SUPPLEMENTARY MATERIAL

Growth rate and projected age at sexual maturity for immature hawksbill turtles and green turtles foraging in the remote marine protected area of Aldabra Atoll, Seychelles

Cheryl L Sanchez[1,2*], Nancy Bunbury[2,3], Jeanne A Mortimer[2,4], Luke A'Bear[2], Michael Betts[2], Rainer von Brandis[2], April J Burt[2], Lorraine Cooke[2], Janske van de Crommenacker[2], Jock C Currie[2,5], Naomi Doak[2], Frauke Fleischer-Dogley[2], Emma Mederic[2], Bruno Mels[2], Pierre Pistorius[2,6], Heather Richards[2], Paolo Casale[1]

*Correspondence: cheryl.sanchez@phd.unipi.it

[1] Department of Biology, University of Pisa, Via A. Volta 6, 56126 Pisa, Italy

[2] Seychelles Islands Foundation, PO Box 853, Victoria, Mahé, Seychelles

[3] Centre for Ecology and Conservation, University of Exeter, Cornwall Campus, Penryn, TR10 9FE, UK

[4] Department of Biology, University of Florida, Gainesville, Florida, 32611, USA

[5] Marine Program, South African National Biodiversity Institute, Kirstenbosch National Botanical Garden, Rhodes Avenue, Newlands 7735, South Africa

[6] Department of Zoology and Institute for Coastal and Marine Research, Nelson Mandela University, Gqeberha, South Africa

Table S1 Total capture statistics for Aldabra (Jul 1981–Mar 2021). CCLn-t = curved carapace length notch-to-tip (cm). Not all first time captures had measurements, therefore the number of first time captures with measurements is less than the total number of first time captures

	Overall			First time captures CCLn-t (cm)		
	Total captures	First time captures	Recaptures	n	Range	Mean ± SD (median)
Green turtle	1439	1197	242	1191	34.3–110.9	51.0 ± 11.4 (46.8)
Hawksbill turtle	848	546	302	538	28.7–89.4	47.7 ± 14.4 (43.6)

Table S2 Sum of the maximum number of captures for individual turtles, ranging from one capture to ten captures. All captures are included but not all captures had measurements taken

Species	Max. number of captures for individual turtles										Total # indiv.
	1	2	3	4	5	6	7	8	9	10	
Green turtle	1023	133	26	10	2	2	0	0	0	1	1197
Hawksbill turtle	375	107	30	19	7	4	1	0	3	0	546

Table S3 Approximate significance of smooth terms for immature green turtle GAMM. CCL = curved carapace length (notch-to-tip).

	k check				**model check**			
	k'	**k-index**	**edf**	**p-value**	**edf**	**Ref.df**	**F**	**p-value**
mean CCL (cm)	9	1.05	1.00	0.64	1.00	1.00	1.98	0.16
Mean year	9	0.99	1.79	0.45	1.79	2.24	0.59	0.56
recapture interval (years)	9	1.06	1.00	0.65	1.00	1.00	0.00	0.96

Table S4 Approximate significance of smooth terms for immature hawksbill turtle GAMM. CCL = curved carapace length (notch-to-tip)

	k check				model check			
	k'	**k-index**	**edf**	**p-value**	**edf**	**Ref.df**	**F**	**p-value**
mean CCL (cm)	8	1.04	3.66	0.61	3.66	4.51	11.28	< 2e-16
mean year	9	0.97	4.09	0.34	4.10	5.08	5.55	1.37e-4
recapture interval (years)	9	1.23	1.51	0.97	1.51	1.84	0.87	0.33

Table S5 Green turtle growth rate (cm year^{-1}) means from published literature grouped into 10-cm size classes. The majority of studies used mean carapace length for models, but some used initial size. CCL = curved carapace length, SCL = straight carapace length, CMR = capture mark recapture, Sk = skeletochronology, USVI = US Virgin Islands, nGBR = northern Great Barrier reef, sGBR = southern Great Barrier Reef. (*) denotes 1 for sample size. Studies differ in samples sizes and recapture interval cutoffs

Location	**CCL/ SCL**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**Method**	**Reference**
WIO													
Aldabra	CCL	-	-	2.1	3.0	3.7	3.6	-	-	-	-	CMR	This study
Aldabra	CCL	-	-	-	-	-	-	-	-	-	0.14	CMR	Mortimer et al. 2022
Atlantic													
Virginia to Florida, Costa Rica, Mexico	SCL	3.3	3.0	2.1	2.5	2.7	3.3	2.4	2.6	1.4	0.3	Sk	Goshe et al. 2010
Florida	SCL	-	-	5.3	-	3.1	2.8	2.2	-	-	-	CMR	Mendonça 1981

