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# GROWTH OF LEATHERBACK SEA TURTLES (*DERMOCHELYS CORIACEA*) IN CAPTIVITY, WITH INFERENCES ON GROWTH IN THE WILD[1]

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## ABSTRACT

Leatherback turtles (*Dermochelys coriacea*) are critically endangered with current population trends in the Pacific indicating that they are nearing extinction. Their recovery will depend on coupling strong conservation measures with knowledge of their life history, particularly growth. Until now, however, there was considerable uncertainty on the growth on both juvenile and adults in the wild. The research reported here marks the first time that several leatherback juveniles have been maintained for over two years in captivity, and we discuss our experiences raising these leatherbacks from hatchlings (50 g) to juveniles (> 40 kg) for studies on their early growth. We derived a length-weight relationship of the form W (kg) = 0.000264 · SCL (cm)^2.806, which fitted both ours, and 10 turtles sampled from the wild. Also, a von Bertalanffy growth curve was derived whose parameters ($SCL_\infty$ = 155 cm; K = 0.266 $year^{-1}$ and $t_0$ = -0.12 year) predicts, for a length at first maturity of 135 cm, an age of 7 years, in agreement with earlier studies of the hard parts of leatherbacks. These results are in agreement with the known biology of leatherbacks; some of their implications for the study of leatherback biology are discussed.

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## INTRODUCTION

All seven species of marine turtle are threatened, with several species listed as endangered or critically endangered (IUCN, 2007). Detailed knowledge of their life-history, notably the time they spend in various feeding grounds and their age at first maturity is essential for conservation (Seminoff *et al.*, 2002; Chaloupka & Musick 1997). This requires a knowledge of growth rate at all stages (or of size-at-age), which is best summarized by the parameters of a growth equation, e.g., the von Bertalanffy Growth Function (VBGF) for length and weight (von Bertalanffy, 1938).

Once a 'standard growth curve' has been established, it is then straightforward to evaluate growth in different populations, which should aid in our understanding of the variability in geographically separated foraging grounds and allow quantitative and qualitative comparisons of the foraging areas, based on the ability of a habitat to meet the ecological requirements of marine turtles (Bjorndal & Jackson, 2003; Bjorndal *et al.*, 2000; Bjorndal & Bolten, 1988).

Most studies of marine turtle growth have focused on the cheloniid species (see Chaloupka & Musick, 1997, Palomares *et al.*, 2008) while relatively few have focused on leatherbacks. This is not surprising when considering the near-exclusive oceanic lifestyle of leatherbacks, of which the female go on land only for nesting, and the near impossibility of maintaining them in captivity (Jones *et al.*, 2000). Yet, leatherbacks are listed as critically endangered (IUCN, 2007) and may be nearing extinction in the Pacific (Spotila *et al.*, 2000). Within two decades the number of adult females in the Pacific declined from ~ 91,000 to under 3,000 (Spotila *et al.*, 2000; 1996). We need to have information on the basic biology of leatherbacks, including demographics and life-history patterns, if we are to stop, and hopefully reverse, their decline.

Leatherbacks are the largest (Buskirk & Crowder, 1994) of the marine turtles, but there are few reports on adult growth rates (Price *et al.*, 2004; Zug & Parham, 1996). The growth of juvenile leatherbacks in the wild, moreover, is completely unknown, due to their distribution being largely unknown, thus precluding marking-recapture studies of their growth.

Marking-recapture studies with marine turtles other than leatherbacks suggest they reach sexual maturity at an age of 20-30 years (Chaloupka & Musick, 1997), but recent evidence based on the study of hard parts in wild leatherbacks suggests an early attainment of minimum nesting sizes, i.e., as early as 3-6 years (Rhodin, 1985), or 6 years (Zug & Parham, 1996).

Herein, we describe how we derived the parameters of the VBGF for length and weight growth in leatherback, by combining and harmonizing the results of several studies, notably our own growth experiment on captive leatherbacks, i.e., 20 hatchlings raised from emergence to > 2 years of age in the laboratory. We then suggest, in the light of the coherence of the results obtained, that the growth curves presented below can serve as standard growth curves for leatherback turtles.

## MATERIALS AND METHODS

### *Captive rearing experiments*

Leatherback turtles were obtained on Canada CITES import permit CA05CWIM0039 and British Virgin Islands CITES Export certificate CFD062005. These animals are housed and maintained for research purposes and we meet all the ethical animal care standards as put forth by the Canadian Council for Animal Care (CCAC) and the UBC Animal Care Committee (UBC Animal Care Protocol: A04-0323).

