

Marine Turtle Newsletter

Directional Locomotion in a Turtle Barnacle, *Chelonibia testudinaria*, on Green Turtles, *Chelonia mydas*

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The coronuloid barnacle *Chelonibia testudinaria* is a common commensal of green sea turtles (*Chelonia mydas*) (Bugoni *et al.* 2001; Pereira *et al.* 2006). Studies suggest that barnacles like *C. testudinaria* receive benefits by attaching to motile hosts that are not typical to barnacles attached to immobile substrates, e.g., increased survival, foraging, and dispersal (Pfaller *et al.* 2006). These benefits, however, are undoubtedly dependent upon the barnacle's ability to attach and remain anchored to a suitable host throughout its lifespan (Caine 1986).

Logan & Morreale (1994) demonstrated that sea turtles possess hydrofoil design elements that maximize laminar flow and minimize drag over their surfaces. Because water flow velocity is greatest over the anterior and vertebral regions of the carapace, one would assume these areas to be more desirable locations for filter-feeding barnacles to settle, in order to increase their feeding potential. Several studies have illustrated concentrations of *C. testudinaria* in this region of the carapace (Caine 1986; Matsuura & Nakamura 1993; Frick *et al.* 1998; Schärer 2003; Pfaller *et al.* 2006), and it has been presumed they preferentially settle there. However, studies of the shore barnacle *Amphibalanus amphitrite*, a common epibiont of loggerhead turtles (*Caretta caretta*) in the southeastern U.S. (Pfaller *et al.* 2006), show that its cyprid larvae actively settle or move into areas of moderate albeit not high water flow (Crisp 1955; Mullineaux & Butman 1991). Barnacles in the lower flow posterior and marginal regions of the carapace do not experience the same foraging potential as barnacles that have settled in areas of greater water flow. It is advantageous for a barnacle to be able to respond to stimuli, such as current or water velocity, in its environment. Some adult sessile barnacles possess the ability to reorient by rotating on their basis, or to be moved short distances by lateral pressure of a neighbor. On the other hand, some pedunculate barnacles, such as *Capitulum mitella* and *Pollicipes pollicipes*, can relocate by extending their peduncles down the bodies of conspecifics on which they had settled to the substratum (Hoffman 1989; Kugele & Yule 2000). Here we report that *C. testudinaria* is capable of substantial post-settlement locomotion, generally from areas of relatively low to higher current flow.

	1	2	3	4	5	6	7	8	9	Average	SD
17 Jan- 17 Feb	1.07	0.7	1.15	0.97	0.6	0.68	1.01	0.68	0.7	0.84	0.21
18 Feb- 15 March	0.64	0.58	1.41	1.01	-	-	0.92	0.95	1.16	0.95	0.29
16 March- 9 April	0.59	0.27	0.76	0.92	-	-	1.09	-	0.7	0.72	0.28
10 April- 6 May	0.55	-	0.71	0.7	-	-	0.62	-	0.65	0.64	0.06

Table 1. Summary of movement rates (mm*d-1) of 9 individual *Chelonibia* barnacles on a green turtle (#3) for each time period.

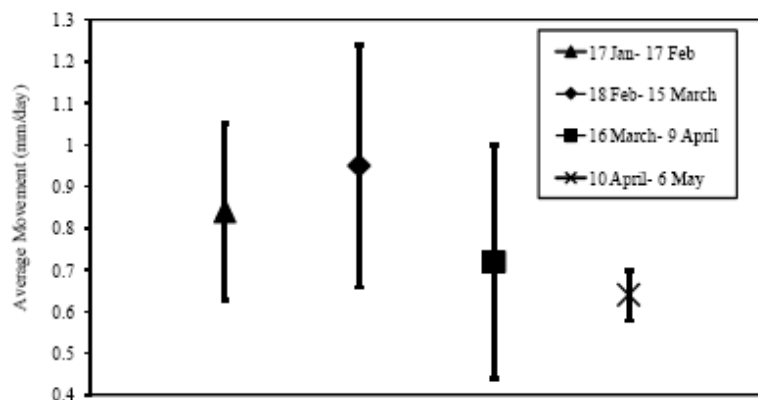


Figure 1. Change in average movement rate per day of *Chelonibia testudinaria* on green turtle #3 from January to May 2005, with standard deviations.

Observations of three juvenile green turtles were made from 2003-2006 on a near-shore rocky hard bottom off of Boca Raton, Florida, in waters between 1 and 6 meters deep. A Sony Cybershot P-73 4.1 mega pixel digital camera was used to take a time series of photographs of the turtles. Individual turtles were identified by scute arrangements on the head, carapace, and flippers, and from shell anomalies and deformations.

