Estimating age and growth of Central North Pacific striped marlin using tagging data and direct observations of age[1]

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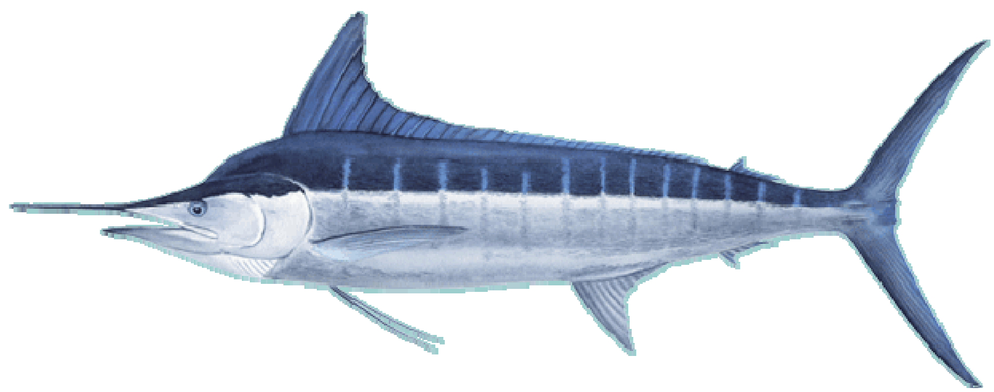

[1]Working paper prepared for the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, Billfish Working Group Data Prep Meeting in Honolulu, January 14-21, 2019.

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Abstract

Age and growth of Central North Pacific striped marlin were modeled by fitting von Bertalanffy growth functions (VBGF) to direct observations of age at size as well as tagging data. Models were fitted using 134 observations of age at size read from striped marlin fin spines and mark-recapture histories from 35 tagged striped marlin. Nine VBGF models are presented based on inclusion of fin spine data, tagging data, inclusion or exclusion of size estimates of age 0, and on estimation of coefficient of variation (CV) for expected size at age. Modeling efforts incorporating tagging data yielded VBGF parameters complementing those generated by independently incorporating fin spines. The asymptotic length (L_∞) was estimated to be 181.7 cm EFL; the annual growth coefficient (K) was estimated to be 0.7 yr^{-1}; the average CV was estimated to be 0.12; and age at size 0 (t_0) was estimated to be -1.09 yr. L_∞ estimates from this study correspond to maximum expected sizes near or below a 50% maturity ogive from the Western North Pacific that is used to assess the entire stock. This may reflect regional variation in life history characteristics of striped marlin in the Pacific Ocean, which reinforces the need to collect and update life history information for this species in the Central North Pacific.

Introduction

A growth model for striped marlin *Kajikia audax* in the Central North Pacific Ocean suitable for use in stock assessment has not been published. This is an important gap in the knowledge of this species because genetic differences among regional groups of striped marlin throughout the Pacific Ocean, including Hawaii in the Central North Pacific, have been documented (Purcell and Edmands 2011). Catch, fishing effort, and size composition data from the Hawaiian longline fishery are used in stock assessments. However, life history information on age, growth, and maturity from Taiwan is used to characterize the biology of striped marlin in both the Western and the Central North Pacific regions (Sun et. al, 2011a, Sun et al., 2011b, ISC, 2015). Regional characteristics in productivity, oceanography, and temperature may manifest to regional differences in growth of highly migratory fishes (Gaertner et al., 2008). Such a condition may exist between striped marlin inhabiting the vast Central North Pacific (including Hawaii) versus the waters immediately surrounding Taiwan.

In this paper, opportunistically collected data, including sizes at release and recapture from a tagging database and annual estimates of age from striped marlin fin spines are used to fit and evaluate growth models. The objective was to improve understanding of the biology of striped marlin in the Central North Pacific Ocean.

Materials and Methods

Annual estimates of ages and corresponding sizes were provided by K. Kopf. Fin spines were read and analyzed to infer ages per Kopf et al. (2009, 2011). These fin spines were obtained from striped marlin caught in the Hawaii longline fishery, collected by the Pacific Islands Region Observer Program (PIROP) during 2003-2010. In total, 134 estimated ages and corresponding observed eye-fork lengths (EFL) were analyzed.

Tagging data were provided by the NOAA Cooperative Billfish Tagging Program (sent December 10, 2018). A total of 288 tags were caught and recovered with complete records of origin during 1965-2018. Length and weight measurements at release and recapture were converted to EFL (cm) by conversion equations from Sun et al. (2011a) and Uchiyama and Humphreys (2005). As with the fin spine data, all tagging information used in this study originated in waters from 140° W to 180° W and from the Equator to 40°N. Records that did not have a release location or recapture location in this region were not used. Tags at liberty for less than 30 days were also deleted because mark and/or recapture size estimates may be subject to excessive observation error relative to actual growth. Lastly, when examining annual incremental growth (cm/yr), tag records with highly negative and highly positive incremenral growth (5th and 95th percentiles) were filtered out due to possible measurement or recording error, leaving 35 complete tagging records.

Because the sample sizes of direct age measurements (n=134) and tagging data (n=35) were relatively small, bootstrapping was employed in each modeling exercise, using 100 sets of 1000 resampled fin spine age and size couplets in each model run. Tagging data was also bootstrapped in 100 sets. Resampling was stratified by each 10 cm EFL bin (corresponding to release and recapture sizes), such that observations in each 10 cm EFL bin are resampled 120 times, with sample equity in each 10 cm bin. In each of the 100 runs, models are fit to the boostrapped data and parameters are produced, resulting in 100 sets of parameter estimates.

Bootstrapped sizes at age from the spine database were used to estimate the parameters of the von Bertalanffy growth function (VBGF, Beverton and Holt, 1957) through non-linear maximum likelihood estimation:

$$\hat{L}_a = L_\infty[1 - e^{-K(a-t_0)}]$$

$\hat{L}_a$ is the estimated length (in cm) at age a (in years), L_∞ is asymptotic size , K is the Brody growth coefficient (yr^{-1}), and t_0 is fitted age (time) at size 0 cm.

Bootstrapped tagging data, including estimated length of striped marlin at tagging (L_{mark}), estimated length of striped marlin at recapture (L_{recap}), and time at liberty (Δt) are incorporated in a modification of the VBGF that uses incremental growth to estimate paramters (Fabens, 1965). This method can jointly estimate growth parameters (*sans* t_0) through a non-linear maximum likelihood estimation:

$$L_{mark} - L_{recap} = (L_\infty - L_{mark})[1 - e^{-K(\Delta t)}]$$

Von Bertalanffy function parameters were jointly estimated using a maximum likelihood procedure in the R Development Core Team (2018) assuming $\varepsilon_{L_a} \sim N(0, {\sigma_a}^2)$, such that maximizing likelihood (MLE) for all observations:

$$MLE(L_\infty, K, t_0, \sigma_a | L_a) = \sum_{a=0}^{a_\lambda} \frac{1}{\sigma_a \sqrt{2\pi}} e^{-\frac{(L_a - \hat{L}_a)^2}{2{\sigma_a}^2}}, L_a - \hat{L}_a \cong 0$$

and such that standard deviation of residual error is proportional to estimated mean size at age times a coefficient of variation, CV:

$$\sigma_a = \hat{L}_a \times C.V.$$

Model configurations consisted of three base models: estimation of growth from tagging only (Fabens method), estimation of growth from fin spines only (VBGF), and joint estimation of growth from tagging and fin spine data through equal data weighting (VBGF+Fabens). These base models were further modified by 1) excluding age 0 fish from spine data to avoid estimation of a highly negative t_0 and/or 2) by changing the estimation of CV (jointly, by tagging data, or by fin spine data).

Results and Discussion

134 estimated ages and corresponding observed eye-forklengths (EFL) were analyzed. Frequencies of EFL (in cm) and ages are provided in Figure 1. Maps of tagging releases and recaptures is provided in Figure 2. Figure 3 depicts estimated size frequencies of tagged fish and of recaptured fish, respectively.

The model configurations and resulting VBGF parameters are listed in Table 1; estimated growth for striped marlin under each model configuration isdepicted in Figures 4-12. Akaike Information Criterion (AIC) values are not provided because effective sample sizes differed among model configuration runs.

Growth model estimates obtained using only tagging data yielded size at age estimates for ages 2+ that were close to the observed age/size data (Figure 4). These estimates were not significantly different from the other model configurations. Likewise, inclusion of tagging data improved estimates for large fish and those that live longer than the sampled fish. One tagged striped marlin was at liberty for 9.67 years before recapture. The maximum age observed in the fin spine database was 5 years in this study and 6 years by Sun et al. (2011a). Both studies are limited by truncation of directly observed ages from hard parts, but this study estimated ages beyond age 6 from several tagging observations. The Fabens approach does not estimate the nuisance parameter t_0, which may lead to underestimation of size at age for very young fish. Other modeling approaches could be explored in the future with tagging data such as Francis (1988) and Wang (1998) which account for individual growth variability and other biases.

