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Effects of Sand Hardness and Human Beach Use on Emergence Success of Loggerhead Sea Turtles On Yakushima Island, Japan

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Although the substrate of loggerhead sea turtle (*Caretta caretta*) nesting beaches varies (Hendrickson and Balasingam, 1966; Stancyk and Ross, 1978; Mortimer, 1982), few studies have examined how substrate characteristics influence the biology of nesting females or developing eggs. Laboratory experiments have shown that temperature, moisture, and gas conditions to which reptilian eggs are exposed affect growth and sexual differentiation (Packard and Packard, 1988).

Studies of egg development of *C. caretta* have shown that the primary causes of egg failure are infertility, early embryonic mortality, and microbial infection (Blanck and Sawyer, 1981; Wyneken et al., 1988). These results were obtained mostly from eggs incubated in artificial hatcheries; there are few comparable data on eggs from natural nests.

Even when embryonic development successfully leads to hatching, some hatchlings fail to emerge from the sand. In the green turtle (*Chelonia mydas*), the proportion of hatchlings involved in such failures is known to be small (Fowler, 1979). However, the extent to which *C. caretta* hatchlings fail to escape from their nests has not been reported previously.

We examined relationships between the hardness of the nesting substrate and human beach use on the emergence success of loggerhead sea turtle hatchlings on Yakushima Island, Japan.

Methods. — From 1 to 31 August 2000, we recorded the emergence of *C. caretta* hatchlings on Nagata Beach, Yakushima Island, Japan (130°30'E, 30°20'N). Nagata Beach is divided into two parts, one restricted from public access (restricted area; 15.5 x 412.0 m^2), and the other freely accessible to the public (free-access area; 30.0 x 300.0 m^2).

We looked for emerging nests every morning and marked those that we found in each area. We measured the hardness of the surface sand at the center of each nest with a Yamanaka-shiki soil hardness tester with resistance (25.0 mm x 30.0 mm) every day from the time found until hatchlings finished emerging. The sand hardness ranged from 1 to 6 kg/cm^2.

We excavated emerged nests 10 days after the first hatchling emerged, and counted the empty egg shells, unhatched eggs, incompletely hatched eggs in which the hatchling had died (pip-deads), live hatchlings, and dead hatchlings left in the nest cavity. Unhatched eggs were opened and examined for signs of development.

We defined mortality at pipping as the percentage of embryos that died during pipping; emergence success as the percentage of hatchlings that reached the beach surface.

Results. — We monitored 32 nests, 20 in the restricted area and 12 in the free-access area. Emergence success was 87.8 ± 12.4% in the restricted area and 77.9 ± 18.9% in the free-access area. The mortality at pipping was 7.0 ± 7.5% in the restricted area and 14.0 ± 13.0% in the free-access area. Pip-deads accounted for the greatest mortality in the nests.

The emergence success in the free-access area was significantly lower than in the restricted area (F-test: F = 1.214, $p < 0.05$), and the mortality at pipping was higher in the free-access area than in the restricted area (F-test: F = 1.722, $p < 0.05$, Table 1).

The relationship between emergence success and sand hardness was significantly negative in the free-access area (Spearman rank test; $r_s = -0.716$, $p < 0.05$, $n = 12$, Fig. 1). In the restricted area, the relationship between emergence success and sand hardness was not significant (Spearman rank test; $p > 0.05$, $n = 20$).

The relationship between mortality at pipping and sand hardness was positive in the free-access area (Spearman rank test; $r_s = 0.718$, $p < 0.05$, $n = 12$, Fig. 2). In the restricted area, the relationship between mortality at pipping and sand hardness was not significant (Spearman rank test; $p > 0.05$, $n = 20$).

Discussion. — Peters et al. (1994) reported that emergence failure on a freely accessible beach was highly correlated with sand composition. Mortimer (1990) reported that

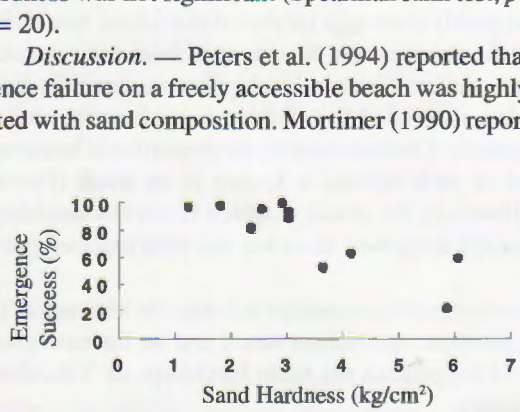

Figure 1. Relationship between emergence success (%) and sand hardness (kg/cm^2) in the free-access area.

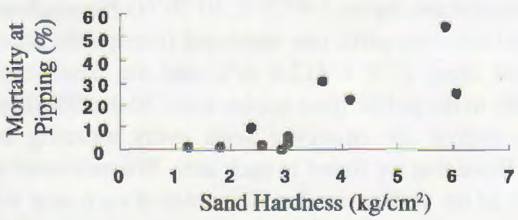

Figure 2. Relationship between mortality at pipping (%) and sand hardness (kg/cm^2) in the free-access area.

Table 1. Comparison (mean ± SD) between emergence success and mortality at pipping between the restricted ($n = 20$) and free-access areas ($n = 12$) (* = $p < 0.05$).

	Restricted	Free-access	F
Emergence success %	87.8 ± 12.4	77.9 ± 18.9	1.214*
Mortality at pipping %	7.0 ± 7.5	14.0 ± 13.0	1.722*

mortality before pipping and mortality during and after pipping were both positively correlated with the mean particle diameter of the sand.

In our results, emergence success in the free-access area was significantly lower than in the restricted area, and mortality at pipping was significantly higher in the free-access area than in the restricted area. In the free-access area, the relationship between emergence success and sand hardness when hatchlings emerged was negative, and the relationship between mortality at pipping and sand hardness was positive. These results indicate that sand compaction caused by humans stepping on nests can inhibit emergence of loggerhead hatchlings through increased mortality at pipping. However, it is necessary to further clarify the mechanisms by which this increased mortality occurs.

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