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ECOLOGY OF THE RIVER COOTER, *PSEUDEMYS CONCINNA*, IN A SOUTHERN ILLINOIS FLOODPLAIN LAKE

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Abstract. In Illinois, the river cooter, *Pseudemys concinna*, is a poorly studied endangered species. During 1994–1996, I quantified growth, population size and structure, and diet of a population from a floodplain lake in Gallatin County, Illinois. For males and females, growth slowed between 8–15 and 13–24 years, respectively. Comparisons between male and female curves revealed that growth parameters and proportional growth toward the asymptote were not significantly different, while asymptotes differed significantly. Differences of scute ring- and Sexton-aged individuals from von Bertalanffy model estimates were not significant through age five for males and six for females. I estimated that 153, 157, and 235 individuals were found in the lake at densities of 5.1, 5.2, and 7.8 turtles/ha in 1994, 1995, and 1996, respectively. Associated biomass estimates were 3.84, 3.94, and 5.90 kg/ha, respectively. The overall sex ratio was female-biased, whereas the adult sex ratio was male-biased; both were not significantly different from equality.

Key Words: Population ecology; Growth; Diet; Population structure; Testudines; Emydidae; *Pseudemys concinna*.

Ecological studies can elucidate specific life history traits which can be utilized in conservation and management planning. Many chelonian ecology studies emphasize population sizes and structures, home ranges, growth rates, feeding ecology, reproductive biology, and demographics (see Bury [1979] and Ernst et al. [1994] for reviews). Some have become the starting point for long-term life history studies (e.g., Congdon et al. 1993). However, most of these studies concern only a few common species (e.g., *Chelydra serpentina*, *Chrysemys picta*, *Trachemys scripta*), whereas many rarer or riverine species have been neglected. I selected *Pseudemys concinna* for study because of its state-endangered status in Illinois (Herkert 1992), and because of the scarcity of information concerning its natural history and ecology.

River cooters are large freshwater emydids, up to 43.7 cm in carapace length (Pritchard 1980), with intricate green, yellow, brown, and black reticulate carapacial patterns. Females attain larger sizes and greater carapace heights than males (Buhlmann and Vaughan 1991). The species ranges from eastern Texas, Oklahoma, and Kansas eastward to the Atlantic coast, and from southern Illinois and Indiana southward to the Gulf Coast (Ernst et al. 1994). Several isolated populations exist in West Virginia along the New and Ohio rivers (Buhlmann and Vaughan 1991; Seidel 1981; Seidel and Green 1982). This predominantly riverine turtle also inhabits lakes, ponds, oxbows, swamps, springs, large ditches, floodplain pools, and, occasionally, the coastal waters along the Gulf of Mexico (Ernst et al. 1994).

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At its northern range limit in southern Illinois, *Pseudemys concinna* is rather patchily distributed, with records from Alexander, Gallatin, Hardin, Jackson, Jersey, Massac, Randolph, Union, Wabash, and White counties (Cahn 1937; Garman 1890; Moll and Morris 1991; Smith 1961). Little is known about *P. concinna* in the state, or even range-wide (see Ernst et al. 1994 for review). The dearth of ecological information is due partly to the turtle's wary nature and herbivorous diet, which precludes capture with baited traps. Its relative rarity in Illinois is not a recent phenomenon. Cahn (1937) wrote that *P. concinna* was too rare to study, except over extended periods. In 1988, several *P. concinna* populations were located in a series of floodplain lakes and ponds along the Ohio River in Gallatin County (Moll and Morris 1991). Subsequent trapping (Dreslik and Moll 1996) suggested this was the largest known concentration of *P. concinna* in the state. In May 1994, I initiated an ongoing ecological study of *P. concinna* at Round Pond, the most accessible lake. Herein I report on some aspects of growth, population size and structure.

MATERIALS AND METHODS

Study Site

Located about 4 km west of the Ohio River, Round Pond (ca. 30 ha) is one of a chain of lakes stretching along the Ohio River floodplain in southeastern Gallatin County. Residents use the pond for recreational fishing and summer vacationing, as numerous small cabins and trailers occupy the western bank. A beach stretches along the southern shore and the remaining shoreline is bordered by floodplain forest. The irregular edges of the pond provide several shallow coves and bays (average depth 1.5 m). Emergent aquatic vegetation, predominantly spatterdock (*Nuphar luteum*), lines parts of the shore. During annual floods, the Ohio River connects with the lake directly or via a slough system.