Expected size at age estimates under each of the configurations depart moderately (Figure 13) from a model from Taiwanese fisheries used to assess the entire North Pacific stock (ISC15 Chang et al., 2015; modified from Sun et al., 2011a), but with a significantly lower L_∞ than the Taiwanese model (on average 181.7 vs 228.7 cm EFL converted from LJFL, Table 1). Growth at age in models presented in this study appear to cease beyond directly observable age ranges (age 0-6) while growth in Sun et al (2011) does not reach cessation by maximum observed ages. Results from this study also yield a faster rate of growth with K estimates (0.53 to 0.8 yr^{-1}) comparable to those summarized by Kopf et al (2011). Striped marlin caught in Hawaii fisheries tend to have growth rates comparable to those in the southwestern Pacific (Kopf et al, 2011) but with significantly lower maximum sizes (Figure 14). Compared to the Taiwan model estimates, growth models presented in this study which incorporate fin direct estimates of size at age generally seem to depart the least from the Taiwan model. Expected sizes for ages 6+ show 4.52 to 16.67% differences (Table 3). Expected mean weight at age for these model configurations depart at older ages (i.e., ages 7 to 10) from the Taiwan model- differing by -25% to -50% relative to models presented in this working document (Table 3). Regional contrast in estimated growth parameters and observed maximum age by region could be due to different biological characteristics and stock structure as noted by genetic differences (Purcell and Edmands, 2011).

Several of the model configurations presented in this working document do not yield expected size at age higher than the length of 50% maturity (L_{50}) ogive recently used in assessing the north Pacific striped marlin stock (177 cm EFL in 2015, tentatively 181 cm EFL). Maturity information from the eastern Pacific suggests an L_{50} of 143.5 EFL (transformed from LJFL: Uchiyama and Humphreys, 2005), or between 155-165 cm EFL (Eldridge and Wares, 1974). These L_{50} estimates correspond to ages 1.5-3 years in the growth models presented in this working document. The values are also consistent with ogive assumptions in other publications: Maunder and Hinton (2010), assessing the EPO striped marlin stock, Langley et al. (2006), assessing the Southwest Pacific striped marlin stock, and Kopf (2011) all assumed at least 50% maturity by age 2.

Findings presented in this working document provide support for research into the life history characteristics of striped marlin from various Pacific Ocean regions. These model configurations are presented for consideration of the ISC Billfish Working Group in such a context.

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Acknowledgements

This work would not be possible without K Kopf, who graciously provided unpublished data from fin spines that he read. Thank you to L Heberer and H Dewar from NOAA/SWFSC for providing updated billfish tagging data.

Table 1. Model configurations to estimate VBGF parameters using direct observations from fin spines and tagging data

Model Configuration to Estimate VBGF Parameters	**L_∞ (cm)**	**K (yr^{-1})**	**CV**	**t_0 (yr)**
Model 1: Growth from Tagging Only, no t_0 estimated	188.04	0.98	0.15	
Model 2: Growth from Fin Spines Only	174.67	0.62	0.08	-1.43
Model 3: Growth from Tagging and Spines, CV estimated jointly	184.44	0.54	0.13	-1.39
Model 4: Growth from Tagging and Spines, CV estimated from Tagging Data	175.82	0.78	0.17	-1.12
Model 5: Growth from Tagging and Spines, CV estimated from Spine Data	183.95	0.53	0.14	-1.52
Model 6: Growth from Spines Only, Omitting Age 0	174.19	0.65	0.06	-1.32
Model 7: Growth from Tagging and Spines, Omitting Age 0, CV estimated jointly	183.14	0.70	0.12	-0.66
Model 8: Growth from Tagging and Spines, Omitting Age 0, CV estimated from Spines	182.56	0.70	0.13	-0.78
Model 9: Growth from Tagging and Spines, Omitting Age 0, CV estimated from Tags	179.79	0.80	0.12	-0.51
Average	180.73	0.70	0.12	-1.09

Table 2. Predicted size at age for striped marlin per respective VBGF model configurations versus estimated size at age from Sun et al. (2011) using a Richard's function, L_∞ = 263.44 cm LJFL (228.73 cm EFL), t_0 = -0.40 yr, K = 0.04 yr^{-1}, and m = -2.05. Ages in bold are for directly observed ages from Kopf's (2011) fin spines taken from Hawaii (0-5 years years of age) and Sun et al. (2011) from Taiwan (0-6 years of age).

Age (yr)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Sun et al 2011
0	***0.00***	***102.70***	***97.37***	***102.42***	***102.18***	***100.33***	***67.89***	***76.33***	***60.21***	***84.30***
1	***117.47***	***135.95***	***133.70***	***142.18***	***135.96***	***135.63***	***126.13***	***129.59***	***126.29***	***124.65***
2	***161.55***	***153.84***	***154.87***	***160.40***	***155.79***	***154.06***	***154.94***	***156.15***	***155.85***	***145.91***
3	***178.10***	***163.47***	***167.21***	***168.75***	***167.42***	***163.68***	***169.19***	***169.39***	***169.08***	***160.51***
4	***184.31***	***168.64***	***174.40***	***172.58***	***174.25***	***168.70***	***176.24***	***175.99***	***175.00***	***171.48***
5	***186.64***	***171.43***	***178.59***	***174.33***	***178.26***	***171.33***	***179.73***	***179.28***	***177.65***	***180.12***
6	187.51	172.93	181.03	175.14	180.61	172.69	181.45	180.92	178.83	***187.11***
7	187.84	173.73	182.45	175.51	181.99	173.41	182.31	181.74	179.36	192.88
8	187.97	174.17	183.28	175.68	182.80	173.78	182.73	182.15	179.60	197.71
9	188.01	174.40	183.77	175.75	183.27	173.98	182.94	182.35	179.70	201.79
10	188.03	174.52	184.05	175.79	183.55	174.08	183.04	182.45	179.75	205.27

Table 3. Average expected size at age (EFL, in cm) from model configuations incorporating fin spines from Hawaiian longline fleet and tagging data, expected weigtht at age (kg) using conversions from Sun et al. (2011) and differences from those in Sun et al (2011).

Age (yr)	**Average Expected EFL at age (cm)**	**Sun et al 2011 Expected EFL at age (cm)**	**% Difference EFL at age (cm)**	Average Expected Weight at Age (kg)	**Sun et al. (2011) weight at age (kg)**	**% Difference Weight at Age (kg)**
0	78.83	84.30	-6.95%	4.61	5.70	-24%
1	131.43	124.65	5.16%	23.19	19.62	15%
2	156.38	145.91	6.70%	40.17	32.27	20%
3	168.48	160.51	4.73%	50.83	43.62	14%
4	174.46	171.48	1.70%	56.75	53.75	5%
5	177.47	180.12	-1.49%	59.91	62.78	-5%
6	179.01	187.11	-4.52%	61.57	70.81	-15%
7	179.82	192.88	-7.27%	62.45	77.94	-25%
8	180.24	197.71	-9.69%	62.91	84.27	-34%
9	180.46	201.79	-11.82%	63.16	89.89	-42%
10	180.59	205.27	-13.67%	63.29	94.88	-50%

