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Daily activities of water monitors (*Varanus salvator macromaculatus* Deraniyagala, 1944) in urban wetland, Bangkok, Thailand

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Abstract

From July to October 2015, a study was conducted on the water monitors (*Varanus salvator macromaculatus*) at Dusit Zoo in Bangkok, Thailand. A total of 90 monitors were captured, measured for SVL, sexed, and marked on the right axilla. The captured monitors included 70 females and 20 males, resulting in a sex ratio of 3.5:1. Body size did not differ significantly between genders. The monitors exhibited bimodal diurnal activity, with a focus on fish hunting in the morning (06:00–08:00 h) and scavenging for fish leftovers in the afternoon (15:00–17:00 h). After the monitor lizards hunted for prey in the morning, they spent 5–7 hours basking and floating in the lake during the afternoon. Sexual behaviors were also occasionally observed. The monitors displayed frequent predatory behavior towards natural prey, especially fish, in the morning, as opposed to opportunistically scavenging on tourist food and fish leftovers observed throughout the day.

Key Words

diet, ethology, sex ratio, Squamata, urban ecosystem, Varanidae

Introduction

The water monitor (*Varanus salvator macromaculatus* Deraniyagala, 1944) is the world's second-largest extant monitor species after the Komodo dragon (*V. komodoensis* Ouwens, 1912) and is widely distributed throughout Thailand, except for a large area in the north and northeast (with the northernmost record being Sukhothai Province), and southward through to Peninsular Malaysia, in various ecosystems, particularly urban wetlands, like those of Bangkok (Shine et al. 1996; Lauprasert 1999; Lauprasert and Thirakhupt 2001; Pauwels et al. 2002, 2003, 2009; Cota et al. 2009; Chan-ard and Makchai 2011; Chan-ard et al. 2011; Chuaynkern and Chuaynkern 2012; Auliya and Koch 2020). Abundant niches in Bangkok attract this species, which faces growing human populations overlapping with established territories, leading to human-wildlife conflicts over resources and habitats (Traeholt 1993; Traeholt 1994a, b; Auliya 2003; Uyeda 2009; Cota 2011; Trivalairat et al. 2016). Despite being protected under the Wild Animal Reservation and Protection Act of 1992 (B.E. 2535) (the newest version is Act of 2019 (B.E. 2562)) in Thailand, hunting of water monitors frequently occurs in overlapped areas, especially in Bangkok, for solving the human-wildlife conflict or harvesting animal products (Luxmoore and Groombridge 1990; Lauprasert and Thirakhupt 2001; Uyeda 2009). To manage conflicts effectively, studies of their population structure, natural history, and behaviors in certain habitats are necessary.

Bangkok, the capital city of Thailand, is situated in the Chao Phraya River delta on the central plain of the country. The region is flat and low-lying, with an average elevation of 1.5 meters above sea level (Sinsakul 2000). Historically, most of the area was swampy, but it was gradually drained and irrigated for agricultural purposes before being transformed into an urban area. Nowadays, many wetlands are fragmented and disconnected from one another. In 1938, one of the largest wetland habitats in Bangkok, covering a total area of 188,000 m^2, was converted into the first zoo in Thailand known as Dusit Zoo or Khao Din Zoo (Sae-ngo et al. 2013). The large lake and surrounding canals are primarily influenced by the Chao Phraya River (Cota 2011). This zoo features various exhibited animals, activity areas, education museums, and restaurants for visitors. However, the increasing human activities have led to an abundance of food leftovers in the environment, which are exploited by local animals such as fish, crows, and especially water monitors. More available niches make the area more attractive for colonization by different species. Therefore, this locality may be one of the most suitable areas in the central part of Thailand for investigating the relationship between humans and water monitors.

The aim of this study was to explore the population structure, daily behaviors, and dietary habits of the free-ranging water monitor population within the Dusit Zoo range. These findings could offer insights into the species' natural history and provide a better understanding of its urban ecosystem's population structure, daily activities, and behavior, aiding in effective wildlife management.

Materials and methods

Sample collection

During the period of 2 to 30 June 2015, catchable subadult and adult water monitors in the Dusit Zoo range (13°46'18.58"N, 100°30'57.98"E) were captured using a noose pole, excluding those with a snout-vent length (SVL) of less than 30 cm, which are considered juveniles (Fig. 1). The direct sampling method was used to

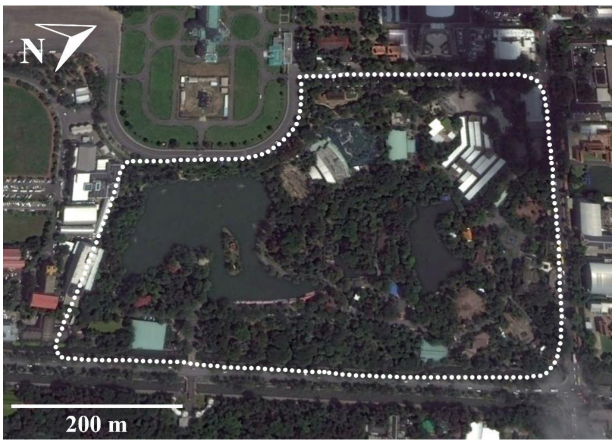


Figure 1. Study area of Dusit Zoo range, Bangkok, Thailand (Google Map 2015).

determine the abundance of the population, and the sex ratio at a specific time was recorded for each captured individual (Skalski et al. 2005; Rodda 2012). SVL was measured ventrally, from the tip of the snout to the vent, and sex was identified via hemipenes eversion or probe insertion. In most cases, males everted their hemipenes themselves during capture. Each individual was tagged on the right axilla for future identification before being released at its capture site. The tracking tag was customized using an elastic hospital tag, cable tie, waterproof paper, and waterproof pens. A different color-coded band was used for each water monitor to identify its body size range, sex, and number, along with a unique identification number (Fig. 2). After the study was completed, each tagged individual was re-captured for a final time, and its tag was removed.

In addition to the previous data on personal hatchling from five clutches (4, 5, 8, 10, 12 individuals/clutch) in Bangkok and metropolitans (from Trivalairat et al. 2016), our research team also classified and compared the proportion of each captured individual during observation. The previous data provide information on the SVL and total length (TL) of the hatchlings, which were found to be 10.68 ± 1.43 cm (range 8.6–13.8 cm, n = 39) and 24.88 ± 1.88 cm (range 21.2–29.3 cm, n = 39) respectively. It is worth noting that the total length of hatchling longer than 30 cm was never found. Therefore, this data was used as a reference for classifying and comparing a proportion of each captured individuals during observation by defined X as a three-time proportion of average hatchling SVL (× = 30.0 cm).

