpea (*Vigna unguiculata*) plantations during the harvesting period due to the access to nesting birds attracted by the fruits.

1.7 Reproduction

Once again, the missing data on the wild ecology leave a blank space in this section that can only be filled with assumptions from the observations in captivity.

Female crocodile monitors reach sexual maturity at three years of age while the males take up to two more years. According to the observations in captivity, there is no fixed breeding season and they seem to breed all year round (Figure 16).

According to the captive breeding data collected by Reh et al. (2021), crocodile monitors lay clutches of 4 to 12 eggs (Figure 17). The eggs are between 750 and 900 mm in length and weight between 40 and 80 grams (Figure 18, Figure 19).

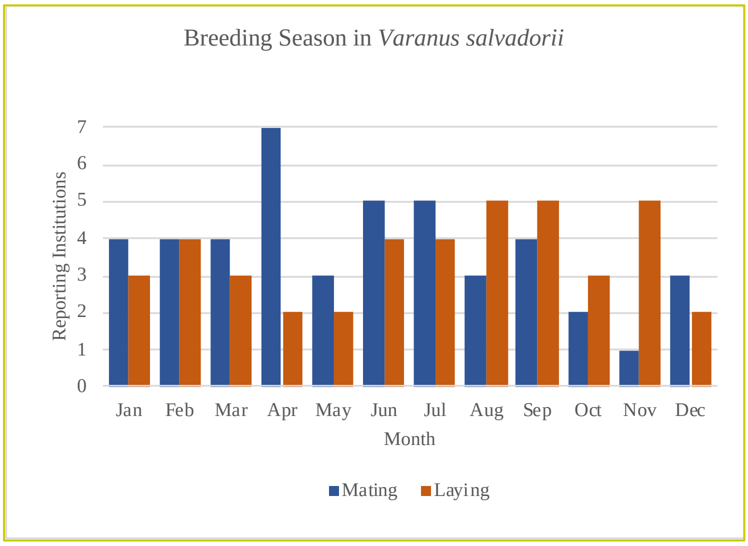


Figure 16. Breeding season in crocodile monitors as reported by different zoological institutions (Reh et al. 2021)

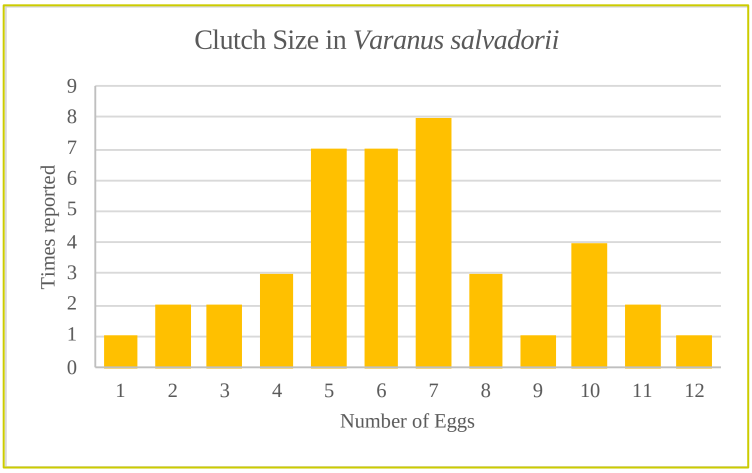


Figure 17. Clutch size in crocodile monitor according to 41 clutches reported from different institutions (fertility not determined) (Reh et al. 2021).

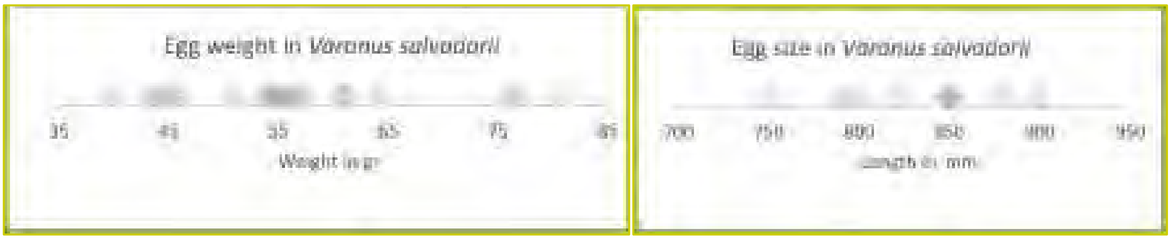


Figure 18. Weight and size records of crocodile monitor eggs. Horn (2004), and Singapore Zoo data (Reh et al. 2021).

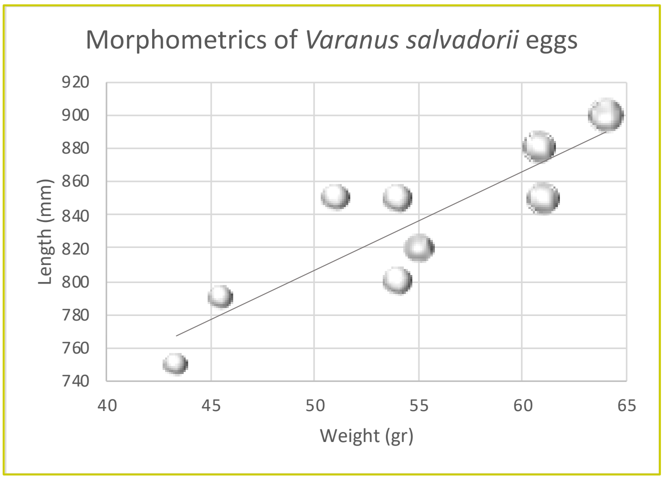


Figure 19. Morphometrics from 9 eggs in two different clutches of a crocodile monitor at Singapore Zoo. The trendline shows the correlation between size and weight (Reh et al. 2021)

Incubation takes from 155 to 240 days at a temperature between 28 to 30º C.

1.8 Behavior

The behavior of this species hasn't been studied, information on social interactions and sexual behavior in the wild have never been published. There are only a few reports of some behaviors in the wild. Cann noted the agility and speed of this species in the canopy when he observed a large animal leaping from tree to tree at a height above 7 meters from the ground (Cann 1974; Horn 2004).

Crocodile monitors are highly arboreal lizards, which suggests that they are very agile, fast moving, and precise. During a collecting trip of reptiles in West Papua, Cann observed crocodile monitors moving in the canopy and described them as the most agile monitors due to their fast running and leaping from branch to branch (Cann 1974; Pianka et al. 2004). Their prehensile tail is used as a counterbalance when they are using dynamic branches to move about in high elements. Their teeth are shaped in a hook like fashion which generates a firm grip after catching a prey to avoid losing it during their struggle. The most frequently observed prey in the wild are birds (De Lisle 1996; Pattiselanno 2007).

Crocodile monitors are unusual among varanids as the adults appear to be ambush predators rather than active search-and-pursuit foragers. A speculation on the behavior of larger animals is that they have quite large home ranges in which they know the locations of fruiting trees, and that they trapline such trees looking for temporary foraging pulses of flocking birds and bats, then lie in wait on canopy branches to ambush unwary prey. Observations by Kai Philipp and others suggest that individuals have "home" trees that are usually large and have hollow trunks with openings 10 m or more above ground (Figure 20) (Sweet pers. Comm.). Such trees have extensive scarring from the lizards' claws.

Figure 20. Photo sequence of a wild crocodile monitor leaving a tree hollow at Wau, Abun, Tambrauw Regency, West Papua, Indonesia. Photo: Martin Mandák – Inaturalist

Section 2: Management in Zoos and Aquariums

Crocodile monitors are large, arboreal lizards and one of New Guinea's apex predators (Heinsohn and Hope 2006). Exhibiting high levels of activity, they are an exciting species to display within zoological institutions, whilst also representing a challenge for those wishing to house them (Reh et al. 2021). Over recent years, efforts to improve the captive management of this species have been made. Exhibit design has been considered a critical factor in successful crocodile monitor management, mainly due to the link between the habitat and the variables that affect breeding in this species, such as physical condition, environmental settings, and nest selection. Here we provide an overview of the critical components that need to be considered, when designing an enclosure for this species, to guarantee positive welfare and correct physical development, with potential applications for other large, arboreal lizards.

2.1 Enclosure

2.1.1 Dimensions and boundaries

Habitat space plays a significant role in the physical development of crocodile monitors. Large enclosures and proper furniture are required to minimize stress and increase activity levels in captive monitor lizards (Card 1995; Fischer 2012; Wilkinson 2015). The data collected from different zoological institutions on space availability for crocodile monitors show that bigger exhibits with higher climbing options are generally selected for keeping this species (Figure 21) (Reh et al. 2021). An abundance of appropriate furniture, with multiple climbing opportunities, helps in encouraging these curious animals to stay active for extended periods. Crocodile monitors utilize vertical space as well as the ground area to explore.

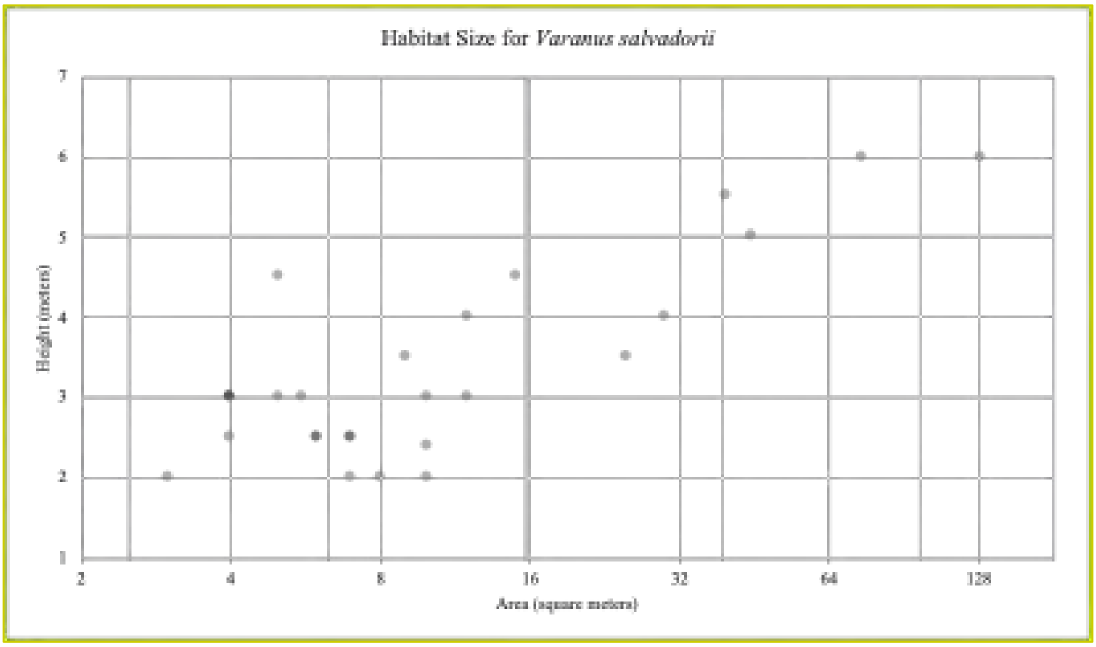


Figure 21. Habitat size for crocodile monitors in selected institutions, including the holding cages (Reh et al., 2021). The X-axis represents the height in meters, and Y-axis represents the area in square meters. Darker dots represent the same size enclosures.

High enclosures with climbing options are always desirable. However, good gripping options and soft bedding are crucial to mitigate trauma from accidental falls. The habitat size has to adapt to the different life stages of the animals. Neonate monitor lizards have a higher metabolic rate due to rapid growth, and therefore energy consumption is higher (Thompson and Withers 1998). Hence, they must be kept in an enclosure large enough for the animals to climb and move around but small enough to allow monitoring and to prevent injuries from falls. As they grow, they require a larger space to develop physically and perform their natural climbing behaviors.

Figure 22. The Riverside County Animal Services officer holding an escaped crocodile monitor in Riverside, California. Photo: Riverside County Animal Services/Facebook

The arboreal skills of crocodile monitors make them a challenging species to contain, and several escapes have been reported. On three occasions, one animal managed to climb over two-meter-long smooth tree cladding and reached heights of 12 meters at the highest part of the tree (Reh et al. 2021) (Figure 26). If they find a way out, crocodile monitors can travel long distances if they have access to the canopy. They do not generally move as far at ground level, however. For instance, an escaped animal in one institution remained on the premises for more than a month before being found again close to where it escaped. There were no connecting canopy trees in that park (Reh, pers. comm.). Crocodile monitor escaping abilities have been also reported in the Honolulu Zoo where a gravid female managed to squeeze through a two-inch gap in the corner of its exhibit (Murphy et al. 2019). The police had to intervene when an animal escaped in Riverside, California (Figure 22).

Different sized animals have different barrier requirements. Hatchlings and younger animals should be kept in fully-enclosed escape-proof tanks (Figure 24, Figure 25). However, as they approach maturity, they require a large space and climbing opportunities that might be challenging to achieve in a cage. Greenhouses and outdoor enclosures, where conditions are favorable, are preferred options, provided the animals can be confined within the enclosure boundaries (Figure 62).

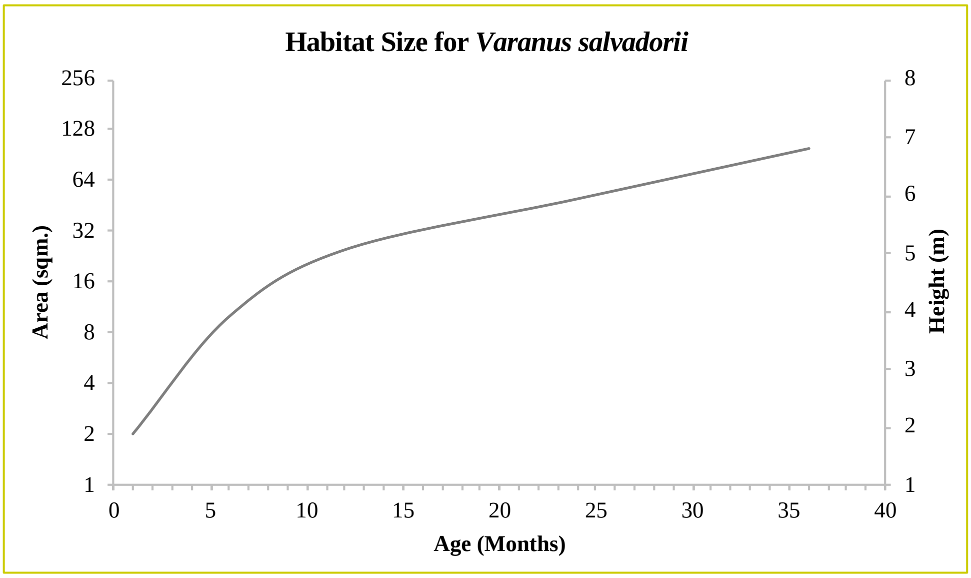


Figure 23. Recommended habitat size (area in sqm and height to which the animal has access) in relation to the animal age. Newborn lizards can be kept in small 2 sqm and 2 meters high tanks. However, after six months, the animals will require a much larger space.

Generally, crocodile monitors are unable to climb over 120 cm flat and smooth surfaces such as glass or steel plates. Porous materials such as wood, concrete, and other surfaces have to be carefully examined regularly as the animals might be able to find tiny imperfections to climb. Glass is an excellent barrier for crocodile monitors, although a careful design is required to prevent collisions with invisible barriers seen regularly in different lizard species (Warwick 1990; Ziegler et al. 2009). Glass corners and transparent overhangs have to be avoided to prevent interaction with transparent boundaries (Warwick et al. 2013).

Figure 24. Tank for baby crocodile monitors with partition to separate during feeding. Photo: Borja Reh

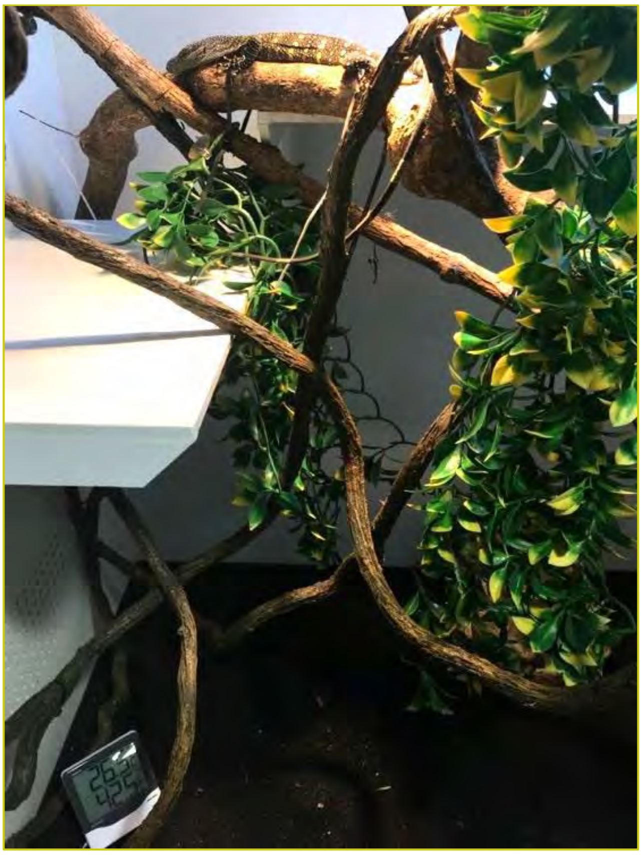


Figure 25. Hatchling crocodile monitor in a tank. Note the temperature gradient provided (26-42ºC). Photo: Borja Reh.

Figure 26. Drone image of a crocodile monitor resting in the top leaves of the tree. Photo: Adil Hakim, Mandai Wildlife Reserve.

Mesh can be used as a barrier for crocodile monitors, but the size and shape of the mesh need to be carefully reviewed to avoid unexpected digit and claw injuries, as well as snout abrasions (Holmes and Divers 2019). The mesh size must be large enough for the animal to climb comfortably and small enough to prevent protrusion of heads or limbs. A one-inch square stainless-steel mesh works well for adults in most cases (Figure 27, Figure 28). All barriers should be buried deep enough to prevent the lizard from digging the way out and also to prevent unexpected wild visitors (Barten and Simpson 2019).

Figure 27. (Left) One-inch square stainless-steel mesh, used to construct off-show crocodile monitor enclosures at Marwell Zoo. Photo: Rob Haines, Marwell Wildlife. Figure 28. (Right) Detail of stainless-steel mesh used at the Singapore Zoo. Photo: Borja Reh

Visual barriers are used to prevent animals from seeing other animals or people. Visual barriers can be made of artificial materials (i.e., wood planks) or natural plants and rocks. As with other factors, different animals will have different preferences depending on their origin and history in captivity. Generally, wild-caught crocodile monitors are extremely sensitive and like to hide from other animals or people; they might suffer stress when unable to do so. In one instance, a wild-caught female chose the heating lamp to rest as it was the only location where the animal could not be seen from anywhere outside the cage; the animal suffered serious thermal burns (Reh, pers. comm.). Visual barriers are required, especially between males and females since both sexes might suffer stress when seeing each other. Courtship and aggression have been observed where visual barriers were not in place (Reh pers. comm.). Visual barriers can also be used to improve compatibility when different animals share a single enclosure during the mating season.

Daily monitoring of the surrounding trees and barriers will help in determining the safety of the infrastructure to contain the animals. Careful monitoring of the vegetation growth and trimming whenever necessary is crucial in tropical countries or after heavy rainstorms. The jumping capabilities of this species should also be considered when inspecting branches and other climbable structures close to the enclosure boundary. Animals housed in outdoor enclosures should overnight in a sheltered area protected from extreme weather events and tree falls.

Preventing lizards from climbing particular trees or to undesired heights is a challenging task. Crocodile monitors are able to grasp and pull up their entire body easily around tree cladding regardless of the material. Transparent overhangs do not function well since animals try to reach further up when they have a clear view (Reh et al. 2021). Any cladding therefore needs to have an opaque overhang (Figure 30).

Figure 29. Detail of tree cladding and overhang to prevent escapes. Photo: Hakeem Osman – Mandai Wildlife Reserve

Figure 30. Crocodile monitors mating at Singapore Zoo. Note the cladding and overhang to avoid escapes. Photo: Borja Reh

Above, the basic barrier needs to prevent animals from escaping have been discussed. However, there is another consideration that needs to be addressed: thievery. Monitor lizards are heavily targeted by thieves due to their high value in the black market (Mendyk 2020). Prevention with security measures such as CCTV cameras and barriers that prevent unexpected visitors from accessing the enclosure are mandatory.

Biosecurity and barrier management

Maintaining effective biosecurity protocols is essential to avoid the spreading of potentially harmful pathogens (Kischinovsky, Raftery, and Sawmy 2017) (see section 2.7 Veterinary: Considerations for health and welfare). Bacterial, parasitic, and fungal pathogens such as *Entamoeba invadens, Cryptospopridium* sp., and *Nannizziopsis* sp. have been reported to spread quickly from other reptiles of the collection, especially herbivorous chelonians and desert lizards (i.e., *Centrochelys sulcata*, *Pogona* sp.) (Reh, pers. comm.). Therefore, it is recommended to assign different keepers to look after monitor lizards or schedule different days for servicing the enclosure, avoiding cross-contamination with the more hazardous species. Additional preventive measures such as hand sanitizer and boot changes, located at the enclosure's door, are also recommended at the entrance of the enclosure.

2.1.2 Habitat design

Habitat preferences, environmental conditions, natural behavior, and metabolic rate are critical considerations when designing a captive environment for any reptile species. Mistakenly considered as primitive animals in the past (Barten and Simpson 2019), new studies suggest a high behavioral complexity level in reptiles, including cognition, play, emotion, and even consciousness (Burghardt 2013). Therefore, reptiles' physical and physiological development depends on well-designed enclosure and management practices aligned with the species-specific biological needs (Burghardt 2013).

