ROUGH DRAFT

10/4

Jerry - This is something Barry was interested in working on before he left. I'd like to carry it through for publication, if possible. When you have the time, maybe you could look it over. The intention is to be a note in J. of Herpetology, or Copeia.

George

Growth Curves for green turtles, *Chelonia mydas*, at Pearl and Hermes Reef

By

Barry K. Choy and George H. Balazs

Work with wild stock green turtles *Chelonia mydas*, in Hawaii, has progressed to a point where there is enough tag and recapture data to formulate growth curves. As a pilot project data from one of the North Western Hawaiian Islands, Pearl and Hermes Reef, was used in growth models, for more information on the location and history of Pearl and Hermes see Amerson et. al. (1974). Between the years of 1964 and 1988 slightly more than 500 turtles were tagged at Pearl and Hermes Reef, of these 18 tag recoveries were made with the morphometric data necessary for the formulation of mathematical growth models for turtles associated with the area. These growth models will serve as another facet of information useful in the conservation and recovery of the species.

Aging turtles by bone or other methods ( ) is without verification and/or refinement as of yet, thus best estimates of age using available data can be achieved mathematically using Fabens (1965) version of the von Bertalanffy growth model, where absolute age does not have to be known. Growth curves as a result of this model for *Chelonia* and *Caretta* in Florida, and *Chelonia* in the U.S. Virgin Islands, is provided by Frazier and Ehrhart (1985), and Frazier and Ladner (1986) respectively. In Frazier and Ladner (1986) a comparison between the von Bertalanffy and Logistic models ability to fit the data revealed a better fit of the data to the von Bertalanffy model, but cautioned that the data fit both models well for the given data (which does not represent the smaller sizes where the curves differ the most).

Straight carapace measurements (**x** = 37.4 - 86.8cm) from tag and recapture data of wild green turtles (N = 18) at Pearl and Hermes Reef (Choy and Balazs, 1989) was fit to a von Bertalanffy and Logistic growth models. Intervals between time of original tagging and recaptured *Chelonia* at Pearl and Hermes Reef ranged from 0.96 to 5.00 years. Turtles were captured while foraging the reef flats from a boat by either hand capture or with the use of a scoop net, and also tagged while basking on the beach.

Fabens (1965) version of the von Bertalanffy model~~, where x is a~~ is

$$x = a(1 - be^{-kt}) \tag{1}$$

where x is a length measurement, in this case straight carapace length, a is the asymptotic length, b is a parameter related to length at time t = 0, k is a constant growth rate, and t is some age at which the measurement x is expected. To get estimates for the parameters **a**, **b**, and **k** Fabens (1965) used some measurement y at time t + d as follows:

$$y = a(1 - be^{-k(t + d)}) \tag{2}$$

$$= a(1 - be^{-kt}e^{-kd})$$

$$= [a(1 - be^{-kt})]e^{-kd} + a - ae^{-kd}.$$

Substituting **x**,

$$y = xe^{-kd} + a - ae^{-kd}$$

$$= a - (a - x)e^{-kd} \tag{3}$$

making substitutions for **x** and **y** with R and **T** respectively where **T** is the straight carapace length of a turtle at time of original tagging and R is the length at time of recapture yields the expression,

$$R = a - (a - T)e^{-kd} \qquad (4)$$

$$dR/da = 1 - e^{-kd} \qquad dR/dk = kae^{-kt} - kte^{-kt}$$

which gives an expression for which a and k can now be estimated using least squares nonlinear regression (SAS Inc., 1979; utilizing NLIN procedure, Marquardt algorithm, and providing dR/da and dR/dk) best fitting the model for given data R, **T**, and **d** (Table. 1). Substituting S_0 for **x** in equation 1 and providing a t value which would correspond to time of hatching **t** = 0,

$$S_0 = a(1 - be^{-kt})$$

for $$t = 0$$

yields $$S_0 = a(1 - b)$$

solving for b $$b = 1 - S_0/a \qquad (5)$$

with S_0 being the straight carapace length of a hatchling (Balazs 198).