The SVL was divided into four sized ranges: 2× range – less than 60.0 cm (yellow tag); 3× range – 60.1 to 90.0 cm (orange tag); 4× range – 90.1 to 120.0 cm (green tag); and 5× range – more than 120.0 cm (purple tag).

Observations

Tagged water monitors were observed between 06:00 h and 18:00 h during the rainy season (July to October 2015) in Dusit Zoo. This observation period overlapped with the breeding season of the water monitor, which occurs between March and October, particularly after the first heavy rains following the long dry period (Shine et al. 1996; Cota 2011). Observations were conducted on Monday, Wednesday, and Friday of each week, with each round of observation starting from an entrance and walking clockwise along the lake. The average time per round was one hour, totaling 12 rounds per day. The first contact activity of the tagged monitors was counted and recorded within 30 seconds of observation. Data were recorded in different time intervals and analyzed separately. Additionally, preys or items consumed by the water monitors were also counted and recorded to identify the diet types.

This study observed and described five activities: 1) basking activity– lying on or being exposed to the sunshine on both lands and trees, with some showing little

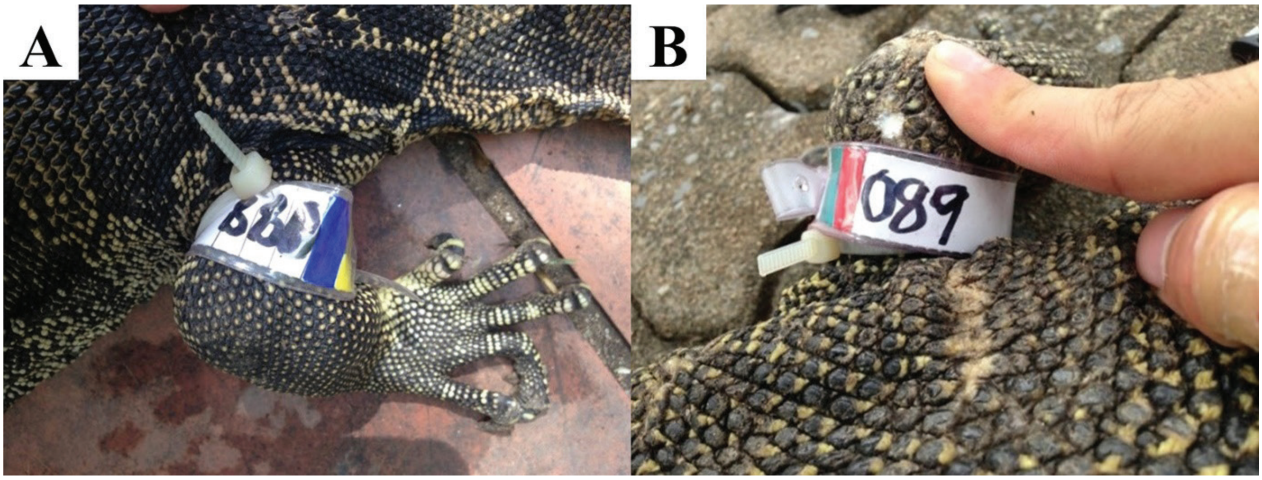


Figure 2. Captured water monitor lizards (*Varanus salvator macromaculatus*) in Dusit Zoo range with customized tag on right axilla. **A.** Male number 088 with snout-vent length ≤ 60.0 cm; and **B.** Female number 089 with snout-vent length between 90.1 and 120.0 cm.

movement for changing position; 2) foraging activity – moving towards prey, hunting, or consuming resources, including the classification of predation behavior into two types (grouped predation, which is predation performed by more than one individual, and solo predation, which is predation performed by an individual); 3) surveying activity – moving for a long distance or time without direction towards nearly attractive thing; 4) floating activity– floating or slowly swimming within a small area in water; and 5) sexual activity – a period wherein each individual displays some pre-courtship or courtship behaviors. Additionally, the calculation of disappeared individuals, referring to those that disappeared or were unable to be observed during the study, was determined for each hour to be included in the analysis of activity rates. This was done by subtracting the number of observed individuals from the total count of tagged individuals (number of disappeared individuals = total count of tagged individuals – number of observed individuals).

Furthermore, in this study, sexual activities were classified into two types: pre-courtship and courtship. Pre-courtship behavior consisted of two observed behaviors. The first behavior, known as male-male competition or wrestling behavior, involved aggression where individuals with an SVL greater than 60 cm stood and pushed each other. The second behavior, called sneaking behavior, was observed in smaller individuals with an SVL shorter than 60 cm. They would wait and satellite around the territory area of larger males, occasionally avoiding the larger male and briefly seizing opportunities to mate with females.

Regarding courtship behaviors, three distinct behaviors were observed. The first was forced mating behavior, characterized by multiple males engaging in polyandrous behavior. The second behavior was single couple mating, indicating monogamous behavior. The third behavior observed was female-harem mating, representing polygynous behavior.

Statistical analysis

The IBM SPSS Statistics 28 software package (SPSS Inc.; Chicago, IL, USA) was used to calculate the mean and standard deviation of body size (snout-vent length, SVL, excluding total length due to potential bias caused by incomplete tails in some individuals), as well as daily activity encounters (basking, foraging, surveying, floating, and engaging in sexual activities) which also accounted for disappeared individuals, and diet types. The body size, daily activities, and diet types were analyzed with a 5% types I error risk. As these parameters were not normally distributed, non-parametric tests were used to compare variables. An independent sample *t*-test was conducted to examine the differences in body size between genders (female and male) and diet types (predating and scavenging diets). The mean daily activities were analyzed using one-way ANOVA, including examining the relationships between six variables of daily activities and monthly mean environmental factors such as temperature (°C) and rainfall (mm).

Results

Sex ratio and body size

Ninety individuals of water monitor (*Varanus salvator macromaculatus*) were captured and tagged in this study, revealing a significantly higher proportion of females (n = 70) than males (n = 20), at a ratio of 3.5:1. Through observation, an additional 32 non-catchable individuals were identified, bringing the total number of individuals to 122. The captured sample had an average SVL of 72.14 ± 12.44 cm (range 46.0–94.0 cm, n = 90) for all captured individuals, with females having a higher SVL (72.89 ± 12.84 cm, range 46.0–94.0 cm) than males (69.51 ± 10.84 cm, range 48.6–81.5 cm). No catchable monitor with an SVL larger than 120 cm was caught.

