TRACKING THE MOVEMENT OF MUD CRABS, GENUS *SCYLLA* FROM MANGROVE AREA USING TELEMETRY SYSTEM

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ABSTRACT. *The study was conducted to determine the movement of mud crabs, genus Scylla, within three sites in Sematan mangrove forest, Sarawak, Malaysia. 10 crabs were tagged using ultrasonic tags attached to the mid-dorsal carapace surface of each crab. Four tagged crabs were released to the small mangrove channel, another four tagged crabs were released to the main estuary channel and the other two crabs were released to the mouth of the estuary. The hydrophone system and portable Global Positioning System (GPS) on board the tracking boat were used to track the crabs' locations. Date of release, tracking time, duration of tracking, distance travelled by the tagged crabs, weather conditions and water current direction were among the parameters recorded during the tracking study. Three tagged crabs remained within the small mangrove channel, three tagged crabs remained within the main estuary channel and only one tagged crab remained in the estuary mouth. Tagged crabs remained in the small mangrove channel more than 173 hours but those in the main estuary channel and estuary mouth are a remained for more than 48 hours. Only one crab covered a much greater distance than the other nine tagged crabs, moving a total distance of 2,600 m within 48 hours monitoring. The mean ground speed of the tracked crabs in the small mangrove channel was slower than in the main estuary channel and estuary mouth. The mean ground speed ranged from 0.2 to 3.8 $m.h^{-1}$ in the small mangrove channel and from 15.2 to 54.2 $m.h^{-1}$, both in the estuary channel and estuary mouth. 390 crab movements were recorded of which 157 (40.3%) crabs moved with the current and 233 (59.7%) crabs moved against the current with 32.45 $m.h^{-1}$ mean ground speed. From the half an hour and hourly interval monitoring, the crabs were mainly active at night with the mean distance travelled being 808.3 m and mean ground speed 44.7 $m.h^{-1}$. During day time, the mean distance travelled was 482.8 m and ground speed 20.7 $m.h^{-1}$. No continuous movement was recorded even though the crabs were active at night especially from midnight till sunrise. The direction of travel was not straight with the straightness index range from 0.2 to 0.3 except for one crab which moved nearly in a straight line with a straightness index of 0.9.*

KEYWORDS. Telemetry system, ultrasonic tag, movement, mud crab, genus *Scylla*.

INTRODUCTION

In the past, marine animal tagging was limited to placing a plastic or metal tag with a number on it on or in an animal. These tags only provided basic information about the biology of the animals and very little about the environment in which they live and swim. Most of the studies done on the movement of mud crabs were based upon mark, release and recapture of tagged crabs (Hill *et al.,* 1982; Hyland *et al.,* 1984). Other studies were done to determine the spawning migration movement of the crabs by recording the total daily catch of commercial fishermen (Heasman *et al.,* 1985; Hill, 1994). The only study of mud crabs using ultrasonic telemetry was done by Hill, (1978), in Kowie estuary, South Africa using *Scylla serrata* species, which dominated the estuary, and not on the other three *Scylla* species. Since then the equipment has improved both by becoming smaller and by allowing greater transmission distances.

Ultrasonic telemetry was used in this study to investigate the movement of two mud crab species, *Scylla tranquebarica* and *Scylla olivacea*. These two species dominate the Sematan estuary, where the study site was located (Ikhwanuddin *et al*., 2011). The study aimed to determine the movement of the two species within the small mangrove channel and the main estuary channel. This then led to an attempt to assess the territoriality and the feeding activity of these two *Scylla* species.

MATERIALS AND METHODS

Study site

The study was done in the Sematan mangrove forest, Sarawak, with an estimated total area of 1,735 ha (Figure 1). The Sematan mangrove forest is located at the most western part of Sarawak, facing the coastal waters of the South China Sea (1°48'N; 109°46'E). The main channel of the Sematan estuary opens to the South China Sea and is about 5 km long before the Sematan River divides into the Sebako River and Serayan River. The study was carried out within two sites: the main channel and the mangrove channel. The first site was located within the Sematan estuary main channel (Figure 2). The second site was the Tanjung Beluku River, a small mangrove channel within the Sematan River (Figure 2).

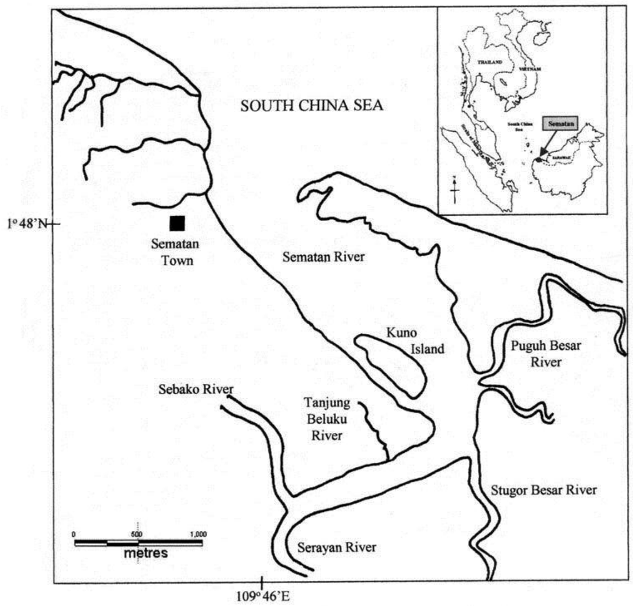

Figure 1. The study site of Sematan mangrove forest which is located at the most western part of Sarawak, Malaysia facing the coastal waters of South China Sea.

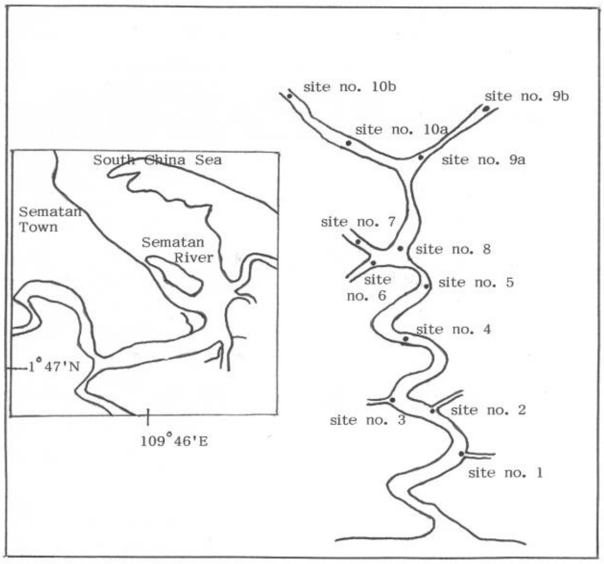

Figure 2. The two study sites within the Sematan mangrove forest. The first site was located within the Sematan estuary main channel and the second site was the Tanjung Beluku River, a small mangrove channel within the Sematan River.