Location	**CCL/ SCL**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**Method**	**Reference**
Florida	SCL	-	3.1	4.4	4.8	5.3	4.1	1.3*	-	-	-	Sk	Zug and Glor 1998
Florida Gulf	SCL	-	-	4.7	4.3	4.8	3.8*	-	-	-	-	CMR	McMichael et al. 2008
Florida	SCL	-	-	2.3	2.6	2.7	-	1.8	-	-	-	CMR	Bresette and Gorham 2001
W Atlantic	SCL	-	3.7	3.9	2.9	2.8	2.6	0.9	0.1	-	-	CMR	Bjorndal et al. 2017
Brazil	CCL	-	-	1.8	2.2	3.0	2.9	2.7	2.9	-	-	CMR	Colman et al. 2015
Trident Basin, Florida	SCL	-	1.76	2.30	1.57	-	-	-	-	-	-	CMR	Kubis et al. 2009
IRL, Florida	SCL	-	-	3.61	4.04	4.55	4.04	2.78	-	-	-	CMR	Kubis et al. 2009
Sebastian reef, Florida	SCL	-	1.31	1.95	2.40	3.00	2.53	-	-	-	-	CMR	Kubis et al. 2009
St. Lucie, Florida	SCL	-	1.18	2.14	2.51	2.64	2.81	-	-	-	-	CMR	Kubis et al. 2009
Caribbean													
Bahamas	SCL	-	-	8.8	4.9	3.1	1.8	1.9	-	-	-	CMR	Bjorndal and Bolten 1988
Virgin Islands	SCL	-	6.9	5.0	4.7	3.5	1.9	3.9	-	-	-	CMR	Boulon and Frazer 1990
Puerto Rico	SCL	-	3.6	5.1	6.0	3.8	3.9	-	-	-	-	CMR	Collazo et al. 1992
Pacific													
sGBR	CCL	-	-	-	0.75	0.95	1.43	1.46	1.1	-	-	CMR	Limpus and Walter 1980
sGBR	CCL						2.1/ 2.2						Limpus and Chaloupka 1997

Location	CCL/ SCL	10	20	30	40	50	60	70	80	90	100	Method	Reference
Galápagos	SCL	-	-	-	0.4	0.5	0.2	0.1	0.1	-	-	CMR	Green 1993
Galápagos	SCL	0.4	-0.6	-0.1	0.8	4.8	-0.8	-2.1	-	-	1.1	CMR	Zárate et al. 2015; black morph
Galápagos	SCL	2.2	1.6	-	5.9*	1.3*	-0.2	-	-	1.4	1.7	CMR	Zárate et al. 2015; yellow morph
NW Mexico	CCL	-	-	3.9	3.5	3.6	2.6	1.5	1.4	0.4	-	Sk	Turner Tomaszewicz et al. 2018
Gulf of California	SCL	-	-	-	-	1.0	1.4	1.2	1.9	1.9	-	CMR	Seminoff et al. 2002a
Hawaii	SCL	-	4.4	3.5	2.1	2.3	2.2	2.1	1.3	0.6	-	Sk	Zug et al. 2002
Hawaii	SCL	-	-	2.5	2.1	2.1	1.7	1.7	1.5	0.5	-	Sk (expect. method)	Murakawa and Snover 2018

Table S6 Hawksbill turtle growth rate (cm year^{-1}) means from published literature grouped into 10-cm size classes. Adapted from Hawkes et al. 2014, Table 1, where growth rate means (cm year^{-1}) were extracted from plots in published papers and grouped into 10-cm size classes. The majority of studies used mean carapace length for models, but some used initial size. CCL = curved carapace length, SCL = straight carapace length, CMR = capture-mark-recapture, Sk = skeletochronology, USVI = US Virgin Islands, nGBR = northern Great Barrier reef, sGBR = southern Great Barrier Reef. (*) denotes 1 for sample size. Studies differ in samples sizes and recapture interval cutoffs.

Location	CCL/ SCL	20	30	40	50	60	70	Method	Reference
WIO									
Aldabra	CCL	-	1.6	2.9	3.6	3.5	0.7	CMR	This study
Atlantic									

Location	CCL/ SCL	20	30	40	50	60	70	Method	Reference
W Atlantic basin	SCL	3.7	3.9	2.9	2.8	2.6	0.9	CMR	Bjorndal et al. 2016
Brazil	CCL		4.0	3.7	3.8	3.0	1.9	CMR	Bellini et al. 2019
Florida	SCL	-	-	4.49	3.42	2.43	1.68	CMR	Wood et al. 2013
Caribbean									
BVI, Anegada	CCL	10.8	8.9	8.7	6.1	-	-	CMR	Hawkes et al. 2014
USVI	SCL	-	4.8	3.3	2.8	2.6*	-	CMR	Boulon 1994
Bahamas	SCL	-	15.6*	7.35	5.21	3.14		CMR	Bjorndal and Bolten 2010
Bahamas	SCL	-	15.7*	5.9*	-	2.6	-	CMR	Bjorndal and Bolten 1988
Barbados	CCL	-	3.28	1.84	0.88	0.43	0.13	CMR	Krueger et al. 2011
Barbados	CCL	-	-	-	-	-	0.40	CMR	Beggs et al. 2007
Cayman Island	SCL	3.46	3.09	2.67	1.93	-	-	CMR	Blumenthal et al. 2009
Dominican Republic	SCL	5.26	6.47	-	-	-	-	CMR	Leon and Diez 1999
Pacific									
Hawaiian Archipelago	SCL	3.8	4.4	5.16	2.24	2.24	3.60	Sk	Snover et al. 2013
W Samoa	SCL	1.29	1.88	0.72	-	-	-	CMR	Witzell and Banner 1980
nGBR	CCL	-	-	-	-	1.67	1.25	CMR	Bell and Pike 2012
sGBR	CCL	-	-	1.29	1.90	1.83	0.96	CMR	Chaloupka and Limpus 1997
sGBR	CCL	-	-	1.39	2.22	1.92	1.01	CMR	Limpus 1992
Panama	CCL		Fastest	45 – 49 slowest				CMR	Llamas et al. 2017