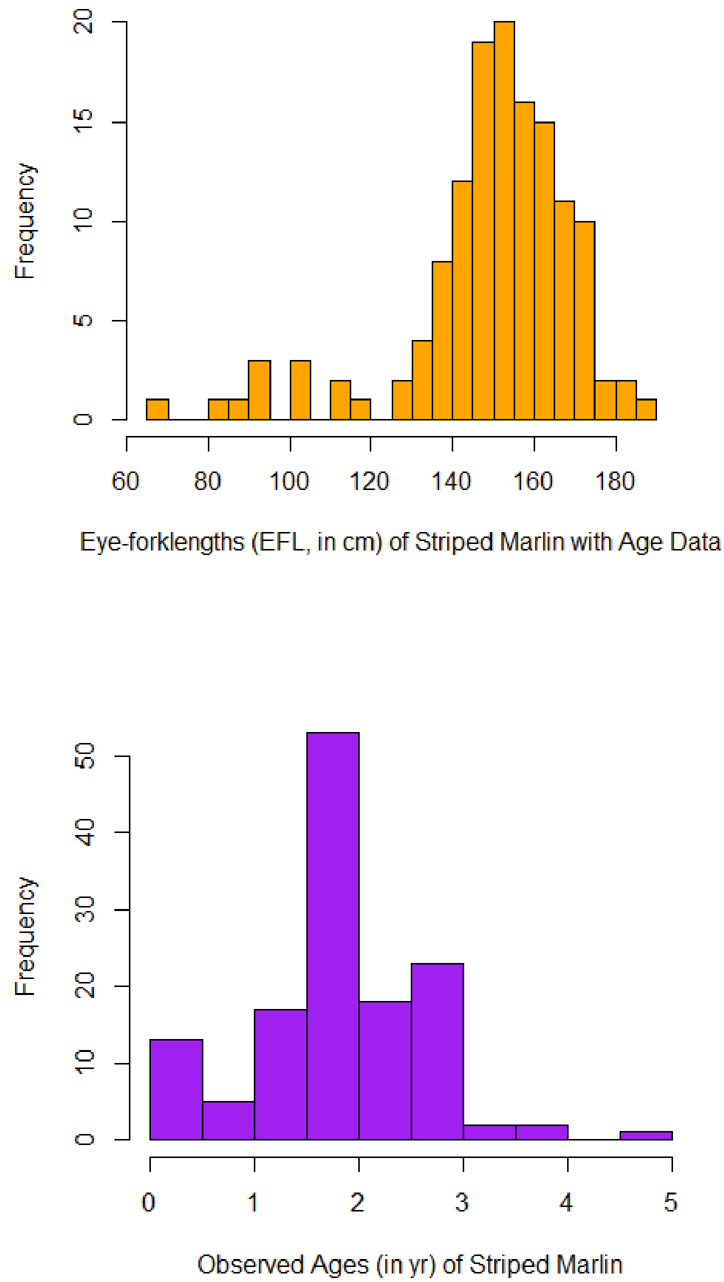
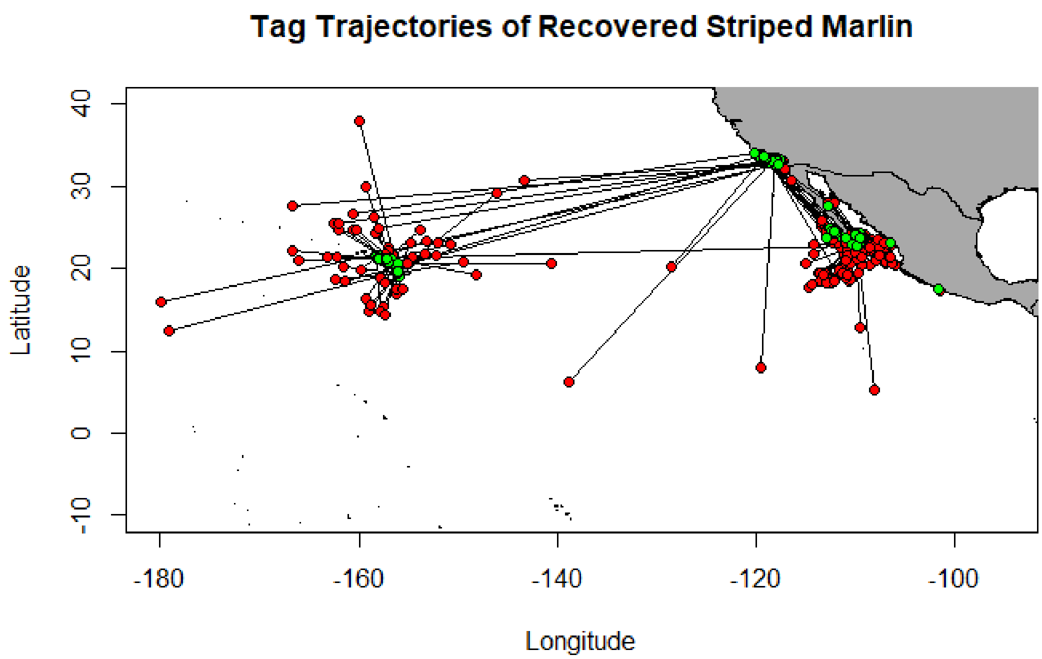


Figure 1. Histograms of observed length frequencies (EFL, in cm) of striped marlin (top) with corresponding age frequencies (bottom). Data consists of 134 specimens from K. Kopf (personal communication).



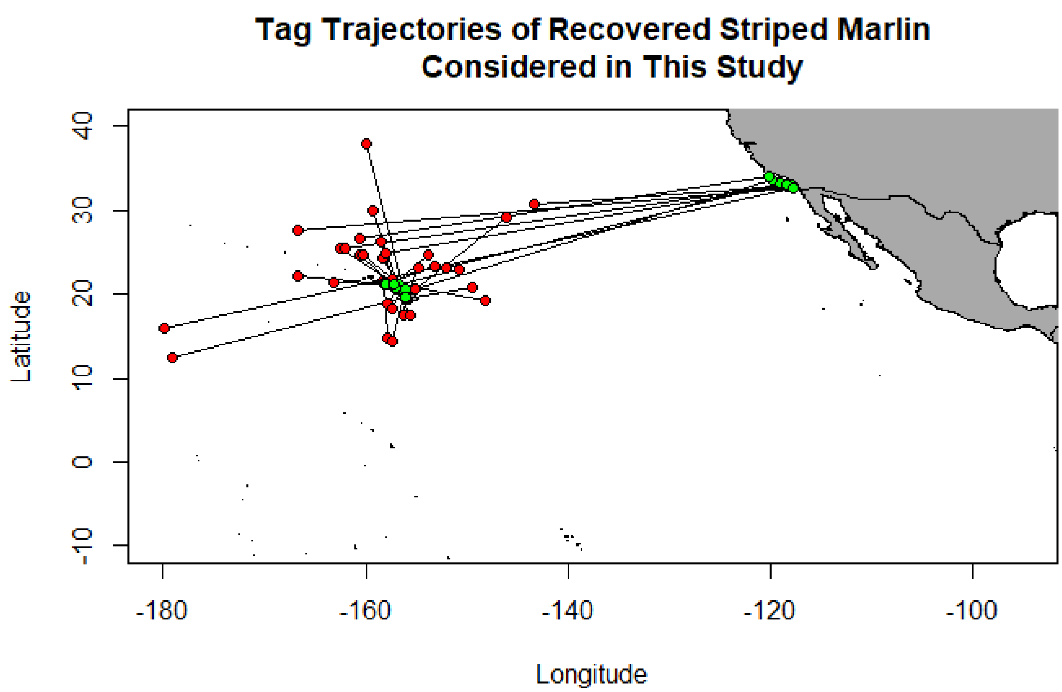


Figure 2. Top: Geographic trajectories of tagged and released striped marlin (green) with their corresponding recaptures (red) from the SWFSC Cooperative Billfish Tagging Program (n=288). Bottom: Trajectories of tagged/released striped marlin with recoveries that were used in this study (n=35).

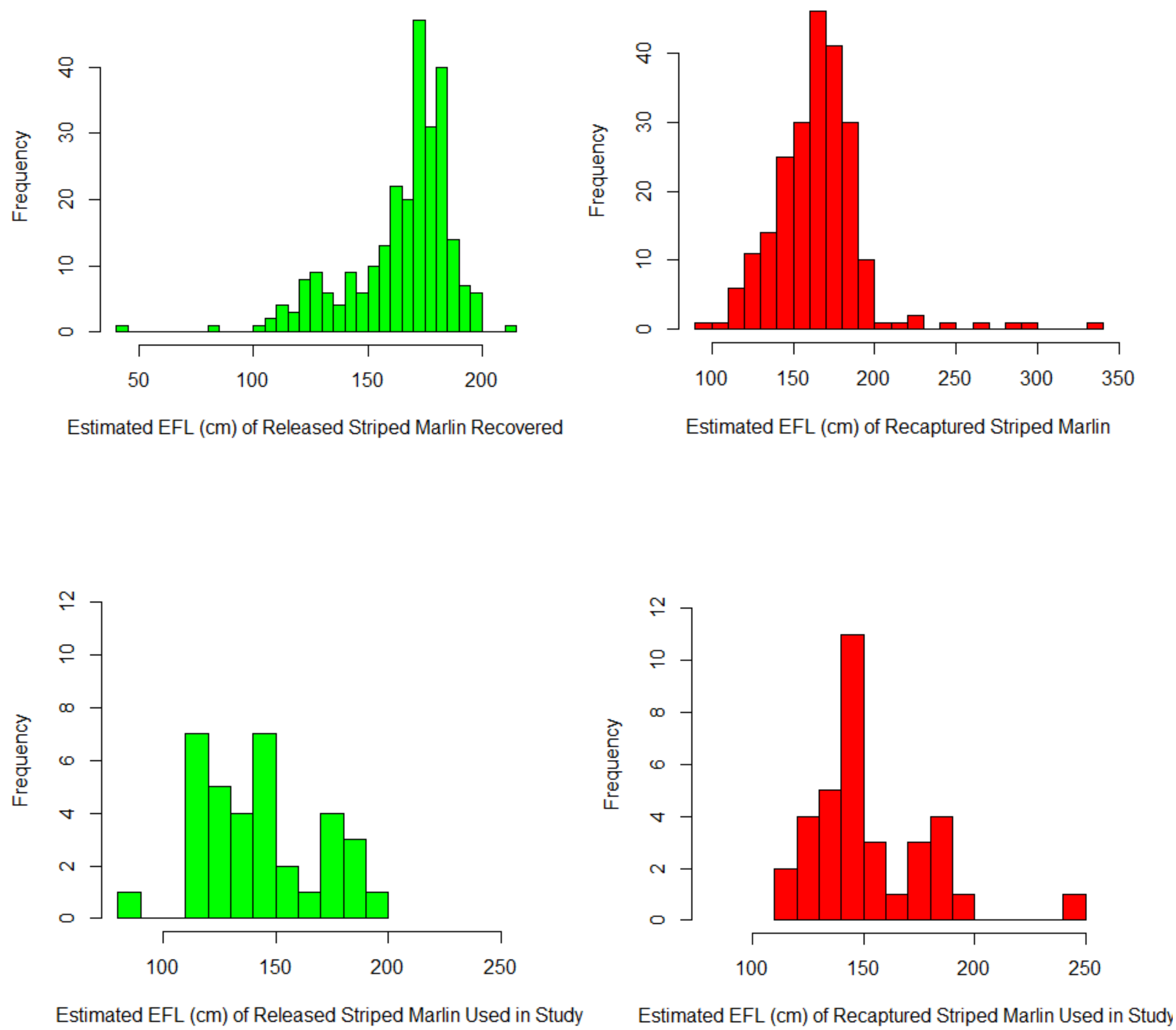


Figure 3. Histograms of estimated EFL (in cm) for all tagged/released striped marlin with complete records (n=288) that were recaptured (top left), estimated EFL for all recoveries with complete records (top right), estimated EFL at release for tagging records analyzed (n=35) in this study (bottom left), and estimated EFL for recovered tagged striped marlin used in this study (bottom right).

