Diet reflects opportunistic feeding habit of the Asian water monitor (Varanus salvator)

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Received 10 September 2021; final revision received 7 December 2021; accepted 16 December 2021; published online 30 December 2021; published in print 16 March 2022

Abstract
The Asian water monitor (Varanus salvator) is a large generalist predator and scavenger lizard. This species has a widespread distribution throughout South and Southeast Asia and is frequently encountered around the edges of urban settlements. Here, we present information on diet diversity and habitat utilisation of a population of Asian water monitors inhabiting the University of Malaysia Terengganu campus located on the east coast of mainland Malaysia. The stomach contents of 30 Asian water monitors were examined by stomach flushing, and 47.6% of stomach contents was mangrove crab, 26.2% was human waste and 26.2% was other natural foods consisting of fruits, fishes, leeches, snails, birds and insects. We then recorded the locations and habitats utilised by patrolling the campus area and found Asian water monitors preferred to use water and mangrove forest habitats that fringed and criss-crossed the campus. The broad diversity of stomach contents reflected food available at this location and indicates the opportunistic feeding habit of this species. Given that this species widely distributed in Southeast Asia, its broad diet diversity and habitat variations may promote the adaptation of Asian water monitor to different environments.

Keywords
Adaptation; Asian water monitor; diet; habitat; varanid
Introduction

The ability of animals to cope with new environments arises from their capacity to respond to environmental variables (Young et al., 1989). Hence, in order to adapt to environmental changes, animals often show morphological and/or behavioural flexibility to new, novel conditions (Corse et al., 2009). Human-induced habitat changes such as land clearing for agricultural and urban purposes are arguably the biggest destroyer of natural environments (Tilman et al., 2017; Williams et al., 2021), and therefore many endangered species will not survive these changes (Pimm & Raven, 2000). However, species that have a widespread distribution across many different habitat types, such as the Asian water monitor \([\text{Varanus salvator} (\text{Laurenti, 1768})]\), are typically more flexible in their behaviour and are therefore able to rapidly adapt to changing environments and are able to exploit human-altered environments (Traeholt, 1994; Shine et al., 1998; Rahman et al., 2017). Living-space is one of the most important resources used by animals and provides food, water and shelter (Guarino, 2002). Animals’ habitat choice can be influenced by a number of factors, such as light (Théry, 2001), temperature (Street et al., 2015), noise (Kleist et al., 2017), predation (Brown, 1999) and population density (Elkin & Reid, 2010). In addition, habitats have substantial influence on the distribution and abundance of animals, and therefore the habitat selected by animals is heavily influenced by the abundance of food in their environment (Boyce et al., 2016). The higher the abundance of food, the greater the potential density of animals can be (Charnov et al., 1976). Therefore, knowledge of food available in the habitat can help explain the spatial ecology of a species (Titeux et al., 2020).

Monitor lizards appear to feed on the most abundant or easily accessible food type in the area where they live. For example, in coastal habitat adjacent to a sea turtle nesting beach on the east coast of Australia, the yellow-spotted goanna \([\text{Varanus panoptes} \text{ Storr, 1980}]\) prefers to occupy dune habitat where they exploit sea turtle eggs during turtle nesting season (Lei et al., 2017). In contrast, lace monitors \([\text{Varanus varius} \text{ (Shaw, 1790})]\) principally use woodland forest habitat inland of the dunes and feed on other food types such as mammals, birds, reptiles and invertebrates (Guarino, 2002; Lei & Booth, 2017). Therefore, understanding the relationship between habitats and diet variation among populations is an active field of ecology (Guarino, 2002; Lei et al., 2017; Rusli et al., 2020). The Asian water monitor is widely distributed throughout South and Southeast Asia (Koch et al., 2007). Like most monitor lizards, Asian water monitors are opportunistic predators, feeding on a wide range of prey, including insects, crustaceans, fish, reptiles, reptile eggs, birds and small mammals (Smith, 1932; Gaulke, 1991; Traeholt, 1997). Furthermore, they are also carnivorous scavengers (Traeholt, 1994). Although previous studies investigated the diet of Asian water monitors in different habitats (Shine et al., 1998; Kulabtong & Mahaprom, 2015; Rahman et al., 2017; Rusli et al., 2020), only a few studies reported the relationship between habitat and diet. Rusli et al. (2020) reported the diet of Asian water monitors adjacent to a human-managed sea turtle rookery, and found a large proportion of human waste in the diet compared to
other natural food, indicating opportunistic exploitation of a food source, and that human activity significantly influenced Asian water monitor diet. Therefore, understanding the relationship between food and habitat choice is essential for monitor lizard conservation and management.

