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Updated length frequency for Pacific Bluefin Tuna caught by Japanese set net with modified method

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Abstract

Due to the complex structure of catch and size data for the PBF caught by Japanese set-net, a modification of previous method was considered. We developed a new procedure, which could keep the assumption about the random sampling as much as possible while reducing the bias such as spikes of the length frequency. Appropriate data stratification and priority for the data aggregation were decided based on GLM analysis. In order to eliminate the spikes, the selection of strata was determined by sensitivity analysis. As a result, it is suggested that the strata with observation of more than 10 and coverage rate of more than 50% would be the best for the estimation of catch at size of this fishery.

1. Introduction

Integrated model stock synthesis needs catch at size by year, quarter and fishery, which is appropriately represent the size composition of catch. Because coverage rate of size data against to catch amount is generally low and has been varied spatially as well as temporary, estimation of catch at size should be needed at least by year, quarter and fishery. For Pacific bluefin tuna (PBF), there has been discussed about the procedure for the estimation of catch at size by each fishery (e.g. Ichinokawa, 2008; Kai and Takeuchi, 2012).

The procedure for the estimation of catch at size of PBF caught by Japanese set-net fishery has been discussed in the ISC PBF WG (Kai, 2011; Kai and Takeuchi, 2012), due to the complex structure of catch and size of this fishery. Set-net was placed throughout Japanese coastal line and PBF was caught in most of prefectures where this gear was conducted (Fig. 1). Thus it is hard to conduct the size sampling of PBF caught by this fishery randomly and comprehensively. Furthermore, the catch amount data of this fishery has been provided by the three kind of data sources which includes the different types of time, space and size information (see section 2.2). Because the size sampling have never conducted in all prefecture, at all month, and by all brand, when the catch at size in the strata with no or few size sampling are estimated, the substitution of length frequency should be need. Therefore the assumptions should be made to estimate the catch at size of this fishery.

The ideal procedure for the estimation of catch at size could keep the assumption about the random sampling, that is, to leave the feature of raw length frequency in lowest resolution, and reduce the bias such as the spike of length frequency at the same time. However, the procedure of previous method (Kai and Takeuchi, 2012) has some problems. For example, the feature of length frequency by brand, season, and year would not reflect directly due to the pooled size frequency, sometimes over size category and/or year used as substitutions when certain strata have no size measurement. Therefor the improved procedure was suggested in this study. In the process of estimation, the criterion of size (SML) was defined in order to classify the age (age-0: S, age1-2: M, over age 3: L) using the length measurement data collected in the prefectures other than Hokkaido and Aomori, because the most of size data was recorded as weight in these two prefectures. The final objective of this study is that the SML criteria is suggested as a definition of set-net fleet.

2. Materials and Methods

2.1. General description of procedure for the estimation of length frequency

2.1.1. Improvement point

Kai and Takeuchi (2012) provided the procedure of estimation catch at size for Japanese set-net. They stratified the data according to the results of generalized liner model (GLM) into prefecture, year, month, and brand name in principal. For the stratum without size sampling data, pooled data were used as the substitutes. Priority of substitution by factor was determined according to the result of GLM analysis.

The main problem of previous method was to be able to use the pooled length frequency over all information (year, quarter, size) except for prefecture or area when the strata have no size sampling. The utilization of pooling size frequency over the wide range of information, such as the pooling over year, tend to diminish the original feature of the size frequency. Thus the maximum stratum for pooling was decided in this study by taking account of the adequacy of the input data for stock assessment and the PBF biology. Each criterion and reason is shown in Table 1.

In addition to the above problem, the inequality substitution in previous study was re-considered. The space information was fixed as the prefecture or area at the first step of the analysis in the previous method (Kai and Takeuchi, 2012). If the prefecture was selected, the size frequency never be pooled over prefecture, even though the all size sampling data in the prefecture was pooled. However, it could be reasonable to use the length frequency collected in the adjacent prefectures at the same time and the same brand as the substitution. Therefore, the development procedure which equivalently use the different types of information (Size, Time and Space) is suggested in this study.

