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Husbandry and Reproduction of *Varanus olivaceus* Hallowell (Sauria:Varanidae) at the Avilon Montalban Zoological Park

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Abstract - A facility for the captive breeding of *Varanus olivaceus* Hallowell, 1857, was established at the Avilon Montalban Zoological Park, Rodriguez (Montalban) Municipality, Rizal Province, Philippines in 1994. Reproductive husbandry and behavior of captive wild-caught adults were observed. A total of five clutches of eggs ranging from 4-16 eggs per clutch were produced by three females of variable sizes, between July and September of 2002-2005. All clutches were artificially incubated. The incubation period for a late-term neonate that expired shortly after being assisted with hatching was 209 days, and 217 days for a surviving, assist-hatched neonate. Feeding techniques and behaviors observed in both the wild-caught adults and the surviving captive-bred neonate are discussed.

Introduction

Of the three currently recognized species of large frugivorous monitor lizards endemic to lowland forests of the Philippines, namely *Varanus olivaceus* of Southern Luzon (Auffenberg, 1988), Catanduanes Island (Ross and Gonzales, 1992), and Polillo Island (Bennett and Hampson, 2003); *V. mabitang* of Panay Island (Gaulke and Curio, 2001; Gaulke et al, 2005); and, the recently described *V. bitatawa* of central and northern Sierra Madre mountain range in northern Luzon (Welton *et al.*, 2010), *V. olivaceus* is hitherto the only species that has been studied extensively, both in the wild and in captivity.

The earliest known captive populations of *V. olivaceus* were those maintained at the research camp of Walter Auffenberg in Caramoan Peninsula, Camarines Sur Province, Luzon, during his final phase of study on *V. olivaceus* from 1982-1983, and outside of the Philippines, those at the Florida State Museum and the Dallas Zoo (Auffenberg, 1988). In 1989, an adult individual of unknown gender was exhibited for the first time at the Manila Zoological and Botanical Garden, City of Manila. This species, known locally as *butaan*, has been observed being sold in pet shops around Manila (D. Bennett, pers. comm.), and has also been kept as pets in private collections inside and outside of the Philippines; unfortunately, most of these captives have perished due to maladaptation to captivity and flawed husbandry.

Published accounts of successful captive breeding in *V. olivaceus* are scant. Between 1984 and 1985, three clutches of nonviable eggs were produced by two females at the Bronx Zoo (Mendyk, in press). The Dallas Zoo was eventually able to produce a single F1 neonate in 1992, but the animal expired shortly after hatching (Card, 1995); death might have been caused by a congenital heart deficiency (W. Card, pers. comm.). Twelve years later, two F1 neonates were produced at the Avilon Montalban Zoological Park, of which only one has survived (now 7 years old at the Avilon Zoo). An article on the captive breeding and rearing of *V. olivaceus* at the Paradise Reptile Zoo in Puerto Galera, Oriental Mindoro Province (Lutz, 2006) is under critical discussion among specialists, and therefore will not be further dealt upon in this report.

Table 1. Morphometric data for *Varanus olivaceus* at Avilon Zoo taken on the day of arrival, 1994-2004.

Year	Locality	No.	Age Class	Sex	SVL (cm)	TL (cm)	ToL (cm)	WT (kg)	Remarks
1994	Bicol Peninsula	1	A	M	120.0	135.2	256.2	12.5	†●■◊
		2	SA	?	42.2	76.6	118.8	2.5	
		3	A	F	54.4	90.0	133.0	5.4	◊
		4	A	F	50.2	89.2	123.4	3.2	
		5	SA	?	44.2	76.3	120.5	3.0	†
		6	SA	?	46.8	80.0	126.8	3.2	□
1998	Bicol Peninsula	7	A	M	70.2	103.2	173.4	7.8	◊
		8	A	F	49.6	88.5	138.1	3.1	
		9	A	M	72.0	105.8	177.8	8.6	
		10	SA	?	44.7	67.4	112.1	3.2	†
		11	A	F	55.6	90.3	145.9	4.2	
		12	A	F	56.2	91.6	147.8	4.5	◊
2001	Cantanduanes Isl.	13	SA	?	43.5	76.0	119.5	2.5	
		14	SA	?	45.2	78.4	123.6	2.3	†
		15	SA	M	58.3	98.5	156.8	4.0	
		16	SA	F	44.6	78.2	122.8	2.8	†
		17	SA	F	46.5	80.9	127.4	2.6	
2004	Bulacan Province	18	A	M	71.0	105.0	176.0	8.0	†○◊

Symbols: † – tail tip missing; ● – 1st, 3rd, 4th, 5th digits of left fore foot missing; ■ – 4th, 5th digit of right fore foot missing; ○ – 2nd digit of left fore foot missing; □ – 5th digit of right hind foot missing; ◊ – prominent scars on head and dorsum.

This article reports on the captive management and breeding of *V. olivaceus* including the husbandry and reproductive behavior of captive adults as well as the successful hatching and post-neonatal care of the world's only surviving captive-bred *V. olivaceus*. A study on feeding, rearing, and growth rate of the neonate will be discussed in a forthcoming report.