Despite having significantly lower energy consumption than endothermic mammals and birds (Nagy 2005), monitor lizards have the highest metabolic rate for any squamate. Furthermore, within the *Varanidae* family, the arboreal species have a higher metabolic rate than the terrestrial ones (Thompson and Withers 1997). It is also worth noting that widely foraging lizards such as crocodile monitors have a higher field metabolic rate than ambush foraging lizards (Nagy 2005).

With the above considerations, crocodile monitors are a challenging species to keep and breed in captivity. Crocodile monitors in zoos have historically had low life expectancy and high premature mortality rates (Mendyk 2015). The main drivers to the high mortality rates in this species are linked to different pathologies such as dystocia and gout (Reh et al. 2021). In contrast, the most likely cause of low breeding rates might be related to suboptimal physical conditions and intraspecific aggression. All issues highlighted above are linked to inadequate provision of captive living conditions. Additionally, being excellent climbers, crocodile monitors are prompt to find unimaginable escape routes from their enclosures, and extreme precautions must be taken before releasing the animals in a new or modified facility.

Lastly, one size enclosure does not fit all. Different life stages will require different exhibit barriers and features; for instance, neonate crocodile monitors will have very different requirements from adult ones (Reh et al. 2021).

Video 1. Crocodile monitor enclosure at Reptopia (Singapore Zoo). Borja Reh	

Indoor and Outdoor Enclosures

Whenever possible, crocodile monitors should be kept outdoors; Honolulu Zoo and Singapore Zoo have appropriate climatic conditions to do so all year round (*Video 1*). Other institutions, like Houston Zoo and Dallas Zoo, have designed new facilities that allow timesharing the animals outdoors during weather permitting periods (*Video 16*, Figure 65) (Mays 2007), (Hartdegen pers. comm). The temperature requirements for this species, however, mean that this is not an option in regions where the required ambient temperatures cannot be achieved outdoors. Where outdoor facilities are not possible, indoor controlled environments can replicate the natural conditions by providing basking zones using high output lights, as well as using artificial rain with misting and sprinkler systems to replicate storms.

A good example of an indoor habitat is the enclosure built at Marwell Zoo in 2016 (Figure 31). It offers ample space and excellent conditions with the provision of natural sunlight through an ETFE (Ethylene tetrafluoroethylene) roof that allows 85% UV penetration. A biomass boiler and two shortwave-infrared (IR-A) radiation quartz-halogen heaters (Star Progetti Helios Infrared Heater IRK Titan 2V) maintain the proper temperature gradient for ambient temperature and basking areas, respectively. High-output T5 fluorescent lamp units (LightWave T5 LW48-HO or Arcadia SuperZoo-T5), combining 6/8 fluorescent tubes each, provide supplementary UV spectrum lighting to mitigate low UV-Index levels during winter and on overcast days. A raceway connects the main exhibit to three off-show enclosures. This configuration allows timesharing of the enclosures between lizards. Additionally, the raceways (Figure 32) have multiple hatches (underneath and on the side) to facilitate veterinary procedures and training activities. Each raceway is ~2m off the ground (Garrick pers. comm).

Figure 31. Indoor crocodile monitor exhibit at Marwell Zoo. Photo: Dan Garrick, Marwell Wildlife.

Figure 32. Raceways between off-show crocodile monitor enclosure at Marwell Zoo. Photo: Dan Garrick, Marwell Wildlife.

2.1.3 Substrate and furnishing

The substrate and vertical components are essential for allowing the expression of important natural behaviors such as nest building and climbing in crocodile monitors.

There are a wide variety of naturalistic substrates, which vary in texture, particle size, absorbency, and physical support (Rossi 2019). The substrate must meet the species-specific requirements for nest building, moisture content, and temperature (Portas 2018), with the aim being to provide a substrate that best replicates the substrate within the species' natural habitat. Thus, a mixture of soil and leaf litter is an example of an appropriate substrate for crocodile monitors. Concrete flooring and other abrasive materials need to be avoided as they might damage skin and claws, making them blunt and incapacitating their climbing abilities. Soft bedding is required to ensure the animals can withstand falls from height, especially during the habituation period (Reh et al. 2021).

Crocodile monitors are highly arboreal animals able to spend several days without touching the ground. Therefore, the provision of several climbing options is paramount for the display of natural behaviors. Natural trees, logs, and branches can be used as climbing options by crocodile monitors, providing the bark is soft enough for their claws.

Figure 33. Thigmothermic behavior and basking in crocodile monitors at Singapore Zoo. Photo: Borja Reh.

Branches of the genus *Quercus* are an appropriate option due to their long-lasting properties and bark which can easily be gripped. The animals easily climb these types of surfaces to move around the enclosure (see section 1.5.2.1 Vegetation type for the list of wild tree species). Nevertheless, the climbing ability of crocodile monitors is impressive, with one adult animal at Marwell Zoo having been observed descending from heights of over 4 meters using only smooth bamboo stems less than 5 cm in diameter on more than one occasion (Haines pers. comm.).

Live plants growing within the enclosure at Marwell Zoo include *Pachira aquatica* and *Ficus lyrata*. Artificial trees can be considered to create support whereby natural branches can be inserted. Concrete is difficult to grip and damages skin and claws, and hence the best perching options should be either a soft material or natural wood.

Thigmothermic behavior (absorbing heat from contact with a surface) is commonly used by different species of lizards for thermoregulatory processes (Dawson 1975). Crocodile monitors expose themselves to radiating heat from rocks (Figure 33) when the ambient temperature is low, and there is limited access to solar radiation (Garrick 2008). Furnishings that facilitate this behavior can therefore be of benefit when incorporated within the enclosure design, provided the animals also have access to other heating sources providing heat through light and IR-A radiation.

Nesting Sites

Selecting the perfect location for nesting is critical for all egg-laying reptiles; the environmental conditions of the nest will determine the success of the incubation (Resetarits 1996). In addition, finding a safe spot will have implications on the survival rate of the eggs from predation (Setyawatiningsih et al. 2016).

Figure 34. A female crocodile monitor covers the eggs carefully. Singapore Zoo, 2019. Photo: Borja Reh.

Crocodile monitors are known to hide the nests like other monitor species do (Doody et al. 2014; Rhind et al. 2016). The female often digs several holes before selecting a site. The hole is then backfilled to avoid detection by possible predators. This ability to camouflage the nest must be taken into consideration when females are about to lay, since the nests will be invisible on most occasions. Finding a nest in a large enclosure can be a challenge if the laying procedure was not observed (Reh et al. 2021). One potential solution to this challenge is to use CCTV or trail cameras to record nesting behavior when keepers are not present. Alternatively, the search area can be reduced by designing the enclosure in a way that limits egg laying to specific areas. This can be achieved, for example, by creating areas with reduced substrate depth. Care must be taken, however, to ensure that multiple nesting options remain available, due to the issues with female selectivity described below. Crocodile monitors are picky when selecting a nest (see section 2.4.3 Nest construction). To address this point, multiple options for nesting should be provided (Reh et al. 2021). The factors considered for nest selection include media, humidity, depth, and temperature. Additionally, the area where the nest is located must be considered a safe location by the animal. Different females show different priorities for nest selection. A large 1.2-meter-high bin with a mixed media of cocopeat, peat moss, sphagnum moss, and sand (40.40.10.10 in weight) has proven successful with some females (Figure 35) (Reh et al. 2021). This nest can be elevated with access from a branch. Nevertheless, some females choose to lay on the ground (Figure 37). Nests offered inside a sheltered area provide security to the animal and have worked well with some females (Reh, pers. comm.).

Figure 35. A crocodile monitor laying eggs in a large plastic bin. Singapore Zoo. Photo: Borja Reh.

The egg chamber of crocodile monitors varies in size depending on the clutch size as well as the individual preferences of the female. Generally, the top eggs are found at least 20 cm deep, and the lowest ones around 50 cm deep. Some females might dig deeper chambers, most likely depending on the humidity level of the substrate (Reh et al. 2021).

The relative humidity of the substrate for nesting must be between 80-90%, and the depth must allow the animals to dig down at least 60 cm (Figure 36). As commented before, the area must be considered safe for the animal to lay.

Figure 36. A custom-made nest used by crocodile monitors for nesting. Photo: Harvey Lienardo – NLI project Indonesia.

Figure 37. Female crocodile monitor laying eggs on the ground at Honolulu Zoo. Photo: Dwain Uyeda, Honolulu Zoo

2.1.4 Lighting and heating

Reptiles rely on the environment to maintain the correct homeostatic balance (Oonincx and van Leeuwen 2017). Natural sunlight offers a diversity of radiation and light spectrum, while the trees and clouds offer natural filtration to the solar rays, creating different microclimates for the animals to select (Baines and Cusack 2019). Illumination has an influence on physiology and behavior (Holick 1995), UVB spectrum light plays a critical role for the physiological processes of reptiles (Baines et al. 2016), and UVA light has been shown to initiate and maintain normal agonistic, reproductive, and signaling behaviors due to the enhancement of natural colors, and even promoting activity levels in some reptiles (Gehrmann 1994; Moehn 1974; Oonincx and van Leeuwen 2017). Full-spectrum light assists prey recognition in some species of reptiles and has been used to stimulate the appetite in reluctant feeders (Oonincx and van Leeuwen 2017). Additionally, full-spectrum light helps to avoid environment-related chronic stress and immunosuppression in reptiles (Adkins et al. 2003). Furthermore, the impact of full-spectrum lighting in reptile welfare needs to be further investigated as many authors believe the positive contribution of light in reptiles is far beyond our current scientific knowledge (Oonincx and van Leeuwen 2017).

With all the considerations mentioned above, natural unfiltered sunlight is the preferred source of light for lizards in general (Adkins et al. 2003). In climates where indoor housing is necessary, transparent, UV-permeable roofing is preferable to a fully opaque roof and total reliance on artificial lighting. High-quality full spectrum artificial light sources can be considered as an alternative where natural sunlight provision is not possible (Reh et al. 2021). Whenever animals are housed inside, however, full spectrum lighting must be provided, even if it is a supplement to natural sunlight that is filtered through a transparent roof. This is because the UV levels and number of daylight hours in temperate regions will be insufficient to meet the needs of tropical species, particularly during the winter months (Baines et al. 2016).

When providing light and heat through artificial means, attempts should be made to replicate natural solar radiation as closely as possible. This means that UVB radiation should be paired with shortwave infrared radiation (IR-A), delivered from above, creating a basking zone that imitates a beam of sunlight (Baines et al. 2016). It should also be noted that artificial basking zones must be large enough to allow an animal to warm its entire body if it wishes to do so. Furthermore, when given access to natural sunlight, crocodile monitors preferentially seek out elevated basking spots within the canopy, rather than at ground level (Reh et al. 2021). Artificial basking zones should therefore be positioned in a way that facilitates this.

Thermal imaging cameras can be utilized to monitor and assess the suitability of artificial basking sites, ensure that the animal is able to evenly warm its entire body, and to ensure that there are no unexpected hot spots that could be at risk of causing thermal burns (Figure 38, Figure 39).

Wet bulb globe temperature meters, such as the HT30 produced by Extech, can also be used to measure temperature, as they account for the effects of humidity, air movement and blackbody radiation and can sometimes give contrasting measurements to those taken via other means (Figure 41, Figure 39).

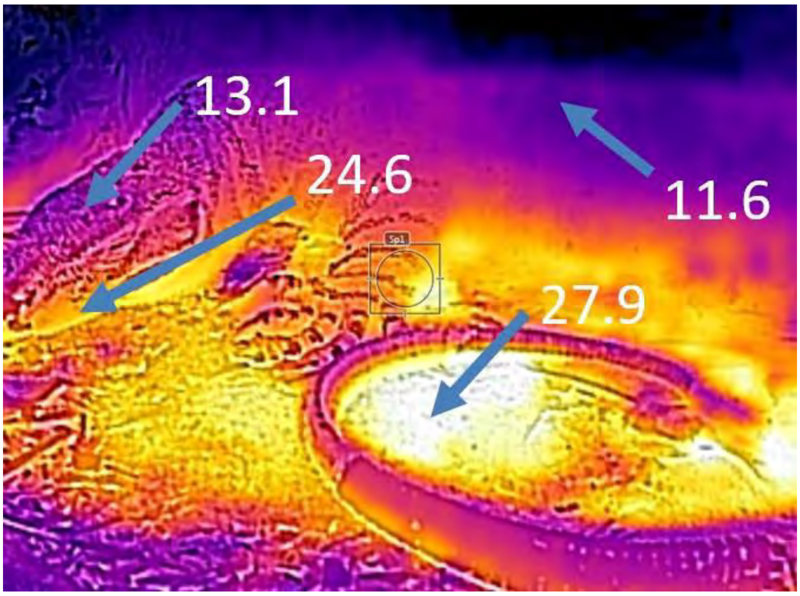


Figure 38. Image generated from Thermal Imaging Camera showing an ineffective heating system for lace monitors. Heating was only provided via a small heat pad and the animal unable to effectively reach preferred body temperature and heating was not sufficient to evenly provide warmth to the entire animal. Photo: Alex Mitchell – Melbourne Zoo

Figure 39. Image from Thermal Imaging Camera showing an effective heating system for lace monitors, whereby a large basking site is provided to allow the animal to evenly reach preferred body temperature across its entire body. Photo: Alex Mitchell – Melbourne Zoo

Exposure to a range of 4-6 UVB Index must be provided for up to four hours a day in order to replicate the behaviors observed in crocodile monitors studied under natural light conditions. At the same time, it is worth noting that crocodile monitors avoid exposure to UVB Index above 9, seeking shelter in the shade during the mid-hours on sunny days (Reh et al. 2021). UV-B monitoring can be easily achieved using a UV-B meter (such as Solarmeter 6.5). Measuring UV-B is highly recommended to guarantee the provision of an adequate spectrum, especially under non-natural light sources.

Figure 40. Using a Solarmeter to monitor UV-B index in a crocodile monitor at the Mandai Singapore Zoo. Photo: Borja Reh

The photoperiod provided should be maintained around 12:12 (light:dark) hours all year round, similarly to their wild habitat, which is located close to the equatorial line. However, implications of photoperiod in the reproduction of this species need to be further studied since some institutions have managed to breed them successfully with seasonal variation in their photoperiod from 15:9 in summer to 9:15 in winter (Reh, pers. comm.).

Figure 41. (Left) Using a wet bulb globe temperature (WBGT) meter to measure the temperature in a patch of sunlight where a crocodile monitor was basking in a transparent-roofed, indoor enclosure. Photo: Dan Garrick, Marwell Wildlife.

Figure 42. (Right) Comparing temperature readings between a WBGT meter and conventional digital infrared thermometer. Note a difference of 4.8ºC between the two. Photo: Dan Garrick, Marwell Wildlife.

2.1.5 Environmental parameters

All organisms are sustained by metabolism, which encompasses the uptake, transformation, and expenditure of energy (Burger, Hou, and Brown 2019). Thermoregulatory responses alongside feeding are the maintenance behaviors found in reptiles; thermoregulatory homeostasis is often linked directly to the behavior in reptiles (Johnson 2017).

The environmental conditions provided in captivity should be as close as possible to the natural environment of the species. Crocodile monitors are found in Papua and Papua New Guinea in lowland tropical forests where the temperature, humidity, and rainfall remain constant throughout the year (Figure 9) (University Of East Anglia Climatic Research Unit (CRU), Harris, and Jones 2017).

There are several environmental factors that need to be considered when designing a habitat for crocodile monitors; these include humidity, temperature, and illumination, among others. We have discussed in sections 2.1.1 Dimensions and boundaries, and 2.1.2 Habitat design the implications of good space provision in the captive well-being for the physical condition of this species, which is also critical to provide the animals with choices to select between the different environmental factors.

Temperature

Crocodile monitors are ectothermic and rely on the environmental temperature to function properly. Temperature gradient and daily thermal oscillation are required to mimic their natural environment.

A common problem observed in captive environments is the provision of adequate temperature (Mendyk et al. 2016). According to Baines *et al.* (Baines et al. 2016), this species is placed in the Ferguson Zone 2: an occasional basker with temperatures at the higher end between 35 and 40ºC. According to Reh (Reh et al. 2021), crocodile monitors should be exposed to a wide temperature gradient with a 26ºC low end to high basking temperatures above 36ºC for at least 4 hours a day. Animals need to have access to different microhabitats within the enclosure, enabling natural thermoregulatory processes. The basking schedule, when conditions are favorable, is between 3 and 5 hours daily. However, animals must be given a choice to escape overheating at all times with the provision of ventilated shaded areas and sprinkled water or a pool to refresh. High temperatures and a controlled UV Index are considered critical factors for the success of breeding programs in the zoo community (Reh et al. 2021).

A study on the thermoregulatory behavior of crocodile monitors conducted at the Singapore Zoo (Reh et al. 2021) showed regular activity patterns (see Figure 43 for environmental conditions references); the animals generally sleep high up in a tree and start their activity around 8:30 am (sunrise in Singapore is at ~7 am) when they start searching for a basking option high up in the tree. Shortly after, depending on their metabolic stage, they move down to an area with a higher incidence of sun rays. The body posture helps to improve heat absorption by flattening and facing the sun to allow maximum exposure like a solar panel. The animals sunbathe until reaching a temperature of around 30/36ºC (Figure 44). It was concluded that the crocodile monitors in the study went down to the ground for sunbathing due to the limited access to the canopy and having full access to the canopy would result in basking at the highest point of the trees. After around one hour of basking, they either patrol the habitat in search of food, a place to nest, or a shaded place to escape from the heat. Generally, animals avoid exposure to UVI above 9. At 3 pm, they resume their basking behavior for a period of 30 to 60 minutes. A temperature gradient is critical to prevent under- or overheating.

Crocodile monitors housed indoors under a transparent roof have been observed to seek out patches of natural sunlight for basking, moving to follow these across the enclosure as the day progresses. Animals housed under these conditions are often less active on overcast days, despite the provision of static, artificial basking zones that combine high-output lighting and shortwave infrared radiation, again highlighting the benefits of natural sunlight (Haines, pers. comm.).

Crocodile monitors use tree hollows and ground holes to escape extreme heat (Figure 45). A cool and humid den should be provided not only for nesting but also as an additional feature for their thermoregulation. When provided, captive crocodile monitors have also been observed to make use of deep leaf litter as a refuge, burying themselves within it entirely, potentially for thermoregulation (Haines, pers. comm.).

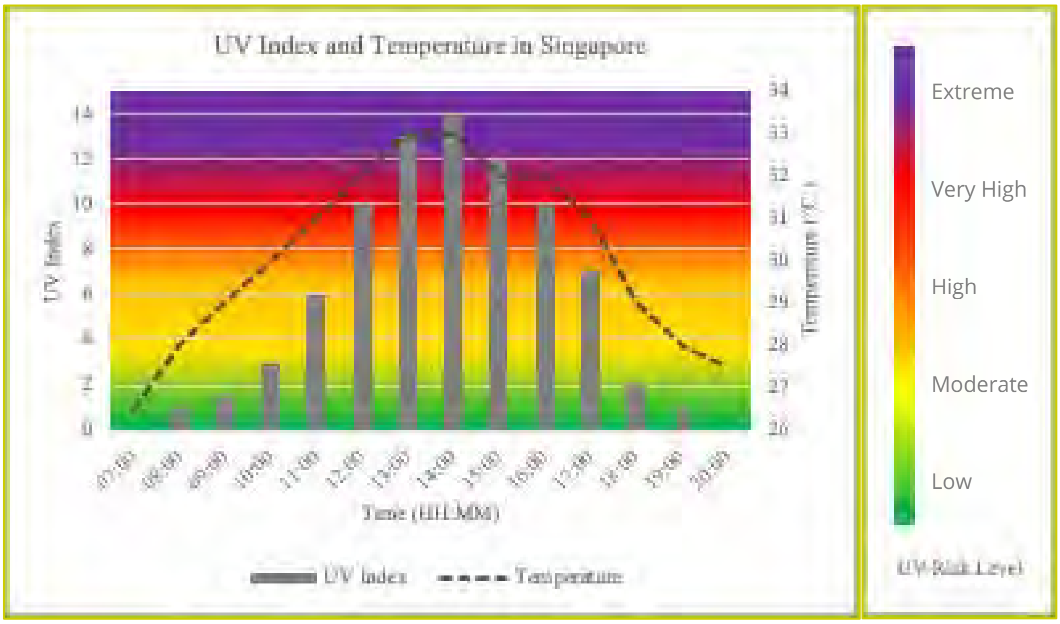


Figure 43. Average UV Index and Temperature on a sunny day in Singapore. (Reh et al. 2021)

Humidity

The crocodile monitor is a tropical species that requires high relative humidity between 70-90% at all times (Reh et al. 2021). High humidity levels also require proper ventilation, especially in indoor enclosures, to avoid bacterial and fungal growth. Signs of inadequate humidity are dysecdysis and dry skin (McCracken et al. 2018). Different skin color patches and soft skin, on the other hand, are signs of excessive moisture and underlying bacterial or fungal infection (Harkewicz 2002). Healthy, hydrated animals have shining skin that reflects the vivid colors of the species and complete the ecdysis process within a week (Reh et al. 2021).

Figure 44. A female crocodile monitor retrieved from the basking spot at 37.5ºC. The animal spent 10 minutes in the spot reaching 30ºC before moving away. Photos: Borja Reh

Figure 45. A hole in the ground maintains a bearable temperature during hot days. The temperature outside was 32ºC, which is 6º higher that the burrow. Photo: Borja Reh

Water Supply

With over 3,000 mm of annual precipitation, Papua New Guinea ranks third in the world for the highest rainfall (IndexMundi.com 2019). Monthly precipitation remains at around 250 mm throughout the year with no real "dry season" whatsoever, and only a slight reduction of rainfall from December to March. Hence, crocodile monitors naturally will not have to seek water at ground level as there is plenty of rain to drink from. In captivity, adequate hydration must be ensured by regularly misting the animals. Some animals refuse to drink from water bowls, cascades, and pools. Therefore, artificial rain through misting and sprinkler systems to replicate storms is always recommended (Reh et al. 2021).

