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Estimation of growth curve using conditional age at length data from otolith aging

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Summary

This paper provides with the comparison of the estimated growth curve externally with those estimated internally with and without conditional age at length data. The result showed that the use of conditional age at length: (1) decreased the length infinity from 249.6 to 240.5 cm: (2) decreased the growth coefficient (Brody's *k*) in relation to the growth rate from 0.173 to 0.160: (3) increased the fork length at age-0 from 15.8 to 23.7 cm. Therefore, there was inconsistency between the estimated growth curves externally and internally. In particular, it seems that the growth curve with conditional age at length underestimates the length at older ages in comparison with observed age at length data. Nevertheless growth curve estimates within the age structured model has an effect to maintain length at age 0 within feasible length while length at age 0 tends to be underestimated with only ageing data. Therefore, we have two possible suggestions: (i) estimate internally the all growth parameters in the SS model: (ii) estimate externally the parameters with fixing the length at age-0 estimated in the SS model or with estimating the length at age-0 within a reasonable limited range. However, it is not recommended to use (i) because there is an uncertainties in the estimation of growth curve at older ages.

1. Introduction

Growth curve is one of the key components in the stock assessment of Pacific Bluefin tuna (PBF), *Thunnus orientalis*. In the previous assessment of PBF, the growth curve was fixed at that estimated by Shimose (2008). This growth curve was updated in 2009 (Shimose *et al*. 2009), 2011 (Shimose *et al*. 2011), and 2012 (Shimose *et al*. 2012). These growth curves were externally estimated using sex combined otolith aging data. Sex specific growth curves are also available, but their use in the assessment is doubtful as observations of sex-specific landings and ages were limited (Shimose *et al*. 2012). Alternatives are to estimate a growth curve inside the model, either with or without including the conditional age at length data. Takeuchi (2012) provided the preliminary results of Stock Synthesis (SS) (Methot 2011) runs estimating growth curve parameters with conditional age at length. It suggested that use of them had an effect stabilizing growth curve parameters within a feasible range, in particular for length at age 0. As described above, there are some candidates of PBF growth curves. However, PBF-working group has not determined as to which is most appropriate to use. This paper provides the test to determine whether PBF growth should be fixed to externally derived estimates or estimated internally in SS.

2. Materials and Methods

Since some growth curves had estimated externally since 2008, we focus on the estimation of growth curve internally in SS model with and without conditional age at length data.

2.1 Age-at-length data

Age-at-length otolith reading data by Shimose *et al*. (2012) were used to estimate the growth curve internally in SS model. These data are from 1636 individual PBF caught in the waters off and landed in ports Japan and Taiwan from 1992 to 2010. The seasonal data covers a large size range from 47 to 260cm associated with a wide age range from 1 to 20 years, which had been sampled from various types of fisheries including longline (i.e. Fleet1: Japanese longline, F10: Taiwanese longline), purse seine (F2: Small pelagic fish purse seine), handline (F13: Others), and set net (F7: Northern part of Japanese Set net, F9: Other areas set net) (**Table1**, **Figure 1**). In the process internal estimation of growth curve, the interval of the length range classes is defined as 1cm. The expected length at age is estimated internally within a specified size range.

2.2 Conditional age at length

Conditional age at length data are essential to use multinomial likelihood stratified by each length bin, allowing ageing error and intending to avoid the effect of size selectivity. The use of the conditional age at length is advantageous: (i) to avoid double use of fish for both age and size information, because the age information is considered conditional on the length information: (ii) to include more detailed information about the relationship between size and age, providing a strong ability to estimate growth parameters, especially the variance of size at age (Method 2011).

2.3 SS model configuration

Configuration of the SS model for each scenario is shown in **Table 2**. Main changes of the model configuration compared to the preliminary base case (Iwata *et al*. 2012) are as follows:

(i) Introduction of population length bin as defined 1cm bins from 10cm to 296cm.

(ii) Age at L2 is changed from 3 to 20 to enable estimation of growth curve parameters.

(iii) Number of age bins is changed from 21 to 20 by leaving out 0-age bin because there is no 0-age data.

(iv) Growth parameters (Length at Amin, Length at Amax, Von-Bertalanffy K, and CV of young) are internally estimated.

2.4 SS run scenarios

Four basic scenarios are provided based on the preliminary base case (Iwata *et al*. 2012).

Run0: Preliminary base case

Run1: Estimation of growth parameters instead of fixed to the values estimated by Shimose (2009).

Run2: Use of conditional age at length data (1cm intervals) with estimation of growth curve parameters.

Run3: Similar with Run2, but the interval of the data is 2cm with same population length bin method as preliminary base case.

3. Results

3.1 *Comparison of estimated growth curve*

The estimated growth curves indicated that the length at age were significantly different between Run0 (Shimose 2009) and Run1-3 (**Table3**, **Figure 2**). The lengths at young ages internally estimated in the SS model (Run1-3) were larger than the value externally estimated by Shimose (2009) (Run0). On the other hand, the lengths at old ages estimated internally (Run1-3) were smaller than the parameter by Shimose (2009) (Run0) and the parameters estimated with conditional length at age data (Run2 and 3) were much smaller than the parameter without conditional length at age data (Run1). Additionally, the growth rates estimated internally in the SS model (Run1-3) were slower than that estimated by Shimose (2009) (Run0). In summary, the use of conditional age at length: (1) decreased the length infinity from 249.6 to 240.5 cm: (2) decreased the growth coefficient (Brody's *k*) in relation to the growth rate from 0.173 to 0.160: (3) increased the fork length at age-0 from 15.8 to 23.7 cm.

3.2 *The results of SS run*

The computation of SS runs were made successfully for all scenarios with hessian matrix and convergence levels were relatively small (**Table 4**). Total likelihood can't be compared directly among them because the conditional age at length data were added to the model. Likelihood of survey by fleet indicated that the fitting to coastal longline to the CPUE data was worse if the growth curves were estimated internally (Run1-3). Likelihood of size composition by fleet seemed that the likelihood of fleets 1, 5, 6, 8, 9 and 13 have conflicts between Run0 and the others (Run1-3). Spawning stock biomass (SSB, tons) with Run1 (Internally estimated without conditional age at length data) showed significant increase since 1990s (**Figure 3**). The trends of SSB were similar between Run2 and 3. The recruitments were similar among them but stronger recruitment was observed in 1990 and 1994 for Run1. The increase of length at age-0 shifted the proportion of the stock (in number of fish) to younger ages and the decrease of length infinity shifted the proportion of stock (in number) to older age (**Figure 4**). Observed and estimated age compositions for run2 and run3 were shown in **Figure 5**. The shapes of the estimated curves were similar but the likelihood by fleet was considerably different, especially for fleet1 (Japanese longline) and fleet13 (Others) (**Table 7**).

4. Discussion

This paper presents that the use of ageing data within model has limited ability to improve growth curve estimate compared with runs without ageing data as described in the previous document (Takeuchi 2012). In particular, it seems that the growth curve underestimates the length at older ages in comparison with observed age at length data. Nevertheless growth curve estimates within the age structured model has an effect to maintain length at age 0 within feasible length while length at age 0 tends to be underestimated with only ageing data.

Additional run was conducted to estimate the growth curve using Richards function with conditional age at length data to improve the estimation of the length at older age. The length infinity, growth coefficient, length at age-0 was 235.7cm, 0.182, and 24.4 cm, respectively. Since there is no improvement of estimation for older ages, it is suggested that Richards growth curve is less appropriate than Bon-vertaranffy growth curve. These results indicated that it is difficult to reduce the uncertainty in the estimation of sizes for older ages.

The wider length bin size of the aging data had no impact on the estimation of the growth curve but the likelihood of age composition improved. It seems that there is a trade-off between the losses of the information on the data and better fitting. This is because that conditional age at length data has 1 cm precision, while a fewer samples in each 1cm bin. The increase of sample size would improve the fitting without losing the information and would result in the precise estimation of growth parameters.