Materials and Methods

Eighteen wild-caught *V. olivaceus* consisting of nine adults (4 males, 5 females), and nine sub-adults (1 male, 2 females, 6 unsexed) were acquired from reptile dealers for captive-breeding purposes by the Avilon Zoo between 1994 and 2004. Of these, twelve were from the Bicol Peninsula, five of Catanduanes Island origin (R. Ramos & M. Domingo, pers. comm.), and one from Norzagaray Municipality, Bulacan Province (J. Gaw *et al*., pers. comm.). Measurements were taken shortly after their arrival (Table 1) using a vernier caliper for head length and width, a retractable steel tape measure for snout-vent (SVL) and tail lengths (TL), and a household weighing scale for bodyweight. Sex was determined by the following methods: (1) hemipeneal probing using stainless steel probes; (2) manual eversion of the hemipenes; (3) hemipeneal extrusion whilst being restrained; and (4) visual comparison of tail base thickness. For identification, each individual was marked by notching the tail crests with a sharp stencil cutter (see Bennett, 2005).

Housing

The 1994 breeding stock (1 male, 2 females, 3 unsexed) was temporarily held at the Hexagonal Aviary while awaiting completion of the enclosures designed specifically for the keeping and breeding of monitor lizards. In 1994, the Hexagonal Aviary comprised a large, circular, central enclosure circumscribed by 11 smaller enclosures situated at each angle of the structure. Of these, nine were occupied by parrots, raptors, hornbills, pigeons, water fowl, and three species of mammal: Palawan bear cats (*Arctictis whitei*), palm civets (*Paradoxurus hermaphroditus*), and Malay civets (*Vivera tangalunga*). Two of these enclosures measuring ca. 1.5 x 1.2 x 3.6 m (l x w x h) were allocated for housing *V. olivaceus,* with one male and two females grouped together in each enclosure according to size and maturity.

The two enclosures were fitted with panels of narrow-slotted steel mesh on all sides but the rear wall. Since these enclosures were not designed for housing reptiles, the entire roof of each enclosure was covered with .4 mm thick pre-painted galvanized iron sheeting. Shallow rectangular wading pools made of concrete were constructed against the rear concrete wall of each enclosure. The clay soil in the enclosures was backfilled with a layer of coarse fluvial sand to a depth of ca. 10 cm. A service door, also made of narrow-slotted steel mesh was constructed at the rear of each enclosure and was accessible only from within the central enclosure. Tree branches were installed at various heights to facilitate climbing and basking, and two concrete drainage pipes large enough for the lizards to squeeze into were provided as retreats.

Large, portable steel cages reinforced with poultry netting were used to temporarily confine individual *V. olivaceus* of the 1998 breeding stock (2 males, 2 females) whilst large, rectangular, outdoor enclosures at the west perimeter wall of the zoo were being constructed. Similar to the enclosures in the Hexagonal Aviary, these enclosures, with an average measurement of ca. 4.5 x 1.5 x 2.5 m (l x w x h), were constructed with heavy-duty, narrow-slotted steel matting. A dug-out concrete pond ca. 35 x 20 x 15 cm (l x w x d) with a cemented rim and a drainage system was installed in each enclosure to facilitate functional waste water disposal. A ca. 10 cm deep layer of fluvial sand was laid over the clay soil. The steel mesh roof was partially covered with panels of pre-painted galvanized sheet to provide shade during midday. Climbing facilities were similar to those in the aviary, and a large hollow log was placed horizontally on the floor to provide refuge. For smaller *V. olivaceus* kept inside the Herpetarium, portable steel cages with tree branches and wooden hide boxes were utilized as holding cages.

The elevated monitor lizard exhibit enclosures that were specifically designed to simulate the natural habitat of monitor lizards varied from one to the other (Fig. 1). The enclosure where breeding took place in 2003 measured 3.0 x 2.0 x 2.0 m (l x w x h). A wading pool 37.5 x 22.5 x 15 cm (l x w x d) was built in the center of the enclosure. The substrate was composed of a 3:1 mixture of coarse fluvial sand and fine-grade coco

Fig. 1. Elevated monitor lizard exhibits at the Avilon Zoo.

peat filled to a depth of 15 cm. A drainage system was installed behind the enclosures. Artificial boulders and tree branches made of cement were strategically placed to facilitate climbing, and shallow caverns and ledges were constructed to serve as tight-fitting retreats and basking sites. The roof, also made of heavy duty steel mesh, was reinforced with 2.5 cm2 of chicken wire and partially covered with thick, transparent polyethylene sheeting to keep excessive rainwater from flooding the interior of the enclosure and to allow access to natural sunlight. The front of the enclosure was fitted with a panel of tempered glass (ca. 1.9 cm thick) to facilitate observation without visual barriers.

Individuals from Catanduanes Island were kept separate from those from the Bicol Peninsula, and were identifiable by their atypical ash-grey coloration (for comparison, see Fig. 2). Individuals purported to have been collected from evergreen forests of the Bicol Peninsula (n=13) exhibited a pronounced olive-green coloration whilst those from limestone forests of Catanduanes Island (n=5) surprisingly were distinctly ash-grey in coloration. Variation in body coloration within species corresponding to color differences in habitat strata has also been observed in *V. exanthematicus*, where individuals inhabiting dark soils of the coastal plain of Ghana tend to be darker in coloration than those inhabiting lighter soils in Agomeda

Fig. 2. Color comparison between a Catanduanes Island *V. olivaceus* (left) and a specimen from the Bicol Peninsula (right). Note the ashy-grey coloration of the Catanduanes Island specimen.

