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Population Structure, Activity, and Conservation of the Neotropical Freshwater Turtle, *Hydromedusa maximiliani*, in Brazil

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Abstract. – Activity and population structure data on the neotropical freshwater turtle *Hydromedusa maximiliani* were obtained from a protected Atlantic rainforest region of southeastern Brazil. We made 141 captures and recaptures of 103 turtles (20 males, 38 females, and 45 juveniles), resulting in a 1:1.9 male:female sex ratio. Using the Jolly-Seber capture-mark-recapture method we estimated a maximum population of 445 turtles for 10 streams surveyed in a 350 ha area. Since all turtles were captured in rivers, actual density within microhabitat was 193.5 turtles/ha, with a biomass of 41.6 kg/ha. Seasonal activity patterns were observed, with the warm and wet spring and summer seasons (September to March), and rainy days specifically, the times of greatest activity. Nesting appears to occur during December and January, while hatchlings probably emerge during September and October. Females and juveniles tended to move mainly in the direction of headwaters whereas males moved mainly downstream, always by water, and sometimes making use of intermittent streams. The species is potentially threatened by environmental degradation of its unique and diminished habitat and should be classified as Vulnerable.

Key Words. – Reptilia; Testudines; Chelidae; *Hydromedusa maximiliani*; turtle; population; sex ratio; conservation; neotropical; South America; Brazil

The coastal Atlantic rainforest of Brazil is among the most endangered ecosystems in the world, yet still harbors a high number of endemic species (Cracraft, 1985; Sick, 1988; Coimbra-Filho, 1990). Notwithstanding such species richness, biological information remains very scarce for many resident taxa. The reasons for this include both difficulty of access to key areas and the limitation or restriction of some species to endangered habitat types, including intact forests and unpolluted streams. The freshwater turtles are included among these taxa.

The two species of the South American chelid genus *Hydromedusa* (*H. maximiliani* and *H. tectifera*) both have poorly known biology and undefined conservation status, with current opinions ranging from "not threatened" (IUCN/SSC, 1989; Bernardes et al., 1990) to "threatened" (IBGE, 1992). *Hydromedusa maximiliani* is characterized by living in a relatively unusual habitat compared to other neotropical freshwater turtles. While many species occur in large, deep, often muddy rivers (Iverson, 1992; Fachin-Teran et al., 1995), *H. maximiliani* inhabits small, shallow, clear-water streams, with many rapids and falls in mountainous regions. It is endemic to the Brazilian coastal Atlantic rainforest, with a geographic distribution limited to parts of southeastern Brazil (Ernst and Barbour, 1989).

In addition to the lack of information on *H. maximiliani* biology (Yamashita, 1990; Guix et al., 1992; Souza and Abe, 1995; Souza and Abe, 1997, in press; but see Souza, 1995b) the species also inhabits an ecosystem constantly threatened with destruction. This paper discusses the activity patterns and some aspects of the population structure of *H. maximiliani*, and is intended as a contribution to the conservation and biology of this poorly known neotropical freshwater turtle.

MATERIALS AND METHODS

The study was carried out from June 1993 to June 1994 at Parque Estadual de Carlos Botelho (PECB), São Paulo state (24°00' – 24°15'S, 47°45' – 48°10'W), a typical mountainous rainforest region in southeastern Brazil. The PECB is a protected reserve that encompasses over 37,000 ha of intact native rainforest, although some peripheral and surrounding areas have suffered extensive anthropogenic degradation, including pasture land development and *Eucalyptus* and *Pinus* culture (see Souza, 1995b for a more detailed area description). During the study period, temperature ranged from 2.5°C (July) to 31.5°C (February) (mean, 17.9°C), while annual rainfall was over 1900 mm (August being the driest month with 49.7 mm and January the wettest with 307.0 mm). Thus, two distinct seasons could be delimited: a cold and dry, from April to June (autumn and winter), and a warm and wet, from September to March (spring and summer).

An area of ca. 350 ha, drained by 10 perennial streams (ca. 8.0 km in total length), was surveyed (see Souza and Abe, 1995). Turtles were hand-collected in the shallow streams. All adult animals were sexed according to external morphological characteristics such as carapace length, body mass, plastral concavity, carapace shape, and plastron color (Guix et al., 1992; Souza, 1995a,b). Turtles were measured, weighed, and marked by notching marginal scutes (Cagle, 1939), and at each collecting point, a colored surveyor's tape recording both specimen number and point of capture was tied to the vegetation near the water's edge. In this way, upstream or downstream movement of recaptured individuals, as well as the spacing between turtles along the stream course was recorded. Ambient water temperature was recorded at each point of capture at a depth of 10 cm. Monthly rainfall values were recorded at the PECB meteorological station, about 2.0 km from the study area. Both stream water temperature and rainfall were compared with the number of turtles captured.