The different estimation of growth curve suggests that there is inconsistency between the observation of aging data and the SS data-set even if with conditional age at length data. In reality, there are some discrepancies between the position of the mode and mean length estimated from the growth curve (Shimose 2009), especially for the troll fishery in quarter 1, which targets small sized fish (**Figure 7**). The length composition of PBF caught by troll fishery can includes two recruitment groups within a year which may strongly influence on the estimation of the growth curve. However, the aging data used for the estimation of the growth curve (Shimose 2009), didn't contain small sized fish corresponding to age-0. In addition, the size length at recruitment on July 1st is much smaller than actual size at recruitment based on the catch data and tagging data in Kochi prefecture. Therefore, we have some reservation on the growth curve by Shimose 2009, in particular estimated length at age-0. In summary, the growth curve estimates within the age structured model has an effect to maintain length at age 0 within feasible length while length at age 0 tends to be underestimated with only ageing data. Therefore, we have two possible suggestions: (i) estimate internally the all growth parameters in the SS model: (ii) estimate externally the parameters with fixing the length at age-0 estimated in the SS model or with estimating the length at age-0 within a reasonable limited range. However, it is not recommended to use (i) because there is an uncertainties in the estimation of growth curve at older ages.

References

Methot, RD.2011. User Manual for Stock Synthesis. Model Version 3.23b, Nov. 7,2011.

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Shimose, T., Tanabe, T., Chen, K.S., and Hsu,C.C. 2009. Age determination and growth of Pacific bluefin tuna, *Thunnus orientalis*, off Japan and Taiwan. Fish. Res., 100: 134-139.

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Tables

Table1. Number of aging data by quarter and fleet.

	Fleet1	Fleet2	Fleet3	Fleet4	Fleet7	Fleet9	Fleet10	Fleet13
Quarter1	13	1	130	53	29	11	0	197
Quarter2	1	1	8	0	31	18	0	264
Quarter3	10	11	3	0	0	4	0	13
Quarter4	442	8	61	16	26	20	257	8

Table2. Configuration of the SS model for each scenario.

	Run0	Run1	Run2	Run3
Growth curve parameters	Fixed	Estimated	Estimated	Estimated
Conditional age at length data	No	No	Yes	Yes
Growth formula	Von-bertaranffy	Von-bertaranffy	Von-bertaranffy	Von-bertaranffy
Amax	age-3	age-3	age-20	age-20
Length bin size of the samples			1cm	2cm
Population length bin in the model	16-224(2cm), 224-252(1cm), 252-290(2cm)	16-224(2cm), 224-252(1cm), 252-290(2cm)	10-296(1cm)	16-224(2cm), 224-252(1cm), 252-290(2cm)

Table3. Estimated growth parameters for each scenario.

	Run0	Run1	Run2	Run3
Length at Amin (cm)	15.840	23.069	23.7956	23.738
Length at Amax (cm)	110.490	111.971	231.708	231.328
Asymptotic length: $L_{infinity}$	249.610	240.826	240.549	239.944
Growth coefficient: *k*	0.173	0.175	0.160	0.161
CV young	0.416	0.246	0.215	0.216

Table4. Likelihood components for each scenario.

	Run0	Run1	Run2	Run3
Component	Covergence level			
	0.0048	2.2042E-05	0.0016757	0.00173
	Likelihood			
TOTAL	6241	6054	8015	7688
Catch	0.00027	0.00026	0.00025	0.00025
Survey	40	66	49	51
Age_comp			1681	1344
SizeFreq	6199	5987	6281	6288
Recruitment	1.65	1.56	4.19	4.27
Parm_softbounds	0.157	0.159	0.153	0.145

Table5. Likelihood of survey by fleet. S14-16: JLL, S17:TPS, S18:TRO(The Sea of Japan), S19: TRO, S20: TRO(Kochi), S21:TRO (Wakayama), S22:TWLL, S23:US-SP, S24: Mexico-PS.

Scenario	Likelihood											
	Total	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24
Run0	40	24	-19	-14	28	-27	71	75	67	5	3	9
Run1	66	42	-18	-18	45	-20	63	73	62	16	4	9
Run2	49	35	-19	-18	28	-24	66	71	63	8	4	10
Run3	51	36	-19	-17	28	-22	65	70	63	8	4	10

Table6. Likelihood of size composition by fleet. F1: JLL, F2:TPS(Young), F3:TPS (The Sea of Japan) F4:TPS(Pacific ocean), F5: TRO, F6: PL, F7-9: Set-net, F10:TWLL, F11:EPO-PS, F12US-SP, F13:Other fishery.

Scenario	Likelihood													
	Total	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
Run0	6199	962	338	399	471	908	324	414	350	1002	175	563	0	292
Run1	5987	964	352	402	462	794	289	426	393	927	157	542	0	278
Run2	6281	1032	337	500	461	892	297	426	384	930	177	557	0	287
Run3	6288	1030	339	500	461	888	297	439	384	929	177	558	0	288

Table7. Likelihood of age composition by fleet.

Scenario	Likelihood								
	Total	F1	F2	F3	F4	F7	F9	F10	F13
Run2	1681	405	23	245	59	119	58	199	574
Run3	1344	336	13	211	50	101	54	169	412

Figure

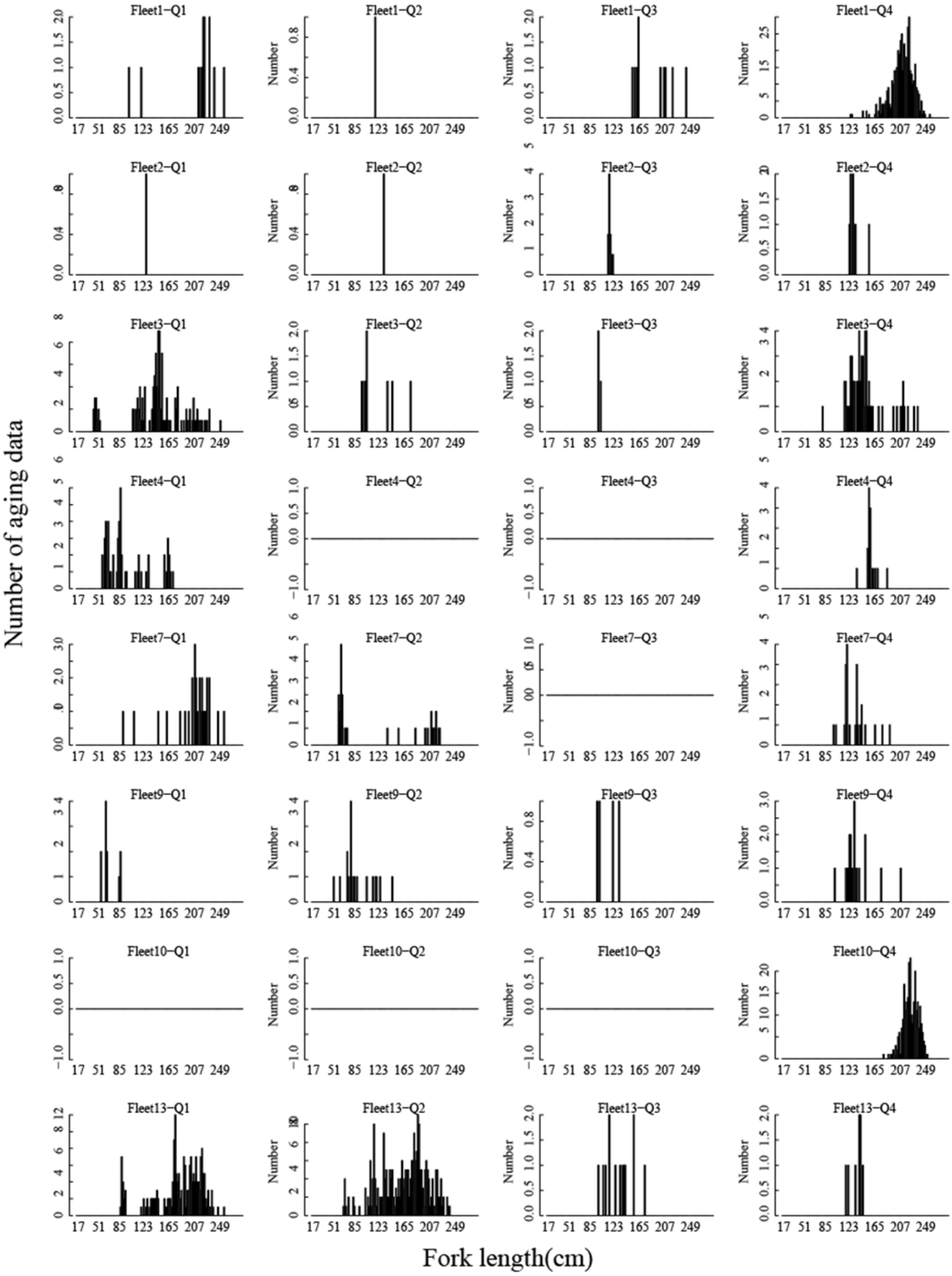


Figure1. Length composition of age-at-length data by quarter and fleet. F1: JLL, F2:TPS(Young), F3:TPS (The Sea of Japan) F4:TPS(Pacific ocean), F7-9: Set-net, F10:TWLL, F13:Other fishery.

