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LENGTH–WEIGHT RELATIONSHIPS AND ADDITIONAL GROWTH PARAMETERS FOR SEA TURTLES[1]

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ABSTRACT

To facilitate field and other work on sea turtles, composite length-weight relationships, based on a wide range of sizes sampled by various authors, are presented for five species, viz. Kemp's ridleys (*Lepidochelys kempi*), olive ridleys (*Lepidochelys olivacea*), loggerheads (*Caretta caretta*), greens (*Chelonia mydas*), and hawkbills (*Eretmochelys imbricata*).

Also, 38 pairs of growth parameters of the von Bertalanffy growth function (VBGF; K; L_∞ and W_∞) are presented for four species, leaving only the growth of the olive ridley undocumented.

INTRODUCTION

There are seven living species of sea turtles: flatback (*Natator depressus*), green sea turtle (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), Kemp's Ridley (*Lepidochelys kempi*), leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), and olive ridley (*Lepidochelys olivacea*). Populations of all these species are threatened throughout the world because of overexploitation, disease, incidental capture by fishers, and destruction of critical nesting habitat (Lutcavage *et al.*, 1997; Mortimer *et al.*, 2000; Lewison *et al.*, 2004; Peckham *et al.*, 2008). Intensive, and sometimes sophisticated research has been conducted to quantify these impacts and inform management practices (e.g., Chaloupka & Balazs, 2007; Bailey *et al.*, 2008; e.g., Sims *et al.*, 2008). In the process, however, basic biological data are frequently overlooked. This applies particularly to morphometric relationships, whose validity is often taken for granted, although they tend to be based on too small a range of sizes to be of any use in building more elaborate models, e.g., turtle growth studies.

This contribution presents key morphometric data for 5 species of sea turtles, namely Kemp's ridleys (*L. kempi*), olive ridleys (*L. olivacea*), loggerheads (*C. caretta*), greens (*C. mydas*), and hawkbills (*E. imbricata*), and complements two other works in this volume, Jones *et al.* (2008) for leatherbacks and Palomares *et al.* (2008) for reptiles (including sea turtles).

MATERIAL AND METHODS

The relationship between total length (L) and weight (W) for most animals is expressed by the equation:

$$W = a \bullet Lb \qquad \ldots 1)$$

whose parameters (a, b) are estimated by the antilog of the intercept, and the slope, respectively, of a regression of the $log_{10}\, W$ against $log_{10}\, L$. The value of b is generally close to 3, implying 'isometry', i.e., the shape of the animal in question remaining the same as they get older and gain in size.

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Table 1. Empirical equations used to convert curved carapace length (CCL; cm) into straight carapace length (SCL; cm) measurements for individual species.

Species	Equation	R^2	Reference
Lepidochelys kempi	SCL = 0.957 * CCL - 0.696	0.99	Plotkin (2007)
Lepidochelys olivacea	SCL = 0.818 * CCL + 9.244	0.91	Whiting et al. (2007)
Caretta caretta	SCL = 0.948 * CCL – 1.442	0.97	Teas (1993)
Chelonia mydas	SCL = 0.932 * CCL + 0.369	0.93	Peckham et al. (2008)
Eretmochelys imbricata	SCL= 0.939 * CCL - 0.154	n.a.	CITES (2002)
Eretmochelys imbricata	SCL = 0.935 * CCL + 0.449	0.99	Limpus (1992) – for Australia

Sea turtles can be measured in a number of ways, requiring standardisation before datasets can be compared. Straight carapace length (SCL) and curved carapace length (CCL) are the most commonly used measurements taken of sea turtles. As their name implies, CCL measurements are taken over the curve of the carapace whereas straight measurements are taken with a set of callipers. Although variations exist in how these measurements can be taken (e.g., notch to notch [NN] or notch to tip [NT]), authors most often do not detail the specific technique used in measuring individuals beyond curved or straight. For the purposes of this analysis, we assumed discrepancies to be minimal. Where necessary, data were converted to SCL using empirical equations listed in Table 1, based on linear regression of paired CCL and SCL data for the species in question.

To ensure that the parameters of length-weight relationships are estimated properly (Safran, 1992), length-weight data pairs from different studies were compiled to cover the widest possible range of sizes, and all developmental stages, i.e., juveniles, subadults, and adults (Table 2).

Table 2. Length weight relationships for 5 species of sea turtles; *a* and *b* are parameters in the equation of the type $W=a\,L^3$.