Crab sample
The study was limited to adult crabs because of the size of the tags and the objectives of the study. All crab samples used in the tracking activities except for crab no. 7 were caught from the study site using baited collapsible crab traps. Crab no. 7, which was bought from the crab pen project nearby, was the only berried female used. The details of the crab samples are shown in Table 1. The collapsible traps were 16cm high made of a rectangular steel frame, 50 x 30cm, covered with 25mm mesh size nylon net. The trap had two entrance funnels with maximum opening of 15cm length at opposite ends. The traps were of the same type commonly used by the local crab fishermen in Sematan. Chopped fish (usually small shark or stingray) were placed in the centre of the trap as bait. After capture an ultrasonic tag was attached to the crab, which was returned to the capture site within a few hours.

Table 1. Size, sex and species of crabs used and the tracking study site.

Study site*	Crab no.	Ultrasonic tag freq. (KHz)	Carapace width (cm)	Sex	Species	Maturity condition
SMC	1	73	11.7	Male	*S. olivacea*	Mature
SMC	2	70	12.2	Male	*S. olivacea*	Mature
SMC	3	71	15.1	Female	*S. paramamosain*	Mature
SMC	4	72	12.5	Female	*S. tranquebarica*	Mature
MEC	5	73	12.9	Female	*S. tranquebarica*	Mature
MEC	6	69	10.8	Female	*S. tranquebarica*	Mature
MEC	7	69	12.1	Female	*S. tranquebarica*	Berried
MEC	8	71	11.2	Female	*S. olivacea*	Mature
EM	9	72	11.7	Female	*S. tranquebarica*	Mature
EM	10	73	14.0	Female	*S. tranquebarica*	Mature

**SMC=Small mangrove channel; MEC=Main estuary channel; EM=Estuary mouth.*

Maturity condition
Female crabs that had undergone the pubertal (or maturity) moult with the accompanying widening and darkening of the abdomen were classified as mature females (Arriola, 1940; Ikhwanuddin *et al*., 2010 and Ikhwanuddin *et al*., 2011). All other females were recorded as immature. Male maturity could not be determined from external characteristics. However the first pair of walking legs of all male crab samples was examined for mating scars which only occur in mature males (Perrine, 1978; Ikhwanuddin *et al*., 2011). These scars are formed by the rubbing of the female carapace on the legs of the male during the pre-copulatory embrace.

Tracking system
The telemetry system equipment was supplied by Sonotronics, Tucson, Arizon, USA. A tag, receiver and hydrophone form the basic system. The ultrasonic tag (IT-95-2 model) emits a pulse signal between 1 and 2 pulses per second at a frequency between 69 and 83 KHz. Each tag has its own individual frequency permitting identification of individual tags. The tag is housed in a plastic cylinder, 45-mm length and 14-mm diameter, weighing 5 gm in seawater with a 12 months predicted lifetime. The tag has a transmission range up to 1,000 meters in open water. The receiving system consisted of a directional hydrophone (DH-2 model), an ultrasonic receiver (USR-90 model), 10 feet of coaxial cable (connected from the hydrophones to the receiver) and a stereo headphone (connected to the receiver). The receiver was a narrow band-scanning receiver with a directional hydrophone, which provides directional information from the volume of the signal.

Telemetry system field trial
In order to test the efficiency of the telemetry ultrasonic transmission, a field trial was made in the main estuary channel of the study site. The ultrasonic tag was placed 3.5m deep on the river bottom near the main channel bank. The hydrophone was placed 0.5m deep from the water surface and 5m away (water surface distance) from the ultrasonic tag (Figure 3). The hydrophone was also placed 0.5m deep from water surface but this time directly on top of the ultrasonic tag (Figure 3). The pulse signal from the ultrasonic tag was assessed from these two positions by increasing and decreasing the gain of the hydrophone amplifier.

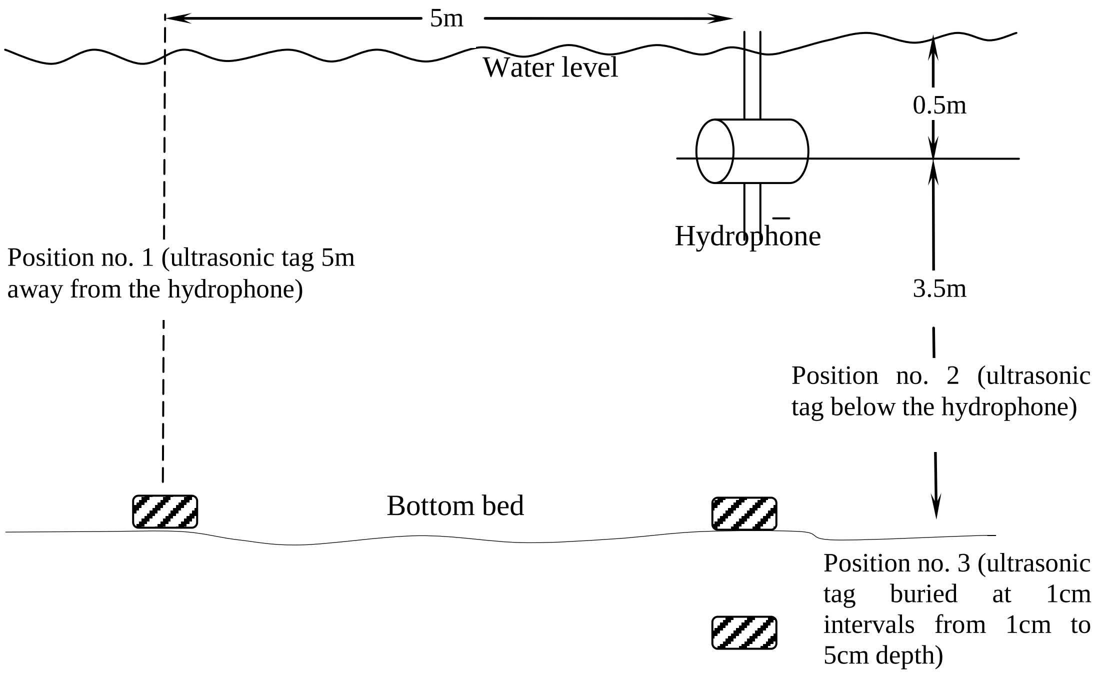

Figure 3. The position of the hydrophone from the ultrasonic tag during the telemetry system field trial.

