Accounting for age uncertainty in growth modeling, the case study of yellowfin tuna (Thunnus albacares) of the Indian Ocean

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APPENDIX A. Presentation of data used in the coupling of ageing error and growth models

TABLE A1. Summarize of data used in ageing error model; *It*: section between nucleus and OTC mark , *Im*: section between the OTC mark and edge, *Ir*: section between the nucleus and edge

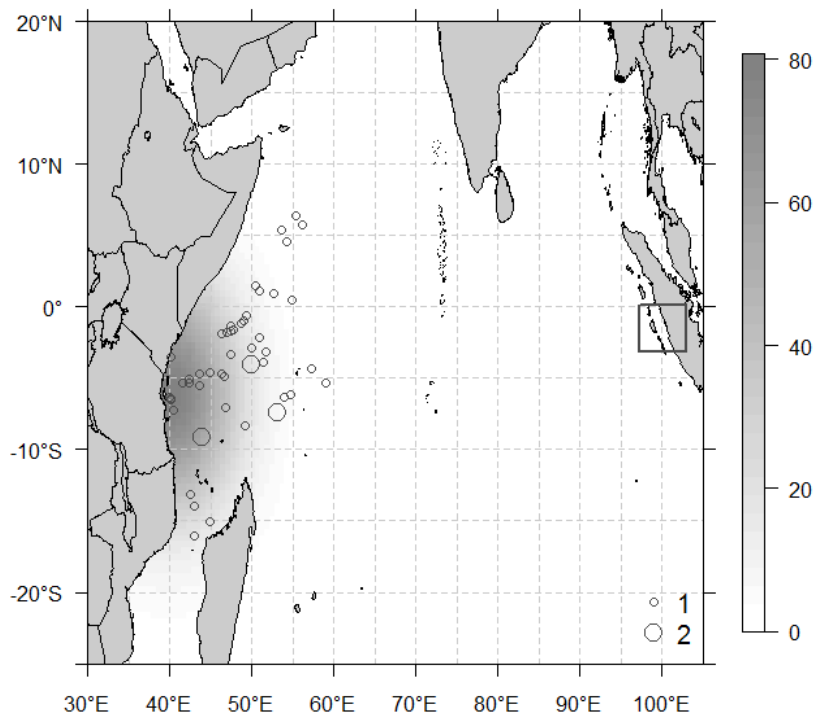| | Fish from RTTP-IO program knowledge of time-at-liberty: | | | | Fish from WSTTP program |
	with			without	
Otolith section	*It*	*Ir*	*Im*	*It*	*It*
Number of fishes	80	14	27	30	38
Fork length at tagging (cm)	43 to 85	50 to 72			
Fork length at recapture (cm)	49.7 to 135.4	59.5 to 114.1	49.7 to 131	47.9 to 146.5	19 to 46.6
Time-at-liberty (days)	43 to 969	33 to 414	43 to 969		

FIG. A1. Tagging area (gray-colored) and points of tag recovery (circles) of RTTP-IO program and sampling area (square) of WSTTP program

APPENDIX B. Evaluation by simulation of ageing error model: general approach and results

Simulation of 500 ages

5 age classes: <1 ; [1,2[; [2,3[; [3,4[; [4,5[

100 ages per class generated according to a uniform distribution

Age of fish i: $Ar_i \sim U(min_{class\ n}, max_{class\ n})$

Simulation of 25 time-at-liberty

Time-at-liberty of fish i: $T_{L\ i} \sim U(30, 970)$

Consideration of a over-daily increment deposition

$R = 0.95$

Number of deposited increments

$Ir_i = R \times Ar_i$

Number of deposited increments between OTC mark and edge

$Im_i = R \times T_{L\ i}$

Simulation of errors due to otolith preparation

Nucleus error: $\psi_{n\ i} \sim \mathcal{N}(0, 3^2)$

Otolith too sanded: until 15 increments lost and estimated with an error of 2-3 increments

Edge error: $\psi_{t\ i} \sim \mathcal{N}(0, 3^2)$

Otolith badly cut: until 20 increments lost and estimated with an error of 3-4 increments

