Supporting Online Material accompanying the manuscript:

"Time in tortoiseshell: a bomb radiocarbon-validated chronology in sea turtle scutes"

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Contained in this document are two figures, three tables, and R code for the MLE routine.

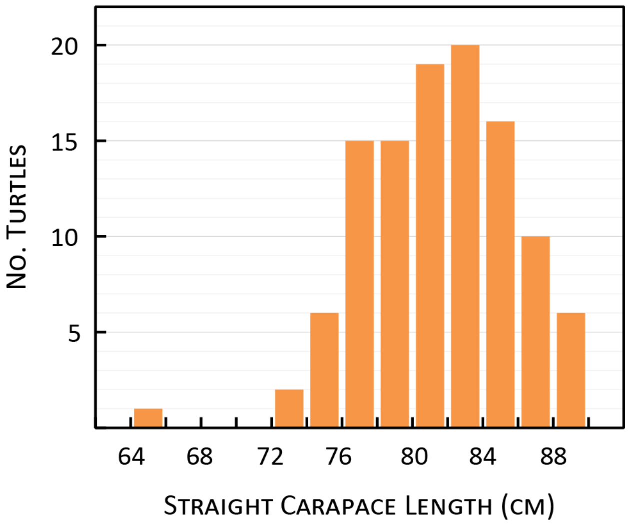

Figure S1, Estimation of the VBGF parameter L_{oo} from empirical population monitoring of nesting female hawksbill sea turtles. Beach monitoring from 1991-2014 documented the measured straight carapace lengths (SCL) of n = 110 nesting females from Hawaii (n = 99) and Maui islands (n = 11). Orange bars accumulate the observations in each 2 cm bin, representing the average measured length (measurements were repeated at each nesting attempt) during the first observed year. The median SCL from of all observed nesting females was 81.0 cm (range 65.0 - 89.0 cm). As turtle growth after breeding maturity is negligible (Frazer & Ehrhart 1980, Price *et al.* 2004, Jones *et al.* 2011), our metric encompasses the full range of the sizes of mature breeding female sizes. Further details on the monitoring programs are provided elsewhere (Seitz *et al.* 2012, Van Houtan *et al.* 2012). For sea turtles, L_{oo} does not represent unattainable growth, but the median breeding size.

Figure S2, Dorsal view of a preserved, archived hawksbill carapace with posterior marginal scute removed. Juvenile male hawksbill measuring 45 cm SCL from Makaha, Oahu Island, Hawaii, in January 1990. The turtle was collected by NOAA as part of the regular strandings response program after it was found dead and entangled in a fishing net. Posterior marginal scute (PM) can often be easily removed from a dry preserved carapace manually, without requiring a saw that may damage adjoining bone or scutes. “c” denotes crustose coralline algae growing on the surface of posterior carapace portion, typically in the lee of scute imbrication. Notice the cracks, chips, and other damage to the vertebral and costal scutes – especially toward the anterior. Unlike other sea turtle species, hawksbills have imbricated scutes meaning more anterior scutes overlap immediately adjoining scutes to the posterior. It is at these imbrications or overlaps where scute damage is most frequent, denoted by white filled circles. Notice how the marginal scute edges to the (left) anterior section are smooth from wear, but towards the (right) posterior those same margins are pointed as they are in the lee and protected during forward motion. Posterior marginal scutes, by their position and due to their thickness (both in contrast to more anterior carapace scutes) are not as easily damaged and therefore have the greatest potential to retain a complete chronological tissue record.