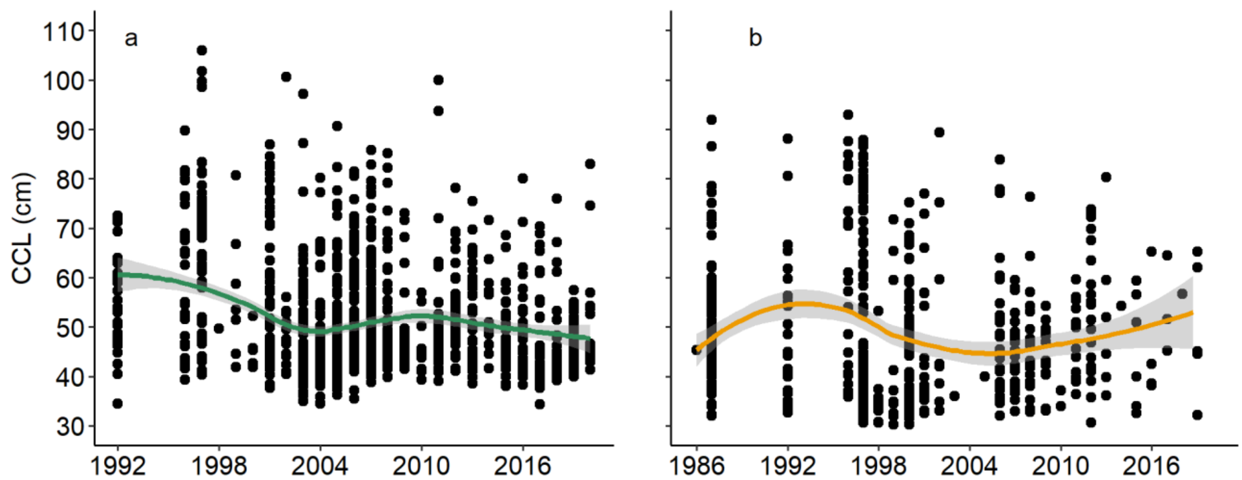

Fig. S1 CCL (curved carapace length; cm) notch-to-tip of first time captured turtles at Aldabra from Jul 1981–Mar 2021 for, (a) green turtles (n = 1191) and (b) hawksbill turtles (n = 538), with LOESS fit and 95% confidence interval.

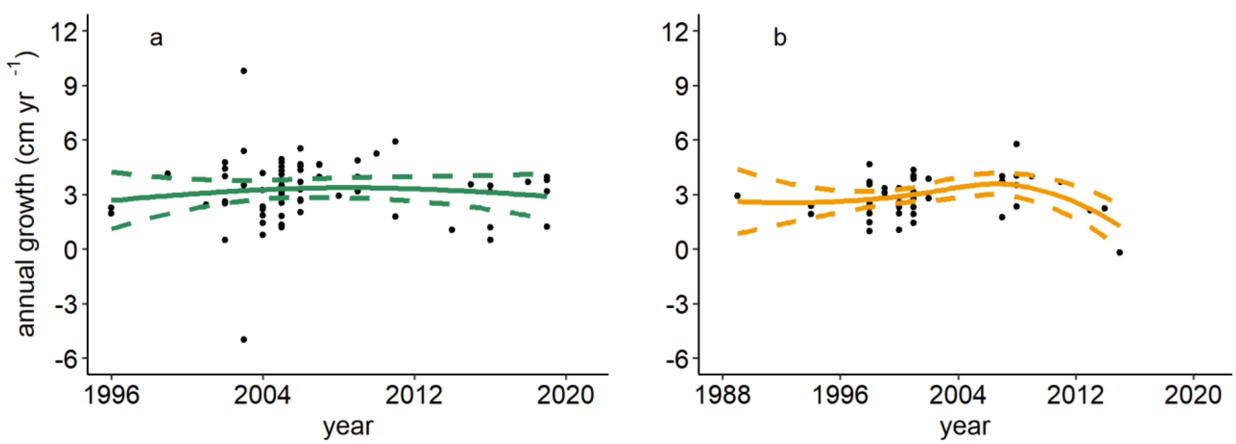

Fig. S2 Generalized additive model predicted annual growth rate (cm year^{-1}) over time and 95% confidence intervals for (a) green turtles in between 40–60 cm CCL (curved carapace length) and (b) hawksbill turtles between 40–50 cm CCL. Not, x-axis covers a different period for a & b