General Methodology

I trapped Round Pond for eight trapping sessions (49 days) between 17 May 1994 and 1 September 1996. Turtles were captured with one to five single-set fyke nets (Vogt 1980). One net had a 1.1 m diameter mouth and 15.2 m lead and wings (3.8 cm mesh size). The remaining four nets had 0.61 m diameter mouths and two 7.6 m wings (3.8 cm mesh size). Nets were set parallel to the shoreline in approximately 1–1.5 m water depth, with the wings in a V-formation, and a buoyant 2 l plastic bottle was placed in the rear of the trap, to prevent the accidental drowning of turtles. I visited Round Pond for two censusing periods (9 days) in 1996 and three (20 days/yr) in each 1994 and 1995. Each turtle was marked with a unique combination of notches on the margin of the carapace (Cagle 1939), measured to the nearest mm with metric Vernier calipers, and weighed to the nearest g with Pesola® pull-spring scales or Ohaus® electronic balances. Standard measurements included mass, carapace length (CL), carapace width (CW), plastral length (PL), shell height (SH), and plastral scute lengths, along the mid-ventral seam (all measurements are maximum distances). For growth studies, rings on the left pectoral scute were measured along the mid-ventral seam to the nearest 0.01 mm. Males were identified by their elongated foreclaws and by having the cloacal vent extending beyond the posterior carapace margin. Turtles exceeding the PL of the smallest confirmed male but lacking male sex characteristics were categorized as females. Because of their endangered status, I did not dissect turtles to determine sex; questionable individuals were classified as juveniles.

Growth Analysis

The correlation between the seam length of each plastral scute and PL in each sex was detected using simple linear correlation. I used a modified Sergeev's formula (Sergeev 1937) to estimate PL at the time a ring was formed. The SAS nonlinear function (SAS 1982) was then used to fit the Sergeev data and mark-recapture data to the Fabens' interval method of the von Bertalanffy growth model (Fabens 1965; von Bertalanffy 1957). The equations used were:

$$PL_r = a - (a - PL_c)^{-kd},$$
$$PL = a\,(1 - be^{-kt}), \text{ and}$$
$$b = 1 - (h/a),$$

where PL_r is the length at recapture, PL_c is the length at first capture, d is the time interval between first and last capture in days, PL is the plastral length, a is the asymptote, b is a variable related to hatchling size, t is the time in days, e is the base of the natural logarithms, k is the characteristic growth parameter, and h is the mean estimated hatchling size. Model estimates were calculated until the largest sex reached 99% of its asymptotic size, then a Kolmogorov-Smirnov test (Zar 1996) was used to test the male and female curves for significant differences. The parameters of a and k for males and females were tested using t-tests (Zar 1996).

Age Estimation

Turtles were aged either by using scute ring counts, whenever the areola was present (Zug 1991), or to age six by Sexton's method (1959), because ring series in larger turtles were incomplete. Simple modification of the von Bertalanffy model yielded a formula to derive ages. The formula is represented as:

$$t = (\ln(((PL/a) - 1)/ -b))/ -k$$

This method is an estimate and should not replace actual known ages, but should merely be a reliable short-term tool to well-fitted von Bertalanffy relationships. This method only works if the estimated asymptote is greater than the largest captured individual. Finally, ages at or near the asymptote may be unreliable since growth slows in large or old turtles (Onorato 1996). I compared model aged and annuli- and Sexton-aged (Sexton 1959) individuals with a Kolmogorov-Smirnov test (Zar 1996). Ages and sizes of sexual maturity were based on the mean ages of deceleration from the von Bertalanffy model, then expected size at that age was calculated.

