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Study on the Foraging Behavior and Diet Preferences of Indian Star Tortoises (*Geochelone elegans*) in Chinnar Wildlife Sanctuary, Kerala, India

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ABSTRACT

Indian star tortoises belonging to the genus *Geochelone* are medium sized land tortoises, found in the dry arid regions in the south- western Asia. This study evaluates the foraging behaviour and diet selection of Indian star tortoise (*Geochelone elegans*) in Chinnar wildlife sanctuary, Kerala. The present study concentrated on the wild population of two Adult (1 male and 1 female) star tortoises along with the 2 Sub-adults (1 male and 1 female) and 5 juveniles which were released in to the thorny scrub forest after successful rehabilitation process. The study was conducted during the period of 5th January to 2nd of March. The diet of *G. elegans* was examined and quantified based on faecal analysis and direct feeding observations. A comprehensive vegetation survey of all plant species within feeding height of the tortoises in the protected area was conducted. The recovered materials of several plant remains, sand remains and insect remains along with animal hairs suggest the feeding on scat of higher vertebrates which was confirmed by *in-situ* observations. These data, combined with daily feeding observations, were used to calculate feeding rates and diet preferences. Faecal samples were also collected to identify the diet components of all the individuals. Individuals were recorded feeding on 29 of 49 recorded plant species, 14 of which were selectively foraged. Species composition of plant species ingested differed between age classes. Wild adults selectively foraged on 13 plant species, Sub adults on 14 plant species and juveniles selectively foraged on 12 species. The array of diet items consumed by *G. elegans* suggests that its diet is complex and it needs to be taken into consideration in further rehabilitation programmes.

INTRODUCTION

The diet of a species is key to its survival. An understanding of the diet of a species also provides information on the role it plays in the ecosystem. Numerous studies have attempted to identify factors that are important in the choice of diet [1]. In reptiles, most species are carnivorous although numerous turtles and lizards are at least partly herbivorous, of which several are known or suspected to play a role in seed dispersal [2-6]. However, few *in-situ* studies have been carried out with a focus on the diet of reptiles in the oriental region [7]. The ranging pattern, foraging behaviour, population size and ecology of the Indian star tortoise (*Geochelone elegans*) living in a mosaic of habitat type in the scrub jungle forest might be affected by the availability of the key nutrients. The diet of the Indian star tortoise mainly constitutes cactus, grass, herbs, seed, insects and millipedes. This information on the free ranging individuals is limited to brief notes based on the local knowledge of the tribal and guides and

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observations in captivity [8]. Captive breeding and subsequent reintroduction has become an important conservation tool in recent decades. Captive breeding programmes for the purpose of rehabilitation of illegally traded and conflicted animals as a part of conservation. However, there is very little known of the ecology and behaviour of *G. elegans* in captivity and, with the species not being observed in the wild for over 150 years, nothing is known about its ecology and behaviour in the wild. The Indian Star Tortoise (*Geochelone elegans*) is a medium sized species of tortoise commonly found in semi-arid scrub forest, along with thorny and grassland habitats, where there is plenty of vegetation both to hide in and munch on. The Indian star tortoise is named for the star-like patterns on its high-domed shell which are distinctive to species of star tortoise. As its name suggests the Indian star tortoise is found across the Indian sub-continent, more specifically, found in the central and Southern parts of India, in West Pakistan and in Sri Lanka. Currently, the Indian Star Tortoise is under Schedule IV of the Wildlife (Protection) Act 1972, which means that the protection accorded to it is less than those listed under Schedules I and II. The Indian Star Tortoise is currently assessed by the IUCN Red List as being of "vulnerable" (Asian Turtle Trade Working Group, 2010). The species is listed under Appendix II of CITES, which permits trade under certain circumstances.

The aim of this study was to produce a comprehensive and accurate description of the foraging activity and diet preferences of a released and wild resident *G. elegans* and also emphasized the diet of Indian star tortoises was quantified and described based on direct observations and analyses of faecal remains.

MATERIALS AND METHODS

Study Area

Chinnar Wildlife Sanctuary is considered as the unique habitat in Kerala of thorny scrub forest which is most suitable for the *Geochelone elegans* populationto survive. The study area is located in rain shadow region of Western Ghats between 10˚ 15'-10˚ 21' N latitude and 77˚ 05'-77˚ 16' E longitude in Devikulam Taluk of Idukki District, Kerala State. An area of 30 Sq. Km was considered suitable for the rehabilitation of star tortoises out of the 98 Sq. Km area of whole sanctuary.

The particular area was selected for the rehabilitation programme undertaken by the KeralaForest department along with Wildlife Trust of India (WTI) for releasing the seized star tortoises from the airports to their naturally occurring wild. On 30th April 2014, 357 confiscated Indian star tortoises (*Geochelone elegans)* were housed at Chinnar Wildlife sanctuary for rehabilitation process. Veterinary care and housing were provided. From them 185 individuals were released into the wild and the rest died due to several infections occurred between the periods. Second batch of seized star tortoises were shifted to Chinnar for the rehabilitation was carried out on 14th of August 2015. Same protocols were implicated as per their experience on the first batch. A total number of 200 juveniles were seized from the Cochin international airport. Unlike from the first batch there was no casualty occurred and all the individuals survives and released into the wild.