Most captured females were in 3× range (76.67 ± 8.66 cm, range 62.6–90.0 cm, n = 49), followed by the 2× range (55.33 ± 4.30 cm, range: 46.0–60.0 cm, n = 16), and the 4× range (92.12 ± 1.46 cm, range 90.2–94.0 cm, n = 5) (Table 1). For the male population, the most frequent SVL was observed in the 3× range (74.01 ± 6.07 cm, range 62.9–81.5 cm, n = 16), followed by the 2× range (51.50 ± 4.40 cm, range 48.6 – 58.0 cm). Although there was a small difference in SVL between females and males, this difference was not statistically significant (t = 1.18, p = 0.12).

Table 1. Number and mean of each snout-vent length (SVL) range of captured female and male water monitor lizards (*Varanus salvator macromaculatus*) in Dusit Zoo range.

SVL range		Female		Male		Total	
		n	Mean ± SD (range) (cm)	*n*	Mean ± SD (range) (cm)	*n*	Mean ± SD (range) (cm)
≤ 60.0 cm	2×	16	55.3 ± 4.17 (46.0–60.0)	4	51.5 ± 3.81 (48.6–58.0)	20	54.6 ± 4.49 (46.0–60.0)
60.1–90.0 cm	3×	49	76.4 ± 8.57 (62.6–90.0)	16	74.0±5.88 (62.9–81.5)	76	76.0 ± 8.14 (62.6–90.0)
90.1–120.0 cm	4×	5	92.1 ± 1.31 (90.2–94.0)	–	–	5	92.1 ± 1.31 (90.2–94.0)
Total		70	72.9 ± 12.8 (46.0–94.0)	20	69.5 ± 10.8 (48.6–81.5)	90	72.1 ± 12.4 (46.0–94.0)

Daily activities

The activity patterns of water monitors ranging in Dusit Zoo were continuously observed for four months during the rainy season (July through October 2015). Observations were carried out for 14 days in July 2015 and 13 days in each month of August, September, and October 2015. The tagged monitors were observed for more than 33.25% in each hour (28.79% for females and 38.85% for males), and no significant difference was found in their activities among each month, except for surveying activity (f = 4.463, p = 0.003) (Table 2). Monthly mean temperature and rainfall did not affect the activities, except for surveying activity, which was influenced by rainfall (r = -0.312, p = 0.015) (Table 3) (Pierson and Pierson 2015a-d).

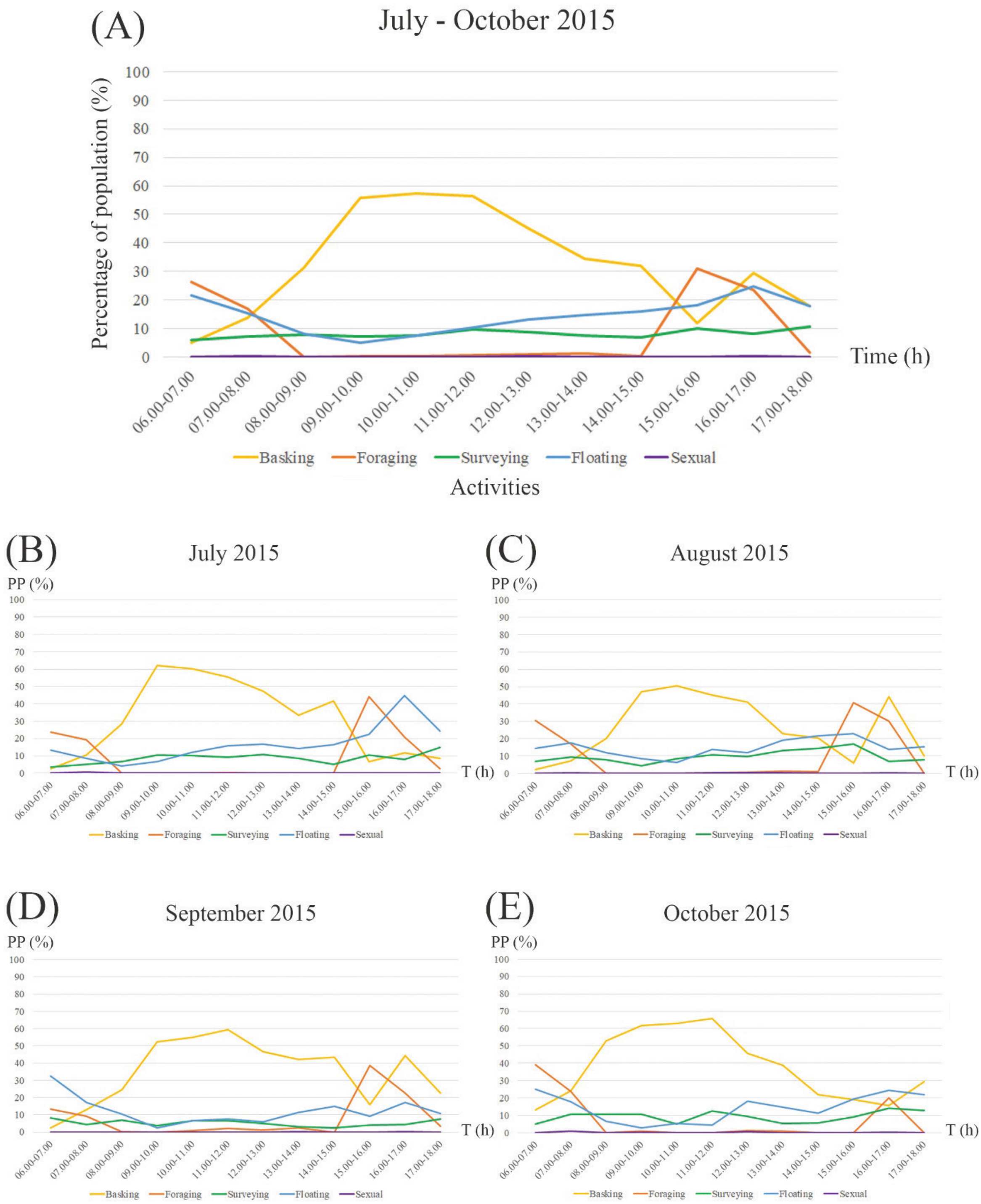
Over forty percent of the monitors (mean 32.53 ± 18.21% per hour, min-max = 2.05–65.81% per hour) mostly spent their time basking between 09:00–13:00 h. The longest average duration of basking activity, with a proportion higher than the mean, was recorded in September (7 hours), followed by October (6 hours), July (6 hours), and August (5 hours) (Fig. 3) (Suppl. material 1). Basking activity significantly increased with decreasing foraging (r = -0.591, p = 0.000), floating (r = -0.619, p = 0.000), and disappeared individuals (r = -0.440, p = 0.000) (Table 3).