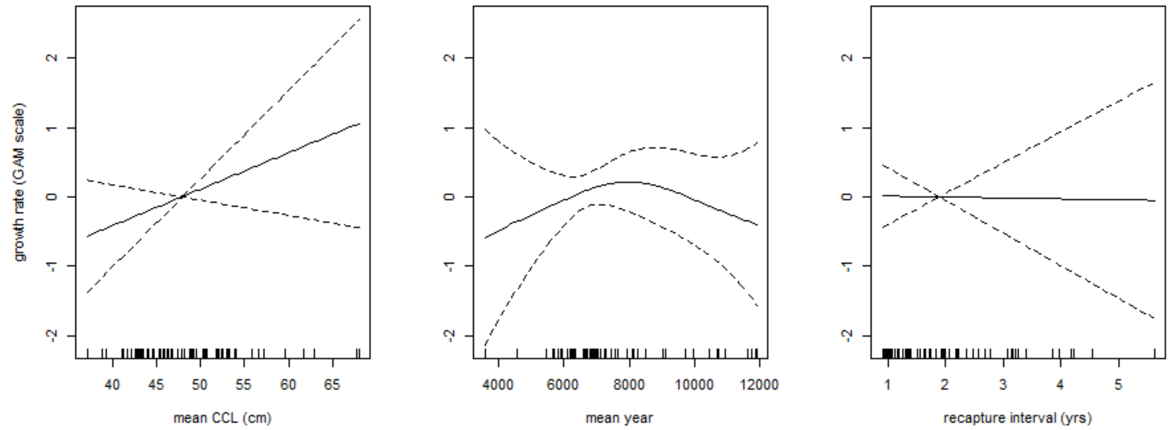

Fig. S3 GAMM model smooth components for the growth rates of immature green turtles at Aldabra with annual growth rate as response variable and the covariates of mean size (curved carapace length notch-to-tip, cm), mean year (in days since start of dataset), and recapture interval (years)

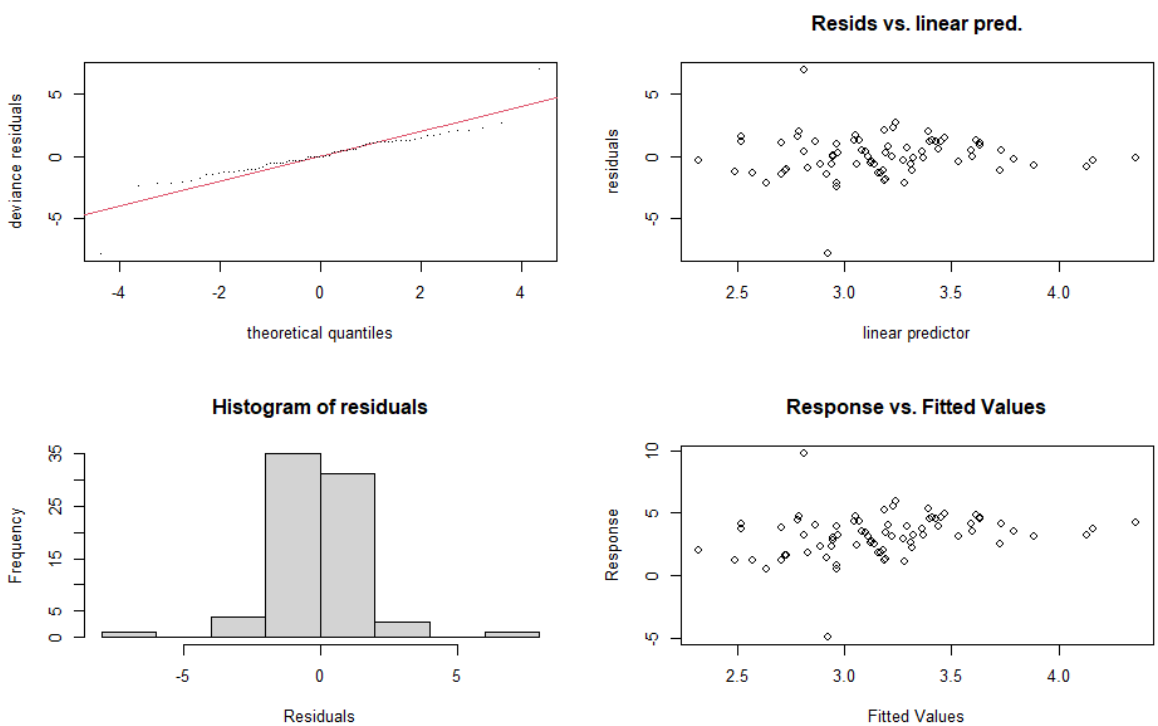

Fig. S4 Aldabra immature green turtle GAMM check results

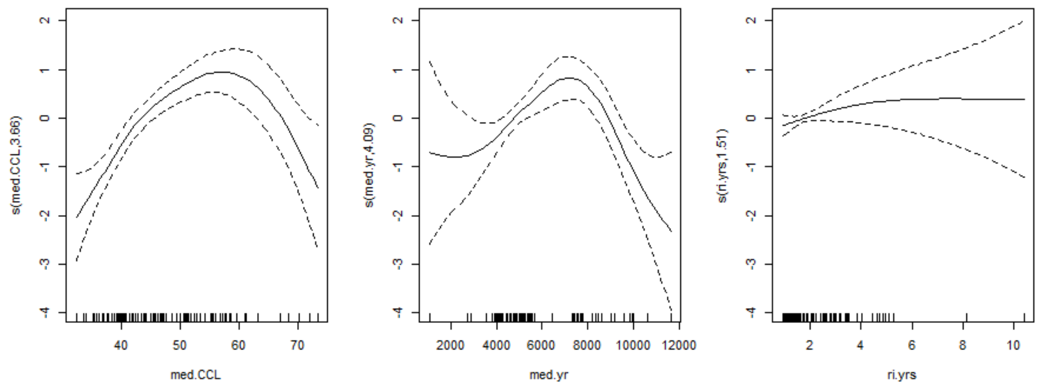

Fig. S5 GAMM model smooth components for the growth rates of immature hawksbill turtles at Aldabra with annual growth rate as response variable and the covariates of mean size (curved carapace length notch-to-tip, cm), mean year (in days since start of dataset), and recapture interval (years)