Twenty hatchlings (emergence July 2nd, 2005) were transported from Tortola, BVI to the Animal Care Center, Department of Zoology, University of British Columbia. Animals were reared at the South Campus Animal Care facility using protocols developed by Jones *et al.* (2000). The three main obstacles to overcome in rearing leatherbacks are (i) their oceanic-pelagic nature (no recognition of barriers), (ii) designing a food matching their gelatinous food in the wild, and (iii) water quality.

As leatherbacks are oceanic-pelagic animals, which do not recognize vertical (tank walls) and horizontal barriers (tank bottom), the animals were tethered to PVC™ pipes secured across the tops of the tanks. Animals < 10 kg were attached to the tether using Velcro™ and cyanoacrylate cement attaching the tether to the posterior portion of their carapace, thus confining them to a section of the tank. Each hatchling could swim or dive in any direction, but was unable to contact other turtles or the tank's bottom and walls. Upon reaching ≥ 10 kg the juveniles were secured to the tether with a harness made of Tygon™ tubing. The harness circled each shoulder like a backpack and then looped around the caudal peduncle of the animal. Harnessing the leatherbacks is necessary as they swim continuously and, failing to recognize physical barriers, would abrade their skin against such barriers, which would lead to infections and usually death (Jones *et al.*, 2000).

The turtles were fed 3 to 5 times daily to satiation during the first 2-months of age and 3 times daily to satiation when > 2 months of age on a squid gelatin diet. The diet consists of squid (Pacific Ocean squid; mantle and tentacles only), vitamins (Reptavite™) and calcium (Rep-Cal™), blended with flavorless gelatin and hot water. As the wild diet of leatherbacks consists solely of gelatinous zooplankton (i.e., jellyfish; see Pauly *et al.* 2008), it is necessary for the food to have the proper texture and consistency.

The food was weighed (Ek-1200 A; Stites Scale Inc., 3424 Beekman Street, Cincinnati, OH 45223) prior to feeding and notes were made as to individual food mass intake per day. The food had a water content of 90 % water, and an energy content of 20.16 ± 0.39 $kJg^{-1}$ (dry weight). Random food samples were dried in a desiccating oven at 60°C for 24 to 72 hours to determine the dry to wet weight ratio. The dried homogenized samples were then sent to the Southwest Fisheries Science Center of NOAA (La Jolla, California, USA) for analysis with a bomb calorimeter (Parr Instrument Co.).

The turtles were maintained in large oval tanks (5 m long x 1.5 m wide x 0.3 m deep) containing ~ 2,500 l of re-circulated/filtered salt water. Water temperature was maintained at 24 ± 1 $^{o}$C. Four fluorescent fixtures (40 W UVA/B; Repti-Glow 8) suspended 0.5 m above each pool provided full spectrum radiation on a 12/12 hour cycle; also, each tank received ambient light. Water quality was maintained to the following levels pH = 8.0 to 8.3; salinity = 28-33, and ammonia < 0.1 $mg^{-1}$. Water quality for each pool was maintained by four systems: a biological filter, a sand filter (Triton II™), an ultraviolet filter (Aqua Ultraviolet™ 114 W UV water sterilizer) and a protein skimmer.

The turtles were weighed and measured on emergence, at 3 and 7 days of age, then weekly. Straight carapace length (SCL), the distance from the center of the nuchal notch to the caudal peduncle (posterior of the carapace), was used for all length measurements, and performed with a digital caliper to the nearest 0.1 mm. The turtles were weighted using an Ek-1200 A scale (Stites Scale Inc., 3424 Beekman Street, Cincinnati, OH 45223) from hatching to weights of 1.2 kg (± 0.1g), and an ADAM CPW-60 scale (Dynamic Scales, 1466 South 8th Street, Terre Haute, IN 47802) for weights ≥ 1.2 kg (± 0.02 kg).

### *Length-weight relationships and growth curves*

We fitted the available length-weight data pairs (Table 1 and 2) with a length weight relationship of the form:

$$W = a \cdot L^b \qquad \text{... 1)}$$

where W is the weight in kg, L the SCL in cm, a is a multiplicative parameter of dimension $L \cdot W^{-1}$, and b is an exponent usually taking values near 3 (which then indicates isometric growth, and allows interpretation of 'a' as a condition factor; Pauly, 1984).

Equation (1) was fitted by first transforming the data of Table 1 into $\log_{10}W_i$ - $\log_{10}L_i$ pairs, and fitting these by a linear regression of the form:

$$log_{10}W_i = \alpha + b \cdot log_{10}L_i \qquad \text{... 2)}$$

where antilog α = a, and all other parameters are as defined previously.