Foraging activity peaked twice a day, with records of at least 10% of proportion (mean 8.59 ± 12.12% per hour, min-max = 0–44.02% per hour), starting with the first period in the morning (06:00–08:00 h) and then in the afternoon (15:00–17:00 h). The proportion of foraging in the afternoon (range 23.42–30.96%) was slightly higher than in the morning (17.04–26.39%) among the study. Accordingly, the foraging activity in the morning was typically group predation for large fishes in the lake, while the foraging activity in the afternoon scavenged on fish leftovers from zookeepers. Moreover, the foraging rate was positively correlated with floating (r = 0.445, p = 0.000), but negatively correlated with disappeared individuals (r = -0.339, p = 0.008).

For floating activity, at least 10% proportion (mean 14.44 ± 5.91% per hour, min-max = 2.38–44.70% per hour) was spent in water during 06:00–09:00 h and 11:00–18:00 h. Approximately 5–11% of the population in each hour performed surveying activity within the Dusit Zoo range (mean 8.13 ± 1.43% per hour, min-max = 2.46–17.01% per hour). Both floating and surveying activities were significantly correlated (r = 0.291, p = 0.024). Additionally, the analysis revealed three specific time intervals during which the tagged population exhibited a disappearance rate exceeding 40%. These intervals were observed from 06:00 to 09:00 h (with a

Table 2. Mean percentage (± SD) and One-Way ANOVA Analysis of daily activities in tagged water monitor lizards (*Varanus salvator macromaculatus*) (*n* = 90 individuals), including disappeared individuals, in the Dusit Zoo Range from July to October 2015.

Times (h)	Total mean percentage (100%)					
	Mean daily activities percentage (%)					Mean disappeared individual percentage (%)
	Basking	Foraging	Surveying	Floating	Sexual	
July to October 2015						
06:00–07:00	5.03	26.39	5.89	21.61	0.00	41.07
07:00–08:00	13.69	17.04	7.30	15.39	0.42	46.16
08:00–09:00	31.34	0.08	7.99	8.26	0.00	52.33
09:00–10:00	55.74	0.19	7.21	5.05	0.08	31.72
10:00–11:00	57.23	0.25	7.55	7.57	0.00	27.40
11:00–12:00	56.46	0.75	9.66	10.34	0.04	22.75
12:00–13:00	45.26	0.86	8.68	13.08	0.23	31.89
13:00–14:00	34.49	1.26	7.44	14.76	0.08	41.97
14:00–15:00	32.05	0.23	6.83	16.08	0.00	44.80
15:00–16:00	12.03	30.96	10.08	18.28	0.00	28.64
16:00–17:00	29.33	23.42	8.20	24.91	0.21	13.94
17:00–18:00	17.76	1.59	10.75	17.97	0.00	51.93
Mean ± SD	32.53 ± 18.21	8.59 ± 12.12	8.13 ± 1.43	14.44 ± 5.91	0.09 ± 0.13	36.22 ± 12.01
F	0.585	0.091	4.463	0.507	0.950	0.571
P	0.675	0.985	0.003	0.731	0.442	0.685



Figures 3. **A–E.** Mean daily activity graph of water monitor lizard (*Varanus salvator macromaculatus*) population in Dusit Zoo range in 2015 **A.** July to October; **B.** July; **C.** August; **D.** September; and **E.** October. PP = percentage of population (%), T = time (h).

disappearance rate ranging from 41.07% to 52.33%), 13:00 to 15:00 h (with a disappearance rate ranging from 41.97% to 44.80%), and 17:00 to 18:00 h (with a disappearance rate of 51.93%). The mean disappearance rate for the entire day was 36.22 ± 12.01% per hour, with a range of 4.70% to 66.75% per hour.

In addition, a total of 51 instances of sexual activities were observed, with varying durations. Two types of pre-courtship behavior were documented. The first type involved male-male competition, which was observed in four pairs, resulting in a cumulative occurrence of eight instances. The second type entailed sneaking behavior, observed in 11 smaller individuals, transpiring a total of 11 times.

Regarding courtship behaviors, three distinct patterns were discerned. Forced mating behavior manifested itself in 13 occurrences. Single couple mating behavior was observed in two pairs, amounting to a total of four instances. Additionally, female-harem mating behavior was observed, featuring a male to female ratio of 1:2, 1:2, 1:3, and 1:4, respectively, with a cumulative occurrence of 15 instances.

Table 3. Spearman's rank correlation (*r*) and *p* – value (*p*) of daily activities (basking (BAS), foraging (FOR), surveying (SUR), floating (FLO), and sexual activities (SEX), including undiscovered individual (UND)) of water monitor (*Varanus salvator macromaculatus*) and mean monthly temperature (TEMP) and rainfall (RAIN).

Activities		TEMP	RAIN	BAS	FOR	SUR	FLO	SEX
BAS	*r*	-0.178	0.193					
	p	0.174	0.139					
FOR	*r*	0.075	-0.076	-0.591*				
	p	0.569	0.562	0.000				
SUR	*r*	0.147	-0.312*	-0.083	-0.003			
	p	0.264	0.015	0.530	0.984			
FLO	*r*	0.128	-0.091	-0.619*	0.445*	0.291*		
	p	0.331	0.488	0.000	0.000	0.024		
SEX	*r*	-0.092	-0.030	-0.038	0.179	0.088	0.006	
	p	0.484	0.821	0.772	0.172	0.504	0.961	
UND	*r*	0.069	-0.070	-0.440*	-0.339*	-0.251	-0.161	-0.141
	p	0.600	0.595	0.000	0.008	0.053	0.220	0.284

* Correlation is significant at 0.05.

Diet evidence

This study identified a total of 18 prey types (5,015 observations). Leftovers showed the highest number of observation (2,857 observations, 56.97%), followed by bony fish (2,084 observations, 41.56%), turtles (68 observations, 1.36%), birds (4 observations, 0.08%), toad (1 observation, 0.02%), and cat (1 observation, 0.02%) (Fig. 4) (Table 4). There was no significant difference found between predated and scavenged prey items by the monitor ($t = -0.833$, $p = 0.417$).

