Reproduction, seasonal activity and growth of the coral snake, *Micrurus corallinus* (Elapidae), in the southeastern Atlantic forest in Brazil

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Abstract. Dissection of 360 specimens of the coral snake *Micrurus corallinus*, combined with data on captive individuals and field observations, provided information on the reproductive ecology of this elapid snake. Clutch size ranged from 2 to 12 eggs, and was correlated with maternal body size. Reproduction seems to be highly seasonal, with mating and vitellogenesis occurring at the onset of the rainy season, oviposition in mid rainy season, and hatching at the end of the rainy season and early dry season. Incubation in the laboratory ranged from 78 to 93 days. Neonates measured 177-197 mm snout-vent length and weighed 2.02-2.76 g. Growth of juveniles is quick, with both males and females attaining sexual maturity at an age of about 18 months. Seasonal patterns of surface activity seem to be related to age and sex.

Introduction

The fossorial coral snakes of the genus *Micrurus* comprise 53 species (Campbell and Lamar, 1989). These snakes are essentially a Neotropical radiation of the cosmopolitan front-fanged family Elapidae (Cadle and Sarich, 1981). Investigations by Quinn (1979) and Jackson and Franz (1981) of *Micrurus fulvius* from the southeastern United States are the main studies on the reproductive ecology of *Micrurus*. For neotropical species, reproductive data are meager (e.g. Duellman, 1978; Solórzano and Cerdas, 1988). Apart from scattered and anecdotal reports on reproduction (Azevedo, 1960, 1961; Amaral, 1978; Pontes and Di-Bernardo, 1988) almost nothing has been published on the reproductive ecology of snakes from the Atlantic forest in Brazil, especially for *Micrurus*. The present study provides information on seasonal reproductive timing, clutch size, neonate size, inferred growth rates and ages at sexual maturity and seasonal surface activity of the coral snake, *Micrurus corallinus* from a tropical region in Brazil.

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Materials and methods

A total of 360 specimens was examined from the collections of the Instituto Butantan (IB), Museu de História Natural Capão da Imbuia (MHNCI), and Museu de História Natural da Universidade Estadual de Campinas (ZUEC). The sample included only specimens from coastal Brazil, between São Paulo (23°20′) and Santa Catarina (27°20′). Snout-vent length (SVL) was measured and a midventral incision was made to determine reproductive status for each specimen. Males were considered mature if they had enlarged testes or opaque efferent ducts (see Shine, 1980a). Females were considered mature if they had either oviductal eggs or ovarian follicles > 5 mm (see Shine, 1980a). Diameter of the largest ovarian follicles or oviductal eggs were recorded in reproductive females (see Shine, 1977).

Data on the period of oviposition were obtained by maintaining gravid females in captivity. The eggs were incubated in moist vermiculite (T = 22-26°C). The snout-vent length (SVL) was recorded for neonates, and a few of them were weighed. Seasonal activity is based on collection dates and dates of reception of snakes in the Instituto Butantan laboratory.