S. serrata construct burrows in the intertidal zone (Macnae, 1968). Study by Hill (1978), shows that one of the crab movements centers around its permanent home site, which is presumed to be the crab burrow. Again to determine the effectiveness of the telemetry system, the ultrasonic tag was buried in the silt mud bottom of the main estuary channel of the study site. The pulse signal was assessed from the buried ultrasonic tag at 1cm intervals from 1cm to 5cm depth, by increasing and decreasing the gain of the hydrophone amplifier with the hydrophone directly on top of the ultrasonic tag (Figure 3). The water depth of the hydrophone where this trial was carried out was also 3.5m from the river bottom. The tag was placed only 3.5m deep on the river bottom because the water depth of the main channel and estuary mouth of Sematan River averages between 3.5 and 4.0m during high tide. The water depth of the small mangrove channel of Tanjung Beluku River averages between 1.5 and 2.0m during high tide.

To test the transmission range of the tag, the tags were placed 500m, 1,000m, 1,500m and 2,000m away from the directional hydrophone at the river bottom of about 3.5m deep. The above field trial was carried out with three replicates for each transmission range.

Tracking methods

An ultrasonic tag was attached to the mid-dorsal carapace surface of each crab (Hill, 1978). Before the tag was attached, the mid-dorsal carapace surface of the crab was sanded with sand paper to produce a rough surface area. Super glue was used first to stick the tag in the proper position onto the mid-dorsal carapace. To make the tag attachment level with the carapace surface and firmly on the crab, 5-ton epoxy glue was then applied (Figure 4). The glue combination was let dry for a few minutes before the crabs were released to the study site.

Figure 4. Ultrasonic tag attached to the mid-dorsal carapace surface of a crab.

The hydrophone system was placed on board the boat during tracking. To determine the position of the tagged crab, the hydrophone was rotated until the maximum signal was received at which point the hydrophone was pointing at the crab. By moving the boat to different locations and determining the direction of the tagged crab, the true location could be located through triangulation. The pulse signal could be heard in all directions when the boat was located vertically above the crab. When the crab was close enough, the crab's position was pinpointed by reducing the amplification of the signals. When the tagged crabs moved out of the normally tracked area, their position was determined at irregular intervals by searching with a boat and the hydrophone system. During tracking, the crab's position was determined roughly by triangulation. When the boat position was directly over the crab, the portable GPS (Global Positioning System) position was recorded. The distance moved from the last tracked position was also determined. Parameters recorded during tracking of individual tagged crabs were location, date of release, tracking time, duration of tracking, distance travelled by the tagged crabs, weather condition and water current direction.

Ultrasonic telemetry study was conducted in three study sites; the small mangrove channel of Tanjung Beluku River, the main estuary channel of Sematan River and the mouth estuary of Sematan River. Four adult crabs were tracked in the small mangrove channel between the months of September 1998 and January 1999. Four adult crabs were also tracked in the main estuary channel of the Sematan River between the months of January 1999 and April 1999. Two more adults crab were tracked in the mouth estuary of the Sematan River between the months of May and June 1999. In the small mangrove channel, the crabs were tracked once a day until they could no longer be located. In the main estuary channel, the crabs were tracked every half an hour for the first 48 hours and then once a day thereafter. In the mouth estuary, the crabs were tracked every hour for the first 48 hours and then once a day thereafter.

Tracking in the main estuary channel and the estuary mouth of the Sematan River was carried out during high and low tide. But tracking in the small mangrove channel of Tanjung Beluku River was only carried out during high tide. This is because the small mangrove channel is located within the intertidal zone and dries out at low tide.

RESULTS

Telemetry system field trial

The signal pulses from the ultrasonic tags were clear with the tag 3.5 m deep under water when the hydrophone was 5 m away (water surface distance) pointing towards the sonic tag and right on top of the sonic tag when decreasing the gain of the hydrophone amplifier (Table 2). On the other hand, the pulse signals were poor to no signal when the 5m away hydrophone position was pointing at 90^0 right angle, 90^0 left angle and opposite direction from the ultrasonic tag with decreased gain on the hydrophone amplifier (Table 2).

Table 2. Pulse signals from sonic tag 3.5 m deep under water at different hydrophone positions

Hydrophone position	Sound signal
1. 5m away; toward the ultrasonic tag	Clear
2. 5m away; 90° away from ultrasonic tag, right hand side	Poor
3. 5m away; 90º away from ultrasonic tag, left hand side	Poor
4. 5m away; opposite the ultrasonic tag	No signal
5. Right on top of the ultrasonic tag	Clear

Table 3 shows pulse signals became weaker as the ultrasonic tag was buried deeper inside the mud bottom when decreasing the gain of the hydrophone amplifier. At 3 cm depth inside the mud bottom, the pulse signal was poor or no pulse signal.

Table 3. Pulse signals from ultrasonic tag at different depths inside the mud bottom, under water, with hydrophone 3.5 m above the sonic tag.

Ultrasonic tag position	Depth (cm)	Pulse signal
1. On surface bottom	0	Very clear
2. Under the mud bottom	1	Clear
3. Under the mud bottom	2	Clear
4. Under the mud bottom	3	Poor signal
5. Under the mud bottom	4	Poor signal
6. Under the mud bottom	5	Poor signal

The signal pulses from the ultrasonic tags were also clear with the tag 3.5 m deep under water when the directional hydrophone was 500 m and 1,000 m away and pointing towards the sonic tag (Table 4). The pulse signals were poor when the hydrophone was 1,500m away and pointing towards the sonic tag (Table 4). On the other hand, no signal was received when the hydrophone was 2,000 m away and pointing towards the sonic tag (Table 4).

Table 4. Pulse signals from ultrasonic tag, 3.5 m deep under water at different hydrophone distances

Hydrophone distance (m) *	Sound signal
500m	Clear
1,000m	Clear
1,500m	Poor
2,000m	No signal

**Distance when the hydrophone was pointing towards the sonic tag.*

Tracking in the small mangrove channel

Only three of four tagged crabs remained within the tracking area for more than 173 hours. Crab no.3 (*S. paramamosain*) was missing from the tracking area the day after it was released in the small mangrove channel. Crab no. 1 showed restricted movement (Figure 5). The crab moved downstream for 42 m and moved upstream to record a gross distance of 52 m and of about 173 hours duration within the tracking area before the crab signal disappeared (Table 5). Crab no. 2 moved upstream for a distance of 100 m and remained in the same location for 485 hours before the signal disappeared (Fig. 6 and Table 5). Crab no. 4a showed a variety of movement, it travelled a total distance of 1,026 m downstream of the mangrove channel into the main estuary channel before been trapped by the local crab fishermen in the small mangrove sandbar island (Figure 7). This crab, *S. tranquebarica* was tracked for 268 hours within the small mangrove and main estuary channels before been caught (Table 5). The same crab was placed back in the tracking area and is referred to as crab no. 4b. Initially, after crab no.4 was release back, the crab showed little movement (Figure 8). The crab travelled a total distance of 37 m down the small mangrove channel in 51 hours before it disappeared again (Table 5).