(Bennett & Thakoordyal, 2003). Gaulke (1991) also mentioned differences in the coloration of *V. nuchalis* between animals from Negros and Panay Islands, and darker individuals from the islands of Masbate, Ticao, and Boracay. These color differences, however, are not attributed to the color of the substratum in their habitat, but rather the influence of geography. The variation in color between *V. olivaceus* populations requires further study.

Diet of captive adults

Feeding was initiated three days after the arrival of specimens. Food was offered once every 2-3 days between 0900 and 1000 h, after the lizards had basked.

Chicken heads were stored in a freezer and then thawed to room temperature before feeding. These were apportioned to each individual (ca. 100-150 g per feeding) and offered in a large plastic basin. All uneaten foods were removed after 1500 h.

Apart from chicken heads, rodents such as laboratory mice (*Mus musculus*), fancy rats (*Rattus norvegicus*), and wild-caught Luzon field rats (*R. argentiventer*) were fed once or twice a month as supplementary items. Because *M. musculus* and *R. norvegicus* had to be purchased from commercial breeders, only about 5% of those purchased were given to *V. olivaceus*, with the remaining 95% allocated to 112 snakes of 50 species maintained at the Herpetarium during early operations of the zoo. The rodents were stunned before being fed to the lizards either in a plastic basin or by tease-feeding using 62 cm long stainless steel hemostats.

Daily cleaning of enclosures was usually carried out in the morning before feeding time. The water in the pool was replenished daily; more often so if contaminated with feces or uneaten food. The top layer of the substrate was periodically scraped off and replenished with fresh material.

Egg incubation

All clutches of eggs were laid in the evening and collected the following morning. Misshapen eggs and those submerged in the pool were discarded. Eggs were marked and numbered with pencil to maintain the same polarity as when they were laid. The eggs were measured (Table 2) with a vernier caliper and weighed using a household gram scale before being placed in perforated and transparent plastic brood containers measuring 24 X 12 X 16 cm. Moist rubber foam cubes 5 cm thick were used as an incubation medium. The cubes were

Table 2. *Varanus olivaceus* eggs produced at the Avilon Zoo from 2002-2005. Values are expressed as mean (range).

Female No.	Date Laid	Clutch size	Length (mm)	Diameter (mm)	Weight (g)
11	17-Jul-02	10	58.0 (51.0-65.3)	42.0 (40.3-42.8)	46.0 (40.5-52.3)
16	5-Jul-03	6	56.2 (52.0-60.3)	38.9 (30.8-40.2)	39.6 (36.0-43.6)
17	14-Jul-03	4	63.5 (59.3-66.2)	33.6 (32.6-35.2)	46.6 (44.7-48.6)
11	25-Sep-03	13	69.8 (64.5-78.2)	40.5 (38.8-42.2)	56.8 (52.0-62.0)
11	18-Sept-04	8	69.3 (63.3-75.5)	40.2 (38.5-42.3)	53.5 (48.6-60.0)
Overall		8.2 (4-13)	64.2 (51.0-78.2)	39.9 (30.8-42.8)	50.0 (36.0-62.0)

moistened with water to a ratio of 1:2 by weight. The eggs were set firmly on the upper level of the cubes. The upper level was kept dry, the middle level relatively moist, and the lower level perpetually submerged in water. Water at the bottom of the brood containers was maintained at a height of 2.5 cm and refilled when necessary. Additional moisture to increase relative humidity was adjusted by misting the interior walls of the container and the upper level of the incubation media only. The egg containers were subsequently placed in a custom-made acrylic box measuring ca. 60 x 60 x 40 cm (l x w x h) with a perforated lid to function as an incubator. A 50 W incandescent bulb was installed in the upper-most corner of the incubator to provide additional heat. The bulb was switched on in the morning at 0600 h and off in the evening at 1800 h over the course of incubation. The bulb was switched off manually during the hottest part of the day and switched on once again if an increase in temperature was necessary. The egg containers were covered with sheets of newspaper to reduce the intensity of light striking the eggs. Temperature and humidity were monitored and recorded twice daily during the hottest hours of the day and coolest hours of the night using a digital, dual-type thermometer and hygrometer with thermal probes. The thermal probes were placed directly on the surface of the eggs to record temperature and humidity readings. The incubator and egg containers were opened daily, or twice a day if necessary, to facilitate the exchange of oxygen and to eliminate carbon dioxide build up during embryonic development.

Temperature and relative humidity for the 2003 clutch were modified in the latter phase of incubation. Daytime temperature was reduced by 4-5 °C. The relative humidity was reduced by 15-25%, but was increased again to 100% beginning on day 183 in attempt to restore moisture to the remaining two eggs which had become severely indented (see Table 3).

Assisted hatching of neonates

Manual dissection following procedures described by Ross & Merzec (1990) was performed on the two critically indented eggs using a pair of 11.5 cm long stainless steel straight-tipped iris scissors. A small 2.5 cm V-shaped slit was cut along the surface of each egg to check the physical condition of the neonate within. Both neonates were assisted out of the egg by using a stainless steel sexing probe to stimulate motor function by lightly touching the tip of the probe to the body. It took neonate #1 more than 30 min and neonate #2 less than 10 min to emerge. Upon emerging, the two assist-hatched neonates were placed in previously disinfected brood containers with cotton sheeting as a substrate, dampened with 70% ethyl rubbing alcohol to prevent infection of the fresh umbilical scar in neonate #1 and the unabsorbed yolk sac in neonate #2. Surgical procedures were performed immediately to separate the unabsorbed yolk sac from the yolk stalk of the surviving neonate #2 (E.B. Maestro, unpub. dat.) to prevent the yolk sac from being dragged about the tank. The fresh umbilical scars of both neonates were dabbed with Povidone-Iodine. Neonate #1 expired 1 h 45 min after being assisted out of the egg. The yolk sac, measuring 3.3 cm in diameter, was preserved in 70% ethyl rubbing alcohol, and the carcass of the neonate was preserved in a 33% formalin solution (ID: AZCBMu001-03-00162); both were deposited at the Animal Hospital of Avilon Zoo.