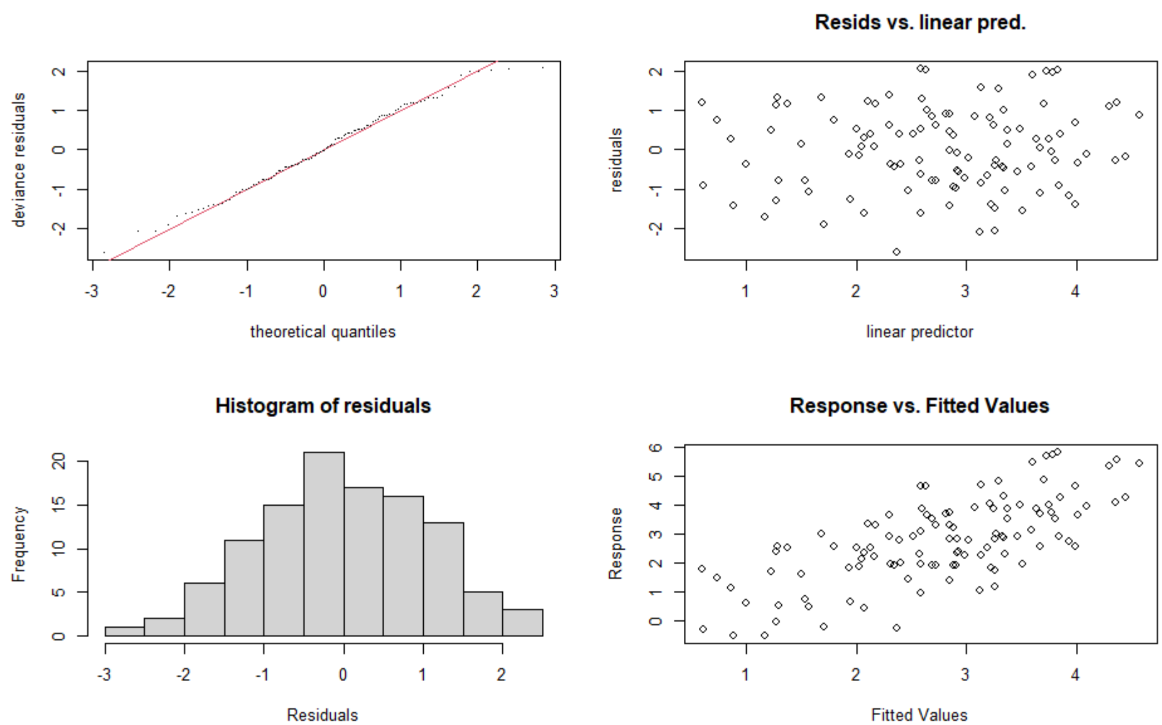

Fig. S6 Aldabra immature hawksbill turtle GAMM check results

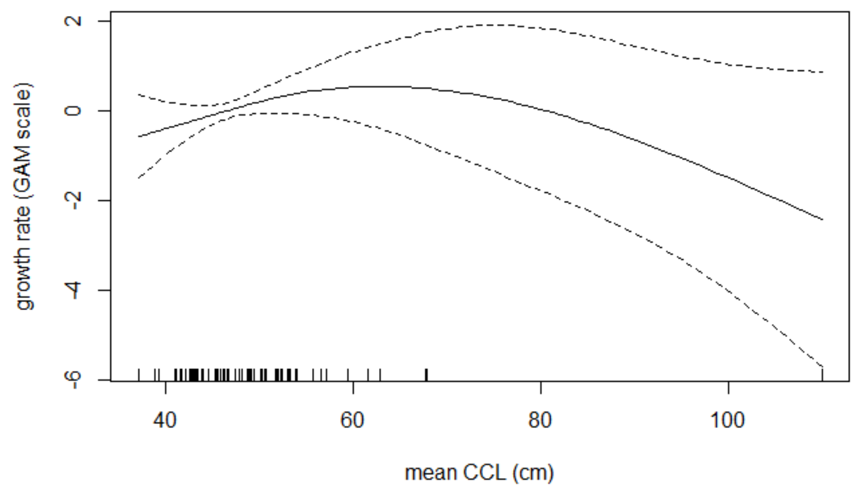

Fig. S7 Green turtle GAMM results for age at sexual maturity at Aldabra, including adult size estimates (Seychelles Islands Foundation unpublished data) and the adult growth rate (Limpus and Chaloupka 1997)

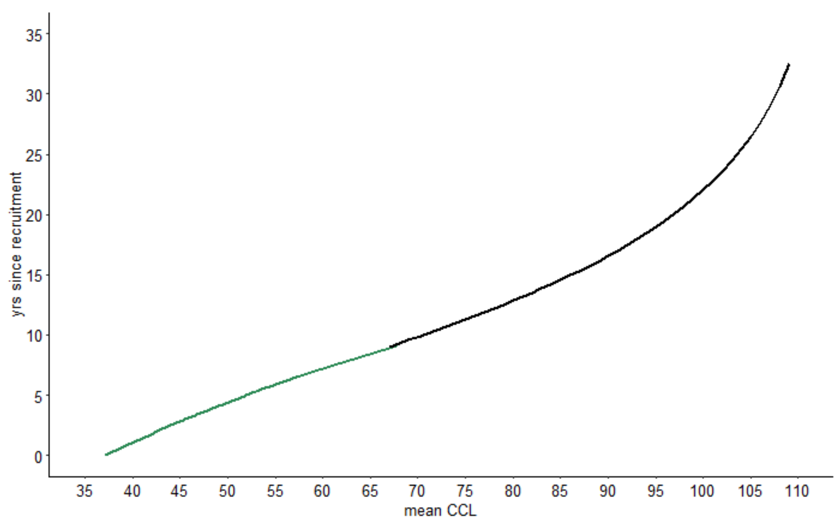

Fig. S8 Green turtle age estimation, since recruitment, for turtles within the Aldabra dataset (green line) to mean adult nesting size (black line) through a numerical equation (Colman et al. 2015; Bellini et al. 2019) modified