TURTLE ACCESSION ID	SCL (cm)	SEX	COLLECT INSTITUTION	COLLECT YEAR	COLLECT REGION	COLLECT LOCATION	TURTLE TREATMENT	GROWTH LINES
Ei11222011Hi04.1	4.1	Unk.	PIFSC	2011	C. N. Pacific	Hawaii	wild	3
Ei10202011Hi04.3	4.3	Unk.	PIFSC	2011	C. N. Pacific	Hawaii	wild	3
Ei09072011Hi4.3	4.3	Unk.	PIFSC	2011	C. N. Pacific	Hawaii	wild	3
Ei09072011hi4.56	4.6	Unk.	PIFSC	2011	C. N. Pacific	Hawaii	wild	3
Ei09072011Hi4.59	4.6	Unk.	PIFSC	2011	C. N. Pacific	Hawaii	wild	4
Ei??????FW14.5	14.5	Unk.	USFWS	Unk.	Pacific	Indonesia	wild	15
Ei08201996iN21	21.4	Unk.	USFWS	1996	W. Pacific	Indonesia	wild	14
Ei11152011FW31	31.0	Unk.	USFWS	2011	W. Pacific	Indonesia	wild	29
Ei04012012Oz38.8	38.8	Unk.	USFWS	2012	S. Pacific	Australia	wild	46
Ei09101962iN39.2	39.2	Unk.	USFWS	1962	W. Pacific	Indonesia	wild	41
Ei06172011Hi39.2	39.2	Unk.	PIFSC	2011	C. N. Pacific	Hawaii	wild	75
Ei08172011Hi39.9	39.9	F	PIFSC	2011	C. N. Pacific	Hawaii	wild	47
Ei02272013To40.4	40.4	Unk.	USFWS	2013	S. Pacific	Tonga	wild	51
Ei05222011Hi41	41.4	F	PIFSC	2011	C. N. Pacific	Hawaii	wild	60
Ei10291992Kw42.6	42.6	M	PIFSC	1992	W. Pacific	Kwajelin	wild	42
Ei02272013To42.7	42.7	Unk.	USFWS	2013	S. Pacific	Tonga	wild	48
Ei04022012Hi44.2	44.2	F	PIFSC	2012	C. N. Pacific	Hawaii	wild	50
Ei05301997Hi44	44.4	F	PIFSC	1997	C. N. Pacific	Hawaii	wild	65
Ei01301990Hi44.5	44.5	M	BPBM	1990	C. N. Pacific	Hawaii	wild	42
Ei11152011Pa44	44.6	Unk.	USFWS	2011	W. Pacific	Palau	wild	52
Ei11291977Hi44.6	44.6	Unk.	USFWS	1977	C. N. Pacific	Hawaii	wild	52
Ei????????FW48.8	48.8	Unk.	USFWS	Unk.	Pacific	Unk.	wild	43
Ei10211992Kw50.3	50.3	F	PIFSC	1992	W. Pacific	Kwajelin	wild	64
Ei????1970Hi52.3	52.3	Unk.	PIFSC	1970	C. N. Pacific	Hawaii	captive	76
Ei04112013Hi54.5	54.5	F	PIFSC	2013	C. N. Pacific	Hawaii	wild	124
Ei04232010Hi57	57.5	F	PIFSC	2010	C. N. Pacific	Hawaii	wild	90
Ei11042011Hi61	61.1	F	PIFSC	2011	C. N. Pacific	Hawaii	wild	78
Ei12211976BP72	72.0	Unk.	BPBM	1976	C. N. Pacific	Hawaii	wild	173
Ei11241978Hi75.2	75.2	Unk.	PIFSC	1978	C. N. Pacific	Hawaii	captive	104
Ei05151979Hi76.4	76.4	M	PIFSC	1979	C. N. Pacific	Hawaii	captive	123
Ei04061987Hi77.8	77.8	M	BPBM	1987	C. N. Pacific	Hawaii	wild	122
Ei11132006FW78	78.4	Unk.	USFWS	2006	Pacific	Unk.	wild	110
Ei05031994FW79	79.2	Unk.	USFWS	1994	Pacific	Unk.	wild	124
Ei09032008Hi82	82.5	F	PIFSC	2008	C. N. Pacific	Hawaii	wild	197
Ei????1966BP82	82.7	Unk.	BPBM	1962	C. N. Pacific	Hawaii	wild	141
Ei09112007Hi83	83.0	F	PIFSC	2007	C. N. Pacific	Hawaii	wild	--
Ei04041988Hi83	83.2	F	BPBM	1988	C. N. Pacific	Hawaii	wild	184
Ei08191996Hi88.7	88.7	F	BPBM	1996	C. N. Pacific	Hawaii	wild	--

Table S1, Raw metadata for all hawksbill carapaces used in this study. For origin institutions, "PIFSC" is the NOAA Pacific Islands Fisheries Science Center, "USFWS" is the U.S. Fish & Wildlife Service, and "BPBM" is the Bernice Pauahi Bishop Museum. "Collect year" is the year of death. Only turtles from the Hawaii population were used in the age determination portion of the study, but all turtles appear in Figure 1c, the basic plot of length to number of apparent scute growth lines. As stipulated in the Methods, we collected and archived all specimens as specified under the U.S. Endangered Species Act (USFWS permit no. TE-72088A-0).