2.1.2. Steps of estimation

(1) When the both measurement and catch data contained observations in the minimum stratum (Prefecture/Year・Month/Brand), the minimum stratum was selected to estimate catch at size for the stratum, except few observations of measurement or low coverage rate.

(2) In the case other than explained above, the data was pooled by criteria including Size (Brand<SML), Time (Month<Quarter) and Space (Prefecture<Area). The order of pooling was decided by the GLM analysis and the maximum stratum was limited by SML/Area/Quarter. In this case, the stratum also for the estimation was selected except few observation of measurement or low coverage rate

(3) For the prefectures with no or few observations of measurement, the area pooled size frequency was used as the minimum area stratum instead of prefecture and estimated the catch at size as the same steps (1) and (2).

(4) The catch at size estimated by “RJB catch” and “RJB measure” was adjusted the catch amount of “SD report” in 1994-2007 and “JFA” in 2008-2013. Because the resolution of each catch data was different like year/month/prefecture for “JFA” and year/prefecture for “SD report”, the catch at size was aggregated to the minimum strata for each data source. “JFA” is provided as the more fine resolution than “SD report”, so the “JFA” was used after 2007 when the “JFA” could be available (See section 2.2.).

2.2. Data sources

Detailed description about the data sources for Japanese set-net fishery was provided by Kai and Takeuchi (2012). Thus a simple explanation is given here.

2.2.1. Catch data

Three different kind of data sources could be available for the catch data of this fishery such as **“RJB catch”**, **“JFA”** and **“SD report”** (Table 2). The available periods, special (prefectural) and temporal coverage and included information are varied by the data sources.

- ✓ **“RJB catch”**: The survey program “The Research of Japanese Bluefin tuna (RJB)” conducted by National Research Institute of Far Seas Fisheries (NRIFSF) have been started since 1992 and the data could be available from 1994. The catch amount of PBF based on sales slips at main landing ports around Japan since 1994. Year, month, date, prefecture, landed port, brand name, product status (e.g. round or gilled and gutted), fishing gear, fishing area, catch in weight and catch in number (if available) data are included in the database.
- ✓ **“JFA”**: Monthly catch data by landing ports, derived from the Survey on Catch of Bluefin Tuna in Japan’s Coastal Areas implemented by Japan Forestry and Fisheries, the government of Japan. The data including the information on year, month, fishing gear and landed port could be available from 2008.
- ✓ **“SD report”**: The Annual Report of Catch Statistics on Fishery and Aquaculture published by the Statistics Department, Ministry of Agriculture, Forestry and Fisheries, the government of Japan (SD report, formerly referred to as “SID report”). The available information such as time (monthly or yearly), space (prefectual or national), size (nothing or including) and fishing category (separated by large-scale, small scale and salmon set-net or only large-scale set-net) was different by recorded year. Therefore the annual catch by prefecture was estimated by available information. The procedure for estimation was described by Kai (2007a) and Kai and Takeuchi (2012).

2.2.2. Size sampling data

The size sampling data has been provided by “**RJB measure**” database since 1992 and available since 1994 (Table 3). As “RJB catch”, this data could be available from 1994. This data contains fork length (FL) by 1cm intervals and/or body weight (BW) of either 1 kg or 0.1 kg precision. The data consists of length, and/or weight for each fish. The fish only weight or length is converted to length by the equation of length-weight relationships (Kai, 2007b).

2.3. Stratification of the data

2.3.1. Size information (Brand < SML)

Brand name is the most accurate information to indicate the size of fish. However, the definition of the brand name and also the variety of brand names has been differed by prefecture. In addition, the variety of brand name has not been much less likely to match between catch data and size measurement data even though the same month and prefecture from RJB database. Moreover, one of the purpose in this study is to provide the catch at size by size category corresponding to the age category. Thus the all brand names were classified into three size categories based on age-class as S (age 0), M (age 1-2) and L (over age 3) as following steps;

(1) Intervals of each size category were defined by quarterly pooled size frequency (1 cm bin) of "RJB measure". The lowest bin between age 0 and age 1 (approximately 40-60 cm), age 3 and age 4 (approximately 100-130 cm) was selected as the boundary of size category (Fig. 2). Because the boundary size of each age should move upward within the year, the interval of each size category was defined by quarter.