The extent to which crocodile monitors use water bodies in the wild is unknown. Despite the fact that this species does not possess the laterally compressed tail indicative of aquatic varanids (Horn 2004), some captive crocodile monitors have been observed to make use of large water bodies when provided with the opportunity. The enclosure at Marwell Zoo incorporates a moat, approximately 1.1 m deep, 15,000 L in volume and heated to 28°C, in which lizards have been observed swimming for extended periods on an almost daily basis (Figure 46) (*Video 2*). This behavior has primarily been observed around late morning and midday, when activity levels are high, and animals are patrolling their enclosure. Animals have also been observed using this same moat to seek refuge when conflict has arisen as a result of introductions between conspecifics. On one such occasion, after a short bout of physical aggression with a male, a female animal fled into the water and swam down to the bottom, where she remained inactive, only resurfacing once the male had wandered off elsewhere to bask (Haines pers. comm.). The same behavior has been observed in the Singapore Zoo when a female used the pond to escape from the male (Reh pers. comm.).

Figure 46. Crocodile monitor enclosure at Marwell Zoo, featuring a 1.1 m deep moat, with an adult animal taking a rest from swimming. Photo: Rob Haines, Marwell Wildlife.

Video 2. Crocodile monitor swimming at Marwell Zoo.

Robert Haines

2.2 Feeding

Crocodile monitors are large and active canopy hunters that feed on different prey depending on availability and development stage. The physical condition of crocodile monitors depends on an adequate and balanced diet. The selection of food should be aligned with their natural history. Despite the limited information available on the wild ecology and behavior of crocodile monitors, their diet seems to be based mainly on birds (De Lisle 1996; Pattiselanno 2007). Small prey is preferred, including birds, eggs, small mammals, invertebrates, and lizards. Food presentation is a powerful resource for enhancing the welfare of crocodile monitors. Being highly food-motivated, providing food in challenging ways for the animal becomes an excellent tool for increasing their activity budget, and improving their physical condition (see section 2.5 Behavioral enrichment and Operant Conditioning).

2.2.1 Basic diet

The diet in captivity often includes large prey such as chicken and rabbits; these items, though, require long periods of sedentary time to digest. Therefore, it is advised to select smaller prey instead and reduce the time between each meal to maintain a higher activity level (Reh et al. 2021). Feeding whole prey is an important way to ensure all micronutrients are being provided, as well as providing an adequate level of protein. This is opposed to giving meat prepared for human consumption, which is overall more concentrated in protein, fat and calcium deficient without bone (Card 1995). Small prey can be fed more often, which is consistent with their arboreal ecological niche, rather than larger prey, which are fed less often. Quails, chicks, rats, mice, smaller lizards, and frogs are all suitable diet options that should be used accordingly depending on the size and age of the individual.

Nutrition Related Issues

Several diseases have been linked to unbalanced diet and chronic dehydration in crocodile monitors (see section 2.7 Veterinary: Considerations for health and welfare, and 2.7.3 Nutrition related issues). In females, dystocia has been reported by zoological institutions as the main cause of death (Herrel et al. 2001; Reh et al. 2021). Dystocia has been linked to lack of muscle tone and obesity. In contrast, gout has been reported as the main cause of death for males and the second for females after dystocia (Reh et al. 2021). Gout has been linked to unbalanced high-protein diet and chronic dehydration (Divers and Stahl 2019). Issues such as cholesterol can arise from a diet to rich in eggs and chicks that have not had their yolks removed; despite being a great source of protein the yolk of one egg contains 237mg of cholesterol in a 63g egg, which is nearly equivalent to a 340g of beef burger. The yolk also contains elevated levels of phosphatidylcholine that once in the intestine gets converted into trimethylamine then trimethylamine N-oxide or TMAO after oxidation, when being absorbed by the liver, with all of the above causing atherosclerosis. (Spence, Srichaikul and Jenkins 2021). Other nutritional issues such as metabolic bone disease (MDB) is also a common occurrence in captive bred animals but can be avoided with the correct diet, UVB and supplementation when needed (McWilliams and Leeson 2001).

2.2.2 Supplements

Provision of full prey and access to full-spectrum light are the ideal requirements for crocodile monitors. However, multivitamin and calcium supplements such as Nutrubal (Vetark), ReptiVite and Repti Calcium (Zoomed), might be used to guarantee enough vitamins and minerals are absorbed, especially during sensitive periods such as female pregnancy and growth of hatchlings.

Many supplements can be used for the general wellbeing of an individual as a preemptive measure to mitigate nutritional related issues and disease (see section 2.7.3 Nutrition related issues). Vitamin D in a dietary context is an effective supplement (Ferguson et al. 2009). The addition of multinutritional supplements can be beneficial, especially when using prey items that have spent an extended period of time in the freezer and will therefore have a deteriorated Vitamin content (Card 1995; Dierenfeld, Alcorn, and Jacobsen 2002; Douglas, Pennine, and Dierenfeld 1994). There is limited information on the use of these supplements in crocodile monitors. Therefore, we recommend using with caution.

2.2.3 Food presentation

Crocodile monitors are highly active specialized canopy hunters. Nutrition must be aligned with their ecology; we must ensure the animals remain slender and healthy through a balanced diet, continuous Body Condition Scoring assessment and adjusting the diet accordingly. Food provision is the most resourceful approach to gaining trust from the animals and ensuring they perform the essential physically demanding activities to maintain the appropriate muscle tone; therefore, feeding should always be accompanied by different enrichment or training programs. Luring and hiding food are some resources available to enhance the species natural behavior (*Video 3*) (Reh et al. 2021).

Another approach to food presentation, which has been used at Marwell Zoo, involves affixing larger feed items, such as a whole rabbit or pigeon, to a vertical section of tree trunk at a height of around 1 to 2 meters. When food is presented in this way, lizards must use a variety of muscles to obtain the food and will often spend several hours exerting themselves, using their teeth and claws to tear off sections to eat. Feeding in this manner could therefore be considered a form of enrichment, as it provides animals with sensory and psychological stimulation for prolonged periods, which would be spent hunting for food in their wild counterparts. One cost of this method, however, is that larger feeds such as these will be followed by periods of inactivity for digestion. Such feeds should therefore only be offered infrequently, with small feed items making up the majority of the diet, to reduce the frequency of undesirable sedentary periods.

Video 3. Luring crocodile monitor at Singapore Zoo. Hakeemulislam Osman	

2.2.4 Ontogenetic diet shift

Ontogenetic diet shift has been reported in several species of lizards, including closely related families (Dessem 1985; Estes and Williams 1984; Mazzotti et al. 2020; Herrel et al. 2001). Neonate monitor lizards have a higher metabolic rate due to rapid growth, and therefore energy consumption is higher (Thompson and Withers 1998). Crocodile monitors start their early life consuming mainly insects and, as they grow, there is a shift towards larger prey (as described above).

Figure 47. A baby crocodile monitor feeds on a grasshopper. Photo: Borja Reh

There have been several reports of lethargic newborn crocodile monitors that refuse to eat despite offering multiple prey options. The first considerations are to verify that abiotic factors have been appropriately addressed, and that the animals have a safe environment, free from stress, with the climatic conditions required (see section 2.1 Enclosure). Additionally, a parasite check is recommended. Endoparasites have been found in newborn crocodile monitors. Fecal examinations of the first feces and treating parasites such as flagellates are suggested if accompanied by clinical signs such as hematochezia and dysorexia. There has been a documented case of appetite improvement within 24 hours of the administration of the appropriate anthelmintics in this species (Reh et al. 2021).

Although the first feeding might be a challenge, it is not recommended to force-feed newborn crocodile monitors. Instead, different food options, underlying health issues, and improvements in their housing should be addressed.

The diet of hatchlings and young animals is based on small-sized prey items, such as insects and small vertebrates (Schmicking and Horn 1997). Juveniles are active foragers that use their keen senses of smell and sight to find insects such as katydids and grasshoppers, among other prey items (Figure 47). When appropriate food and space are provided, the development of hatchlings is very fast, doubling the weight within ten weeks (Figure 48). However, this fast growth must be compensated for with plenty of activity options, large enclosures, and two feedings a day alternated with fasting days, which are preferred for hatchlings and young animals (see Figure 24, and Figure 25). Hatchlings seem to be selective over the first meals offered, and they seem to like freshly killed newborn mice. Once the response to prey is positive, they are likely to start choosing other offered options such as locusts and grasshoppers, which can be presented either alive or frozen. Insects can be used as the primary food source for the first months since they allow a more regular feeding schedule that helps in enhancing activity levels. Newborn mice can be offered once weekly in combination with the invertebrates (Reh et al. 2021).

There is no feeding "golden rule" for baby crocodile monitors; weekly weight monitoring and daily behavioral observations will provide enough information to adapt the diet to each animal. When hungry, crocodile monitors will actively forage around the enclosure actively flicking the tongue; this is a good sign of when to feed.

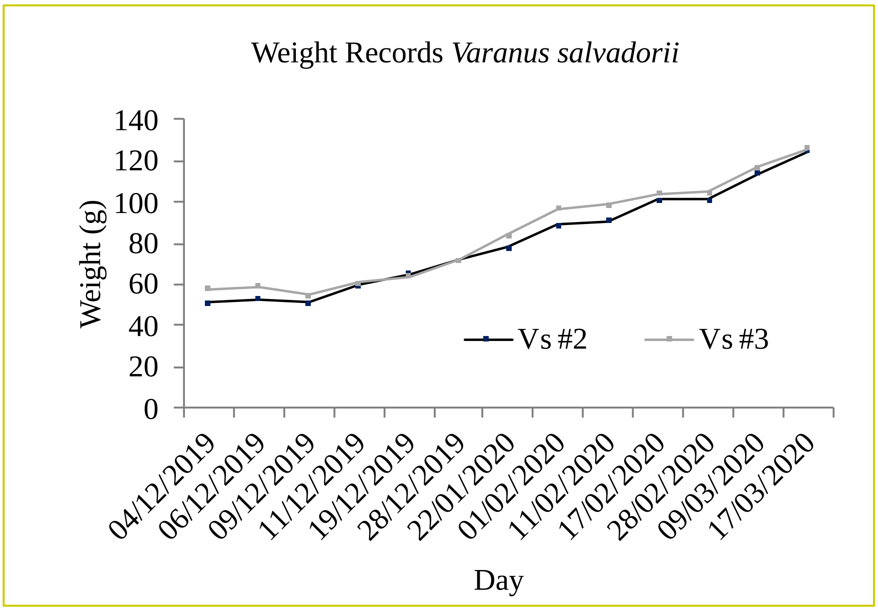


Figure 48. Weight records during the first months of life of two crocodile monitors hatchlings (Reh et al. 2021)

2.2.5 Water

With over 3,000 mm of annual precipitation, Papua New Guinea ranks third in the world's countries with the highest rainfall (IndexMundi.com 2019); monthly precipitation remains at around 250 mm throughout the year with no real "dry season" whatsoever, and only a slight reduction of rainfall from December to March. Hence, crocodile monitors naturally will not have to seek water at ground level as there is plenty of rain to drink from. In captivity, adequate hydration must be ensured by regularly misting the animals. Some animals refuse to drink from water bowls, cascades, and pools. Therefore, artificial rain with misting and sprinkler systems to replicate storms is always recommended (Reh et al. 2021).

2.3 Social structure

The social structure in monitor lizards can be of high complexity (Tsellarius and Tsellarius 1997). However, there have been no studies of crocodile monitor behavior in the wild, and therefore their social structure remains a mystery (Reh et al. 2021). To get a glimpse of the complexity of their social interactions, we have to rely on observations in captivity. Intraspecific aggression has been reported on several occasions (Camina, Salinas, and Cuevas 2013; Hartdegen 2012; Horn 2004; Mays 2007; Reeves 2019; Reh et al. 2021).

Nevertheless, there are many reports of compatibility that highlight the unique responses from each particular individual. Some institutions have reported compatibility of same-sex animals, while others have successfully kept pair or even small groups for years without incidents. A young one-year-old crocodile monitor was mixed with a full-grown male in Madrid Zoo and shared the space for years without incidents nor any stress indicators (Figure 49) (Reh, pers. obs.). The mentioned male was very tame, and this report is not meant to be taken as a conclusive argument to mix smaller animals with adults (Reh et al. 2021).

Figure 49. A full-grown male crocodile monitor shares enclosure with a one-year-old female at Madrid Zoo. Photo Borja Reh

The lack of genetic studies, combined with the wide distribution of this species and the different color patterns that exist (Figure 2), unfolds interrogations about the possibility of different localities or even subspecies to be discovered. Genetic differences could be linked to potential social compatibility issues. This field needs to be further investigated (Hartdegen pers. comm.).

2.3.1 Behavior Categories and Indicators

Animal welfare is often linked to the display of "highly motivated natural behaviors" (Kleiman, Thompson, and Baer 2010). As large arboreal lizards, crocodile monitors should perform a number of behaviors related to their condition (Horn 2004). Similarly, animal welfare is also linked to the prevention of undesirable abnormal behaviors, usually caused by psychological distress (Bacon 2018). Some abnormal behaviors include aggressive response towards other animals or keepers, stereotypic behaviors, and lethargy during peak hours.

Through a complex behavior repertoire, crocodile monitors share critical information about their ability to cope with their environment.

In reptiles, stressors are perceived challenges to their ability to meet their needs (Greenberg 2002). The phenotype of animals adjusts to cope with these stressors as they develop (Abram et al. 2017; Ma et al. 2018). Exposure to a mild level of certain stressors enhances resilience to stress and, therefore, might be considered positive in some instances or life traits (Monaghan and Haussmann 2015). Many hormones have been identified in responses to stress in vertebrates (Martínez Silvestre 2014; Wingfield et al. 1998), however more species-specific research needs to be done to understand the natural ranges of hormones in the target species, as well as the connection with other biomarkers of stress (Sopinka et al. 2015).

Desired behaviors in crocodile monitors might include locomotion, including vertical locomotion using branches or jumping from branch to branch (*Video 4*), foraging using the claws to dig holes in search for underground food, constant tongue flicking, and exploring around the habitat.

Here we follow the categories suggested by Stanton (Stanton, Sullivan, and Fazio 2015) and Greenberg (Greenberg 1977) for felid and lizard ethograms, respectively. Nonessential categories and categories that were considered not useful for crocodile monitors were removed.

The proposed list of categories includes Maintenance behaviors (feeding and thermoregulatory), Affiliative / Reproductive behaviors (courtship, mating, and nesting), Aggressive / Fear behaviors (attack, intimidatory, avoidance, and fight), Social / Communication behaviors (visual and chemical), Active behaviors (exploratory, stereotypic, and locomotion), and lastly Sedentary behaviors (resting). These categories are then split into a total of 42 different behaviors (See Appendix I: List of common behaviors in crocodile monitors).

2.3.1.1 Maintenance Behaviors

All organisms are sustained by metabolism, which encompasses energy uptake, transformation, and expenditure (Burger et al. 2019). Thermoregulatory responses alongside feeding are the Maintenance Behaviors found in reptiles; thermoregulatory homeostasis is often linked directly to reptiles' behavior (Johnson 2017). Physiological processes such as feeding, metabolic rate, and enzyme kinetics depend on temperature (Monaco, McQuaid, and Marshall 2017), and therefore, different behaviors are expected to help reptiles in maintaining body temperature at the correct level.

Thermoregulatory Behaviors

Thermoregulatory behaviors include augmenting, maintaining, and reducing the temperature by exposure and avoidance to external heat sources such as heating lamps, solar rays, or warm surfaces. Heat transfers through conduction, convection, and radiation. Exposure to sun rays is the most common behavior to increase body temperature, and retreat from direct sunlight using shaded areas is the resource to decrease body temperature when the ambient temperature is too high.

Basking can be considered a positive behavior when the animal does it following a natural schedule with the objective of reaching the desired temperature to allow physiological processes and to start other activities (Ruibal 1961). Peak basking temperature in crocodile monitors is between 34 and 38ºC. Basking for 3 to 5 hours daily is considered normal in this species (Reh et al. 2021). The body posture improves heat absorption by flattening and facing the sun to allow maximum exposure like a solar panel. Thigmothermic behavior (absorbing heat from contact with a surface) is commonly used by different lizards species for thermoregulatory processes (Dawson 1975). Crocodile monitors expose themselves to radiating heat from rocks (Figure 33) when the ambient temperature is low, and there is limited access to solar radiation (Garrick 2008). Thigmothermy is less common in crocodile monitors, and it could be considered an indicator of environmental deficiency whereby the animal cannot reach the desired temperature with basking alone. This consideration should be made when the abovementioned behavior is prolonged in time.

Crocodile monitors avoid exposure to UVB Index above 9 and temperatures above 30ºC for prolonged periods of time; therefore, seeking shelter under a shade is considered a natural behavior when those circumstances are found (Reh et al. 2021). Still, the younger animals naturally avoid the ground, and the selected cooler areas should be found at height.

Hunting, Feeding, and Drinking Behaviors

While feeding and hunting behaviors are naturally linked to the nutrition domain, some behaviors can be conditioned by environment factors, and health (Mellor and Beausoleil 2015). When conducted at appropriate times and under normal circumstances, foraging, lunging, stalking, and watching are positive indicators of natural hunting behavior. Hungry lizards express stronger chemosensory responses and increase their exploratory and searching rates in response (Martín and López 2008). Contrarily, vomiting, regurgitation, or food avoidance are linked to inappropriate environmental conditions, stress, or disease (Divers and Stahl 2019).

Excess of confidence by the animal towards a keeper can result in a strong feeding response whenever the keeper enters the exhibit. Luring the animal with a prey item or target before entering the exhibit will significantly reduce the animal's response. Where luring from outside the exhibit is not feasible, conditioning with routine husbandry is proposed to prevent an unwanted feeding response. Bites from crocodile monitors have been recorded on several occasions (see section 2.6 Handling). Often, the bites are suffered on hands and forearms, and therefore, wearing bite-proof gloves drastically reduces the risk of injuries (Reh et al. 2021).

Video 4. Luring a crocodile monitor during a feeding presentation at Singapore Zoo.

Borja Reh

With over 3,000 mm of annual precipitation, Papua New Guinea ranks third in the world's countries with the highest rainfall (IndexMundi.com 2019); monthly precipitation remains at around 250 mm throughout the year. Hence, crocodile monitors in the wild have permanent access to water from the rain. In captivity, adequate hydration must be ensured by regularly misting the animals. Some animals refuse to drink from water bowls, cascades, and pools. Therefore, artificial rain with misting and sprinkler systems to replicate storms is always recommended (Reh et al. 2021).

2.3.1.2 Reproductive and Affiliative Behaviors

As solitary animals, reproductive and affiliative behaviors are some of the few social encounters seen in crocodile monitors. These are linked to positive behavior experiences such as sexual gratification, affectionate sociability, and maternal reward (Mellor 2017). Behaviors in this category include those related to courtship, mating, nesting, and parental behavior.

Reproductive and affiliative behaviors belong to the nonessential activities group that are suspended during the “emergency state” to prioritize activities directed towards counteracting and surviving the threat (see section 2.3.1.3 Aggressive and Fear Behaviors) (Monaghan and Haussmann 2015).

Courtship Behaviors

Courtship rituals include some of the most interesting and unusual behaviors seen in reptiles. Male monitor lizards of different species perform highly energetic wrestle fights whereby the dominance is disputed, and the winner gets to mate with the resident female (Pianka et al. 2004). However, in captivity, these wrestle fights have to be avoided or conducted in a controlled environment to ensure no animal gets hurt in the process.

Courtship starts with the visual location of a mate. Crocodile monitors do not recognize the sex of a partner until they receive enough information through chemical cues (Reh et al. 2021). Tongue-flicking plays an important role in determining the sex and reproductive stage of the female. Similarly, the female might show aggression upon seeing the male until the courtship behavior of the male begins. After confirming the location of a receptive mate, the male performs spasmodic head movements and constant tongue-flicking while gently approaching the female (*Video 5*, *Video 10*) (Carter 1990). Receptive females will show submission by lying flat and sometimes with their eyes shut or partially closed (Reh et al. 2021).

Video 5. Male crocodile monitor gently tongue touching the female during courtship.

Borja Reh

Mating Behaviors

Upon reaching the female, the male crocodile monitor will lay diagonally across the female with his vent adjacent to the side of her tail. Hind feet are sometimes used to stimulate the female to raise her tail base and even grip the tail and lift it. The male then curves the base of the tail under the female’s and inserts the hemipenis (Carter 1990) (Figure 50).

Nesting Behaviors

Selecting the perfect location for nesting is critical for all egg-laying reptiles; the environmental conditions of the nest will determine the success of the incubation (Resetarits 1996). At the same time, finding a safe spot will have implications on the survival rate of the eggs from predation (Setyawatiningsih et al. 2016).

During the last two weeks prior to laying, pregnant female crocodile monitors spend most of their active time searching for the appropriate nesting area. As their activity drops before nesting, females choose to spend more time test digging in different locations (Reh et al. 2021). Crocodile monitors are known to hide nests; the female often digs several holes before selecting a site. The hole is then backfilled to avoid detection by possible predators (Reh et al. 2021).

Figure 50. Crocodile monitors mating on the ground. Singapore Zoo. Photo: Borja Reh.

The nest construction starts with the female scratching and gouging with the claws of one forelimb at a time, often swapping to the other forelimb after a few strokes. The egg chamber varies in size depending on the size of the clutch as well as the individual preferences of the female. Generally, the top eggs are found at least 20 cm deep, and the lowest ones around 50 cm deep. Some females might dig deeper chambers, most likely depending on the humidity level of the substrate. While digging, the female uses the snout to touch the substrate; this behavior has no proven motivation. Still, it is suspected to help determine the chamber's environmental conditions since the snout is sensitive to temperature and humidity. The whole digging and laying process takes around three hours to complete.