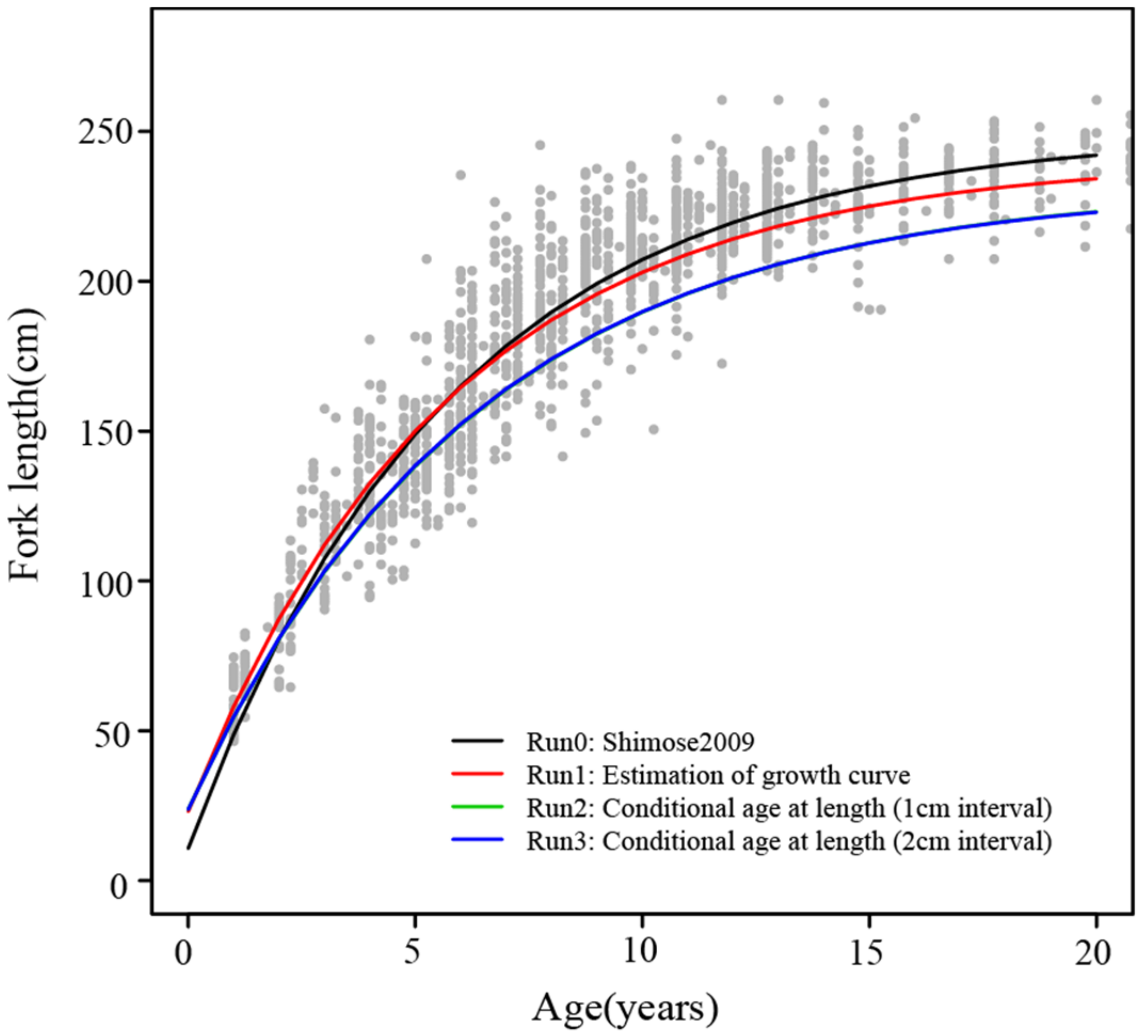
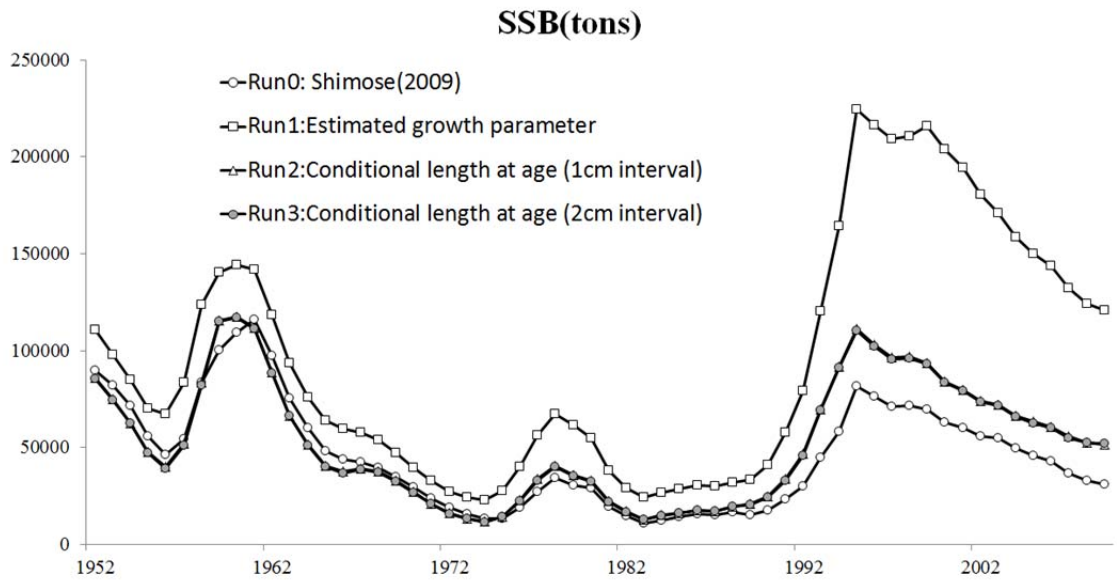


Figure2. Fork length at age and the fitted growth curve for each scenario.