Population Attributes

Use of the Schnabel method (Schnabel 1938) has been questioned in chelonian studies due to

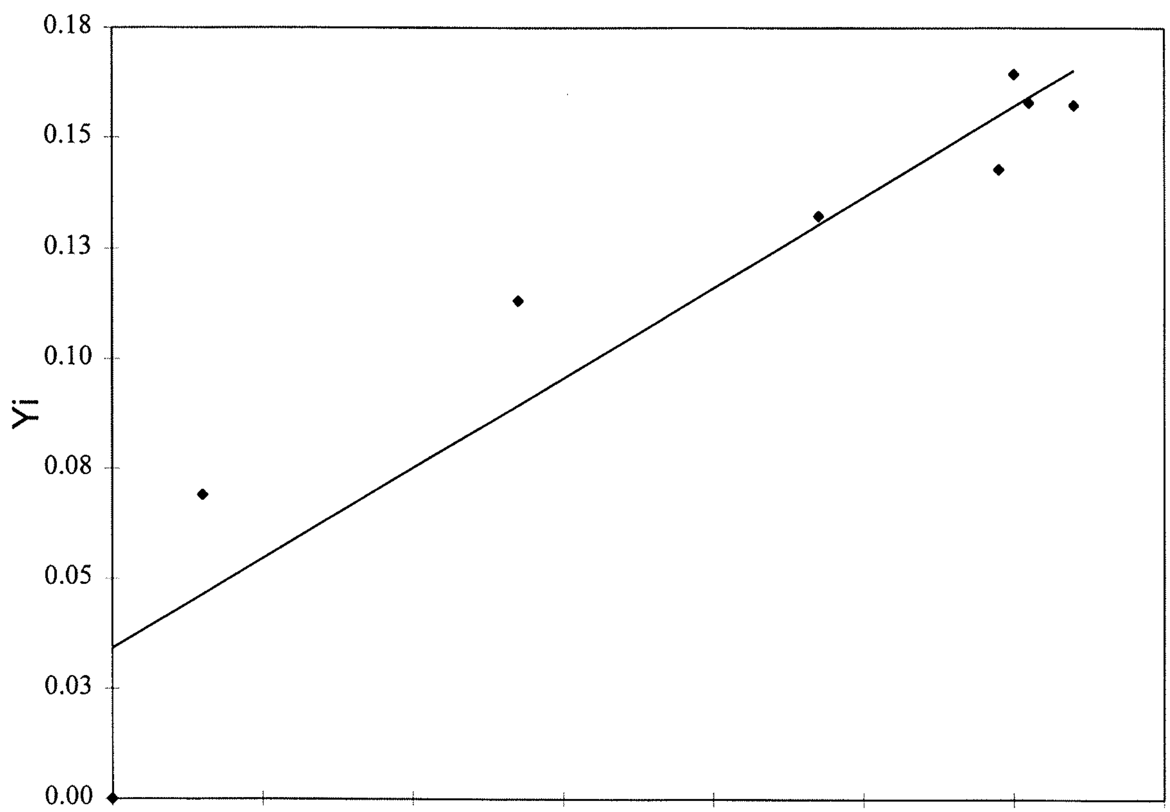

Figure 1. Scatter-plot and regression line for the proportion of marked individuals catch i (y_i) versus the number of marked individuals in the population before sample t (M_t) relationship on successive capture period of *Pseudemys concinna* at Round Pond, Gallatin County, Illinois during the Summers of 1994, 1995, and 1996.

failures in meeting population closure and equal catchability assumptions (Lindeman 1990), but multiple censusing can provide a validity test (Krebs 1989). Plotting the proportion of marked individuals catch i (y_i) versus the number of marked individuals in the population before sample t (M_t) should yield a line through the origin when the assumptions are met (Krebs 1989; Seber 1973). Data from this study revealed the linear relationship (Fig. 1) $y_i = 0.002M_t + 0.034$, $r^2 = 0.87$, with $p < 0.001$ for slope 0, and $p = 0.0509$ for the y-intercept = 0 ($n = 8$). Therefore, the Round Pond population does not violate the closure and equal catchability assumptions. Krebs (1989) and Seber (1973) recommended using the Schumacher and Eschmeyer (1943) regression modification of the Schnabel population estimator (Schnabel 1938), especially when the relationship between y_i and M_t is linear.