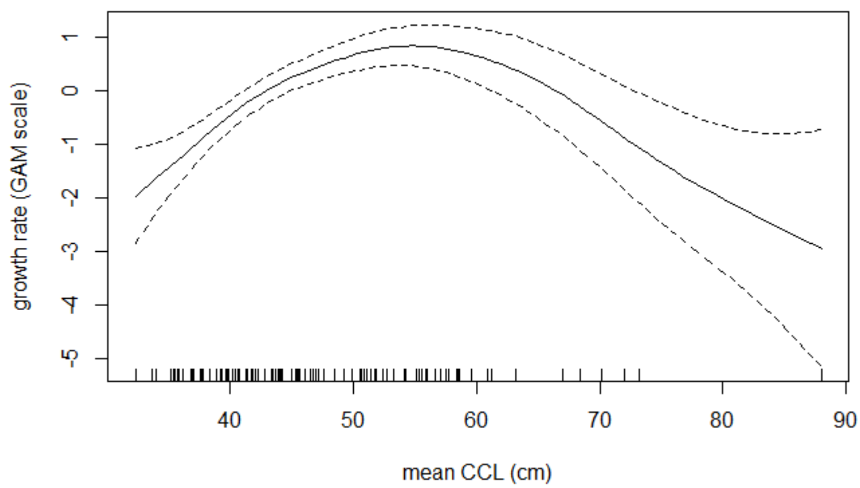

Fig. S9 Aldabra hawksbill turtle GAMM results including the adult growth rate (Mortimer et al. 2022)

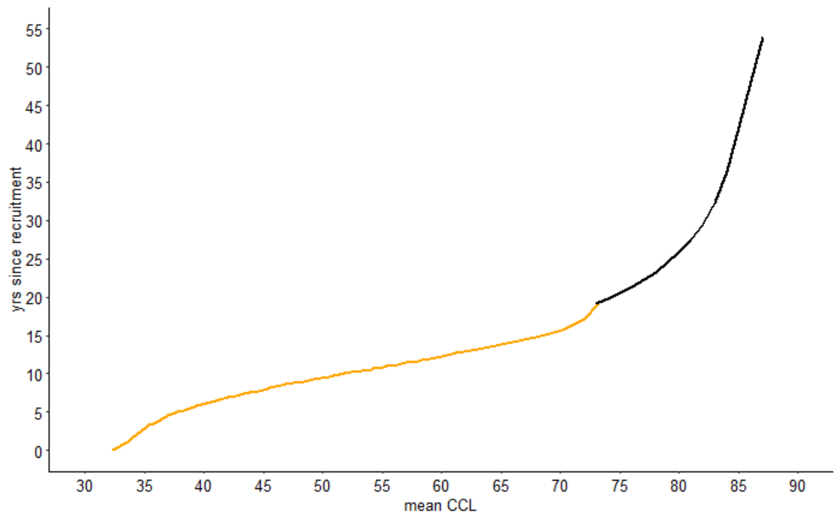

Fig. S10 Hawksbill turtle age estimation, since recruitment, for turtles within the Aldabra dataset (orange line) to mean adult nesting size (black line, Gane et al. 2020) through a numerical equation (Colman et al. 2015; Bellini et al. 2019) modified

REFERENCES

Beggs J, Horrocks J, Krueger B (2007) Increase in hawksbill sea turtle *Eretmochelys imbricata* nesting in Barbados, West Indies. Endanger Species Res 3:159–168. https://doi.org/10.3354/esr003159

Bell I, Pike D (2012) Somatic growth rates of hawksbill turtles *Eretmochelys imbricata* in a northern Great Barrier Reef foraging area. Mar Ecol Prog Ser 446:275–283. https://doi.org/10.3354/meps09481

Bellini C, Santos A, Patrício A, Bortolon L, Godley B, Marcovaldi M, Tilley D, Colman L (2019) Distribution and growth rates of immature hawksbill turtles *Eretmochelys imbricata* in Fernando de Noronha, Brazil. Endanger Species Res 40:41–52. https://doi.org/10.3354/esr00979

Bjorndal KA, Bolten AB (1988) Growth rates of immature green turtles, *Chelonia mydas*, on feeding grounds in the Southern Bahamas. Copeia 1988:555–564. https://doi.org/10.2307/1445373

Bjorndal KA, Bolten AB (2010) Hawksbill sea turtles in seagrass pastures: success in a peripheral habitat. Mar Biol 157:135–145. https://doi.org/10.1007/s00227-009-1304-0