The aim of our study was to investigate the diet and spatial distribution of a population of Asian water monitors living on the fringes of an urban habitat. We wanted to determine how important human-supplied foods were to this population, and how frequently Asian water monitors entered urban spaces in search of human foods.

Materials and methods

Study area

This study was conducted at the Universiti Malaysia Terengganu (fig. 1), which is located on the east coast of Peninsular Malaysia (5.4068–5.4158°N, 103.0838–103.0958°W; GPS datum 1/4 WGS84; fig. 1A). Kuala Terengganu’s climate is tropical with peak rainfall during the monsoon season (November–March). The study site supports a healthy population of Asian water monitors in water, mangrove, and urban open areas on an urbanised campus (Baizul et al., 2019). The habitat inland from the sandy areas was covered in shrubs and bramble bushes, and beyond

Figure 1. (A) Location of the study site at the University Malaysia Terengganu in Malaysia. (B) Locations and numbers of traps for capturing Asian water monitors in the study are indicated by red circles with white Arabic numerals. The number of Asian water monitors captured in each trap is indicated in the white labels above the red circles. The habitat descriptions are: yellow: sandy plain; light green: bushland; medium green: rainforest; dark green: mangrove; blue: water; black solid line, road and walkway; light grey: urban area; dark grey: building.
this the habitat was mangrove and rainforest dominated by Dipterocarpaceae, Rhizophoraceae and palm trees (Arecales) (fig. 1B). Several saltwater estuaries are distributed across the campus (fig. 1B).

**Animal capture**

During the 2019 dry season (1 July–10 September), adult Asian water monitor lizards were captured using wire-mesh cage traps baited with chicken carcasses housed inside wire mesh that prevented the Asian water monitor lizards from eating the bait. Once caught, the snout-to-vent length (SVL) and total length of the Asian water monitor lizard was measured with a flexible fibreglass measuring tape (±1 cm), mass was recorded with a hanging digital scale (±0.01 kg), and the sex determined by squeezing the tail base to evert the hemipenis of males or examining the thickness and scales at the tail base (Auffenberg et al., 1991). Most of the male monitor lizards exposed their hemipenes when the base of the tail was squeezed. If the hemipenes were not everted by squeezing, a blunt probe was inserted into the cloaca to make sure no hemipenes were present (Lei & Booth, 2018).

**Stomach flushing**

The stomach of each Asian water monitor lizard was flushed within 1 hour of capture. This involved inserting a plastic tube (diameter 10 mm) down the oesophagus into the stomach. Fresh water (2–3 l) was then pumped into the stomach using an aquarium pump (Hasbur, mode FP-9025, Guangzhou, China). Flushed water was filtered through 2-mm mesh. All material flushed from the stomach was separated and examined immediately. Any content apart from human food wastes (e.g. rice, noodle, cooked meat, cooked vegetable and chopped bones), such as crabs, fish, fruits, leaches/snails, birds and insects were identified to the closest taxon. Each constituent of stomach content was weighed using an electronic scale and the volume was measured by adding individual food items to a known volume of water in a graduated volumetric measuring cylinder, and then subtracting the volume of water from the reading.

**Habitat selection**

All Asian water monitor locations were recorded when sighted. Individual locations were recorded by patrolling the campus area focussing on active periods (Lei et al., 2021): morning (07:00 to 11:00 h), midday (11:01 to 14:30 h), and afternoon (14:31 to 18:30 h). Once a lizard was located its position (fix) was recorded using a handheld global positioning system (GPS; Garmin eTrex 30; Estimated Position Error [EPE] 5 ± 1.2 m).

**Calculating index of relative importance of diet**

Frequency of each food type in samples was quantified as percentage of the total sample and the mean of the volume percentage of each food type in each sample.
This information was used to calculate an index of relative importance (IRI), as modified by Bjorndal et al. (1997) from the original index developed by Pinkas (1971) and Pinkas et al. (1971)

$$\text{IRI} = 100 \left( \frac{F_i V_i}{\sum_{i=1}^{n} (F_i V_i)} \right)$$

where $F_i =$ percentage frequency of occurrence, $V_i =$ percentage volume, $n =$ number of food types, and $i =$ food type.