Species	Location	*a*	*b*	r^2	N	Size range (SCL; cm)	References
Lepidochelys kempi	Chesapeake, Florida, UK & France	0.000247	2.834	0.958	145	19-67	Carr & Caldwell (1956); Byles (1988); Campbell & Sulak (1997); Coles (1999); Witt *et al.* (2007)
Caretta caretta	Chesapeake, Florida, UK & France, Japan	0.000282	2.823	0.966	431	12-105	Byles (1988); Sato *et al.* (1995); Barichivich *et al.* (1997); Campbell & Sulak (1997); Coles (1999); Witt *et al.* (2007)
Chelonia mydas	Florida, Tortuguero, Ascension, Suriname, Baja, Solomon Islands	0.000206	2.895	0.992	449	5-124	Carr & Caldwell (1956); Pritchard *et al.* (1969); Barichivich *et al.* (1997); Campbell & Sulak (1997); (2000); Gilbert (2005); Seminoff *et al.* (2006); CCC (Unpublished); Krueger (unpublished); Seminoff & Jones (Seminoff & Jones)
Lepidochelys olivacea	Hawaii, Brazil, Suriname, Mozambique, Thailand, Australia	0.000479	2.673	0.9955	46	4-74	Pritchard *et al.* (1969); Hughes (1972); Chantrapornsyl (1992); Work & Balazs (2002); de Castilhos & Tiwari (2007); WWF-Australia (WWF-Australia)
Eretmochelys imbricata	Honduras, Cayman, Barbados, Suriname	0.000278	2.736	0.988	112	22-99	Pritchard *et al.* (1969); Beggs *et al.* (2007); Blumenthal *et al.* (2008); Dunbar *et al.* (2008)

Although other growth curves exist to describe the growth of sea turtle (e.g. Bjorndal & Bolten, 1988; Chaloupka, 1998; Bjorndal *et al*., 2000a; Chaloupka *et al*., 2004), we have used the von Bertalanffy growth function (VBGF; von Bertalanffy, 1938) to ensure compatibility with the other growth parameters in this report. The VBGF for length has the form:

$$L_t = L_\infty(1 - e^{-K(t-t_0)}) \quad \ldots 2)$$

where L_t is the predicted length at age t, L_∞ (also L_{inf}) 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 t0 is the age the turtles at length = 0.

Using the parameters K (quantifying the curvature of the VBGF), and L_∞ (or W_∞, W_{inf}) one can then summarize and compare growth data by means of so called auximetric plots (Pauly, 1998).

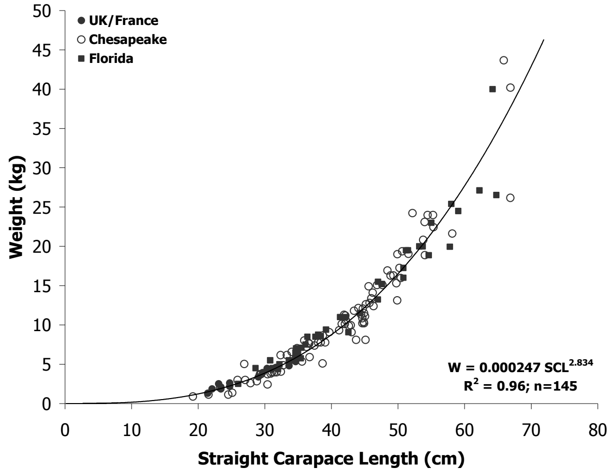
The parameters K and L_∞ used for this analysis were taken from the published literature (see Table 3). Length-weight (L/W) relationships for each species, as described in Table 2, were then used to calculate W_∞ (Table 3).

Results and Discussion

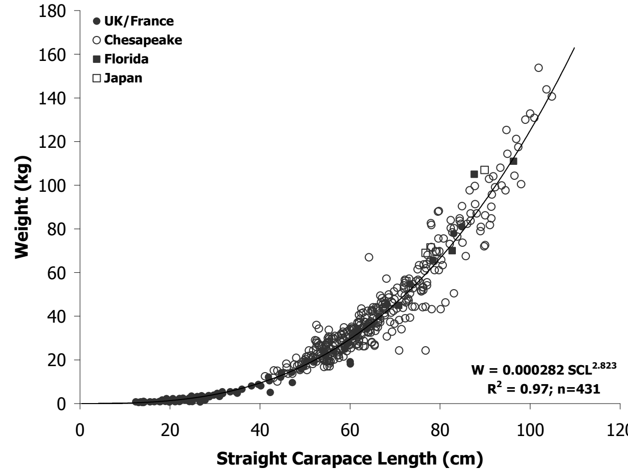
Table 1 summarizes available relationships between SCL and CCL, while Table 2 summarizes the L/W relationships and related data. The r^2 values for all L/W relationships were greater than 0.95. Estimates of parameter b ranged from 2.673 for olive ridleys to 2.895 for green turtles. When split into individual 'populations' for each species b spanned values between 2.495 and 3.134. This increased range in estimates reflected differences in 'population' sample sizes and length ranges. The L/W relationships for all 5 species, and the 'population' data used to derive them, are presented in Figure 1.