To evaluate turtle population size, the Jolly-Seber capture-mark-recapture method was utilized (Caughley, 1980):

$$\mathbf{Ni} = \frac{\mathbf{n_i} + \mathbf{n_i Z_i R_i}}{\mathbf{m_i r_i}}$$

where $\mathbf{Ni}$ = estimated population size, $\mathbf{n_i}$ = size of sample, $\mathbf{m_i}$ = number of marked animals in the sample, $\mathbf{R_i}$ = total number of animals marked and released, $\mathbf{r_i}$ = number of marked animals of the R_i released that are subsequently recaptured, and $\mathbf{Z_i}$ = number marked before the *i*th occasion that were not recaptured on *i*th occasion but were recaptured subsequently.

RESULTS

We made 141 captures and recaptures of 103 turtles (20 males, 38 females, and 45 juveniles). Captures of animals occurred once each for 73 turtles, twice each for 23 turtles, and three times each for 7 turtles. The overall recapture rate was 29.1% but varied between the streams, from 11.1% to 55.56%. Turtle size (straight line carapace length, CL) ranged from 47.3 to 198 mm. Body size distribution was clearly bimodal, with one group comprising juveniles and a few small females (CL 47.3–124 mm) and a second group comprising large males and females (CL 125–198 mm) (Fig. 1). Sex ratio of adult males to females was 1:1.9, a significant difference from 1:1 ($\chi^2 = 5.58$, $p < 0.025$).

There was clear seasonal variation in capture rate, ranging from 30 in October (spring) to 0 in June (winter) (Fig. 2). Juvenile captures occurred only from September to March, with the greatest capture rate (40 juveniles) from September to January (spring to summer). Females were captured all year round, except July and August (winter), but mainly (35 turtles) from September to January (spring to summer). In contrast to juveniles and females, males were usually caught (17 turtles) from September to December (spring to early summer). There was positive correlation between capture frequency and rainfall (Fig. 2). Out of 141 captured (and recaptured) turtles, 115 (81.6%) were taken from September to January, the months of highest rainfall. A significant relationship between increased rainfall and capture of turtles was found for actual sampling days ($r = 0.62$, $p < 0.05$, $n = 13$) that is, immediate rainfall was much more predictive of capture than the overall wet season. There was no significant relationship between stream water temperature and capture of turtles ($r = 0.14$, $p > 0.05$, $n = 27$). There

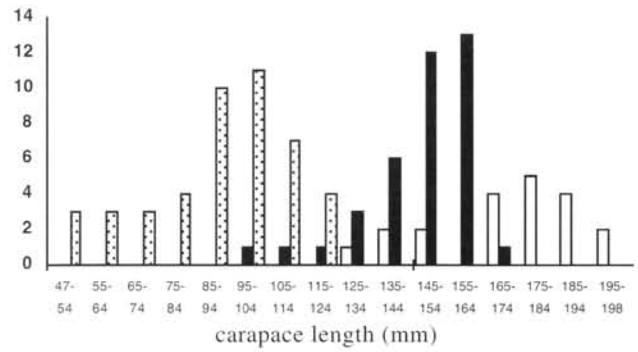

Figure 1. Population structure (number of turtles captured per carapace length) exhibited by *Hydromedusa maximiliani* at Parque Estadual de Carlos Botelho, southeastern Brazil, from June 1993 to June 1994. Males = open bars, females = black bars, juveniles = shaded bars.

was an expected strong positive relationship ($p < 0.0001$) between carapace length and body mass for all turtles (Fig. 3).

The mean distance observed between any two adjacent animals was 213 m (range, 4–840 m, $n = 89$). Males and females were more widely spaced than were juveniles (Table 1), and these mean distances between sexes were statistically different ($F = 2.517$, $p = 0.0424$, Student Newman Keuls test for repeated measures ANOVA). Based on recapture data, the mean daily displacement of individuals was 2.0 m, ranging from 10.6 m (370 m in 35 days) to 0.1 m (10 m in 87 days). Females appeared to move further between sucessive captures than did males or juveniles, although the differences were not significant ($F = 1.283$, $p = 0.301$, one way ANOVA). The main direction of movement for females and juveniles was upstream. Recaptures for females were upstream in 66% of cases, recorded mostly in spring and summer. For juveniles, upstream recapture rates were 60%, mainly in summer. Conversely, males most often moved downstream (75% of recaptures), usually during spring.