(2) The median of FL was estimated by "RJB measure" by month, prefecture and brand name. The brand name of each stratum recorded by "RJB measure" were classified into size category (SML) by matching the quarterly size definition and the median of FL.

(3) The brand names of each stratum (month/prefecture) of "RJB catch" were classified into size category when the same brand name was existing in the same stratum in "RJB measure".

(4) When the same brand name was not existing in the same stratum, the median of FL was estimated by "RJB measure" by quarter or year, prefecture and brand name, then the brand names of "RJB catch" were classified into the size category when the same brand name were existing in the same stratum (quarter/prefecture or year/prefecture) in "RJB catch".

(5) When "RJB catch" included the brand names which were only recorded in "RJB catch", the defined size category of similar brand name in the same prefecture was referred to decide the size category of those brand names.

2.3.2. Time information (Month < Quarter < Year)

Although the size sampling data has been recorded on a daily, the daily catch data could be provided by only recent "RJB catch". Thus the minimum stratum for the time information was defined as month.

2.3.3. Space information (Prefecture < Area)

All data sources in this study could be available prefectural catch and size data over the entire period. However the observation number of size sampling was differ among the prefectures (Table 2). In order to complement the size sampling data for the prefectures with the missing or few observation (the total number of sampling was less than 200 individuals in 20 years; Table 3), appropriate area definition was needed. Thus the area was defined as follows;

(1) The tentative catch at size was roughly estimated with year/quarter/size/prefecture strata by "RJB catch" and "RJB measure" without the extrapolating using the substitution.

(2) The prefectures of tentative catch at size were assigned the number as the position order from Iwate prefecture to Yamagata prefecture as circle the Honshu, Shikoku and Kyusyu Islands (Fig. 3).

(3) The following GLM was made and the AIC value was estimated by the tentative catch at size.

$$\text{Log (FL)} = \text{(Intercept)} + \text{(Year)} + \text{(Quarter)} + \text{(Prefecture)} + \text{error}, \ \text{error} \sim N(0, \theta^2)$$

(4) The tentative catch at size by prefecture was combined with a neighboring prefecture one by one and the AIC value was estimated for all combination. The combination with lowest AIC was selected, subsequently the same step was repeated until the all prefectures was combined.

(5) The area was decided in the view of the AIC value and the positions of boundary.

2.4. Determination of appropriate order for the data pooling

The order for the data pooling was decided by GLM. The seven models changed the criteria of size (Brand<SML), time (Month<Quarter) and space (Prefecture<Area) were considered to evaluate the impact of pooling. The order of pooling strata was decided by the AIC value of each model in the order of lowest to highest. The GLMs in this analysis are as follows;

- ✓ One of three criteria pooled model
  - M1: Log (FL) = (Intercept) + (SML) + (Month) + (Prefecture) + error
  - M2: Log (FL) = (Intercept) + (Brand) + (Quarter) + (Prefecture) + error
  - M3: Log (FL) = (Intercept) + (Brand) + (Month) + (Area) + error
- ✓ Two of three criteria pooled model
  - M4: Log (FL) = (Intercept) + (SML) + (Quarter) + (Prefecture) + error
  - M5: Log (FL) = (Intercept) + (SML) + (Month) + (Area) + error
  - M6: Log (FL) = (Intercept) + (Brand) + (Quarter) + (Area) + error
- ✓ All criteria pooled model
  - M7: Log (FL) = (Intercept) + (SML) + (Quarter) + (Area) + error

For all models, error~N $(0, \theta^2)$

2.5. Sensitivity analysis

The fine scale strata could be provide the catch at size sufficiently reflect the size frequency of landing catch when the number of size sampling were adequate. However, the finer scale strata was used, the lower number of size sampling would be used for the estimation. When the several number of observation were used to estimate the large amount of catch, the spike of size frequency would be produced. In order to consider the appropriate criteria of the lowest number of observation and the cover rate for each strata, the three scenario of the different criteria were considered in this study. The scenarios are shown in Table 4. The combination of lowest observation and cover rate were considered as the criteria whether the pooling size frequency should be used in the stratum or not.