One potential application of such length-weight relationships is the computation of biomass estimates from length-frequency distributions. This is of great value when, for example, site and season-specific weights have not been collected due to logistical difficulties and/or lack of time required to record weight in the field. Although weight can be reliably estimated from length using equations such as those presented here, it should be noted that the exact relationship between length and weight may differ depending on the 'condition' of individual animals. Condition may reflect differences in food availability and population densities at individual sites (Bjorndal *et al*., 2000a), and is likely to vary between seasons and years for a given population. In instances where the individuals of a population remain below the average curve, its individuals can be considered comparatively 'skinny'; conversely, when individuals lie above the curve, they can be considered 'stout'.

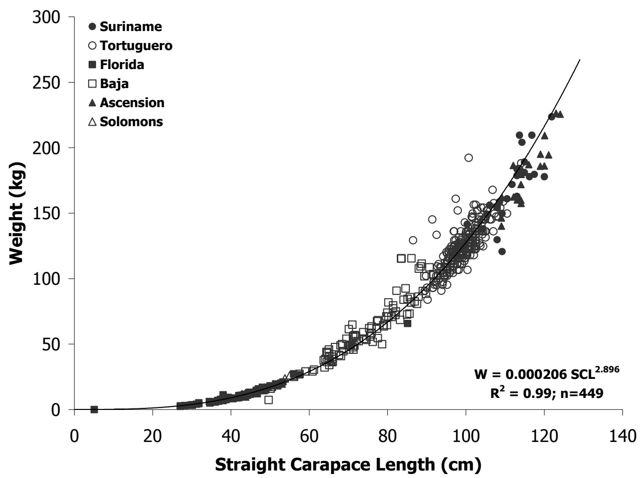
Notably, the compiled data presented here highlight the importance of obtaining 'true' estimates of population parameters through comprehensive sampling of a species size range. Relationships derived from morphometric data for a location-specific population may be biased by being representative of only a narrow size range. For example, because the majority of sea turtle programs operate on nesting beaches, length-weight data pairs are likely to be primarily, if not solely, collected from mature females. This can lead to erroneous population-level L/W relationships, as the juvenile-subadult phase is missing.



A



B



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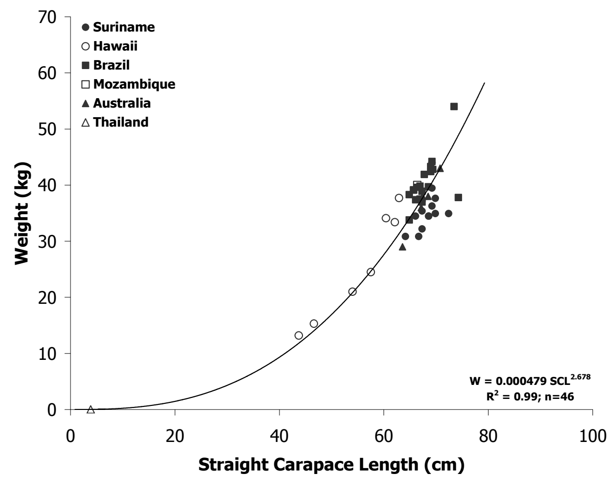

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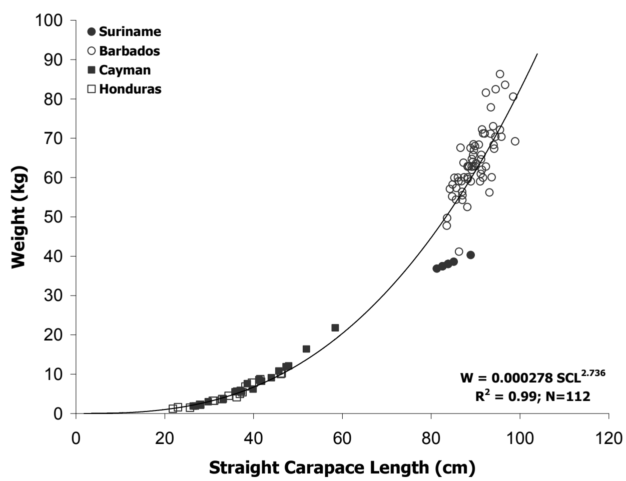

E

Figure 1. Correlations between straight carapace length (SCL, cm) and weight (W, kg) for five species of sea turtles: A. Kemp's ridley (*Lepidochelys kempi*); B. loggerhead (*Caretta caretta*); C. green (*Chelonia mydas*); D. olive ridley (*Lepidochelys olivacea*); E. hawksbill (*Erytmochelys imbricata*) discussed here.