The formulae used are as follows:

$$N = (C_tM_t^2)/(R_tM_t),$$

$$\text{Variance } 1/N = ((R_t^2/C_t) - (R_tM_t)^2/(C_tM_t)^2)/(S-2),$$

$$\text{Standard Error } 1/N = (\text{Variance } 1/N)/(C_tM_t^2),$$

and

$$\text{Confidence Interval} = 1/N \pm t \text{ S.E.},$$

where C_t is the total number of turtles captured in sample t, R_t is the total number of recaptures in sample t, M_t is the number of marked individuals in the population before the t[th] sample is taken, S is the number of samples taken, and t is the Student's t-value at a respective alpha. Biomass was determined in kg/ha for each age and sex category by multiplying the mean mass of the age and sex category by the estimated number of individuals in each category. Finally, I summed all age and sex categories for a total populational biomass value.

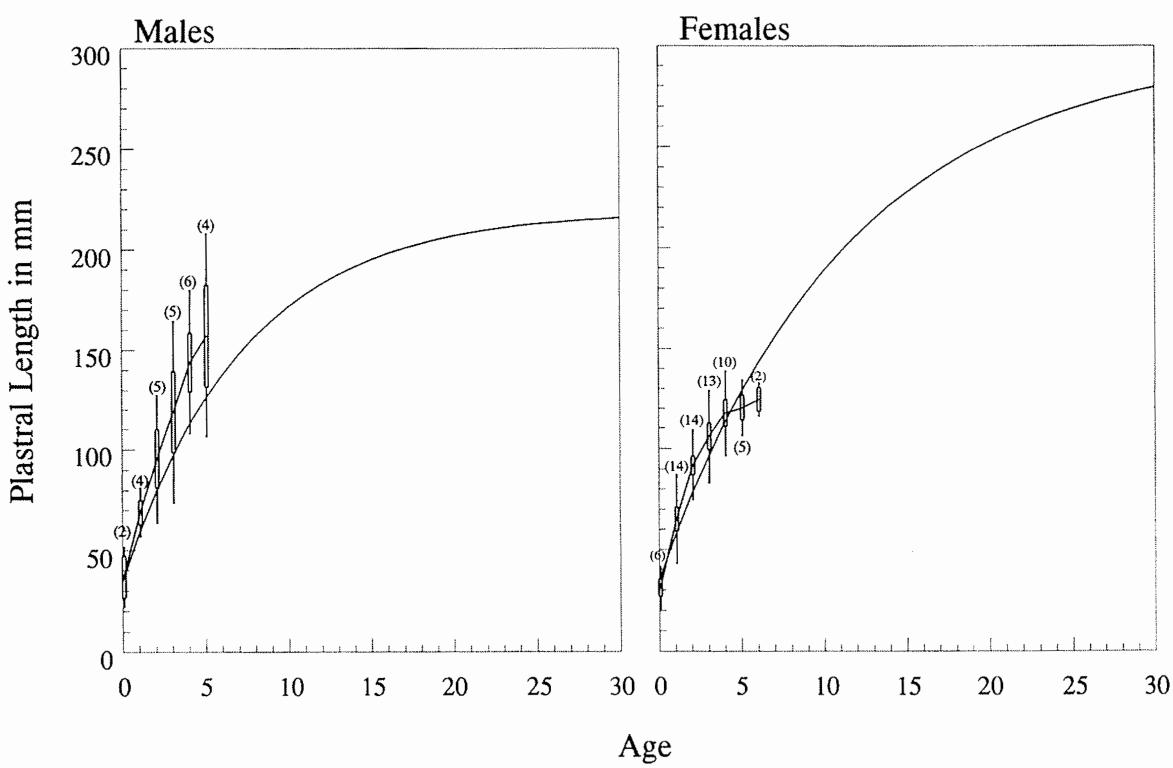

Figure 2. Composite representation of the von Bertalanffy growth trajectories (lines) calculated using Sergeev's formula and recapture data (male $n = 15$, female $n = 34$), and annuli-age and Sexton-aged individuals (expressed with high-low, mean and standard error boxes, numbers in parentheses are annuli sample sizes) of river cooters (*Pseudemys concinna*) captured at Round Pond, Gallatin County, Illinois.

TABLE 1. Descriptive statistics for morphological measurements taken from *Pseudemys concinna* captured at Round Pond, Gallatin County, Illinois, during the summers of 1994 and 1995, as described by sex/age category.