3. Results

3.1. Size definition

Quarterly size frequency of raw size data are shown in Fig. 2. Each brand was classified into the size category (SML) by following definitions;

Quarter 1; S: median FL < 64.0, M: 64.0 <= median FL < 119.0, L: 119.0 <= median FL,

Quarter 2; S: median FL < 41.0, M: 41.0 <= median FL < 101.0, L: 101.0 <= median FL,

Quarter 3; S: median FL < 46.0, M: 46.0 <= median FL < 107.0, L: 107.0 <= median FL,

Quarter 4; S: median FL < 62.0, M: 62.0 <= median FL < 114.0, L: 114.0 <= median FL.

Fig.3 shows the accumulated size frequency by SML category and quarter for “RJB measure”. In quarter 1, the size frequency of S includes up to 64cm FL which should be categorized into M. However, in other quarter, the size frequencies of SML category were relatively less overlap.

3.2. Area definition

For the GLM analysis of area stratification, the tentative catch at size based on “RJB measure” and “RJB catch” was utilized. Thus, 12 prefectures with adequate size sampling were only defined the area (Table 5). The five area stratification (Step 9) was selected in this study (Fig. 1), because the four area stratification (Step 10) includes the extremely wide area (from Kanagawa prefecture to Yamaguchi prefecture) and six area stratification (Step 8) includes single prefecture (Kanagawa prefecture and Mie prefecture).

As not all prefectures were classified into area, vacant regions between Miyagi prefecture and Kanagawa prefecture, and also Yamaguchi prefecture and Ishikawa prefecture, where the boundary should be decided, were existed. The boundary between Miyagi prefecture and Kanagawa prefecture was decided in between Ibaragi prefecture and Chiba prefecture in consideration of the geographical features, and this boundary was corresponding to previous study (Kai and Takeuchi, 2012). The boundary between Fukui prefecture and Ishikawa prefecture was also decided by the geographical features of Toyama bay, because the most of PBF catch in Ishikawa prefecture has been landed along to the Toyama bay according to “RJB catch”. Thus it is suggested that Ishikawa prefecture and Toyama prefecture would have similar pattern, while the Fukui prefecture and Ishikawa prefecture would have different catch pattern. As a result, the five area were applied to estimation of catch at size.

3.3. Appropriate order for the data pooling

The result indicates that the model include the explanatory variable of Brand name shown the lower AIC values than SML category (Table 6). Within the models with the same Size information (Brand or SML), Time information (Month or Quarter) influenced the AIC values more than Space information (Prefecture and Area). The impact of each information was suggested as Size > Time > Space. Consequently, the order for data pooling was decided as follows;

Brand/Month/Prefecture < Brand/Month/Area <Brand/Quarter/Prefecture < Brand/Quarter/Area< SML/Month/Prefecture < SML/Month/Area < SML/Quarter/Prefecture < SML/Quarter/Area.

These eight strata were used to estimate the catch at size in this order.

3.4. Sensitivity analysis

The three scenarios which changed criteria for the utilization of strata was conducted. The results of size frequency by quarter are not shown remarkable difference among the scenarios (Fig. 4), but those by year and quarter, which is used as input file for stock assessment, indicate differences in several cases (Fig. 5). Because the scenario 1 could be use the size frequency data as a substitution even though the number of observation was one fish, the size frequency tend to show the spike. Some spikes found in Scenario 1, but in Scenario 3, for example size frequency in 1994 at quarter 4 and in 2003 at quarter 2. For Scenario 2, those spikes were existed.

Comparison of the pecentage (%) of estimated catch amount of length frequency against to total RJB catch amount by senario and estimation step were shown in Table 7. The percentage of estimated catch by steps were not largely different among scenarios. For all scenarios, the percentage of accumulated estimated catch by step 4, which is estimated by the substitution using Brand name, were extremely low (less than 3%). Final amount of estimated catch were not remarkably different as well, and the scenario 3 more than 90 %.