Neonate #2 was transferred to the Rearing Department and placed in an acrylic rearing tank measuring 60 x 30 x 30 cm (l x w x h) for post-surgery care and observation. Newspaper was used as substrate. Water was provided in a small, shallow ceramic cup. A Y-shaped tree branch was placed at an angle so that the forked end was 5 cm beneath the wire mesh cover. The rearing tank and all materials within it were

Table 3. Modified incubation parameters for the 2003 clutch of *V. olivaceus* eggs. Abbreviations: DTH = day time high; NTL = night time low; RH = relative humidity.

	Day	Temperature (°C)		RH (%)	No. incubating eggs	No. decomposed eggs	Remarks
		DTH	NTL				
Phase 1	1-50	32.0	30.0	100	3	10	A plastic sheet with minimal perforations covered the top of the brood container; minimal misting
	51-75	31.2	29.0	90	-	-	-
	76-122	31.0	29.0	90	2	1	-
Phase 2	123-154	28.0	25.0	75	-	-	Perforations in the plastic sheet cover were increased; no misting
	155-182	27.5	24.0	75	-	-	-
	183-217	27.0	24.5	100	-	-	Perforations in the plastic sheet cover were decreased; maximum misting

Table 4. Morphometric data of captive-bred *V. olivaceus* hatchlings. Abbreviations: SVL = snout to vent length; TL = tail length; ToL = total length; HW = head width; HL = head length; DistL = distance between front and rear limbs; TBC = tail base circumfrence; WT = mass.

Hatcling No.	SVL (cm)	TL (cm)	ToL (cm)	HW (cm)	HL (cm)	DistL (cm)	TBC (cm)	WT (g)
1	9.95	14.42	12.52	0.18	3	5.2	2.86	12.56
2	11.03	14.51	25.55	0.2	3.22	5.71	3.05	18.28

disinfected using Virkon® S (Pharmacal Research Laboratories, Inc.: Naugatuck, Connecticut, USA). A 25 W incandescent light bulb was placed above the wire mesh cover 10 cm away from the forked end of the tree branch to provide a basking spot for thermoregulation. Morphometric data (Table 4) were taken on day 3 for neonate #2 and upon the death of neonate #1.

Food and feeding of the neonate

Mango puree mixed with NutriBird p15® pellets (Versele-Laga: Deinze, Belgium) and softened in lukewarm water, diced ripe bananas, and week-old crickets (*Acheta domestica*) were offered on day one. Although fish is not a known food item of *V. olivaceus*, small guppies (*Poecilla reticulata*) placed in a dish of swallow water were also offered on the same day as an experiment.

A decision was made to tube-feed the neonate on day two. Neonate #2 was tube-fed using a 3 ml syringe with a small-gauged (ca. 3 mm) feeding tube. A dinner fork was used to pry open the mouth of the neonate as the lubricated catheter was inserted between the tines of the dinner fork and carefully into the stomach through the esophagus. Chicken egg yolk with a pinch of Nutri-Cal® (Vetoquinol USA, Inc: Forth Worth, Texas, USA) amino acid paste at 1 ml was given on a once-every-two-days basis for the first week (days 2-8) and 2 ml for the second week (days 9-15). Starting day 17, live food consisting of freshly-molted mealworms (*Tenebrio molitor*), superworms (*Zophobas morio*), *A. domestica* (dabbed with Reptocal® [Tetra-Terrafauna: Morris

Plains, New Jersey, USA] prior to feeding), tiny chunks of fresh, lean chicken and beef were offered in feed cups.

Neonate #2 received natural sunlight twice per week, between 0830 and 0930 h. Temperature of the neonate's skin was recorded using a hand-held infrared thermometer (La Crosse Technology, China).

Results and Discussion

Feeding behavior in captive adults

Owing to the complexity of its frugivorous feeding habit, *V. olivaceus* is considered one of the more difficult species to maintain and breed in captivity when compared to its more adaptable, carnivorous congenerics such as *V. komodoensis* (*e.g.*, Visser *et al*., 2009); *V. salvator macromaculatus* (*e.g.*, Dwyer & Perez, 2007; Yuyek, unpub. dat.); *V. cumingi* (*e.g.*, Wicker *et al*., 1999); and *V. exanthematicus* (*e.g.*, Bennett & Thakoordyal, 2003).

During initial feeding trials, all captive *V. olivaceus* refused commercially available fruits such as bananas, watermelon, papaya, and cantaloupe. Captives at the Dallas Zoo that had been subsisting on rodents also rejected commercial fruits, but later on accepted grapes (Card, 1995). Grapes were not offered to captives at the Avilon Zoo due to their high cost, seasonality, and limited availability in local markets. The Santol (*Sandoricum koetjape*) of the family Meliaceae was reported to have been eaten by wild *V. olivcaeus* (Auffenberg, 1988), but *S. koetjape* on Polillo Island, according to Bennett (pers. comm.), grows to the size of a baseball and if swallowed whole might result in blockage of the esophagus of a *V. olivaceus*. When offered as whole or sliced, the smaller variety of *S. koetjape* growing in Avilon Zoo was rejected by captives (pers. obs.).