Number of present increments

$Ir_i = (R \times Ar_i) - \psi_{t\ i} - \psi_{n\ i}$

Number of present increments between OTC mark and edge

$Im_i = (R \times T_{L\ i}) - \psi_{t\ i}$

Simulation of variability between repeated readings of the same otolith

$p_i \sim U(0, 0.3)$

$p_i \sim U(0, 0.1)$

Simulation of l noisy repeated readings

$Ir_{i,l} \sim \mathcal{N}(Ir_i, (Ir_i \times p_i)^2)$

Simulation of l noisy repeated readings

$Im_{i,l} \sim \mathcal{N}(Im_i, (Im_i \times p_i)^2)$

Estimation of posterior distributions of R and ψ_t

Estimation of age of each fish from the mean of $It_{i,l}$
Traditional method

Estimation of age of each taking account uncertainties around $It_{i,l}$
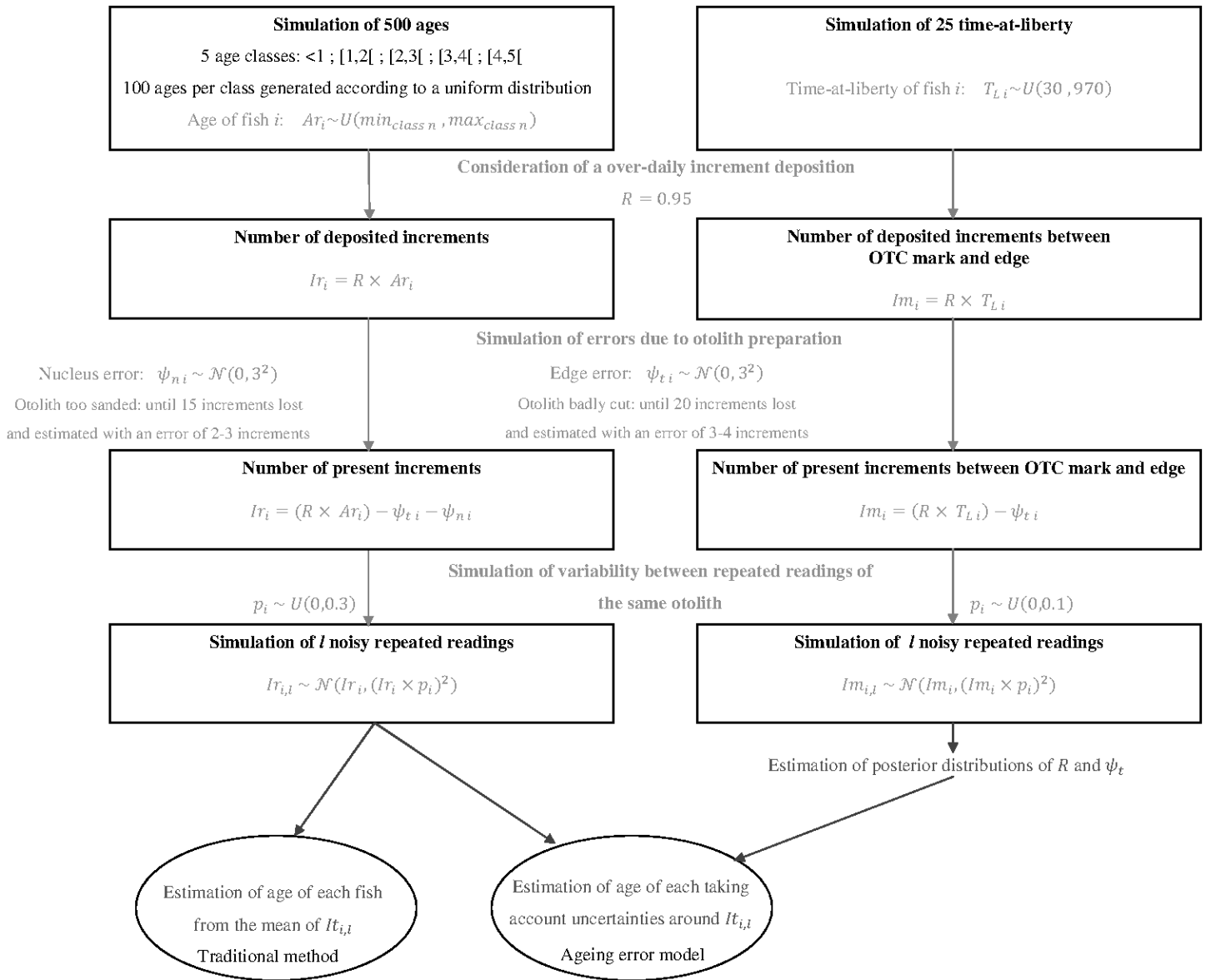Ageing error model