Casual inspection of the photographs indicated that the barnacles were moving on the carapace of these turtles over a period of months. To investigate this, we assembled a series of photographs for each of the three turtles. An in-water estimate of turtle carapace length (straight length) was made and all subsequent measurements are relative to that measurement. We measured the time period (in days) between photographs and calculated the barnacle movement rate by measuring the change in position of the barnacle from the preceding photograph (Table 1; Figure 1). To avoid scaling issues between photographs, we determined the location of each barnacle throughout the series by comparing the center point of the barnacle to the adjacent scute margins. These points were plotted onto the first image in each movement sequence. The three composite images were analyzed using Image J photo processing software, where we measured the carapace length and the relative change in position of the center of each barnacle. Simple linear regression was used to find out if initial barnacle diameter predicts movement rate. Barnacle mortality was determined by the disappearance of barnacles. Daily survival rates were calculated using $DSR = 1 - (\#deaths / \#animal\ days)$.

Average barnacle movement rate varied from 1.4 to 0.27 mm per day throughout several time periods (Table 1). The average movement of barnacles on turtle # 3 increased and then decreased as the year progressed from January to May (Fig. 1). Barnacle diameter was not a significant predictor of movement rate ($p = 0.38$, $R^2 = 0.036$).

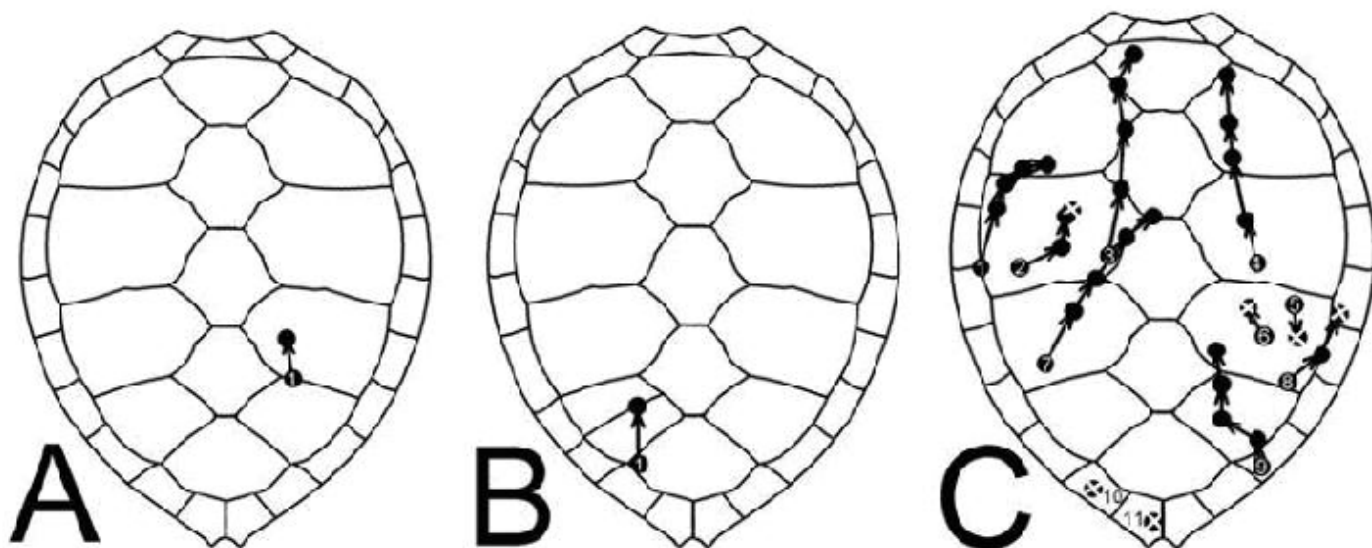


Figure 2. Diagram showing the position of *Chelonibia testudinaria* on the carapace of green turtles # 1 (A), # 2 (B), and # 3 (C) as dark circles. Arrows indicate relocation to the subsequent position by the start of the next time period. An "X" indicates that the barnacle died by the beginning of the subsequent time period.

Barnacles on turtles # 1 and # 2 moved anteriorly and medially (Fig. 2A & 2B). Eighty-eight percent (n=8) of barnacles on turtle # 3 (n = 11; Figure 2C) relocated to a more anterior position on the carapace. Of those, 87.5% (n=8) relocated medially and 12.5% (n=8) moved laterally (Fig. 2C). All eight of the barnacles that moved anteriorly on turtle # 3 deviated in direction no more than $\pm 61^\circ$ from the longitudinal axis of the barnacle (bearing 0° corresponding with the anterior end of the turtle) (Table 2). Of the barnacles on turtle # 3, 55% experienced mortality during the 110 day observation period - resulting in a 0.992 daily survival rate. Out of the four barnacles that were positioned on the marginal scutes of turtle # 3 (Fig. 2C), 75% experienced mortality. Two deaths occurred during the first time period so no movement was recorded for these individuals (Barnacle #'s 10 & 11; Fig. 2C).