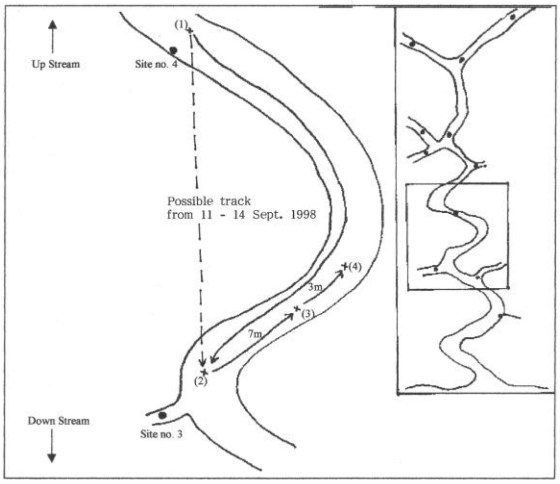

Figure 5. Tracking the movement of crab no. 1 (*S. olivacea*; male; 11.7cm CW). Tracking site: Small channel of Tanjung Beluku River (off Sematan River). Crab positions: (1) Crab released on September 11 at site no. 4; (2) September 14 near site no. 3; (3) September 16; (4) September 18, mid way between site no. 3 and site no. 4. On intermediate days, the telemetry signal could not be received. It is possible that the crabs cross through the mangrove from position 1 to position 2. When the crab is away from the mangrove channel the signal is reduced.

Table 5. Summary of results obtained by tracking 10 crabs. Tracking duration, duration after 48 hours, gross distance and mean ground speed.

Crab no.	Tracking duration (hrs.)			Duration after 48 hrs. (hrs.)	Gross distance (m)			Mean ground speed (m/hrs.)			Remarks
	Day	Night	Total		Day	Night	Total	Day	Night	Total	
1			173.5				52			0.3	Missing
2			485.1				100			0.2	Missing
3			0				0			0.0	Missing
4a			268.7				1026			3.8	Caught
4b			51.8				37			0.7	Missing
5	24	24	48	310	1210	1390	2600	50.4	57.9	54.2	Caught
6	24	24	48	258	177	525	702	7.4	21.9	14.6	Caught
7	24	24	48	53	40	690	730	1.7	28.8	15.2	Caught
8	6	6	12	0	0	350	350	0	58.3	29.2	Caught
9	24	24	48	0	1200	835	2035	50	34.8	42.4	Moved
10	18	16	34	0	270	1060	1330	15	66.3	39.1	Moved
Mean	20	19.7	110.6		482.8	808.3	814.7	20.7	44.7	18.2	

Note:
Tracking duration = total time spent by the crab within the tracking area;
Duration after 48 hrs. = the duration crab remained within the tracking area after 48 hrs. monitoring before disappearing;
Gross distance = total distance covered by the crab within the tracking area;
Average ground speed = calculated by dividing gross distance by tracking duration;
Missing = missing in the mangrove forest;
Caught = been caught by the local fishermen;
Moved = moved towards the open sea;
Day = duration between sunrise andsunset;
Night = duration between sunset andsunrise;
**Time of sunrise and sunset are determined from Muslim prayer timetable for Sematan local time, issued by Sarawak State Mufti Office.*

Tracking in the main estuary channel

Only three of four tagged crabs (no. 5, no. 6 and no. 7) remained within the tracking area for more than 48 hours. They were tracked every half an hour within the first 48 hours and once a day thereafter until the ultra sonic signal could not be detected. Crab no. 5 was released in the afternoon and crossed the main estuary channel at midnight. The crab then moved along the channel upstream with a few zigzag movements up and down stream (Figure 9). The crab also made a nearly straight run along the x-axis of the channel. After the first 48 hours the crab remained within the tracking area for another 310 hours (about 13 days) before the signal could no longer be detected. During these 13 days the crab moved along the channel bank and made an almost straight run up stream. This crab covered the greatest distance compare to the other 9 ultrasonic tagged crabs, moving a total distance of 2,600 m within 48 hours monitoring (Table 5).

After release, crab no. 6 moved upstream along the channel bank. The crab occasionally made a zigzag movement up and down stream also parallel to the channel bank (Figure 10). The crab remained within the tracking area for another 258 hours (about 11 days) after the 48 hours monitoring before it disappeared. The crab tended to move generally upstream with zigzag movement of up and down stream after the first 48 hours monitoring. The distance covered by the crab overlapped considerably with a total distance of 702 m within 48 hours monitoring (Table 5).

Crab no. 7 was released in the middle of the estuary channel where the crab slowly moved straight across to the channel bank (Figure 11). Within the first 48 hours monitoring the crab moved up and down stream several times along the x-axis of the channel bank. The crab remained within the tracking area for another 53 hours (about 2 days) before it could not be tracked. The distance covered by the crab also overlapped considerably with a total distance of 730m within 48 hours monitoring (Table 5).

Crab no. 8 was also released in the middle of the estuary channel and moved immediately straight towards the sandbar island (Figure 12). The crab remained close to the sandbar island for about 12 hours before it disappeared. The crab covered a total distance of 350 m within the 12 hours monitoring (Table 5). The local fishermen caught all the ultrasonic tagged crabs that were tracked in the main estuary channel (Crab no. 5, 6, 7 and 8) in May 1999. They were caught 30 days after the end of the tracking period in the main estuary channel.

Tracking in the estuary mouth

Out of two ultrasonic tagged crabs, only one crab remained within the tracking area for 48 hours. The crab was tracked every hour during the first 48 hours monitoring period. Crab no. 9, moved more extensively up and down stream along the x-axis of the estuary mouth bank (Figure 13). After 46 hours of tracking the crab made a left angle turn and moved out of the tracking area towards the open sea where the signal was lost after the 48 hours monitoring . The crab covered a total distance of 2,035 m during the 48 hours monitoring. Crab no. 10 also tended to move towards the open sea with a few turns (Figure 14). The crab remained within the tracking area for about 34 hours before moving towards the open sea. The crab travelled a total distance of 1,060 m before the signal was lost (Table 5).