The Chinnar wildlife sanctuary is located in the rain shadow region of Western Ghats, possessing the unique thorny scrub forest. The sanctuary lying in the altitude of 440 m to 2372 m. 50% of the area is covered by the dry deciduous forest and thorny scrub forest. The main tree composition of this area includes *Albizia amara, Atalantia monophylla, pleiospermium alatum, Prosopis juliflora, Dichrostachys cinerea, Anogeissus latifolia, Chloroxylon swietenia, Hardwickia binata, Boswellia serrata*and *Santalum album.* Cactus and euphorbia predominates the ground level along with the grass species including *Trichodesma indicum* and *Echinochloa colonum.*

The present study was conducted during 5th January to 2nd of March. From the two batch of released star tortoises 2 sub adults (first batch released) and 5 Juveniles (second batch released) were monitored from the wild and daily observations were done on them. Individuals below 80 mm Straight Carapace Length (SCL) were considered as juveniles, sub adults are considered having SCL below 150 mm and greater than that was considered as adult.

Faecal Analysis

Faecal remains have been widely used to examine dietary components of tortoises [3-5]. Faecal samples collected during daily observations and most of them encountered during their active times (morning and evening). The faecal samples were collected in polythene pouches separately and dried under sunlight for 1-2 hours. The dried material was then examined using a 10X hand-held lens and separated into diet components of; plant parts (flower, seeds, leaves, and bark), sand, cactus remains, insect remains and unidentified materials (those remained unidentified using lens.). Animal hairs were identified using microscope Leica EZ4 (™) at 35 x magnification, following a mammal hair identification key.

The evaluation and statistical analysis of diet was based on a study of *Testudo horsfieldii*, the steppe tortoise [9]. Vegetation survey was the method used and the relative abundance of plant species present at the site was censured. Forty five quadrats (1 m^2) were placed randomly along 5 random 30-m transects throughout the scrub jungle of Chinnar, near to the foraged areas. Plant species were identified using keys provided by the experts and following the manual of flora of Chinnar wildlife sanctuary. The number of plants of each species in each quadrat was multiplied by the mean above ground biomass of 10 individual plant samples of each corresponding species in order to estimate plant species biomass. Each part (flower, stem, seed, and leaf) of each recorded plant species was also weighed in order to ascertain the mean biomass (based on 10 randomly selected samples)

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of individual plant parts. These were weighed using a Kern CM 60-2N pocket balance (maximum=60 g, d=0.1 g) in the field to eliminate desiccation errors. For plant species that weighed above 60 g, the plants were dissected into smaller pieces, and the sum of the smaller pieces combined in order to ascertain the total above ground biomass.

Only plants, 60 cm tall or with edible parts, 60 cm above ground were recorded. Anything taller than this was deemed to be above the tortoises' reach. 60 cm was the maximum reach of the largest individual (AM-1), ascertained by measuring the height from the ground of suspended food items taken. Fallen leaves and seed from trees and other taller plants were also recorded. Plant species were classified as graze, browse, or opportunistic (fallen fruit and leaves) in terms of how the tortoises fed upon them. The proportion that each feeding mode made up of the diet was calculated as the mass of any one of the categories consumed divided by the total mass consumed.

Sampling events began before sunrise and ended when the individual took up a sleep position at dusk. Individual tortoises were located in the evening prior to their sampling in order to minimize search time on the day of sampling. Tortoises were always found in the same spot at dawn which they occupied the previous dusk. However, because no nocturnal sampling occurred, nocturnal activity cannot be completely ruled out. Active time was taken as the total time from initial arousal post sunrise until movement into a sleep spot position at dusk, minus all inactive periods during the sampling event. An individual was judged to be inactive when not actively foraging or showing any obvious movement. All individuals exhibited some activity during each sampling event. Each individual was subject to a total of 50 hours of observation and Juveniles were observed with 30 hours per individual. Pilot observation suggested that human presence within 2-4 m resulted in disturbance. For juveniles near 2 m found to be disturbance and for sub adult it varies to 3 m and therefore all observations were made using binoculars from greater than 3 m but less than 10 m.

Statistical Analysis

The proportion of any given plant species in a tortoise's diet (pi), based on aboveground biomass, was calculated as the percentage of estimated fresh vegetation consumed for the species (g) divided by the total estimated fresh matter consumed for all species (g). A pi was calculated for each plant species consumed over the entire sampling period for each individual, sex group, and the total population. Taxonomic availability of plant species (qi) was calculated as the percentage of fresh mass (g) of each species of plant relative to the total fresh mass (g) of plant material recorded during the vegetation survey of the site. Hunter's index (Hi = pi/qi;) was used to determine whether plant species were preferred (Hi < 1) or avoided (Hi > 1). Hunter's index, unlike chi-square (X^2) tests, takes into account spatial heterogeneity of the vegetation structure and inter individual diet heterogeneity [9].

Direct Observations

Daily monitoring was carried out to find out the feeding activities of the tortoises based on their age class. Whenever possible, opportunistic observations of feeding behaviour were also made. Ad-libitum observations were made by a single observer located 5-6 m away from the animal to avoid disturbance. The plant or animal parts which a tortoise fed upon were collected and identified.