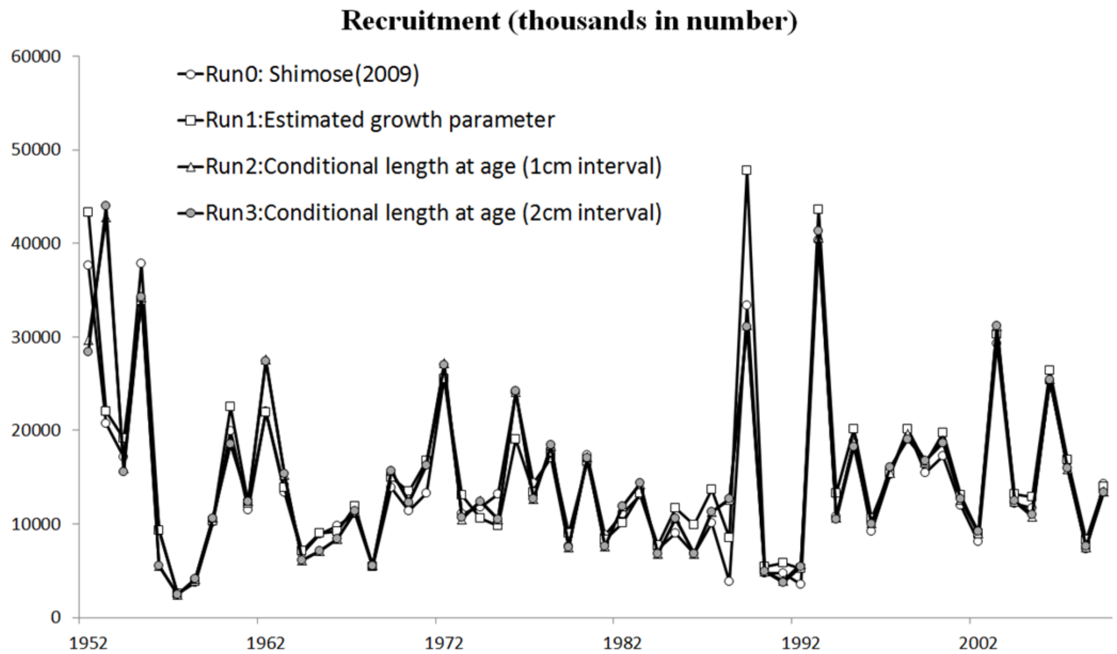


Figure3. Estimated SSB(tons) and recruitment(thousand in number).

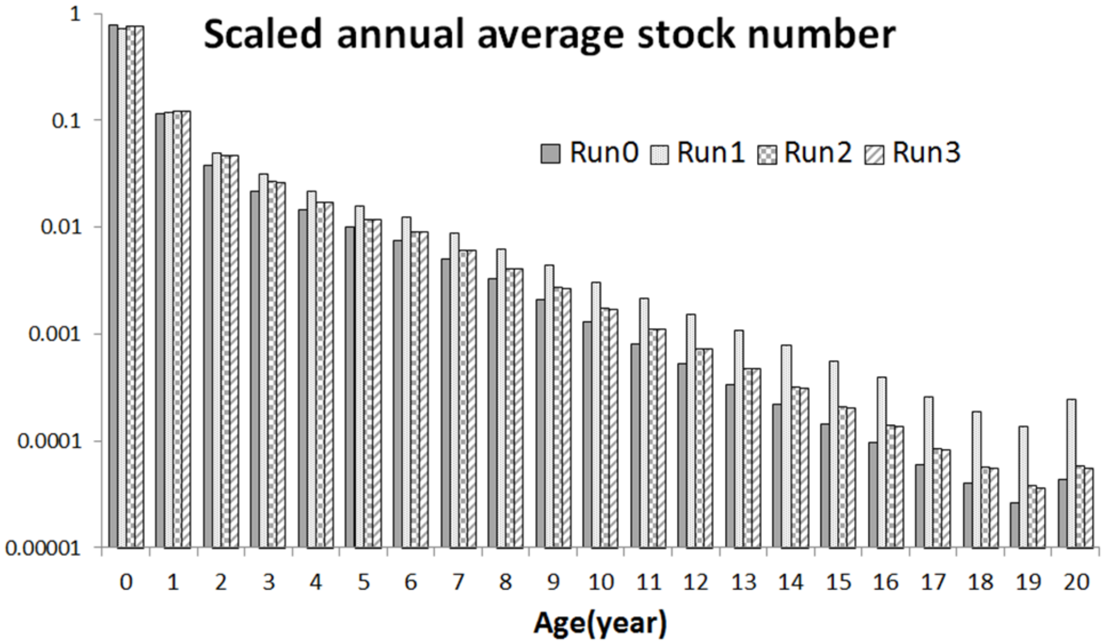


Figure4. Annual estimated stock number at age scaled by total stock number.

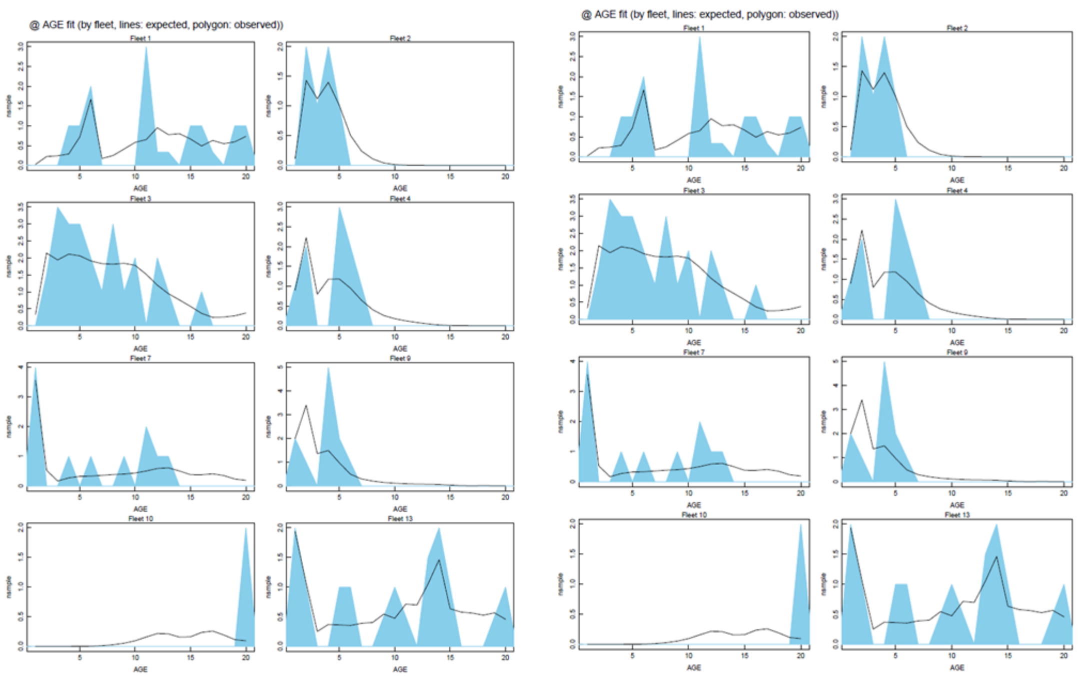


Figure5. Observed and estimated age compositions for run2 (left 8panels) and run3 (right 8panels).