FIG. B1. Simulation framework for testing the ageing error model; different sources of uncertainty are added to simulated ages to randomly generate noisy increments that were then used as inputs in the model
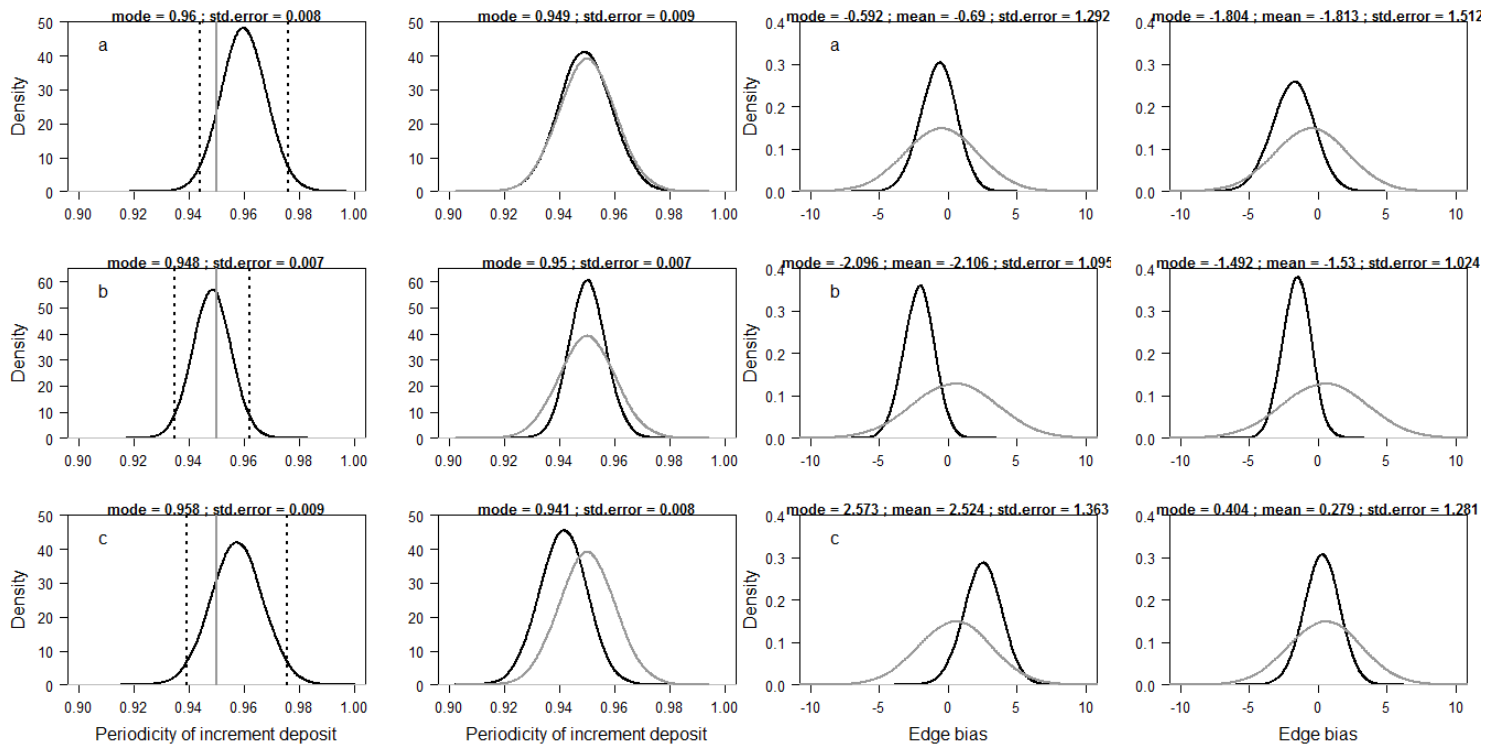
FIG. B2. Marginal posterior distributions of the ageing error model parameters (black) compared with the simulated distributions (grey) with