Movement pattern

Almost all the ultrasonic tagged crabs were inactive for an hour or more after release except for crab no. 8. This might be caused by trapping and attachment of transmitters (Hill, 1978). The average ground speed of the tracked crabs in the small mangrove channel was slower than in the main estuary channel and estuary mouth (Table 4 & 5). The average ground speed ranged from 0.2 to 3.8 $m.h^{-1}$ in the small mangrove channel and from 15.2 to 54.2 $m.h^{-1}$ in the estuary channel and estuary mouth. The fastest speed of 54.2 $m.h^{-1}$ was recorded for crab no. 5 (Table 5). The movement of most crabs was less than 9 $m.h^{-1}$ for crabs tracked in the main estuary channel (78.1%) and estuary mouth (43.9%) (Figure 15 and 16). However 13% of the crabs in the main channel also moved at speeds over 50 $m.h^{-1}$. In the estuary mouth, speeds were even higher with 36.6% moving more than 50 $m.h^{-1}$. A total of 390 crab movements were recorded from the estuary channel and estuary mouth. 40.3 % (157 movements) of the tagged crabs moved with the current and 59.7 % (233 movements) moved against the current with 32.45 $m.h^{-1}$ mean ground speed (Table 6). These results (Table 6) were obtained during the incoming tide. Crabs were mainly active at night according to the results from the half hour interval (no 5, 6, 7, and 8) and hourly interval (no 9 and 10) monitoring. The night mean ground speed was faster than the day mean ground speed except for crab no. 9 (Table 5). The distance travelled was also farther during the night as compared to the daytime except for crab no. 9. The mean distance travelled was 808.3 m during night time and 482.8 m during daytime (Table 5). The same pattern was also recorded for the mean average ground speed with 44.7 $m.h^{-1}$ during night time and 20.7 $m.h^{-1}$ during daytime (Table 5). The crabs were also active from midnight till sunrise (Figure 9, 10, 11, 13 and 14) but did not show any continuous movement. The results also indicate that, during the same period of tracking, the crabs (no. 5, 6, 7 and 8) were less active on the 2nd night of tracking than on the 1st night but no significant differences were recorded between the two periods (Figure 9, 10, 11 and 12). All crabs were inactive between 6.30 and 9.00 a.m. and an hour or more before sunset in the evening except for crab no. 9, of Fig. 13 (Fig. 9, 10, 11, 12, 13 and 14). Stationary periods of half an hour or more were recorded for all ultrasonic tagged crabs tracked in the estuary channel and estuary mouth. The direction of travel for most crabs was not straight with the tagged crabs in this study showing an index range from 0.2 to 0.3 (Table 7). Crab no. 8 was the exception with a straightness index of 0.9, which indicated that the crab movement was nearly in a straight line (Table 7).

Table 6. Summary of results obtained by tracking six crabs. Crab movement direction with or against water current.

Crab no.	With current	Against current	No. recorded	Mean ground speed ($m.h^{-1}$)*
5	32	63	95	54.2
6	49	46	95	14.6
7	38	57	95	15.2
8	9	14	23	29.2
9	17	31	48	42.4
10	12	22	34	39.1
Total	157	233	390	194.7
Percentage	40.3	59.7	100	
Mean				32.45

**Average ground speed within 48 hours or less monitoring periods.*

Table 7. Summary of results obtained by tracking six crabs. Net distance, gross distance and straightness index.

Crab no.	Net distance (m)	Gross distance (m)	Straightness index
5	650	2600	0.3
6	150	702	0.2
7	155	730	0.2
8	304	350	0.9
9	400	2035	0.2
10	450	1330	0.3
Mean	351.5	1291.2	0.3

Note:
Gross distance = total distance covered by the crab within the tracking area;
Net distance = the shortest distance from the point of release to the point where the crab was lost or stopped tracking;
Straightness index =calculated by dividing net distance by gross distance.

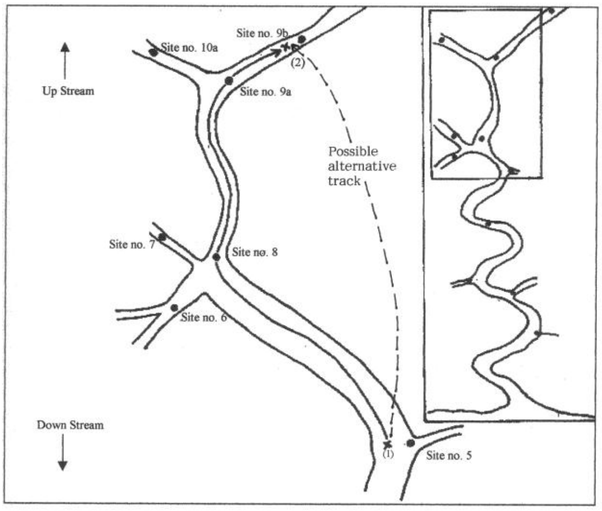

Figure 6. Tracking the movement of crab no. 2 (*S. olivacea*; male; 12.2cm CW). Tracking site: Small channel of Tanjung Beluku River (off Sematan River). Crab positions: (1) Crab released on September 16 at site no. 5; (2) October 5 at site no. 9b. Tracking was attempted every day but the telemetry signals could not be received. Track up the channel represents the search locations. The dotted line represents a possible route for the crab, which would hide signal while it returned to the channel on October 5.

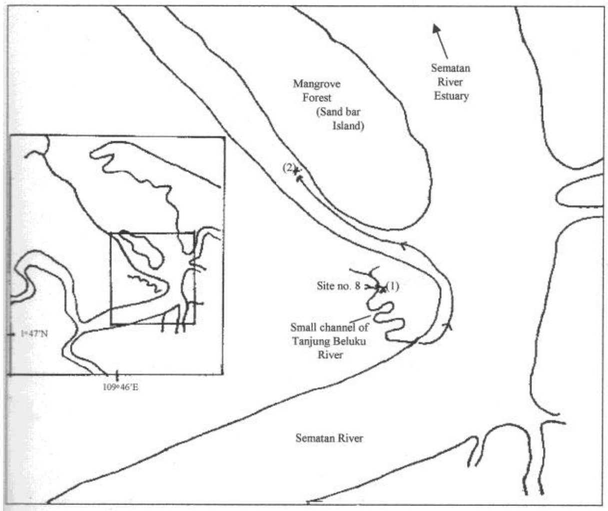

Figure 7. Tracking the movement of crab no. 4a (*S. tranquebarica*; female; 12.5cm CW). Tracking site: Small channel of Tanjung Beluku River (off Sematan River). Crab positions: (1) Crab released on October 5 at site no. 8 within the study site for the small channel; (2) October 16, sonic tag crab was caught by fisherman in the crab trap near the sand bar island of the Sematan River. The crab was not found from October 6 to October 15.