Measurement	Subadult Males	Mature Males	Subadult Females	Mature Females	Juveniles
Mass (g)					
Mean ± 1 *SD*	350.3±111.9	741.7±176.25	405.5±316.0	2461.7±514.7	156.4±46.9
Range (n)	160–460 (7)	450–1056 (17)	167–1810 (30)	1550–3250 (9)	78–262 (16)
CL (mm)					
Mean ± 1 *SD*	142.3±18.3	194.5±17.44	148.3±26.8	288.3±25.4	105.9±11.2
Range (n)	111–158 (6)	160–221 (17)	107–218 (32)	245–322 (13)	82–124 (15)
CW (mm)					
Mean ± 1 *SD*	114.7±12.3	147.8±10.0	117.8±16.4	207.6±14.0	89.9±8.1
Range (n)	93–126 (6)	131–161 (17)	94–162 (32)	188–227 (13)	72–104 (15)
PL (mm)					
Mean ± 1 *SD*	131.8±17.4	174.0±13.1	137.8±23.9	264.6±23.8	97.3±11.3
Range (n)	101–147 (6)	154–196 (17)	102–198 (32)	219–292 (13)	75–118 (15)
SH (mm)					
Mean ± 1 *SD*	51.0±4.9	64.6±4.7	54.6±9.0	100.9±11.7	41.8±3.2
Range (n)	43–55 (6)	57–77 (16)	42–78 (32)	85–125 (13)	36–48 (13)

RESULTS

Growth and Sexual Maturity

The highest correlation coefficients existed between PL and the gular (r = 0.98), abdominal (r = 0.95), and pectoral (r = 0.95) scutes. I used the pectoral scutes for growth calculations because they possessed the clearest rings. Curves for annuli- and Sexton-aged (Sexton 1959) turtles revealed rapid growth for males through year five and slower, steadier growth for females through age six (Fig. 2). Based on the von Bertalanffy equations, modified by Fabens (1965) for unknown ages (Fig. 2), males decelerated growth between 7 and 15 years (PL range 149–196, $\bar{x}$ = 176, n = 9) and females between 13 and 24 years (PL range 214 to 266, $\bar{x}$ = 249, n = 12). The von Bertalanffy formulae are:

$$\text{Male PL} = 219\,(1 - 0.842e^{-0.13615t}),\ \text{and}$$
$$\text{Female PL} = 299\,(1 - 0.884e^{-0.08724t}).$$

Results of the Kolmogorov-Smirnov test on male and female growth models revealed no significant difference with respect to proportional growth toward the asymptote (D_{max} = 0.1566, D_{crit} = 0.1848, n = 52). Comparisons between male and female asymptotes revealed a significant difference (t = 36.04, $p < 0.001$, n = 40), while characteristic growth parameters did not differ (t = 0.570, p = 0.2911, $1\text{-}\beta$ = 0.9746, n = 49).

Individual Size and Population Structure

With mean sizes at maturity estimated from the growth models above, a population size structure histogram (Fig. 3) was constructed containing age/sex categories, with relative proportions as follows in parentheses: juveniles (26.0%), subadult males (7.8%), mature males (20.7%), subadult females (28.6%), and mature females (16.9%). The length-frequency histogram (Fig. 3) was bimodal, with one mode encompassing subadults, juveniles and mature males, and a second containing mature females. The morphometric measurements of *Pseudemys concinna* were variable with subadult females showing the greatest variation (Table 1). Differences in PL between mature males and females was significant (t = 12.39, df = 17, p < 0.0001), demonstrating sexual dimorphism.