During the study, two types of observed predation behaviors were documented. The first type is group predation, which was observed regularly in *V. salvator macromaculatus* at Dusit Zoo. This behavior usually occurred during the morning hours, between 6:00 and 8:00 h, at a specific location in the lake (13°46'16.7"N, 100°31'00.2"E). The target of this behavior was usually a large fish, typically striped catfish (*Pangasianodon hypophthalmus* (Sauvage, 1878)), which could be more than one meter in length. The individuals initiated the hunt by swimming and diving in a swirling pattern. Once they had caught a fish, they would drag it to the surface and other individuals would join in to help drag the fish to the bank for consumption. The individuals involved in group predation shared the meal together. Additionally, another target of this behavior was the Chinese softshell turtle (*Pelodiscus sinensis* (Wiegmann, 1835)), an allochthonous species that had been released and thrived in this lake.

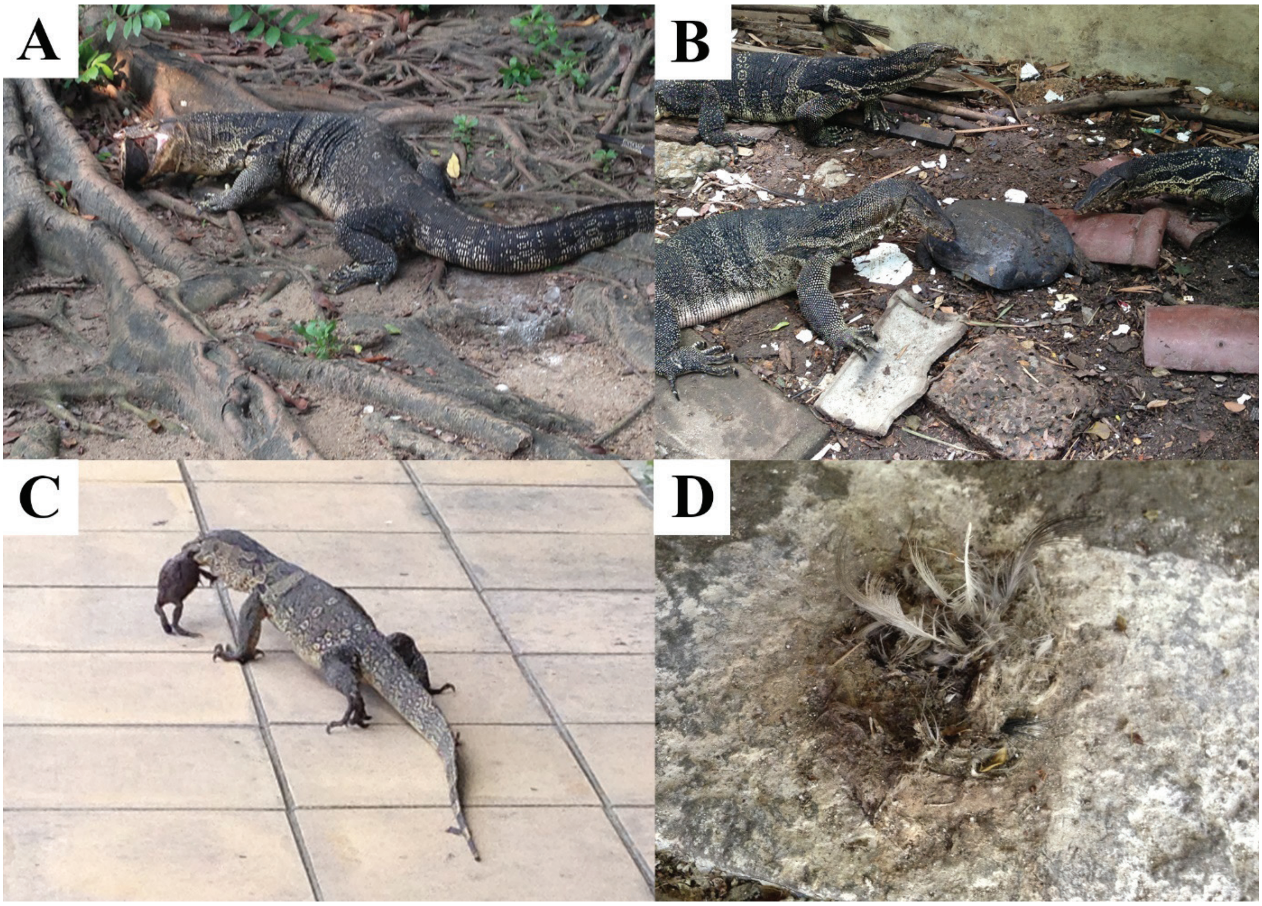
Solo hunts were also recorded for other prey types, such as small fish, toads, turtles, birds, and cats. Juvenile *V. salvator macromaculatus* were observed eating Asian common toads (*Duttaphrynus melanostictus* (Schneider, 1799)). Upon sensing a toad, the juvenile monitor lizard quickly ran towards it and caught it by the head before retreating to the water to search for a safe place on the island to eat. The caught toad was swallowed whole, beginning with the head. Similar prey-swallowing behavior was observed in the case of fishes and turtles that were small enough to fit into the monitor lizard's mouth.

Typically, it is difficult for *V. salvator macromaculatus* to catch a flying bird such as the Black-crowned night heron (*Nycticorax nycticorax* (Linnaeus, 1758)). However, during the breeding period, some birds try to protect their nests by spreading their wings against climbing monitors, which proves to be ineffective. In one instance, the monitor was able to rush at the bird and catch it before dropping the body into the lake. Based on observation, heron nests are usually constructed on tree limbs that hang over the lake at a height of 2–3 meter from the ground.

The cat was an unexpected prey in this observation. It began with the cat approaching the large monitor that was basking on the bank, seemingly to play with the monitor's tail. However, when the tail was drawn back and thrashed towards the cat, it became motionless. Subsequently, the monitor proceeded to flick and tear the cat into pieces before consuming it.

Table 4. Types of diet evidence of water monitor lizard (*Varanus salvator macromaculatus*) in Dusit Zoo. P = predated diet, S = scavenged diet.

