ORIGINAL ARTICLE

Asian Herpetological Research 2021, 12(3): 323–330
DOI: 10.16373/j.cnki.ahr.200107

Diet of Juvenile *Crocodylus porosus* at Kuching Wetlands National Park, Sarawak, East Malaysia

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Abstract The diet of juvenile, including hatchlings and presumed yearlings of the Saltwater Crocodile, *Crocodylus porosus*, was studied at the Kuching Wetlands National Park, western Sarawak, East Malaysia (Borneo), using both frequency of occurrence and volumetric composition of diet through the stomach flushing technique. Crustaceans form the primary component of the diet of juvenile crocodiles, comprising shrimps of the family Atyidae (*Caridina* sp., and *Penaeus indicus*), occurring in the stomach of 17 individuals (53% by occurrence). An estimated 91.7% of hatchlings stomach-flushed had shrimps, and the emergence of hatchlings may be associated by inland migration of its shellfish prey, as reported in the literature. The secondary food item of hatchlings and presumed yearlings was ocypodid crabs, occurring in 16 individuals (in addition to a subadult), and comprise 47%–50% by occurrence. Other items taken incidentally include rodents (in large yearlings, exceeding 100 cm in total length), and fish (in seven hatchlings and in one subadult), or in 29% of total individuals captured (47.7% in hatchlings and 15% in yearlings). A dietary change in ontogeny is therefore evident, as reported earlier in crocodilians.

Keywords saltwater crocodile, *Crocodylus porosus*, food, ecology, Borneo

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Received: 14 June 2020 Accepted: 19 January 2021

1. Introduction

The diet of the Saltwater Crocodile, *Crocodylus porosus*, is known to vary with habitat type, size, and age (Taylor, 1979). Yearling crocodiles in tidal rivers eat small mud crabs, prawns, and insects during the dry season, but predominantly consume insects during the wet season (Grenard, 1991). Juveniles in freshwater environments feed mainly on insects, while larger individuals (≥ 2 m) in tidal waters continue to eat crabs, fish and prawns, as well as small birds, aquatic reptiles (including turtles), rodents, and other mammals that venture to the water's edge (Webb *et al.*, 1982).

Among crustacean prey, ocypodid crabs and atyid prawns are frequently consumed, especially in mangrove habitats (Webb *et al.*, 1991; Shahrul and Stuebing, 1996). Unlike fishes, crabs and other aquatic macroinvertebrates, mammals and birds are typically found sporadically in or next to water, and crocodiles appear to search for sites of prey concentration, such as under trees hosting a flying fox colony or spots where herds of water buffaloes habitually feed (Bayliss *et al.*, 1986). Subadult crocodiles weighing 8.7–15.8 kg and measuring 1.36–1.79 m in length have been recorded killing and eating goats (*Capra aegagrus hircus*), weighing 50%–92% of body mass in Odisha State, eastern India, so are capable of attacking large prey from an early age (Webb and Manolis, 1991). The diet of early stages has been summarized to be more diverse than adults, which often ignore prey below a certain size (Magnusson, 2017).

There has been no studies focusing on the diet of crocodilians in Sarawak, and during the course of a wider investigation on the spatial ecology of *Crocodylus porosus* at the Kuching Wetlands National Park, between 2011–2012, data on the diet of juveniles were collected via stomach flushing. The intention of the study was to document the diet of this population in

western Borneo, and to compare with the only other similar regional study, made in Sabah State, northern Borneo (Shahrul and Stuebing, 1996).

2. Materials and Methods

2.1. Study Area Kuching Wetlands National Park (KWNP) is located in Kuching Division, ca. 15 km to the northwest of Kuching City. It was gazetted as Sarawak's 15th National Park, under the National Parks and Nature Reserves Ordinance 1998, in 2002. The Park is located between two main rivers, the Sungei Sibu to the west and Batang Salak in the east. To the south, the boundary of the KWNP runs close and nearly parallel to the Kuching-Matang-Lundu Road. The stretches between the southern boundary and the main road had mostly been taken up by settlements and other development projects. The northern boundary of the area is demarcated by Sungei Loba Kelong, which cuts through the region from west to the eastern part and flows into Batang Salak via Loba Belanga and Muara Gelugor. General descriptions of the site are in Beavitt and Tuen (2010) and Soo *et al.* (2015).