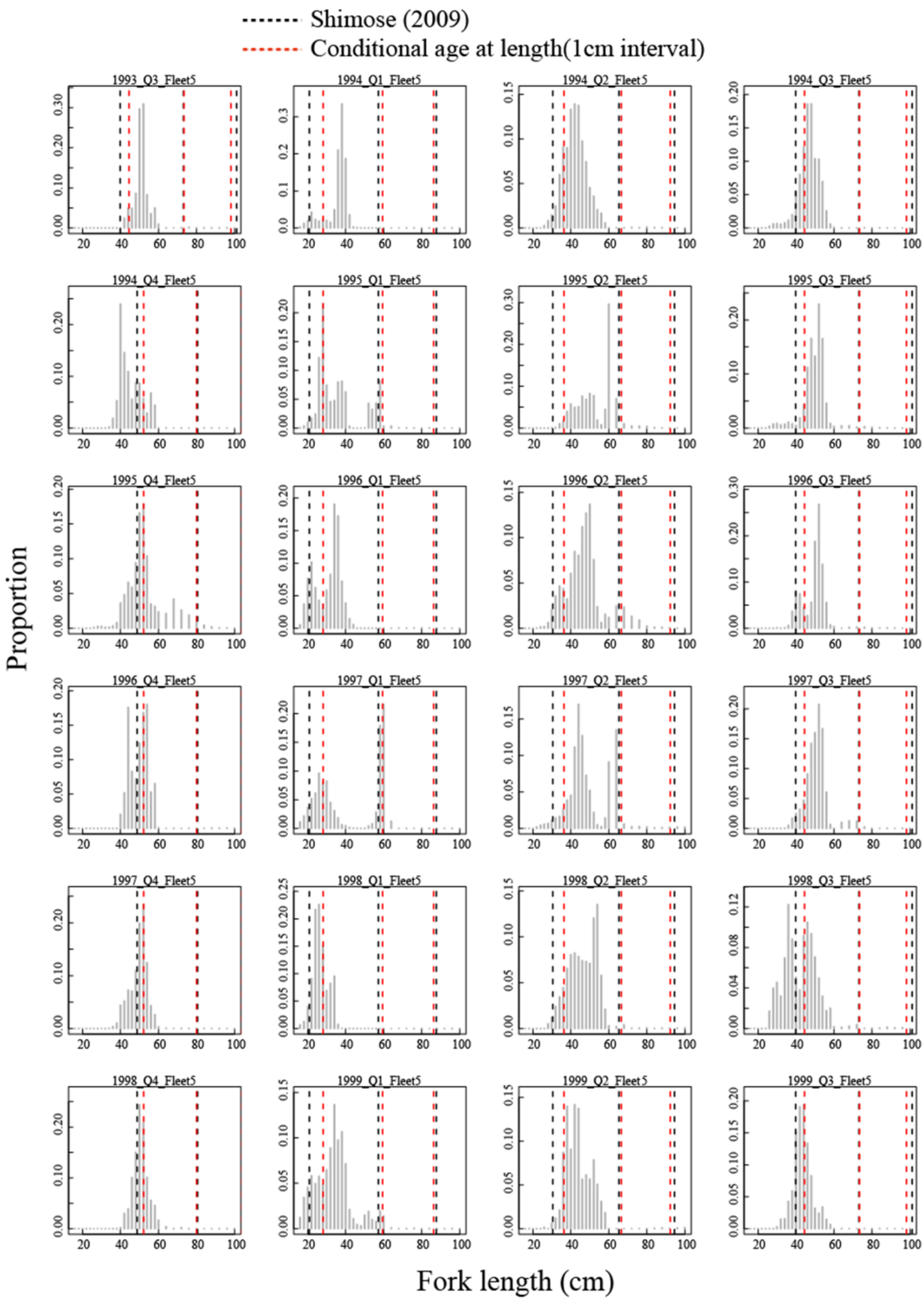


Figure7a. Length composition of PBF caught by troll fishery from 1993 to 1999 and mean length at mid-season estimated by growth curves.

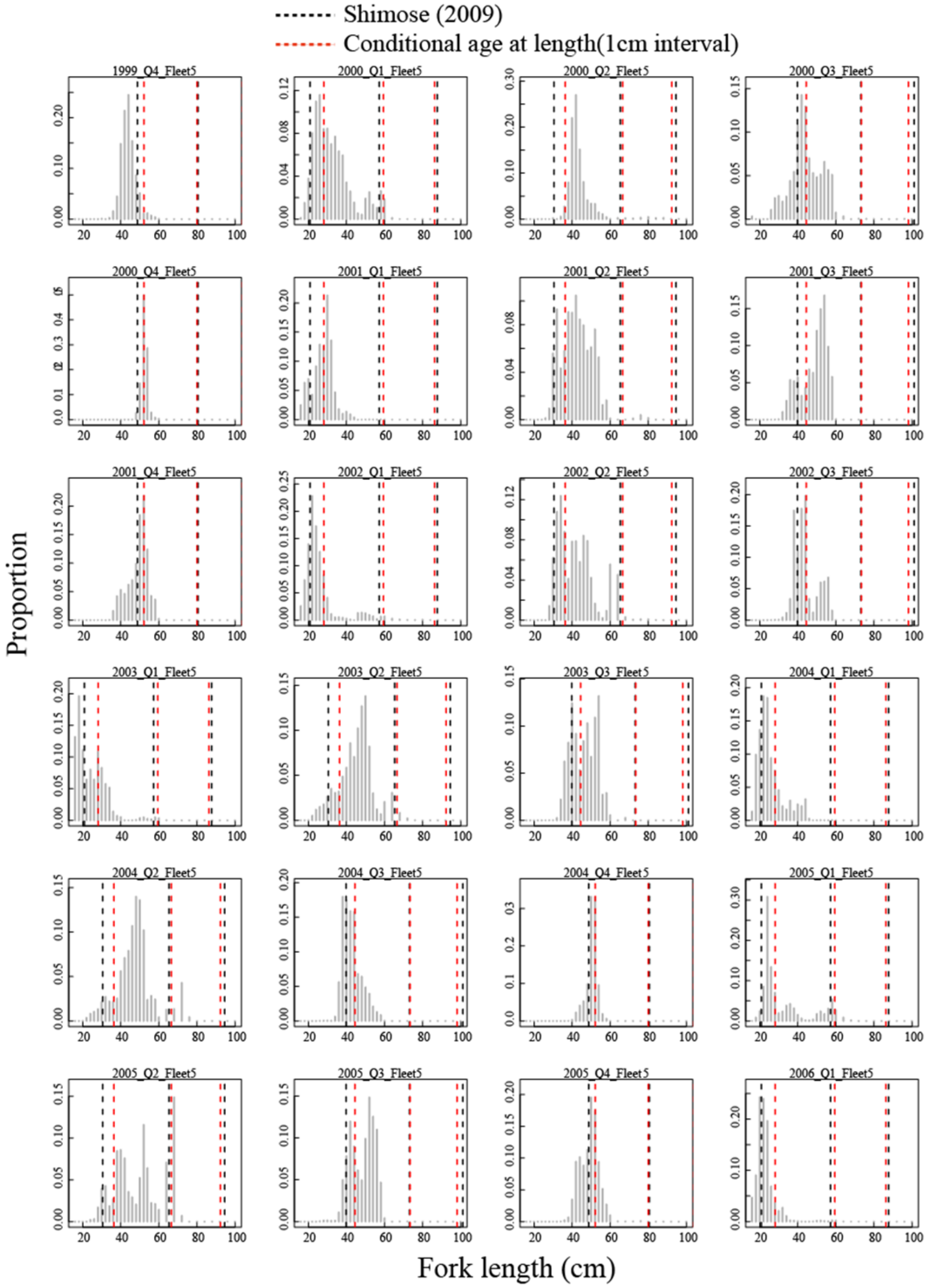


Figure7b. Length composition of PBF caught by troll fishery from 1999 to 2006 and mean length at mid-season estimated by growth curves.