RESULTS

Faecal Analysis

All Eighteen faecal samples collected from 2 adult wild (1 male and 1 female), 2 sub adult released (1 male and 1 female) and 5 juvenile star tortoises during this study were contained the remainder of at least one dietary item. Overall plant matter had the highest contribution with more than 50% in the obtained faecal samples in all three age classes of star tortoises. This constituted of flower parts, plant seeds, leaves, bark of the stem and cactus remains etc. 51.6% plant parts identified in the faecal samples of wild adults, 50.4% and 48.2% were the plant parts present in released sub adults and juveniles respectively. In adults and sub adults samples undigested full leaves were also identified. The materials present in the faecal matter were only partially digested and was easy to recognise using hand lens. Among the plant parts, cactus remains possess greater proportion in released individuals, 18.2% and 20.3% in sub adult and juveniles respectively.

In the four faecal samples, leaf parts were greater than cactus remains in wild ones. In wild adult star tortoises, sand particles including small stones and sand grains constitutes the major portion with 24.0%, leaf parts were identified in 16.2% were full and leaf pieces were observed. Among them 9% contained seeds, 11% of flower parts, insect scales constitute 11.4% (millipede and bug scales), bark of the plants and dried logs were constituted 2.1%, and cactus remains constituted 12.4%. 13% of the total faecal matter encountered was too small to identify and assign to any of the diet categories **(Table 1)**. In the faecal samples few number of hair were also detected which indicates the feeding on the scat of carnivorous animals such as wild dog and leopard. The proportion of dietary components between sexes did not significantly differ.

Analysis of four faecal samples evidenced that sub adults were more preferable to the cactus and insects and the proportion of cactus remains comes beneath to sand remains and constitute of 18.2%. Flower remains were present 8%, seed constitute 2.2%, leaf parts constitute of whole leaves and parts contributed 12.9%. 16% of insect remains were identified in the sample, which of millipedes and of centipedes and sand remains found greater in proportion of 22.2%. Bark remains were of 9.1% and the unidentified materials constituted 11.4% **(Table 2).**

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Ten released juvenile samples were analysed and the proportion of cactus remains were higher and constituted 21.2% of total. Sand possessed 18%. Plant remains constituted 49%; among them flower remains constituted 7.3%, leaf parts 12.4%, bark remains 7.3% and cactus with the rest. Seed remains were absent in all the ten samples. Insect remains seemed higher in juveniles which constituted 18.1%. Millipede scales, centipede scales and of small bug scales were identified. 15.7% were remains unidentified, which can be of any of these classes **(Table 3)**.

Table 1. Percentage composition of plant and non-plant components in the diet of Indian star tortoise (*Geochelone elegans*) of different age classes.

Categories	Plant components (%)					Non-plant components (%)		Others (%)
Age class	**FP**	**S**	**LP**	**CR**	**BR**	**SD**	**IR**	**UI**
Juvenile	7.3	-	12.4	21.2	7.3	18	18.1	15.7
Sub adult	8	2.2	12.9	18.2	9.1	22.2	16	11.4
Adult	11	9	16.2	12.4	3.0	24	11.4	13

Note; Abbreviations: FP-Flower parts, S- Seed, LP- Leaf parts, CR- Cactus remains, BR- Bark remains, SD-Sand, IR- Insect remains, UI-Unidentified

Statistical Analysis

The statistical analysis of feeding and foraging of star tortoises based on their plant preferred was studied using Hunter's Index. Wild adult tortoises found more active than the other categories during their feeding periods and recorded the attempt/consumption of 29 plant species. Out of them they selectively foraged 13 plant species which constitute majority of their diet **(Table 4)**. Plants such as: *Talinum portulacifolium, Commelina ensifolia, Opuntia monocantha, Opuntia vulgaris, Tridax procumbens, Sida acuta, Sida rhombifolia, Boerrhavia diffusa, Cissus quadrangularis, Ipomoea asarifolia, Apluda mutica, Echinochloa colonum and Cynodon dactylon*. Out of these *Cissus quadrangularis* is considered as an opportunistic food. The main dietary food species included the same plant species provided by the tribes and local knowledge's.

The adults predominantly foraged on some species like *Opuntia spp.* (54.15%), *Tridax procumbens* (7.62%) and *Boerhavia diffusa* (8.89%). They together constitute 70.66% of total food. 10.47% grass species constituted in their diet and it indicates the variability they adapted in the foraging behaviour to satisfy the dietary needs.

Hunter's Index preferably denotes the food species selected depending on their taxonomic availability and it excludes other dietary items which possess a good proportion in the diet. According to the observed values from Hunters Index species with more than 1 denotes it was selectively foraged. While increasing the value from 1 indicates its preference in the diet relative to its abundance in the inhabiting area. Species such as *Boerhavia diffusa (3.06), Opuntia monocantha (2.53)* and *Apluda mutica (2.06)* possess higher value of Hunters Index. The foraging strategy was found to consist of 12.81% opportunistic feeds (fallen fruit, cactus and leaves), 61.37% graze and 25.82% of browsing. Due to the less availability of opportunistic foods star tortoises more preferred feeding on ground. Due to the unavailability of fresh plant matters some tried to eat the dried grass in a less proportions to sustain their daily dietary needs.

Table 2. Vegetation availability and use by wild adult (n=2) Geochelone elegans ranked according to Hunter's index value.