Similarly the logistic model (Schoener and Schoener, 1978),

$$x = a/(1 + be^{-kt}) \qquad (6)$$

with the same parameters as the von Bertalanffy model, can be rearranged in to a form,

$$R = aT/[T + (a - T)e^{-kt}] \qquad (7)$$

$$dR/da = [(T + ae^{-kt})T - aT(e^{-kd})]/[(T + ae^{-kd} - Te^{-kd})]$$

$$dR/dk = [-aT(-kae^{-kd} + kTe^{-kd})]/[(T + ae^{-kd} - Te^{-kd})^2]$$

where R and T are also the same as the R and T in the von Bertalanffy model. For t = 0 and solving equation 6 for b yields:

$$b = S_0/a - 1 \qquad (8)$$

where S_0 is the same as defined for the von Bertalanffy model. Utilizing the NLIN procedure (SAS Inc, 1979) again, a least squares nonlinear regression could then be performed which gave the best estimates of **a** and k from which **b** could be computed (equation 8) and applied to equation 6. Values for t could then be input into equation 6 and corresponding length values calculated and plotted (Lotus,).

Table 1.--Striaght Carapace Measurement(cm) at Original Tagging and Recapture of Chelonia at Pearl and Hermes Reef.

Tag	Date R	Date T	Years	SL(R)	SL(T)	Growth	cm/yr
7095	06/27/88	06/30/83	5.00	41.1	37.4	3.70	0.74
8283	08/26/86	07/13/83	3.12	41.5	39.5	2.00	0.64
7093	06/14/88	06/30/83	4.96	43.5	40.0	3.50	0.71
5582	07/29/84	08/09/81	2.97	49.5	47.2	2.30	0.77
6990	07/16/84	05/12/83	1.18	49.9	48.4	1.50	1.27
7000	07/12/84	05/24/83	1.14	50.7	49.7	1.00	0.88
6982	07/16/84	05/11/83	1.18	51.3	49.7	1.60	1.35
7353	06/25/84	07/11/83	0.96	50.0	50.0	0.00	0.00
5570	05/30/88	05/24/83	5.02	55.0	50.0	5.00	1.00
6973	07/23/84	05/07/83	1.21	51.9	50.8	1.10	0.91
6969	07/12/84	05/05/83	1.19	56.1	54.7	1.40	1.18
6968	07/12/84	05/02/83	1.20	56.3	54.9	1.40	1.17
7070	07/19/84	06/18/83	1.09	59.2	58.4	0.80	0.74
6957	07/08/84	04/30/83	1.19	60.1	59.5	0.60	0.50
6965	07/12/84	05/02/83	1.20	80.5	78.1	2.40	2.00
6953	08/23/86	04/30/83	3.32	83.3	79.2	4.10	1.24
7021	08/23/86	06/01/83	3.23	80.9	80.1	0.80	0.25
6995	08/23/86	05/19/83	3.27	87.8	86.8	1.00	0.31
						Ave	0.87

Utilizing the growth interval equations for the von Bertalanffy and Logistic models, and performing the non linear regression giving estimates for **a** and **k** and the analysis of variance (ANOVA Table. 2),

Table. 2--Analysis of variance (ANOVA) for **a** and **k** in the von Bertalanffy and Logistic models (applying data from table. 1).

	a	k
Chelonia mydas		
von Bertalanffy	110.05cm (12.69)	0.013 (0.064)
Logistic	110.00cm (0.00)	0.030 (0.603)

Incorporating a into equations 5 and 8 yields values for b,

von Bertalanffy $b = 1 - 5.3/110.05$

$b = 0.95$

Logistic $b = 5.3/110.00 - 1$

$b = -0.95$

and then a, b, and k can be substitutded into equations 1 and 6, yielding

von Bertalanffy $x = 110.05(1 - 0.95e^{-0.013t})$

and

Logistic $x = 110.00/(1 + -0.95e^{-0.030t})$

respectivily.

Values for t can then be inputted to get values for x and the result plotted (Graph. 1).

Graph 1.--von Bertalanffy and Logistic growth curves for Pearl and Hermes Reef, Hawaii.