Parental Care Behaviors

The female covers the nest carefully after laying the eggs (Figure 34). She then remains in the area for prolonged periods of the day (Figure 51) (Kirshner 2016; Tsellarius, Men'shikov, and Tsellarius 1995). Different females have been observed often defecating on the nest, a behavior that could be linked to predator deterrence (Lee 2001; Trout 2007), which has been observed in other species of monitor lizards as well (Mendyk 2019).

While the previous behaviors are strong indicators of parental care, more research needs to be done to fully understand the complexity of these conducts. Similarly, no studies have been conducted on the role of the male in parental care. Interestingly, males do not show predatory behavior towards eggs or aggression towards the female. Many females, though, have been reported to attack males after nesting.

Figure 51. Female crocodile monitor guarding the nest. Photo: Borja Reh

Intraspecific egg predation is a rare behavior observed in several lizard species (Polis and Myers 1985). Ovophagy by females right after laying has been observed on several occasions in this species (Reh et al. 2021). The reasons for this behavior are unknown. The distress caused by a lack of a proper nesting site has been proposed as a possible cause (Mendyk, Newton, and Baumer 2013).

2.3.1.3 Aggressive and Fear Behaviors

Intimidatory, avoidance, and fight are behaviors included in the aggressive and fear category, which are often linked with negative experiences. Sometimes, it might be difficult to determine the origin of these behaviors. For example, intimidatory behavior is not always linked to aggression; indeed, it can be part of a pre flee performance due to fear (defensive attack). On the other hand, Fight is considered an aggressive behavior that can also be linked to natural pre-copulatory rituals between males and not always necessarily a negative experience for the animal.

Under imminent danger, animals enter an "emergency state" in which activities directed towards counteracting and surviving the threat are prioritized over nonessential activities (Monaghan and Haussmann 2015). At the same time, providing novel and energizing opportunities carry potential positive experiences for some animals. Therefore, these behaviors could be acceptable under close monitoring to ensure a stressful experience does not become a negative one.

Figure 52. An adult crocodile monitor flicking the tongue. Photo: Borja Reh

Body posture and hissing are important signs of defensive (avoidance) behavior commonly observed during intraspecific interactions as the first response to visual contact (Bels et al. 1995; Phillips and Millar 1998; Reh et al. 2021). Aggressivity levels might increase or decrease depending on the compatibility of individuals. When an incompatibility situation is prolonged, the animals might attack by tail whipping or even biting if neither animal retreats.

Aggressive behaviors can also be displayed towards humans, usually when cornered and unable to flee. Crocodile monitors show a clear warning display by flattering their body, inflating the pouch, coiling the tail, and hissing loudly (Horn 2004). However, if the animal is cornered and the display is unsuccessful, most animals will not hesitate to give a warning bite. Warning bites are lightning-fast and can be tremendously harmful (see section 2.6.6 Bite wounds and envenomation) (Reh et al. 2021).

Displacement behaviors, in which a dominant individual approaches the submissive directly, until the submissive individual moves away, allowing the dominant individual to take its previously occupied space, have been observed (Uyeda et al. 2015).

Most crocodile monitors adapt well to captivity. However, constant aggressive behavior has been observed in some animals for unknown reasons, in which case, improving the environment and offering different hiding options (preferably higher up) are critical to avoid distress.

The respiratory rate is an adequate visually obvious stress indicator. Crocodile monitors show an increased respiratory rate when under distress (Reh et al. 2021).

2.3.1.4 Social and Communication Behaviors

Crocodile monitors are solitary animals that use mainly chemical and visual cues to communicate. Communication plays a critical role during courtship (see above).

Tongue-flicking is associated with vomeronasal chemoreception. This easily perceptible behavior is commonly used in investigations of chemical communication in lizards (Mason and Parker 2010).

Vent dragging and rubbing the head and neck are behaviors used by crocodile monitors of both sexes to disperse chemical cues, mainly to mark territories (*Video 6*).

Video 6. Scent marking on a female crocodile monitor. Borja Reh	
Video 7. Scent tracking behavior on a crocodile monitor. Borja Reh	

Ritual combats between males have been reported before (Horn, 2004). However, attempts to observe this behavior in captivity were unsuccessful in Madrid Zoo and Singapore Zoo. In Madrid Zoo, males seemed to tolerate each other even with females around. In contrast, a male in Singapore Zoo showed aggression and dominance to another male even without females around. No ritual combats were observed in any case, only chasing and bite attempts.

Figure 53. A vigilant young male crocodile monitor. Photo: Borja Reh

2.3.1.5 Active Behaviors

Most locomotion and exploratory behaviors are highly motivated behaviors encouraged by enriched environments that promote higher activity levels in captive animals.

Locomotion Behaviors

Crocodile monitors are fully arboreal lizards. Locomotion has to be aligned with the species natural behavior such as climbing (Figure 54), jumping, and running on the trees. Additionally, they are highly energetic animals that move long distances in the wild to forage and seek mates; therefore, behaviors that promote physical exercise such as swimming and walking on the ground are highly recommended even if not aligned with their behavioral preferences.

Stereo-typic behaviors are unusual in crocodile monitors and mostly associated with an inappropriate environment. Interaction with invisible barriers has been reported in small enclosures.

Exploratory Behaviors

Crocodile monitors use primarily their keen senses of smell and eyesight to explore their surroundings (Pianka et al. 2004). Tongue-flicking is a commonly seen behavior during exploring activities.

Vigilant behavior is less obvious than others in the Active category. Vigilant animals remain motionless with the abdomen held in an erect position, and the head and neck held high (Figure 53). The animal shows interest in the surroundings by slowly swinging the head towards visual and auditory cues (Thompson et al. 1995).

More evident is the scent tracking behavior whereby the animal follows a trail of smell by detecting chemical cues through tongue-flicking and tongue-touching the substrate (*Video 7*) (Mason and Parker 2010).

Figure 54. Active male crocodile monitor walking around the enclosure. Singapore Zoo. Photo: David Tan / Mandai Wildlife Reserve

2.3.1.6 Sedentary Behaviors

Sedentary behaviors are referred to when the animal is lying either asleep or awake. Here the full body, including the head, rests on the ground or perch. The limbs might be extended or partially extended, and eyes might be open or closed (Figure 55) (Bashaw et al. 2016).

Figure 55. Sedentary behavior on a crocodile monitor. Photo: Borja Reh

2.3.2 Introduction methods

Behavioral observations help to assess the compatibility of the animals before attempting to mix the animals; the main factors to observe are the aggressive cues from the female towards the male and the courtship signs of the male towards the female. Adjacent mesh cages were used to introduce the animals safely. The mesh allows the animals to see and smell each other without the risk of sudden bites. At this stage, the response is, however, inconclusive since, generally, this species might not show aggression until close contact happens. In cases of extremely aggressive response from the female, adjacent cages are usually enough proof of non-compatibility. However, after not showing aggression in adjacent cages, the female might show aggression after a period of tolerance. Assessing behavior in adjacent cages is the first step, after which the female can be released into the male's area. Females usually start showing dominance towards the males before showing aggression and attacking the male (*Video 9*). Close observation and fast intervention might be required at this stage. In case of submission, the female generally will tolerate the male for some weeks, depending on the reproductive stage. Once signs of nesting are observed, the male should be removed to prevent stress and allow the female to use the full space available.

Besides the abovementioned behavioral signs, monitoring follicle development with ultrasound can help assess the most suitable periods to mix the animals in this species (See Appendix II: Follicle monitoring in a crocodile monitor) (Reh et al. 2021).

Video 8. Male crocodile monitor reaction upon seeing a female. Borja Reh	
Video 9. Female crocodile monitor showing dominance towards a bigger male. Borja Reh	

2.3.3 Mixed species display

There are limited studies on the interspecific interactions in *Varanus* (Lei and Booth, 2018). From captive observations, crocodile monitors seem to tolerate different species without aggression, including chelonians, mammals, and other lizards (Horn, 2004). Once adapted to food conditioning by keepers, they seem to ignore free-ranging animals and potential prey such as squirrels and birds in captivity.

Figure 56. Green crested lizards are commonly found inside the crocodile monitor habitat at Singapore Zoo. Photo: Borja Reh

Singapore Zoo has managed to mix crocodile monitors with painted terrapins (*Batagur borneoensis*), Fly River turtles (*Carettochelys insculpta*) (Figure 57), and cichlids (*Sciaenochromis* sp.) without problems. Additionally, the exhibit is frequented by wild native and introduced fauna including common sun skinks (*Eutropis multifasciata*), changeable lizards (*Calotes versicolor*), green crested lizards (*Bronchocella cristatela*) (Figure 56), Sumatran gliding lizards (*Draco sumatranus*), Asian toads (*Duttaphrynus melanostictus*), four-lined tree frogs (*Polypedates leucomystax*), plantain squirrels (*Callosciurus notatus*), slender squirrels (*Sundasciurus tenuis*), Sunda colugos (*Galeopterus variegatus*), Asian glossy starlings (*Aplonis panayensis*), pink-necked green pigeons (*Treron vernans*), black-naped orioles (*Oriolus chinensis*), olive-winged bulbuls (*Pycnonotus plumosus*), olive-backed sunbirds (*Cinnyris jugularis*), and crimson sunbirds (*Aethopyga siparaja*) among other species to which the animals seem to ignore (Reh et al. 2021).

Figure 57. A Fly River turtle and a painted terrapin share the crocodile monitor exhibit in Reptopia (Singapore Zoo). Photo: Borja Reh

Madrid Zoo used to take the animals outdoors where they were released close to other species including snakes, tortoises and wild birds. Once again, the animals always ignored these wild and free-ranging animals (Reh pers. obs.). Pagel reported an adult crocodile monitor to share enclosure with four large sail-tailed water lizards (*Hydrosaurus amboinensis*) without aggression (Pianka et al. 2004). At Marwell Zoo, crocodile monitors have been mixed with edible orb weavers (*Trichonephila edulis*) and Australian red claw crayfish (*Cherax quadricarinatus*), with no noteworthy interactions observed (Haines pers. comm.).

2.4 Breeding

2.4.1 Reproductive strategies

Crocodile monitors reproduce sexually by internal fertilization. Females reach sexual maturity at around two years of age while males may take one more year to be sexually active. Males are larger than females, and females are usually much more aggressive towards males (Reh et al. 2021).

Parthenogenesis has been observed in several *Varanus* species including the yellow-spotted monitor (*V. panoptes),* the Komodo dragon *(V. komodoensis),* the ornate monitor *(V. ornatus),* the Kimberley rock monitor (*V. glauerti),* and the Rainer Günther's monitor (*V. rainerguentheri)* (Iannucci et al. 2019). Genetic studies are undergoing to determine parthenogenesis in a crocodile monitor bred by Tom Crutchfield in the USA. The animal did not share enclosure with a male and the babies are believed to be parthenogenic (Edward pers. comm.).

Reproductive season in crocodile monitors occur throughout the year, though in higher latitudes animals seem to prefer the beginning of spring and autumn for mating (Figure 16) (Reh et al. 2021).

Studies on the wild reproductive strategies of this species are absent (See section 1.7 Reproduction).

2.4.2 Courtship

Courtship rituals include some of the most interesting and unusual behaviors seen in reptiles. Male monitor lizards of different species perform highly energetic wrestle fights whereby the dominance is disputed, and the winner gets to mate with the resident female (Pianka, King, and King 2004). However, in captivity, these wrestle fights must be avoided or conducted in a controlled environment to ensure no animal gets hurt in the process.

Courtship starts with the visual location of a mate (*Video 9*). Crocodile monitors do not recognize the sex of a partner until they receive enough information through chemical cues (Reh et al. 2021). Tongue-flicking plays an important role in determining the sex and reproductive stage of the female. Similarly, the female might show aggression upon seeing the male until the courtship behavior of the male begins. After confirming the location of a receptive mate, the males perform spasmodic head movements and constant tongue-flicking while gently approaching the female (*Video 10*) (Carter 1990). Receptive females will show submission by lying flat and sometimes with their eyes shut or partially closed (Reh et al. 2021).

Video 10. Spasmodic behavior in a male crocodile monitor upon seeing a female. Borja Reh	

Video 11. Female crocodile monitor backfilling the nest after laying eggs. Borja Reh	
Video 12. Female crocodile monitor placing the eggs and backfilling. Borja Reh	

2.4.3 Nest construction

Selecting the perfect location for nesting is critical for all egg-laying reptiles; the environmental conditions of the nest will determine the success of the incubation (Resetarits 1996). At the same time, finding a safe spot will have implications on the survival rate of the eggs from predation (Setyawatiningsih et al. 2016).

During the preoviposition period, the behavior of female crocodile monitors will change significantly with a drop in activity level. Behaviors include basking; spending extended periods of time under the sun, they also perform regular surveillance in their enclosure by constantly assessing the substrate and scent marking different areas which are selected as priority for nesting. During the last two weeks prior to laying, pregnant female crocodile monitors spend most of their active time searching for the appropriate nesting area. They start to dig small "test-holes" where they introduce their snouts presumably to assess the environmental conditions. As their activity drops before nesting, the females choose to spend more time test digging in different locations and more time basking (Figure 58) (Reh et al. 2021).

Crocodile monitors are known to hide nests (Reh et al. 2021). The female often digs several holes before selecting a site. The hole is then backfilled to avoid detection by possible predators. This ability to camouflage the nest must be considered when the female is about to lay since the nests will often be invisible. Finding a nest in a large enclosure can be challenging if the laying procedure was not observed (Reh et al. 2021).

The nest construction starts with the female scratching and gouging with the claws of one forelimb at a time, often swapping to the other forelimb after a few strokes. The egg chamber varies in size depending on the number of eggs of the clutch as well as the individual preferences of the female. Generally, the top eggs are found at least 20 cm deep, and the lowest ones around 50 cm deep. Some females might dig deeper chambers, most likely depending on the humidity level of the substrate. While digging, the female uses the snout to touch the substrate (*Video 12*). There is no proven reason for this behavior, although it is suspected to help determine the chamber's environmental conditions, since the snout is sensitive to temperature and humidity. The whole digging and laying process takes around three hours to complete.

Figure 58. Female crocodile monitor basking days before laying eggs. Note the distended skin. Photo: Borja Reh

It's recommended to offer multiple options for nesting. The factors considered for nest selection include media, humidity, depth, and temperature. Additionally, the area where the nest is located must be considered a safe location by the animal. Large plastic bins (1.2-meter-high) have been offered successfully on different occasions. The media offered can be a mix of cocopeat, peat moss, sphagnum moss, and sand (40.40.10.10 in weight). This nest should be offered inside a sheltered area that provides security to the animal. Despite the multiple nesting options in the outdoor habitat, the female at Singapore Zoo only chose to nest outside the sheltered area once, in a heavily planted area of bushes (*Video 12*), selecting a place with little disturbance (Reh et al. 2021).

2.4.4 Egg laying

Dystocia is the most frequent cause of death in captive female adult crocodile monitors. While the physical condition must be adequately addressed, we also must ensure the animals have suitable nesting options. No research has been done into the wild reproductive ecology of crocodile monitors (Horn 2004; Mays 2007), and very few data exist about their nesting in captivity. Distress has been reported in gravid female monitor lizards with a wide array of consequences, including dystocia and inappropriate nesting

(Mendyk et al. 2013). Egg retention for unknown reasons is common in this species. Sometimes the eggs are laid at a very late stage of development. Often, they are simply dropped on the ground without even digging a nest.

The relative humidity of the substrate for nesting must be between 80-90%, and the depth must allow the animals to dig down at least 60 cm. As commented before, the area must be considered safe for the animal to lay.

Figure 59. Female crocodile monitor in a defense posture during the nest guarding period. Photo: Borja Reh

After laying, the female will carefully cover the nest. She will remain in the area for prolonged periods of the day, performing what is referred to as a nest guarding behavior (Figure 59) (Kirshner 2016; Tsellarius et al. 1995). Different females have been observed often defecating on the nest, a behavior that could be linked to predator deterrence, which has been observed in other species of monitor lizards as well (Lee 2001; Mendyk 2019; Trout 2007). While the previous behaviors are strong indicators of parental care, more research needs to be done to fully understand the complexity of these conducts. Similarly, no studies have been conducted on the role of the male in parental care. However, we have not observed predatory behavior towards eggs or aggression towards the female. Many females, though, have been reported to attack males after nesting (Reh et al. 2021).

Ovophagy has been reported from a female in Madrid Zoo on several occasions right after laying. Whether this is a consequence of distress caused by lack of a proper nesting site is unknown since different females nested in the same enclosure without problems before. One hypothesis could be stress; the exhibit was small and exposed to visitors (Reh, pers. obs.). However, Gladys Porter Zoo have reported a similar behavior with their reproductive female in a larger enclosure; the only hatchlings from this institution were rescued eggs from the female while she was consuming the clutch (Adams, pers. comm.).

2.4.5 Incubation

Like any large varanid species, crocodile monitors have long incubation periods (Thompson and Pianka 2001) which vary between 155 and 251 days. There seems to be a correlation between temperature and incubation time; higher incubation temperature translates into a shorter incubation time (Figure 60). The incubation temperature reported by different institutions varies from 28 to 30ºC. However, no daily temperature fluctuations or accuracy of maintenance were considered. The data collected suggest that incubation at a range of 29-30ºC has been used in most successful breeding attempts (Figure 60). The first incubation attempts at 28.5ºC did not produce offspring in Singapore Zoo in 2018, with hatchlings only produced at the higher incubation temperature of 29.5ºC (Reh et al. 2021). The preferred media for incubation of crocodile monitor eggs is 1:1 weight ratio of vermiculite mixed with water. We recommend sterilizing the media and the use of filtered water. In Singapore Zoo, a 10% weight of activated carbon is added to the incubation media for prevention of fungal growth. Most successful breeding institutions affirm to Reh et al. 2021). Some institutions have reported incubation in airtight containers, while others use microperforated containers. Dehydration must be considered due to the long incubation period; Reeves (2019) suggests monitoring the weight of the container every two weeks and replacing the water loss to prevent dehydration.

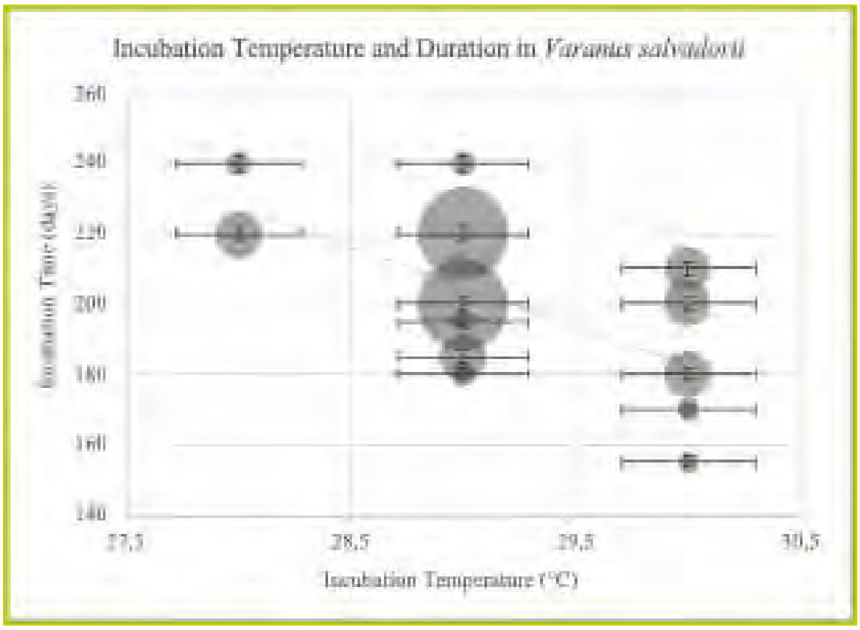


Figure 60. Incubation times and temperature ranges in 24 successful crocodile monitor incubations reported by selected institutions. The trendline shows the correlation between incubation temperature and time to hatch. Datapoint size relates to the number of repetitions of that particular parameter. X error bars show potential deviation in temperature during incubation. Y error bars show deviation in hatching within the clutch (Reh et al. 2021).

Manipulating the eggs during any part of the incubation period seems to negatively impact the success rate of the clutch, and therefore we advise not to move the eggs even for morphometric data collection. Two eggs in Singapore Zoo were being regularly handled for morphometric data collection, and the fetuses of both eggs, although fully formed, died inside the egg. A similar case with the same outcome was reported at Faunia, Madrid, in 2011 (Reh, pers. obs.).

Stillbirths have been reported in this species at Madrid Zoo, Faunia, Singapore Zoo, Honolulu Zoo, and Houston Zoo (Mays 2007); (Uyeda, pers. comm., Reh, pers. obs.). While further research is needed to understand the causes of egg abortion in crocodile monitors, the incubation parameters mentioned above have been proven successful on several occasions. Similarly, further data is required to reach a consensus on the most appropriate incubation parameters.

2.4.6 Hatching

After 150 to 250 days of incubation, the baby crocodile monitors hatch. Once again, it is important not to disturb the eggs especially during the last stage of development.

The animals hatch fully autonomous and should start feeding within the next 72 hours.

Figure 61. Hatchling crocodile monitor being measured at Singapore Zoo. Photo: Borja Reh

2.4.7 Raising hatchlings

The diet of hatchlings and young animals is based on small size prey items such as insects and small vertebrates (Schmicking and Horn 1997). Juveniles are active foragers that use their keen senses of smell and sight to find insects such as katydids and grasshoppers, among other prey items. When appropriate food and space are provided, the development of hatchlings is very fast, doubling the weight within ten weeks (Figure 48). However, this fast growth must be compensated with plenty of activity options; large enclosures, and two feedings a day, alternated with fasting days, are preferred for hatchlings and young animals. The first meal accepted at Singapore Zoo was newborn mice, and once the response to prey was positive, they were offered other options. Frozen grasshoppers were used as the main source of food for the first months since they allow a more regular feeding schedule and enhanced activity (Figure 47) (Reh et al. 2021).