SAMPLE ID	FORM. MODERN	Fm ERR	Δ^{14}C raw	FORM. YEAR	Δ^{14}C CALIB.	Δ^{14}C ADJUST.
Ei----1962BP82-D	0.9151	0.004	-86.72	1942	-86.67	-84.01
Ei----1962BP82-E	0.9358	0.003	-66.01	1945	-66.01	-63.63
Ei----1962BP82-F	0.9458	0.0026	-56.00	1947	-56.03	-53.86
Ei----1962BP82-C	0.9466	0.0031	-55.24	1956	-55.23	-54.09
Ei----1962BP82-B	0.9652	0.0036	-36.70	1960	-36.67	-35.97
Ei----1962BP82-A	0.9681	0.0031	-33.73	1963	-33.77	-33.36
Ei04061987Hi77.8-F	1.0342	0.0033	31.05	1969	29.58	31.86
Ei04061987Hi77.8-H	1.085	0.0025	80.19	1971	80.15	82.25
Ei04061987Hi77.8-E	1.0877	0.0033	84.46	1974	82.84	84.61
Ei04061987Hi77.8-D	1.0733	0.0039	70.10	1975	68.51	70.12
Ei04061987Hi77.8-C	1.0909	0.0027	87.65	1977	86.03	87.34
Ei04061987Hi77.8-G	1.0725	0.0034	69.26	1979	67.71	68.77
Ei04061987Hi77.8-B	1.0728	0.0032	69.55	1982	68.01	68.62
Ei04061987Hi77.8-A	1.0317	0.0035	28.61	1987	27.09	27.06
Ei12211976Hi72-E	0.9313	0.0024	-71.67	1955	-71.62	-69.23
Ei12211976Hi72-F	0.9548	0.0024	-48.17	1959	-48.20	-46.24
Ei12211976Hi72-D	0.9508	0.0024	-52.16	1961	-52.19	-50.46
Ei12211976Hi72-G	0.9841	0.0025	-19.01	1964	-18.99	-17.51
Ei12211976Hi72-C	1.0694	0.0025	66.02	1969	66.04	66.95
Ei12211976Hi72-B	1.074	0.0027	70.58	1970	70.63	71.40
Ei12211976Hi72-H	1.1053	0.0029	101.86	1972	101.83	102.36
Ei12211976Hi72-A	1.1043	0.0032	100.84	1974	100.83	101.10
Ei04041988Hi83-H	0.9683	0.003	-36.14	1962	-36.14	-33.15
Ei04041988Hi83-I	0.9895	0.003	-15.09	1965	-15.04	-12.23
Ei04041988Hi83-J	0.9928	0.0027	-11.80	1965	-11.75	-9.00
Ei04041988Hi83-G	1.0401	0.0032	35.38	1968	35.33	37.84
Ei04041988Hi83-K	1.0511	0.0022	46.24	1969	46.28	48.69
Ei04041988Hi83-F	1.0689	0.0027	63.98	1971	64.00	66.19
Ei04041988Hi83-L	1.0774	0.0026	72.45	1973	72.46	74.41
Ei04041988Hi83-E	1.108	0.0036	102.92	1976	102.92	104.52
Ei04041988Hi83-D	1.0703	0.0028	65.36	1980	65.39	66.42
Ei04041988Hi83-B	1.0862	0.0035	81.23	1984	81.22	81.74
Ei04041988Hi83-A	1.0566	0.0044	51.77	1988	51.75	51.72
Ei05022011Hi41.4-B	1.0519	0.0031	44.17	2005	44.17	44.94
Ei05022011Hi41.4-A	1.0587	0.0035	50.87	2011	50.92	50.87
Ei05301997Hi44.4-B	1.045	0.0035	39.09	1991	39.08	39.77
Ei05301997Hi44.4-A	1.0625	0.0038	56.52	1997	56.48	56.42
Ei04022012Hi44.2-B	1.0576	0.003	49.69	2005	49.70	50.60
Ei04022012Hi44.2-A	1.0536	0.0032	45.73	2012	45.73	45.69
Ei04232010Hi57.5-B	1.0656	0.003	57.90	2001	57.89	59.10
Ei04232010Hi57.5-A	1.0317	0.0031	24.19	2010	24.24	24.20
Ei11042011Hi61.1-B	1.0918	0.0036	83.80	1998	83.77	85.45
Ei11042011Hi61.1-A	1.0463	0.0033	38.63	2011	38.61	38.57
Ei09032008Hi82.5-D	1.0752	0.0033	67.69	1976	67.68	71.77
Ei09032008Hi82.5-C	1.095	0.0033	87.30	1982	87.34	90.77
Ei09032008Hi82.5-B	1.0735	0.0031	65.95	1986	65.99	68.84
Ei09032008Hi82.5-A	1.0689	0.0035	61.47	2009	61.43	61.34
Ei11291974Hi44.6-B	1.1151	0.0034	111.92	1971	111.87	112.25
Ei11291974Hi44.6-C	1.115	0.0025	111.74	1973	111.77	111.90
Ei11291974Hi44.6-A	1.0856	0.0037	82.43	1975	82.45	82.34
Ei01301990Hi44.5-B	1.12	0.0034	114.64	1984	114.59	115.42
Ei01301990Hi44.5-A	1.0822	0.0054	76.98	1990	76.98	76.97
Ei08191996Hi88.7-A	1.0419	0.0029	36.14	1997	36.12	36.04
Ei09112007Hi83-A	1.0431	0.0052	35.92	2008	35.93	35.85