The climate in KWNP is moderately warm, at 20–23°C, and the area receives a substantial amount of rainfall of 3800 to 4000 mm per year (Anonymous 2009). The wettest periods are during the Northeast Monsoons, in the months of November to February, where floods usually occur and a number of low-lying small islands within the Park are partially inundated.

The habitat consists predominantly of mangrove forests, a mixture of *Sonneratia alba* that occurs along river bank, deltas and estuaries, *Rhizophora apiculata*, *Xylocarpus granatum*, *Avicenia alba*, and *Nypa fructicans* interspersed with numerous rivers and deltas, that inundate most of the area during high tide. There are patches of Kerangas (Bornean heath) forests towards the center of the Park, particularly the Pulau Liak area, which are not affected by high tide or flood.

2.2. Field Techniques The diet of the target species was determined from 32 small individuals, caught between 5 May 2011 and 13 November 2012 (Appendix I), representing hatchlings and presumed yearlings, that were captured by the use of cast and scoop nets during the surveys. Individuals were measured (with a measuring tape) for total length (TL), snout-vent length (SVL: snout tip to anterior edge of cloaca), and body weight was recorded; sex was determined by observation of the spreading the cloacae carefully with fingers, to examine the genital morphology, following the technique of Webb *et al.* (1984). Individuals under 60 cm were treated as hatchlings, while presumed yearlings were in the size-range 60–120 cm. All captured crocodiles were tagged using serial-numbered, plastic floy-T-shaped tags attached to the dorsal part of the tail before release for subsequent identification.

2.3. Stomach Flushing Technique To analyze stomach contents of captured individuals, the stomach flushing technique, using the hose-and-Heimlich method, was employed, as described by Fritzgerald (1989); see also, Webb *et al.* (1991) and Shahrul and Stuebing (1996). The method involves insertion of a hose down the esophagus and into the stomachs within 4–6 hours of capture. The other end of the hose was connected to a water pump to gently fill up the crocodile stomach with water. With the hose still in place with running water, the abdominal region was squeezed towards the spine and forward, in a motion analogous to the Heimlich manoeuvre. A mixture of stomach contents and water was expelled, which was sifted by using a piece of fine nylon material to separate the water and the dietary items. The procedure was repeated several times until only water free of stomach contents was obtained. The mixture of stomach contents from each individual was kept in plastic containers, sorted, weighed and identified to the lowest possible taxonomic category with the help of magnifying glass. The sorted stomach contents were then preserved in 70% ethanol or in 10% formalin for further analysis in the lab, under an Olympus™ SZX dissecting microscope. Individuals were tagged and released into its habitat after data, such as snout length, head length, body weight, and when possible, sex, were recorded. Stomach contents were classified and analyzed as dietary remains, incidentally ingested items, and internal parasites. Both frequency of occurrence and volumetric estimation were computed to quantify crocodilian diet. Because certain body parts (e.g., bone, muscles, and shells) and digested more rapidly than others (such as chitins, scales, and hair) in crocodile stomachs (see Platt *et al.* 2013), variations in results in comparisons of the two methods are expected.

3. Results

A total of 32 small individuals, of the size range (total length) 33.6–135.5 cm of *Crocodylus porosus* were examined for diet at KWNP.

Crustaceans (crabs and shrimps) were the most frequently recovered food, encountered in the stomachs of all (32) hatchlings (< 60 cm in total length) and yearlings (60–120 cm in total length) (Table 1). Atyid shrimps (*Caridina* sp.) were the most common crustacean among food items, found in 17 individuals, while ocypodid crabs, consisting almost exclusively of individuals of the genus *Scylla* (likely, *olivacea* or *tranquebarica*) were recorded from the stomachs of 15 juveniles (hatchlings and yearlings). In terms of volume, ocypodid crabs comprised 89.8 mL of food, occupying 23% of the total stomach contents, while atyid shrimps composed 23.6 mL or 6.05% of diet.

Small shrimps, likely to be of *Caridina* sp., are relatively plentiful during the night surveys in November to February

at KWNP, suggested by the large numbers demonstrating an aerial 'jump', a behavior in response to the use of spotlights during these surveys. *Penaeus indicus* was also found to comprise a major part of the diet of hatchlings captured in the Park.