Species (i) Species (i)	Mass c Mass consumed (g) on)	Pro Proportion of diet (pi) n of diet (p	Tax Taxonomic availability (qi)availability	Hunt Hunter's Index (Hi) e
Caralluma umbellata	10.03	1.11	1.28	0.86
Blepharis madarasapatensis	16.97	1.89	3	0.63
Talinum portulacifolium	32.65	3.63	2.57	1.41
Commelina ensifolia	33.11	3.68	1.98	1.85
Tephrosia villosa	9.88	1.1	3.87	0.28
Oldenlandia corymbosa	3.01	0.33	2.39	0.13
Spilanthus radicans	1.8	0.22	0.3	0.73
Opuntia monocantha	378.7	42.19	16.64	2.53
Opuntia vulgaris	89	9.91	6.18	1.6
Opuntia stricta	18.45	2.05	2.58	0.79
Tridax procumbens	68.4	7.62	6.06	1.25
Sida acuta	20.44	2.27	2.2	1.03
Sida rhombifolia	7.08	0.78	0.55	1.41
Boerrhavia diffusa	79.8	8.89	2.9	3.06
Synedrella nodiflora	6	0.66	1.1	0.6
Urena lobata	4.5	0.5	1.07	0.46
Cissus quadrangularis	18.19	2.02	1.06	1.9

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Xanthium indicum	1.8	0.2	1.18	0.17
Pentanema indicum	1.02	0.11	0.99	0.11
Ipomoea asarifolia	19.8	2.2	1.05	2.09
Acacia torta	0.8	0.09	0.61	0.14
Ipomoea obscura	0.5	0.05	0.08	0.62
Echinochloa colonum	29.13	3.24	3.18	1.01
Apluda mutica	21	2.34	2.29	1.02
Cynodon dactylon	26.69	2.97	1.81	1.64
Trachys muricata	9.8	1.09	2.3	0.45
Meremmia tridentate	7	0.78	1.4	0.24
Trichodesma indicum	-	-	4.13	-
Dipteracanthus prostrates	-	-	0.8	-
Cyathula prostate	-	-	1	-
Euphorbia hirta	-	-	1.1	-
Aerva lanata	-	-	8.34	-
Cajanus scarabacoides	-	-	1.44	-
Crotalaria stipitata	-	-	0.8	-
Tephrosia purpurea	-	-	0.6	-
Brachiaria distachya	-	-	0.1	-
Sehima nervosum	-	-	1.37	-
Anthoxanthum indicum	-	-	1.01	-
Conyza bonariensis	-	-	0.04	-
Abutilon hirtum	-	-	0.4	-
Hibiscus micranthus	-	-	0.71	-
Corchorus tridens	-	-	0.45	-
Rothia indica	-	-	0.09	-
Emilia sonchifolia	-	-	0.21	-
Parthenium histeropherus	-	-	1.19	-
Evolvulus alsinoides	-	-	0.12	-
Unknown species	-	-	1.87	-
Total number of species	47			
Number of species consumed	27			
Total amount of plants consumed	897.55 gm			

Note: All indices are based upon biomass. Hunter's index greater than 1 (Hi > 1) indicates preferred species. Hunter's index less than 1 (Hi < 1) indicates species whose occurrence in the diet is less than their relative availability (selectively avoided).

Table 3. Vegetation availability and use by released sub-adult (n=2) Geochelone elegans ranked according to Hunter's index value.

Species (i) Species (i)	Mass co Mass consumed (g) ns(g)	Proportion o Proportion of diet (pi) f diet (p	Tax Taxonomic availability (qi) no availability (q	Hu Hunter's Index (Hi) n(H
Caralluma umbellata	10.12	1.67	1.31	1.27
Blepharis maderasapatensis	21.02	3.47	2.59	1.33
Talinum portulacifolium	17.77	2.93	2.4	1.22
Commelina ensifolia	21.8	3.59	2.1	1.7
Tephrosia villosa	1.32	0.21	2.42	0.08
Oldenlandiacorymbosa	1.01	0.16	0.29	0.55
Opuntia monocantha	238.12	39.31	21.01	1.87
Opuntia vulgaris	77.02	12.71	9.38	1.35
Opuntia stricta	10.23	1.69	2.89	0.58
Tridax procumbens	57.21	9.44	6.43	1.46
Sida acuta	20.01	3.3	0.92	3.58
Sida rhombifolia	8.09	1.33	0.69	1.92
Boerrhavia diffusa	50.01	8.25	4.74	1.74
Synedrella nodiflora	-	-	1.19	-
Urena lobata	0.29	0.04	1.31	0.03
Cissus quadrangularis	19.09	3.15	2	1.57
Xanthium indicum	0.03	0.005	0.98	0.005

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Pentanema indicum	2.01	0.33	0.89	0.37
Ipomoea asarifolia	11.79	1.94	1.34	1.44
Acacia torta	0.9	0.14	0.76	0.18
Pseudarthria viscida	2.19	0.36	0.64	0.56
Echinochloa colonum	-	-	2.18	-
Apluda mutica	19.9	3.28	2.11	1.55
Cynodon dactylon	13.32	2.2	1.17	1.88
Trachys muricata	2.05	0.33	1.1	0.3
Meremmia tridentate	-	-	0.36	-
Trichodesma indicum	-	-	1.02	-
Spilanthus radicans	-	-	0.65	-
Dipteracanthus prostrates	-	-	0.06	-
Euphorbia hirta	-	-	1.02	-
Aerva lanata	-	-	9.78	-
Cajanus scarabacoides	-	-	0.77	-
Crotalaria stipitata	-	-	1.02	-
Tephrosia purpurea	-	-	0.34	-
Cyathula prostrate	-	-	0.12	-
Brachiaria distachya	-	-	1.06	-
Sehima nervosum	-	-	1.01	-
Anthoxanthum indicum	-	-	0.45	-
Conyza bonariensis	-	-	0.02	-
Abutilon hirtum	-	-	0.23	-
Hibiscus micranthus	0.31	0.05	1.09	0.04
Corchorus tridens	-	-	0.64	-
Rothia indica	-	-	0.71	-
Emilia sonchifolia	-	-	1.1	-
Parthenium histeropherus	-	-	2.12	-
Evolvulus alsinoides	-	-	0.3	-
Total number of plant species	46			
Total number of plant species consumed	24			
Total amount of plant consumed	605.61 gm			