Calculating habitat selection index

To determine if Asian water monitors had a preference for a particular habitat type, fixes were first plotted on landscape maps by combined visual mapping of habitat type with data imported from Google maps using the adehabitat R package (Calenge, 2006) in R (R x64 v3.1.3; R Core Team 2016), so that each fix could be assigned to a habitat type. A habitat selection index ($\hat{W}$) was calculated for each of the habitat types (sandy plain, bushland, rainforest, mangrove and walkway) using the equation (Manly et al., 1993):

$$\hat{W} = O_i / \pi_i$$

where $O_i =$ the proportion of the population sampled in each habitat type, and $\pi_i =$ the proportion of total study area each habitat type covers. Then the standardised habitat selection index ($B_i$) for each habitat type was calculated using the equation (Manly et al., 1993):

$$B_i = \frac{\hat{W}_i}{\sum \hat{W}}$$

All of the statistical analysis were performed in R. ANOVA was used to make comparisons between variables, which are reported as mean ± SE and $P < 0.05$ was considered to be significant. All datasets generated and analysed during the study will be available on the GitHub repository: https://github.com/Juan881204/Asian-water-monitor-diet-at-campus

Results

Diet

We captured and sampled stomach contents from 30 adult Asian water monitor lizards (fig. 1B), of which 80% (24/30) were males. The average SVL of all individuals was 65.0 ± 7.9 cm and their average mass was 5.6 ± 2.4 kg. Eight different types of food were flushed from the stomachs of these lizards (table 1). There was no significant difference ($P = 0.999$) between mass and proportion between food types and no significant difference ($P = 0.674$) between food types and sex. Mass and index of relative importance indicated the diet of Asian water monitors in our
Table 1.
The frequency of occurrence (FO) (%) of each food item in stomach contents flushed from Asian water monitor lizards ($n = 30$), and their fraction (%) of the total mass, volume and index of relative importance (IRI). Trap site number and the number of Asian water monitors containing each food item.

<table>
<thead>
<tr>
<th>Food Item</th>
<th>FO</th>
<th>% of total mass</th>
<th>% of total volume</th>
<th>IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crab</td>
<td>47.6</td>
<td>53.8</td>
<td>54.7</td>
<td>49.7</td>
</tr>
<tr>
<td>Human waste</td>
<td>26.2</td>
<td>36.7</td>
<td>36.4</td>
<td>29.7</td>
</tr>
<tr>
<td>Fruit</td>
<td>9.5</td>
<td>3.3</td>
<td>3.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Fish</td>
<td>7.1</td>
<td>3.9</td>
<td>3.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Leech</td>
<td>2.4</td>
<td>1.2</td>
<td>1.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Snail</td>
<td>2.4</td>
<td>0.9</td>
<td>0.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Bird</td>
<td>2.4</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Insect</td>
<td>2.4</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>1.6</td>
</tr>
</tbody>
</table>

study area consisted principally of crabs (IRI = 49.67). In all, 66.7% (20/30) of the Asian water monitor lizards had crabs flushed from their stomachs. The reminder of the diet included human food waste, fruits, fishes, birds, leeches, snails and insects. Human food waste represented a large proportion of the remaining diet (IRI = 29.70). Prey groups representing less than 5% included birds, leeches, snails and insects.

**Habitat selection**

In all, 233 sightings of Asian water monitors were made during our study (table 2, fig. 2). Habitat selection analysis showed that the water ($B_i = 0.45$) was the most frequently used habitat. Mangrove, rainforest and bushland ($B_i = 0.25, 0.15$ and $0.09$ respectively) were occasionally used, and the urban open area and sandy plain were rarely used ($B_i = 0.02$ and $0.03$; table 2).

**Discussion**

Our results suggest the diet of Asian water monitors consisted mainly of crabs. Population and community dynamics can be strongly influenced by nutrients of prey items (Polis et al., 1997). In previous studies of Asian water monitors, food abundance influenced the foraging activity of this species. For example, human food waste attracted Asian water monitor to a sea turtle research station (Rusli et al., 2020), and resulted in large-size males occupying relatively small home ranges (Lei et al., 2020). Monitor lizards in general have good memories (Rusli et al., 2020), for example, free-ranging yellow-spotted goannas ($Varanus panoptes$) can learn to not eat cane toads [$Rhinella marina$ (Linnaeus, 1758)] (Ward-Fear et al., 2016), indicating yellow-spotted goanna have good memories and the ability to avoid eating harmful prey. In our study, Asian water monitor lizards no doubt remember the location of high crab abundance areas in waterways, and thus exploit this food
Table 2.
Calculation of standardized habitat index \( (B_i) \) as a proportion of selection index \( (\hat{W}) \) based on sightings of Asian water monitors. Population proportion \( (\pi_i) \) was calculated as a percentage of the total area, for each of the habitats covered. Sample counts are the number of fixes in each habitat. Sample proportion \( (O_i) \) is the sample count as a percentage; selection index is calculated by \( \hat{W} = O_i / \pi_i \) (Manly et al., 1993).