No.	Prey group	Prey type (P/S)	Frequency (times)	Proportion (%)
1	Giant gourami (*Osphronemus goramy*)	Bony fish (P)	512	10.21
2	Striped catfish (*Pangasianodon hypophthalmus*)	Bony fish (P)	1,368	27.28
3	Siamese giant carp (*Catlocarpio siamensis*)	Bony fish (P)	192	3.83
4	Unidentified fish	Bony fish (P)	12	0.24
5	Asian common toad (*Duttaphrynus melanostictus*)	Amphibians (P)	1	0.02
6	Asian box turtle (*Cuora amboinensis*)	Turtles (P)	11	0.22
7	Chinese softshell turtle (*Pelodiscus sinensis*)	Turtles (P)	38	0.76
8	Red-eared slider turtle (*Trachemys scripta*)	Turtles (P)	13	0.26
9	Unidentified turtle eggs	Turtles (P)	6	0.12
10	Black crowned night heron (*Nycticorax nycticorax*)	Birds (P)	2	0.04
11	Mynas (*Acridotheres* sp.)	Birds (P)	2	0.04
12	Cat (*Felis catus*)	Mammalia (P)	1	0.02
13	Bread	Leftover (S)	15	0.30
14	French fries	Leftover (S)	15	0.30
15	Fried Chicken	Leftover (S)	32	0.64
16	Plastic bag	Leftover (S)	9	0.18
17	Processed meat (Meatballs, sausages, or crab sticks)	Leftover (S)	16	0.32
18	Yellow-stripe scad (*Selaroides leptolepis*)	Leftover (S)	2,770	55.23
Total			5,015	100



Figures 4. Diet evidence of water monitor lizards (*Varanus salvator macromaculatus*) **A.** Asian box turtle (*Cuora amboinensis*); **B.** Chinese softshell turtle (*Pelodiscus sinensis*); **C.** Asian common toad (*Duttaphrynus melanostictus*); and **D.** Feather of mynas (*Acridotheres* sp.) in stool.

Discussion

Life history patterns

Foraging activity

Activity pattern in different spatial populations of intraspecific species, particularly water monitors (*Varanus salvator macromaculatus*), may occur convergently or divergently, depending on adaptive shifts towards food availability and ecological systems (Traeholt 1997a, b; Uyeda et al. 2013; Rahman et al. 2017; Gautam 2020). In this study, we observed that the Dusit population exhibited a routine bimodal diurnal pattern, with a preference for preying on big fish in the early morning (06.00–08.00 h) and scavenging on fish leftovers in the afternoon (15.00–17.00 h) during the rainy season, even when there were no leftovers. This circadian rhythm is similar to that of other water monitor populations, such as those found in the Philippines, Bangladesh, and Tulai Island (located east of mainland Peninsular Malaysia), where they are active foraging twice during the day (Gaulke 1992; Traeholt 1997b; Rahman et al. 2017). Bimodal diurnal patterns have also been observed in other monitors, such as Bengal monitor (*V. bengalensis* (Daudin, 1802)), sand monitor (*V. gouldii* (Gray, 1838)), desert monitor, (*V. griseus* (Daudin, 1803)), Komodo dragon (*V. komodoensis*), lace monitor (*V. varius* (Shaw, 1790)), and perentie monitor (*V. giganteus* (Gray, 1845)), during summer (Corkill 1928; King 1980; King et al. 1989; Auffenberg 1994; Trembath 2000; Guarino 2002; Ibrahim 2002; Yuni and Purwandana 2022). However, the foraging pattern of the Dusit population contrasts with those of the Tinjin island (Philippines) and Timor Oil Palm Estate (Malaysia) populations, which adapt to the food availability in nighttime and predator pressure (i.e., pythons, civets, dogs, and leopards), respectively (Traeholt 1997b; Uyeda et al. 2013). Consequently, this evidence may support the idea that food availability is one of the primary determinants in adapting their foraging patterns based on available diet (Auffenberg 1994; Gaulke 1989; Trembath 2000; Cota et al. 2008; Yong et al. 2008; Uyeda et al. 2013).

Basking activity

Monitor lizards are ectothermic organisms that rely on environmental temperature or solar radiation to generate their metabolism and regulate their body temperature through behavioral means (Pianka 1970; Pafilis et al. 2007; Mendyk et al. 2014). In the wild, the average body temperature of water monitors during activity was found to be around 29.9 °C in Sri Lanka and 30.4 °C Malay Peninsula, while captive juveniles presented an average temperature of 35–36 °C (Gleeson 1981; Wikramanayake and Green 1989; Traeholt 1995). The average activity temperature of monitor lizards varies depending on their body size, species, and the heat they receive from the sun and ambient environment. It reaches its highest in the late afternoon (32.7 °C), does not exceed 30 °C in the morning, and drops at night (Gleeson 1981; Auffenberg 1994; Traeholt 1995).

Normally, monitor lizards need to elevate their body temperature by basking in the sun after experiencing a cooling period overnight, before they can partake in activities such as foraging (Traeholt 1997a; Abayaratna and Mahaulpatha 2006; Rahman et al. 2017). Surprisingly, the Dusit population of monitor lizards exhibits an unusual pattern by initiating their first active behavior (hunting) prior to sunrise, before engaging in basking. This exceptional phenomenon might be influenced by favorable ecological factors, particularly high ambient temperatures that benefit the water monitor lizard. In Bangladesh and Tulai Island, the water monitor lizard populations exhibit basking behavior before hunting after colder nights (9.2 °C) or during rainy nights, respectively (Traeholt 1997a; Rahman et al. 2017). The wetter month also delays their activity until 09.00, resulting in a unimodal diurnal pattern. However, the Dusit population does not experience cool nights during the study period despite the occurrence of rainfall. Instead, they endure warm weather overnight (mean 27.83±1.85 °C at midnight: 28.74±2.10 °C in July; 28.03±1.56 °C in August; 27.30±1.95 °C in September; 27.23±1.36 °C in October) transitioning to warmer dawns (mean 26.76±1.32 °C at midnight: 27.45±1.59 °C in July; 27.03±1.05 °C in August; 26.37±1.27 °C in September; 26.16±0.90 °C in October) (Date and Time 2015). Consequently, the Dusit population is able to raise its body temperature sufficiently from the surrounding conditions in order to engage in active behavior without basking. Therefore, the choice between being active before basking or basking before being active may be influenced by ambient temperature and the retained body heat during the night.