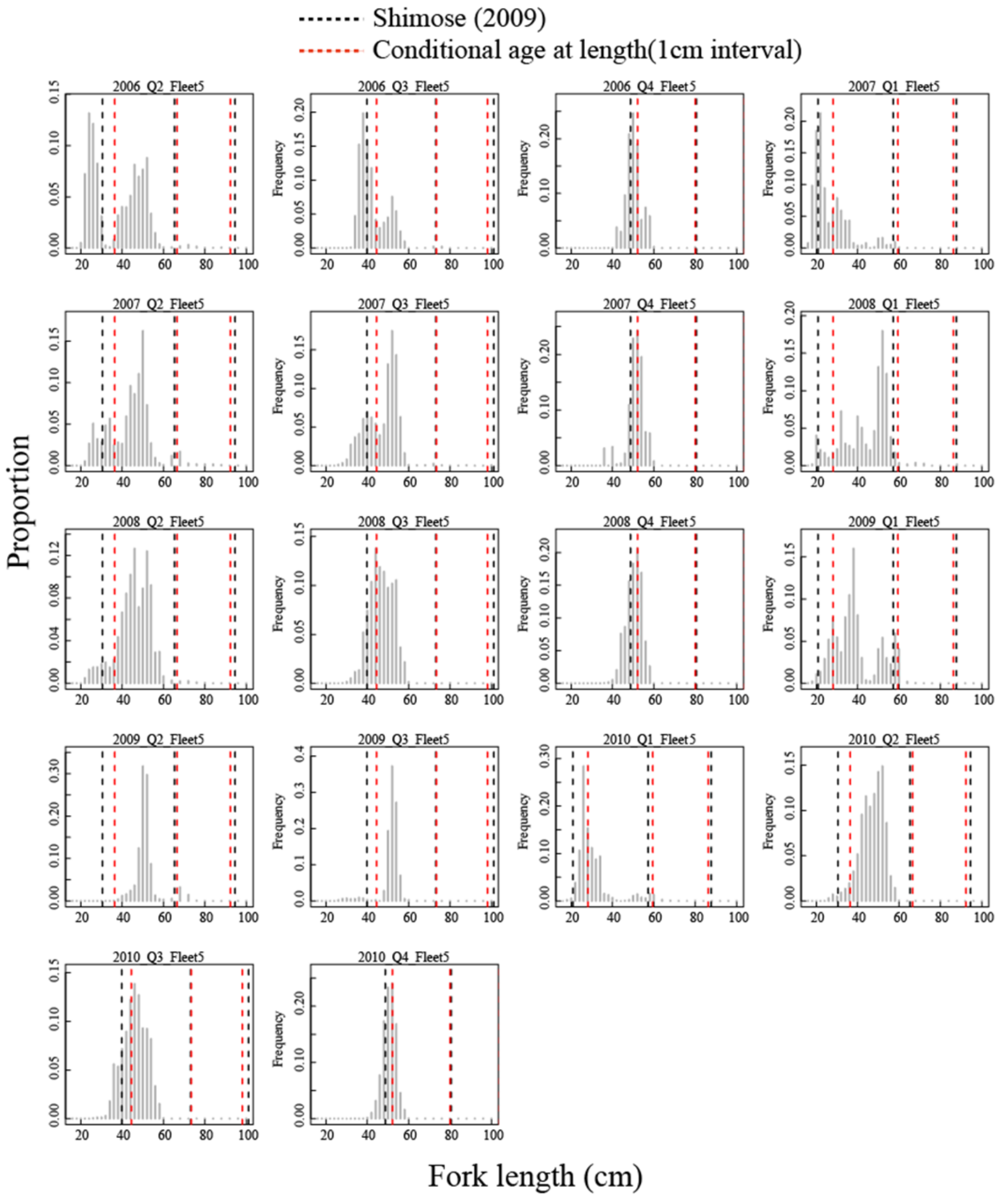


Figure7c. Length composition of PBF caught by troll fishery from 2006 to 2010 and mean length at mid-season estimated by growth curves.

Appendix figure

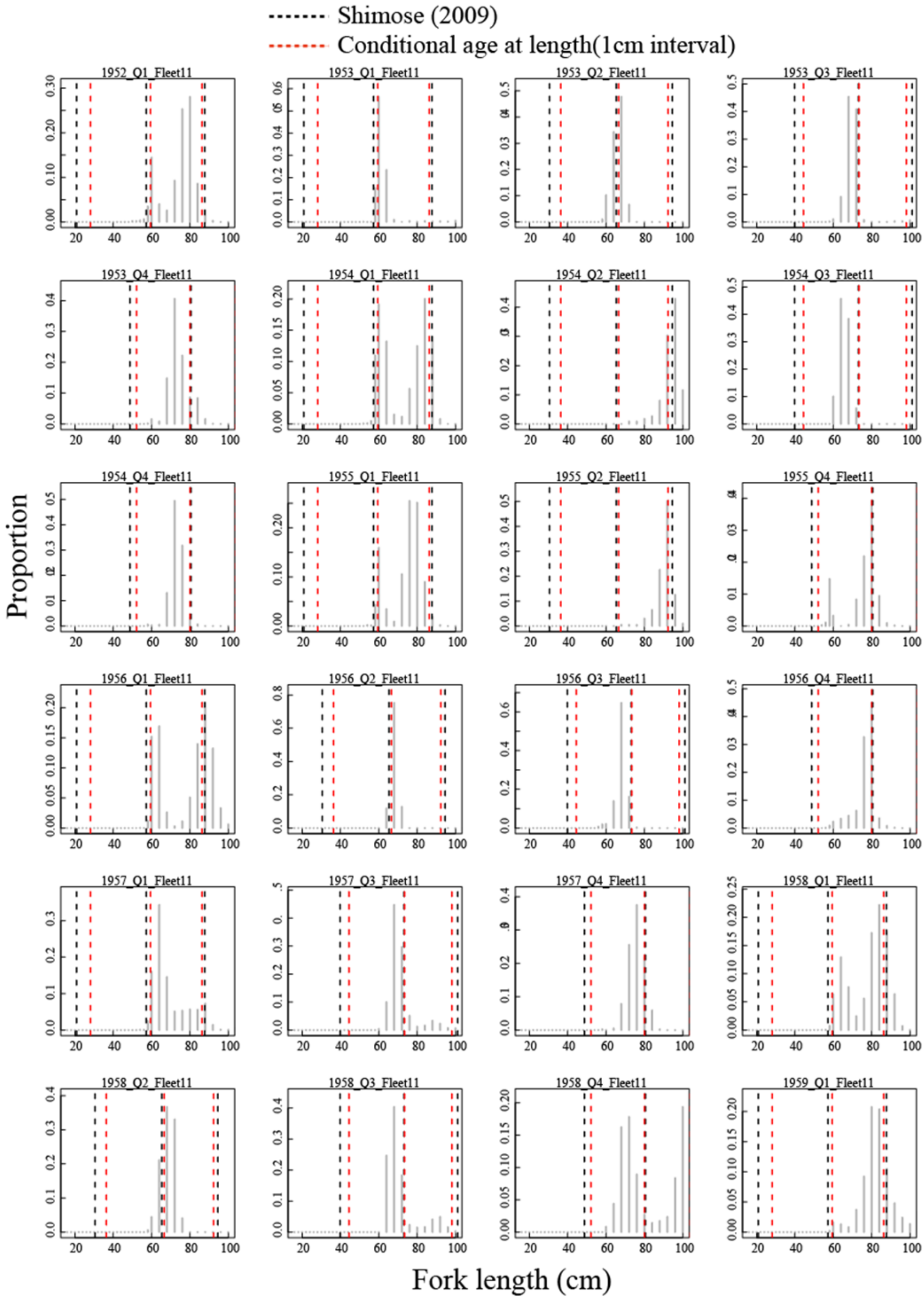


Figure A1. Length composition of PBF caught by EPO purse seine fishery from 1952 to 1959 and mean length at mid-season estimated by growth curves.

