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Sex Ratio of Immature Green Turtles Inhabiting the Hawaiian Archipelago

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A variety of reptiles possess temperature-dependent sex determination (TSD) (see reviews by Bull, 1980; Raynaud and Pieau, 1985; Ewert and Nelson, 1991; Janzen and Paukstis, 1991), including all species of sea turtles examined to date (Yntema and Mrosovsky, 1980; Morreale et al., 1982; McCoy et al., 1983; Mrosovsky et al., 1984; Dalrymple et al., 1985; Rimblot et al., 1985). Sea turtle sex ratios resulting from TSD are of ecological and conservation significance, since they affect reproduction. Further, a comprehensive knowledge of naturally-occurring sex ratios is a prerequisite for understanding the evolutionary basis of the wide range of sex ratios reported for reptiles with TSD (Bull and Charnov, 1988, 1989). In the current study, a serum androgen sexing technique is used to estimate the sex ratio of immature green turtles, *Chelonia mydas*, inhabiting certain foraging grounds of the Hawaiian Archipelago.

Turtles were captured at Punaluu Bay (19°N, 155°W) and Kiholo Bay (20°N, 156°W) off the island of Hawaii with large mesh tangle nets made of 2.0 mm nylon

line. Nets were set at night vertically through the water column at shallow (<3.0 m) foraging grounds frequented by turtles (Balazs et al., 1987). The nets were checked every 30 min or less to remove entangled turtles. Turtles were also captured at nearshore foraging grounds off Palaau (21°N, 157°W) on the island of Molokai. At this location, a pound net was used during the night, and turtles were removed from its central enclosure just after sunrise. Turtles were captured during a time period spanning from 17 December 1983 to 30 August 1984. At all three locations, turtles were taken to shore after capture, and then measurements and blood samples were taken prior to the turtles being released into the wild. Blood samples were taken from the bilateral cervical sinus as described by Owens and Ruiz (1980). Following centrifugation, sera were decanted, temporarily placed on ice, and then transferred into a ≤ 20 C freezer until they were assayed.

A serum androgen sexing technique was used to sex the immature sea turtles (Owens et al., 1978; Wibbels et al., 1987, 1991; Wibbels, 1988). A detailed description of the testosterone radioimmunoassay procedure, including validation with sera from immature *C. mydas*, has been reported previously (Wibbels et al., 1987, 1990, 1991; Wibbels, 1988). A total of three assays were conducted during this study. Extracted water blanks were included in duplicate in all assays, and they consistently generated values under the sensitivity of the assay. A minimum of two control samples also were included in each assay. The intraassay coefficient of variation was 8.2%, and the interassay coefficient of variation was 23.9%. Assay sensitivity averaged 3.12 pg, and extraction efficiency averaged 73.0%. The testosterone levels of three of the turtles fell within an overlap zone between male and female ranges (Wibbels et al., 1987; Wibbels, 1988). Therefore, those three turtles were not used in estimating the sex ratio.

Sixty-six turtles were captured during this study

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TABLE 1. Sex ratios of immature green turtles captured on Hawaiian foraging grounds.

Location	Female	Male	Unknown ^a	N	Size range ^b	Sex ratio ^c
Punaluu	19	16	0	35	39.8 to 75.3	1.19:1.00
Kiholo	2	2	0	4	48.2 to 66.3	1.00:1.00
Palaa	11	13	3	27	39.6 to 71.8	0.85:1.00
Pooled	32	31	3	66	39.6 to 75.3	0.96:1.00

^a Turtles with serum androgen concentrations greater than 20 pg/ml and less than 30 pg/ml (see text).

^b Straight carapace length in cm.

^c Male:female.

(Table 1). Their straight-line carapace lengths (SCLs) ranged from 39.6 to 75.3 cm ($\bar{x} = 58.5 \pm 1.2$ SE), indicating that all turtles were immature since minimum SCL recorded for adult turtles in this population is approximately 80.0 cm (Balazs, 1980; Balazs et al., 1987). Straight carapace lengths did not differ significantly between capture locations (ANOVA, $P > 0.05$). Additionally, the predicted sex ratios from the three capture locations were not significantly different from one another (replicated goodness of fit test, $P > 0.05$). The pooled sex ratio (0.96 females:1.00 males; see Table 1) did not differ significantly from a 1:1 sex ratio (replicated goodness of fit test, $P > 0.05$). To investigate possible variation in sex ratios relative to size class of turtle, the data were divided into subsets based on SCL. In the first instance, the sex ratio of turtles with SCLs greater than the mean SCLs of the entire group (57.5 cm) was compared to that of turtles with SCLs less than the mean SCL. In the second instance, the mean SCL of each subset was used to generate two additional subsets, and the sex ratios of the four groups were compared. In both cases no significant differences between sex ratios were detected (replicated goodness of fit tests, $P > 0.05$).

Green turtles are the most abundant sea turtle species in Hawaiian waters, and they are members of a single population which appears genetically isolated from other central Pacific populations (Balazs, 1980, 1982a). Turtles in the population appear to mature slowly, requiring an average of approximately 26 yr to reach sexual maturity (Balazs, 1982b). The wide range in the size of turtles captured in the current study suggests that this sampling included turtles produced from numerous year classes of hatchlings. Thus, the sex ratio represents a distillation of many hatchling sex ratios. The data from the current study suggest a sex ratio approximating 1:1, which appears homogenous relative to capture location and size of turtle. If this sex ratio of immature turtles reflects the primary sex ratio in this population, then the data are consistent with the 1:1 ratio predicted by sex allocation models initially predicted by Fisher (1930). However, although hatchling and adult sex ratio appear to correspond in some turtle species (Ewert and Nelson, 1991), the relationship between the sex ratios in the hatchling, immature, and adult portions of a sea turtle population is not clear (Mrosovsky et al., 1984; Wibbels et al., 1987, 1991). Thus, one must be cautious when interpreting the evolutionary significance of results such as those in the current study.

Regardless of the evolutionary implications, the results of the current study are consistent with those of a previous study of immature sea turtles (Limpus and Reed, 1985) suggesting that temperature-dependent sex determination is capable of producing un-

biased sex ratios in sea turtle populations. However, studies of other sea turtle populations suggest that female-biased sex ratios (Wibbels et al., 1987, 1991; Mrosovsky and Provancha, 1989, 1991) and male-biased sex ratios (Limpus, 1985; Mrosovsky et al., 1992) may also exist. Wide variation in sex ratios has also been reported in freshwater and terrestrial turtles with TSD (reviewed in Ewert and Nelson, 1991). While several hypotheses have been proposed to account for this variation and for the existence of skewed sex ratios (reviewed in Ewert and Nelson, 1991), their validity is currently unknown. The gradual accumulation of population sex ratio data should provide some insight as to the basis of this variation. However, a thorough understanding of this subject will require comprehensive studies which (1) examine population sex ratios relative to factors affecting sex ratio such as the physical parameters of nesting beaches, reproductive ecology, and nesting behavior in a given population, and (2) compare sex ratios of different age classes of turtles (e.g., hatchlings, juveniles, subadults, adults) within a population.

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