The VBGF for length has the form:

$$L_t = L_\infty(1 - e^{-K(t-t_0)}) \qquad \text{... 3)}$$

where $L_t$ is the predicted length at age t, $L_\infty$ is the mean the adults of the population in question would reach if they were to grow for a very long time (indefinitely, in fact), K is a growth parameter (not a growth rate) of dimension time$^{-1}$, and $t_0$ is the age of the turtles at length=0.

It is a property of the VBGF that its first derivative (dl/dt) declines linearly with length, reaching zero at $L_\infty$. Hence, its parameter K can be estimated by plotting observed growth increments ($\Delta l/\Delta t$) against the mid-lengths of the increments (Pauly, 1984; Gulland & Holt, 1959), or

$$Y_i = a - K\overline{X_i} \qquad \text{... 4)}$$

where $Y_i = L_{i2}-L_{i1}/t_2-t_{i1}$, $\overline{X_i} = L_{i1}+L_{i2}/2$, and $L_{i1}$ and $L_{i2}$ are length measurements taken at the start and end of an arbitrary time interval $t_{i1}$ to $t_{i2}$. Also, we have $L_\infty = a/K$. This method leads to robust estimate of K, provided that the intervals $t_{i1}$ to $t_{i2}$ are relatively short, as in this case (Gulland & Holt, 1959). Its main advantage is that it provides for visualization of the data, and thus to identify outliers or incompatible data sets (Pauly, 1984). The method can also be modified to allow for estimation of K even when growth increments are available only for juveniles. In such cases, a forcing value of $L_\infty$ is used, and $K = \overline{Y}_i/(L_\infty - \overline{X}_i)$ (Pauly, 1984). We used 155 cm SCL (mean length of nesting females) as forcing value of $L_\infty$, based on studies in both the Atlantic (Boulon *et al.*, 1996) and the Pacific (Price *et al.*, 2004).

Another approach to fitting the VBGF is iterative, non-linear fitting (e.g., Fabens, 1965). Here, this was performed using the Sigma Plot software, with $L_\infty$=155 cm as constraint, given that the narrow range of the length-at age data fitted (Table 1) would not have otherwise lead to convergence.

The VBGF for weight has the form:

$$W_t = W_\infty(1 - e^{-K(t-t_0)})^b \qquad \text{... 5)}$$

where $W_\infty$ is the weight corresponding to $L_\infty$, e.g., as estimated by Equation (1), b the exponent of that same length-weight relationship, and all other parameters are defined as for the VBFG for length (Equation 3).

## RESULTS AND DISCUSSION

The hatchlings averaged 0.046 ± 0.001 kg body mass and 6.32 ± 0.13 cm SCL (straight carapace length) upon emergence. All hatchlings began feeding on the formulated squid gelatin by 3-5 days post emergence. Four turtles survived 18 months post emergence, with only 2 surviving more than 2 years. The largest animal was 42.65 kg and 72.0 cm SCL at 26 months old (age at death). Due to space constraints, we give here only a subset of the length and weight measurements taken during the life span of all 20 hatchlings (Table 2). Despite the deaths, the feeding regime seemed adequate, as assessed by the fact that our captive animals matched the condition of wild leatherbacks (Figure 1). The

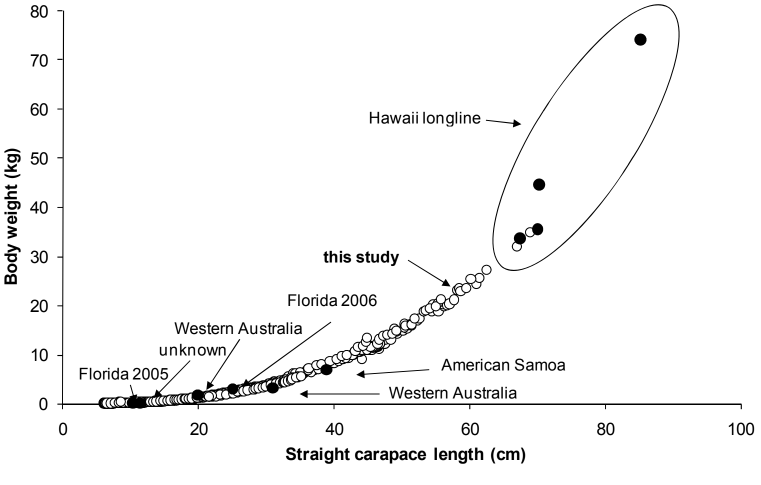

**Figure 1**. Plot of weight *vs*. length in 20 leatherbacks turtles maintained in captivity, from hatchlings to > 2-years (this study, Table 1) compared with weight *vs*. length from strandings and by-catch (Table 2). The overlap between the two data sets suggests that conditions for the captive turtles corresponded to those in the wild (c.f. with Figure 2).

relationship we obtained from the N = 101 log-transformed length and weight data pairs in Tables 1 and 3 ($r^2 = 0.998$) is:

$$W = 0.000264 \cdot L^{2.806} \quad \ldots 6)$$

where W is the weight in kg and L the SCL in cm.