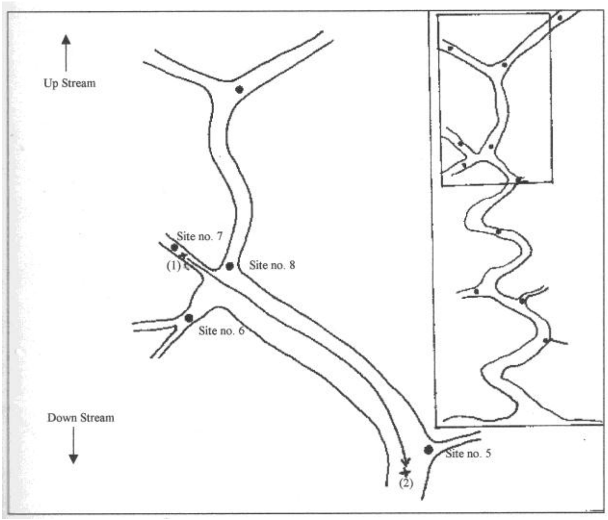

Figure 8. Tracking the movement of crab no. 4b *(S. tranquebarica*; female; 12.5cm CW). Tracking site: Small channel of Tanjung Beluku River (off Sematan River). Crab positions: (1) Crab no. 4a released back on October 17, crab no. 4a was caught in the crab trap at the sand bar island on October 16; (2) October 19. This was the same female as in Figure 7.

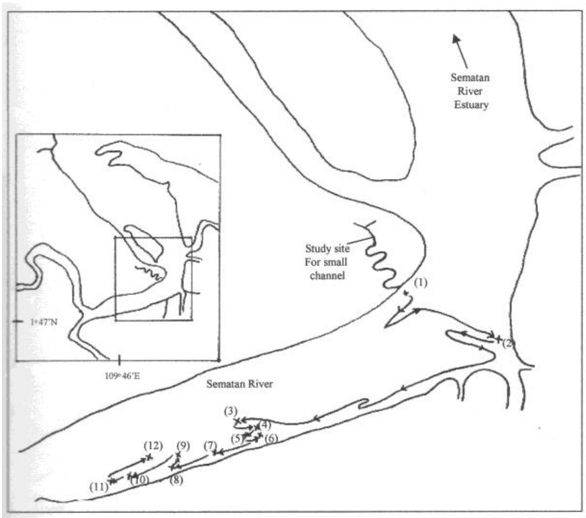

Figure 9. Tracking the movement of crab no. 5 *(S. tranquebarica*; female; 12.9cm CW). Tracking site: Main channel of Sematan River. Crab positions: (1) Crab released on January 27 at 1530 hours and monitored every half hour; (2) January 28 at 0030 hours; (3) January 29 at 0630 hours; (4) January 29 at 1530 hours, end of every half hour monitoring for 48 hours; January 30 at 1100 hours, start of every 24 hours monitoring; (5) January 31 at 0925 hours; (6) February 1 at 0845 hours; (7) February 2 at 0835 hours; (8)February 4 at 1100 hours; (9) February 6 at 0922 hours; (10) February 8 at 0840 hours; (11) February 9 at 0947 hours; (12) February 11 at 1330 hours, end of every 24 hours monitoring. When searched again, no signal received, not in the main river. May have entered a small creek in the mangrove.

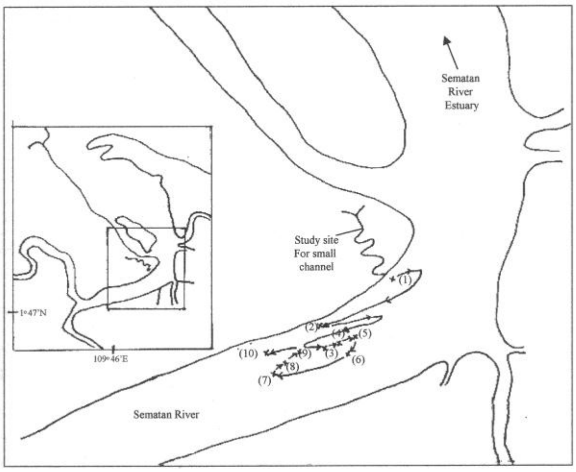

Figure 10. Tracking the movement of crab no. 6 *(S. tranquebarica*; female; 10.8cm CW). Tracking site: Main channel of Sematan River. Crab positions: (1) Crab released on January 27 at 1530 hours and monitored every half hour; (2) January 28 at 0200 hours; (3) January 29 at 1530 hours; end of every half hour monitoring for 48 hours; (4) January 30 at 1055 hours, January 31 at 0920 hours; (5) February 1 at 0830 hours; (6) February 2 at 0830 hours; (7) February 4 at 1055 hours; (8) February 6 at 0917 hours; (9) February 8 at 0830 hours; (10) February 9 at 0930 hours and 0944 hours. When searched again, no signal received, not in the main river.

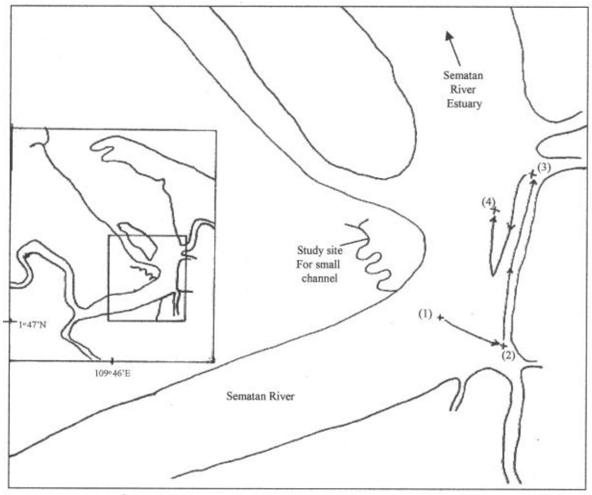

Figure 11. Tracking the movement of crab no. 7 *(S. tranquebarica*; berried female; 12.1cm CW). Tracking site: Main channel of Sematan River. Crab positions: (1) Crab released on March 9 at 1600 hours and monitored every half hour; (2) March 9 at 1630 hours; (3) March 10 at 0017 hours; (4) March 11 at 1600 hours, end of every half hour monitoring for 48 hours; March12 at 1620 hours; March 13 at 2120 hours; March 15, sonic tagged crab not located.

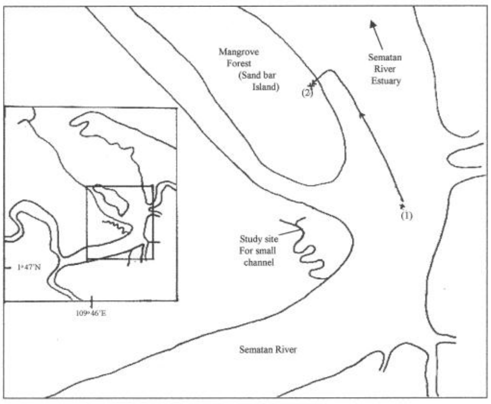

Figure 12. Tracking the movement of crab no. 8 *(S. olivacea*; female; 11.2cm CW). Tracking site: Main channel of Sematan River. Crab positions: (1) Crab released on April 7 at 2300 hours and monitored for every half hour; (2) April 7 at 2330 hours, searched after lostin the mangrove but not found.