After finishing their morning feeding session, a majority of tagged individuals (30–65%) spend 5–7 hours per day basking. The proportion of time spent basking continually increases and peaks at 10:00–12:00 h before dramatically falling in the afternoon. However, this basking period is representative of population activity by time and does not indicate a specific or exact individual rate. Some intra- and interspecific individuals show specific and exact individual rates, such as Malaysian water monitor population (38 minutes per day), Komodo dragons (110 minutes per day), and sand monitors (60–102.5 minutes per day) (King 1980; Auffenberg 1981; Traeholt 1995).

Two ideas could explain the length of time spent basking in these monitors. Firstly, the previous studies of King (1980), Auffenberg (1981) and Traeholt (1995) were performed in the hot season, while this study was done in the rainy season. Even though the monthly mean temperature and rainfall in Bangkok Metropolis since July through October 2015 revealed no relationship with basking activity, rainfall could directly affect the sunlight and the relatively narrow range of ambient and ground temperature (which was absent in this study) that facilitate thermoregulation in the body (King 1980; Gleeson 1981; Traeholt 1995). Accordingly, mean rainfall showed a significant quantity in September (352.4 mm), which was related to an average basking rate of 7 hours in the same month, followed by October (334.2 mm, 6 hours), July (220.8 mm, 6 hours), and August (50.5 mm, 5 hours) (Pierson and Pierson 2015a-d). Consequently, rainfall can directly influence the basking duration of the monitors by reducing sunlight exposure and increasing heat loss during rainy conditions. This may lead to an increase in basking behavior as they attempt to compensate for the decreased heat availability and ensure sufficient heat gain.

Another reason that could have influenced the prolonged basking time was the significant number and size of prey available. At Dusit Zoo, the water monitor's diet consisted mostly of large-sized fish, including iridescent shark catfish (*Pangasianodon hypophthalmus* (Sauvage, 1878)), giant gourami (*Osphronemus goramy* (Lacépède, 1801), and Siamese giant carp (*Catlocarpio siamensis* Boulenger, 1898). In contrast, the population from Malaysia primarily fed on crabs and small invertebrates (Rahman et al. 2017). Therefore, consuming a significant number and size of prey may have affected the lizard's basking time, as noted by Bontrager et al. (2006).

Floating and surveying activities

The frequency of floating activity increased twice a day, with the first peak occurring in the morning (06:00–09:00 h) as water monitors prepared to hunt for fish in the lake. The second period was observed after basking, from 11:00 h through 18:00 h, during which most water monitors spent time floating in the lake without movement, spreading their forelimbs and hindlimbs. This behavior may serve as a cool-down mechanism to regulate their body temperature, as noted by Traeholt (1995), who reported a similar behavior in the population from Tulai Island, Malaysia, where the monitors entered the sea to cool down and escape tourists. The increase in floating activity in the afternoon could also be influenced by visitors, who tend to visit the zoo more frequently in the afternoon, and the presence of leftover fish on the banks of the lake, which attracted the water monitors. Thus, the water monitors may enter the water for different reasons at different times, such as hunting, cooling down, or escaping.

Sexual behavior

Sexual behaviors were observed randomly throughout the day during the study period. Cota (2011) suggested that changes in weather conditions between the cold (November to February) and hot seasons (March to May) may trigger hormonal changes in water monitors in the Dusit

Zoo range. However, this study was conducted during the late rainy season (May to October) (Pierson and Pierson 2015a-d). Therefore, the long duration between the initial triggering of sex hormones in March and the observation period may have led to a decrease in sex hormones and a reduction in sexual behaviors, which were rarely observed in this study.

However, some sexual behaviors, including pre-courtship and courtship, were recorded. Firstly, the most well-known male-male competition behavior, wrestling behavior, occurred between large male monitors during the breeding season. This behavior was observed to compete and territorially defend to gather an area, resources, and a chance to court other females (Auffenberg 1981; Wikelski et al. 1996; Cota 2011; Uyeda et al. 2015). Male-male competition behavior also occurs in other reptiles such as the marine iguana (*Amblyrhynchus cristatus* Bell, 1828), which displays head-bobbing behavior to gather a lek area (a rich-resourced territory area) and also females (Wikelski et al. 1996). Unfortunately, many people, especially Thai people, frequently perceive this behavior as courtship behavior between males and females, but they are mistaken. Additionally, the dominant male in this competition usually attracts many females to the area, forming a harem (polygamous behavior).

Sometimes, wrestling competitions were absent, and numerous similar-sized males attempted to mate with only one female, displaying polyandrous behavior. This behavior is also observed in other reptiles, such as the keeled earless lizard (*Holbrookia propinqua* Baird & Girard, 1852), where males compete in "sperm competition" to inherit their genetics (Cooper 1984).

Surprisingly, smaller, non-territorial males, triggered by sex hormones, also develop strategies to court during the breeding season. Observations suggest that these smaller individuals swim or sneak around the females in the territory of dominant males like satellites, called sneakers, and wait for the dominant male to appear careless or drive away other males before quickly moving towards the females to court briefly before the dominator returns. The non-territorial marine iguana also displays this behavior around the lek areas of the dominant male (Wikelski et al. 1996).

Therefore, water monitors display five sexual behaviors during the breeding season: 1) single couple mating behavior; 2) wrestling behavior (male-male competition behavior) by large males; 3) harem behavior (polygyny) by dominant males; 4) forced mating behavior (polyandry) by large males; and 5) sneaking behavior (non-territorial competition behavior) by small males.

Sex ratio bias

Sex ratio is the most basic demographic parameter that involves birth, death, immigration, and emigration rates, providing a relative change in the number of females and males in particular conditions (Galliard et al. 2005; Skalski et al. 2005; Sapir et al. 2008). According to Fisher's principle, dioecious species tend to maintain a sex ratio close to 1:1, the most common evolutionary stable strategy (ESS), due to independent segregation of chromosomes during meiosis for balancing the gender ratio in the next generation (Fisher 1930; Komdeur 2012; Mitchell et al. 2013). Some monitor populations, including water monitors from Singapore, Bengal monitors from India, and spiny-tailed monitors (*V. acanthurus* Boulenger, 1885) from northern Australia, have displayed a sex ratio close to 1:1 (King and Rhodes 1982; Auffenberg 1994; Rashid 2004). However, maintaining an equal sex ratio after fertilization is more complicated when environmental factors come into play (Bulmer and Bull 1982; Janzen 1994; Janzen and Phillips 2006).