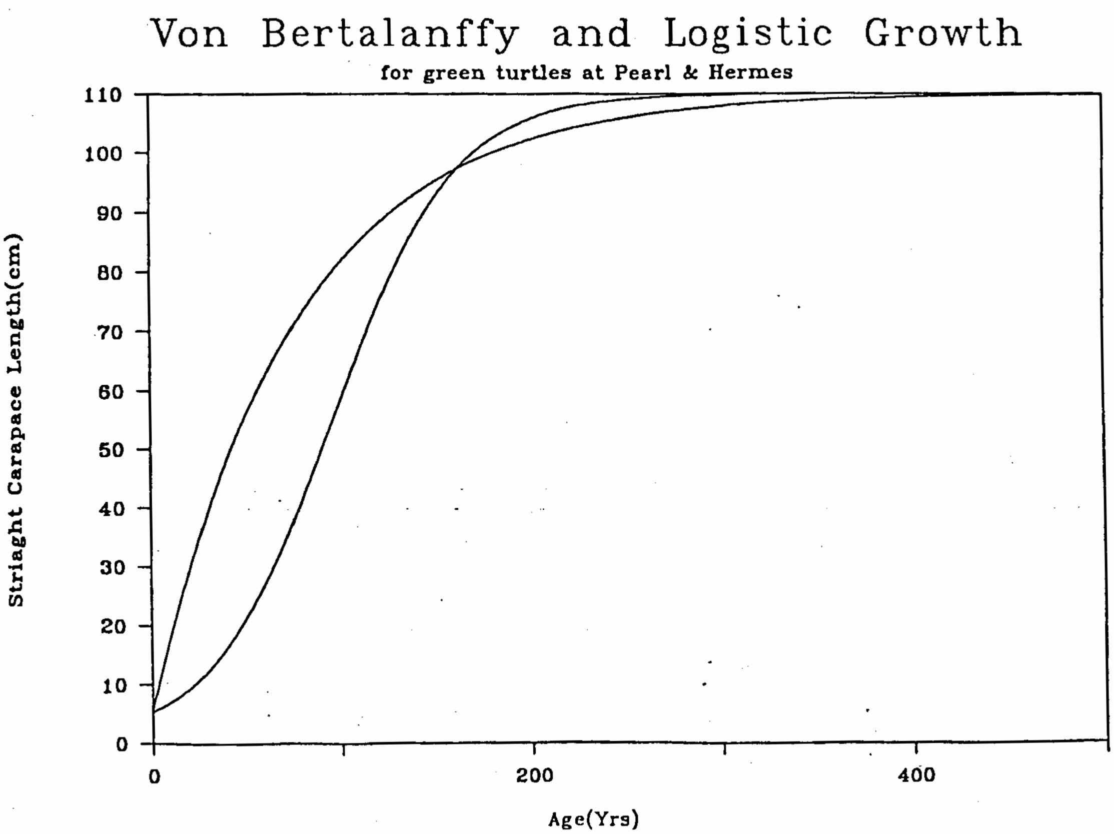
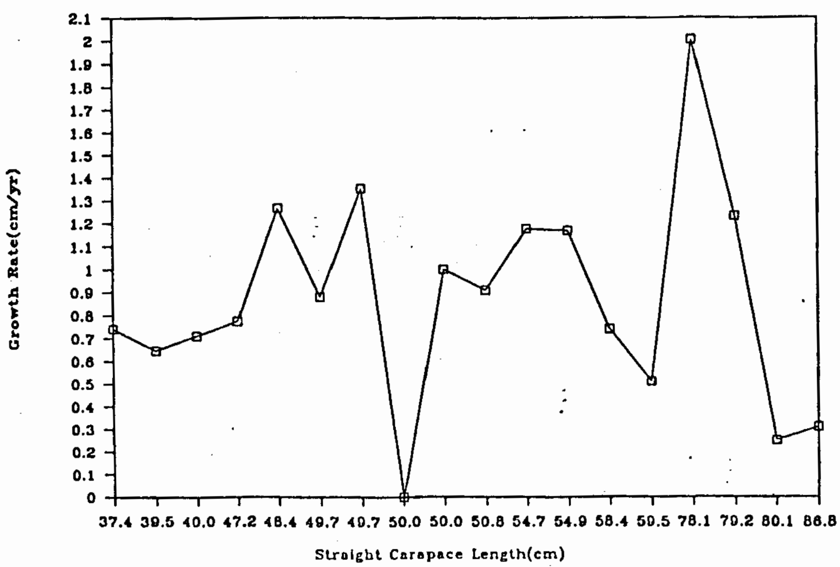