Sex Ratio and Age Composition

Among captured individuals, the adult sex

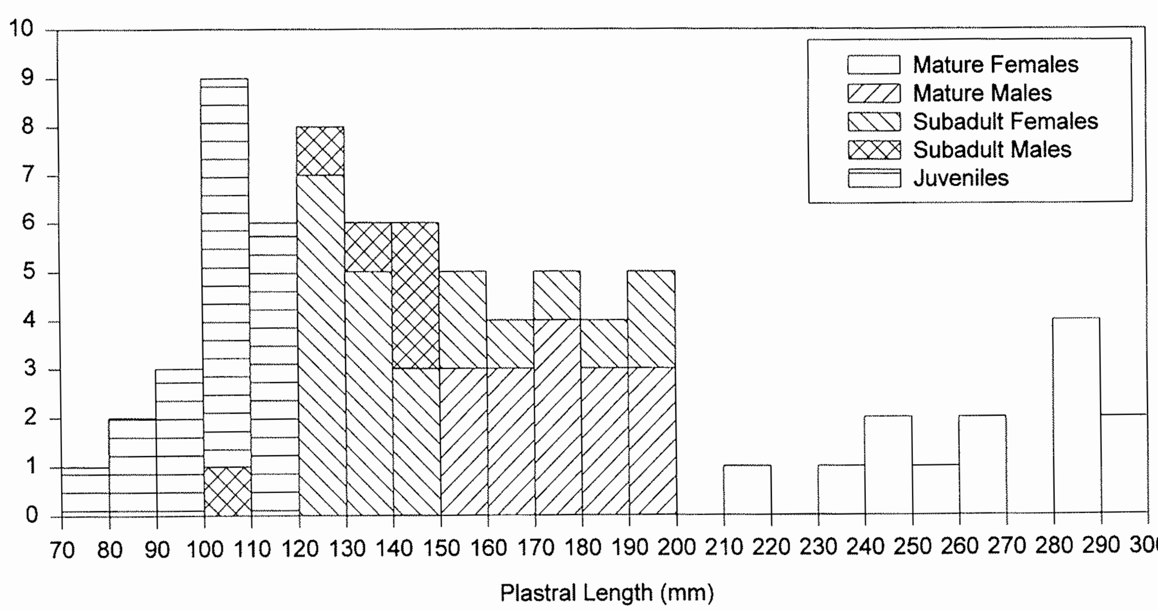

Figure 3. Population size-frequency histogram for *Pseudemys concinna* captured at Round Pond between 1994 and 1996. Only sizes at initial capture are included (n = 77).

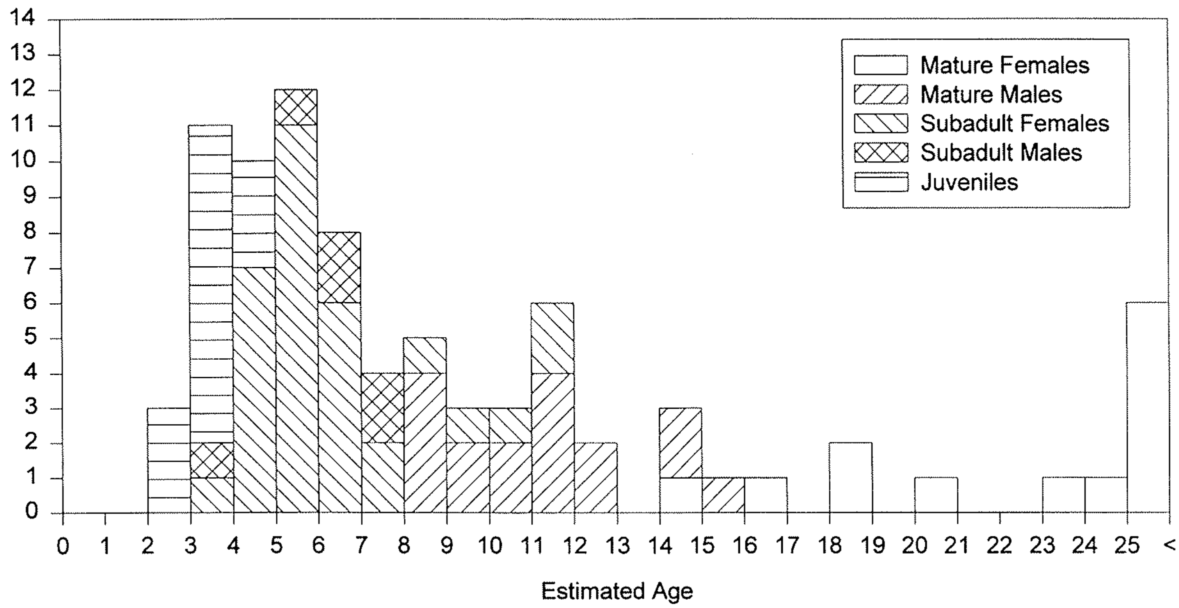

Figure 4. Estimated age-frequency histogram of *Pseudemys concinna* captured at Round Pond between 1994 and 1996 (n = 75), with ages estimated from a modification of the von Bertalanffy equation (von Bertalanffy 1957).