Note: All indices are based upon biomass. Hunter's index greater than 1 (Hi > 1) indicates preferred species. Hunter's index less than 1 (Hi < 1) indicates species whose occurrence in the diet is less than their relative availability (selectively avoided).

Sub adult star tortoises were more frequently active during the evenings. A total of 45 plant species were available to them and out of them they consumed 24 plant species. Statistical analysis with Hunter's index indicated the dietary preference of 14 plant species which were encountered using the proportion of the diet along with their taxonomic availability.

The selectively foraged species includes: *Caralluma umbellata, Blepharis maderasapatensis, Talinum portulacifolium, Commelina ensifolia, Opuntia monocantha, Opuntia vulgaris, Tridax procumbens, Sida acuta, Sida rhombifolia, Boerrhavia diffusa, Cissus quadrangularis, Ipomoea asarifolia, Apluda mutica and Cynodon dactylon.* Out of which *Cissus quadrangularis* was an opportunistic food for them. Comparing with the adult tortoises the sub adult ones specifically preferred these dietary items as their preferred food. They were more preferred to engage with eating from ground, gave more preference to the opportunistic foods. The foraging strategy was found to consist of 69.87% grazing, 21.01% opportunistic feeding and 9.12% of browsing behaviour. Human interference was found less in these animals, as they continue to forage within seconds.

Like adults, sub adults more preferably foraged *Opuntia* sp. (53.71%) along with *Tridax procumbens (9.44%)* and *Boerhavia diffusa (8.25%)* and they possess the major part of their diet (71.40%). *Cynodon dactylon* and *Apluda mutica* are the grass species selectively foraged by the sub adults.

Table 4. Vegetation availability and use by released juvenile (n=5) Geochelone elegans ranked according to Hunter's index value.

Species (i)	Mass consumed (g)	Proportion of diet (pi)	Taxonomic availability (qi)	Hunter's Index (Hi)
Caralluma umbellata	7.98	2.12	1.98	1.07
Blepharis maderasapatensis	19.12	5.09	2.54	2
Talinum portulacifolium	11.12	2.96	2.78	1.06
Commelina ensifolia	23.34	6.22	2.89	2.15
Tephrosia villosa	-	-	1.9	-

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Oldenlandiacorymbosa	0.12	0.03	0.98	0.03
Spilanthus radicans	-	-	1.02	-
Opuntia monocantha	146.32	39.01	19.05	2.04
Opuntia vulgaris	39.1	10.42	7.02	1.48
Opuntia stricta	3.67	0.97	2.14	0.45
Tridax procumbens	21.5	5.8	5.21	1.11
Sida acuta	5.89	1.64	2.32	0.7
Boerrhavia diffusa	53.02	14.13	11.32	1.24
Synedrella nodiflora	-	-	1.43	-
Urena lobata	0.96	0.25	1.5	0.16
Cissus quadrangularis	9.94	2.65	2.57	1.03
Xanthium indicum	0.21	0.02	0.7	0.02
Pentanema indicum	-	-	1.11	-
Ipomoea asarifolia	7.41	1.97	1.02	1.93
Acacia torta	1.98	0.52	0.76	0.68
Echinochloa colonum	0.3	0.08	2.09	0.03
Apluda mutica	11.7	3.12	1.09	2.86
Cynodon dactylon	9.44	2.57	1.79	1.43
Trachys muricata	-	-	1.03	-
Trichodesma indicum	0.68	0.18	0.87	0.2
Spilanthus radicans	-	-	0.78	-
Dipteracanthus prostrates	-	-	0.32	-
Euphorbia hirta	-	-	1.05	-
Aerva lanata	-	-	9.37	-
Cajanus scarabacoides	-	-	0.78	-
Crotalaria stipitata	-	-	0.9	-
Tephrosia purpurea	-	-	1	-
Cyathula prostrate	-	-	0.21	-
Brachiaria distachya-	-	-	0.38	-
Sehima nervosum	-	-	1.07	-
Anthoxanthum indicum	-	-	0.87	-
Abutilon hirtum	-	-	0.19	-
Hibiscus micranthus	1.23	0.32	1.2	0.26
Corchorus tridens	-	-	0.32	-
Rothia indica	-	-	0.2	-
Emilia sonchifolia	-	-	0.5	-
Parthenium histeropherus	-	-	2.08	-
Evolvulus alsinoides	-	-	0.9	-
Unknown species	-	-	1.26	-
Total number of plant species	44			
Total number of plant species consumed	21			
Total amount of plants consumed	375.03 gm			

Note: All indices are based upon biomass. Hunter's index greater than 1 (Hi >1) indicates preferred species. Hunter's index less than 1 (Hi < 1) indicates species whose occurrence in the diet is less than their relative availability (selectively avoided).