The length and weight data pairs from our study match those of leatherback taken from the wild (Figure 1), and hence equation (4) may be proposed as standard L-W relationship for leatherback turtles. On the other hand, the data in Figure 1, and Equation (4) suggest that the turtles raised by Deraniyagala (1939) and Bels *et al.* (1988) suffered from sub-optimal condition, notably inadequate nutrition (i.e., algae, beef heart, and French bread; see Table 2), resulting in elevated mortality (Table 2), emaciation (Figure 2), and reduced growth (see below).

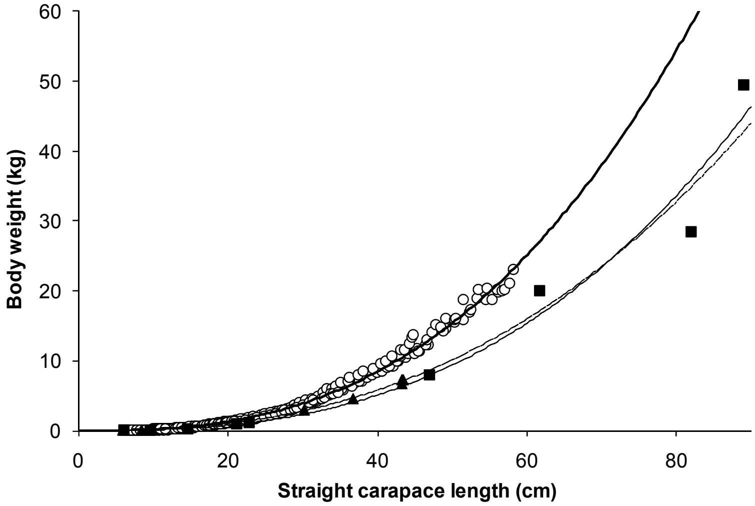

**Figure 2**. Length-weight relationships of leatherback turtles. Solid black line: relationship based on length and weight (open dots) of the turtles we maintained in captivity from hatchlings to > 2-years (this study, Table 1). Thin black line: relationship based on the turtles (black squares) reared by Bels *et al.* (1988). Dotted line: relationship based on the turtles (black triangles) reared by Deraniyagala (1939). The low weight at length of the turtles reared by Bels *et al.* and Deraniyagala suggest that they suffered from less than optimal conditions (c.f. with Figure 1).

Figure 3 contrasts the growth rates obtained in this study (Table 1) with those reported by Deraniyagala (1939) and Bels *et al.* (1988). Despite much variability, our turtles exhibited higher growth rates than theirs. Moreover, the juvenile growth rates we obtained appear compatible with the adult growth rates reported by Price *et al.* (2004). Figure 3 also demonstrates the compatibility of our results with those Zug and Parham (1996), who found that juvenile leatherback growth rates were 31.6 cm $year^{-1}$ for juveniles 8-37 cm SCL and 23.1 cm $year^{-1}$ for juveniles 37-65 cm SCL [data converted from curved-carapace lengths using the equation of Tucker & Frazer (1991)].

Our growth rate data, combined with a value of $L_\infty$ set at 155 cm allows estimation of a preliminary value of K = 0.232 from the slope of the plot in Figure 3. Fitted non-linearly, the same inputs yielded the VBGF for length:

$$L_t = 155(1-e^{-0.266(t+0.12)}) \quad \ldots 7)$$

The resulting curve is shown in Figure 4, and contrasted with a curve based on the length-at-age data of Deraniyagala (1939) and Bels *et al.* (1988). As might be seen, our juvenile growth data suggest faster growth than theirs, as also shown in Figure 3.

Using 135 cm SCL as the minimum size at nesting, based on Boulon *et al.* (1996) for the Atlantic and Price *et al.* (2004) for the Pacific, Equation (8) suggests that it would take leatherbacks 7 years to reach sexual maturity, in agreement with the 6 years proposed by Zug & Parham (1996).

Combining Equation (6) with (7) leads, finally, to a VBGF for the growth in weight in leatherbacks, i.e.:

$$W_t = 370(1-e^{-0.266\,(t+0.12)})^{2.806} \quad \ldots 8)$$

which can be used to predict mean weight at any age.