Natural selection often results in a balance between individuals in a population, which depends on the existing sex ratio and the relative costs and benefits of producing offspring of each gender (Sapir et al. 2008; Komdeur 2012). The quality and stability of the environment, both temporal and spatial, can influence the dynamic of a population by establishing a gender that is cheaper to exist under minimum environment conditions and can create a bias in the sex ratio (Skalski et al. 2005; Sapir et al. 2008; Fišer 2019). Even genetic elements, such as genetic-dependent sex determination (GSD), can contribute to the balancing of the primary sex ratio in some monitor lizards, such as spiny-tailed monitors, rock monitors (*V. albigularis* (Daudin, 1802)), Nile monitors (*V. niloticus* (Linnaeus, 1766)), and lace monitors (*V. varius*) (Valenzuela 2004; Bachtrog et al. 2014). In other reptile species, sex determination has evolved in response to environment effects, especially ambient temperature transition, known as temperature-dependent sex determination (TSD) (Viets et al. 1994; Valenzuela 2004; Bachtrog et al. 2014; Pipoly et al. 2015; Cornejo-Páramo et al. 2020). This development occurs in amniotes, including water monitors. As environments vary spatio-temporally, TSD may fluctuate in populations after fertilization, making them susceptible to experiencing maladaptive sex-ratio skews, up to 4–20 times more than GSD species due to fluctuation of ambient temperature in nests (Auffenberg 1994; Valenzuela 2004). Therefore, the TSD system associated with global warming might be the first reason for indicating bias in the secondary sex ratio of water monitors from the skew in birth rate. Furthermore, TSD species are more at risk of encountering inbreeding and genetic diversity loss than GSD from a single sex dominance due to the present global warming effect, but this thermal sensitivity might also generate an adaptive maternal nesting behavior for sex ratio selection in some individuals (Nelson et al. 2004; Mitchell et al. 2013).

The other reason why sex allocation in a population of relatively long-lived individuals might be skewed at any time is due to various effects, including food availability, maternal condition or quality, attractiveness or quality of males, social environment, sibling competition, sexual conflict, and life-history traits, which can cause changes in mortal and migration rates (Komdeur 2012; Cornejo-Páramo et al. 2020). The results suggested that the observed duration overlapping with the breeding season showed a greater number of adult female water monitors than males. Additionally, the increasing production of sex hormones during the breeding season might be the main effect that triggers sexual behaviors and biases in the sex ratio for both females and males (Cota 2011). Aggression, which is the most common male sexual emotion, triggered by testosterone, could lead to territorial behaviors by displaying male-male competition for dominance and hierarchical ranking, providing a chance to sire offspring, including guarding them from sneakers, the smaller or non-territorial individuals (Bradbury 1977, 1981, 1985; Emlen and Oring 1977; McNicol and Crews 1979; Svensson and Petersson 1988; Wiley 1991; Wikelski et al. 1996; Galliard et al. 2005). However, aggressions between male and female or among females were absent in this study. Furthermore, in the non-breeding season, aggressions and conflicts are rare or absent (Cota 2011). In summary, the skew in female monitors during the breeding season might be affected by non-conflict toward the population and the attractiveness of alpha males as a sexual selection. In contrast, male individuals might decrease due to competition and limited area. A diet resource was abundant. Thus, the bias in the tertiary sex ratio (ratio in sexually mature) of water monitors in Dusit Zoo range during breeding season might exist in females rather than males affected mainly by individual conflicts in population.

Consequently, the sex ratio at any one time or area might not reflect the true ratio in the robust population, but it can represent the ratio in some season, age range, and habitat, as well as the ratio in this study, which represented the greater female ratio in adult water monitors during the breeding season (July to October 2015) in Dusit Zoo.

Sexual dimorphism

Sexually dimorphism is typically observed in monitor lizards (Khan 1969; Auffenburg 1994; Shine 1993; Shine et al. 1996). Previously, studies have reported on morphological differences between sexes, such as male Bengal monitors being 9.2% larger than females, and male water monitors being heavier and longer in tail than non-pregnant females at the same SVL (Khan 1969; Auffenberg 1994; Shine et al. 1996). In this study, captured female individuals indicated a greater length in SVL than males, but there was no significant difference in SVL between females and males. This similarity might be influenced by dominant and territorial males driving other males out of the study area, leaving mostly females. Thus, in the non-breeding season, a comparison of body size characters might show some differences like other water monitor populations when conflict is absent, but not in this breeding season.

Diet preference

Total dietary evidence indicated no significant difference between predation and scavenger behaviors of monitors in the Dusit Zoo range. As a result, the fish prey had a strong influence on this population, as they likely learned to hunt and at the designated leaving area (13°46'23.5"N, 100°31'01.8"E). This area is where zookeepers consistently deposit the leftover food and waste materials generated by zoo animals at a specific time each day (15:00–17:00 h), even on days when no additional resources are provided. In addition, they also habituated to opportunistic feeding on leftovers from visitors such as bread, French fries, fried chicken, and processed meat (meatball, sausage, or crab stick), including food-contained plastic bags, without harming tourists. The leftover scavenging and foraging time of water monitors occurred similarly relative to the availability of humans' leftovers in various urban ecosystems, such as Indonesia, Malaysia, and Thailand) (Traeholt 1994a; Uyeda 2009; Uyeda et al. 2013, 2015; Kulabtong and Mahaprom 2015). This opportunistic scavenging provides reduced energy loss from foraging, encountering, and handling (Kane et al. 2017). Accordingly, this adaptive change in feeding habits associated with an absence of hunting or human harm might occur convergently in the maintenance and coexistence of water monitor populations in overlapping urban areas (Traeholt 1994a; Auliya 2003). However, the well-adaptive shift in diverse ecosystems and wide-ranging diet preferences of this monitor currently causes conflicts with humans in various areas due to the bad attitude perception toward this species (especially among Thai people) and commercial damage from domestic and farm animal loss (Shine et al. 1998; Lauprasert 1999; Uyeda 2009; Uyeda et al. 2012, 2013, 2015; Kulabtong and Mahaprom 2015; Rahman et al. 2017). Thus, to reduce the conflict from scavenging in urban areas, the leftover management must be done well to eliminate the attractive factor, especially food leftovers.

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Supplementary material 1

Mean percentage (± SD) of daily activities in tagged water monitors (*Varanus salvator macromaculatus*)

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Data type: docx

Explanation note: Mean percentage (± SD) of daily activities in tagged water monitors (*Varanus salvator macromaculatus*) (*n* = 90 individuals), including disappeared individuals, in Dusit Zoo range during July through to October 2015.

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