Figure 62. Outdoor cage for a one-year-old crocodile monitor. Photo: Jose Cairos – Mandai Wildlife Reserve

Baby crocodile monitors can be kept in groups of the same age and size when mixed while young. However, some have shown aggression in the early stages of development, and care must be taken to ensure compatibility. Even compatible animals should be separated during feeding to avoid accidental bites (Reeves 2019). Despite their size, their sharp teeth are capable of causing severe injuries to each other.

Endoparasites have been found in newborn crocodile monitors. Fecal checks of the first feces and treating parasites such as flagellates are suggested if accompanied with clinical signs such as haematochezia and dysorexia. The appetite of the two neonates treated at the Singapore Zoo improved within 24 hours of the administration of the appropriate anthelmintics (Reh et al. 2021).

Baby crocodile monitors can be identified by looking at the unique pattern of their spots; photo identification is recommended until they are large enough to be microchipped (Ziegler et al. 2009).

2.4.8 Population management

Crocodile monitors are under EAZA monitoring by Marwell Wildlife but not under any management plan yet. The number of animals in collections is low and there are challenges to find specimens in Europe. Nevertheless, there are plans to discuss the future of the species as more institutions are showing interest, and new breeding successes can provide stock. In the meantime, It is recommended to reach out to the EAZA Reptile TAG before attempting breeding, to find suitable holding institutions in case of breeding success. The Association of Zoos and Aquariums (AZA) holds a studbook managed by the Omaha's Henry Doorly Zoo.

The species is suspected to be parthenogenic and therefore separating breeders might not work. Alternatively, the eggs can be discarded when breeding is not intended.

Figure 63. Freshly hatched crocodile monitor with the egg tooth visible. Photo: Harvey Lienardo - NLI Project Indonesia

2.5 Behavioral enrichment and Operant Conditioning

Crocodile monitors respond well to environmental enrichment and operant conditioning. In fact, this is a key point to ensure the animals build up the muscle tone needed in a captive environment. A regular training and enrichment program benefits this species and increases activity (Mcnally et al. 2015; Whittaker, Whittaker, and Coe 2005; Wilkinson 2015), also ensuring a better display when animals are on exhibit.

2.5.1 Environmental enrichment

Many modern zoos are aiming to replicate wild behavior as much as possible for the species in their care (Gray 2017). In many cases this includes targeting wild activity budgets for animals as well as diet, habitat, and environmental parameters (Crockett and Ha 2010). By doing so, we try to provide the most important features of nature with the exception of disease and predators (Burghardt 2013). Reptiles may often be perceived to have a more simplistic diversity of wild behaviors than other commonly kept taxa, and as a result enrichment for reptiles may be incorrectly viewed as limited and/or difficult or even unnecessary to implement. However, according to Sweet and Pianka, monitors are alert and agile diurnal carnivores that typically search widely for prey, relying on acute vision and extremely sensitive chemoreception. They then added that monitor lizards are superb predators, the most advanced and most intelligent of all lizards (Sweet and Pianka 2007). Therefore, of all reptile species, large varanids, including crocodile monitors, can greatly benefit from a properly developed enrichment program tailored to deliver specific outcomes. Such an enrichment program should be considered as an essential component for the contemporary captive management and husbandry of these species. As wild activity budgets of this species are likely unknown, data from other similar varanid species can be used to develop an enrichment program.

Figure 64. A crocodile monitor engaged in resolving a puzzle box at Singapore Zoo. Photo: Hakeemulislam Osman

In many instances, it is unlikely that captive varanids move or travel daily across comparable distances to their wild counterparts. It is evident that in some instances wild Komodo dragons ranging between 16 and 22kg may travel distances on average of 2.5km per day. On occasion radiotelemetry has demonstrated that this species may travel as far as 11km per day, often over steep terrain (Imansyah et al. 2008). Similar data has been collected for a range of other varanid species. A significantly smaller, arboreal species, the black-tailed monitor (*V. tristis*), has a mean daily linear distance travelled of 139.2m, however distances of up to 890m have been recorded in a single day (Thompson, De Boer, and Pianka 1999). Another species, the lace monitor (*V. varius*), has been recorded as travelling up to 1800m in a single day (Guarino 2002). Although such data are not yet available for crocodile monitors, we can estimate that the daily movement patterns of this species may be consistent with other Varanid species.

A well-designed enrichment program can assist in increasing the daily activity patterns of captive varanids, counteract obesity and increase subsequent fitness as a result of increased movements and exploratory behaviors. The introduction of novel items, scent trails and other environmental changes can increase the frequency of such behaviors.

Melbourne Zoo and Singapore Zoo have implemented an enrichment program for their monitor lizard species whereby scent trails are introduced to enclosure in the day(s) prior to feeding to increase exploratory behavior and daily movements prior to food being delivered (*Video 15*).

Ideally food items should always be offered to varanids in a manner that facilitates a direct training or enrichment outcome, rather than animals fed out of a bowl or dish. Frozen jelly mixed with meat (Video *15*), puzzle boxes (*Video 14*), and luring (*Video 3, Video 16*) are some of the enriching ways of feeding these active lizards. Such procedures can lead to significant health and welfare benefits for the animal.

Singapore Zoo has used puzzle boxes successfully to stimulate and increase activity budget in this species (*Video 15, Video 17*, Figure 64).

Many aspects of the husbandry of this species may also be enriching such as providing seasonal variation in temperature, humidity or photoperiod or regular movement and repositioning of enclosure furniture or refreshment of enclosure substrates.

Video 13. Scent trail followed by a crocodile monitor at Singapore Zoo. Borja Reh	
Video 14. Crocodile monitor enrichment with a puzzle box at Singapore Zoo. Hakeemulislam Osman	
Video 15. Crocodile monitor enrichment with frozen gelatin at Madrid Zoo. Borja Reh	
Video 16. Luring crocodile monitor at Madrid Zoo. Borja Reh	

Video 17. Crocodile monitor food enrichment with a puzzle ball at Madrid Zoo. Borja Reh	
Video 18. Crocodile monitor glove conditioning. Borja Reh	
Video 19. Crocodile monitor conditioning for topic treatment. Sarah Chin	

2.5.2 Operant conditioning

Training programs have been used in captive reptiles to improve husbandry routines and veterinary care. Furthermore, training programs with large monitor lizards such as Komodo dragons are widely used and recommended by zoological institutions for the management of large, potentially dangerous lizards (Hellmuth et al. 2012; Montgomery et al. 2002). Described as the college graduates of reptiles by the Honolulu Zoo reptile keepers (Uyeda pers. comm.), crocodile monitors can be easily conditioned with a consistent training program. Being extremely food motivated, the results of regular interactions with their caretakers are immediate.

Operant conditioning has been successfully used to enhance trust between animals and keepers. Conditioning to accept the gloved hands of the keepers is considered the first step in direct contact with the species. Once the caretaker is tolerated inside the exhibit, positive reinforcement can be used to avoid aggression towards the gloves and to encourage bonding with the keeper (*Video 18*).

A training program conducted in Madrid Zoo allowed the free-ranging of crocodile monitors; from early spring to late autumn, and during weather-permitting times, the animals were lured outside the reptile house into a training area with trees where they were released (*Video 16*, Figure 65). With opportunities for climbing, basking, and interacting with each other for periods of two to three hours daily, the animals responded with vigorous activity which resulted in a more desirable body condition and improved reproductive output (Reh, pers. comm.).

The animals at Singapore Zoo were put under a training program to encourage physical exercise. The primary resource used to encourage physical exercise was to lure the animal with a target. A prey item can be used as a target, a method widely used with monitor lizards (Kane 2019). The animals showed improvements in their body condition score two months after starting the program. Furthermore, the weight of the female dropped from 3 to 2,5 Kg, where it stabilized. The male decreased from 7 to 5,5 Kg. As previously discussed, these weights were considered ideal for adult reproductive crocodile monitors according to the displayed behaviors observed, especially the new climbing abilities and the more dynamic behavior shown by the animals. The use of climbing options was considered a key indicator of the good physical fitness of crocodile monitors, especially the use of high branches for resting overnight.

Figure 65. Training area for crocodile monitors at Madrid Zoo. Photo: Borja Reh

Medical conditioning was used successfully for ultrasound monitoring females at the Singapore Zoo. The animals were trained to perch on a gloved hand using food as a positive reinforcer. The training allowed the procedure to be conducted safely for the animal care staff and made it stress-free for the lizards (Figure 66). Allowing the animal to perch on a branch or a gloved hand generally allows the sonographer better access to the areas of interest, which would otherwise be obscured if the animal flattens itself to the ground. Medical conditioning has also been used to apply topical treatments to crocodile monitors at Singapore Zoo (*Video 19*).

Crate training may be implemented as an animal management tool with potential safety benefits to keepers and welfare benefits to the animal (Figure 67). Crate training may allow for animals to be weighed, inspected, moved between facilities and some veterinary treatments/procedures to occur without capture/restraint being required. An example of such a crate that could be used for crate training of this species is below. Crate training has been implemented at many zoos for other large Varanid species, such as *V. komodoensis* and *V. varius,* and some crocodilian species such as *Crocodylus mindorensis.*

Figure 66. Medical conditioning of the crocodile monitor for coelomic ultrasonography. Photo: Mandai Wildlife Reserve

Figure 67. Training crate used for large reptiles at Melbourne Zoo. Photo: Alex Mitchell

2.5.3 Desired behaviors and welfare indicators

According to Mellor (Mellor and Beausoleil 2015), the mental state of an animal is conditioned by a combination of survival-related factors (Nutrition, Environment, and Health) and situation-related factors (Behavior). Hence, in order to maintain a positive mental state, the survival and situation related factors have to be adequately addressed. We can use the "Five Domains Model of Animal Welfare" (Mellor and Beausoleil 2015) to match behavior indicators with their respective welfare areas (see section 2.3.1 Behavior Categories and Indicators). The physical/functional domains, including Survival-related Nutrition, Environment and Health factors, and the Situation related to Behavior factors, are matched against the behaviors in the indicators. It is critical to understand if the observed behavior is positive or negative. Ethograms can help us to assess the activity budget and the undesired behaviors.

Figure 68. Detail of crocodile monitor skull. Photo: Adrien Farese. Skull prepared by Ludovic Faure and Patrick Prévost

2.6 Handling

Crocodile monitors are not only among the longest lizards but also some of the most dangerous reptiles to handle. They are equipped with powerful claws and sharp teeth, which they do not hesitate to use when they feel threatened. Similarly, excess of confidence by the animal towards a keeper can result in a strong feeding response whenever the keeper enters the exhibit. Luring the animal with a prey item or target before entering the exhibit will significantly reduce the response of the animal. Where luring from outside the exhibit is not feasible, conditioning with routine husbandry is proposed as a way of preventing an unwanted feeding response. Bites from crocodile monitors have been recorded on several occasions. Often, the bites are suffered on hands and forearms, and therefore, wearing bite-proof gloves drastically reduces the risk of injuries (*Video 20*) (Reh et al. 2021; Rehák & Velenský, 1997).

2.6.1 Safety equipment

Working safely with this species can be easily achieved by taking some preventive measures such as using bite-proof gloves, boots, or long tweezers, hemostats or tongs for feeding, to prevent incidents. Other safety equipment to have at disposal for emergencies include a push board, noose pole and a large sturdy net. Not sharing space with a crocodile monitor (particularly an aggressive one) is always a good safety measure.

Giving them access to an elevated shift box is useful. They are intelligent and can easily be trained to go inside when cued to do so.

Figure 69. A young crocodile monitor shows a defensive display with the inflated pouch and coiled tail. Photo: Borja Reh

Video 20. A young crocodile monitor in defensive posture giving warning bites. Borja Reh	

Figure 70. Elevated shift box for crocodile monitors at Denver Zoo. Photo: Tim Trout

2.6.2 Restraining

Manual restraint with this species should generally be considered a last resort, since their potential to inflict damage is significant. Mechanical (i.e. crate/squeeze box) or chemical restraints are preferred for both animal and handler safety. However, if manual restraint is necessary, gauntlet-length bite-proof gloves should always be used. For larger animals, 2-3 people should be involved. One for head/neck restraint, one for the torso and limbs, and a third to manage the tail. This provides optimal safety for handlers while minimizing risk of injury to the animal.

2.6.3 Identification

Identifying individuals is relatively easy based on size, spot pattern and general appearance. However, a permanent marking is mandatory for this species. The use of passive integrated transponders (microchips) is considered the best means of permanent marking available. According to the guidelines for microchip transponder sites by the British Veterinary Zoological Society, microchips in this species should be implanted in the lateral aspect of left femoral area, over quadriceps muscle (BVZS 2003).

When keeping several animals together as a group (for example if rearing young together) a quick temporary visual marker—such as paint at the base of the tail—may be useful.

2.6.4 Sexing

Morphological sexing is possible, particularly in adults. Adult males are significantly larger and heavier bodied than females. Their rostrums are also broader and "boxier" than females. Hemipenile bulges are present, but not pronounced enough to offer definitive sexing. Moreover, females show well developed hemiclitoris that are often mistaken for the male sexual organs when everted (Figure 71).

Figure 71. Female crocodile monitor with prolapsed hemiclitoris. Photo: Borja Reh

Hemipenal bones in adult males can be detected by radiography (Figure 72) (Card 1995), however it is not known at what size or age these become visible, making it a tool that cannot be reliable for young animals. Furthermore, females also present similar radio-opaque structures (Figure 73) (Böhme 2009).

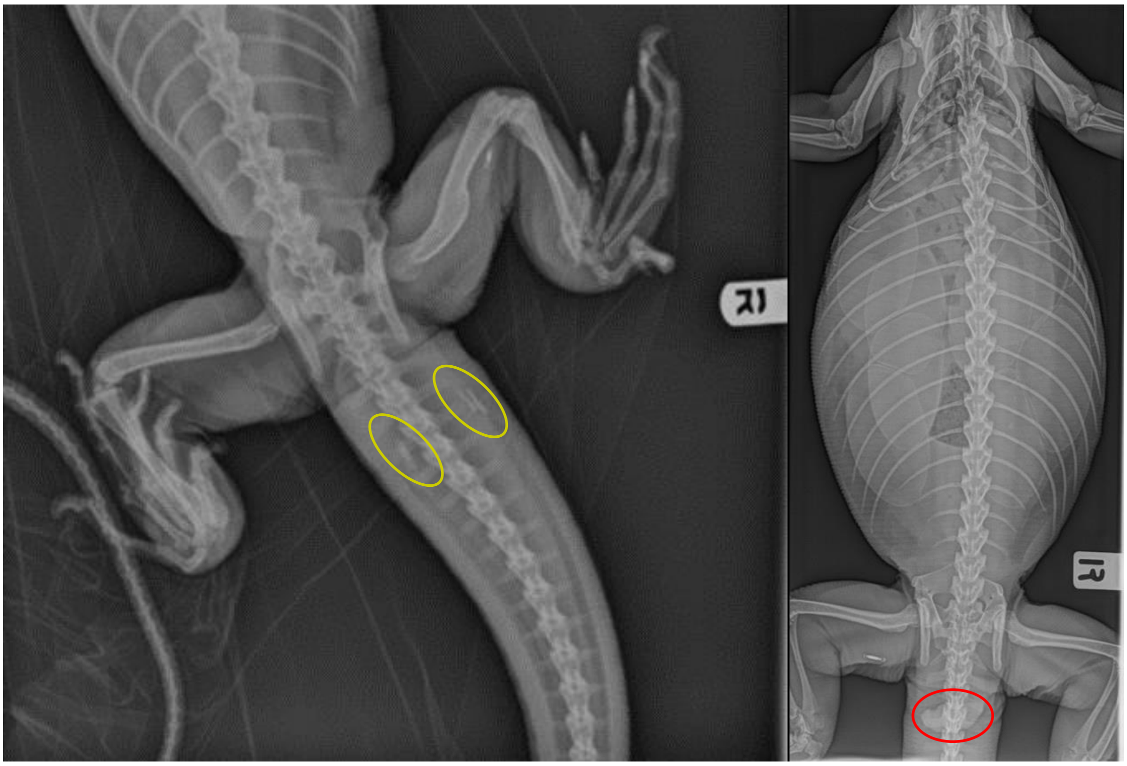


Figure 72. Left. Radiograph of a male crocodile monitor. Yellow circle showing the hemipenal bones. Photo: Michael Wenninger – Fresno Chaffee Zoo/ Figure

73. Right. Radiograph of a female crocodile monitor. Red circle showing the hemiclitoris structure. Photo: Mandai Wildlife Reserve.

Similarly, ovaries and testes can be observed with ultrasonography once the animal reaches a certain size (Figure 74). Blood testosterone levels have been used in sex determination of younger animals with some success. Females have had T levels of 2.8 - 6.7 mg/ml and males have had T levels of 132 – 143.7 mg/ml (Reeves 2019).

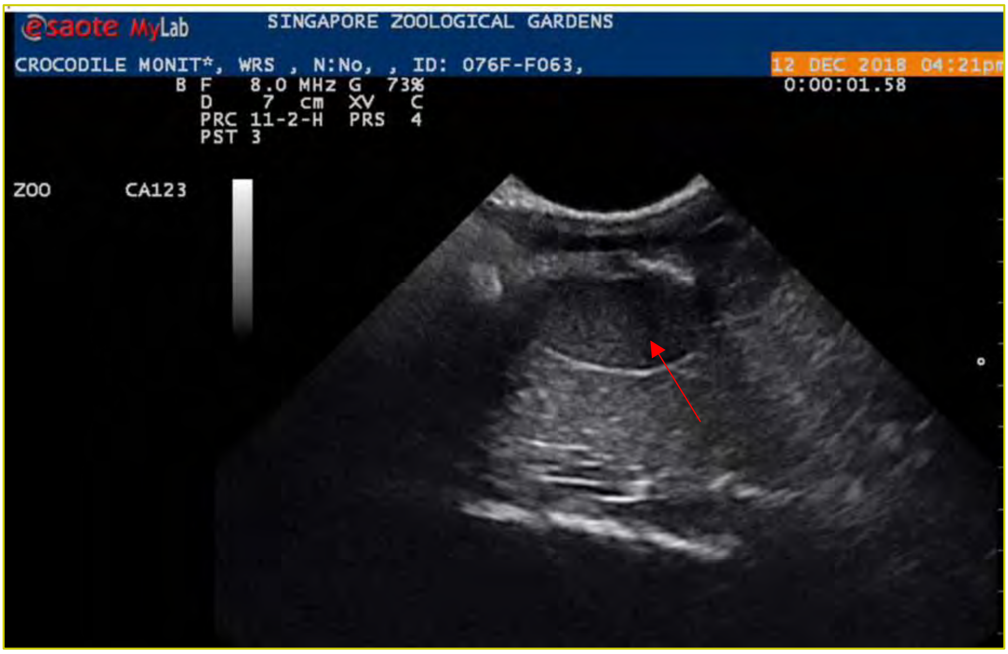


Figure 74. Ultrasound image of a two-year-old crocodile monitor testes. Photo: Mandai Wildlife Reserve

There have been great advances in DNA sexing, and this should become the industry standard. We can reliably determine the gender of any age crocodile monitor simply by placing a dime-sized drop of blood on an FTA card and mailing it to a lab (for a fee). The only lab that has an assay for crocodile monitor currently is Pisces Molecular in Boulder, CO, USA (pisces-molecular.com) (Reeves pers. comm.).

2.6.5 Transportation

Transporting animals for short distances within a facility can generally be done in an appropriately sized container so long as it can be secured. For longer transport (i.e. between facilities) is best accomplished using an appropriately sized wooden crate. The crate should be adequately ventilated and if being transported via airlines, preferably have secondary containment, and following the International Air Transport Association (IATA) Live Animals Regulations (IATA 2021). The temperature during transfer should remain within a tolerable rate for the species and ideally between 24 and 26ºC.

2.6.6 Bite wounds and envenomation

The teeth of crocodile monitors are long, serrated, and slightly curved (Horn 2004) (Figure 68); the bite can cause severe injuries. Aggressive bites towards keepers are uncommon; crocodile monitors prefer to show a clear warning display by flattering their body, coiling the tail, inflating the pouch, and hissing loudly (Figure 69) (Horn 2004). However, if the animal is cornered and the display is unsuccessful, most animals will not hesitate to give a warning bite (*Video 20*). Warning bites can be tremendously harmful (Figure 76, Figure 77, Figure 78). Severe injuries caused by crocodile monitor bites will likely necessitate medical intervention and can pose the risk of permanent morbidity.

2.6.6.1 Venom

Physical damage is the main concern; however, toxins delivered with the bite should not be underestimated. Venom in monitor lizards has recently been discovered and further studies are needed to identify the detailed function and scope of these toxins in each species (Fry et al. 2010, 2012). However, crocodile monitor venom has already proven twice as potent as the Gila monster (*Heloderma suspectum*) in an experiment (Dobson et al. 2021).

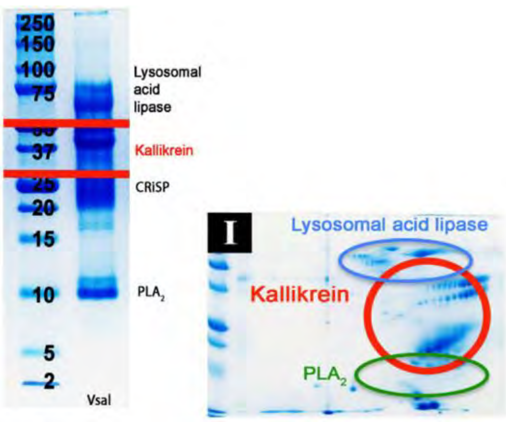


Figure 75. Proteomic analyses show the diversity of components present in the crocodile monitor venom. Left 1D gel, right 2D gel (figures extracted from Koludarov et al. 2017)

Figure 76. Adult male crocodile monitor bite. Photos: Julien Barillon

Figure 77. Bite in the forearm caused by a young 1.3 Kg crocodile monitor. Photos: Mario Pascual.