ratio was slightly, but not significantly, male-biased (1.2:1, 16 males:13 females, $\chi^2 = 0.31$, $p = 0.5775$). The total sex ratio was female-biased (1.6:1, 35 females:22 males, $\chi^2 = 2.965$, $p = 0.0851$), but also not significantly. Finally, the adult to immature (subadults and juveniles combined) ratio was significantly biased toward immature individuals (0.6:1, 29 adults:48 immature individuals, $\chi^2 = 4.688$, $p = 0.0304$). An estimated age-frequency histogram, based on the modifications to the von Bertalanffy equation, was constructed (Fig. 4), whereby mature females only occurred in estimated age brackets > 14 yr and males never exceeded 16 yr. The youngest estimated individuals of either sex occurred in the 2-yr age class. Of those individuals with areolae, seven were judged the same age using both methods, two were judged older using rings, and 16 were estimated as older based on the model (nine differed by 1 yr, five by 2 yr, and two by 3 yr). Results of the Kolmogorov-Smirnov tests indicated that ring- and Sexton-aged (Sexton 1959) curves did not significantly differ from model curves for males ($D_{max} = 0.0408$, $D_{crit} = 0.51926$, $p < 0.05$, $n = 6$) through age five, and females ($D_{max} = 0.3671$, $D_{crit} = 0.4834$, $p < 0.05$, $n = 7$) through age six.

Population Estimate, Density and Biomass

Of the 77 *Pseudemys concinna* captures, 17 (22%) were recaptured over the 3-yr study. The *P. concinna* population estimates and densities (turtles/ha) were 153 and 5.1, 157 (95% CI 109, n = 281) and 5.2, and 235 (95% CI 152, n = 525) and 7.8 during 1994, 1995, and 1996, respectively (confidence intervals for 1994 could not be calculated because the denominator in the variance equation reduces to zero). Biomass estimates (Table 2) revealed that mature females comprised the greatest biomass in all years.

DISCUSSION

Growth and Estimated Sexual Maturity

Jones and Hartfield (1995) reported that the pectoral scute was inadequate as a PL indicator in *Graptemys oculifera*, and Moll and Legler (1971) found the abdominal scute inadequate for *Trachemys scripta*. Therefore, it is crucial to verify correlations between plastral scute length and size before any estimations are made. In this study, correlation coefficients for the pectoral and abdominal scutes were 0.95 and 0.98, respectively, making either useful to back-calculate previous PLs lengths in *Pseudemys concinna*.

Statistical analysis suggests the von Bertalanffy model is a reliable estimator of growth in *Pseudemys concinna* through age 6 for females and age 5 for males. Similar analyses of chelonian growth have effectively used the von Bertalanffy model (Dunham and Gibbons 1990; Frazer and Ehrhart 1985; Frazer and Ladner 1986; Frazer et al. 1991, 1994; Iverson 1991; Jones and Hartfield 1995; Lindeman 1996; Lovich et al. 1990; Mushinsky et al. 1994; Onorato 1996; St. Clair et al. 1994; Zug and Parham 1996), and all reveal that growth rates are most rapid for juveniles. Interval estimated and known-age curves for *Trachemys scripta* were not significantly different (Frazer et al. 1990) as were back-calculated and interval-estimated curves in *Graptemys oculifera* (Jones and Hartfield, 1995). Therefore, we would expect no difference between known-age and back-calculated curves. If this is true, it lends more creedence to the *Pseudemys concinna* curves depicted herein.