Bjorndal KA, Chaloupka M, Saba VS, Diez CE, van Dam RP, Krueger BH, Horrocks JA, Santos AJB, Bellini C, Marcovaldi MAG, Nava M, Willis S, Godley BJ, Gore S, Hawkes LA, McGowan A, Witt MJ, Stringell TB, Sanghera A, Richardson PB, Broderick AC, Phillips Q, Calosso MC, Claydon JAB, Blumenthal J, Moncada F, Nodarse G, Medina Y, Dunbar SG, Wood LD, Lagueux CJ, Campbell CL, Meylan AB, Meylan PA, Perez VRB, Coleman RA, Strindberg S, Guzmán-H V, Hart KM, Cherkiss MS, Hillis-Starr Z, Lundgren IF, Boulon Jr RH, Connett S, Outerbridge ME, Bolten AB (2016) Somatic growth dynamics of West Atlantic hawksbill sea turtles: a spatio-temporal perspective. Ecosphere 7:1–14. https://doi.org/10.1002/ecs2.1279

Bjorndal KA, Bolten AB, Chaloupka M, Saba VS, Bellini C, Marcovaldi MAG, Santos AJB, Bortolon LFW, Meylan AB, Meylan PA, Gray J, Hardy R, Brost B, Bresette M, Gorham JC, Connett S, Crouchley BVS, Dawson M, Hayes D, Diez CE, van Dam RP, Willis S, Nava M, Hart KM, Cherkiss MS, Crowder AG, Pollock C, Hillis-Starr Z, Muñoz Tenería FA, Herrera-Pavón R, Labrada-Martagón V, Lorences A, Negrete-Philippe A, Lamont MM, Foley AM, Bailey R, Carthy

RR, Scarpino R, McMichael E, Provancha JA, Brooks A, Jardim A, Lopez-Mendilaharsu M, González-Paredes D, Estrades A, Fallabrino A, Martinez-Souza G, Velez-Rubio GM, Boulon Jr RH, Collazo JA, Wershoven R, Guzmán Hernández V, Stringell TB, Sanghera A, Richardson PB, Broderick AC, Phillips Q, Calosso M, Claydon JAB, Metz TL, Gordon AL, Landry Jr AM, Shaver DJ, Blumenthal J, Collyer L, Godley BJ, McGowan A, Witt MJ, Campbell CL, Lagueux CJ, Bethel TL, Kenyon L (2017) Ecological regime shift drives declining growth rates of sea turtles throughout the West Atlantic. Glob Chang Biol 23:4556–4568. https://doi.org/10.1111/gcb.13712

Blumenthal JM, Austin TJ, Bell CDL, Bothwell JB, Broderick AC, Ebanks-Petrie G, Gibb JA, Luke KE, Olynik JR, Orr MF, Solomon JL, Godley BJ (2009) Ecology of hawksbill turtles, *Eretmochelys imbricata*, on a Western Caribbean foraging ground. Chelonian Conserv Biol 8:1–10. https://doi.org/10.2744/CCB-0758.1

Boulon R, Frazer NB (1990) Growth of wild juvenile Caribbean green turtles, *Chelonia mydas*. J Herpetol 24:441–445. https://doi.org/10.2307/1565071

Boulon RH (1994) Growth rates of wild juvenile hawksbill turtles, *Eretmochelys imbricata*, in St. Thomas, United States Virgin Islands. Copeia 1994:811–814. https://doi.org/10.2307/1447200

Bresette M, Gorham J (2001) Growth rates of juvenile green turtles (*Chelonia mydas*) from the Atlantic coastal waters of St. Lucie County, Florida, USA. Mar Turt Newsl 91:5–6. http://www.seaturtle.org/mtn/archives/mtn91/mtn91p5.shtml

Chaloupka M, Limpus C (1997) Robust statistical modelling of hawksbill sea turtle growth rates (southern Great Barrier Reef). Mar Ecol Prog Ser 146:1–8. https://doi.org/10.3354/meps146001

Collazo JA, Boulon R, Tallevast TL (1992) Abundance and growth patterns of *Chelonia mydas* in Culebra, Puerto Rico. J Herpetol 26:293–300. https://doi.org/10.2307/1564884

Colman LP, Patrício ARC, McGowan A, Santos AJB, Marcovaldi MÂ, Bellini C, Godley BJ (2015) Long-term growth and survival dynamics of green turtles (*Chelonia mydas*) at an isolated tropical archipelago in Brazil. Mar Biol 162:111–122. https://doi.org/10.1007/s00227-014-2585-5

Gane J, Downs CT, Olivier I, Brown M (2020) Nesting ecology and hatching success of the hawksbill turtle (2004–2014) on Cousine Island, Seychelles. African J Mar Sci 42:53–65. https://doi.org/10.2989/1814232X.2020.1727952

Goshe LR, Avens L, Scharf FS, Southwood AL (2010) Estimation of age at maturation and growth of Atlantic green turtles (*Chelonia mydas*) using skeletochronology. Mar Biol 157:1725–1740. https://doi.org/10.1007/s00227-010-1446-0

Green D (1993) Growth rates of wild immature green turtles in the Galápagos Islands, Ecuador. J Herpetol 27:338–341. https://doi.org/10.2307/1565159

Hawkes LA, Mcgowan A, Broderick AC, Gore S, Wheatley D, White J, Witt MJ, Godley BJ (2014) High rates of growth recorded for hawksbill sea turtles in Anegada, British Virgin Islands. Ecol Evol 4:1255–1266. https://doi.org/10.1002/ece3.1018

Krueger BH, Chaloupka MY, Leighton PA, Dunn JA, Horrocks JA (2011) Somatic growth rates for a hawksbill turtle population in coral reef habitat around Barbados. Mar Ecol Prog Ser 432:269–276. https://doi.org/10.3354/meps09125

Kubis S, Chaloupka M, Ehrhart L, Bresette M (2009) Growth rates of juvenile green turtles *Chelonia mydas* from three ecologically distinct foraging habitats along the east central coast of Florida, USA. Mar Ecol Prog Ser 389:257–269. https://doi.org/10.3354/meps08206

Leon Y, Diez C (1999) Population structure of hawksbill turtles on a foraging ground in the Dominican Republic. Chelonian Conserv Biol 3:230–236.