Table. 3-- Table of Variance Analysis for the Non-Linear Regression of the von Bertalanffy and Logistic Growth Models.

	dt	SS	MS	F
Chelonia				
von Bertalanffy:				
Regression	2	64753.16	32376.58	
28877.16				
Residual	16	17.93	1.12	
Total	18	64771.10		
Logistic:				
Regression	2	64786.86	32393.43	44374.61
Residual	17	12.33	0.73	
Total	19	64799.19		

These values for a and k fit the convergence criterion equally as well as several other a and k values, indicating that within the grid there are several local depressions, but no values fitting this particular data precisely. Observing the data directly indicates variability in growth rates which wouldn't conform to either of the curves unless some of the points are excluded. If there was indication of data not being taken in the proper manner this might be acceptable practice, but this not being the case all data must be considered and the nonlinear regression considers these points equally weighted. In lieu of this it is prudent to say that the growth of turtles at Pearl and Hermes Reef, based on this limited data, is not consistent with other areas where data fit these growth models. Possibly influx of turtles from other locations in the chain where growth rates are faster may explain for faster growth in near adult turtles compared to some of the immatures (Graph. 2).

Graph. 2
Variability in Average Growth Rates



Growth rate of pelagic stage turtles, being carnivorous, should be considerably faster then that of the herbivorous turtles which come into areas such as Pearl and Hermes indicating there maybe a step in the actual growth curve during the transitional period, but this wouldn't effect the areas of the graph defined by this data set. A higher concentration of Tiger sharks *Gleocerdo cuvier* (De Costa, 1984; Witzell, 1987), the primary predator of *Chelonia*, at Pearl and Hermes may also effect growth indirectly by changing the feeding of the turtles to evade predation. Seasonal and cyclic (ENSO) temperature regimes, effecting metabolism of turtles confined to the area (non-migrants), may be another growth rate variable. A combination of several reasons is most likely the case the next step is to use data from other parts of the chain and compare the results.

Experience with green turtles from other parts of the Hawaiian archipelago indicate a considerably faster growth rate for immature turtles at more of the southern locations compared to those in the NWHI. Recovery efforts in the future should possibly entertain the idea of transplanting immature turtles from an area such as Pearl and Hermes Reef where there is an abundance to an area which has greater foraging capacity and where turtles grow at faster rates.

Acknowledgments

We would like to thank Robert Morrow, Robert G. Forsyth, and Alan Kam for their efforts in data collection at Pearl and Hermes Reef, and Timothy Gerrodette who was instrumental in the statistical analysis. The support of NMFS and FWS personnel, and the transportation to and from Pearl and Hermes primarily on the NOAA vessel <u>Townsend</u> <u>Cromwell</u> and chartered fishing vessels is greatly appreciated.

Literature Cited

Balazs, G. 1982. Growth rates of immature green turtles in the Hawaiian Archipelago, p. 117-125. *In*: Biology and conservation of sea turtles. K. A. Bjornal (ed.). Smithsonian Institution Press, Washington, D. C.

Balazs, G. 1980. Synopsis of biological data on the green turtle in the Hawaiian Islands. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-7, 141 p.

Choy, B.K., and G.H. Balazs 1989. Green turtle at Pearl and Hermes Reef, 1983- 1988. Manuscr. in prep.

De Crosta, M.A. 1984. Age determination, growth, and energetics of three species of carcharhinid sharks in Hawaii. Masters thesis Universitry of Hawaii Oceanography Department.

Fabens, A.J. 1965. Properties and fitting of the von Bertalanffy growth curve. Growth 29:265-289.

Frazier, N.B., and L.M. Ehrhart 1985. Preliminary growth models for green, *Chelonia mydas*, and Loggerhead, *Caretta caretta*, turtles in the wild. Copeia 1985(1), pp. 73-79.

Frazier, N.B., and R.C. Ladner 1986. A groeth curve for green sea turtles, *Chelonia mydas*, in the U.S. Virgin islands, 1913-14. Copeia 1986(3), pp. 798-802.

Everhart, W., and W.D. Youngs 1981. Principles of fishery science. Cronell University Press, 349 p.