Since fresh chicken heads were acquired in bulk quantities to feed carnivorous animals at the zoo and were freely accepted by captive *V. olivaceus,* they were selected as their staple diet; chicken, however, was absent from the guts of both captive and wild *V. olivaceus* studied by Auffenberg (1988). Not all captives voluntarily accepted rodents; some individuals required tease-feeding. Eventually, all captives subsisted on a diet of chicken heads and rodents without any trace of fruits whatsoever.

Protein derived from animal sources is essential for growth and breeding activities in varanids (Sprackland, 1992). Chicken heads, which are a good source of protein, fats and calcium, constituted a large portion of the captives' dietary intake. However, there have been negative effects from feeding a purely animal-based diet to *V. olivaceus*. Individuals subsisting on this diet for long periods of time tended to develop visceral gout and gastrointestinal infections as a result. Post-mortem examinations performed on seven captive adults indicated that necrotic tissues found in the gastrointestinal lining were most likely associated with long-term intake of protein-rich foods, which are very low or totally deficient in roughage (P. Hidalgo, unpub. dat.).

Although molluscivory is partial to the diet of *V. olivaceus* (Auffenberg, 1988; Bennett & Hampson, 2003; Bennett, 2005; King, 2008) and of other varanid species (*e.g.*, Bennett, 2000, 2002, 2003; Arbuckle, 2009), apple snails, *Pomocea canaliculata*, inhabiting rice paddies near the Avilon Zoo (up to 150 individuals per m2 [Cowie, 2006]) were never fed to captive *V. olivaceus* for fear that that some might have been contaminated with molluscicides (Hairston, 1965) that were periodically applied to the those areas (pers. obs.).

Apart from land snails, crustaceans are also preyed on by *V. olivaceus* in the wild (Auffenberg, 1988; Bennett & Hampson, 2003). Other varanids are also known to eat crabs (Bennett, 2002). Crabs were never offered to captive adult *V. olivaceus*, but *talangka,* or small river crabs (*Varuna litterata*) were offered to the captive-bred neonate. Blue marine crabs (*Portunus pelagicus*), known locally as *alimasag*, were reported to have been accepted by a captive adult in a private collection in which only the legs and pincers were consumed (N.H. Margarico, pers. comm.).

In captivity, *V. olivaceus* were observed to be fastidious feeders. Since olfaction predominates other senses in this species, thawed chicken heads and pre-stunned rodents were first investigated and tongue-flicked repeatedly for up to 10 min, and sometimes longer, before they were consumed. Uneaten chicken heads left inside the enclosure for long periods of time were rejected by captives, particularly those on the verge of decomposition and infested with flies.

Clusters of *Pandanus* (most likely the fragrant screw pine, *P. tectorius*) and black fiber palm (*Pinanga insignis*) have been planted in the zoo but have yet to mature and bear fruits. Fishtail palms (*Caryota rhumphiana*) and MacArthur palms (*Ptychospermum macarthurii*) at the zoo have recently begun bearing fruits, but these have yet to be test-fed to captives.

Reproductive behavior

Sex determination in varanids can be problematic (Horn & Visser, 1997). Sexing by way of hemipeneal probing is unreliable (Andrews & Gaulke, 1990; Card, 1995; Gaulke *et al.*, 2005). Radiography, one of the reliable methods for accurately sexing *V. olivaceus,* was described by Card (1995). In addition, Auliya & Erdelen (1999) explained that radiographing the hemibacula is not a reliable method for all varanid species. Due to the lack of radio-opaque tissues, *V. salvator* cannot be reliably sexed using radiography (Card & Kluge, 1995). Conclusive sex determination is best achieved by using endoscopy (Schildger & Wicker, 1992; Schildger *et al*., 1993; D. Bennett, pers. comm.). In contrast to these above-mentioned methods, all *V. olivaceus* at the Avilon Zoo had been sexed using traditional methods (e.g., hemipeneal probing and comparison of morphological differences) since endoscopy and radiography were inaccessible at that time, and 80% of the determined genders were found to be correct.

Reproductive behaviors were observed from 1995-2004. Pre-copulatory interactions began in May and continued throughout the rainy months of June, July, and August. Similar interactions were also observed during these months in other varanids at the zoo, including *V. marmoratus* (Yuyek, unpub. dat.; N.H. Margarico, per. comm.), *V. cumingi* (Yuyek, 2004c), *V. exanthematicus* (Yuyek, 2005a), *V. salvadorii* and *V. bengalensis nebulosus* (Yuyek, unpub. dat.).