Limpus C (1992) The hawksbill turtle, *Eretmochelys imbricata*, in Queensland: population structure within a southern Great Barrier Reef feeding ground. Wildl Res 19:489–505. https://doi.org/10.1071/WR9920489

Limpus C, Chaloupka M (1997) Nonparametric regression modelling green sea turtle growth rates (southern Great Barrier Reef). Mar Ecol Prog Ser 149:23–34. https://doi.org/10.3354/meps149023

Limpus CJ, Walter DG (1980) The growth of immature green turtles (*Chelonia mydas*) under natural conditions. Herpetologica 36:162–165. https://www.jstor.org/stable/3891481

Llamas I, Flores EE, Abrego ME, Seminoff JA, Hart CE, Donadi R, Peña B, Alvarez G, Poveda W, Amorocho DF, Gaos A (2017) Distribution, size range and growth rates of hawksbill turtles at a major foraging ground in the eastern Pacific Ocean. Lat Am J Aquat Res 45:597–605. https://doi.org/10.3856/VOL45-ISSUE3-FULLTEXT-9

McMichael E, Seminoff J, Carthy R (2008) Growth rates of wild green turtles, *Chelonia mydas*, at a temperate foraging habitat in the northern Gulf of Mexico: assessing short-term effects of cold-stunning on growth. J Nat Hist 42:2793–2807. https://doi.org/10.1080/00222930802357335

Mendonça MT (1981) Comparative growth rates of wild immature *Chelonia mydas* and *Caretta caretta* in Florida. J Herpetol 15:447–451. https://doi.org/10.2307/1563536

Mortimer JA, Appoo J, Bautil B, Betts M, Burt AJ, Chapman R, Currie JC, Doak N, Esteban N, Liljevik A, Mahoune JT, Onezia C, Pistorius P, Richards H, Samedi U, Sanchez CL, Seabrook W, Underwood A, van de Crommenacker J, von Brandis R, Hays GC (2022) Long-term changes in adult size of green turtles at Aldabra Atoll and implications for clutch size, sexual dimorphism and growth rates. Mar Biol 169–123. https://doi.org/10.1007/s00227-022-04111-1

Murakawa SKK and Snover ML (2018) Impact of exceptional growth rates on estimations of life-stage duration in Hawaiian green sea turtles. Endanger Species Res 35:181–193. https://doi.org/10.3354/esr00885

Seminoff JA, Resendiz A, Nichols WJ, Jones TT (2002) Growth rates of wild green turtles (*Chelonia mydas*) at a temperate foraging area in the gulf of California, México. Copeia 2002:610–617. https://doi.org/10.1643/0045-8511(2002)002[0610:GROWGT]2.0.CO;2

Snover ML, Balazs GH, Murakawa SKK, Hargrove SK, Rice MR, Seitz WA (2013) Age and growth rates of Hawaiian hawksbill turtles (*Eretmochelys imbricata*) using skeletochronology. Mar Biol 160:37–46. https://doi.org/10.1007/s00227-012-2058-7

Turner Tomaszewics CN, Seminoff JA, Avens L, Goshe LR, Rguez-Baron JM, Peckham SH, Kurle CM (2018) Expanding the coastal forager paradigm: long-term pelagic habitat use by green turtles *Chelonia* mydas in the eastern Pacific Ocean. Mar Ecol Prog Ser 587:217–234. https://doi.org/10.3354/meps12372

Witzell W, Banner A (1980) The hawksbill turtle (*Eretmochelys imbricata*) in Western Samoa. Bull Mar Sci 30:571–579

Wood LD, Hardy R, Meylan PA, Meylan AB (2013) Characterization of a hawksbill turtle (*Eretmochelys imbricata*) foraging aggregation in a high-latitude reef community in southeastern Florida, USA. Herpetol Conserv Biol 8:258–275

Zárate PM, Bjorndal KA, Seminoff JA, Dutton PH, Bolten AB (2015) Somatic growth rates of green turtles (*Chelonia mydas*) and hawksbills (*Eretmochelys imbricata*) in the Galápagos Islands. J Herpetol 49:641–648. https://doi.org/10.1670/14-078

Zug GR, Glor RE (1998) Estimates of age and growth in a population of green sea turtles (*Chelonia mydas*) from the Indian River lagoon system, Florida: a skeletochronological analysis. Can J Zool 76:1497–1506. https://doi.org/10.1139/z98-090

Zug GR, Balazs GH, Wetherall JA, Parker DM, Murakawa SKK (2002) Age and growth of Hawaiian green sea turtles (*Chelonia mydas*): an analysis based on skeletochronology. Fish Bull 100:117–127