Table A1 summarizes the growth parameters (K, L_∞ and W_∞), while the auximetric plot of Figure 2, which does not include outliers, shows that these growth parameters are mutually consistent.

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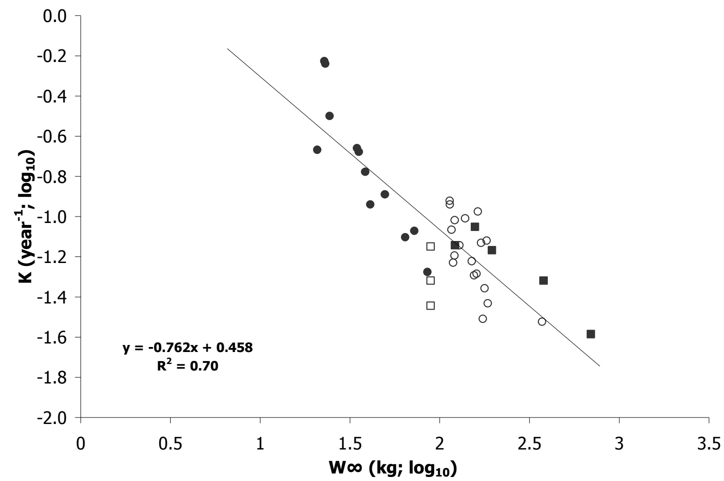

Figure 2. Auximetric plot of von Bertalanffy growth parameters for 38 data pairs of four species of sea turtles (see Table 3 for details). Dark circles represent data for *Lepidochelys kempi*, open circles *Caretta caretta*, dark squares *Chelonia mydas*, and open squares *Erytmochelys imbricata*

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Table A1. Additional growth parameter estimates for 4 species of sea turtles. Method: MR=Mark recapture; SC=Skeletochronology; LF=Length frequency. All data are from wild sea turtles except for data by Caillouet (1995) for *L. kempii*. Reported average lengths from http://www.nmfs.noaa.gov/pr/species/turtles /loggerhead.htm.

Species (reported average length; cm)	Area	*K* (year^{-1})	L_∞ (SCL; cm)	W_∞ (kg)	Sample size	Size range (cm)	Comments; reference [method]
Lepidochelys kempii (56-79)	Gulf of Mexico	0.317	62.3	24.4	117a		Caillouet *et al.* (1995) [MR]
	Atlantic: Gulf of Mexico	0.129	80.0	49.5	36	21.5–60.3	Schmid & Witzell (1997) [MR]
	Atlantic: Cape Canaveral	0.577	61.1	23.0	12c	21.5-60.3	Probably underestimated due to lack of adult sized Kemp's ridley turtles in the database; Schmid (1995) [MR]
	Atlantic: Cape Canaveral	0.594	60.8	22.7	10	21.5-60.3	60% 20-40cm; probably underestimated due to lack of adult sized Kemp's ridley turtles in the database; Schmid (1995) [MR]
	Atlantic	0.215	58.9	20.8	56		Zug et al. (1997) [SC]
	Gulf of Mexico	0.219	70.5	34.6	15		Zug et al. (1997) [SC]
	Atlantic: Gulf of Mexico	0.079	87.7	64.2	70		Zug et al. (1997) [SC]
	Gulf of Mexico: Cedar Keys	0.085	91.4	72.2	24		Schmid (1998) [SC]
	Atlantic	0.167	73.2	38.5	38		Turtle Expert Working Group (2000)b [SC, MR]
	Gulf of Mexico	0.210	71.1	35.4	58		Turtle Expert Working Group (2000) [SC, MR]
	Atlantic	0.115	74.9	41.0	109	21.7–50.5	Snover *et al.* (2007) [SC]
	Gulf of Mexico	0.053	97.0	85.4	660	20-61	Bjorndal & Bolten (1997) [LF]
Caretta caretta (92)	Atlantic: Cape Canaveral	0.059	96.1	118	51c	38.2-110	80%<80 cm SCL; 20%>80cm; Schmid (1995) [MR - Adults include males and females]
	Atlantic: Cape Canaveral	0.037	112	185	17	38.2–110	Growth model for captures and recaptures by the contract vessel; size range for study but not specified for N=19; Schmid (1995) [MR]
	Chesapeake Bay	0.076	112	182	83	13-42	Klinger & Musick (1995) [SC]
	Atlantic (Florida, Georgia & South Carolina)	0.031	110	174	118	45–110	Size range for study, no specified for N=118; Henwood (1987) [MR]
	Azores, North Atlantic	0.072	98.9	129	574	10-64	Assuming 105.5 CCL, where CCL=1.388+(1.053)(SCLnt); Bjorndal *et al.* (2000b) [LF]
	Florida, Mosquito lagoon	0.120	94.6	114	28	53.3-77.3	Frazer & Ehrhart (1985) [MR]
	Florida	0.115	94.7	114	41	53.3–77.	Size range based on 8 individuals with specified lengths, 20 adults with lengths not specified, and 13 individuals with no specified lengths but assumed <82 cm; Frazer (1987) [MR]
	North Carolina	0.052	107	160	57	45.1–75.8	Braun-McNeill *et al.* 2002 in Epperly *et al.*(2001) [MR]

