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Growth characteristics of Wood Ducks from two southeastern breeding locations.—Recently, advances have been made in the application of the Richards sigmoid model to the study of avian growth. These studies (White and Brisbin 1980, Brisbin et al. 1986) have provided a means of evaluating bird growth by making independent estimates of the three major components of the growth process: (1) *size*, or asymptotic limit approached, (2) *rate*, a measure of the total amount of time required for growth to be completed, and (3) *shape*, a quantity which expresses the specific path or trajectory taken by the growth process to approach asymptote within the time constraints of the total growing period. In this reparameterized process error model, these three characteristics are quantified by the parameters W_{∞} , T, and m, respectively (Brisbin et al. 1986).

Preliminary studies that used these procedures to analyze the growth of waterfowl and other organisms have suggested that, following exposure to a variety of environmental stressors, changes in growth curve shape (m) are more likely to occur than are changes in either size (W_{∞}) or growth rate (T) (Brisbin et al. 1986). Fendley and Brisbin (1977), however, found that sigmoid growth characteristics of captive-reared Wood Ducks (*Aix sponsa*) also can vary according to the breeding location. In that study, growth rates were found to vary between birds from different locations, but no difference was found in asymptotic sizes. There was also a suggestion of a change in the shapes of the growth curves, as evidenced by a shift in the ages at the point of inflection, although this could not be tested conclusively as analyses in that study were based on the use of the logistic rather than the Richards sigmoid model. (The logistic model is a special case of the Richards model that is obtained by constraining $m = 2$, and therefore changes in the value of m cannot be detected.)

We report here the use of the reparameterized Richards process error model to analyze the sigmoid growth characteristics of captive-reared Wood Ducks that were collected as

TABLE 1
 PROBABILITY LEVELS FOR MULTIVARIATE (MANOVA) AND UNIVARIATE ANALYSES OF ASYMPTOTIC WEIGHT (W_{∞}), GROWING PERIOD (T), AND CURVE SHAPE (m) FOR RICHARDS SIGMOID MODELS FOR CAPTIVE-REARED WOOD DUCKS FROM TWO BREEDING LOCATIONS (UNDERLININGS EMPHASIZE SIGNIFICANT EFFECTS [$P < 0.05$])

Source of variation	MANOVA	W_{∞}	T	m
Sex	<u>0.003</u>	<u><0.001</u>	0.651	0.458
Breeding location	<u>0.003</u>	<u><0.001</u>	0.626	0.386
Sex × breeding location	0.464	0.221	0.398	0.893

hatching eggs from nest boxes from two breeding locations approximately 220 km apart. Eggs were collected from Clemson, Anderson County, South Carolina (34°41'N, 82°50'W), and Rome, Floyd County, Georgia (34°15'N, 85°10'W). Details concerning the collection of eggs, incubation, hatching, rearing, and weighing of birds used in this study are in Mayack et al. (1981), who report the results of chronic cadmium feeding in combination with two levels of dietary protein (18 and 30%). Data for the Clemson ducklings of the present study were those collected for the control birds used in the study by Mayack et al. (1981). All ducklings were combined in rearing pens and raised under identical conditions.

Growth data for body weights of the ducklings were fit to the Richards process error model defined by the equation:

$$\frac{W_{i+1} - W_i}{t_{i+1} - t_i} = \frac{2(m+1)}{T(1-m)} (W_{\infty}^{1-m} W_i^m - W_i) + e_i$$

where: W_i is the body weight at time t_i , W_{∞} is the asymptotic weight, T is the overall growing time, indicative of growth rate, m is the Richards shape parameter, and e_i is the stochastic error at time t_i .

Further details concerning the derivation of the parameters m and T are provided by Brisbin et al. (1986), and a description of the incorporation of e_i into the model is provided by White and Brisbin (1980).

The three parameters (W_{∞} , T, and m) were estimated for each duck and then treated as the vector (W_{∞} , T, m) for multivariate analysis of variance (MANOVA) (Brisbin et al. 1986). For the multivariate analysis of variance, a fixed effect model was used, containing effects for sex, breeding location, and their interaction. Parameter estimation and MANOVA procedures were carried out using procedures NLIN and GLM, respectively, of the Statistical Analysis System (Sas Institute Inc. 1982).