Ritualistic bipedal combat between male *V. olivaceus* reported by Auffenberg (1988) was not observed in the 2002 breeding group when two males were housed together with two females. Observations of most breeding attempts indicated that breeding males and females regularly stayed in close contact to one another for several days prior to the onset of actual courtship. Courtship was observed to have always been initiated by the male and would continue sporadically for a period of 2-3 weeks. During the breeding season of 1995, it was noted that courting male #1 exhibited much greater interest in the larger female #3 than the smaller female #2, persistently following female #3 around the enclosure, flicking its tongue along her tail base, and staying close together. Auffenberg (1988) described cohabitation in wild *V. olivaceus*; however, it is unknown whether male #1 and female #3 had been cohabiting in the wild prior to being captured. It was also suspected that female #2 was probably non-receptive at the time of this courtship. Female #2 avoided these two sexually active individuals by retreating to, and curling up in the corner of the enclosure during the peak of courtship activities, and never ascended the tree branches. This submissive behavior in smaller, non-receptive females was also observed in captive *V. cumingi* (1:3 male to female ratio) during the breeding season in 2007. The *V. cumingi* male's sexual interest was directed at the larger female of the group at all times. Smaller females tended to move away when approached by the larger female, often retreating to a nearby shelter and remaining there for days without showing interest in food (pers. obs.). Copulation in captive *V. olivaceus* was opportunistically observed in 1995, 2003, and 2004, but was often interrupted by human activity around the enclosure.

Dominance and aggression similar to those seen in male varanids were not observed in any captive female *V. olivaceus*, but were observed in other varanid species at Avilon Zoo, and size appears to be a major factor. For example, conspecific aggression in *V. cumingi* occurred after the introduction of a non-resident female to the enclosure of a resident male during the breeding season of 2003 (Yuyek, 2004c). Aggression was initiated by the female at the very instance when the male attempted to mount the female. As a result, the left hind foot of the female was severely mutilated from bites inflicted by the male and had to be amputated. Eleven days after amputation, the female died from a systemic infection, and egg follicles were retrieved from the oviducts during necropsy (E.B. Maestro, unpub. dat.). Engle (unpub. m. s.) observed aggressive behavior in a gravid female *V. keithornei* towards males and other females, and female dominance behavior has also been observed in captive *V. marmoratus* and *V. bengalensis nebulosus* (pers. obs.).

In the 1994 *V. olivaceus* breeding stock, pre-copulatory interactions took place unexpectedly on 29 July and continued sporadically until 17 August. Copulation was observed in the morning of 18 August 1995 between male #1 and female #3 (Table 5). Due to the shy nature of *V. olivaceus* (Bennett, 2005), observations were made at a distance of ca. 3 m from the enclosure whilst the pair was engaged in copulation. Copulation was not repeated with the same female or attempted with the smaller female afterwards.

Despite a noticeable enlargement of the female's abdomen in the following months, oviposition did not occur. *Varanus olivaceus*, both in the wild and in captivity, have never been reported to consume their own eggs, the eggs of conspecifics, or those of other animals. Although ovophagy appears to be a common dietary character in other monitor species (*e.g*., Arbuckle, 2009; Cota, 2011), it is unlikely to occur in *V. olivaceus*. Therefore, it is doubtful that eggs were laid and then eaten. No reports on the resorption of oviductal eggs in gravid *V. olivaceus* exist at the time of this writing, although it has been reported in other species of reptiles (Blackburn, 1998).

Table 5. Copulatory data for *V. olivaceus* at Avilon Zoo.

Year	Male No.	Female No.	Date	Time	Duration of Copulation	Temperature (°C)	RH (%)	Weather Condition
1995	1	3	18-Aug	1045 h	8 min 15 s	29.6	78	Sunny
2003	9	11	8-Aug	0610 h	9 min 20 s	26.5	72	Overcast
			10-Aug	0645 h	7 min 06 s	27.6	74	Raining
			11-Aug	0710 h	11 min 25 s	30.2	82	Sunny
			14-Aug	0620 h	4 min 03 s	26.2	77	Raining
			21-Aug	0605 h	6 min 42 s	27.5	70	Overcast
2004	18	11	2-Aug	1415 h	10 min 28 s	29.5	72	Sunny
			5-Aug	0810 h	4 min 55 s	26.5	77	Sunny

Breeding attempts were temporarily suspended from 1998 until 2001 due to high mortality rates when three adults and two sub-adults from the 1995 brood stock died of chronic respiratory tract infections between 1997 and 2000. Clinical signs resembled that of inclusion body disease (IBD), a commonly encountered viral infection in the family Boidae (Stahl, 1996). Conclusive diagnosis could not be determined due to the absence of a veterinary staff and laboratory at that time.

Breeding attempts were reinstated in early 2002. Although copulation was not observed in those pairs from the 1998 breeding stock (male #7 and female #12; male #9 and females #11), 10 eggs were found scattered on the substrate by female #11 (R. Madriaga, pers. obs.) and 6 were submerged in the pool. These eggs began to decompose after 15 days of incubation.

In early July 2003, two separate cases of oviposition were observed in two young adult females (#16 and #17) from Catanduanes Island that were housed with male #15. A number of misshapen eggs were laid in both clutches. Three weeks prior to oviposition, sporadic courtship interactions between individuals were observed. On 5 July 2003, female #16 deposited a clutch of six eggs, with an additional five eggs, all of which were misshapen, laid three days later. A clutch of seven eggs was laid by female #17 on 14 July, of which four appeared viable. Eggs from both clutches (A and B) were simultaneously incubated in the same manner as that used for the 2002 clutch. These eggs became flaccid and began to sweat on the third day of incubation and eventually began to deteriorate, becoming infested with maggots by day 10.

The zoo's third breeding attempt between male #9 and female #11 began in late June 2003. These individuals were selected on the basis of pre-copulatory behaviors observed after being introduced to one another. Female #11 was removed from Cage A of the outdoor enclosure and transferred to the newly constructed outdoor exhibit enclosure. Four weeks prior to the onset of monsoon rains, male #9 was introduced to the female. Vigorous courtship activities began on 30 July and continued infrequently for another two weeks. Copulation was observed on 8 August at 0610 h and lasted 9 min 20 s. Temperature and humidity inside the enclosure at this time was 26.5 °C and 72%, respectively. Four subsequent copulations were observed, ending on 21 August (Table 5).