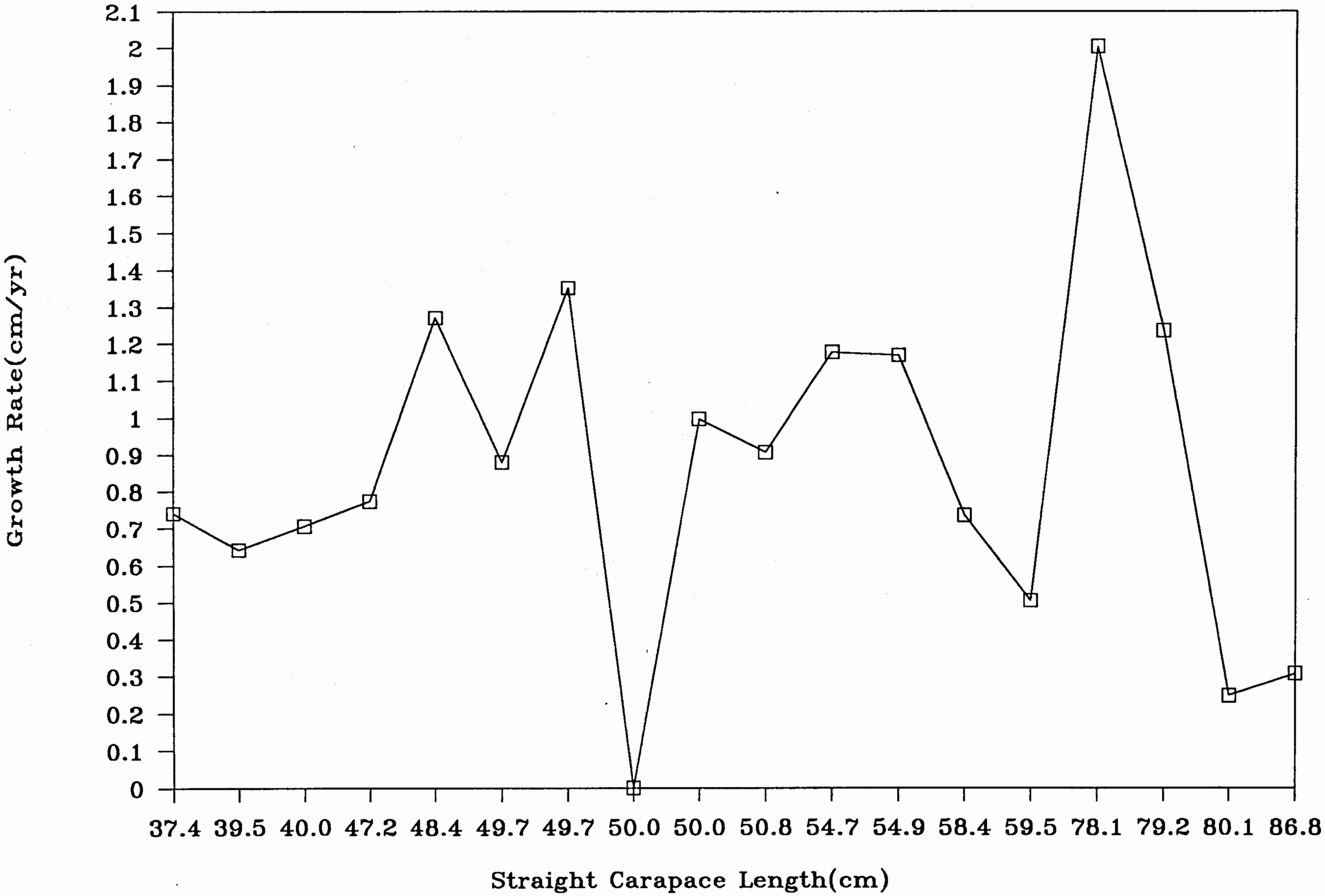
Salas, S.L., E. Hille 1982. Calculus one and several variables. John Wiley and Sons, Inc., 1038 p.