Vertebrates, consisting mainly mammals (rodents) and fishes of the family Hemiramphidae or Engraulidae, were the second-most frequently-observed food item. Of a total of 18 mammalian remains in the stomachs of juvenile crocodiles, 10 were strands of hair, cranial remains and mandibles of rodents, probably of rats (Muridae), likely of *Rattus* sp. In terms of volume, it is the highest quantity (263.40 mL) of food items consumed by juveniles, particularly yearling. The figure comprises of 67.47% of the food items of yearling crocodiles (Table 1). Fish, almost entirely comprising species belonging to the family Engraulidae, were found in seven juveniles, mostly that of hatchlings. Fish remains were discovered in seven (or eight, if a subadult is included) individuals, or 29% of the total individuals captured (47.7% in hatchlings and 15% in yearlings). As all fish recovered were small, the category formed 0.97% of total food items, by volume, in juvenile crocodiles. Remains of a skink, *Eutropis* sp. were found in one of the juveniles (volumetrically, 1.9 mL), and forms 0.47% of the diet (Table 1).

Insects, of the family Formicidae (ants) and species under subclass Orthoptera (grasshoppers), were encountered twice. Insect consisted less than 0.5 mL, by volume, and formed about 0.03% of its diet, while the total volume of nematodes in eight individual juveniles was 4.9 mL or 1.26% of stomach contents. Plant remains, on the other hand, were commonly found in stomachs (18 individuals), although total volume was relatively small (2.4 mL). These comprised leaves, woody parts of stems and a seed, although no identifiable remains of fruits were found.

Among non-dietary items occasionally reported from crocodilian stomach are stones, referred to as 'gastroliths' (Wings, 2007). However, in the present study, no stones were found in stomach contents of juvenile crocodiles. At least two morphotypes of nematodes were found in eight hatchlings and yearlings.

In terms of percentage, 91.7% of the captured hatchlings (total number captured, n = 12) were found to have consumed shrimps, 50% crabs, 41.7% fishes, and 8.3% insects (Table 2). Plant materials, such as leaves, small twigs and bark, were discovered in 83.3% of hatchlings, while at least two nematodes were found in 16.7% of this size-class (Table S1). No remains of vertebrates or snails were found in hatchling stomachs.

In comparison, only 40% of yearlings (total number captured, n = 20, inclusive of one young juvenile) contained shrimps, 50% had crabs, 15.0% fish, 50% had remains (cranium, mandible and hair-balls) of small mammals, likely that of murid rats, 5% each had skinks and snails (Table 2). Plant materials, such as leaves, small twigs and bark also formed part of its stomach contents, found in 40% of yearlings, while at least two morphotypes of nematodes were found in 30% of yearlings. Food items in the stomach samples of hatchlings (H) and yearlings (Y) in KWNP are shown in Figure 1.

Plant remains were found in 18 (56%) of total individuals examined, and 83.3% by occurrence among hatchlings and 40% among yearlings.

4. Discussion

Crustaceans are the major food category of juvenile crocodiles at the study site, comprising shrimps of the family Atyidae (*Caridina* sp., and *Penaeus indicus*). Stuebing *et al.* (1985) reported that in Batang Lupar, further east, also in Sarawak State, juvenile *C. porosus* feeds on *Penaeus*, while (Stuebing *et al.*, 1992) reported that in the Klias River, Sabah State, only *Caridina* is consumed.

The relatively high prevalence of shrimps in the diet of hatchlings may be an environmental cue that regulates breeding cycles in crocodilians at KWNP and in surrounding areas. Chong (1980) found that in Peninsular Malaysia, large numbers of shrimps emigrate from the sea into shallow coastal estuaries, beginning March to June, with its peak noted during the Northeast Monsoons, between November and December. The synchronous emergence of crocodile hatchlings during the period may thus be related to the inland migration of shrimps (their dietary mainstay). Jongkar *et al.* (2009) listed four species of *Penaeus* (*P. indicus*, *merguensis*, *monodon*, and *pennicilatus*) from the region.

The second most frequently taken dietary item of hatchlings and yearlings is ocypodid crabs, which occurred in 16 individuals, and comprise 47%–50% by occurrence. This is in contrast to the findings of Taylor (1979) in Australia, where insects, apart from ocypodid crabs, were commonly eaten by juveniles inhabiting the lower and upper mangrove areas. Stuebing *et al.* (1985), however, stated that crocodiles are opportunistic feeders and are adept at exploiting local 'blooms' of prey, and the situation seemed to be applicable to the study area, where atyid shrimps and ocypodid crabs appear plentiful during the sampling period. Unlike the results of Taylor (1979), no *Macrobrachium* species was represented in dietary samples in the present study.