Major assumptions have been made in the experimental design of this study and for the results to have any validity they must be addressed. Firstly, the VBGF requires that growth be monotonic throughout postnatal development, as it displays no inflection points (Choulpka & Musick, 1997). Therefore, polyphasic growth data, or displaying an initial lag phase, would require another growth function, e.g., the Gompertz, logistic or others. However, the leatherback turtles we raised, and our longitudinal sampling (repeated sampling on the same individuals; Choulpka & Musick, 1997) resulted in growth data exhibiting neither polyphasic growth, nor a lag phase. Therefore, the use of the VBGF is justified in our case, and by extension, in leatherbacks as a whole. We also suspect this to be the case in other species of marine turtles, as well.

Captive growth does not necessarily reflect wild growth. However, our captive specimens exhibited the same length-weight relationships as wild juvenile leatherbacks (stranded or by-catch; Fig 1.), suggesting appropriate rearing conditions - at least compared with earlier captive growth studies. On the other hand, the problem of accelerated growth in captivity, seem to be limited to cheloniids (Swingle *et al.*, 1993;Wood & Wood, 1980), and may not occur in leatherbacks, whose chondro-osseous development characteristic suggests rapid growth (Rhodin *et al.*, 1996; Rhodin, 1985). Also, Zug & Parham (1996), whose growth data match ours almost perfectly (Figure 3), found rapid growth rates in wild leatherbacks (15 adults and 2 juveniles) and stated that the early captive growth pattern of leatherbacks closely matches the growth curves of wild individuals.

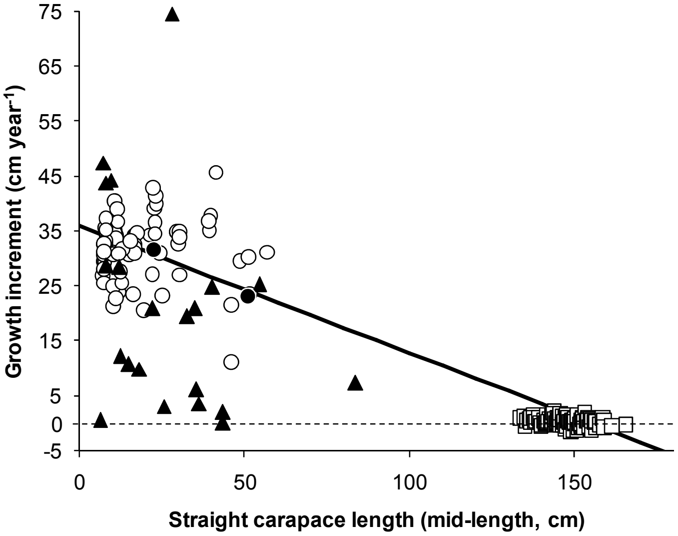

**Figure 3**. Plot of growth rates ($\Delta l/\Delta t$) against the corresponding mid-lengths of the growth increments in leatherback turtles, computed from Table 1 (open dots, our study), the studies of Deraniyagala (1939) and Bels *et al.* (1988) (black triangles), Zug & Parham (1996) (2 black dot) and adult growth rates from Price *et al.* (2004) (open squares). The solid line links the means of the values from our study (open dots) and $L_\infty$ = 155 cm (SCL); its slope allows a preliminary estimation of K = 0.232 year$^{-1}$. The data points from Deraniyagala (1939) and Bels *et al.* (1988) were omitted, as their turtles probably experienced suboptimal condition (c.f. Fig. 2, and see text).