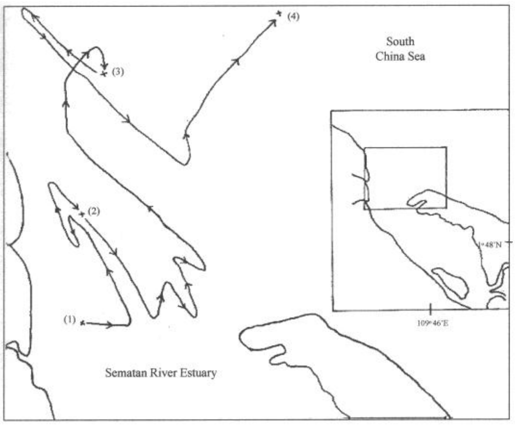

Figure 13. Tracking the movement of crab no. 9 *(S. tranquebarica*; female; 11.7cm CW). Tracking site: Sematan River Estuary. Crab positions: (1) Crab released on May 27 at 1500 hours and monitored every hour; (2) May 28 at 0100 hours; (3) May 29 at 0200 hours; (4) May 29 at 1500 hours, end of every hour monitoring for 48 hours. Crab could notbe found on May 30.

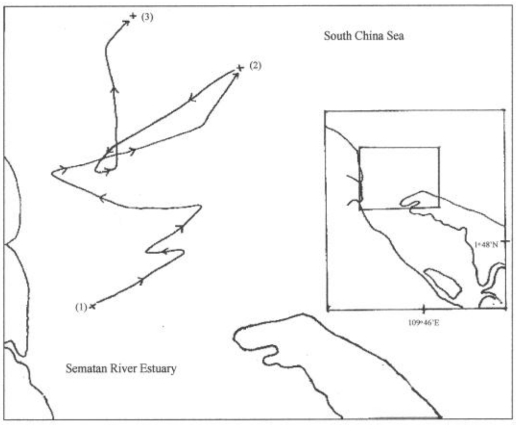

Figure 14. Tracking the movement of crab no. 10 *(S. tranquebarica*; female; 14.0cm CW). Tracking site: Sematan River Estuary. Crab positions: (1) Crab released on June 9 at 1300 hours and monitored every hour; (2) June 10 at 0200 hours; (3) June 10 at 2300 hours after that the sonic tagged crab could not be located.

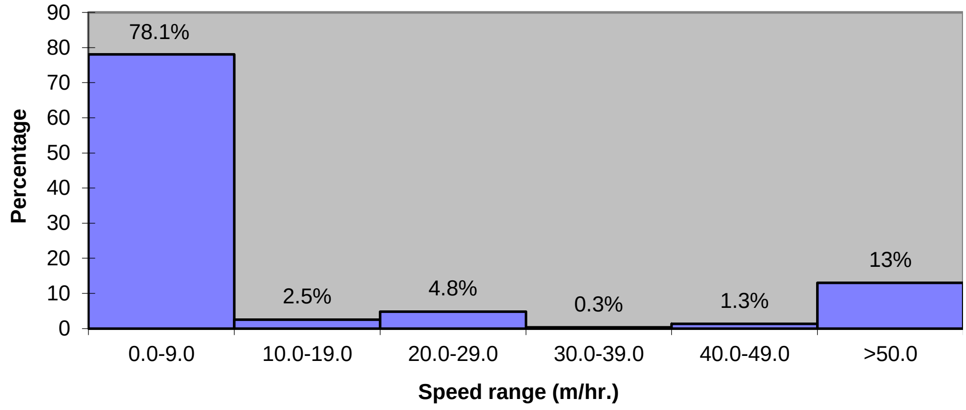

Figure 15. Frequency of speed of movement in 30 minute intervals by four crabs (crab no. 5, 6, 7 and 8) in the main estuary channel.

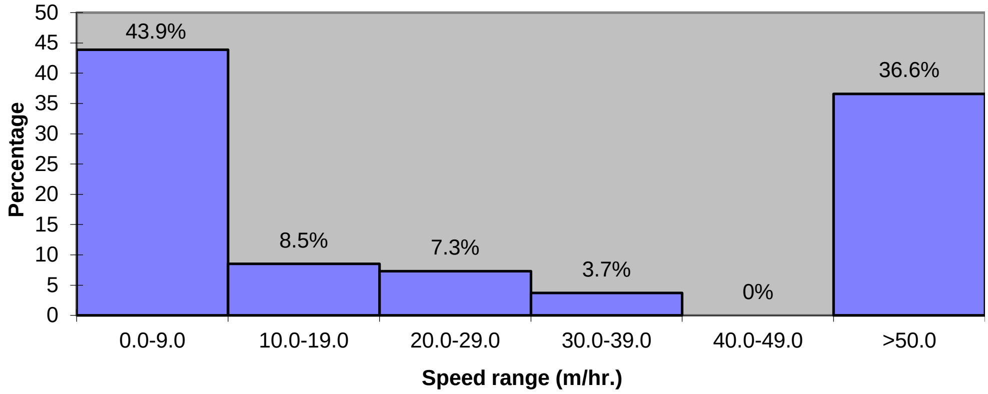

Figure 16. Frequency of speed of movement in 1hour intervals by two crabs (crab no. 9 and 10) in the estuary mouth.

DISCUSSION

In decapod crustaceans, there are two modes of chemoreception, contact chemoreception and olfaction (Hill, 1978). Chemoreception is used by mud crabs to determine the location of food items in a muddy estuary especially at night (Hill, 1978). Contact chemoreception are sites at the dactyls of crabs and by walking over it, food can be located (Hill, 1978). This contact chemoreception is independent of water movement as compared to olfaction. Studies by Hill (1976), on foregut contents show that crab (*Scylla* spp.) samples from Australia and South Africa consume mainly molluscs (both bivalves and gastropods) and crustaceans (mainly grapsid crab); and rarely fish. Study in Tamil Nadu, India by Joel and Sanjeevaraj (1986), also shows that the mud crabs mainly consume molluscs (shallow water gastropods), crustaceans (prawns) and fish. Study shows that the mud crab is a predator of slow moving and sessile prey mainly the benthic invertebrates (Hill, 1976). This suggested that the mud crab movement was most probably related to foraging for slow moving and sessile benthic invertebrates. In this study the mean ground speed for crabs tracked in the estuary channel and estuary mouth was quite slow at less than $9m.h^{-1}$. This slow movement of ultrasonic tagged crabs over the estuary bottom may involve foraging of slow moving and sessile benthic invertebrates using contact chemoreceptors.