individual variability (right) and without (left); a, b and c represents the first, second and third simulated data set respectively
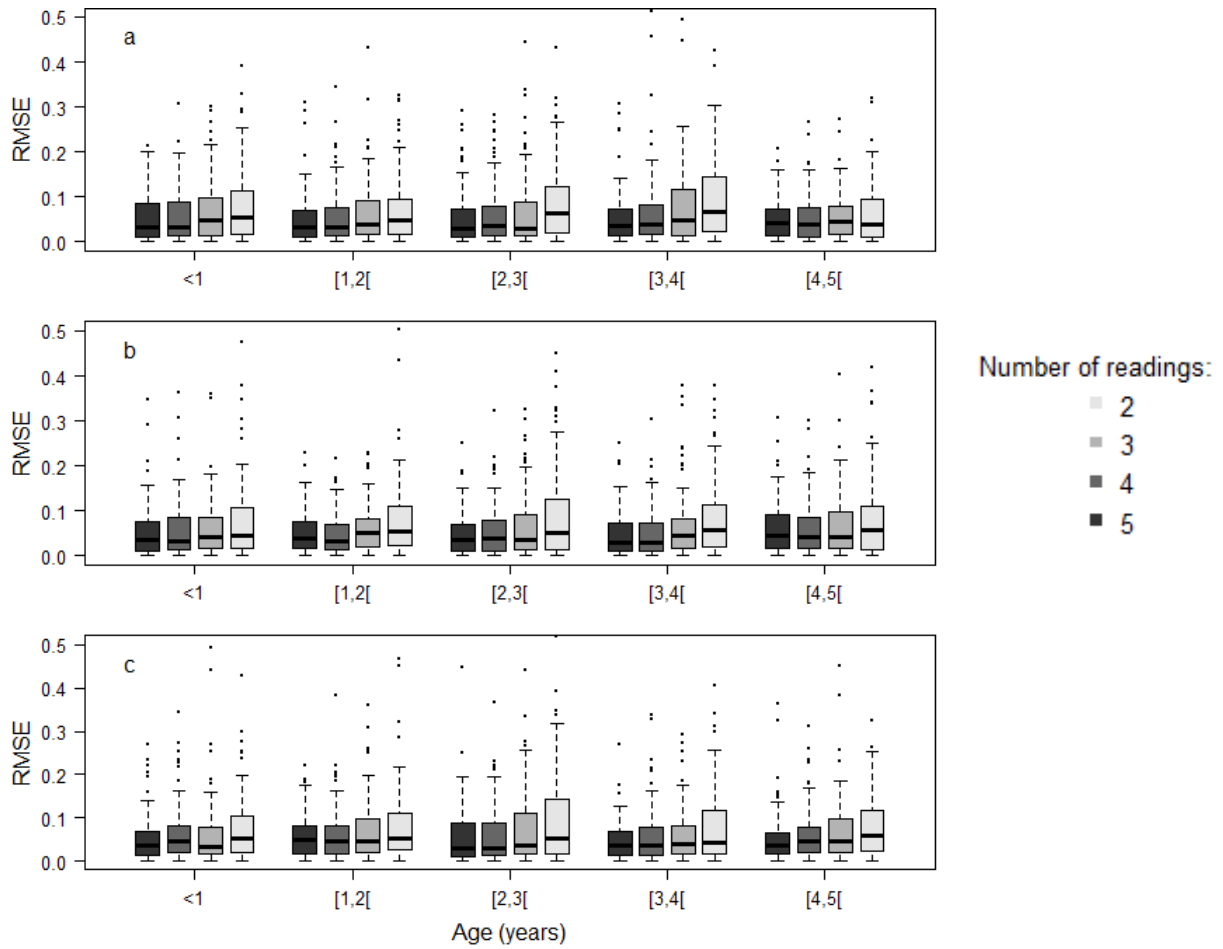
FIG. B3. Boxplot of the relative mean square error (RMSE) of estimated age by ageing error model for 2,3,4 or 5 readings of the same otolith; a, b and c represents the first, second and third simulated data set respectively