Table 5. Vegetation availability and use by all (n=9) Geochelone elegans individuals ranked according to Hunter's index values.

Species (i) S Species (i)(i)	Mass consumed (g) Mass consumed (g)	Proportion of diet (p Proportion of diet (pi)	Taxonomic availability (q Taxonomic availability (qi)	Hunter's Index (Hunter's Index (Hi)
Caralluma umbellata	28.13	1.52	1.52	1
Blepharis madarasaatensis	57.11	3.04	3.01	1.01
Talinum portulacifolium	61.54	3.27	2.29	1.42
Commelina ensifolia	78.25	4.16	2.23	1.86
Tephrosia villosa	11.2	0.59	2.73	0.21
Oldenlandiacorymbosa	4.14	0.22	1.22	0.18
Spilanthus radicans	1.8	0.01	0.37	0.02
Opuntia monocantha	762.54	40.6	18.9	2.14
Opuntia vulgaris	205.12	10.92	7.86	1.39

e-ISSN:2321-6190
p-ISSN:2347-2294

Opuntia stricta	32.35	1.72	2.67	0.64
Tridax procumbens	147.11	7.83	6.56	1.19
Sida acuta	46.34	2.46	1.98	1.24
Sida rhombifolia	15.17	0.8	0.25	3.2
Boerrhavia diffusa	182.83	9.73	6.43	1.51
Synedrella nodiflora	6	0.32	1.24	0.25
Urena lobata	5.75	0.3	2.17	0.14
Cissus quadrangularis	47.22	2.51	1.87	1.34
Xanthium indicum	2.04	0.11	0.75	0.14
Pentanema indicum	3.03	0.16	1	0.16
Ipomoea asarifolia	39	2.07	1.47	1.4
Acacia torta	3.68	0.19	0.72	0.26
Ipomoea obscura	0.5	0.02	0.03	0.66
Pseudarthria viscida	2.19	0.11	0.21	0.52
Echinochloa colonum	29.43	1.57	3.35	0.47
Apluda mutica	52.6	2.8	2.03	1.4
Cynodon dactylon	49.45	2.63	1.92	1.37
Trachys muricata	11.85	0.63	1.61	0.39
Meremmia tridentate	-	-	0.58	0
Trichodesma indicum	7.69	0.4	1.67	0.24
Spilanthus radicans	-	-	0.48	0
Dipteracanthus prostrates	-	-	0.39	0
Euphorbia hirta	-	-	1.02	0
Aerva lanata	-	-	9.16	0
Cajanus scarabacoides	-	-	1.01	0
Crotalaria stipitata	-	-	0.9	0
Tephrosia purpurea	-	-	0.65	0
Cyathula prostrata	-	-	0.11	0
Brachiaria distachya	-	-	0.64	0
Sehima nervosum	-	-	1.35	0
Anthoxanthum indicum	-	-	0.77	0
Conyza bonariensis	-	-	0.02	0
Abutilon hirtum	-	-	0.27	0
Hibiscus micranthus	1.54	0.08	1.01	0.08
Corchorus tridens	-	-	0.47	0
Rothia indica	-	-	0.33	0
Emilia sonchifolia	-	-	0.73	0
Parthenium histeropherus	-	-	1.8	0
Evolvulus alsinoides	-	-	0.44	0
Unknown species	-	-	0.71	0
Total number of plant species	49			
Total number of plant species consumed	29			
Total amount of plant species consumed	1878.19 g			

Note: All indices other than abundance are based upon biomass. Hunter's index greater than 1 indicates preferred species. Hunter's index less than 1 indicates species whose occurrence in the diet is less than their relative availability (selectively avoided).

Juvenile star tortoises (n=5) were more frequently active during the mornings. A total of 44 plant species were available to them and out of them they consumed 21 plant species. Statistical analysis with Hunter's index indicates the dietary preference of 12 plant species which were encountered using the proportion of the diet along with their taxonomic availability. Juveniles consumed *Opuntia* spp. in a much higher proportion (40.40%), they preferably consumed them as their main diet, along with *Boerhavia diffusa (14.3%).* Both together consumed 54.7%. Grass species possess a proportion of 5.95%. These plants possess main constituents in their diet. Succulent plants possess a higher proportion in the diet of the species. Succulent plants such as *Opuntia monocantha, Opuntia vulgaris, Ipomoea asarifolia, Blepharis maderasapatensis* and *Commelina ensifolia* constituted the 67% of the diet and predominantly constituted by the tortoises. Rest of the 33% of preferences went to the herbs and annual plants which are non-succulents.

The selectively foraged plant species by the star tortoises includes: *Caralluma umbellata, Blepharis maderasapatensis,*

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p-ISSN:2347-2294

Talinum portulacifolium, Commelina ensifolia, Opuntia monocantha, Opuntia vulgaris, Tridax procumbens, Boerrhavia diffusa, Ipomoea asarifolia, Cissus quadrangularis, Apluda mutica and Cynodon dactylon. Out of which *Cissus quadrangularis* was an opportunistic food for them. These 12 species formed a greater proportion of the tortoises' diet than their availability would predict, based on the Hunter's index. (Hunter's index) and taxonomic availability based on plant biomass (qi).