Rodents of the family Muridae, were the third-most common food item preferred by juveniles, particularly the larger yearlings. These were evidenced by the remains of hair-ball and parts of cranium and mandibles of rats, exclusively found in stomachs of larger yearlings of total length over 100 cm. Presumably, they become prey when foraging or drinking at the water's edge. Rats, however, did not seemed to be part of

Table 1 Stomach contents of hatchling and yearling *Crocodylus porosus* (n = 32) from Kuching Wetlands National Park, Sarawak.

Species	Frequency of occurrence		Volume (mL)	
	Total	(%)	Total	(%)
Crustacea	32	100		
Ocypodidae	15	47	89.8	23
Atyidae (*Caridina* sp.)	17	53	23.6	6.05
Total	32	100		
Mollusca	1	3		
Potamidae (*Cerithidea* sp.)	1	3	0.1	0.03
Insecta	2	6		
Hymenoptera				
Formicidae	1	3	0.5	0.03
Orthoptera	1	3		
Total	2	6		
Vertebrata	18	56		
Mammalia				
Muridae	10	31	263.4	67.47
Reptilia				
Scincidae	1	3	1.9	0.47
Pisces				
Engraulidae	7	29	3.8	0.97
Hemiramphidae				
Total	18	56		
Parasites (nematodes)	8	25	4.9	1.26
Plant remains	18	56	2.4	0.61

Table 2 Percentage frequency of occurrence of stomach content categories of hatchling (H) and yearling (Y) *Crocodylus porosus* at Kuching Wetlands National Park, Sarawak.

Food items	H%	Y%
Shrimp	91.7	40
Crab	50	50
Fish	41.7	15
Insect	8.3	0
Rat	0	50
Skink	0	5
Snail	0	5
Plant	83.3	40
Parasite	16.7	30

the diet of smaller yearlings and hatchlings, probably due to the fact they may not be strong or adept enough to capture them, or that hatchling may not forage in areas far from water.

'Ikan Pusu' (or local anchovies), a species from the family Engraulidae (comprising nine genera and about 32 species in Malaysia alone), were the most common fish in the diet of hatchlings and some yearlings. These small fish (< 60 mm) are surface feeders in shallow waters, and are common in estuarine and mangrove habitats. Jongkar *et al.* (2009) recorded six species of the family in the region. The aforementioned appears

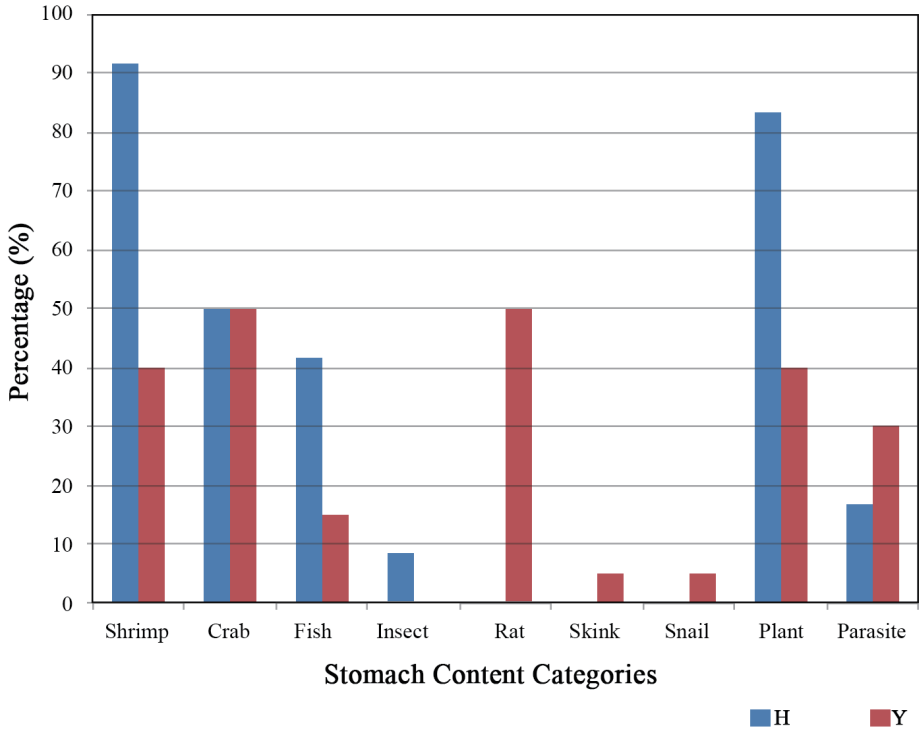

Figure 1 Comparison on types of food items among hatchlings (H) and yearlings (Y) of *Crocodylus porosus* at the Kuching Wetlands National Park, Sarawak.