TABLE B1. Comparison of the RMSE values of estimated age by ageing error model using a Wilcoxon test; 2L, 3L, 4L and 5L correspond to the number of readings of the same otolith; a, b and c represents the first, second and third simulated data set respectively

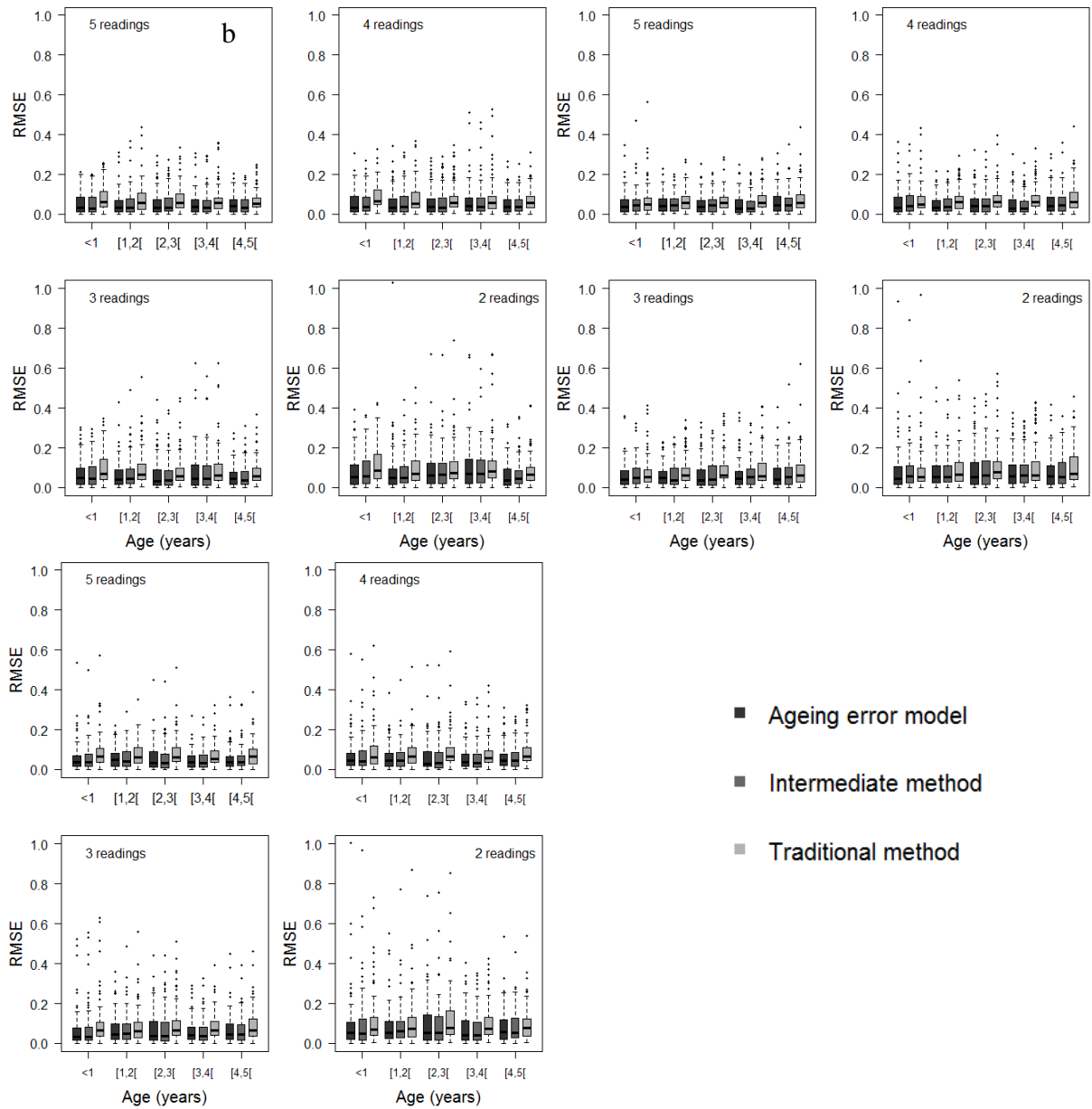|		4L	3L	2L
a	5L	V = 54527 p-value = 0.01224		
	4L		V = 48750 p-value = 1.767e-05	
	3L			V = 45892 p-value = 2.260e-07
b	5L	V = 54789 p-value = 0.01535		
	4L		V = 69539 p-value = 0.0324	
	3L			V = 45324 p-value = 8.683e-08
c	5L	V = 46959 p-value = 1.257e-06		
	4L		V = 69539 p-value = 0.0324	
	3L			V = 45324 p-value = 8.683e-08