Model 1: Growth from Tagging Only, no t_0 estimated

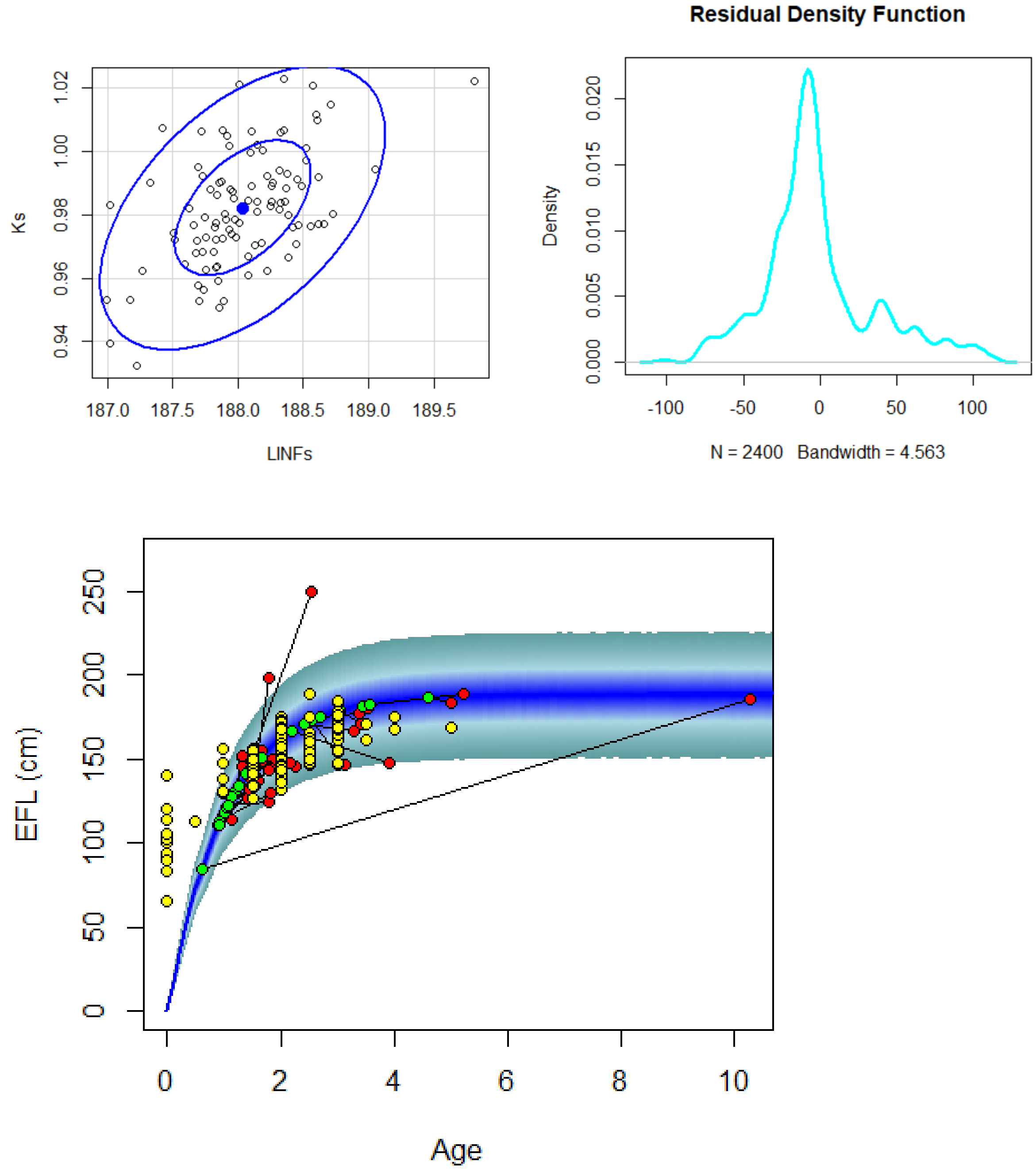
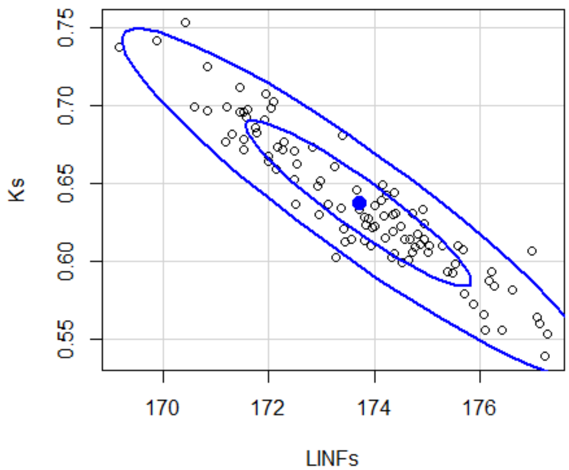
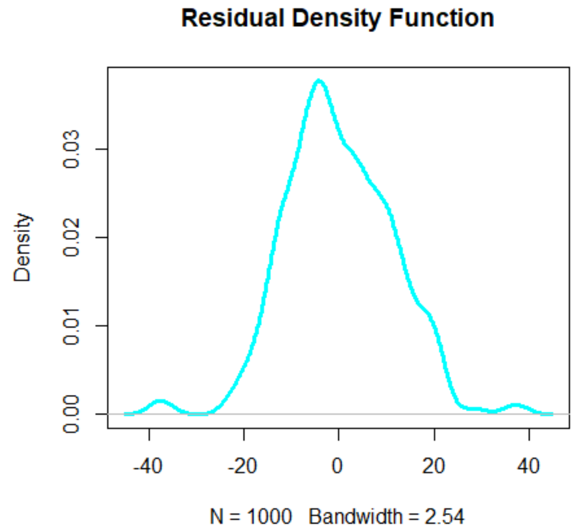


Figure 4. Model results from estimation of growth with tagging data only. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100^{th} bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=188.04 cm EFL, K=0.98 yr^{-1}, and CV=0.15. Green points are released tags, red points are recoveries, and yellow points are directly observed sizes at age from fin spines (not used in this estimation)

Model 2: Growth from Fin Spines Only





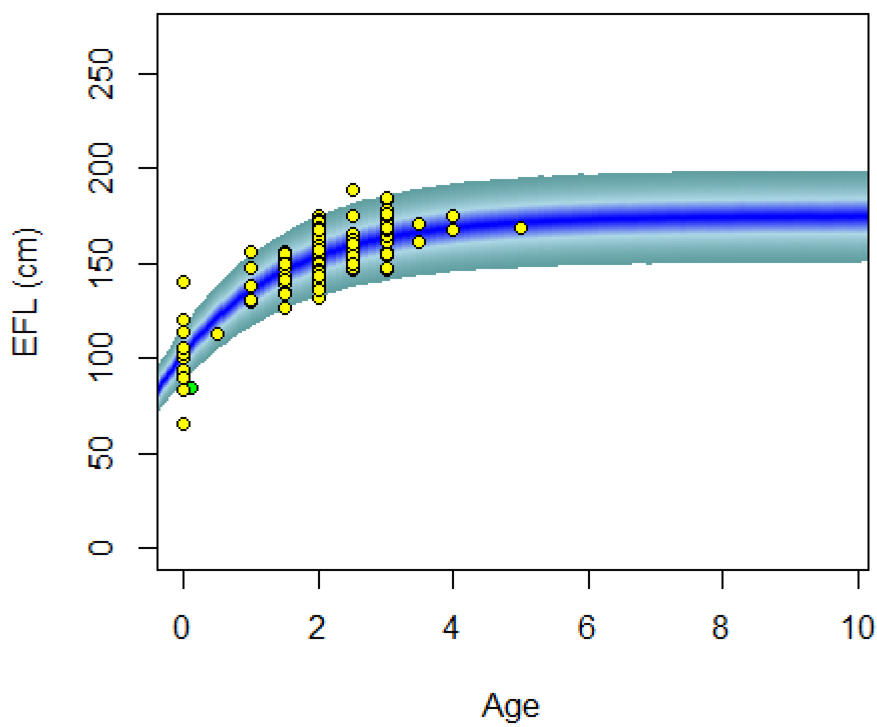


Figure 5. Model results from estimation of growth from observed fin spines only. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100th bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=175.67 cm EFL, K=0.62 yr^{-1} , CV=0.08, and t_0=-1.43 yr . Yellow points are directly observed sizes at age from fin spines