According to the Jolly-Seber capture-mark-recapture method, the mean *H. maximiliani* population size estimate

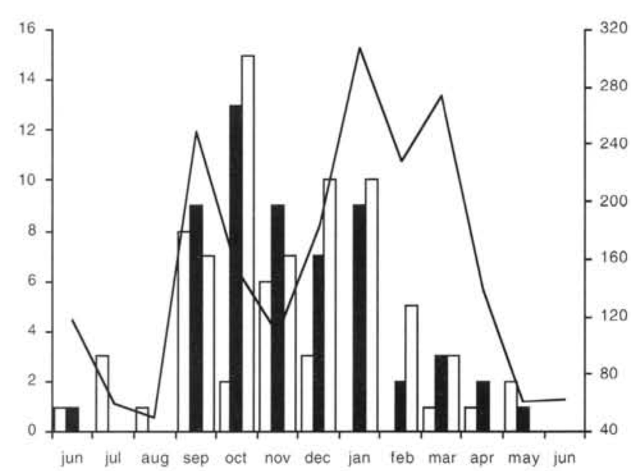

Figure 2. Number of males (open bars), females (black bars), and juveniles (shaded bars) of *Hydromedusa maximiliani* collected in streams at Parque Estadual de Carlos Botelho, southeastern Brazil, in relation to season and monthly rainfall (solid line), from June 1993 to June 1994 (horizontal axis). Left axis, number of turtles captured, right axis, monthly rainfall (mm).

was 139 turtles, ranging from 103 (actual number of captured turtles) to 445 (95% confidence interval = 155–1045 for the maximum population size estimate). Tests for violations of assumptions showed no significant differences in capture histories either between adult males and females ($\chi^2 = 2.37$, 1 df, $p > 0.05$) nor between adults and juveniles ($\chi^2 = 0.43$, 1 df, $p > 0.05$). The wide range in estimated population size was related to the wide variation in captures through the year (Fig. 2), in which two distinguishable patterns could be verified: a high capture rate in September – January (115 turtles), and low capture rates in June – August and February – June (26 turtles). Based on the upper estimate of 445 turtles inhabiting the 350 ha surveyed area, density is 1.3 turtles/ha. However, all turtles were captured in streams and the 10 surveyed streams had 2.3 ha of water surface. Therefore the density could be considered to be 193.5 turtles/ha of actual microhabitat, and with a mean body mass of 0.22 kg the biomass of *H. maximiliani* in these streams is 41.6 kg/ha.

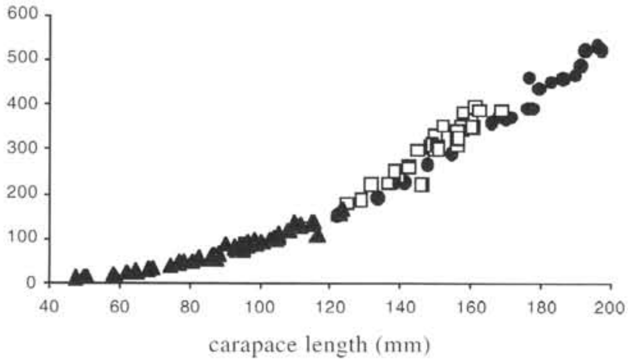

Figure 3. Relationship between carapace length (mm, x axis) and body mass (g, y axis) for males ($y = -521.4 + 5.28x$, $r = 0.99$, $p < 0.0001$, $n = 20$), females ($y = -447.7 + 5.00x$, $r = 0.94$, $p < 0.0001$, $n = 38$), and juveniles ($y = -99.2 + 1.98x$, $r = 0.97$, $p < 0.0001$, $n = 45$) of *Hydromedusa maximiliani* from Parque Estadual de Carlos Botelho, southeastern Brazil. Males = ●, females = □, juveniles = ▲.