FIG. B4. Boxplot of the relative mean square error (RMSE) of estimated age by the ageing error model, the conventional method and the intermediate method for 2, 3, 4 or 5 readings of the same otolith; a, b and c represents the first, second and third simulated data set respectively

TABLE B2. Comparison of the RMSE values of estimated age by ageing error model, the traditional method and the intermediate method using a Wilcoxon test; 2L, 3L, 4L and 5L correspond to the number of readings of the same otolith; a, b and c represents the first, second and third simulated data set respectively

			Traditional method	Intermediate method
a	Ageing error model	2L	V = 28741, p-value < 2.2e-16	V = 55196, p-value = 0.02155
		3L	V = 28165, p-value < 2.2e-16	V = 57314, p-value = 0.1004
		4L	V = 28080, p-value < 2.2e-16	V = 59300, p-value = 0.3037
		5L	V = 28796, p-value < 2.2e-16	V = 59429, p-value = 0.3229
	Intermediate method	2L	V = 17140, p-value < 2.2e-16	
		3L	V = 16009, p-value < 2.2e-16	
		4L	V = 16139, p-value < 2.2e-16	
		5L	V = 18954, p-value < 2.2e-16	
b	Ageing error model	2L	V = 37313, p-value = 4.85e-15	V = 52640, p-value = 0.002009
		3L	V = 35248, p-value < 2.2e-16	V = 49274, p-value = 3.623e-05
		4L	V = 32274, p-value < 2.2e-16	V = 53918, p-value = 0.007069
		5L	V = 35057, p-value < 2.2e-16	V = 55195, p-value = 0.02153
	Intermediate method	2L	V = 36636, p-value = 8.97e-16	
		3L	V = 35714, p-value < 2.2e-16	
		4L	V = 29036, p-value < 2.2e-16	
		5L	V = 32230, p-value < 2.2e-16	
c	Ageing error model	2L	V = 26437, p-value < 2.2e-16	V = 60299, p-value = 0.4719
		3L	V = 26608, p-value < 2.2e-16	V = 62971, p-value = 0.9149
		4L	V = 22487, p-value < 2.2e-16	V = 67331, p-value = 0.1455
		5L	V = 23658, p-value < 2.2e-16	V = 68155, p-value = 0.08714
	Intermediate method	2L	V = 24027, p-value < 2.2e-16	
		3L	V = 19659, p-value < 2.2e-16	
		4L	V = 14297, p-value < 2.2e-16	
		5L	V = 15527, p-value < 2.2e-16	