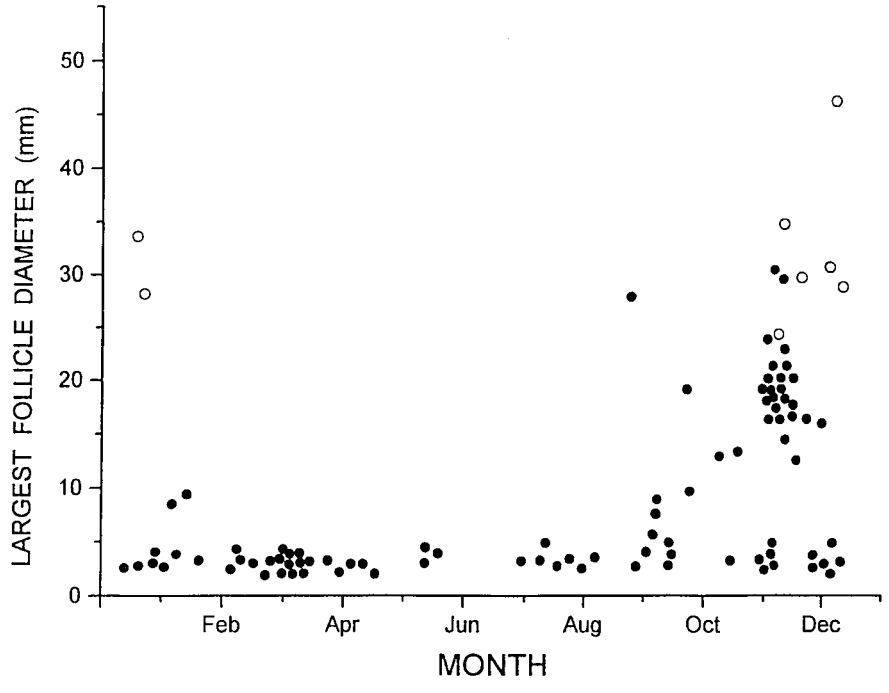

Figure 1. Seasonal variation in the diameter of the largest ovarian follicles in adult females of *Micrurus corallinus* from southeastern Brazil. Open circles represent oviductal eggs.

Results

Body size. The sample of 360 *Micrurus corallinus* comprised 125 mature male, and 194 mature females. The mature males averaged 563 mm SVL, s (standard deviation) = 73 (range 440 to 740), and mature females averaged 672 mm SVL, s = 125 (range 425 to 950).

Reproduction. Examination of ovarian follicles in dissected specimens indicates that *Micrurus corallinus* has a highly seasonal reproductive cycle (figs 1, 3), with vitellogenesis occurring at the onset of the rainy season (September to December) and oviposition in the middle of the rainy season (December and January). Egg-laying in 21 captive females confirms data from dissected specimens, since the first egg laying occurred on 14 December and the last on 27 January (fig. 3). Clutch sizes of 21 females ranged from 2 to 12 eggs, with a mean of 4.5 (s = 2.6). Clutch size was correlated with female body size (fig. 2). The period of egg incubation ranged from 78 to 93 days, $\bar{x}$ = 87, s = 5.7, n = 14.

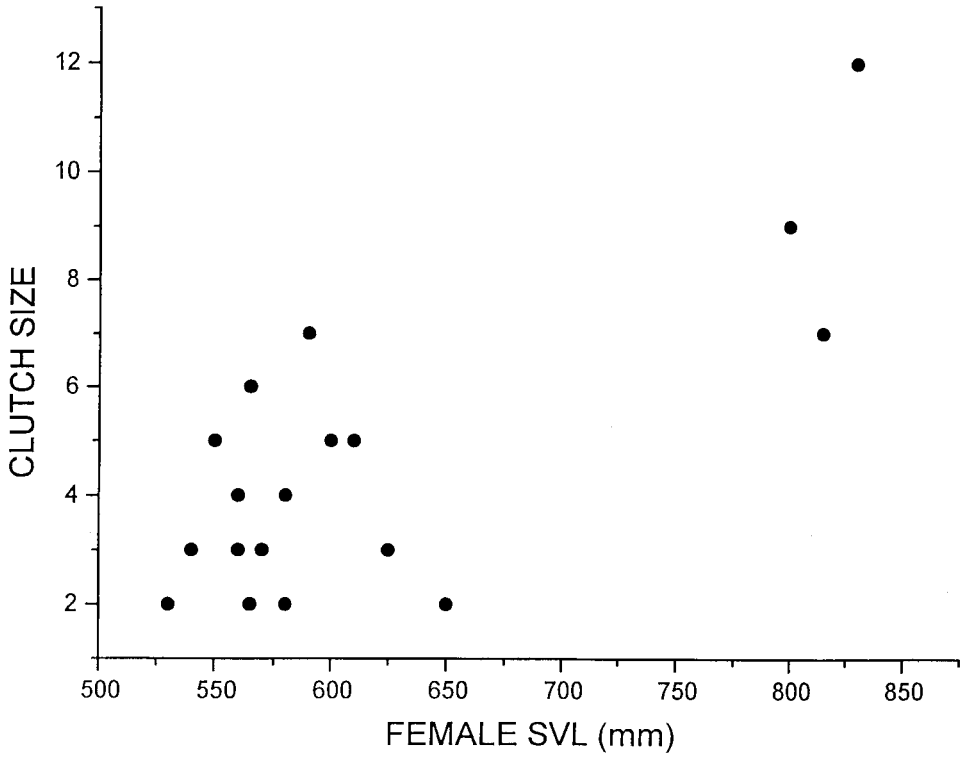

Figure 2. Relationship between female snout-vent length and clutch size in *Micrurus corallinus*, from southeastern Brazil (r_s = 0.45068, $P < 0.05$, n = 21).