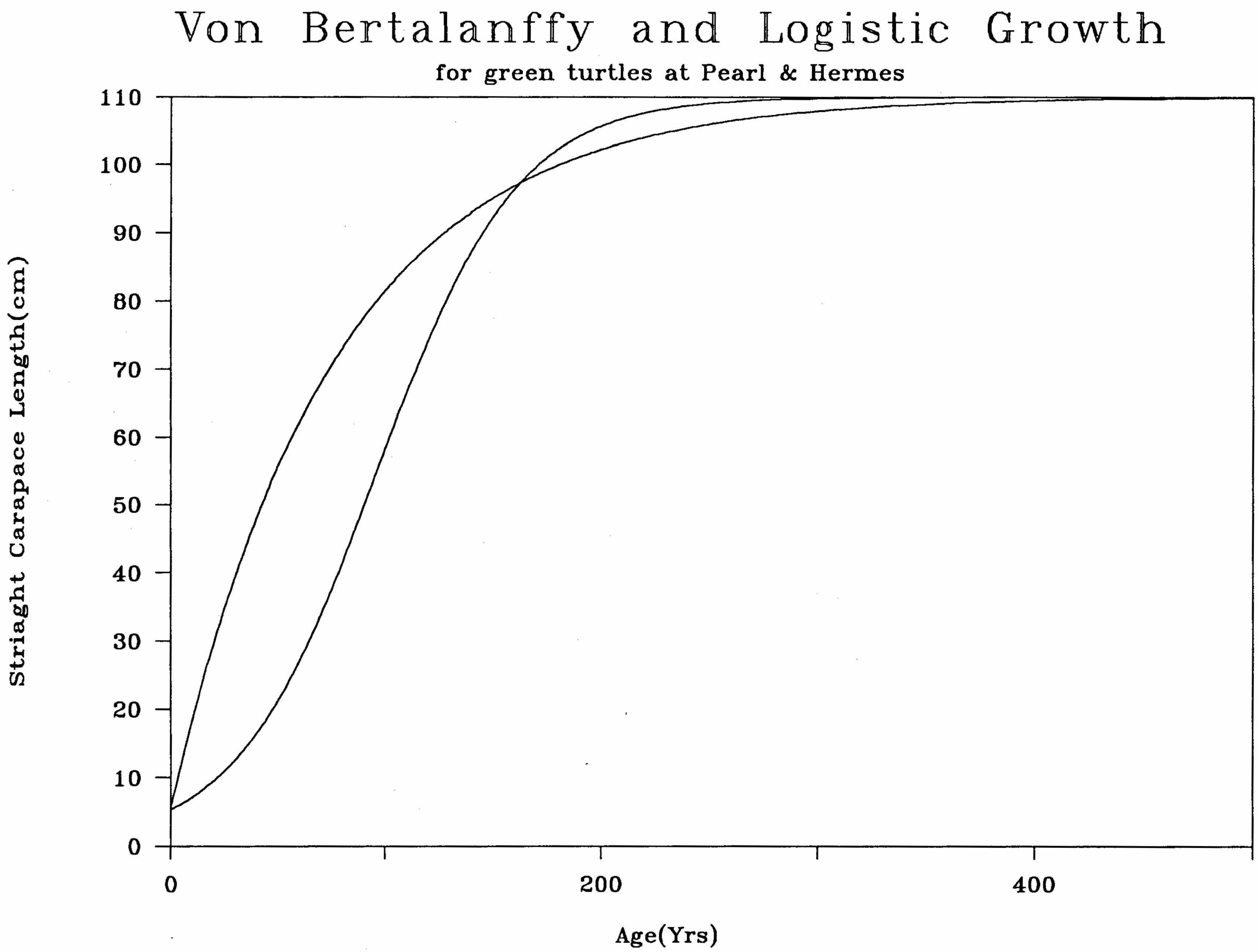
SAS Inc. 1979. SAS users guide. Statistical Analysis Systems, Inc., Carey North Carolina.

Schoener, T.W., and A. Schoener. 1978. Estimating and interpreting body-size growth in some *Anolis* lizards. Copeia 1978:390-405.

Witzell, W.N., 1987. Selective predation on large Cheloniid sea turtles by tiger sharks (*Galeocerdo cuvier*). Japanese journal of herpetology 12(1):22-29.

Variability in Average Growth Rates





Von Bertalanffy and Logistic Growth
for green turtles at Pearl & Hermes
110
100
90
80
70
60
50
40
30
20
10
0
0
200
400
Striaght Carapace Length(cm)
Age(Yrs)