4. Discussions

In this study, we developed the modified estimation method for the catch at size of PBF caught by Japanese set-net. The new method could solve the problems of previous method due to apply the maximum strata for the data pooling. In addition, the modified method could reduce the bias of estimation by analyzing the three kind of information (Size, Time and Space) equally as much as possible and applying the criteria for the decision which substitution should be used.

It is considered that the result of scenario 3 would be appropriate for the catch at size for Japanese set-net fishery. The criteria of scenario 3 (observation >10, coverage rate > 50%) could eliminate of bias and estimate the catch as size over 90% of catch amount (Table 7). Even though the scenario 1 (observation > 0, coverage rate > 0%) was applied, about 4 % of catch amount could not estimate the size frequency because the size sampling were not conducted in maximum stratum, that is, in the same size category (SML), quarter and area. Although about 9 % of catch amount could not estimate the size frequency by scenario 3, the estimation of catch at size for those less information strata would be possible to produce the serious biases. Consequently, it is suggested that the scenario 3 would be the best method for the estimation of catch at size of this fishery.

The modified method has the advantage as the input data for the stock assessment model. Because the size frequency and catch amount could be provided by size category (SML), as well as year and quarter, this size category could be used as a definition of set-net fleet. The fleet definition of set-net have been decided by area and quarter in the stock assessment in 2014 (ISC, 2014), however, this fleet definition include several age classes despite the definition of area and quarter was decided to divide the age class as much as possible. This method could provide the catch at size by relatively accurate size category based on age category at least the period after 1993. Therefore the size category (SML) could be suggested as the new fleet definition for the upcoming stock assessment.

5. Reference

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Table 1 The maximum strata for the pooling and the reasons.

Type of information	Abailabe criteria	Maximum strata	Reason
Size	Brand < SML*	S/M/L	S/M/L indicates the representative of each age category
Time	Month < Quarter < Year	Quarter	Annual and sasonal difference of size frequency are needed to be remain for the input data for the stock assessment
Space	Prefecture < Area**	Area	The size frequency of age 0 have the different size frequency between the fish spawned in the Pacific Ocean and Japan sea, which depends on the area.

* : The criterion is defined in section 2.3.1.

** : The criterion is defined in section 2.3.3.

Table2 Total catch amount (t) by year, prefecture and data sources and the minimum strata of spcae information (Prefecture or Area). .