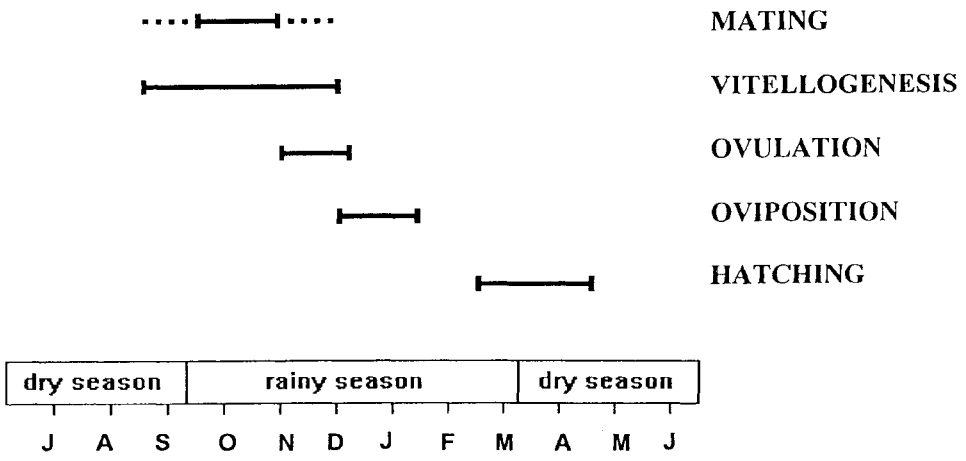

Figure 3. Stages of reproductive cycles of *Micrurus corallinus*, from southeastern Brazil.

Hatching. Neonates born in captivity averaged 184 mm in snout-vent length (177-197 mm, $s = 7.4$, $n = 52$) and mass averaged 2.40 g (2.02-2.76 g, $s = 0.27$, $n = 14$). Births occurred in March and April, except for one clutch in early May. The single field collected very young specimen caught in late February measured 185 mm SVL.

Mating. Copulation of *M. corallinus* was observed at 07:00h on 12 October 1989 in a cocoa plantation in the north Atlantic forest at Ilhéus, Bahia (A.S. Argolo, pers. comm.). The male measured 560 mm SVL and weighed 45 g (preserved), and the female measured 615 mm SVL and weighed 65 g (preserved). The female had vitellogenic follicles, the largest measuring 17.5 mm. Another male (520 mm SVL, 25 g) was observed near a female (700 mm SVL, 64 g), at 07:00h on 4 November 1991 in the forest at Caraguatatuba, São Paulo (B. Leduc, pers. comm.). Dissection of this female showed five vitellogenic follicles with the largest one measuring 10.0 mm. One male and one female were observed together at 10:00h on 18 October 1992 in Mogi-Guaçu, São Paulo (C.R. Demello, pers. comm.). The male measured 520 mm SVL and weighed 31 g, whereas the female measured 570 mm SVL and weighed 47 g. Palpation of this female revealed presence of four vitellogenic follicles. The data on the main stages of reproduction in *M. corallinus* are summarized in fig. 3.

Seasonal abundance. Juvenile *M. corallinus* are most often collected in the late rainy season and early dry season, especially in March and April (fig. 4). Adult males and females were collected during all months of the year (fig. 5), but were less common in the dry (April-September) than in the rainy seasons (October-March). This seasonal difference in number is highly significant ($\chi^2 = 73.539$, 1 df, $n = 282$, $P < 0.001$).