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Population proportion ( (\pi_i) )</th>
<th>Sample count</th>
<th>Sample proportion ( (O_i) )</th>
<th>Selection index ( (\hat{W}) )</th>
<th>Standardized habitat index ( (B_i) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>6.40</td>
<td>79</td>
<td>33.91</td>
<td>5.30</td>
<td>0.45</td>
</tr>
<tr>
<td>Bushland</td>
<td>21.28</td>
<td>55</td>
<td>23.61</td>
<td>1.11</td>
<td>0.09</td>
</tr>
<tr>
<td>Rainforest</td>
<td>8.14</td>
<td>34</td>
<td>14.59</td>
<td>1.79</td>
<td>0.15</td>
</tr>
<tr>
<td>Manmade ground</td>
<td>44.23</td>
<td>33</td>
<td>14.16</td>
<td>0.32</td>
<td>0.03</td>
</tr>
<tr>
<td>Mangrove</td>
<td>3.30</td>
<td>23</td>
<td>9.87</td>
<td>2.99</td>
<td>0.25</td>
</tr>
<tr>
<td>Sandy plain</td>
<td>16.65</td>
<td>9</td>
<td>3.86</td>
<td>0.23</td>
<td>0.02</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>233</td>
<td>100</td>
<td>11.74</td>
<td>1.00</td>
</tr>
</tbody>
</table>

source to save energy expenditure. Most Asian water monitors were captured adjacent to estuaries (fig. 1B), indicating this species preferred to use water habitat, which is the key activity area of this species in this study. In addition, Lei et al. (2021) reported the temperature of sandy ground in the study area during midday was higher than 50°C, a temperature that exceeds the lethal body temperatures of

Figure 2. Asian water monitors’ locations recorded in the study (1 July–10 September) are indicated by red circles.
most reptiles, and thus Asian water monitors may avoid such areas during midday and forage in the cooler waterway habitat at this time. Future studies are required to explore the movement pattern of this species, specifically during the hottest time of day to discover the behavioural thermoregulation in Asian water monitors.

Asian water monitors are scavengers and generalist predators known to consume a wide variety of prey (Gaulke & Horn, 2004) that can be found in different habitats, including islands (Traeholt, 1994; Rusli et al., 2020), mangrove forest (Rahman et al., 2017), and urban areas (Shine et al., 1998; Kulabtong & Mahaprom, 2015). Different habitats selected by Asian water monitors result in different diet component. Shine et al. (1998) reported 44 food item types in Asian water monitors inhabiting urban areas, whereas only five prey types were observed in an island habitat (Rusli et al., 2020). Although diet composition varies widely in different habitats of this species, Asian water monitor are able to maintain healthy populations, suggesting a wide dietary range is a key factor allowing the widespread distributed of this species in Southeast Asia (Koch et al., 2007). During our study, we did not capture or observe any juvenile Asian water monitors. The establishment of size-based dominance hierarchies in this species has been reported (Uyeda et al., 2015; Lei et al., 2020) and is a possible reason why we failed to observe any juveniles. In a persisting population, some juveniles must exist, so future studies might attempt to discover their preferred habitat and diet.

Coastal mangrove system possesses a large variety of marine and terrestrial creatures and supports complex food webs (Hogarth, 1999; Ellison & Farnsworth, 2000). In our study, Asian water monitor mainly consumed mangrove crabs. However, only 3.3% of our study area consisted of mangrove habitat, the only source of crabs in the area. So any future clearing of mangrove habitat will most probably cause a decline in the Asian water monitor population in this area. Our result also indicated human waste is the second-largest food source (26.19%) of Asian water monitors, suggesting human activity may alter Asian water monitor foraging behaviour. Rusli et al. (2020) reported Asian water monitors relied on human waste food at a sea turtle research station, and therefore the presence of human food waste may lead to lizards’ establishing size-based dominance hierarchies, similar to what was found in another study in an area with concentrated garbage on Tinjil Island, Indonesia (Uyeda et al., 2015), which may result in an unbalanced population structure. Future studies are required to explore the effect of human waste food on Asian water monitor foraging behaviour at the campus area, with a focus on discovering which individuals of the population were frequently feeding on human waste food.

Conclusion

Our study provides insights into the behavioural ecology of Asian water monitors in an urbanised environment adjacent to waterways. First, the preferred habitat of Asian water monitors in our study site was the waterways. Second, the diet of Asian water monitor consisted mainly of crabs at this coastal site, but human food waste...
was the second most important food type. Hence, because the preferred habitat was waterways, which is also the habitat of crabs, it was not surprising that the principal food item identified was crabs.

Acknowledgements

This study was supported by School of Marine and Environmental Sciences, Universiti Malaysia Terengganu, Terengganu, Malaysia. All work was approved by a Universiti Malaysia Terengganu Animal Ethics Committee (Permit no. UMT/JKEPHT/2019/31).

References