Figure 78. Accidental bite from an adult crocodile monitor while feeding. Photo: Tommy Edward

Proteomic analyses revealed the venom of crocodile monitors contain a large diversity of components including AVIT, CRiSP, Kallikrein, Lysosomal Acid Lipase, Natriuretic peptide, and PLA_2 (Koludarov et al. 2017). These components are likely linked with symptoms reported beyond the mechanical damage inflicted by the bite itself. These include a burning sensation, prolonged bleeding, and inflammation. Furthermore, anticoagulant effects have been reported in most bites by crocodile monitors (Koludarov et al. 2017) (Reh, pers. comm.). Neurotoxic symptoms have not been recorded in crocodile monitor bites, however, if present, these would be masked by the pain caused by the severe mechanical damage produced by the bite (Dobson et al. 2021).

2.7 Veterinary: Considerations for health and welfare

As with other varanid species, many health issues in crocodile monitors can be complicated by husbandry conditions (Mendyk et al. 2013). Crocodile monitors in zoos have historically had low life expectancy (Mendyk, 2015) and high premature mortality rates. The main drivers to the high mortality rates in this species are linked to different pathologies such as dystocia and gout (Figure 79). In contrast, the most likely cause for the low breeding rates might be related to suboptimal physical condition and intraspecific aggression, among others. It is therefore important that the husbandry provisions are optimal to prevent diseases in the animal.

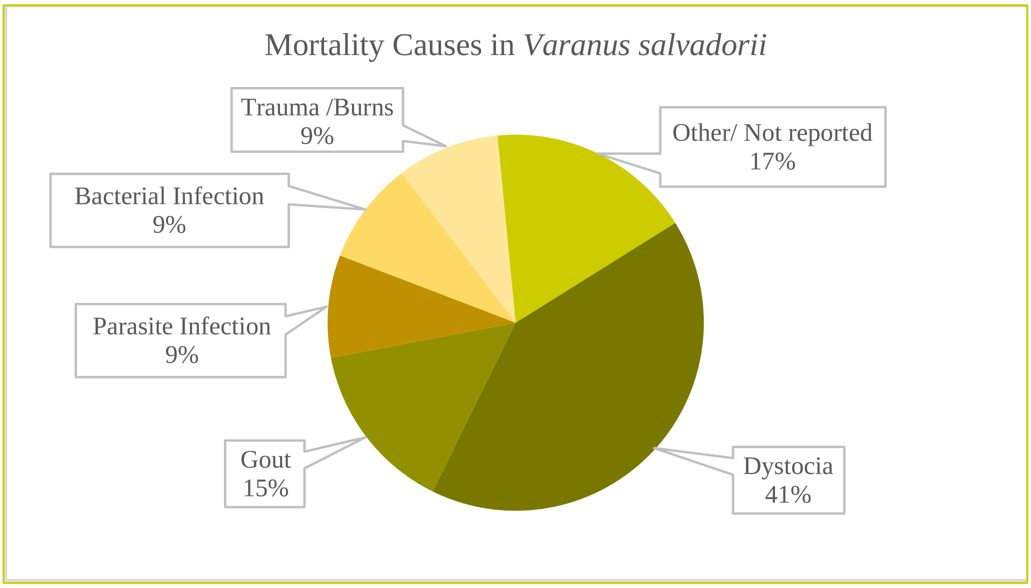


Figure 79. Percentage of causes of mortality in 38 reported crocodile monitor deaths by ten institutions (Reh et al. 2021)

2.7.1 Diagnostic tools and techniques

Simple veterinary procedures can be carried out with manual restraint, although prolonged procedures may require injectable anaesthesia. Intravenous alfaxalone 6.6 mg/kg administered through the tail vein provided rapid anaesthetic induction, which can be easily maintained with isoflurane. Anaesthetic combinations using ketamine, dexmedetomidine and midazolam followed by intubation and maintenance with inhalant gaseous anaesthesia also provide rapid and safe anaesthesia that are partially reversible for rapid recovery.

2.7.1.1 Blood sampling

Blood samples are easily obtained from the ventral coccygeal vein for routine haematology and biochemistry, with either the ventral or lateral approach. This is also a reliable site for blood collection in neonates. The cephalic vein is also accessible although this is more commonly used for the establishment of intravenous catheters during longer procedures.

2.7.1.2 Diagnostic Imaging

Ultrasonography of the coelomic cavity is most commonly done for the assessment of folliculogenesis. The animals can be conditioned to stay relatively still for this procedure. A lateral coelomic approach is commonly used on both sides. The size, position and echogenicity of the follicles can then be assessed. A general ultrasound scan can also be performed on the liver, spleen, gall bladder, gonads, gastrointestinal tract and bladder, although the ventral coelomic approach is preferred for accurate visualisation.

Radiography is useful for assessing the lung fields of animals with suspected respiratory tract infections and calcification of eggs in breeding females. Contrast radiography with barium can diagnose gastrointestinal obstructions. Skeletal deformities like fractures and arthritic changes can also be identified.

Non-invasive endoscopy is useful for the collection of samples. Bronchoscopy can assist with transtracheal washes and bronchoalveolar lavages. Upper and lower gastrointestinal endoscopy can also guide biopsies of the intestinal tract. Coelioscopy, however, yields limited information as the intestinal structures are covered by a thick membrane. Exploratory coeliotomy is therefore more useful to explore lesions of the gastrointestinal tract as the thick membrane can be incised.

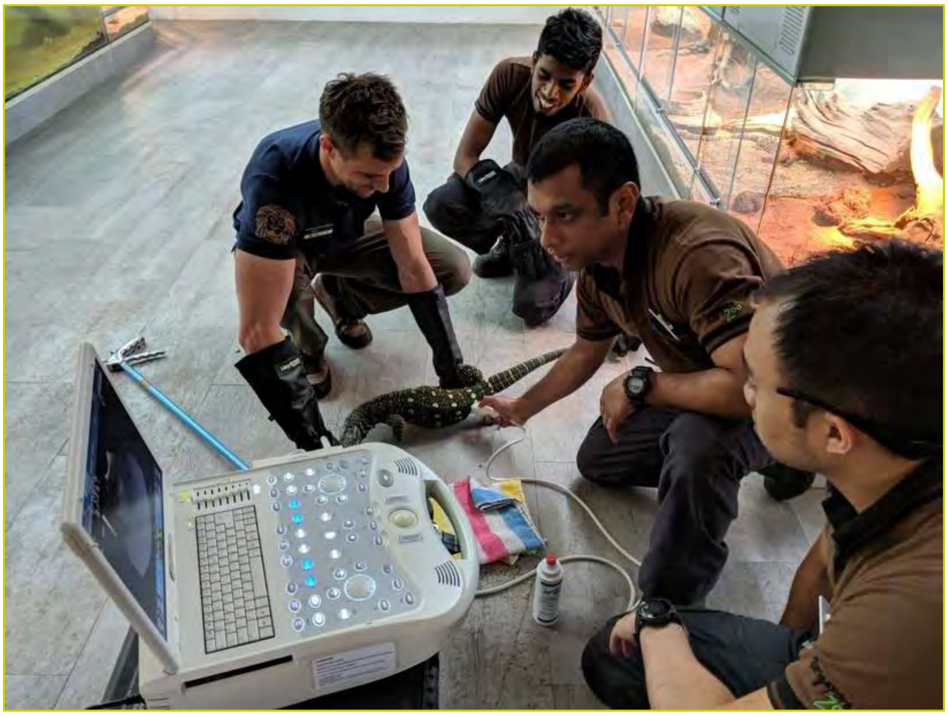


Figure 80. Medical conditioning of the crocodile monitor for coelomic ultrasonography. Photo: Claudia Tay

Figure 81. Vitellogenic follicles with measurements (1.95 cm X 1.58 cm) lined up in the uterus (See Appendix II). Photo: Mandai Wildlife Reserve.

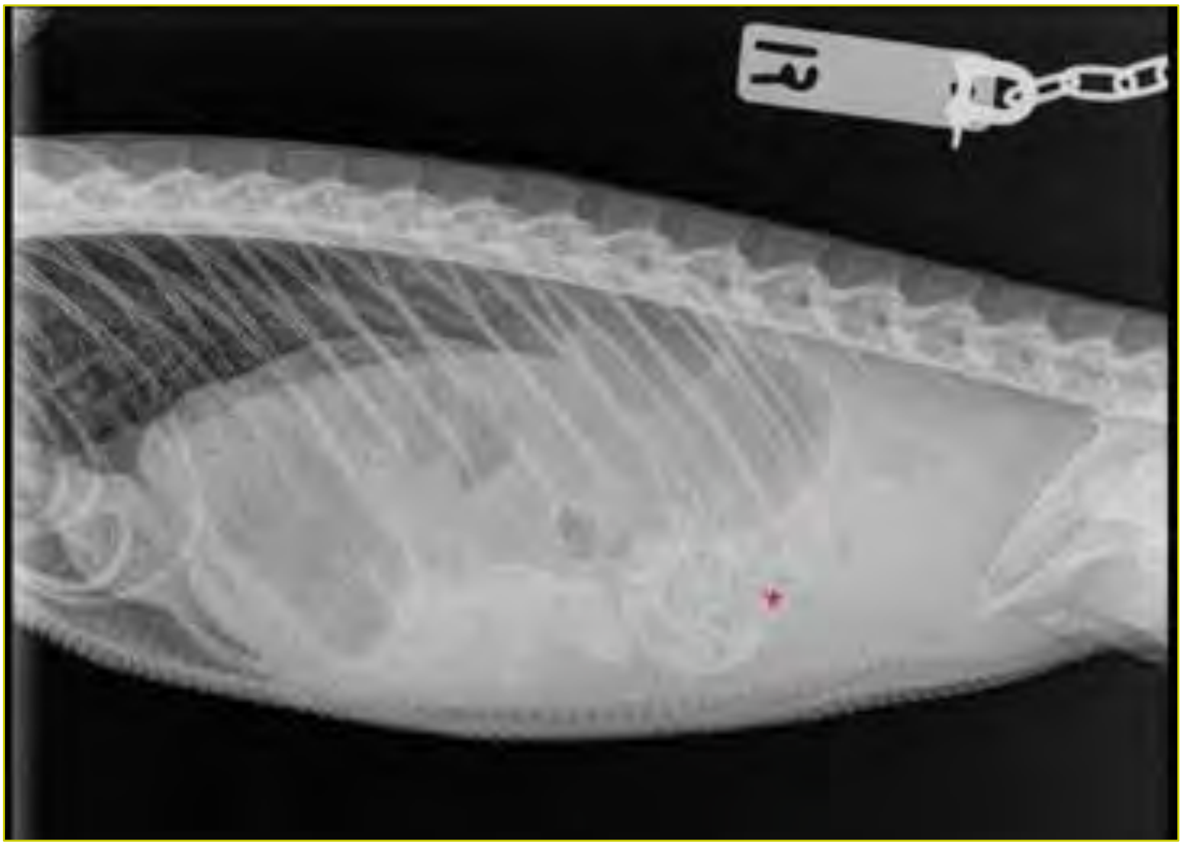


Figure 82. Lateral coelomic radiography highlight a nodular lesion (*). Photo: Mandai Wildlife Reserve

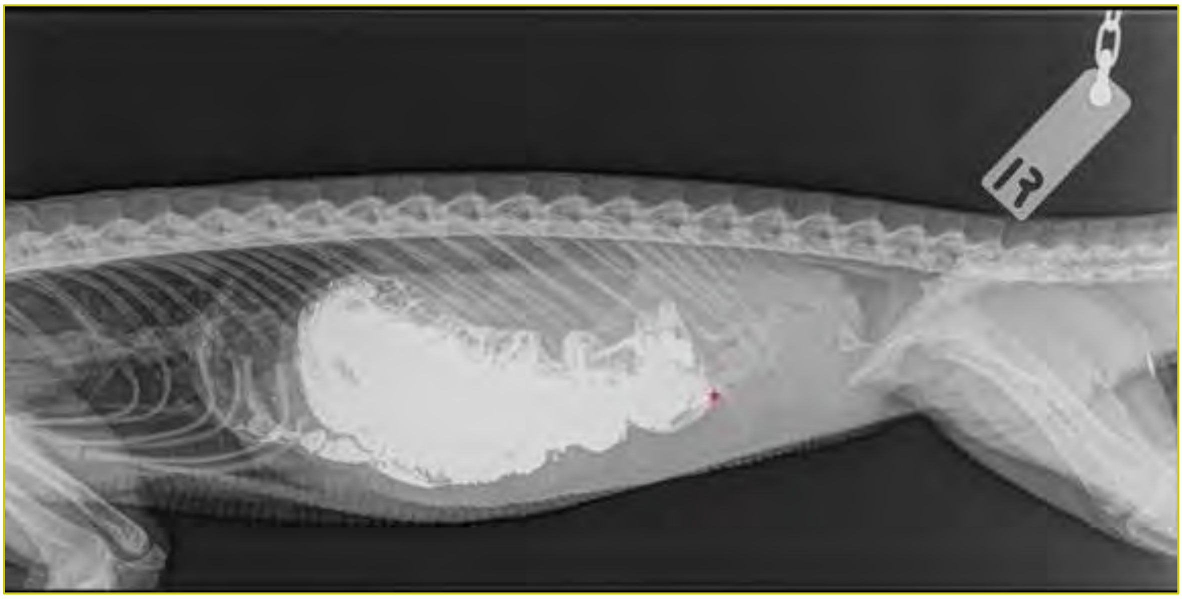


Figure 83. Barium contrast radiography suggesting an obstruction of the gastrointestinal tract. Photo: Mandai Wildlife Reserve

Figure 84. Membrane covering intestines seen on coelioscopy. Photo: Mandai Wildlife Reserve*

2.7.2 Preventive medicine

A preventative health program is paramount to the wellbeing of crocodile monitors in human care. Physical examination including weight, body condition assessment, visual inspection of integument, cardiopulmonary auscultation, coelomic palpation, oral exam, cloacal exam, and neurologic and musculoskeletal evaluation should be performed prior to acquisition or upon intake to a quarantine facility. Fecal floatation and direct evaluation should be performed several times throughout the quarantine period with treatment aimed at symptomatic individuals or those with frequently pathogenic or zoonotic parasites. *Cryptosporidium* PCR or acid-fast stain should also be performed. Baseline complete blood counts and serum biochemistry should be obtained at or before intake and prior to release from quarantine. Whole body radiographs should be obtained prior to release from quarantine. Adult female crocodile monitors should have coelomic ultrasound performed to evaluate reproductive status. Established individuals should be evaluated visually, annually, with complete workup performed at the discretion of the attending veterinarian or whenever showing symptoms of disease. Minimally, complete evaluations should be performed upon acquisition, at sexual maturity, and when geriatric.

2.7.3 Nutrition related issues

Nutritional diseases in crocodile monitors are poorly documented. Cases of renal disease, gout, metastatic mineralization, obesity, and hepatic lipidosis are likely sequelae to improper nutrition or inadequate hydration. Care should be taken to provide appropriate varied prey to maintain the individual in good body condition, ambient temperatures within the preferred optimal temperature zone, suitable basking temperatures, and access to dripping and pooling water sources.

Gout has been reported as the main cause of mortality in monitor lizards (Mendyk et al. 2013); referred to as the deposition of uric acid in tissues (Divers and Stahl 2019), it is the most frequent cause of death in crocodile monitor males, and the second in females, after dystocia, according to a recent study (Figure 79) (Reh et al. 2021). Overfeeding is typically the main cause of gout in captive reptiles (Divers and Stahl 2019). However, other causes such as renal disease or chronic dehydration can cause gout as well. The one case of severe systemic gout seen in the Singapore Zoo was diagnosed during postmortem examination of a reproductively active female adult crocodile monitor and thought to be attributed to the high protein diet offered to meet the increased nutritional requirements of her egg laying cycles (Figure 85).

In order to prevent gout, we suggest implementing mitigating measures, including a balanced diet, physical exercise as well as sufficient hydration during all stages of their life. Future studies on protein requirements may also be beneficial for this cause.

Metabolic bone disease (MBD) is less common in this species except during egg development. Concentration of vitamin D3 in blood is considered useful in assessing the vitamin D status in crocodile monitors. Captive animals with no daily UVB exposure have lower levels (Gillespie et al. 2000).

Figure 85. Postmortem images showing severe gout crystallization seen grossly on the (a) extensor tendons of the distal limb, (b) liver, (c) kidneys, (d) heart, and (e) tongue.

2.7.4 Reproductive related issues

Not uncommon in Varanids, female crocodile monitors are susceptible to follicular stasis and dystocia. If either of these conditions are not addressed (usually this involves surgery and probable ovariosalpingectomy) then it generally leads to coelomitis, septicemia and ultimately death. Males do not appear to have reproductive issues.

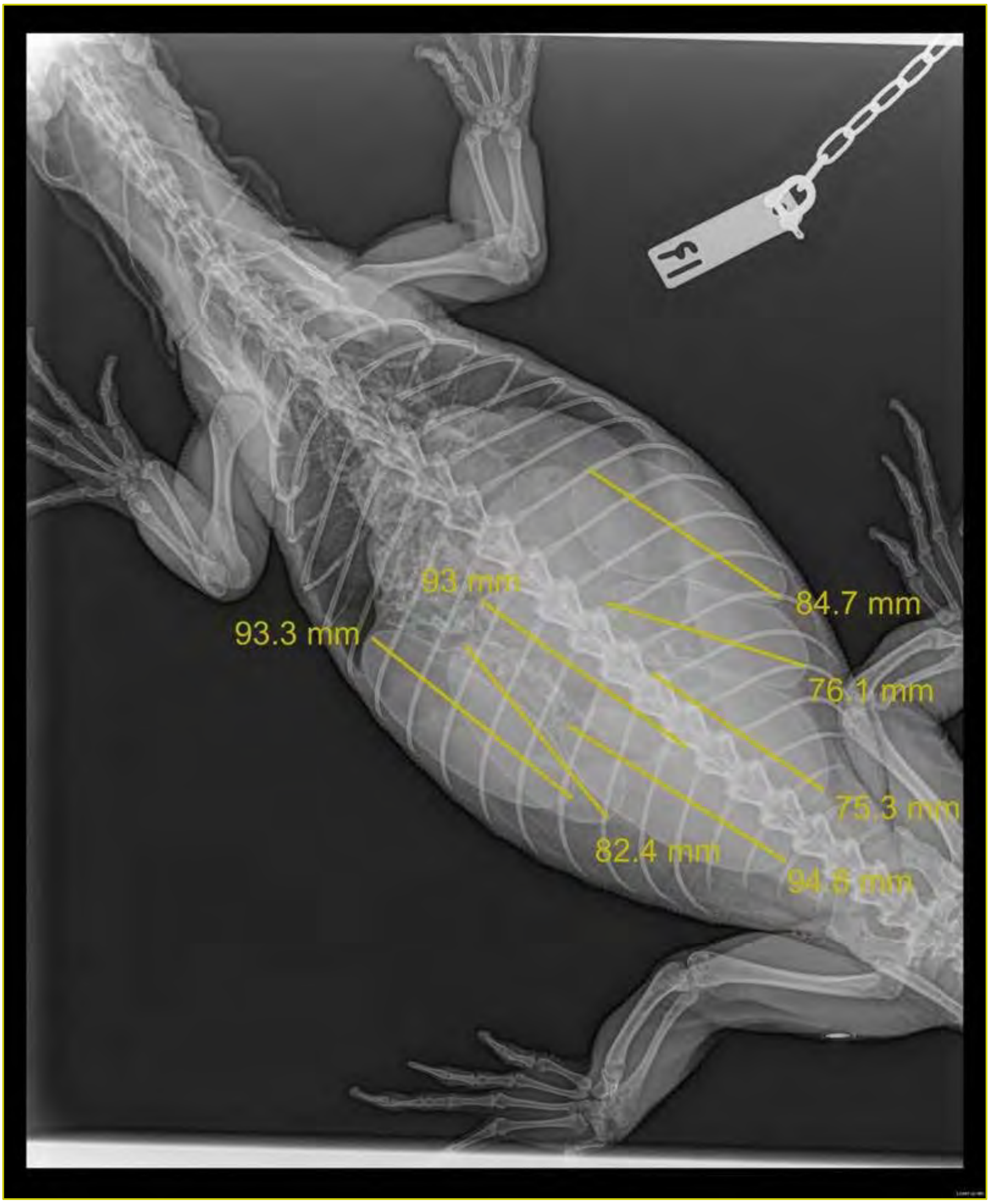


Figure 86. An x-ray image shows seven fully formed eggs six days before egg deposition in a crocodile monitor. Singapore Zoo. Photo: Mandai Wildlife Reserve

2.7.5 Ectoparasites and endoparasites

Imported crocodile monitors often present with both internal and external parasites. Ectoparasites are generally ticks that can be manually removed. Numerous endoparasites that have been reported include flagellates, *Coccidia*, pinworms, strongyles, cestodes, tapeworms, *Capillaria*, *Trichomonas*, *Troglodytella* and pentastomids. Due to the large and varied types of endoparasites found in wild specimens, faecal analysis should be done as soon as possible after acquisition. This will determine which anti-parasitic drugs are appropriate for the treatment of the endoparasites present.

2.7.6 Infectious diseases

2.7.6.1 Nannizziopsis vriesii

The *Chrysosporium* anamorph of the fungus *Nannizziopsis vriesii*, which colonizes the epidermis of the skin, can cause severe, fatal dermatitis in multiple reptile species (Bowman et al. 2007). The factors that influence the pathogenicity of this naturally occurring fungus in captive reptiles is poorly understood, although there is some evidence that it can act as a primary pathogen (Jean A. Paré et al. 2006). Superficial lesions associated with this fungus have been reported in one crocodile monitor (Figure 87). The individual presented with a hyperkeratotic exudative dermatitis (crusting). A skin scraping was prepared for cytology using a potassium hydroxide (KOH) preparation, which revealed fungal colonies. A skin biopsy was then obtained and sent away for *Nannizziopsis* culture, which was positive. The animal was treated topically with povidone (contact time: 10 minutes) and systemic antifungals, to make a complete recovery.