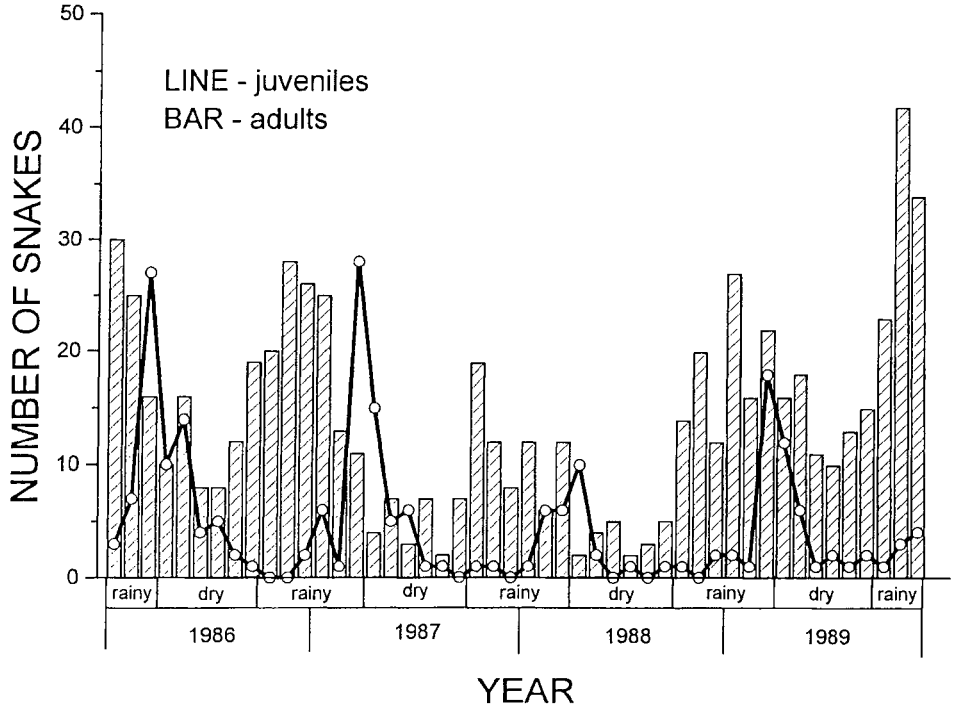

Figure 4. Seasonal abundance of adults (> 300 mm) and juveniles (< 300 mm) of *Micrurus corallinus* based on animals registered by the Instituto Butantan between 1986 and 1989. Juveniles (n = 223) and adults (n = 680).

The frequency of capture of adult males peaks in October whereas adult females show a peak in frequency in November (fig. 5).

Growth and sexual maturity. Seasonal distribution of body lengths reveals the growth pattern of juvenile *M. corallinus* (fig. 6). I infer that juvenile *M. corallinus* attain about 400 mm by the end of their first calendar year of birth. The smallest male (IB 1476) found with large testes and opaque efferent ducts was 440 mm in snout-vent length and was collected in December. The smallest female (IB 4603) found with ovarian follicles > 5 mm measured 490 mm SVL and was collected in November. One female (IB 772) with oviductal eggs, measured 425 mm SVL (no date of collection). Hence, both sexes probably attain sexual maturity at about 18 months of age.

Discussion

Reproduction. The Atlantic forest lies in a tropical area with seasonal rainfall and temperature (Nimer, 1989). Vitellogenesis in the early rainy season and ovulation at