Adults consumed a slightly higher diversity of species than other age classes and also consumed higher than the sub adults, suggesting that males are slightly less selective than females. Juveniles selectively forages some species and majorly preferred them. Their foraging strategy was found 68.57% grazing, 10.43% browsing and 21% opportunistic feeding patterns.

67% of the diet plants constituted succulent plants (*Opuntia sp., Commelina ensifolia, Talinum portulacifolium*) and remaining 33% contained non-succulent plants **(Figure 1)**.

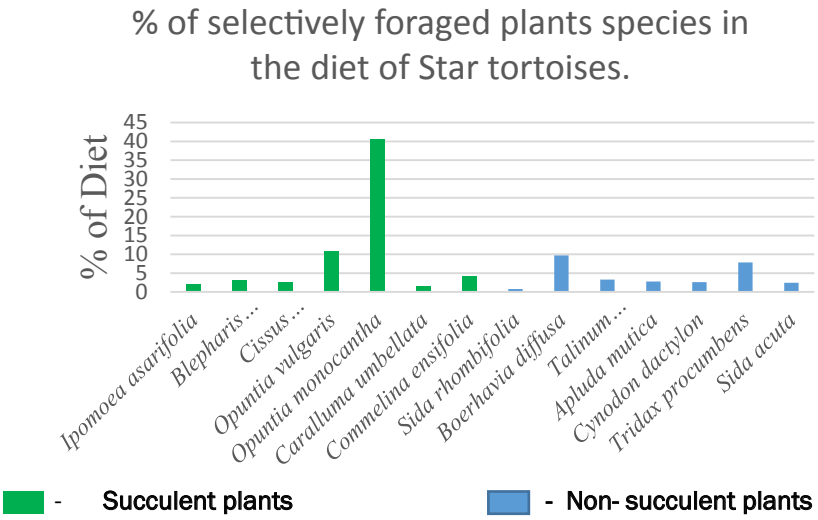

Figure 1. Diagram showing the percentage of succulent and non-succulent plants in the diet of star tortoises.

Direct Observations on the Feeding Pattern of Start Tortoises

Released and wild star tortoises were suggested for direct observations. One wild male star tortoise was found feeding on scat of wild dog. One juvenile found trying to feed snail shell, but successive feeding doesn't observe. A juvenile was also observed drinking water, when precipitation occurred. Juveniles were also observed feeding on faecal matters of other vertebrates. Two other observations were made on scavenging cactus fruit by the tortoises. Opportunistic observations of feeding tortoises were also recorded. Primary observations revealed the affinity of star tortoises on scats of carnivores such as Wild dog and leopard. In wild adult tortoises hairs were present in two of the faecal samples. One of the sub-adults was encountered while eating the dry faeces of tufted grey languor and of bonnet macaques. Both the observations were occurred during the hot period were the summer seasons began early and almost the food species began to dry.

Table 6. List of direct observations on feeding star tortoises. Abbreviations are A-adult, S-sub-adult and J-Juvenile

S No	Date	Time	Location	Id and Animal	Feeding
1	21/01/2016	17.16	Udumpuvaipura	Wild adult male	Feeding on scat of wild dog
2	1/02/2016	18.10	Chinnar	Juvenile 1	Trying to feed on snail shell
3	2/02/2016	10.34	Near watch tower	Juvenile 3	Feeding on fresh scat of wild dog.
4	6/02/2016	17.49	Chinnar	Juvenile 2	Juvenile drinking water on cactus sheath.
5	12/02/2016	10.59	Kalleduthupura	Juvenile 3	Juvenile feeding on leopard scat
6	14/02/2016	10.31	Chinnar	Sub-adult male	Feeding on languor faecal matter
7	14/02/2016	11.01	Chinnar	Sub-adult female	Feeding on macaque faecal matter
8	18/02/2016	17.02	Near koottar	Juvenile 4	Juvenile eating on dried log

DISCUSSION

The data collected during this study indicated clearly that these tortoises are not strictly herbivorous. Observations were made their consumption on small insects and faecal matter of larger vertebrates as occasional diet. It is likely that some invertebrates present on the plant material were consumed but not voluntary. Possibility of such occurring through feeding on scat and other faecal matters of higher vertebrate animals cannot be ruled out. These tortoises are strict grazers; at suitable occasions they prefer more to browse their food and also to collect food occasionally too. The concept of having cactus in very large amount in their diet could be explained satisfactorily. However, seasonal variations could change their browse, graze activities and also could change their diet preferences too. Habitat of the star tortoises was drier so in summer they more prefer for occasional feedings and cactus like fleshy foods.

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Plant matter constituted approximately 50% of the faecal sample of *Geochelone elegans.* Adults, sub-adults and juveniles were subjected for faecal analysis and all individuals faecal sample contained plant and non-plant materials. Flower parts, seed, leaf parts, bark of dried log, cactus remains, sand and insect remains were identified. Sand particles were in a higher proportion of 24.1% in wild adults, 22.2% in sub adults and 18.7% in juveniles. Sand and small stones are reported from the diet of many species of tortoises. The presence of sand in faecal samples of star tortoises may be due to accidental ingestion or consumption for the purpose of digestion. However, sand may also act as an important abrasive agent which enhances the digestion of fibrous plant material. Such plant material constitutes an important part of the diet of *G. elegans*. Omnivory and opportunistic feeding therefore seems to be characteristic for the members of the genus *Geochelone*.