Figure 87. Yellow fungus lesions in a crocodile monitor. Photo: Borja Reh

2.7.6.2 Entamoeba invadens

Entamoeba invadens is a commensal protoazoan, found in the gastrointestinal tract of herbivorous reptiles, that can cause clinical amoebiasis in carnivorous reptiles (Denver 2008). *Entamoeba invadens* causes damage to the intestinal mucosa resulting in enteritis and colitis, with secondary hepatitis. Whilst it is not considered to be zoonotic, it is highly contagious and can spread rapidly through a reptile collection. Clinical disease and associated mortalities have been reported across a range of species including Komodo dragons (*Varanus komodoensis*), water monitors (*V. salvator*) and lace monitors (*V. varius*) (Mayer and Donnelly 2012). *Entamoeba invadens* was isolated in one case of perforating enteritis in a crocodile monitor (Figure 88). The animal presented with general inappetence and lethargy and regurgitated some of its food. It was treated with systemic antibiotics, but when there was no response to this treatment, exploratory coelioscopy and coeliotomy were performed. This confirmed a perforation of the large intestine, and the animal was euthanized whilst it was still under general anesthesia.

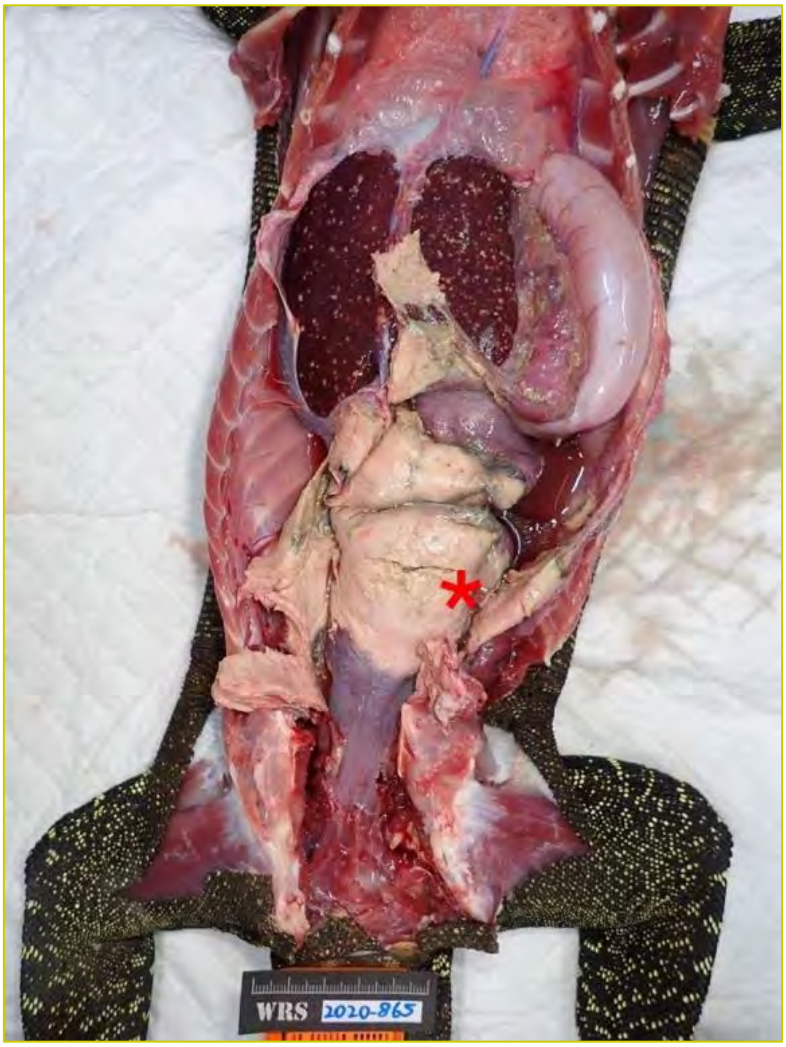


Figure 88. Fibrinous adhesions surrounding a perforation of the colon (*) due to necrotizing enteritis caused by E. invadens. Photo: Mandai Wildlife Reserve

2.7.6.3 Aeromonas spp

Aeromonas spp have been isolated from healthy animals, but have also been associated with disease in reptiles, including pneumonia, oral lesions, skin lesions and septicemia in which they are the sole isolate or have been isolated in high numbers (J. A. Paré et al. 2006). It was isolated from one neonatal crocodile monitor, who presented dead with an umbilical infection.

2.7.6.4 Pneumonia

Pneumonia can be a life-threatening condition in reptiles if it is not aggressively treated. Whilst there are some bacterial, fungal, and viral agents that are capable of causing primary disease, many cases are secondary to stress caused by poor husbandry conditions. Primary and secondary bacterial pneumonia have been reported in crocodile monitors. Clinical signs included coughing and exudate present at the glottis. In other monitor species, open mouth breathing, neck extension and increased respiratory rates and efforts are also reported (Murray 2006). Complete blood cell counts and biochemistry are often unremarkable, but may give an indication of prognosis if they reveal signs of other organ systems being affected. Plain radiographs may reveal lung pathology and can be used to monitor response to treatment. Transtracheal washes (performed under sedation) are the most useful diagnostic tool. The sample that is obtained should be used for a wet mount (to look for larvae, eggs and protozoa), cytology, bacterial and fungal cultures and sensitivities, and/or viral isolation. Cultures obtained from crocodile monitors have been mixed and/or contained *Klebsiella* sp; a commensal bacterium of the oral cavity, but significant when isolated from the lower respiratory tract. Transtracheal washes may fail to culture any organisms if the infectious cause has resulted in a granulomatous response.

2.7.6.5 Septicemia

Septicaemia may occur secondary to other infectious disease processes, most commonly from wounds. Clinical signs reported in crocodile monitors include inappetence, weakness and inability to move and loss of muscle control. Aggressive treatment is required and should be guided by blood culture and sensitivity.

Figure 89. Bites on a males' tail, delivered by an unreceptive female. Photos: Borja Reh

2.7.7 Trauma related issues

Bite wounds are common when crocodile monitors are mixed for breeding, although the level of aggression displayed is dependent on the individual involved. Females can become very aggressive towards males during nesting, causing significant lacerations to the tail base and hindlimbs. Aggression between gravid females has also been reported. Most superficial skin wounds should heal without intervention. This can take several months and is dependent on temperature and nutritional status (Cooper 2006). Hygiene is important; a solution of 1:10 povidone iodine can be used as an antiseptic agent. Wounds should be investigated, using chemical restraint as needed, whether they extend into the muscle or whether coelomic involvement is suspected. Bacteria that are isolated in unusually high numbers or as a sole isolate, should be treated. Culture and sensitivity should be considered in these cases. Potential sequalae of wounds, reported in crocodile monitors, include septicemia and shock.

2.7.8 Weight and size monitoring

Obtaining regular morphometric measurements, including weights, allows assessment of husbandry, response to veterinary treatment and disease progression. A validated body condition scoring system currently does not exist for crocodile monitors. Weight in relation to snout-vent length is used to determine body condition in other lizards, but length references ranges are not currently available for this species. Suggested measurements include snout-vent length, head length, body length, tail length, forelimb length and hindlimb length.

Figure 90. Crocodile monitor weight taking using a hanging weighing scale at Singapore Zoo. Photo: Hakeemulislam Osman

Morphometric measurements, including weight, may be obtained opportunistically if an animal is placed under general anaesthesia or restrained for veterinary examination.

However, there are benefits to obtaining regular weights; including the prevention of under and overdoing of veterinary drugs such as antibiotics, pain relief and anesthetic agents, which can impact clinical outcomes. Crocodile monitors are very intelligent, making them amenable to conditioning or animal training when food is used as a re-enforcer. Individuals can be stationed on a board that is on top of conventional veterinary scales or on a board hanging from a Pesola spring scale. The use of a Pesola spring scales may be preferable as it does not require batteries or a power source and is constructed using corrosion-free components, making it ideal for use in hot and humid environments. It can stay in place permanently within the enclosure and the board added when measurements are needed. Other morphometric measures may be taken if an animal can be stationed in an overhead raceway.

At Singapore Zoo, crocodile monitors are trained to cling on a branch attached to a hanging scale (Figure 90, *Video 20*)

Video 21. Crocodile monitor conditioning for weight taking during a public presentation at Singapore Zoo

Hakeemulislam Osman / Micky Li Jia Wong

Figure 91. Left. Weight taking on a hatchling crocodile monitor at Singapore Zoo. Photo: Borja Reh. Figure 92.Right. Conditioning an animal for weight taking using a Pesola spring scale. Photo: Marwell Zoo

The average weight of adult female crocodile monitors in zoological collections is above the recommended according to the information gathered from the ZIMS database (Species360 2014). Similarly, reported average weights of males in captivity are above recommended (>7 Kg).

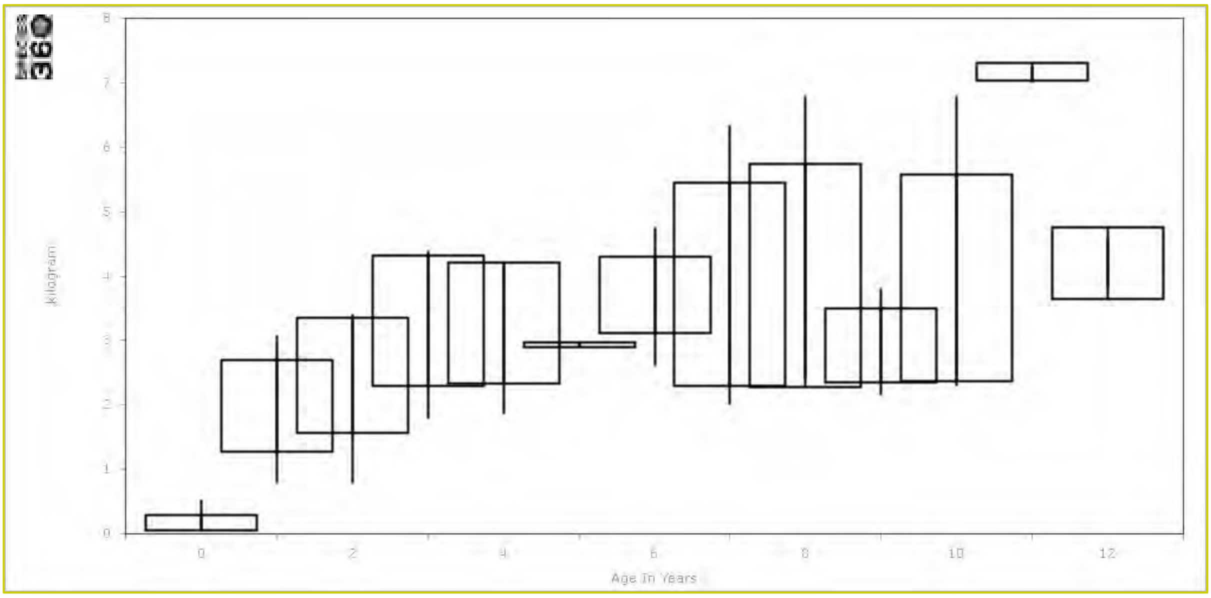


Figure 93. Female Crocodile monitor Weight Report. Information extracted from ZIMS Species 360. Type: Global Number of Animals: 15 Number of Weight Records: 143.

2.7.9 Euthanasia

AVMA, EAZA, and AZA guidelines for humane euthanasia should be followed. Sodium pentobarbital intravenously via the ventral coccygeal vein is easily performed in obtunded animals. Sedation prior to euthanasia may make venous access safer in larger individuals.

2.7.10 Necropsy

Performing a thorough necropsy on all deceased crocodile monitors is a necessary tool in furthering our understanding not just of commonly occurring medical issues but also advancing our knowledge of husbandry. By recognizing the cause of death, as well as subclinical conditions, we can better understand diet and environmental areas of improvement.

There have been cases of female mortality from sepsis/coelomitis secondary to follicular stasis/dystocia. With males, often mortality can be caused by conditions generally attributed to senescence. These include but are not limited to sepsis, neurologic degeneration, gout and endocardiosis. Neoplasia (including adenocarcinoma and chondrosarcoma) has also been observed in the species.

2.8 Specific problems

According to the observations, relevant literature available, and feedback received, the five main factors that play a major role in the husbandry and successful reproduction of crocodile monitors are physical condition, environmental conditions, social dynamics, nest selection, and egg incubation.

A study on veterinary issues in zoological institutions unveiled the most common issues found in this species (Reh et al. 2021).

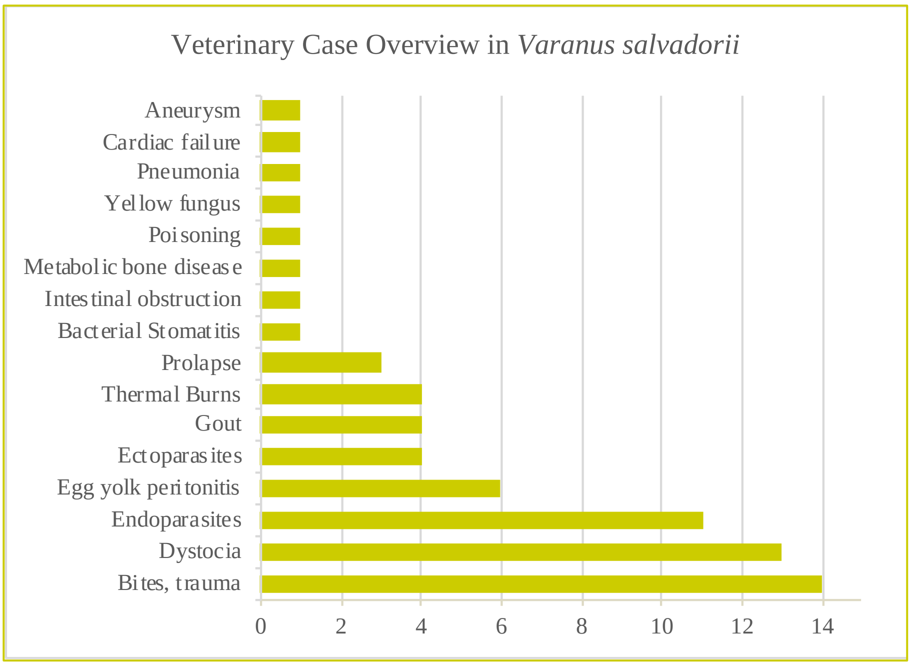


Figure 94. Veterinary case overview of crocodile monitors in eleven zoological collections (Reh et al. 2021)

2.9 Recommended research

The limited knowledge on the ecology and behavior of this species in the wild is the first pressing problem if we are to replicate the natural conditions and encourage natural behaviors in this species. Additionally, we are only beginning to understand their basic needs to thrive and breed in captivity, so we need to keep collecting information from zoological institutions to improve and provide evidence of our practices.

2.9.1 Biology and genetics

Physiological parameters in crocodile monitors have been poorly studied and require attention.

Hormone analysis is a promising field of research, yet no studies have been conducted with this species. Hormone levels can be used to determine physiological processes in reptiles including vitellogenesis and stress levels (Bourne, Stewart, and Watson 1986; Brown et al. 1989; Jessop et al. 2015; Jessop, Chan, and Stuart-Fox 2009; Mayes, Bradshaw, and Bradshaw 2007; Moore and Jessop 2003; Scheun, Greeff, and Ganswindt 2018; Umapathy et al. 2015). Monitoring hormone levels can be achieved by analyzing a blood or fecal sample. Plasma analysis offers a quick and reliable hormone measurement resource but requires restraining and blood collection, which can be stressful for the animal (Phillips and Millar 1998), whereas fecal and urine collection are a noninvasive and less stressful option (Bertocchi et al. 2018; Rittenhouse et al. 2005). However, hormone analysis through fecal collection has been poorly studied in reptiles. Previous fecal hormone studies have been unsuccessful for varanids (Atkins, Jones, and Edwards 2002), while studies in chameleons, turtles, and ball pythons (*Python regius*) have shown promising results in assessing reproductive cycles with fecal-collected hormones (Bertocchi et al. 2018; Kummrow et al. 2010; Umapathy et al. 2015). This field has great potential for research in the zoo setting.

The lack of genetic studies, combined with the wide distribution of this species and the different color patterns that exist, unfolds interrogations about the possibility that *V. salvadorii* exhibits some intraspecific differentiations as is seen in many other New Guinean species across this strongly structured island, which might result in the description of new subspecies. Such phylogeographically correlated differences in genetics could be linked to potential social compatibility issues. This field needs to be further investigated (Hartdegen pers. comm.).

Ontogenetic anatomical changes in teeth could be studied to identify the changes in the diet throughout their life.

2.9.2 Ecology and behavior

The recent findings of animals at an elevation of 1,500 meters show how poorly studied this species has been in their natural habitat. Further studies on the ecology and behavior of wild animals are desperately needed to form an evidence-based husbandry aligned with their wild behavior. Zoos have an opportunity to unveil the ecology of one of the top predators of New Guinea by assisting and funding in-situ projects.

Potential problems caused by the invasive cane toad on crocodile monitors could be studied in captivity and in the wild. No research has been done so far to identify the threat posed by this invasive species.

Further information on incubation parameters is necessary to validate the predictions of previous studies conducted with the limited data on incubation.

Parental care behavior in crocodile monitors needs further research. For instance, no studies have been conducted on the potential role of the male in parental care. Interestingly, males do not show predatory behavior towards eggs or aggression towards the female. Many females, though, have been reported to attack males after nesting.

Section 3: Acknowledgements, References and Appendixes

3.1 Acknowledgements

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Appendix I: List of common behaviors in crocodile monitors

Category	Sub-Category	Behavior	Description
Maintenance	Thermoregulatory	Microhabitat selection	Moving around the enclosure looking for a place to rest or bask (state)
		Basking	Resting or rest/awake directly under the heat source (state). Thermal orientation
		Thigmothermy	Flattening dorsal surface against a heated substrate, usually settling backward (state)
		Shade	Resting or rest/awake with at least 2/3 of its body in the shadow of an object or substrate (state)
	Hunting	Foraging	Swinging from side to side and tongue constantly flicking and moving towards a particular interest (state). (Video)
		Lunge	Rapidly propelling the whole body directly to a target (event)
		Stalking	Slowly approaching a target on which its attention is focused (event)
		Watching	Focusing eyes directly on target, body motionless, head-on posture (event)
	Feeding	Defecating	Discharge faeces from the body (event)
		Drinking	Consuming water (event)
		Foraging	swinging from side to side and tongue constantly flicking and moving towards a particular interest (state)
		Eating	Action of ingesting food (event)
		Vomiting	Ejecting matter from the stomach through the mouth (event)

		Regurgitation	Bringing swallowed food up again to the mouth (event)
Reproductive/ Affiliative	Courtship	Head shuddering (spasmodic body movements)	Males held their bodies raised from the ground, the head frequently jerked from side to side in a spasmodic, shuddering fashion. This head shuddering became more frequent and pronounced when closely approaching a female." moved slowly with wide sweeps of the head and rapid flicking of the tongue consistent with detecting and following a scent trail (state) (Video, Video 2)
		Laying flat/ submissive	Receptive females will remain still or moved slowly, always with their bodies flat on the ground and necks extended along the ground (state).
		Flank bite	Using the teeth to inflict an injury to the other animal in the flank. It is observed in any gender combination (event)
	Mating	Copulation	The male brings his head up to the right of the females, his body lying diagonally across hers and his vent adjacent to the left side of her tai l. He then reaches over the base of her tail with his right hind foot and scrabbles at the right side of her tail with his claws apparently to stimulate her to raise the base of her tail. She recurves her back, lifts her hindquarters off the ground and raises her tail in a high arch. With his right hind foot still over the top of her tail and holding it firmly, he curves the base of his tail under hers to insert the hemipenis (state)
		Pelvic thrust	The male pushes intensely with his pelvis against the female (event)
	Nesting	Test digging	The female excavates a small hole and introduces the snout to check the suitability (state)

		Burrowing	Scratching and gouging with the claws of one forelimb at a time, often swapping to the other forelimb after a few strokes (state) (Video, Video 2)
		Nest guarding	The animal remains on top of the nest after backfilling and reacts aggressively when approached (state)
Aggressive / Agonistic / Fear	Intimidatory	Displace	Displace behaviors in which a dominant individual approached the submissive individual directly until the submissive individual moves away, allowing the dominant individual to take over its previously occupied space
		Tail whipping	Whipping the tail aiming an intruder such as another animal (event)
		Hissing	Inflating the pouch and emitting a hissing sound (event) (Video)
	Avoidance	Fleeing	Moving rapidly away from stimulus (state)
	Fight	Biting	Using the teeth to inflict an injury to another animal or thing (event) (Video)
		Attacking	Using primarily bites and wrestling as attacking mechanisms (event)
		Wrestling	Ritual combat between males with no bites involved (event)
Social / Communication	Visual	Eye contact	The animal becomes aware of the presence of another animal or thing and keeps the attention towards it (event)
		Posturing	Inflated body including gular pouch (event)
		Head movements	Change the head orientation (Event)

	Chemical	Vent dragging / Scenting	Pressing down the cloaca and while dragging the hind legs Scent trails and marking of particular sites are used to communicate over long distances or periods of time (state) (Video)
		Rubbing	Rubbing head, neck and throat on trees, rocks, soil (state)
Active	Exploratory	Vigilant	body remaining motionless, the abdomen held in either a prone or erect position, and the head and neck held high (state)
		Scent tracking	Following a trail of smell by detecting chemical cues through tongue-flicking and tongue-touching the substrate (state) (Video)
		Tongue-flicking	The animal collects chemical stimuli using the tongue to be delivered to the vomeronasal organ situated in the roof of the mouth (state) (Video)
		Turn head	Moving the head so as to be pointed in a particular direction (event) (Video)
		Tongue-touching Repeated tongue flicking	Moving closer to and further from a surface while in/exhaling, no tongue extrusion (state) (Video)
		Tongue touch	Extruding and retracting the tongue and touching an object or substrate (event)
	Locomotion	Crawling	Moving forward dragging the body close to the ground (state)
		Jumping	Pushing off a surface and into the air by using the leg muscles (event) (Video)
		Climbing	Using the claws and any other part of the body to ascend a steep topographical object such as a rock, tree or wall (state) (Video)

		Running	Moving rapidly with the body raised above the ground (state) (Video)
		Stereo-typic	Frequent repetition of the same purposeless movement (state)
		Swimming	Propulsion of the animal through water using body motions (state) (Video)
Sedentary behaviour		Rest	Lying with eyes closed (state)
		Rest/Awake	Lying or standing with eyes open, not engaged in any active behaviour (state)

References: Abram et al. 2017; Bashaw et al. 2016; Bels et al. 1995; Carter 1990, 1992; Davis, Darling, and Darlington 1986; Divers and Stahl 2019; Fischer 2012; Greenberg 1977; Guarino 2002; Horn 2004; Huang et al. 2019; Kirshner 2016; Lee 2001; Mason & Parker 2010; Phillips and Millar 1998; Planka et al. 2004; Resetarits 1996; Rhind et al. 2016, 2016; Setyawatiningsih et al. 2016; Thompson 1995; Trout 2007; Tsellarius and Tsellarius 1997; Uyeda et al. 2015; Warwick et al. 2013; Wingfield et al. 1998.