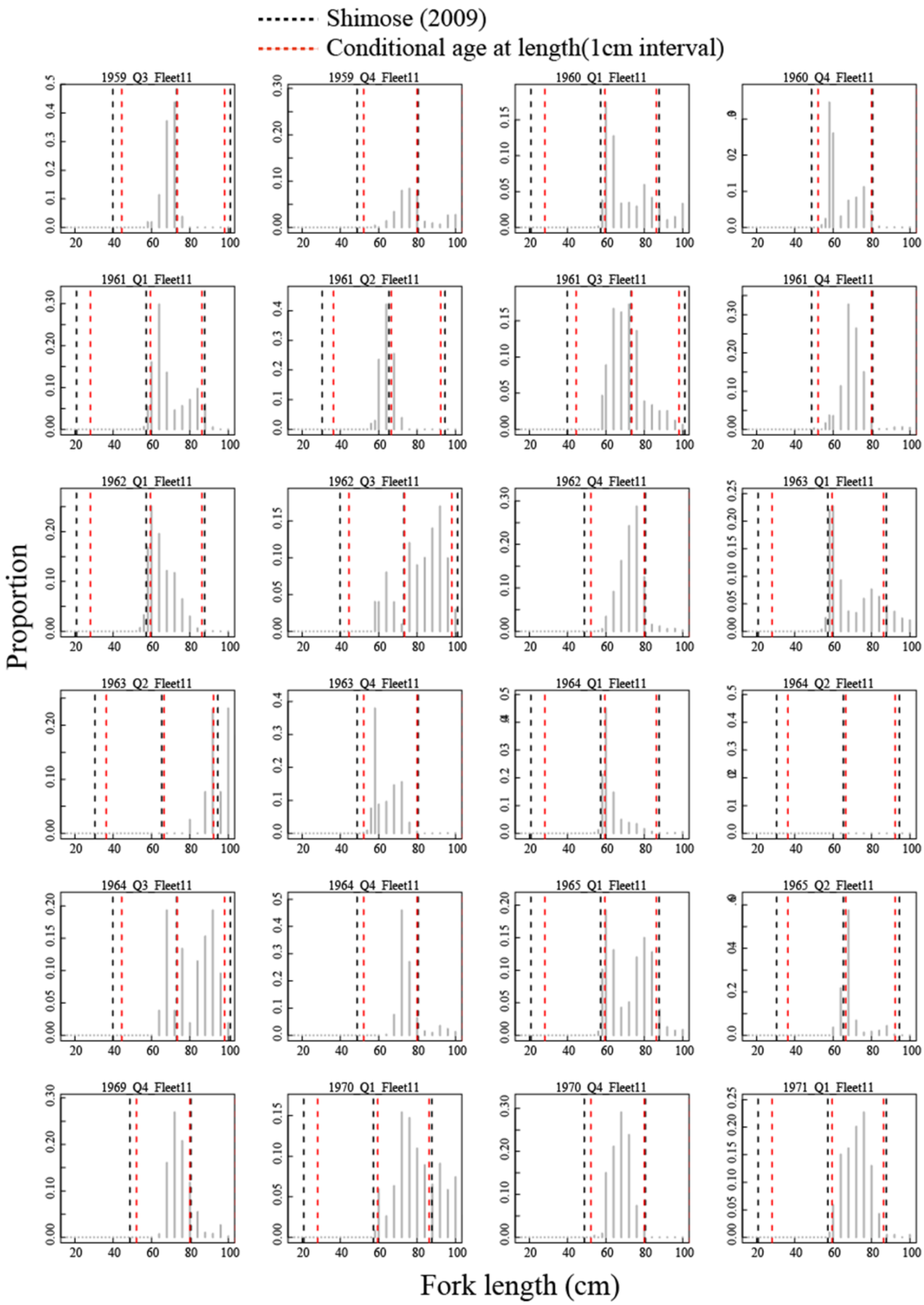
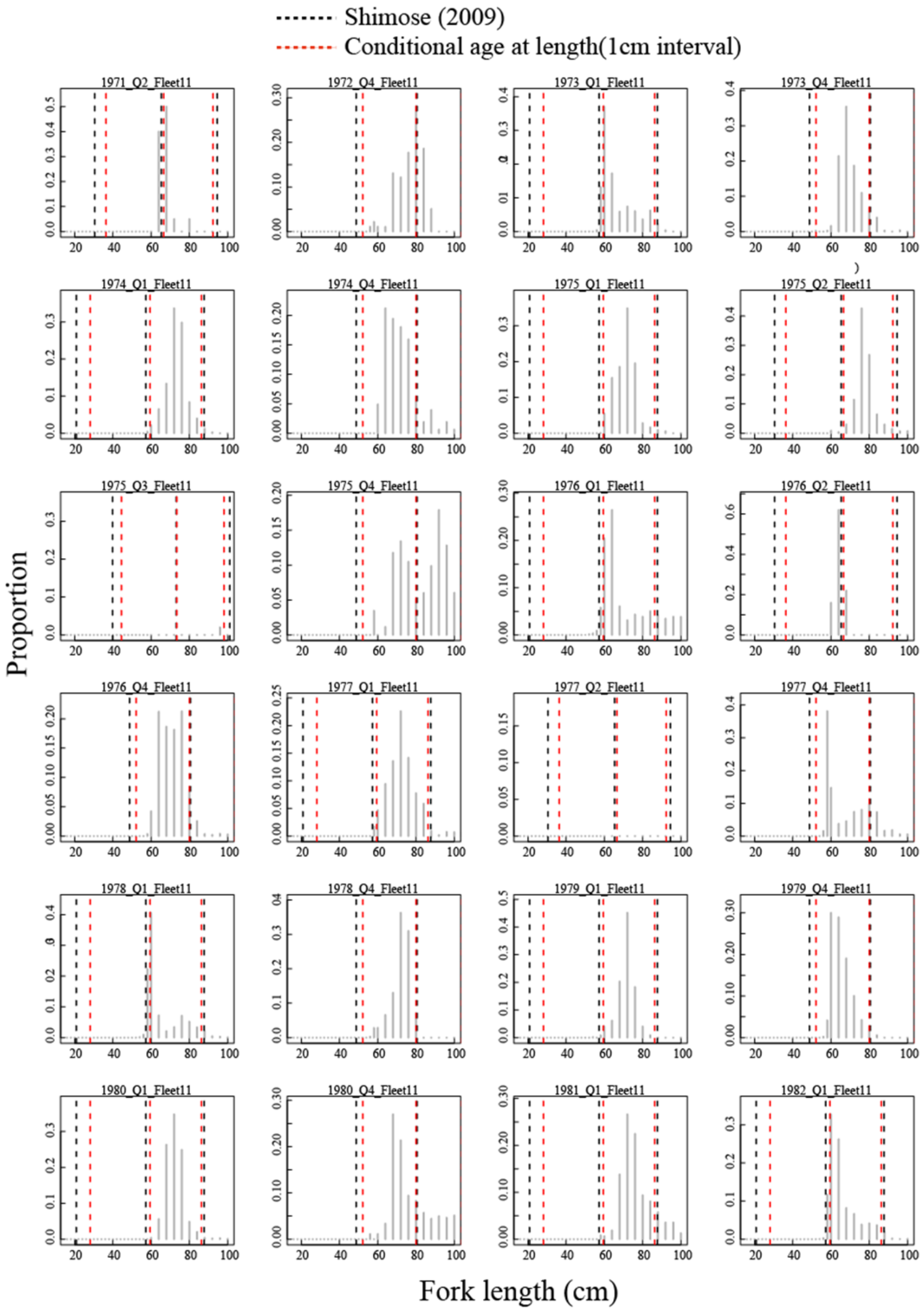
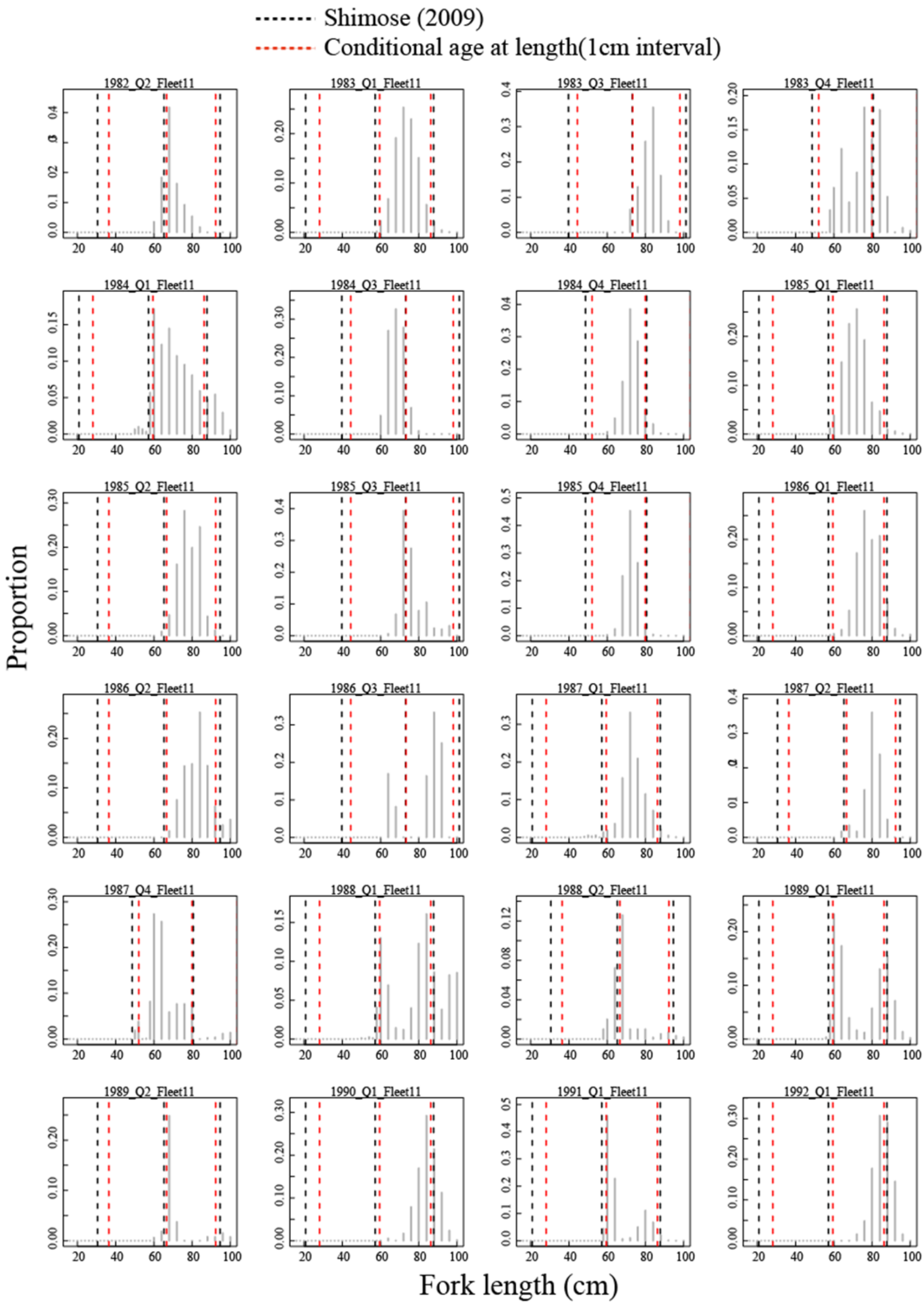