DISCUSSION

The greatest capture rates of *H. maximiliani* took place during spring and summer seasons. Thus, it seems reasonable to conclude that these periods represented seasons of greater activity for this turtle. In most chelonian species, activity patterns are seasonal and are related to reproductive periods, with males actively searching for females, and females seeking nesting places (Ernst, 1976, 1986; Carrol and Ehrenfeld, 1978; Burbidge, 1981; Brown and Brooks, 1993; Kuchling, 1993). We found no direct evidence of nesting or mating in our population of *H. maximiliani* but several lines of evidence lead us to tentative conclusions regarding the reproductive season.

Yamashita (1990) related that a *H. maximiliani* female from PECB captured in November 1988 laid 3 eggs (40 x 25 mm) in January 1989, and Guix et al. (1992) X-rayed another female from PECB with 2 eggs (X-ray egg sizes: 42.1 x 21.3 mm and 42.0 x 21.1 mm) laid in captivity in December 1986 (F. Molina, *pers. comm.*). A clear activity increase of all turtles was verified from September to January, when captures reached nearly 82% (115 of 141 captured and recaptured turtles) (Fig. 2). This five-month period, a time of both high rainfall and increasing temperatures, included the spring and summer seasons. Juveniles were first found in September (Fig. 2). We collected our smallest juvenile (CL 47.3 mm, weight 15.0 g) in October. Two other small juveniles were also captured, one in November (CL 50.2 mm, weight 16.0 g) and the other in December (CL 49.6 mm, weight 16.0 g). These three small juveniles all had soft shells. Assuming that *H. maximiliani* mean egg size is 41 x 23 mm, it appears reasonable that these smallest turtles captured were presumably recent hatchlings. These sizes and weights of *H. maximiliani* hatchlings are very similar to those reported for *Phrynops gibbus* (mean CL 47 mm, mean weight 12.8 g [Mittermeier et al., 1978]). Thus, it can be hypothesized that nesting may occur during December and January and emergence during September and October. This suggests an incubation time of 250 to 300 days. Emergence occurring in spring, preceding the high rainfall months of December to March, is also observed in another neotropical chelid species, *Phrynops geoffroanus* (Guix et al., 1989; Molina, 1991). Thus, ephemeral rainy season streamlets could be used by hatchlings and small juveniles to reach permanent or developmental habitat. Indeed, in December a juvenile turtle (CL 112.0 mm) was captured in a small temporary pool along a trail that was dry during most of the year. This suggests that *H. maximiliani* makes opportunistic use of temporary or intermittent water flows for migrations. In this way, genetic interchange among turtles inhabiting several streams may be achieved.

Guix et al. (1992), in an earlier study at PECB, also collecting specimens by hand, noted that *H. maximiliani* density was greater (1 turtle/60 m) along wider and deeper streams than narrow, shallow ones (1 turtle/800 m). However, these may have been biased results. We found a positive correlation between rainy days and the number of turtles captured. Thus, along one stream surveyed during the present study, only 1 turtle was collected in July on dry days (< 0.1 mm rainfall/d) but 6 turtles in January on wet days (> 12 mm of rainfall/d). Sampling during dry days resulted in fewer turtles captured in relation to distance traversed than during rainy days.

Table 1. Spacing (meters) verified between adjacent males (M), females (F), and juveniles (J) of *Hydromedusa maximiliani* collected in streams at Parque Estadual de Carlos Botelho, southeastern Brazil, from June 1993 to June 1994. Results are expressed by mean ± SD (range, n).

	M	F	J
M	352.0 ± 233.0 (60–630, 5)	226.0 ± 167.8 (30–550, 16)	224.0 ± 236.0 (20–600, 8)
F	—	327.8 ± 196.3 (160–840, 10)	184.0 ± 156.9 (7–690, 37)
J	—	—	137.0 ± 98.1 (4–330, 13)

Galbraith et al. (1987) suggested territoriality and aggressive behavior between male *Chelydra serpentina* during reproductive periods. Harrel et al. (1996) noted aggressive displays between male *Macroclemys temminckii* during mating interactions. Aggressive interactions have also been observed between male *Phrynops geoffroanus* during mating (Molina, 1992). Dominance hierarchies were suspected in the latter species, since attacked animals did not display any counterattack behavior. Aggressive behavior was not observed between *H. maximiliani* of either sex but the mean distances found between males (352 m) and females (328 m) were significantly larger than those found between juveniles (137 m). Whether such increased spacing between males or females reflects territoriality, or whether aggressive displays may occur in this species is not known — this deserves further study.