(A) RJB catch

		3	4	6	7	8	14	15	16	17	22	24	30	31	32	35	38	39	42	45	46	47
RJB catch	1994	103.0	20.1	0.5	0.0	0.0	4.8	161.8	73.1	0.0	0.0	5.7	0.6	0.4	19.0	0.8	0.1	3.3	0.0	0.0	1.1	0.0
	1995	499.8	100.0	0.0	0.0	0.0	34.8	139.8	90.6	127.7	0.0	2.3	1.4	0.2	37.2	8.4	0.2	6.7	0.0	0.0	2.3	0.0
	1996	116.8	56.0	0.1	0.0	0.0	11.9	80.9	86.5	80.6	3.7	2.4	2.1	0.0	16.2	4.3	0.3	6.3	4.9	0.0	2.6	0.0
	1997	89.9	38.6	0.2	0.0	0.0	7.8	45.0	40.9	77.8	0.7	1.4	4.7	0.0	25.1	0.4	2.4	8.1	17.3	0.0	7.2	0.0
	1998	60.4	22.3	0.0	0.0	0.0	25.7	140.6	45.7	103.0	5.0	5.3	1.8	0.0	9.9	0.3	0.2	2.8	0.0	0.0	1.4	0.0
	1999	66.6	33.8	0.0	0.0	0.0	4.5	111.8	95.4	130.4	1.1	1.0	1.2	0.0	8.9	0.0	0.5	3.7	0.0	0.1	2.0	0.0
	2000	162.9	121.6	0.0	0.0	0.0	19.3	54.3	205.9	113.8	1.6	3.2	6.2	0.0	19.6	0.2	0.4	5.8	0.0	0.0	1.0	0.0
	2001	146.7	63.2	0.0	0.0	59.5	12.9	52.9	161.4	102.2	2.8	6.9	2.8	0.0	5.4	6.4	1.0	2.9	0.0	0.2	1.2	0.0
	2002	68.6	105.6	0.0	0.1	18.1	15.0	30.3	79.9	103.9	9.6	6.5	1.5	0.0	3.0	0.6	1.5	5.8	0.0	0.3	0.9	0.0
	2003	56.3	41.3	0.0	0.0	9.7	4.7	65.2	66.7	30.4	8.1	5.0	1.0	0.0	2.1	0.4	0.5	5.4	0.0	0.8	0.3	0.0
	2004	91.3	65.2	0.0	0.0	1.7	3.3	130.4	114.9	74.8	2.1	6.0	2.8	0.0	2.2	2.5	0.4	2.0	0.0	1.0	0.9	6.6
	2005	124.6	115.6	0.0	0.0	8.8	16.7	336.0	133.3	87.0	10.2	31.4	6.3	0.0	111.2	6.8	0.8	20.5	0.0	3.5	0.9	5.4
	2006	189.8	189.9	0.0	0.2	0.0	6.7	159.5	171.1	98.4	7.9	6.9	2.8	0.0	4.8	3.8	0.3	4.5	0.0	0.6	1.8	3.2
	2007	114.3	54.5	0.0	0.1	0.0	30.7	102.1	262.4	119.5	23.3	13.2	5.7	0.0	2.8	2.2	0.2	2.1	0.0	0.3	1.0	0.0
	2008	254.8	232.8	0.0	0.0	0.0	38.0	318.6	413.8	298.5	19.8	14.8	2.1	0.0	25.4	31.2	0.8	4.1	0.0	0.1	1.2	0.0
	2009	245.0	220.8	0.0	0.3	0.0	4.6	293.3	230.7	138.4	4.7	9.0	4.8	0.0	17.8	20.6	0.5	4.4	0.0	0.3	9.4	0.0
	2010	145.1	114.4	0.0	0.0	0.0	20.7	226.1	160.5	158.7	20.1	7.4	2.3	0.0	26.6	20.8	0.2	3.2	0.0	0.0	2.1	0.1
	2011	55.7	2.1	0.0	0.0	0.0	31.1	194.5	194.5	100.1	15.1	12.2	5.8	0.0	16.0	10.4	0.3	5.8	0.0	0.5	3.0	0.2
	2012	115.2	108.9	0.0	0.0	0.0	22.7	213.7	128.4	148.0	8.9	9.3	4.0	0.0	42.4	23.1	0.4	8.6	0.0	2.7	4.0	0.0
	2013	153.9	124.1	0.0	0.0	0.0	2.9	96.2	73.8	61.6	3.1	11.0	2.7	0.0	11.8	15.0	0.0	3.0	0.0	1.4	9.1	0.1
Strata		P	P	A	A	A	P	P	P	P	A	P	P	A	A	P	P	A	A	A	P	A

Table 2 Continued

(B) JFA

		3	4	5	6	7	8	12	13	14	15	16	17	18	22	24	26	28	30	31	32	35	36	38	39	40	41	42	43	44	45	46	47
	2008	288.2	231.0	0.0	0.0	0.0	0.0	27.9	0.0	41.8	291.8	357.4	276.5	36.6	19.5	13.8	0.0	0.0	12.1	0.0	51.1	34.2	0.0	0.2	3.6	0.0	0.9	61.9	0.0	0.0	0.4	15.5	0.0
	2009	264.0	218.0	0.0	0.0	0.3	0.0	12.1	0.0	3.6	279.7	170.9	135.6	44.4	5.8	31.2	0.0	0.0	9.0	0.0	89.2	41.3	0.0	0.4	7.3	0.0	3.5	98.4	0.0	0.0	0.0	39.2	0.0
JFA	2010	146.5	114.3	0.6	1.1	0.0	0.4	20.3	0.6	20.6	227.1	160.5	157.1	51.7	21.0	6.8	35.0	0.5	11.5	1.0	47.5	20.0	0.0	0.1	6.1	0.1	0.2	53.9	0.2	0.0	0.1	9.2	0.0
	2011	6.7	2.1	28.9	1.3	0.0	0.1	18.8	1.9	29.5	177.3	194.5	100.1	24.4	15.1	12.2	32.7	1.6	20.2	4.0	28.2	10.2	3.0	0.2	15.6	0.0	0.5	70.9	2.2	1.4	0.1	11.0	0.0
	2012	129.3	108.9	40.6	0.2	0.0	0.8	8.1	0.4	22.7	166.9	128.4	148.0	33.2	9.1	9.3	64.1	3.0	17.7	1.6	58.6	23.3	2.8	0.1	21.3	2.2	4.8	85.4	0.8	1.2	0.0	18.0	0.0
	2013	153.3	124.1	4.8	0.7	0.0	2.4	7.4	2.5	2.6	118.4	73.8	61.6	26.9	4.2	11.0	43.6	2.7	17.0	0.1	19.9	25.2	9.4	4.4	32.6	1.0	1.4	110.6	1.5	5.7	2.6	41.6	0.0
Strata		P	P	A	A	A	A	A	A	P	P	P	P	A	A	P	A	A	P	A	A	P	A	P	A	A	A	A	A	A	A	P	A