Table S2, Radiocarbon results from the National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility at the Woods Hole Oceanographic Institution. Sample ID is the same as in Table S1, with the ultimate addition of a letter code for the microsample transect. See main text Methods for descriptions of the column headings Formation Modern, its error, $\Delta^{14}C$ values, adjustments and calibrations. Formation year is listed for the median growth ageing scenario (i.e. displayed in the main text Figure 4, Figure 5c).

TURTLE	COLLECT	HATCH YEAR DATE RANGE			AGE		
ID	DATE	VBGF	$\Delta^{14}C$	OVERLAP	MIN	MED	MAX
hatchlings	n/a	n/a	n/a	n/a	0.0	0.0	0.0
Ei02112015Hi9.2	2015	n/a	n/a	n/a	0.1	0.3	0.6
Ei----1966BP82	1966	1882-1943	1944-1952	1936-1942	24.0	27.0	30.0
Ei04061987Hi77.8	1987	1947-1976	1966-1971, 1983-2012	1966-1971	16.0	18.6	21.1
Ei12211976Hi72	1977	1949-1969	1930-1958	1949-1958	19.0	23.5	28.0
Ei04041988Hi83	1988	1904-1965	1958-1964	1958-1964	24.3	27.3	30.3
Ei05022011Hi41.4	2011	2002-2009	1966-2012	2002-2009	2.4	5.9	9.4
Ei05301997Hi44.4	1997	1987-1994	1966-1974, 1980-2012	1987-1994	3.4	6.9	10.4
Ei04022012Hi44.2	2012	2002-2009	1966-2012	2002-2009	3.3	6.8	10.3
Ei04232010Hi57.5	2010	1995-2006	1967-2009	1995-2006	4.3	9.8	15.3
Ei11042011Hi61.1	2011	1993-2006	1967-2001	1993-2001	10.3	14.3	18.3
Ei09032008Hi82.5	2009	1925-1986	1967-2005	1967-1986	22.7	32.2	41.7
Ei11291974Hi44.6	1975	1965-1972	1970-1992	1970-1972	2.5	3.7	4.9
Ei01301990Hi45.9	1990	1979-1987	1970-1992	1979-1987	2.9	7.0	11.1

Table S3, Age determination metadata for the Hawaii hawksbills analyzed in this study. See main text Methods for more detailed descriptions of the three age scenarios of slow (min), mean (med), and fast (max) growth. “VBGF” represents the date range from the constraints on k for the von Bertalanffy growth model, “$\Delta^{14}C$” is the estimated date range from the reported radiocarbon values for that tissue sample, and “Overlap” is where the series coincide. The data in the three columns on the right are used for the MLE procedure to fit the VBGF models, to estimate the growth somatic parameter k, shown in in the main text Figure 5.