The presence of insect remains in the faecal samples denotes the feeding of insects and bugs by the tortoises. But, from the direct observations it was clear that tortoises shows such behaviour of eating the faecal matter of higher vertebrates, which tends to show the nature of eating small insects. So, the presence of insect remains in the samples can be intentionally occurring through the feeding on scat. Animal matter provides an additional source of high quality protein, calcium and high sodium potassium in tortoise diets [5]. Animal matter has been previously reported to occur in the diet of some herbivorous and frugivorous tortoises [3,4,10-12]. However, the contribution of animal matter in general was observed to be lower than that of plant matter while the proportion was not significantly different between age-sex classes. Significant different in the foraging rate and in the amount of food taken was identified from the three age classes. But, apart from that there was not much difference in their selective foraging. All the individuals were selectively foraged some plant species and avoided some plants. Adult star tortoises were selectively foraged on 13 plant species, 14 species were selectively foraged by sub-adults and 12 species foraged by the juveniles according to the Hunter's Index. Out of the 49 species available to them a total of 29 plants were identified consumed by all the individuals. Adults consumed 27 plants, sub-adults 24 plants and juveniles consumed 21 plant species respectively.

Hunter's index confirms that *G. elegans* is a selective forager. The results of the analysis support the statement that star tortoises do not simply selectively forage those plant species that are present in high biomass or high abundance. Of the 9 plant species available at highest biomass (*O. monocantha, O. vulgaris, B. diffusa, T. procumbens, T. portulacifolium, B. maderasapatensis, E. colonum, A. mutica and A. lanata*), all except 2 species (*B. maderasapatensis and A. lanata*) was specifically preferred (above their relative biomass) by the wild adult star tortoises **(Table 4)**. Of the 8 most abundant species (*O. monocantha, O. vulgaris, B. maderasapatensis, T. porcumbens, B. diffusa, A. lanata, C. quadrangularis and C. ensifolia),* all except one species *(T. procumbens*) only 1 was avoided (*Aerva lanata*) by the released sub-juveniles **(Table 5)**. Of the 8 plant species available for juveniles, (*O. monocantha, O. vulgaris, B. maderasapatensis, T. porcumbens, B. diffusa, A. lanata, C. quadrangularis and C. ensifolia),* all except one species *(A. lanata)* were preferentially (above their relative biomass) consumed by the released juveniles. With the exception of *S. rhombifolia,* which exhibits less taxonomic availability and abundance **(Table 6)**, each selectively foraged species contributed less than 2% of the overall biomass and plant species abundance. Factors other than biomass availability and individual abundance determine food selection.

In general, it is more energetically expensive to feed upon large numbers of small nutrient-poor plant species than larger nutrient-rich ones, providing that energetic output while feeding is similar. Whether this is actually the case for the population of *Geochelone elegans* is dependent on the biochemistry of the plant species. However, biochemical information is lacking for the majority of plant species recorded during this study. Of the 14 selectively foraged plant species, *Sida sp. (Sida acuta* and *Sida rhombifolia)* was the most preferred (having the highest Hunter's index) overall. Why this species was selectively foraged? It has a high energetic value and has an above average energy conversion rate. Its high energy conversion rate may be the factor that makes it one of only 2 species selectively foraged by adult, sub-adult and juvenile tortoises. *Opuntia sp.* along with *Boerhavia diffusa* was the most preferred by all three categories. *Opuntia* species provides a large and succulent energy-rich fruit. Star tortoises which inhabits in the xeric conditions are adapted to forage on the Xerophyte plants such as cactus species and other succulents. Due to the dry nature of the environment it was clear that they are less accessible to gain water reservoirs. As an adaptation they could withdraw water from fleshy stems or other parts of plants. Succulent plants such as *Opuntia monocantha, Opuntia vulgaris, Ipomoea asarifolia, Blepharis maderasapatensis* and *Commelina ensifolia* constituted the 67% of the diet and predominantly constituted by the tortoises. Rest of the 33% of preferences went to the herbs and annual plants which are non-succulents. Wild adults found foraged on various plant species even among them was not selectively consumable, but they tried to eat. But the released individuals showed the affinity to consume more on their main dietary items which were predominantly provided to them at the time of housing. Slight variations were also noted on the response to the disturbances. Wild star tortoises were more alert comparing to the released ones. Even a slight noise made them alert and for a while they remained in the shell, but, sub adults and juveniles were less cared about the disturbances and come out quick even after withdrawing in to the shell.

CONCLUSION

Direct observations were an absolute method which could further explain the feeding and foraging behaviour of an animal. In several occasions it was noted that most of the individuals were fed on faecal matters of the higher vertebrates such as; Leopard, wild dog, Macaque, and of Languor. This attribute shows that it satisfying the nutrition requirements through eating the digested carnivorous or omnivorous food, and they can sufficiently provide calcium, potassium mineral requirements. Feeding on fruits and fleshy leaves and stems are their only possible ways to acquire required amount of water. It was an interesting

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observation that one juvenile found drinking water when small amount of precipitation occurred. The affinity of the land tortoises to active during precipitation and to drink water while it less available was revealed. The lack of water availability in their inhabited areas was forced them to drink water directly. But, previous studies have already proven that the advanced tortoises cannot take the foods from the water [12-34].

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