to differ from observations reported by Stuebing and Shahrul (1992) in the Klias River, Sabah where 'halfbeaked' fish of the family Hemiramphidae (genus *Dermogenys*), locally known as 'Ikan Jolong-jolong', were abundant in habitats frequented by the juveniles. Taylor (1979) found no fish eaten by juvenile crocodiles in northern Australia, and suggested that other larger vertebrates are important in the diet of *C. porosus* of more than 120 cm total length. Platt *et al.* (2006) generalized a bimodal ontogenetic shift, with the broadening of the cranium, once body size exceeds 60 cm. With the increase in body size, the ingestion of arthropods decline strongly, apparently compensated by the consumption of fish and other small vertebrates.

All 32 hatchlings and yearlings contained shrimps and crabs, the figure similar to that reported from Klias, in Sabah, northeast of the present study locality, where over 90% of the diet of hatchlings comprised shrimps (Stuebing and Sharul, 1992). The low prevalence of mammals (and birds) in the diet of the crocodilians suggest that they were consumed rather opportunistically by larger crocodiles (Platt *et al.*, 2006), and this seemed to be consistent with the recovered diet of juveniles at the present study site, where remains of small mammal were found in 10 yearlings, which formed 50% by occurrence and 31% for overall occurrence. Platt *et al.* (2006b), in his study on *C. moreletii* in Belize, central America, found that with increasing mass, there was an associated increase in prey species richness and significant declines in realized dietary niche, dietary breadth, and mean number of prey items. Individual-level analyses showed that larger yearlings of *C. porosus* were generalist feeders, having greater diversity of food intake in terms of species, where several food items were found in stomachs. These included crabs, rodents, fishes, shrimps, lizards, and also gastropods, while subadults and adults are said to be specialized on particular prey items, and there was no significant change in dietary diversity, evenness, or number of equally common prey species (Taylor, 1979). This, of course, could be the subject of future research on the crocodile population at the present site. Further, there being little in the literature on relative rates of digestion of prey of different taxonomic groups in crocodilians, any conclusions on dietary preference need to be made with caution.

Webb *et al.* (1982), in his Australian study, found plant remains in 40% of stomachs of *C. johnstoni*, and suggested that ingestion may have been intentional. In the present study, juvenile crocodiles, especially hatchlings may have inadvertently swallowed plant debris, which were found in abundance in rivers. Similar result were reported by Stuebing and Shahrul (1996) in their study in Klias River, where as many as 75% of

juvenile stomachs contained plant remains. Platt *et al.* (2013a) presented evidence of frugivory in 13 of 18 crocodilian species, indicating this behavior is widespread among the group. Nonetheless, the importance of plant matter as a component of crocodile diet, and the potential ecological significance of the same (including seed dispersal), remain poorly understood.

Nematode worms were found in eight (25%) of the total samples (16.7% occurrence in hatchlings and 30% among yearlings), while incidence of parasitism in the Klias was low (Stuebing and Shahrul, 1996). The present data suggest that parasitism are not a freshwater phenomenon, but may also occur in estuarine habitats, such as areas and rivers in KWNP. The route of infected remain unclear, and parasites may be ingested along with food items, particularly, from small mammals or reptiles. The occurrence of parasites was high among yearlings (30%) that fed on rats, compared to hatchlings, which did not ingest this food category.

That no gastrolyths were found in stomachs examined at the present study area is consistent with the condition of the river bed, which is composed entirely of fine sand and mud. Similar results were reported by Stuebing and Shahrul (1996) from their samples from the Klias, and by Taylor (1979) in tidal rivers in Australia, as compared to the freshwater-obligate *C. johnstoni* in northern Australia, where as much as 88% of the stomach samples contained gastrolyths (Webb *et al.*, 1982).

The current study reports the diet of hatchlings and yearlings of *Crocodylus porosus* at the Kuching Wetlands National Park, Sarawak, employing the stomach flushing technique. Crustaceans, including shrimps (family Atyidae) were found in the stomachs of over half the individuals examined, and it is speculated that hatchling emergence may be associated with inland migration of its shellfish prey. Other dietary items include ocypodid crabs, rodents and fish. No gastrolyths were found in the present study area, presumably as the river bed comprised of fine sand and mud.