Table A1. Continued.

Species (reported average length; cm)	Area	*K* (year^{-1})	L_∞ (SCL; cm)	W_∞ (kg)	Sample size	Size range (cm)	Comments; reference [method]
Caretta caretta (92)	Florida	0.064	96.7	121	54	62.2–104.2	Foster (1994) [MR]
	Georgia, Cumberland island	0.096	96.8	121	69	>49.76-103	Reported in CCL and converted to SCL using SCL=(0.948×CCL)–1.442 ; Teas (1993); Parham & Zug (1997) [SC–1979 ; regression growth protocol]
	Georgia, Cumberland island	0.098	102	138	25	>49.76–103	Reported in CCL and converted to SCL using SCL=(0.948×CCL)–1.442 ; Teas (1993); Parham & Zug (1997) [SC–resampled 1979 data–correction factor protocol]
	Georgia, Cumberland island	0.086	95.4	116	25	>49.76–103	Reported in CCL and converted to SCL using SCL=(0.948×CCL)–1.442 ; Teas (1993); Parham & Zug (1997) [SC–resampled 1979 data–regression growth protocol
	Georgia, Cumberland island	0.106	108	163	26	>36.04–103	Parham & Zug (1997) [SC – 1980 correction factor protocol]
	Georgia, Cumberland island	0.074	109	170	26	>36.04–103	Parham & Zug (1997) [SC – 1980 regression growth protocol]
	Gulf of Mexico	0.051	106	155	570	>36.04–103	Bjorndal *et al* .(2001) [LF]
	Florida, Atlantic coast	0.044	111	178	1234	42.2-81.03	Reported in CCL and converted to SCL using SCL=(0.948×CCL)–1.442 ; Teas (1993); Bjorndal et al. (2001) [LF]
	Texas	0.030	144	372	819	46-87	Bjorndal & Bolten (1997) [LF]
	Great Barrier Reef, Australia	0.060	105	151	172	63–90.3	Reported in CCL and converted to SCL using SCL=(0.948×CCL)–1.442 ; Teas (1993); Frazer *et al.* (1994) [MR]
Chelonia mydas (91)	Florida, Mosquito lagoon	0.089	109	157	11	27.7->69.6	Frazer & Ehrhart (1985) [MR]
	Florida, Atlantic	0.026	182	694	976	25-70	Bjorndal & Bolten (1997) [LF]
	Inagua, Bahamas	0.072	99.7	122	964	25-70	Bjorndal & Bolten (1995) [LF]
	US Virgin Islands	0.048	148	379	41	25.6–62.3	Size range at first capture; Boulon & Frazer (1990) [MR]
	Watamu, Kenya	0.068	117	195	563	31-108	Reported in CCL and converted to SCL using SCL=0.932*CCL+0.369 ; Peckham *et al.* (2008) ; Watson (2006) [MR]

Table A1. Continued.

Species (reported average length; cm)	Area	*K* (year^{-1})	L_∞ (SCL; cm)	W_∞ (kg)	Sample size	Size range (cm)	Comments; reference [method]
Eretmochelys imbricata (63-90)	St Thomas, Virgin islands	0.071	100	88.9	9	36-43	Boulon (1994) as in Heppell & Crowder (1996) [MR]
	Mona Island, Puerto Rico	0.036	100	88.9	15	-	Van Dam and Diez (1994) as in Heppell & Crowder (1996) [MR]
	Queensland, Australia	0.048	100	88.9	41	33-82	Reported in CCL and converted to SCL using SCL=SCL=0.935*CCL+0.449; Limpus (1992) as in Heppell & Crowder (1996)