Model 3: Growth from Tagging and Spines, CV esimated jointly

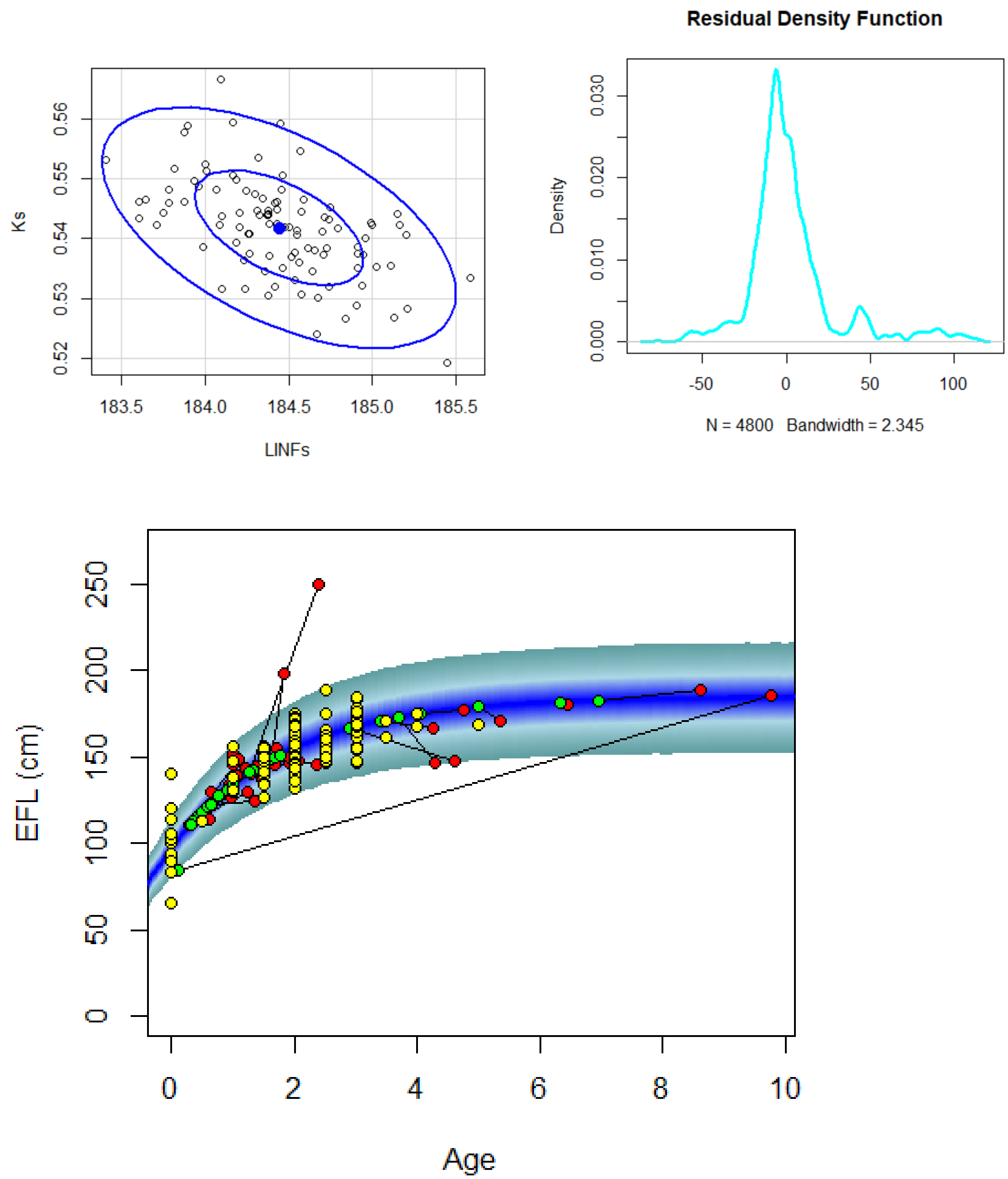


Figure 6. Model results from estimation of growth from observed fin spines and tagging data with jointly estimated CVs. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100th bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=184.4 cm EFL, K=0.54 yr^{-1}, CV=0.13, and t_0=-1.39 yrs. Green points are released tags, red points are recoveries, and yellow points are directly observed sizes at age from fin spines.

Model 4: Growth from Tagging and Spines, CV estimated from Tagging Data

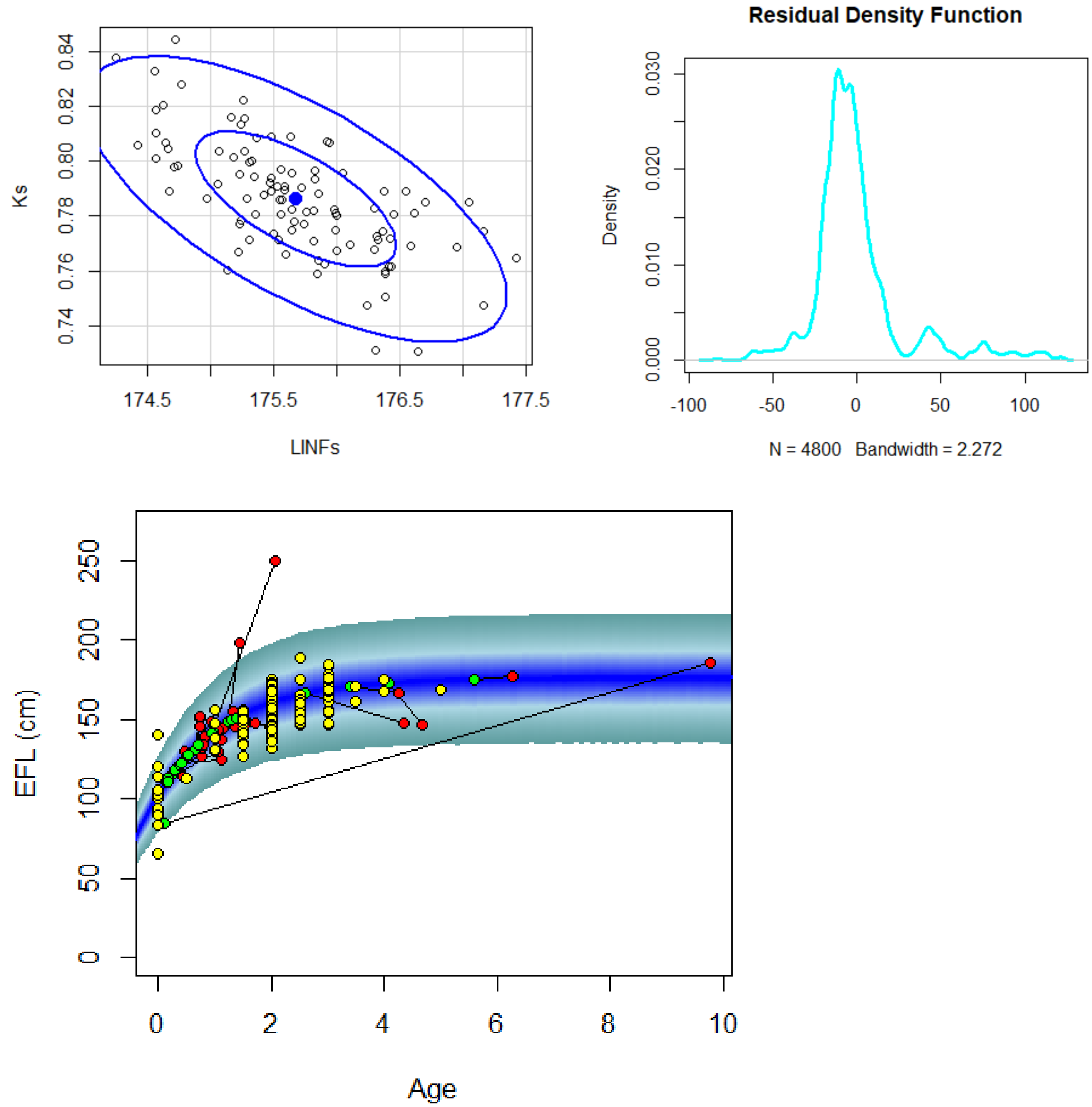


Figure 7. Model results from estimation of growth from observed fin spines and tagging data with CVs estimated from the tagging data. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100^{th} bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=175.82 cm EFL, K=0.78 yr^{-1}, CV=0.17, and t_0=-1.12 yrs . Green points are released tags, red points are recoveries, and yellow points are directly observed sizes at age from fin spines.