Another breeding attempt using male #18 and female #11 was carried out on 2 August 2004. After copulations were observed and the female had lost sexual interest, the male was removed from the enclosure. Although frequently investigated, a hollow coconut palm trunk nest box was ignored by the gravid female, and eight eggs were deposited atop the substrate. The eggs were incubated in the same manner used for the clutch in 2003, but decomposed shortly thereafter (Fig. 3).

Copulatory positions in *Varanus* are generally similar to those exhibited by other lizards including the families Iguanidae, Agamidae, Gekkonidae, and Scincidae. Captive male *V. olivaceus* usually mounted submissive females from behind, following a series of jerking head movements, tongue flicking, and scratching of the female's body along the head, neck and back. Males differed in their usage of the hemipenes during copulation; male #1 in 1995 and male #7 in 2003 used the right hemipenis, whereas male #18 in 2004 used the left. Copulation always occurred on land and never in water as observed in *V. cumingi* (Wicker *et al*., 1999; Yuyek, 2007, pers. obs.) and *V. salvator macromaculatus* (Cota, 2011).

Table 6. Comparison of egg production in captive *Varanus* at Avilon Zoo 1995-2008.

Species	No. females	Year	No. eggs laid	No. incu-bated	No. hatched	No. of surviving hatchlings	Comments
marmoratus	1	2002	8	8	5	5	Captive-hatched from wild-collected eggs
cumingi	1	2002	8	5	-	-	Three full term embryos died in egg; in preservative
exanthematicus	1	2003	12	6	5	3	Captive-bred and hatched
olivaceus	6	1995	10	41	2	1	One hatchling died shortly after being assisted hatched; in preservative
		2003	23				
		2004	8				
salvadorii	1	2007	4	4	-	-	Mated in captivity

Unlike other varanid species that deposit their eggs in burrows dug in the ground (*e.g.*, Wicker *et al*., 1999; Dwyer & Perez, 2007; Coiro, 2007; Visser, *et al*., 2009) or in termite mounds (*e.g.*, Bennett & Thakoordyal, 2003), hollow tree trunks are probably utilized as nesting sites by *V. olivaceus* in the wild. Despite having various nest sites provided, egg deposition atop the substrate has also been observed in *V. keithornei* (Engle, unpub. m.s.), and is identical to the egg laying behavior of captive *V. olivaceus* at Avilon Zoo. This abnormal behavior is likely related to insufficient nest sites or nesting options.

Clutch sizes, egg morphometrics, and incubation

Communal housing of 1.2 (males.females) *V. olivaceus* in 1995, 2.2 in 2002, 1.2 in 2003, and 1.1 in 2004 resulted in zero egg production in 1995 and non-viable eggs in 2002, 2003 and 2004. A total of five clutches (n=64) were produced by the three females between 2002 and 2005 (Table 5). Single clutches of 16, 16, and 14 eggs were laid by the same female (#11) on 17 July 2002, 25 September 2003, and 18 September 2004, respectively. In addition, single clutches of eleven and seven eggs were laid by two Catanduanes females (#16 and #17) on 5 and 14 July 2003, respectively. Of the 64 eggs produced, 23 were either misshapen or found submerged in the pond. The average number of viable eggs (n=41) per clutch was 8 (range 4-13), with an average of 20 eggs received per year. Mean and overall range in egg length, diameter, and weight was 64.2 mm (51.0-78.2), 39.9 mm (30.8-42.8), and 50.0 g (36.0-62.0), respectively. Table 6 compares clutches produced by captive varanids at the Avilon Zoo.

Reptilian clutch size is often associated with the size and age of a female (Auffenberg, 1988; Sumiller, 1998). Card (1994) reported double-clutching in *V. olivaceus* at the Dallas Zoo. Multi-clutching (*e.g.*, Retes & Bennett, 2001; Bennett & Thakoordyal, 2003; Mendyk, in press), parthenogensis (Lenk *et al*., 2005; Hennessy, 2010), and twinning (*e.g.*, Mendyk, 2007) were not observed in *V. olivaceus* or any other varanid species at the zoo.

Using foam rubber cubes to incubate reptilian eggs was described by Schmidt (1995). Eggs of various species of snakes and lizards have been successfully hatched at the Avilon Zoo using this method (Yuyek, 2004b, 2005a, 2006). Reptile eggs incubated at the zoo using a mixture of fluvial sand, coco peat, potting

Figure 3. Deteriorating eggs of *V. olivaceus* laid in 2005. Photograph courtesy of **Neil Hendrix Margarico**.

soil, and humus resulted in high egg mortality, except for those of *Python reticulatus* which were maternally brooded on soil substrate (Yuyek, 2004d).

Eggs of *V. olivaceus* laid between 2002 and 2004 were artificially incubated in a similar fashion to the methods described by Andrews & Gaulke (1990) for *V. salvator*, except for the type of incubation medium used, which followed Schmidt (1995). Most eggs, however, began to deteriorate within the first 10 days of incubation, probably due to infertility or since all eggs were not nested properly. Several factors, such as inadequate nesting sites or eggs that were held too long by the female might have contributed to poor egg success during incubation. The lack of egg viability for the two clutches laid by Catanduanes females (#16 and #17) was most likely associated with poor nesting conditions since nesting areas were not provided and the eggs were laid on the floor of the steel holding cage.