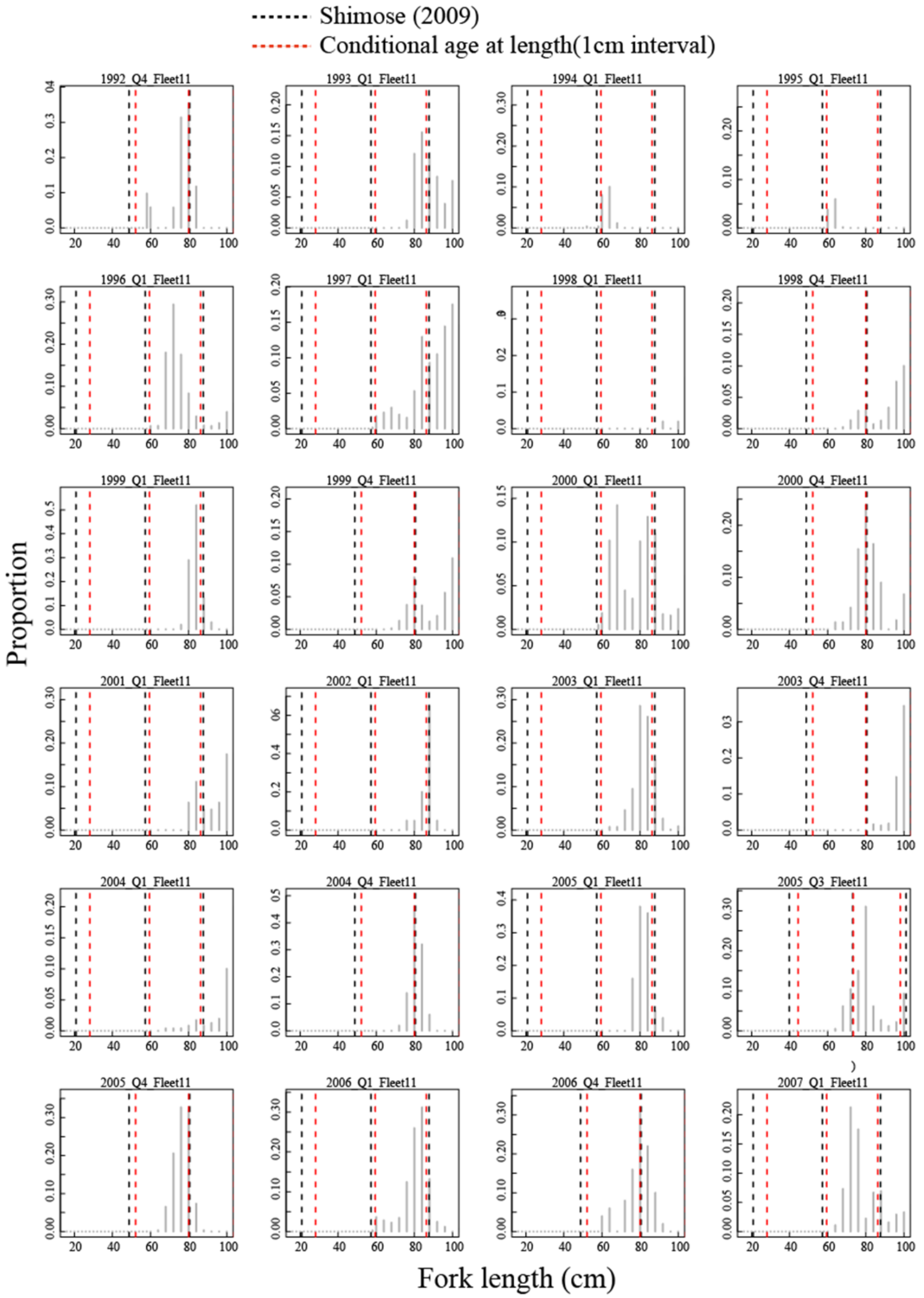
Figure A2. Length composition of PBF caught by EPO purse seine fishery from 1959 to 1971 and mean length at mid-season estimated by growth curves.



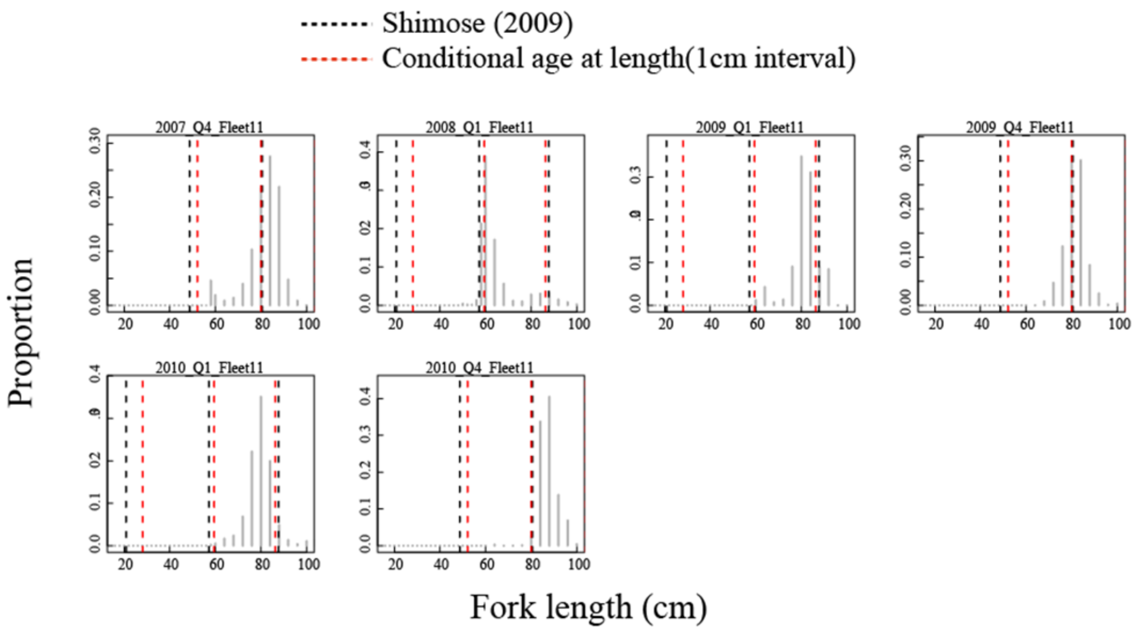
FigureA3. Length composition of PBF caught by EPO purse seine fishery from 1971 to 1982 and mean length at mid-season estimated by growth curves.



FigureA4. Length composition of PBF caught by EPO purse seine fishery from 1982 to 1992 and mean length at mid-season estimated by growth curves.



FigureA5. Length composition of PBF caught by EPO purse seine fishery from 1992 to 2007 and mean length at mid-season estimated by growth curves.



FigureA6. Length composition of PBF caught by EPO purse seine fishery from 2007 to 2010 and mean length at mid-season estimated by growth curves.