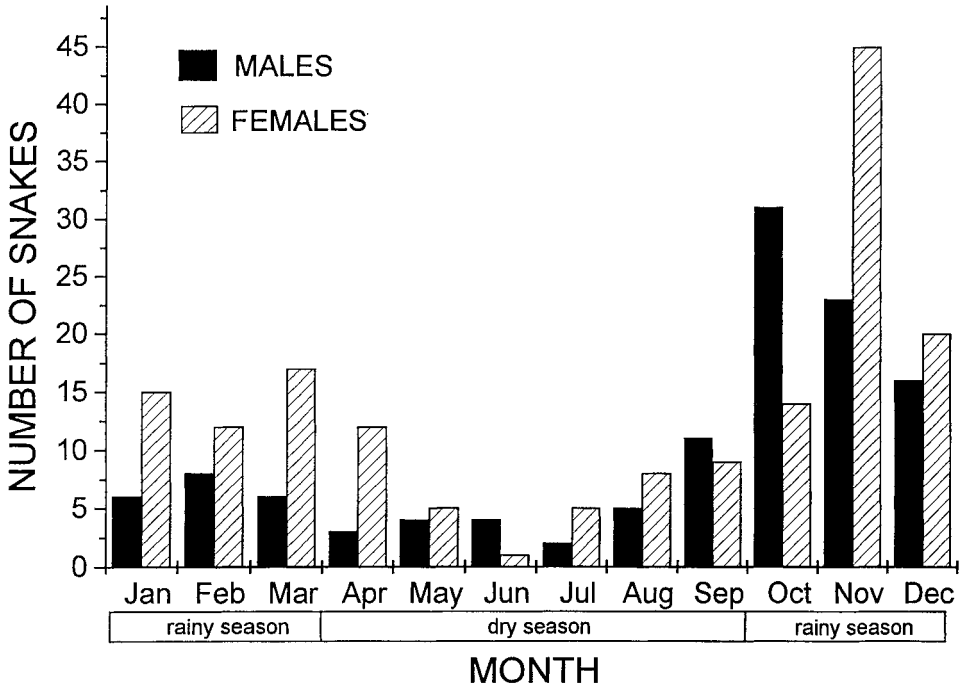

Figure 5. Seasonal abundance of male and female *Micrurus corallinus*, as shown by collection data for museum specimens from southeastern Brazil. Males ($n = 119$) and females ($n = 163$).

the onset of the rainy season ensure that *M. corallinus* females will be in reproductive activity when high and constant body temperatures are easiest to attain (see Shine, 1977). Since oviposition occurs in mid the rainy season, eggs will be incubated during the warmer months. This speeds embryonic development, and may reduce the incidence of anomalies (Vinegar, 1974). Recruitment of juveniles begins in mid-February and ends in mid-May. The diet of juveniles is similar to that of adults and consists of fossorial elongate vertebrates (Marques, 1992). The amphisbaenian *Leposternon microcephalum* is the predominant prey of *M. corallinus* (Marques, 1992). Birth of captive *Leposternon* from the Atlantic forest have been recorded in mid-February (C. Jared, unpubl. data), and Gans (1971) found eggs of *Leposternon* in initial embryonic stages in December. Thus, a conveniently sized prey is available for the juvenile *M. corallinus* from hatching.

The seasonal reproductive cycle of *M. corallinus* is very similar to that of *Micrurus fulvius* from southeastern United States (Quinn, 1979; Jackson and Franz, 1981) and to those of Australian elapids (Shine, 1977, 1980b). Snakes of the tropical zone show both seasonal and aseasonal reproduction (Fitch, 1982; Seigel and Ford, 1987). The tropical zone in Brazil contains several regions with different climates (Nimer, 1989). The suggested relationship between rainfall, temperature, and female reproductive ac-