Possibilities of bias in sex ratios in turtle populations must be taken into account. Sampling in different seasons may yield different apparent sex ratios. In a long-term study of *Trachemys scripta*, Gibbons (1990) reported sex ratio variation by year and season. Yamashita (1990) captured 15 *H. maximiliani* (2 males, 10 females, and 3 juveniles) in November 1988 at PECB, producing an apparent 1:5 male:female sex ratio. During the present study, in a single month (November 1993), 6 males, 9 females, and 7 juveniles were collected, giving a 1:1.5 sex ratio. Later in the study, a sex ratio of 5:1 was obtained in winter, but an opposite pattern in summer (1:6); in other seasons, the apparent sex ratio was 1:1.9 in spring and 1:1.5 in autumn. We concluded that the true sex ratio cannot be determined from observations in a single season.

Sampling methodology is another potential factor that could affect the sex ratio (Ream and Ream, 1966; Gibbons, 1990). Hand-collecting was utilized for *H. maximiliani* in that the streams surveyed were shallow (0.05–1.20 m depth) with clear water, and thus turtles could be easily visualized. But obviously turtles that were hidden would pass unrecorded. Expression of secondary sexual characteristics in smaller turtles also exerts great influence on sex ratio estimation (Gibbons, 1990). External morphological characteristics were utilized in discriminating sex in *H. maximiliani*. However, as observed in Fig. 1, overlap between the sizes of juveniles and females introduces subjectivity into our analysis of sex ratio. A long-term study of this population, utilizing various sampling methods (including traps) would be necessary for determination of a more accurate sex ratio.

The estimated high biomass of turtles in streams at PECB (193.5 turtles/ha and 41.6 kg/ha) was similar to figures obtained for *Trachemys scripta* in North America (190.3 turtles/ha, 40.5 kg/ha biomass; Iverson, 1982). This very high biomass per hectare may well attract predators. The only published information related to natural predators of *Hydromedusa* was given by Martuscelli (1995) who observed that a giant otter, *Pteronura brasiliensis*, ate an adult *H. tectifera* in the Atlantic rainforest of southern Brazil. During the study period, only one animal was found dead at PECB (a juvenile turtle, CL 100.4 mm). The area harbors many potential predators such as jaguar (*Panthera onca*), cougar (*Puma concolor*), and raccoons (*Procyon cancrivorus*) but the predator in this case was most likely the river otter, *Lutra longicaudis*, in that the pattern of predation (head, neck, anterior limbs, and internal organs eaten) was very similar to that reported by Martuscelli (1995) for *H. tectifera*. Furthermore, a river otter was observed swimming and searching for food in one of the streams surveyed for this study.

The geographic range of *H. maximiliani* encompasses the region of greatest development in Brazil and one of the most endangered ecosystems in the world. Although the montane Atlantic rainforest that the species inhabits is relatively inaccessible, some degradation of habitats is apparent. Constant Atlantic rainforest deforestation may lead to fragmentation and isolation of *H. maximiliani* populations. Rocha e Silva and Kischlat (1992) reported that a population of *H. maximiliani* from Tijuca National Park (Rio de Janeiro state) may now be extinct as a result of urban development.

In spite of excellent conservation of the ecosystem at PECB, where rivers and streams are protected by a wide forest canopy, and there is no human degradation, it would be excessively optimistic to claim that *H. maximiliani* is neither endangered nor threatened with extinction. Whether the spotty species distribution pattern, with some abundant local populations, as at PECB, represents depletion of a once-widespread species, or is a reflection of its cryptic life style, are questions that may be answered by research in other areas where the species occurs. In any case, it can be verified that this species is very closely associated with intact habitat with no human influence. Aquatic prey (insects and crustaceans) that form the bulk of the species' diet (Souza, 1995b; Souza and Abe, 1995) inhabit only rivers with a broad forest canopy and oxygenated, unpolluted water (Leandro G. Oliveira, *pers. comm.*) and may be susceptible to environmental changes. In the same way, even terrestrial prey such as *Fimoscolex sacii* (Oligochaeta) could eventually disappear because of their highly specific soil requirements (Righi, 1971).

We believe that the current conservation status for the species (according to the categories established by IUCN/SSC, 1994) must be *Vulnerable*. According to this category, a taxon is considered Vulnerable when facing a high risk of extinction in the wild in the medium-term future due to, for instance, a decline in area of occupancy, extent of occurrence, and/or quality of habitat (e.g., pollutants, deforestation). Our preliminary results must serve as a stimulus for future studies of *H. maximiliani* conservation and biology.

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