Congdon and van Lobel Sels (1991) showed that growth of female Blanding's turtles (*Emydoidea blandingii*) slowed between 10–20 yrs of age. This deceleration in *E. blandingii* coincides with the female's ages of sexual maturity, 14–20 yrs (Congdon et al. 1993). If decelerating growth signals onset of sexual maturity in turtles, then the female *Pseudemys concinna* may mature between 13–24 yrs. of age and males between 7–15 yrs. of age. Thus, the minimum estimated PLs at estimated sexual maturity, based on curve deceleration, for Round Pond *P. concinna* are 149 mm for males and 214 mm for females. For males, the estimate falls very close to the sizes when foreclaw elongation becomes evident. Excluding two unusually small males (101 and 123 mm PL), the first males with secondary sexual characteristics correspond to an age of 6 yr (134 to 138 mm PL). D. R. Jackson (pers. comm., 1996) has found that *P. concinna suwanniensis* males exhibit foreclaw elongation 1 yr before sexual maturity. The Round Pond population may also exhibit this trend, however, only further analysis of sexual maturity can confirm this. Estimates for both sexes suggest female *P. concinna* mature later and at greater sizes than males. However, estimations of ages and sizes of sexual maturity must be corroborated with actual observations derived from a comprehensive, long-term, life history study.

Since the proportional growth toward asymptotic size and characteristic growth parameters were insignificantly different for both sexes, they essentially possess identical growth curves, with only asymptotic sizes differing, suggesting some selective factor has caused females to continue growth, most likely the fecundity advantage conferred to large females (Gibbons and Lovich, 1990).

Population Density, and Biomass

Of the population estimates for 1994–1996, the 1995 estimate of 157 appears most reliable because of the narrow confidence limits; my sampling effort was greatest this year. The corresponding estimated density of 5.2 turtles/ha and biomass of 3.9 kg/ha fall between the only other published estimates, 0.7 and 2.3 turtles/ha (no biomass reported) for three sites along the New River (Buhlmann and Vaughan 1991) and 170 turtles/ha and 384.2 kg/ha for Rainbow Spring Run (Iverson 1982, from data in Marchand 1942). The variation of estimates suggests the low density in Illinois and West Virginia may be due to their location near the northern range limit. However, other factors, such as habitat productivity, may be more important than latitude in dictating turtle density and biomass.

Population Structure, Sex Ratio, and Age Composition

The absence of individuals with < 70 mm PL may reflect trapping biases (either fyke net throats would allow smaller individuals to escape or juveniles inhabit water too shallow to place fyke nets) or juveniles in the Round Pond population are truly rare. The former is more likely since juveniles of other emydid species are seen basking and swimming within aquatic woody vegetation in shallow water, and smaller turtles from other species are also absent from capture. If *Pseudemys concinna*'s wary nature is also true of juveniles, then individuals would easily be missed in the heavily vegetated shallow water. The adult sex ratio at Round Pond is slightly but not significantly skewed toward males (1.2:1) and is similar to a Florida population (1.16:1) of *P. concinna* (Jackson 1970). Also, the overall sex ratio of Round Pond (1.6:1) and New River (1.9:1; Buhlmann and Vaughan 1991) are similar. Several factors can bias sex ratio calculations, especially season and trapping method

TABLE 2. Relative biomass estimates (kg/ha) for each age/sex category from 1994, 1995, and 1996 for *Pseudemys concinna* captured at Round Pond, Gallatin County, Illinois.

	1994	1995	1996
Juveniles	0.21	0.21	0.32
Subadult Males	0.14	0.14	0.21
Mature Males	0.78	0.80	1.20
Subadult Females	0.59	0.61	0.91
Mature Females	2.12	2.18	3.26
Total	3.84	3.94	5.90

(Gibbons 1990; Lovich and Gibbons 1990).

Recent criticisms have arisen concerning the efficacy of scute ring age estimation in wild and captive-reared turtles (Litzgus and Brooks *in press*; Tracy and Tracy 1996) because of their subjectivity. When ring counts are compared to respective individuals aged by the von Bertalanffy model, the results are similar. Nine individuals differed by one year; because eight of these represented two different cohorts, the differences may reflect cohort-specific growth patterns. Since the model estimates mean size at an age, the possibility of cohorts experiencing different environmental conditions affecting growth is entirely plausible; this can only be tested by creating cohort-specific curves. Because the differences between ring- and Sexton-aged individuals were insignificant from the Fabens (1965) unknown-age model, it suggests that ring-based and Sexton's method (Sexton 1959) both work for aging *P. concinna* at Round Pond. Further testing will be required to determine when, and if scute rings cannot properly age individuals. Most likely this will be near the asymptote of each curve.

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