Acknowledgments We thank Andrew Alek Tuen, former Director and other staff of the Institute of Biodiversity and Environmental Conservation, for support of our research; and Jongkar Grinang for his help with identification of crustaceans and fish remains in dietary samples. Pui Yong Min assisted with the preparation of the text figure. Former Directors of the Sarawak Forest Department, Datu Haji Len Taliff Salleh, Datu Haji Ali bin Yusop and Tuan Haji Sapuan Ahmad approved and supported the project. The Ministry of Natural Resources and Environment, Malaysia provided financial support to the project, particularly for acquisition of field equipment, which included outboard engine, fuel and field staff costs. Micheal Tupong, Nixon Grang, Dayang Nuriza, Nur Afiza, Chombi, Rodgers, Munau Jawa, Mohidin Morni, Ramon Tuton, Kuye, Latiff Lay, Sam Akhbar Jobeli, Jeffri, Wan, Hossen, and Goswin assisted in the field. Two anonymous reviewers improved the manuscript through their comments. We extend our thanks to villagers in the vicinity of the study site, particularly Abol of Telaga Air and Sudin and family of Kampung Salak, who provided us a place to stay and for assistance during field work, and finally, to Bujang Abong and sons of Kampung Bako for helping with crocodile capture.

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Handling Editor: Heling Zhao

How to cite this article:

Lading E., Das I. Diet of Juvenile *Crocodylus porosus* at Kuching Wetlands National Park, Sarawak, East Malaysia. Asian Herpetol Res, 2021, 12(3): 323–330. DOI: 10.16373/j.cnki.ahr.200107

Appendix

Table S1 Types of stomach contents of hatchling (H) and yearling (Y) *Crocodylus porosus* in Kuching Wetlands National Park, Sarawak.

Date	Tag number	Size class	Total length (cm)	Stomach contents
5 May 2011	MYSA 0013	H	40.7	shrimp, plant
2 February 2012	MYSA 0014	H	35.6	shrimp, crab
17 April 2012	MYSA 0015	H	42.0	crab, parasite (nematode), plant
18 April 2012	MYSA 0016	H	39.7	crab, shrimp, fish, plant
19 April 2012	MYSA 0017	Y	94.1	fish, plant
26 April 2012	MYSA 0018	H	34.4	fish, shrimp, plant
6 November 2012	MYSA 0024	Y	75.6	shrimp, plant
10 November 2012	MYSA 0025	Y	69.5	shrimp
10 November 2012	MYSA 0026	Y	68.2	shrimp
11 November 2012	MYSA 0027	Y	92.0	skink, crab, shrimp, fish, parasite (nematode), plant
11 November 2012	MYSA 0028	Y	103.4	crab, shrimp, parasite (nematode), plant
11 November 2012	MYSA 0029	Y	65.0	shrimp
11 November 2012	MYSA 0030	Y	77.1	shrimp, fish
11 November 2012	MYSA 0031	H	56.6	shrimp, crab
11 November 2012	MYSA 0032	H	42.0	shrimp, plant
11 November 2012	MYSA 0033	Y	88.4	crabs, rat
11 November 2012	MYSA 0034	Y	102.3	crabs, snail, parasite (nematode), rat
11 November 2012	MYSA 0035	Y	75.1	shrimp, rat, plant
12 November 2012	MYSA 0036	Y	71.5	crab
12 November 2012	MYSA 0037	Y	97.0	rat, plant
12 November 2012	MYSA 0038	Y	113.7	rat, plant
12 November 2012	MYSA 0039	Y	99.5	crab, rat
12 November 2012	MYSA 0040	H	47.0	shrimp, fish, parasite (nematode), plant
12 November 2012	MYSA 0041	H	33.6	shrimp, fish, plant
12 November 2012	MYSA 0042	H	35.3	shrimp, plant
13 November 2012	MYSA 0043	SA	135.5	crab, plant
13 November 2012	MYSA 0044	Y	117.9	crab, rat, parasite (nematode)
13 November 2012	MYSA 0045	Y	112.9	crab, rat
13 November 2012	MYSA 0046	Y	73.3	rat, parasite (nematode)
13 November 2012	MYSA 0047	Y	88.1	crab, rat, parasite (nematode), plant
13 November 2012	MYSA 0048	H	55.0	shrimp, crab, fish, plant
13 November 2012	MYSA 0049	H	38.6	shrimp, crab, insect, plant