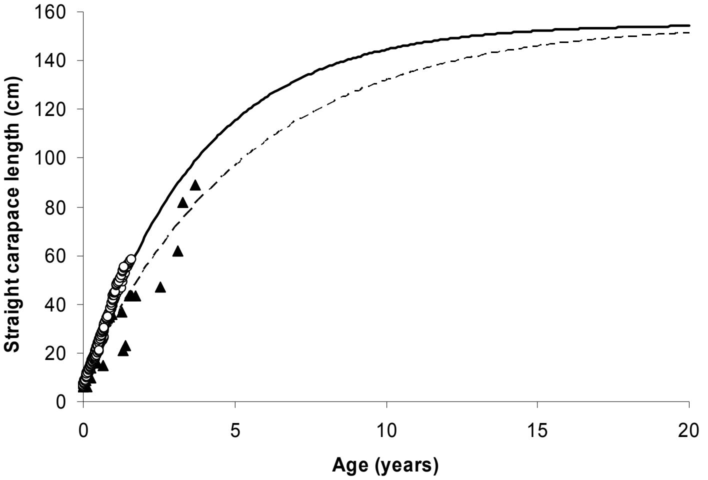

**Figure 4**. Von Bertalanffy Growth Functions for leatherback turtles: Solid line: VBGF with a fixed value of $L_\infty$ = 155 cm, K = 0.266 year$^{-1}$and $t_0$ = -0.12 year, based on length-at-age data in Table 1 (this study, open dots) fitted with SigmaPlot™ version 10. Dotted line: same $L_\infty$ and fitting method, with K = 0.185 year$^{-1}$ and $t_0$ = -0.03 year, derived from the length-at-age data in Table 3 (i.e., from studies of Deraniyagala, 1939 and Bels *et al.*, 1988, black triangles). The sub-optimal conditions suggested to have occurred in these studies affected the growth of the turtles.

Our findings confirm that leatherbacks mature a younger age (6-7 years, see above), but at a larger size than cheloniid turtles. For example, loggerheads take > 15 years to reach a sexually mature size of about 90 cm carapace length (Frazer & Ehrhart, 1985; Mendoca, 1981), whereas green turtles take > 20-30 years to reach sexual maturity at a carapace length of about 100 cm (Frazer & Ladner, 1986; Frazer & Ehrhart, 1985; Mendoca, 1981; Limpus & Walter, 1980). Similarly, green turtles with size of 30 cm spend nearly 20 years in juvenile habitats, before they acquire adult features (Seminoff *et al.*, 2002; Bjorndal & Bolten, 1988).

**Table 1.** Length and weight of 20 turtles raised in captivity from hatchling to ages of over 2 years, using the protocol and feed described in the text. N = 20 ≤ 12 months; 4 from 12 to 18 months; 2 from 18 months to > 24 months.