Model 5: Growth from Tagging and Spines, CV estimated from Spine Data

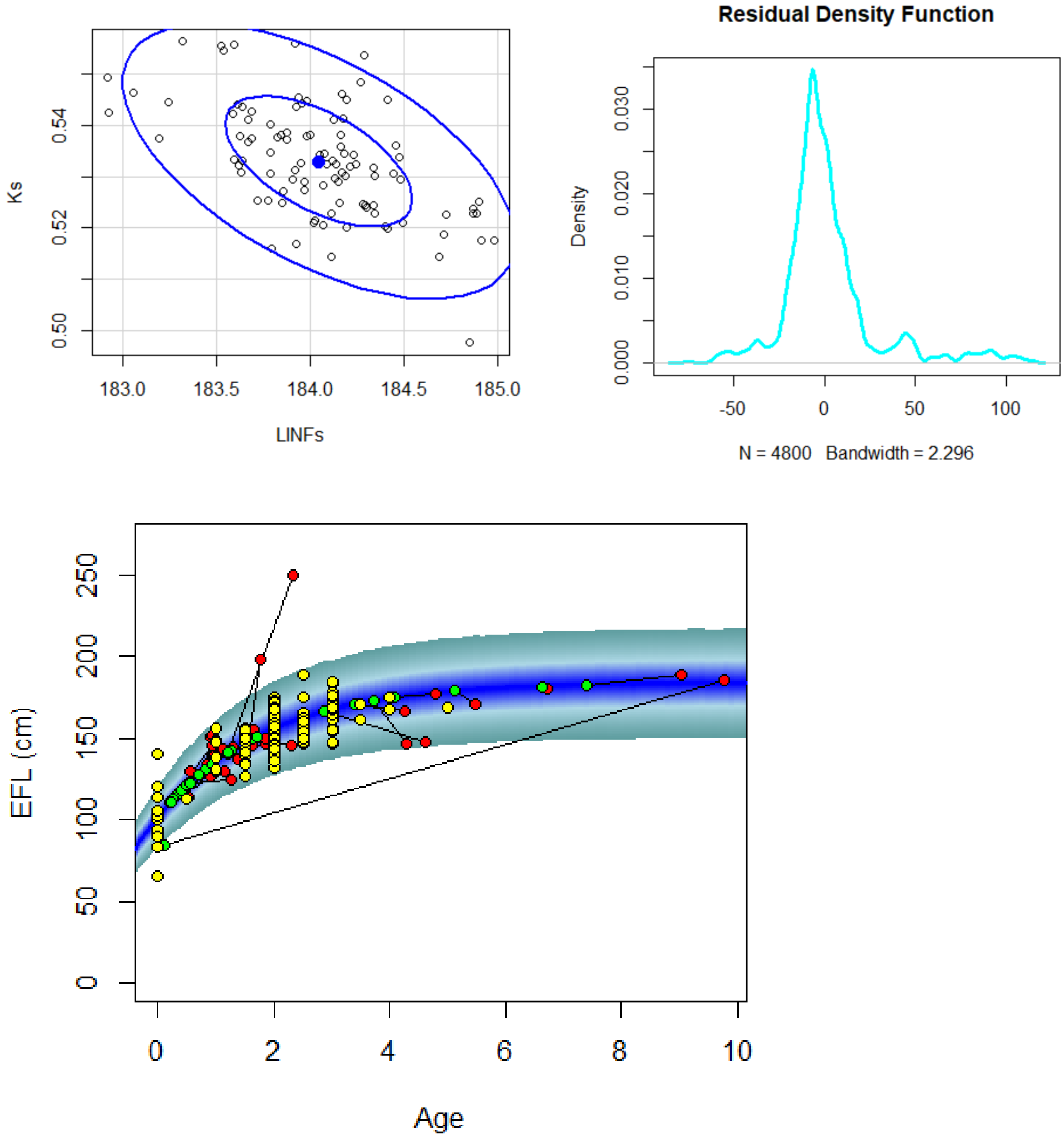


Figure 8. Model results from estimation of growth from observed fin spines and tagging data with CVs estimated from the spine data. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100th bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=183.95 CM EFL, K=0.53 yr^{-1}, CV=0.13, and t_0=-1.52 yrs . Green points are released tags, red points are recoveries, and yellow points are directly observed sizes at age from fin spines.

Model 6: Growth from Spines Only, Omitting Age 0

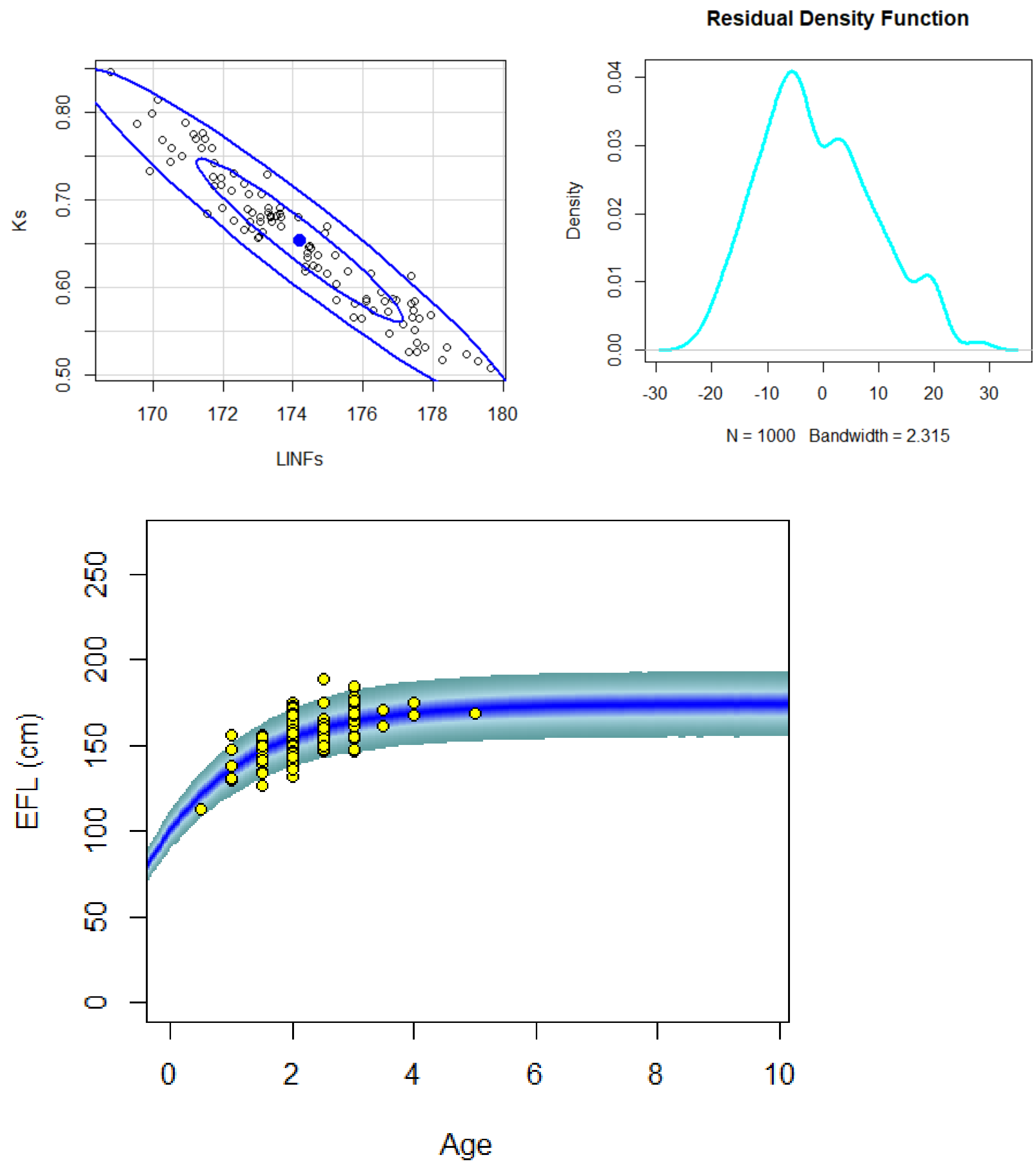


Figure 9. Model results from estimation of growth from observed fin spines only, omtting Age 0 observations. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100^{th} bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=174.19 cm EFL, K=0.65 yr^{-1}, CV=0.06, and t_0=-1.32 yrs . Yellow points are directly observed sizes at age from fin spines