Bearing ($^\circ$)	1	2	3	4	6	7	8	9
Date								
17 Jan- 17 Feb	335	306	348	16	26	337	299	15
18 Feb- 15March	352	2	356	16	-	334	331	51
16 March- 9April	323	338	8	7	-	332	-	11
10 April- 6May	299	-	315	9	-	312	-	12

Table 2. Directional movement of individual barnacles on green turtle #3. Each point indicates the bearing at which *Chelonibia testudinaria* traveled during each time period. 0° bearing indicates anterior movement.

A turtle's swimming motion and shape causes water to flow over the carapace in a manner that minimizes recruitment of epibionts, especially in the high flow anterior region (Logan & Morreale 1994). The lower shear stress environment on the posterior region of the carapace increases the likelihood for cyprid settlement to occur (Mullineaux & Butman 1991); however, these individuals are in a less optimum position for feeding as they experience turbulence caused both by the shape of the shell as well as other epibionts located anteriorly. Micro-eddies created by adjacent epibionts would alter flow direction (Pfaller *et al.* 2006). In addition, barnacles located posteriorly to other barnacles may receive less particulate matter as it may be consumed before it reaches them. The high incidence of anterior and medial repositioning of *C. testudinaria* indicates that the barnacles are actively seeking an alternative, presumably more favorable attachment site as they grow. Thus, while differential recruitment may still be a factor in initial settlement (Pfaller *et al.* 2006), it apparently is not the sole factor influencing the survival of *C. testudinaria*.

Barnacles #5 and #8 on turtle #3 displayed movement patterns not observed in the other turtles. Barnacle #5 moved posteriorly while barnacle #8, which was positioned only a few mm behind #5 moved laterally instead of medially (Fig. 2C). It is possible that turbulence from adjacent barnacles disrupted the stimulus (e.g. water flow) that directs repositioning, resulting in movement. However, additional observations of barnacle movement patterns on other turtles will be needed to determine the cause of this unusual movement.

Figure 2C demonstrates that barnacles change location relative to other individuals on the same scute, thus moving independently of each other. Individuals frequently move across several scutes. As scutes grow and are periodically shed, small barnacles not in sutures, and individuals mostly attached to areas being shed, are lost in the process. This is evidently not a significant cause of mortality in large individuals, which are more frequently knocked off of the turtle's carapace by their rubbing against reef structures (Frick & McFall 2007). Because the rate at which barnacles relocate is not sufficient to escape removal by the host turtle, barnacle movement is not thought to avoid self-grooming by turtles. However, since barnacles can move substantial distances, "barnacle pattern documentation" might not be a feasible means by which to identify individual sea turtles, even over a relatively short time-span.



Figure 3. Green turtle # 1 bearing the gray locomotion trail of a relocated *Chelonibia testudinaria*.

Gray locomotion trails of *C. testudinaria* indicate the direction and distance traveled by the barnacle (Fig. 3). It appears *C. testudinaria* leaves behind a cementing substance similar to that described by Kugele & Yule (1993) when the barnacle *Pollicipes pollicipes* relocates. *Pollicipes* moves by base extension in a directional manner via cementing of the leading edge (rostrum) while simultaneously sloughing the trailing edge (carina). Muscular activity is not believed to be involved. However, Kugele & Yule (2000) demonstrated that *Capitulum* barnacles move quite differently. While sloughing is believed to account for the release of the trailing edge, the leading edge appears to advance via muscular activity.

Certain balanomorph barnacles, like *Semibalanus balanoides*, can be induced to move laterally short distances by applying pressure to one side (Crisp & Bourget 1985). It has a membranous basis like *C. testudinaria* and its wall is held down to the basis by fibrils canting inward at about 40°. Each fibril includes a contractile portion which relaxes during each growth increment (Gutmann 1960). *Chelonibia testudinaria* likely grows in the same fashion. If so, the process provides a plausible hypothesis for locomotion in *C. testudinaria*. In other words, unequal contraction of the fibrils immediately following each growth increment, with minimal tension at the trailing or carinal end and maximum tension at the leading or rostral end of the animal, advances the shell forward with each growth increment. For examples of sequential photos depicting barnacle movements on turtles 1, 2 and 3, please see .

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