| Turtle ID | Age (days) | Weight (kg) | SCL (cm) | Turtle ID | Age (days) | Weight (kg) | SCL (cm) | Turtle ID | Age (days) | Weight (kg) | SCL (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dc 7 | 1 | 0.048 | 6.37 | Dc 13 | 31 | 0.115 | 8.61 | Dc 19 | 500 | 20.360 | 55.40 |
| Dc 7 | 31 | 0.139 | 9.25 | Dc 13 | 73 | 0.305 | 12.59 | Dc 20 | 1 | 0.047 | 6.55 |
| Dc 7 | 73 | 0.355 | 13.17 | Dc 13 | 157 | 1.260 | 20.04 | Dc 20 | 31 | 0.131 | 9.26 |
| Dc 8 | 1 | 0.046 | 6.10 | Dc 13 | 206 | 2.140 | 23.67 | Dc 20 | 73 | 0.349 | 13.49 |
| Dc 8 | 31 | 0.129 | 8.78 | Dc 14 | 1 | 0.048 | 6.32 | Dc 20 | 150 | 1.180 | 20.00 |
| Dc 8 | 73 | 0.342 | 13.29 | Dc 14 | 31 | 0.115 | 8.75 | Dc 20 | 206 | 2.480 | 26.33 |
| Dc 9 | 1 | 0.047 | 6.41 | Dc 14 | 101 | 0.489 | 14.99 | Dc 20 | 297 | 5.440 | 34.74 |
| Dc 9 | 31 | 0.123 | 8.82 | Dc 14 | 157 | 1.180 | 20.29 | Dc 21 | 1 | 0.045 | 6.29 |
| Dc 9 | 73 | 0.326 | 12.85 | Dc 14 | 206 | 2.160 | 24.93 | Dc 21 | 31 | 0.119 | 8.81 |
| Dc 9 | 157 | 1.280 | 20.69 | Dc 14 | 304 | 5.460 | 34.27 | Dc 21 | 87 | 0.300 | 12.05 |
| Dc 10 | 1 | 0.046 | 6.42 | Dc 14 | 402 | 11.000 | 44.14 | Dc 22 | 1 | 0.047 | 6.37 |
| Dc 10 | 31 | 0.124 | 9.03 | Dc 14 | 507 | 17.280 | 52.60 | Dc 22 | 31 | 0.127 | 9.11 |
| Dc 10 | 73 | 0.335 | 12.99 | Dc 14 | 611 | 25.600 | 61.50 | Dc 22 | 129 | 0.701 | 16.00 |
| Dc 10 | 157 | 1.220 | 20.20 | Dc 15 | 1 | 0.046 | 6.43 | Dc 23 | 1 | 0.047 | 6.24 |
| Dc 10 | 206 | 2.180 | 25.10 | Dc 15 | 31 | 0.133 | 9.05 | Dc 23 | 31 | 0.140 | 9.29 |
| Dc 10 | 304 | 5.420 | 34.46 | Dc 15 | 122 | 0.580 | 15.01 | Dc 23 | 122 | 0.754 | 17.15 |
| Dc 10 | 402 | 10.900 | 44.57 | Dc 16 | 1 | 0.045 | 6.13 | Dc 24 | 1 | 0.048 | 6.43 |
| Dc 10 | 500 | 12.060 | 47.50 | Dc 16 | 31 | 0.119 | 8.52 | Dc 24 | 31 | 0.117 | 8.72 |
| Dc 10 | 628 | 21.240 | 55.80 | Dc 16 | 73 | 0.360 | 13.16 | Dc 24 | 73 | 0.301 | 12.24 |
| Dc 11 | 1 | 0.046 | 6.04 | Dc 16 | 157 | 1.320 | 20.67 | Dc 24 | 150 | 1.020 | 19.21 |
| Dc 11 | 31 | 0.105 | 8.23 | Dc 16 | 248 | 3.420 | 28.38 | Dc 24 | 206 | 2.360 | 25.78 |
| Dc 11 | 73 | 0.264 | 11.90 | Dc 17 | 1 | 0.046 | 6.41 | Dc 24 | 332 | 5.580 | 35.13 |
| Dc 11 | 150 | 0.943 | 18.38 | Dc 17 | 31 | 0.144 | 9.32 | Dc 25 | 1 | 0.046 | 6.16 |
| Dc 11 | 206 | 2.000 | 23.65 | Dc 17 | 73 | 0.367 | 13.79 | Dc 25 | 31 | 0.117 | 8.83 |
| Dc 11 | 255 | 2.960 | 26.74 | Dc 18 | 1 | 0.047 | 6.38 | Dc 25 | 108 | 0.375 | 13.61 |
| Dc 12 | 1 | 0.046 | 6.44 | Dc 18 | 31 | 0.131 | 9.19 | Dc 26 | 1 | 0.046 | 6.33 |
| Dc 12 | 31 | 0.111 | 8.55 | Dc 18 | 66 | 0.263 | 11.57 | Dc 26 | 31 | 0.132 | 9.24 |
| Dc 12 | 73 | 0.303 | 12.59 | Dc 19 | 1 | 0.046 | 6.34 | Dc 26 | 108 | 0.496 | 15.03 |
| Dc 12 | 150 | 1.146 | 19.71 | Dc 19 | 31 | 0.135 | 9.20 | Dc 27 | 1 | 0.045 | 6.35 |
| Dc 12 | 206 | 2.460 | 25.73 | Dc 19 | 73 | 0.346 | 13.06 | Dc 27 | 31 | 0.125 | 8.91 |
| Dc 12 | 304 | 5.620 | 34.47 | Dc 19 | 157 | 1.280 | 20.39 | Dc 27 | 101 | 0.558 | 14.85 |
| Dc 12 | 402 | 10.420 | 43.87 | Dc 19 | 206 | 2.400 | 25.73 | Dc 27 | 150 | 0.900 | 17.98 |
| Dc 12 | 479 | 13.040 | 48.40 | Dc 19 | 304 | 6.360 | 35.03 | Dc 27 | 213 | 1.520 | 21.50 |
| Dc 13 | 1 | 0.046 | 6.19 | Dc 19 | 402 | 13.780 | 47.31 | - | - | - | - |

**Table 2.** Length and weight of 10 loggerhead turtles taken from the wild (stranded or as by-catch). Date, location and source are given for each turtle, except one, for which only the length and weight are known.

| Date | Location | Weight (kg) | SCL (cm) | Source |
|---|---|---|---|---|
| Aug-93 | American Samoa | 7.00 | 39.0 | MTN (1994; no 66, p. 3-5) |
| Sep-05 | Florida (2005) | 0.19 | 10.4 | J. Wyneken (*pers. comm.*) |
| Mar-06 | Florida (2006) | 3.10 | 25.0 | J. Wyneken (*pers. comm.*) |
| Apr-98 | Hawaii | 44.50 | 70.4 | NOAA (NMFS/PIFSC) |
| Apr-99 | Hawaii | 74.10 | 85.3 | NOAA (NMFS/PIFSC) |
| Apr-06 | Hawaii | 35.45 | 70.0 | NOAA (NMFS/PIFSC) |
| Jul-06 | Hawaii | 33.60 | 67.5 | NOAA (NMFS/PIFSC) |
| Jul-02 | W. Australia | 1.85 | 20.0 | MTN (2004; no. 104, p. 3-5) |
| 1983 | W. Australia | 3.30 | 31.0 | MTN (2004; no.104, p. 3-5) |
| Unknown | Unknown | 0.17 | 11.5 | M. Conti (*pers. comm.*) |