Model 7: Growth from Tagging and Spines, Omitting Age 0, CV estimated jointly

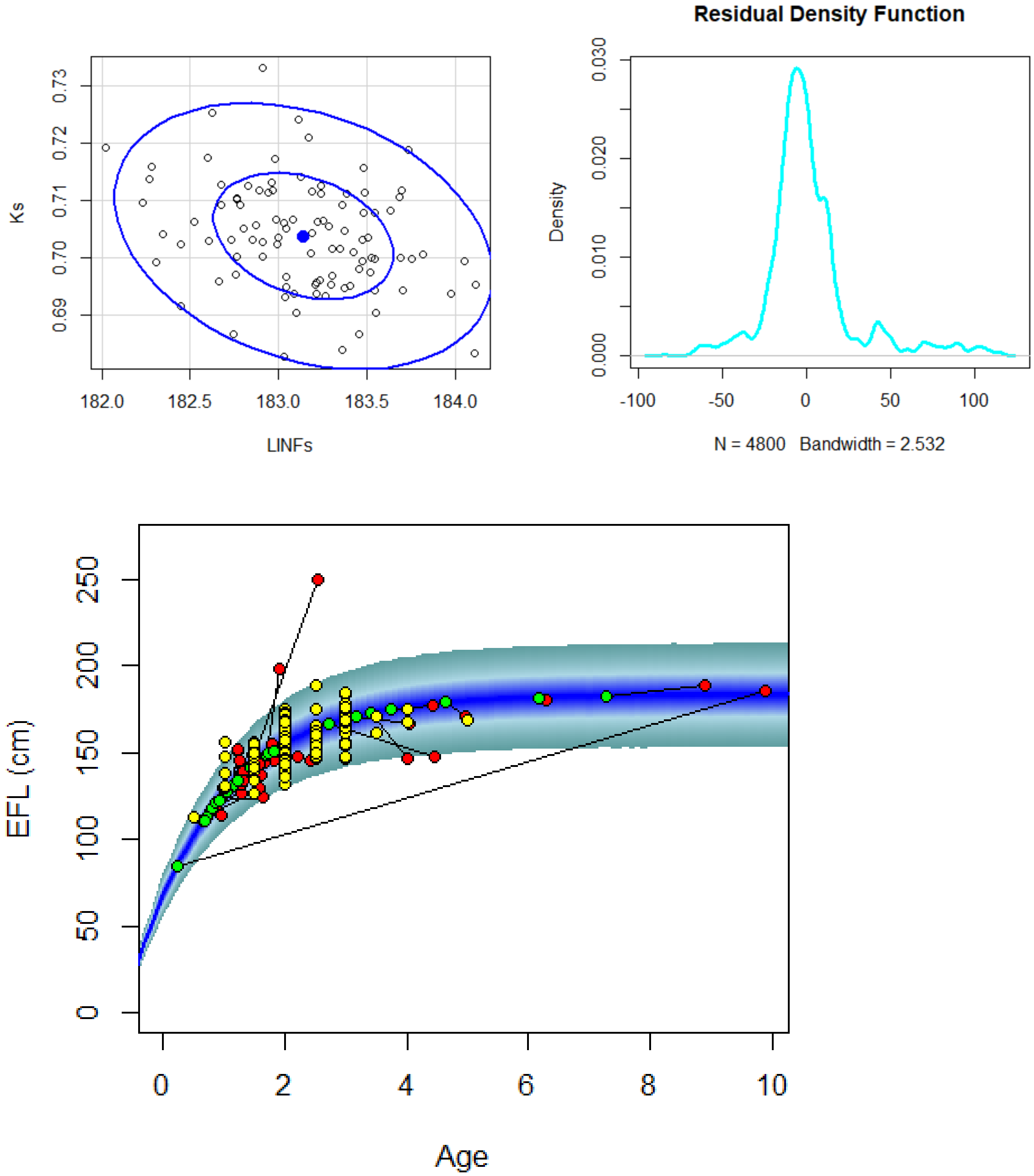


Figure 10. Model results from estimation of growth from observed fin spines and tagging data, omitting Age 0 observations, with CVs estimated jointly. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100^{th} bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=183.14 cm EFL, K=0.70 yr^{-1}, CV=0.12, and t_0=-0.66 yrs. Green points are released tags, red points are recoveries, and yellow points are directly observed sizes at age from fin spines.

Model 8: Growth from Tagging and Spines, Omitting Age 0, CV estimated from Spines

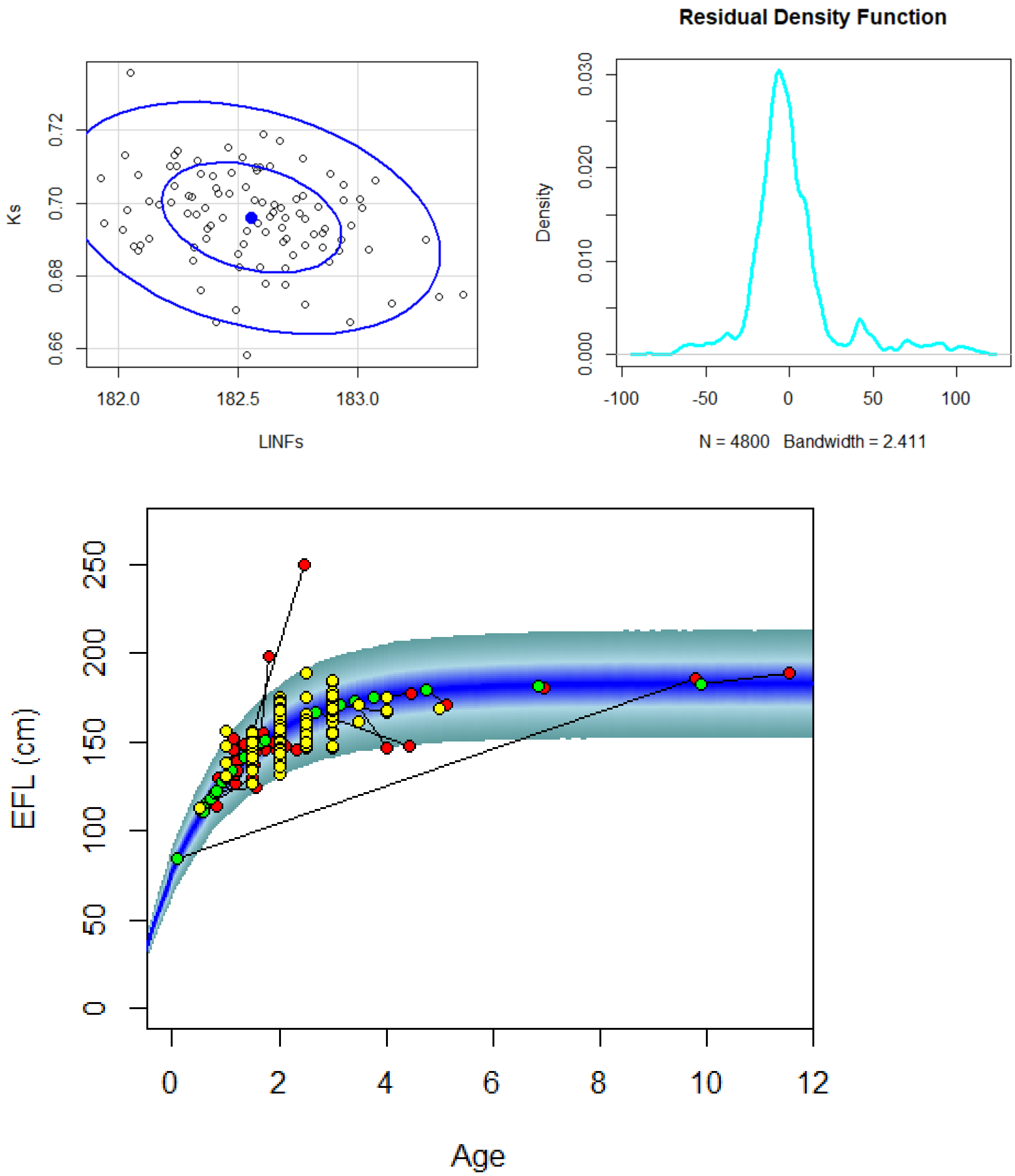


Figure 11. Model results from estimation of growth from observed fin spines and tagging data, omitting Age 0 observations, with CVs estimated from spine data. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100^{th} bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=182.56 cm EFL, K=0.70 yr^{-1}, CV=0.12, and t_0=-0.78 yrs. Green points are released tags, red points are recoveries, and yellow points are directly observed sizes at age from fin spines.

Model 9: Growth from Tagging and Spines, Omitting Age 0, CV estimated from Tag Data