APPENDIX C. Bayesian fit of the growth model coupled with the ageing error model
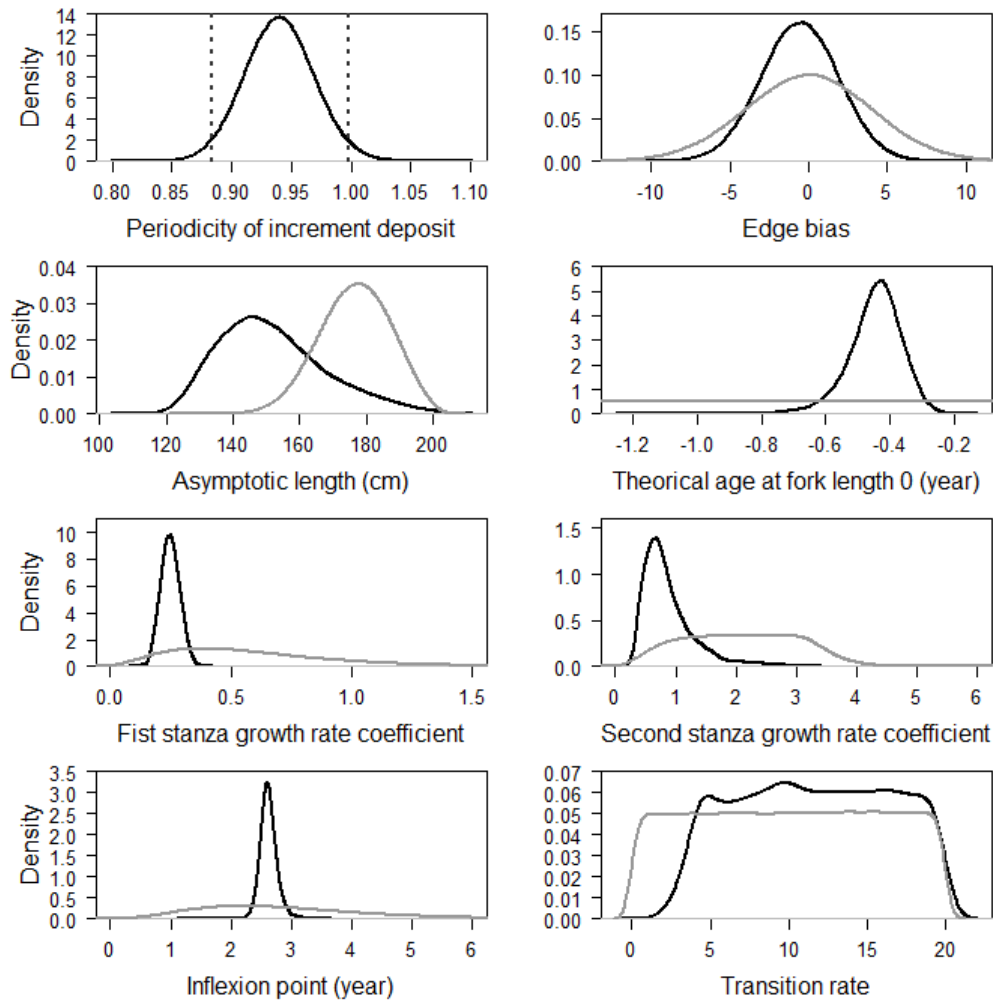

FIG. C1. Marginal posterior distributions of the parameters of the growth model coupled with the ageing error model (black) compared with the prior distributions (grey)

TABLE C1. Correlation-covariance matrix of growth parameters; numerals in bold represent the covariances

	L_∞	k_1	k_2	α	β	t_0
L_∞	**254.808**	-0.93	-0.8	-0.29	-0.027	-0.43
k_1	**-0.593**	**0.002**	0.8	0.21	0.093	0.67
k_2	**-5.527**	**0.014**	**0.189**	0.48	-0.12	0.34
α	**-7.568**	**0.001**	**0.034**	**0.026**	-0.3	-0.074
β	**-2.044**	**0.018**	**-0.259**	**-0.236**	**23.11**	0.17
t_0	**-0.601**	**0.002**	**0.013**	**-0.001**	**0.074**	**0.007**