Turtles experience strong ontogenic habitat shifts. Thus, green turtles enter the oceanic-pelagic habitat as post-hatchling, and then turn into coastal-benthic feeders as juveniles (Bjorndal & Bolten, 1988), which probably induce a shift from an omnivorous to a herbivorous diet. These ontogenic habitat, diet and hence niche shifts may be the reason why the somatic growth of marine turtles often appears to be polyphasic (Hendrickson, 1980; Chaloupka & Musick, 1997). Leatherbacks, however,

**Table 3.** Length and weight at age of leatherback turtles raised from the hatchling stage to ages of over 1 year Deraniyagala (1939; initial N = 10; food: algae, beef hearts and French bread) and Bels *et al.* (1988; initial N = 14; food: mussels). Deraniyagala lost 90% his turtles in the first month, with 2 lasting 169 days, and 1 from day 169 to 662. Bels *et al.* lost 70% of their turtle within 2-months, with 1 lasting from day 183 to 1351.

| **Deraniyagala (1939)** | | | **Bels *et al.* (1988)** | | |
|---|---|---|---|---|---|
| **Age (days)** | **Weight (kg)** | **SCL (cm)** | **Age (days)** | **Weight (kg)** | **SCL (cm)** |
| 1 | 0.033 | 5.9 | 1 | 0.046 | 6.1 |
| 21 | 0.096 | 8.5 | 41 | 0.047 | 6.2 |
| 22 | -- | 7.3 | 85 | 0.075 | 9.6 |
| 32 | -- | 8.5 | 239 | 0.312 | 14.7 |
| 32 | -- | 8.9 | 478 | 0.950 | 21.2 |
| 46 | -- | 10.2 | 506 | 1.125 | 22.8 |
| 91 | -- | 13.7 | 726 | 3.720 | -- |
| 169 | -- | 16.0 | 847 | 4.500 | -- |
| 183 | -- | 25.4 | 928 | 8.020 | 47.0 |
| 195 | -- | 25.5 | 1140 | 20.000 | 61.7 |
| 203 | 2.438 | -- | 1200 | 28.500 | 82.0 |
| 218 | 3.005 | 30.2 | 1351 | 49.500 | 85.0 |
| 308 | -- | 35.0 | -- | -- | -- |
| 344 | -- | 35.6 | -- | -- | -- |
| 466 | 4.536 | 36.8 | -- | -- | -- |
| 562 | 6.804 | 43.3 | -- | -- | -- |
| 586 | 7.258 | 43.3 | -- | -- | -- |
| 624 | 7.265 | 43.5 | -- | -- | -- |
| 662 | -- | 42.0 | -- | -- | -- |

are oceanic-pelagic animals throughout their life-history (Bolten, 2003) and do not exhibit an ontogenetic diet shift; the diet consists solely of gelatinous zooplankton, throughout all life-history stages (Salmon *et al.*, 2004; Bjorndal, 1997). This, then, would justify the use of the VBGF.

Eckert (2002) used reports of visual sightings and incidental captures in north Atlantic to show that leatherbacks do not move above ~30° N and into water < 26 ℃ until they are over 100 cm in carapace length, corresponding given Equation (6) and (7), to an age of 3.8 years, and a weight of 108 kg, respectively. The latter value, used as an input for the leatherback thermoregulatory model of Bostrom & Jones (2007), suggest that these leatherbacks could maintain body temperatures 1.63 to 8.15 ℃ above ambient temperatures. This would allow them to move into colder waters where they can exploit different assemblages and perhaps greater abundance of gelatinous zooplankton, without their metabolism and growth being much reduced by the lower ambient temperatures. A review of reptilian growth by Avery (1994) showed that growth was not affected by cooler temperatures when the organisms were allowed to behaviorally thermoregulate. Although leatherback thermoregulation is endogenously driven, it is also a consequence of a large mass and locomotion (Bostrom & Jones, 2007). Thus, the benefit of higher body temperatures with regards to growth rates would not be lost to increased thermoregulatory costs.

The decline in the Pacific leatherback population is daunting. The presumed cause is decades of intense egg harvest at most nesting beaches, exacerbated by widespread incidental by-catch from fisheries practices (Eckert & Sarti, 1997). Although the numbers of adults are higher in the Atlantic (~30,000), fishing practices continue to take their toll and the numbers from artisanal fisheries is unknown but probably severe (Peckham *et al.*, 2007). The good news is that with 7 years time to first nesting, leatherbacks still have a chance, as there is potential for a rapid rebound (at least compared with the slow-growing cheloniids) if fisheries by-catch can be reduced through moratoria and regulation.

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