Complete R code for the MLE estimation of the VBGF model fit to age data

```
### R CODE BEGINS HERE
### SUPPORTING ONLINE MATERIAL, R CODE, AND NOTES FOR THE FOLLOWING STUDY
### TIME IN TORTOISESHELL: A BOMB RADIOCARBON VALIDATED CHRONOLOGY…
### Generated by Kyle S. Van Houtan (kyle.vanhoutan@gmail.com, +1 808 228 1112)
### At the time with NOAA Fisheries, based in Honolulu, Hawaii, in June 2015
### Purpose is to fit growth models to length-age data for hawksbill sea turtles using R
### Uses empirical data for t0 and Loo, and use MLE to optimize for growth parameter k
### Do this by first generating the negative log-likelihood function, then call models within

### Read in the data from csv files
### create vectors from lengths and ages within
captive.data <- read.csv("captive_ages.csv",header=T)
wild.data <- read.csv("d14c_ages.csv",header=T)
captive.ages <- captive.data$AgeCap
captive.lengths <- captive.data$Length
wild.ages.min <- wild.data$AgeMin
wild.ages.med <- wild.data$AgeMed
wild.ages.max <- wild.data$AgeMax
wild.lengths <- wild.data$Length
n.captive <- length(captive.lengths)
n.wild <- length(wild.lengths)
Linf <- 81.0
t0 <- (62.5/365.25)

### FIRST RUN VBGF FOR CAPTIVE-REARED HAWKSBILL DATA
### VBGF formula in general terms is Lt <- Linf(1-exp(-k(t-t0)))
### get negative log-likelihood first for VBGF
### generate predicted lengths vector from VBGF
NLL.captive <- function(Linf, k, sigma, t0, captive.ages, captive.lengths, n.captive) {
  pred.Lt.cap <- Linf*(1-exp(-k*(captive.ages-t0)))
  NLL.captive <- n.captive*log(sigma) + 0.5*sum(((captive.lengths-pred.Lt.cap)/sigma)^2)
  return(NLL.captive)
}
### run with some dummy values to check if it works
NLL.captive(Linf=Linf, k=0.25, sigma=10, t0=t0, captive.ages=captive.ages, captive.lengths=captive.lengths,
n.captive=n.captive)
##fit data to models VBGF and optimize using MLE
##distinguish between estimated parameters and fixed variables in the mle code
vbgf.mle.cap <- mle(NLL.captive, start = list(k=0.2, sigma=2), fixed = list(Linf=Linf, t0=t0,
captive.ages=captive.ages, captive.lengths=captive.lengths, n.captive=n.captive))
summary(vbgf.mle.cap)
### result is -2 log L = 76.56483

### NEXT RUN VBGF FOR WILD-REARED HAWKSBILL DATA
### begin with minimum age estimate scenario
```

```
NLL.wild.min <- function(Linf, k, sigma, t0, wild.ages.min, wild.lengths, n.wild) {
  pred.Lt.min <- Linf*(1-exp(-k*(wild.ages.min-t0)))
  NLL.wild.min <- n.wild*log(sigma) + 0.5*sum(((wild.lengths-pred.Lt.min)/sigma)^2)
  return(NLL.wild.min)
}
NLL.wild.min(Linf=Linf, k=0.08, sigma=10, t0=t0, wild.ages.min=wild.ages.min, wild.lengths=wild.lengths,
n.wild=n.wild)
vbgf.mle.min <- mle(NLL.wild.min, start = list(k=0.23, sigma=10), fixed = list(Linf=Linf, t0=t0,
wild.ages.min=wild.ages.min, wild.lengths=wild.lengths, n.wild=n.wild))
summary(vbgf.mle.min)
### result is -2 log L = 75.13572

### next move is to run MLE for median age estimate scenario
NLL.wild.med <- function(Linf, k, sigma, t0, wild.ages.med, wild.lengths, n.wild) {
  pred.Lt.med <- Linf*(1-exp(-k*(wild.ages.med-t0)))
  NLL.wild.med <- n.wild*log(sigma) + 0.5*sum(((wild.lengths-pred.Lt.med)/sigma)^2)
  return(NLL.wild.med)
}
NLL.wild.med(Linf=Linf, k=0.08, sigma=10, t0=t0, wild.ages.med=wild.ages.med, wild.lengths=wild.lengths,
n.wild=n.wild)
vbgf.mle.med <- mle(NLL.wild.med, start = list(k=0.12, sigma=6), fixed = list(Linf=Linf, t0=t0,
wild.ages.med=wild.ages.med, wild.lengths=wild.lengths, n.wild=n.wild))
summary(vbgf.mle.med)
### result is -2 log L = 62.9941

### finally run MLE for maximum age estimate scenario
NLL.wild.max <- function(Linf, k, sigma, t0, wild.ages.max, wild.lengths, n.wild) {
  pred.Lt.max <- Linf*(1-exp(-k*(wild.ages.max-t0)))
  NLL.wild.max <- n.wild*log(sigma) + 0.5*sum(((wild.lengths-pred.Lt.max)/sigma)^2)
  return(NLL.wild.max)
}
NLL.wild.max(Linf=Linf, k=0.08, sigma=10, t0=t0, wild.ages.max=wild.ages.max, wild.lengths=wild.lengths,
n.wild=n.wild)
vbgf.mle.max <- mle(NLL.wild.max, start = list(k=0.34, sigma=6), fixed = list(Linf=Linf, t0=t0,
wild.ages.max=wild.ages.max, wild.lengths=wild.lengths, n.wild=n.wild))
summary(vbgf.mle.max)
### result is -2 log L = 63.71403
### END OF R CODE
### ENJOY
```