Appendix II: Follicle monitoring in a crocodile monitor

Determination of follicle size in crocodile monitor (*Varanus salvadorii*) via ultrasonography image, and behavioral response during mixing attempts.

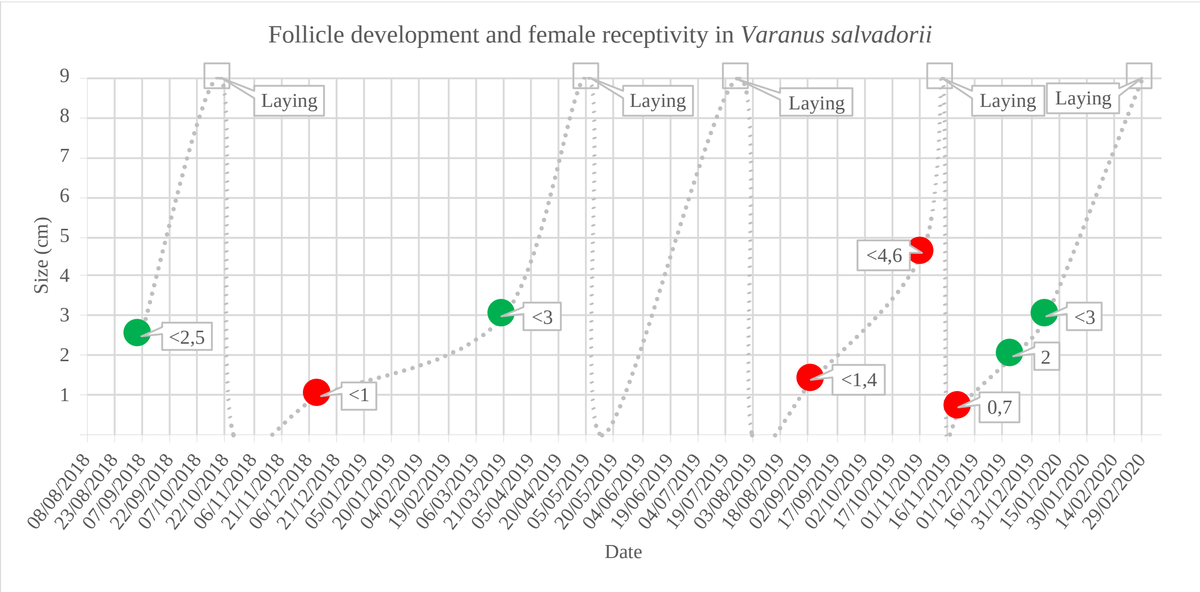


Figure 95. Ultrasound monitoring of follicle development in a female crocodile monitor at Singapore Zoo. Ultrasonography indicated with a circle including the maximum follicle size. Green circle indicates female receptive; Red circle indicates aggression observed. The square represents egg laying. (Reh et al. 2021).

Ultrasound images of female crocodile monitor

Date: 12/12/2018

Maximum follicle size: 1cm. Behavioral response: Aggressive response to males

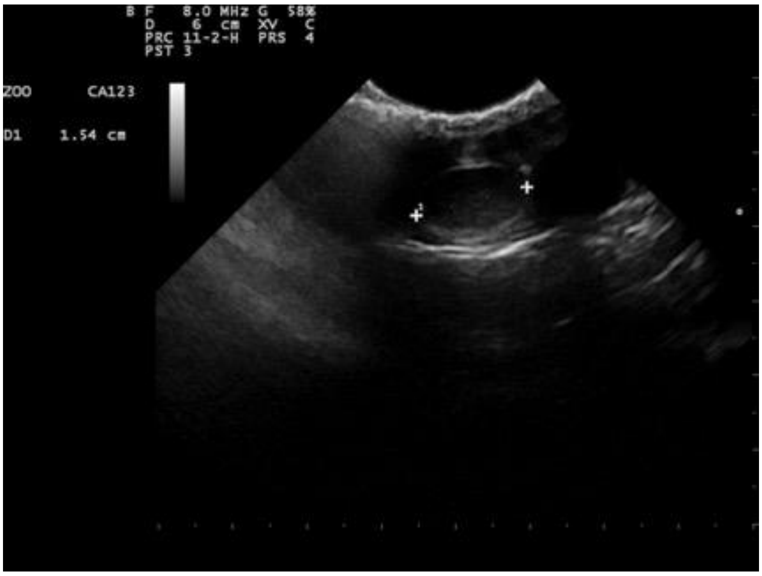
	
	
Ultrasound images of female crocodile monitor Date: 21/03/2019 Maximum follicle size: 2,9cm. Behavioral response: Submissive response to mates	

Ultrasound images of female crocodile monitor

Date: 04/09/2019

Maximum follicle size: 1,20cm.

Behavioral response: Aggressive response to males

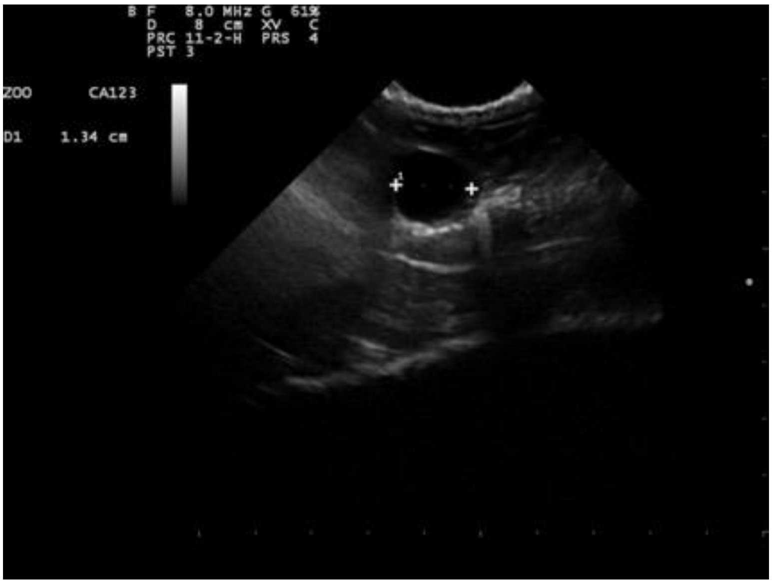


Ultrasound images of female crocodile monitor

Date: 04/09/2019

Maximum follicle size: 1,40 cm.

Behavioral response: Aggressive response to males

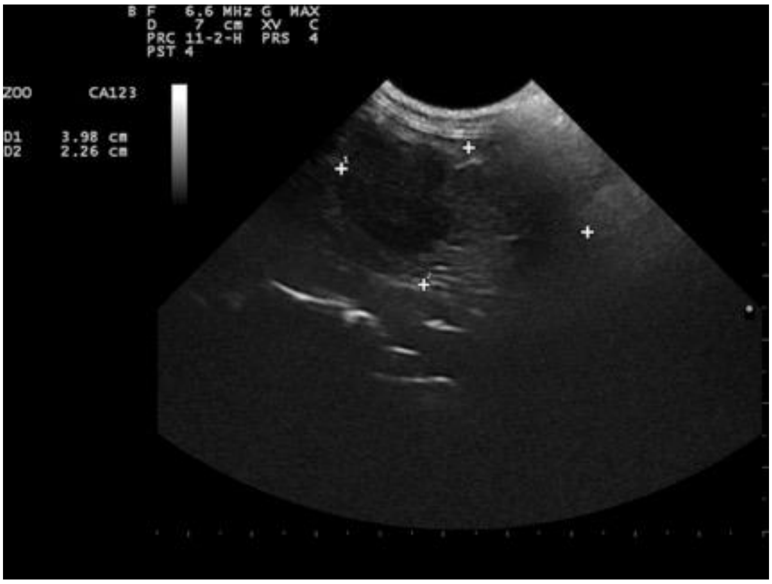


Ultrasound images of female crocodile monitor

Date 02/11/2019

Maximum follicle size: 4,60 cm.

Behavioral response: Aggressive response to males



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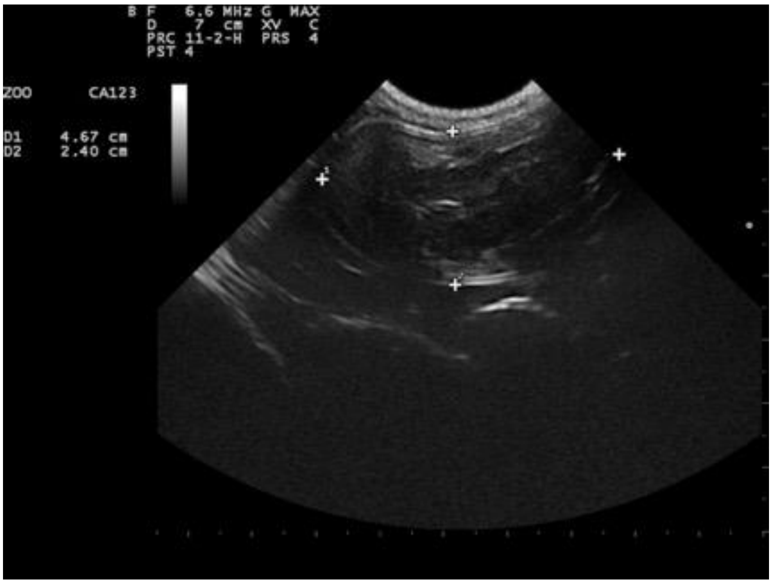
<tr><td></td><td>
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<tr><td>Ultrasound images of female crocodile monitor

Date: 02/11/2019

Maximum follicle size: 4,60 cm.

Behavioral response: Aggressive response to males</td><td>
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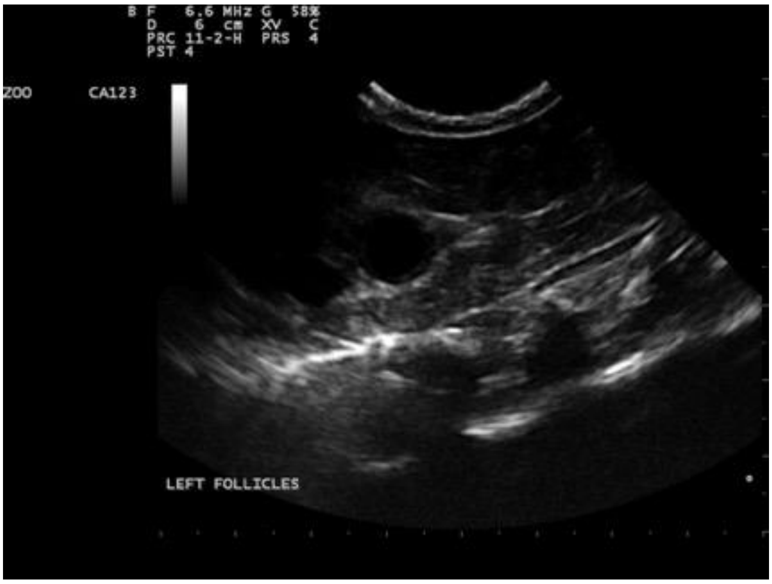
Date: 22/11/2019

Maximum follicle size: 0,70 cm.

Behavioral response: Aggressive response to males</td>
<td>
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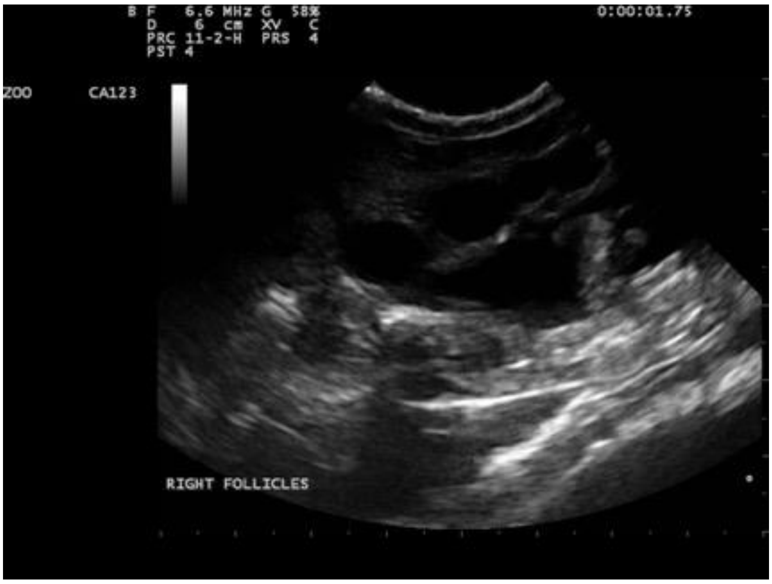
<td>
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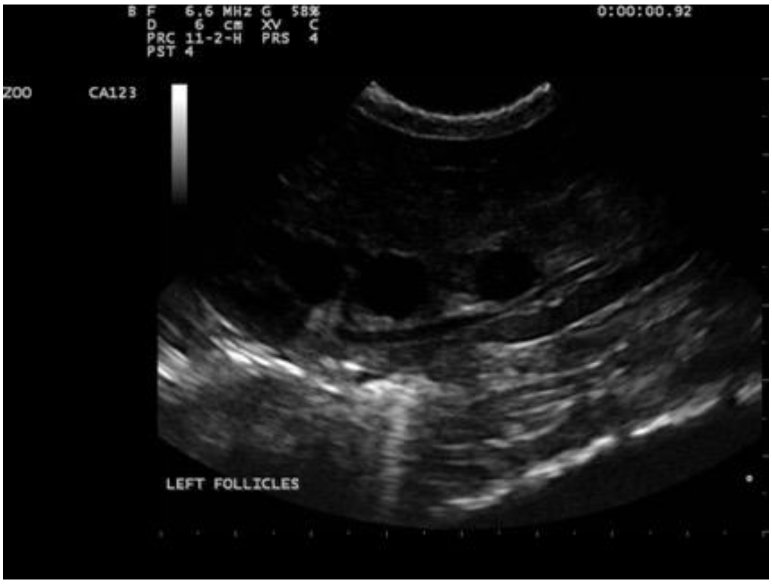
Date: 22/11/2019

Maximum follicle size: 0,70 cm.

Behavioral response: Aggressive response to males</td>
<td>
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Date: 21/12/2019

Maximum follicle size: 2 cm. Behavioral response: Not aggressive response to males. Male not showing high interest on female</td>
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<tr>
<td>Ultrasound images of female crocodile monitor

Date: 21/12/2019

Maximum follicle size: 2 cm.

Behavioral response: Not aggressive response to males. Male not showing high level of interest</td>
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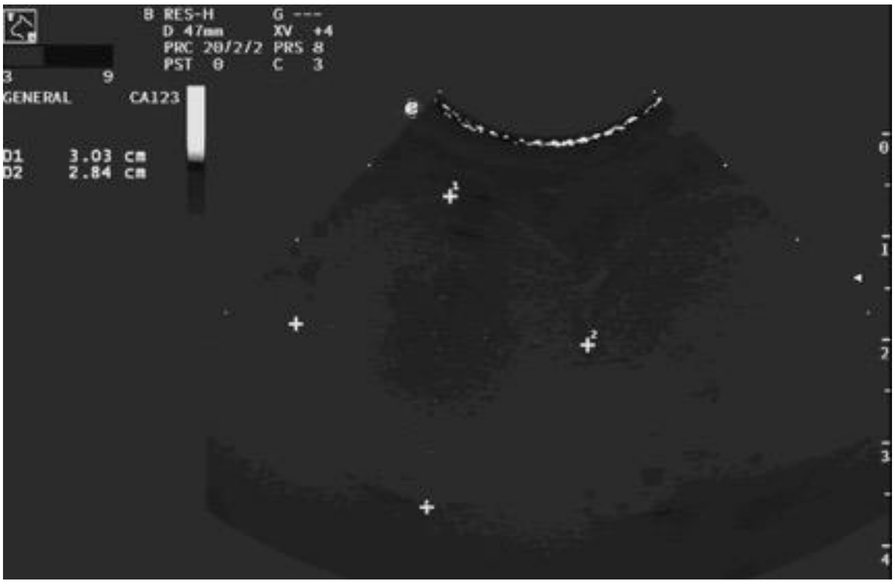
Ultrasound images of female crocodile monitor Date: 08/01/2020 Maximum follicle size: 3 cm. Behavioral response: Female submissive to males. Male showing high interest on female	

Table of Figures

Complete list of crocodile monitor behavior and enrichment videos.

Borja Reh

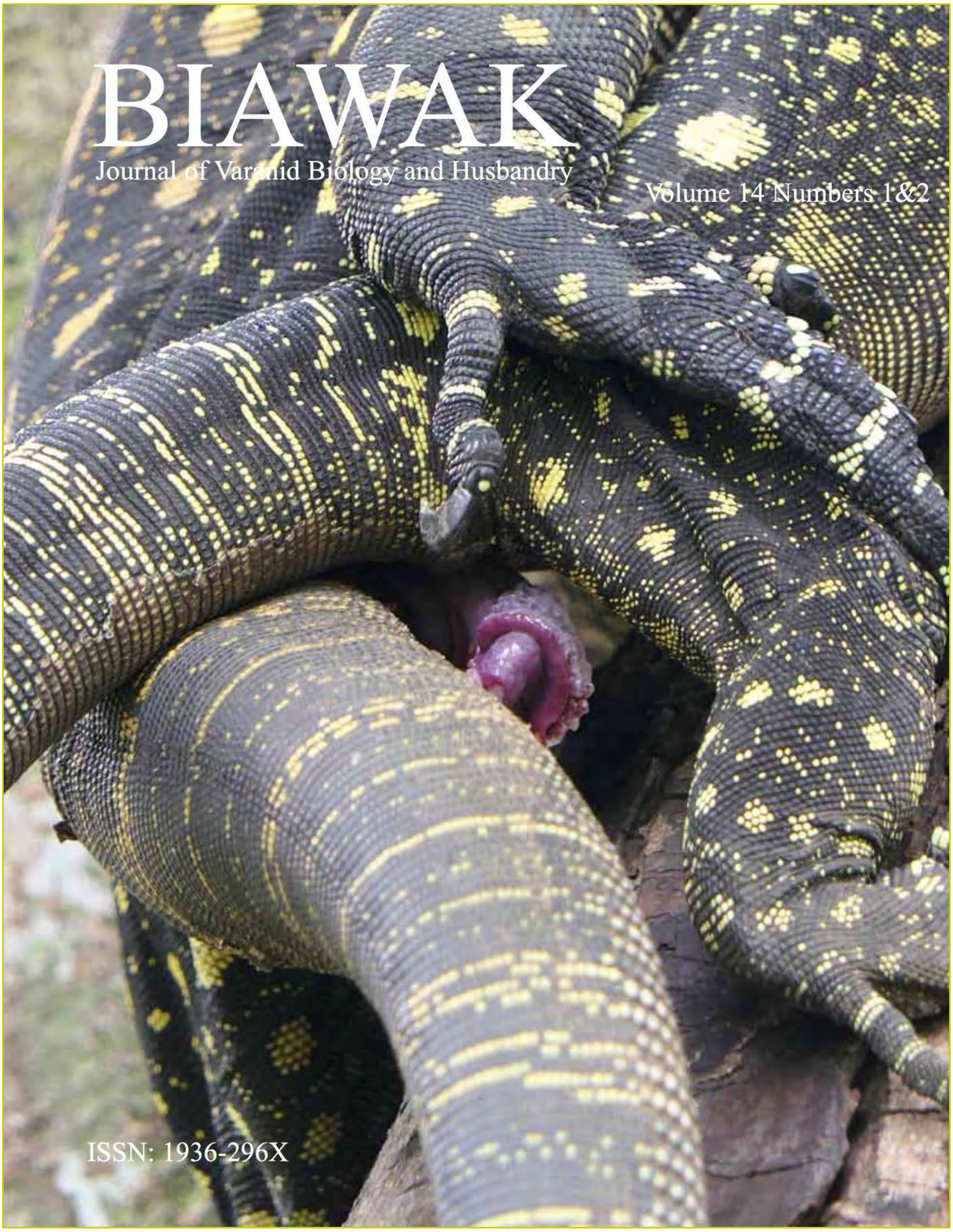


Figure 96. Crocodile monitors mating in the cover of the Biawak Journal Volume 14. Photo: Borja Reh