Joel & Sanjeevaraj (1986), shows that like most crustaceans the mud crab were found to be nocturnal in feeding activity. Study by Hill (1976) in the laboratory shows that the *Scylla* spp. emerged from the sand during the sunset and buried itself again shortly before or within 30 minutes after sunrise. Results from this study show that the ultrasonic tagged crabs are more active at night. The crab also shows several stationary periods of half an hour or more throughout the night. This locomotory behaviour where the crab spends most of the night either foraging over the bottom or stationary but not buried is important in locating slow-moving or sessile benthic invertebrate prey. As pointed out by Hill (1976), the stationary periods during the night foraging represent part of the hunting behaviour. In this stationary position, the crabs are capable of locating and digging out buried prey especially bivalves (Hill, 1976). Study on feeding strategy of *Scylla* spp. in the laboratory by Hill (1979) showed that food location by the crab appeared to be mainly by contact chemoreception, where the crab used the dactyls of the walking legs to locate a prey animal such as the siphons of a burrowed bivalve. The crab then stopped walking and moved to a position approximately above the prey and repeatedly probed to a depth of 20-50mm into the substrate using the dactyls of the walking legs. After the prey was located, the chela was used to pull the bivalve out. Study by Hill (1979), also showed that burrowing bivalves were eaten 3.5 times as frequently as attached bivalves by those crabs whose gut contents were analysed. The same study by Hill (1979), also demonstrated the crab used contact chemoreception to locate the attached bivalves. Using the dactyl to locate the bivalves and the chelae to pull the bivalves from the rock before they were crushed. Hill (1979) also suggested that the slow mobile prey such as small crabs were trapped by the legs and then picked up by the chela. All the evidence suggests that foraging using contact chemoreception is the main method used for food location by *Scylla* spp.

Mud crabs do also, however, use olfaction to locate food, and react to water borne substances. These olfactory receptors on stimulation would elicit counter-current movement of the crab (Hill, 1978). This may explain why about 60% of the crab movement observed in the study was against the water current. Study by Hill (1976), in the laboratory, showed that the crabs only ate prawns that became incapacitated or died. Hill (1976) also pointed out that live penaeid prawns and fish are capable of rapid escape and are apparently too mobile for *Scylla* spp. It is suggested that the smell of dead mobile prey can be transmitted through water-borne chemical attractants where the crabs moved against the water current to get the dead prey using the olfactory receptors.

Hill (1978) pointed out that movement in crabs could be divided into three categories. The first category was restricted movement centring on a more or less permanent home-site. Second category was free-ranging movement during which crabs may forage over extensive distances and not return to a fixed place each day. The third category was migration associated with reproduction. Hill (1978) also concluded that *Scylla* spp. displays all three categories of movement. The tagging experiment carried out in Moreton Bay, Queensland, Australia on *Scylla* spp. showed the movement in crab can be categorised into two; a free ranging type and an offshore migration by females (Hyland *et al.,* 1984).

The tracking results in this study indicate that both *S. olivacea* and *S. tranquebarica* show restricted movement centring on a more or less permanent home-site. This home-site is assumed to be the crab burrow. *Scylla* spp. of all sizes construct burrows in the intertidal zone (Macnae, 1968). Study in Moreton Bay, Queensland, Australia, shows that crabs in a narrow creek with mangrove-covered banks displayed little or restricted movement (Hyland *et al.,* 1984). This can be clearly seen in the tracking results from the small mangrove channel and main estuary channel of the study. In the small mangrove channel, the intertidal zones are covered by heavy mangrove vegetation, which is suitable for the crabs to burrow and probably provided sufficient food. The tracking results show that the crabs moved less in this habitat despite having been in the tracking area for days.

The tracking results in the present study also indicated *S. tranquebarica* shows free-ranging movement. In the area with large intertidal flats bare of mangroves, crabs moved more in a free ranging pattern (Hyland *et al.,* 1984). It is hard to conclude if *S. olivacea* use this free ranging movement, since the crabs did not display this movement type. However the unpublished results from another study in the same study site show that *S. olivacea* is mainly an intertidal species and perhaps has little mud to move regularly.

Studies show that females *Scylla* spp. migrate offshore to spawn (Hill, 1994; Hill, 1975 and Hill, 1978). Ovigerous females of *Scylla* spp. were also reported in inshore water in several places for example in Malaysia (Ong, 1966), the Philippines (Arriola, 1940), Hawaii (Brick, 1974), Ponape (Perrine, 1978) and Australia (Hyland *et al.,* 1984). Unpublished results from another study in the same study site show that only *S. tranquebarica* were caught during the course of biological surveys in the estuary mouth. The tracking results in this study show that berried females of *S. tranquebarica* move towards the open sea after 48 hours (crab no. 9) and 34 hours (crab no. 10) tracking periods. This suggests that female *S. Tranquebarica* migrate to sea to spawn in the same manner as *Scylla* spp. females from other studies. But more detailed studies should be carried out to conclude that the berried female *S. Tranquebarica* migrates to sea to spawn.

Tracking results in the study indicated that *S. Olivacea*a reconfined to a restricted area probably centring on their own permanent home-sites. Unpublished observations in the laboratory show that *S. olivacea* is more aggressive than *S. tranquebarica*. The tracking results also show that *S. olivacea* restricted their activities only within the small mangrove channel. This small mangrove channel is totally within the intertidal zone. There is insufficient tracking data to determine whether *S. olivacea* remain permanently in this restricted habitat. However, our tracking data suggest that *S. olivacea* moved into the upper intertidal zone within the mangrove forest during high tide and remained there during low tide. The tracking data also suggest that *S. Tranquebarica* inhabits the subtidal zone especially the river channel compared to *S. olivacea*. *S. tranquebarica* moved to the intertidal zone during high tide and returned to the subtidal zone during the low tide. Thus, these subtidal *S. Tranquebarica* lead a free-ranging, non-territorial existence and although not restricted to a home-site, may live in the same area for a long time in the same manner as has been reported for other *Scylla* spp. (Hill, 1978). It is not known how long crabs can live in the same area. This is because the local fishermen caught the ultrasonic tagged crabs (crab no. 4a, 5, 6, 7 and 8) in the study. Other ultrasonic tagged crabs (crab no. 1, 2, 3 and 4b) whose signal was lost may have moulted in the burrow and left their old carapace with the sonic tag inside the burrow. The field trial on the ultrasonic tag shows that the pulse signal is poor to no signal when the ultrasonic tags were placed under the mud bottom at depth of 3cm and more.

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