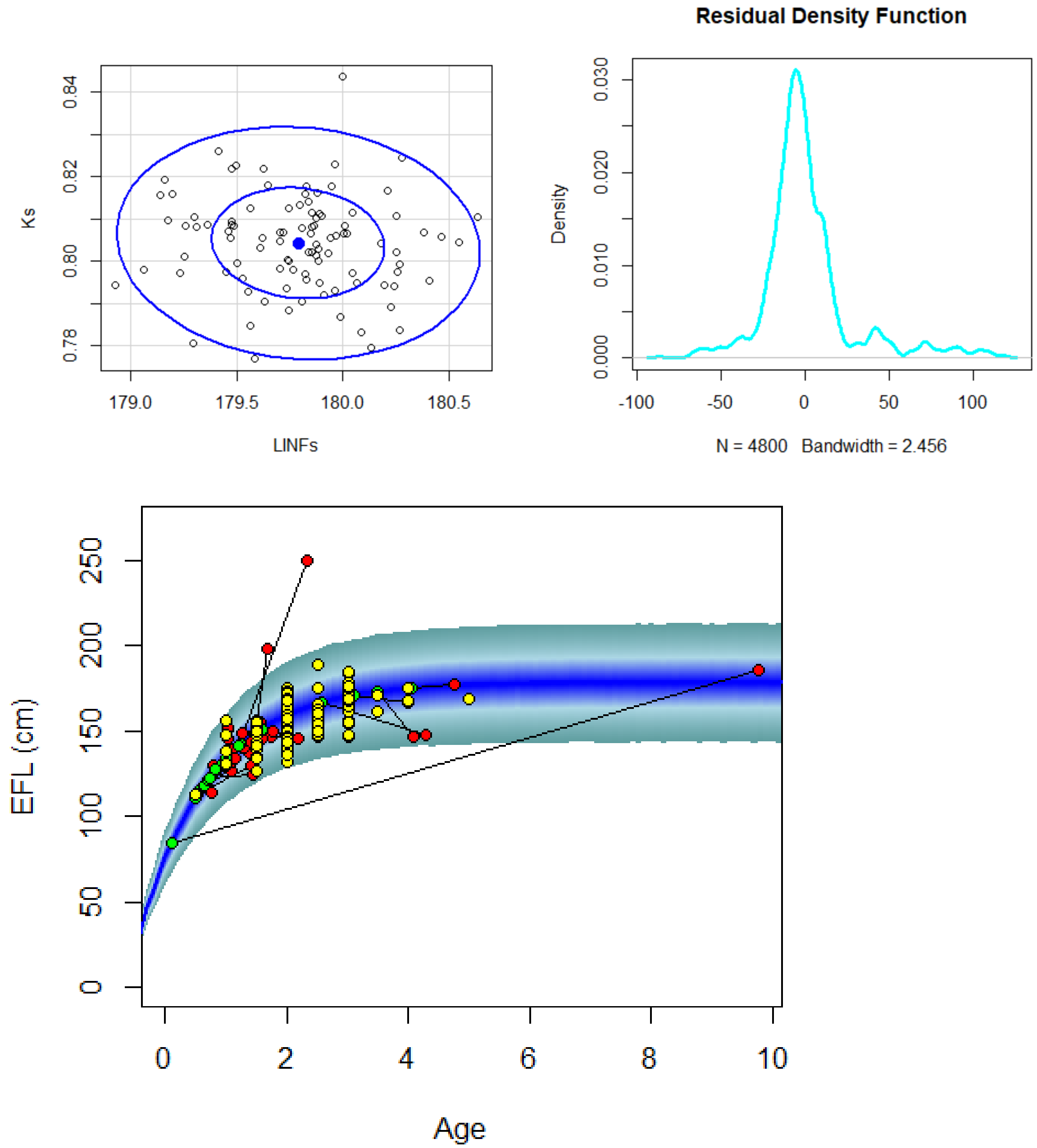


Figure 12. Model results from estimation of growth from observed fin spines and tagging data, omitting Age 0 observations, with CVs estimated from spine data. Top left: ellipse plot of L_∞ and K jointly estimated for each bootstrap run. Top right: Residual density plot for the 100^{th} bootstrap run using mean parameters. Bottom: fanplot for estimated VBGF with L_∞=179.79 cm EFL, K=0.80 yr^{-1}, CV=0.12, and t_0=-0.51 yrs . Green points are released tags, red points are recoveries, and yellow points are directly observed sizes at age from fin spines.

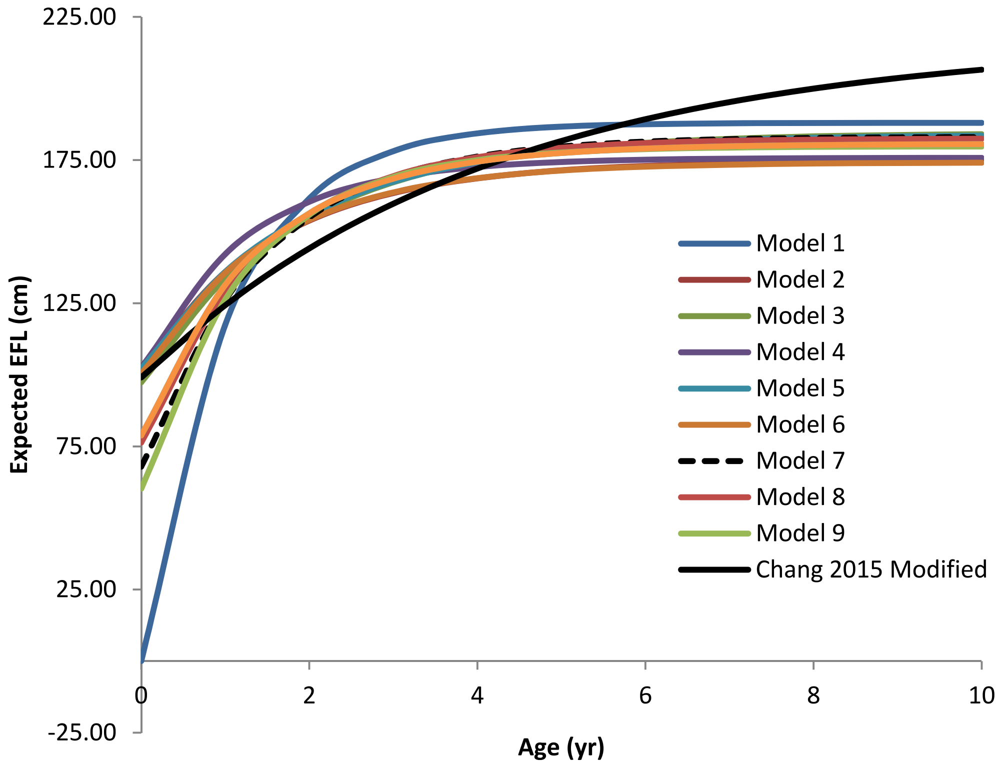


Figure 13. Expected size (EFL, cm) at age for models in this working paper compared to a growth curve by ISC15 (Chang et al.,2015) modified from Sun et al. (2011) used in the most recent stock assessment.

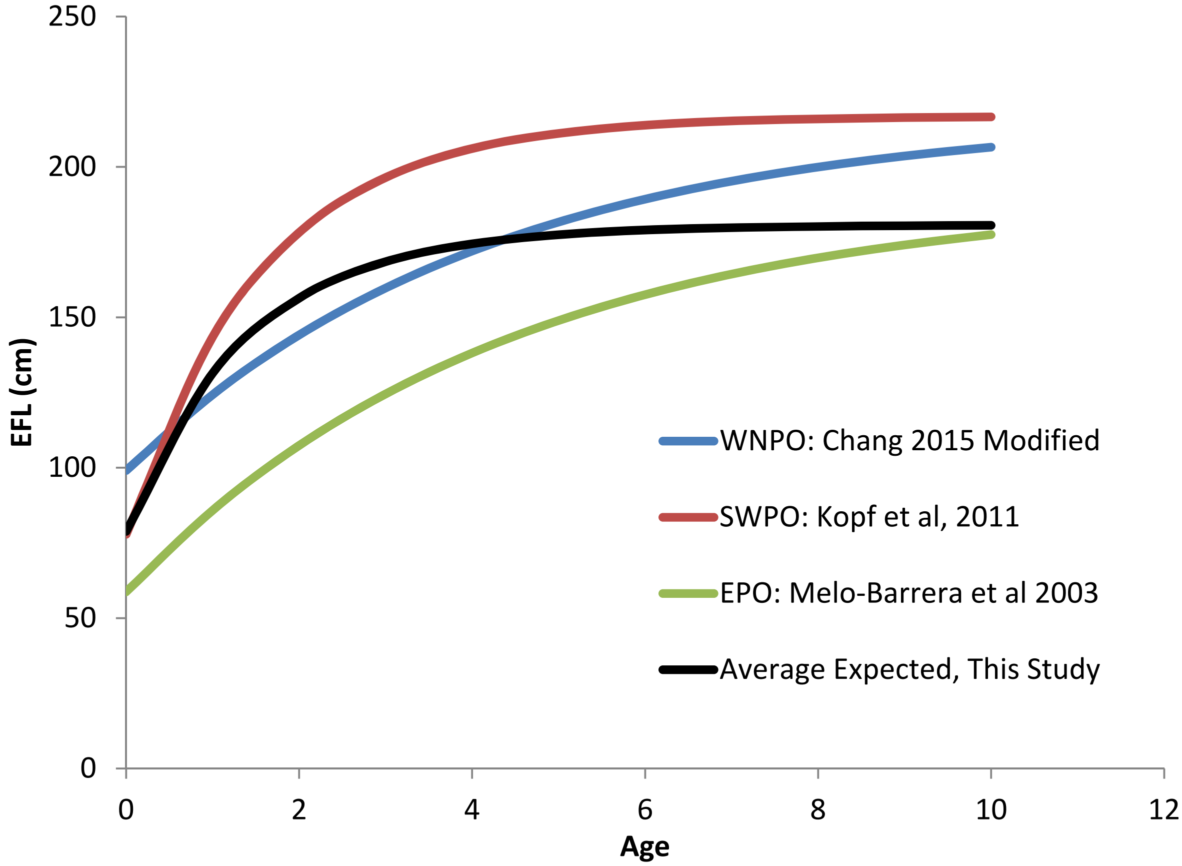


Figure 13. Expected size (EFL, cm) at age from average of expected sizes at age from models presented in this working paper compared to growth curves of striped marlin in other regions: Eastern Pacific (Melo-Barrera et al., 2003), Southwestern Pacific (Kopt et al, 2011), Western North Pacific (ISC15 Chang et al. 2015; modified from Sun et al., 2011) used to assess the North Pacific stock.