Auffenberg (1988) reported that spermatogenesis in male *V. olivaceus* is largely influenced by seasonality, and takes place from July through September, with May to July being peak months. Courtship and copulatory behaviors in captive *V. olivaceus* at the Avilon Zoo from 2002-2004 coincided with these months when spermatogenesis is greatest.

Assisted hatching

Many eggs from the September 2003 clutch (n=13) began to deteriorate during the early stages of incubation. On day six, egg #s 2, 3, 9, and 11 appeared discolored and bloated, and by day 14, all but egg #s 4, 7, and 8 had deteriorated. Egg #4 deteriorated after 102 days of incubation. No near-term embryos were found in any of the deteriorated eggs.

On Day 182, depressions started to develop in the remaining two eggs (#7& 8), with the denting in egg #7 more severe than that of egg #8. Humidity inside the egg container was increased to 100% under the assumption that doing so would restore moisture to the eggs; however, despite this increase, no significant changes in the egg were observed. In contrast to the 214 day incubation period recorded at the Dallas Zoo (Card, 1995), *V. olivaceus* incubation at the Avilon Zoo took 209 and 217 days, under the modified incubation setting.

On Day 209, a decision was made to manually open the first egg to prevent the neonate from dying inside. Upon dissection, the late-term neonate was found lodged between its large, unabsorbed yolk sac and the indented portion of the egg. After it was freed from the egg, neonate #1 showed poor prognosis in neuromuscular and respiratory functions and expired 3 h 45 min later, despite efforts to prolong its life.

Neonate #2 was also assisted with hatching in the same manner as neonate #1. Upon its emergence, vital signs appeared normal, except for the attached yolk sac that required immediate ligation (Figs. 4 & 5). Engle (unpub. ms.) reported unabsorbed yolk syndrome in a captive-bred *V. keithornei*, which was also surgically ligated. The respiratory rate of neonate #2 was recorded at 10 breaths per min (E.B. Maestro, unpubl. dat.).

The low hatch rate of *V. olivaceus* eggs may suggest flaws in captive diets for adults as well as incubation techniques. Husbandry and reproductive management practices were based largely on trial and error due a lack of comprehensive literature on the keeping and breeding of frugivorous monitor lizards.

Neonatal coloration and pattern

The coloration and pattern of neonatal *V. olivaceus* are different from that of adults. The upper half of the

Figs. 4 & 5. The assist-hatched captive-bred *V. olivaceus* with attached yolk sac minutes after emergence.

dorsum is yellowish-brown in ground color and speckled with tiny black spots, with five solid black transverse bands extending from the nuchal to axilla regions (Figs. 6 & 7). The lower half of the dorsum is black in ground color with numerous irregular bluish-white spots forming seven light, irregularly-spaced transverse bands that terminate at the dorsolateral region. The upper and lower labials are splashed with bright orange coloration. The cranium is bright olive green with tiny black spots, and a distinct black temporal stripe extends from the postocular to the anterior part of the ear. The forelimbs and hind limbs are bluish-black with numerous tiny white spots, and the base color of the tail is solid black with 8-15 distinct white bands. The underside of the head and throat and the venter are tannish grey with thin transverse grey bands (Fig. 8).

Rearing of the captive-bred neonate

Selecting specific types and quantities of food items for the neonatal *V. olivaceus* was initially problematic in that there appears to be a slight difference in the dietary preferences between this species and other neonatal varanids. It is likely that neonatal varanids have similar dietary preferences for insects and other invertebrates, then transition to different food items when a certain size or level of maturity is reached. *Acheta domestica* let loose on the tank floor were ignored by the neonate, but were later accepted when offered in feed cups. Hermann (1999) reported similar observations, where some captive-bred neonatal *V. salvator* would only take food from feed cups.

The neonate did not show any interest in solid food until day 17. The first food items taken from the feed cups were three recently molted *Z. morio*, followed by five *A. domestica*, and finally, one small chunk of beef and two small chunks of chicken after they were tongue-flicked several times. Olfaction appeared to be more important to *V. olivaceus* for detecting prey than eyesight, which agrees with observations made on juvenile *V. exanthematicus* (Bennett, 2000).

The maximum skin temperature recorded for the neonatal *V. olivaceus* during thermoregulation at 0945 h was 41.3 °C (E.B. Maestro, unpub. dat.). When this maximum body temperature was achieved, the neonate moved away from the basking spot; even if it was repeatedly returned to the same place by the keeper. Core body temperatures were not recorded due to the fragile condition of the neonate. The lighter head coloration of the individual and its wide dorsal bands speckled with irregular, tiny white spots are presumably capable of reflecting solar radiation, enabling a higher degree of tolerance to solar radiation exposure than other species with darker overall body coloration. Captive *V. olivaceus* adults at the Avilon Zoo weighing 4.2-8.6 kg have been recorded thermoregulating at a range of 39.5-40.2 °C for durations of up to four hours without showing signs of heat distress (pers. obs.). Auffenberg (1988) reported

Figs. 6 & 7. Dorsal coloration and pattern of captive-bred neonatal *V. olivaceus.*

Fig. 8. Fresh umbilicus and ventral coloration and pattern of captive-bred neonatal *V. olivaceus.*

heat distress in *V. olivaceus* (age not specified) at a range of 41.6-42.4 °C.

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