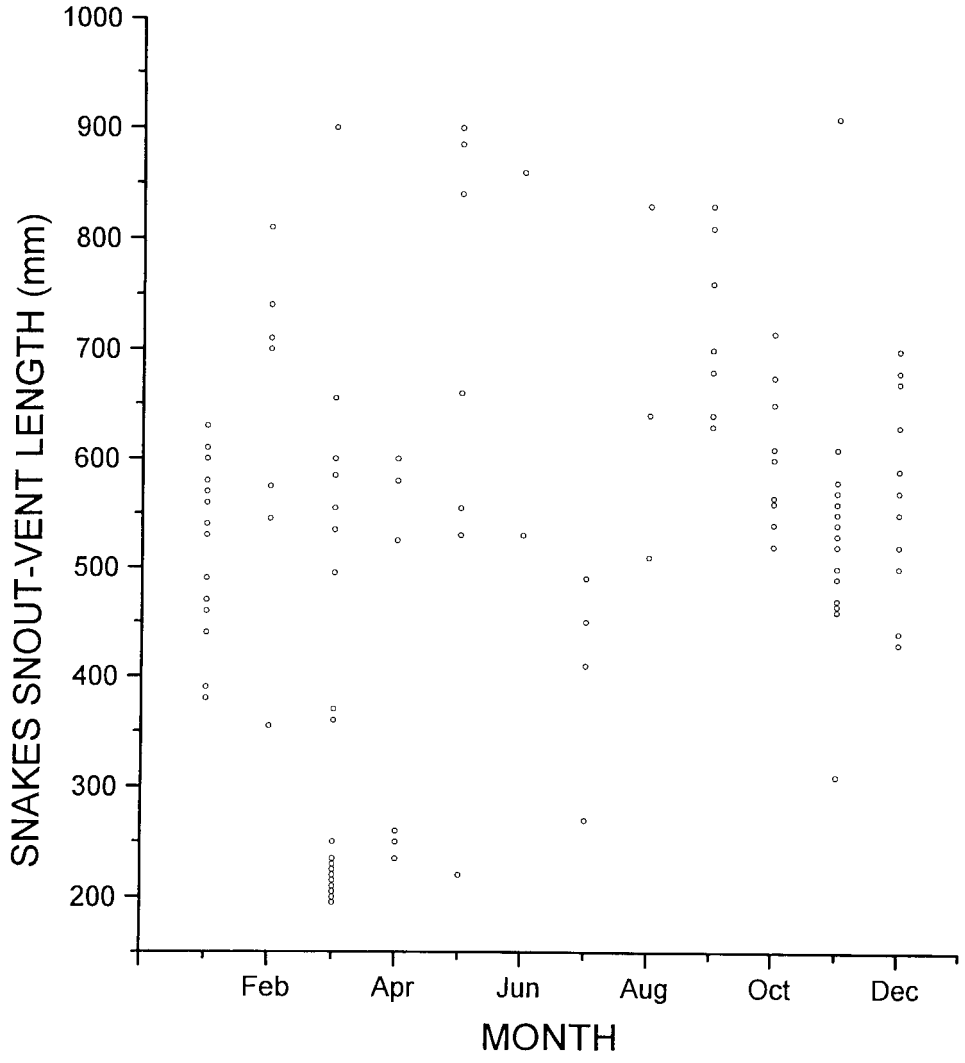

Figure 6. Seasonal distribution of body size of *Micrurus corallinus*, received in the Instituto Butantan from 1991 to 1992 ($n = 132$).

tivity indicates that rainfall and temperature may explain a considerable portion of the seasonality of reproduction in *M. corallinus*. However, data for the Amazonian species of *Micrurus* and the central American *Micrurus nigrocinctus* from localities that tend to be more aseasonal than the southeastern Atlantic forest indicate reproduction limited to a short period of the year (Duellman, 1978; Dixon and Soini, 1986; Solórzano and Cerdas, 1988; Martins, 1994). The available evidence for *Micrurus* suggests that seasonal reproduction may be characteristic of the genus and possibly independent of locality. Studies

on the reproductive cycles of additional species of *Micrurus*, especially in the tropical portion of the range are needed to test this hypothesis.

Seasonal activity. Analysis of the frequencies at which coral snakes are collected at different times of year reveals a seasonal activity pattern. Juveniles are most abundant in March and April, soon after hatching. An unimodal activity pattern characterizes the adult population of *M. corallinus* of the southeastern Atlantic forest. This coral snake is able to catch its fossorial prey at the ground surface (Marques, 1992) and its seasonal activity may be related to the surface activity of its main prey, amphisbaenians, during the rainy season (Marques, 1992). The peak of activity for males occurred in October, which corresponds to the recorded mating periods of *M. corallinus*. The peak of females in November corresponds to the time when they contain enlarged ovarian follicles. Thus, more intense surface activity in females may be due to their thermoregulatory needs during egg development (Shine, 1979; Gibbons and Semlitsch, 1987).

Growth and sexual maturity. Growth is quick in *M. corallinus*. Apparently, body length doubles during the first year. This high growth rate is similar to those of several Australian elapid snakes (Shine, 1978). Quinn (1977) estimates that males of *M. fulvius* mature at ages of 12 to 21 months, and Jackson and Franz (1981) calculated an age of 11 to 16 months for mature males. These authors disagree as to the age of sexual maturity in females: Quinn (1979), based on females with sperm in the oviduct, suggested that females may lay their first eggs at an age of about 21 months. Jackson and Franz (1981), based on females with expanded oviducts or enlarged ovarian follicles, estimated that females lay their first eggs at the age of 34 months. In most snakes females tend to mature later than males (Shine, 1978; Parker and Plummer, 1987). However, data for *M. corallinus* indicate that both males and females attain sexual maturity in about 18 months.

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