Multivariate analyses revealed that both sex and breeding location significantly affected the growth of the Wood Ducks. The interaction between these two variables failed to show significance in either the MANOVA or univariate cases (Table 1). Univariate analyses indicated that W_{∞} was the only growth parameter that differed significantly between the sexes and breeding locations. Male ducks tended to grow to larger asymptotic weights than females, and males and females from Clemson were larger than those from Rome (Table 2).

The pattern of differences in growth between the sexes of Wood Ducks, as reported here, was similar to those reported previously (Brisbin et al. 1986), using these same analytical procedures to study the growth of this species. In each case, the growth of the sexes differed significantly, with males growing to larger asymptotic weights than females. In no case has sex ever interacted significantly with any other primary treatment variable. Thus, with respect

TABLE 2
MEANS OF ASYMPTOTIC WEIGHT (W_{∞}), LENGTH OF GROWING PERIOD (T), AND CURVE SHAPE (M) FOR RICHARDS SIGMOID MODELS FOR CAPTIVE-REARED WOOD DUCKS FROM TWO BREEDING LOCATIONS

Sex	Breeding location	N ^a	W_{∞} (g)	T (days)	m
Male	Clemson, South Carolina	21	520.0 (7.8) ^b	55.4 (10.6)	1.25 (28.2)
	Rome, Georgia	17	469.7 (5.6)	57.8 (12.4)	1.35 (25.7)
Female	Clemson, South Carolina	24	469.7 (10.6)	57.4 (15.8)	1.34 (31.8)
	Rome, Georgia	10	443.6 (4.7)	56.6 (14.2)	1.42 (35.1)

^a Number of estimates of each parameter determined for individual birds.

^b Mean (% coefficient of variation).

to growth, Wood Ducks of either sex seem to respond similarly to external stressors and environmental variables such as breeding location.

The lack of significant differences in either overall growing times or growth curve shapes between birds from the two locations (Tables 1 and 2) suggests that although ducklings from the Clemson population tended to add more body weight per day, they still showed the same timing of maximum growth rate (point of inflection of the growth curve) as did birds from the Rome location. At both locations, time of maximum growth (point of inflection) occurred at approximately 19–20 days of age. An average shape parameter of 1.33, pooled for birds of both sexes from both locations, suggests a curve shape intermediate between the Gompertz ($m \rightarrow 1.0$) and logistic ($m = 2.0$) growth models.

With the exception of laying and early incubation, all birds used in this study were produced and raised under identical captive conditions. This strongly suggests that the differences observed in growth asymptote were genetic in nature. Some environmental influence might have taken place, however, if differential habitat quality or stress affected egg quality in the study areas and thus duckling nutrient reserves at hatching (Marcstrom 1966). Localized genetic differences, on the other hand, might be minimized by the relatively short distance between the study sites, and by the fact that Wood Ducks tend to pair on the wintering grounds after which the drake tends to return with the hen to breed in her natal area (Grice and Rogers 1965).

Our finding of no significant differences in either total growing time or shape of the growth curves is in contrast to the earlier findings of Fendley and Brisbin (1977). This suggests that allowing growth curve shape to vary freely may change the conclusions from those which would have been reached by analyses in which curve shape was not allowed to vary (e.g., the monomolecular, logistic, Gompertz, von Bertalanffy).

Finally, and perhaps most significantly of all, is the fact that even when quantified and allowed to vary, growth curve shape in the present study did not differ between treatment groups. In every other study which has used the curve-fitting and analytical procedures described here, curve shape has been the most frequent to differ of all the growth parameters tested (Brisbin et al. 1986). Our findings indicate that there is no intrinsic mathematical artifact that causes such variation in curve shape between treatment groups. Furthermore, the results presented here support the contention (Brisbin et al. 1986) that growth curve shape represents a "first line of defense" by which the growth strategy of an organism may respond to externally imposed environmental stress or perturbation. As all ducklings used in this study grew under identical environmental conditions that were aimed at minimizing stress and optimizing the environmental conditions for growth, we expected that, within

each sex, growth curve shape should not vary between groups from different breeding locations. Under these conditions, however, differences in asymptotic size could still be expressed between the sexes and could be evaluated in a straightforward manner.

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Effect of snow cover on starling activity and foraging patterns.—Winter is often a time of high mortality for temperate bird populations (Dunnett 1956, Gibb 1960). Low food availability may be worsened by periods of prolonged snow cover (Hamilton 1949). Moreover, a bird must be able to acquire more food during the short winter day than at any other time to maintain its body weight; lighter birds suffer significantly higher mortality than their heavier conspecifics (Kendeigh 1934).