(C) SD report

		3	4	5	6	7	8	12	13	14	15	16	17	18	22	24	26	28	30	31	32	35	36	38	39	40	41	42	43	44	45	46	47
	1994	104.0	19.0	3.0	0.7	1.0	6.8	17.0	0.0	2.0	200.0	109.0	272.0	80.0	4.0	28.0	118.0	5.0	0.0	0.0	63.2	2.0	0.5	0.0	8.9	0.0	0.0	21.3	0.0	0.0	0.0	10.0	0.0
	1995	539.0	87.0	5.0	0.0	13.0	17.3	0.0	0.0	42.2	147.0	120.0	170.0	41.9	19.5	12.7	33.0	4.0	4.6	0.0	97.9	34.7	0.0	0.0	5.6	0.0	0.0	15.3	0.0	0.0	0.0	8.8	0.0
	1996	129.0	51.0	3.0	0.0	2.0	6.8	0.0	2.8	21.0	92.0	158.0	115.0	42.0	37.9	22.8	50.0	4.0	9.8	0.0	83.2	12.9	2.0	0.0	24.7	0.0	1.0	0.0	0.0	0.0	0.0	11.3	0.0
	1997	110.0	39.6	1.0	0.0	3.0	0.0	10.5	1.1	0.0	55.0	78.0	77.3	41.4	8.3	12.0	20.8	8.0	10.3	0.0	107.4	34.7	0.0	0.0	55.5	0.0	1.0	30.3	0.0	11.0	1.0	7.2	0.0
	1998	75.0	23.0	14.0	0.0	2.0	3.8	34.4	1.7	33.0	149.0	81.0	125.0	29.0	22.0	22.5	31.6	0.0	8.8	0.0	46.8	9.9	1.0	0.0	12.7	0.0	1.0	17.2	0.0	10.0	0.0	7.2	0.0
	1999	95.0	33.0	13.0	0.7	0.0	2.3	48.0	0.6	1.3	140.0	106.0	151.3	222.9	4.0	6.0	51.3	3.0	14.3	0.0	61.5	7.9	1.0	0.0	14.9	0.0	2.0	11.6	0.0	0.0	1.0	9.5	0.0
	2000	201.0	114.0	8.0	0.0	0.0	0.0	26.4	1.0	24.0	0.0	203.0	140.0	60.0	10.0	14.9	43.3	4.0	18.4	0.0	20.5	39.6	2.0	0.0	27.8	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0
	2001	170.0	48.3	15.0	0.0	0.0	0.0	14.0	0.5	5.5	77.0	314.0	107.1	29.7	8.0	7.5	20.4	5.0	18.3	0.0	13.7	27.7	2.0	0.0	20.0	0.0	0.0	4.2	1.0	0.0	2.0	2.8	0.0
	2002	89.0	76.0	3.0	0.0	0.0	0.0	18.0	0.0	0.0	0.0	111.0	99.0	0.0	24.6	18.0	21.8	1.0	2.0	0.0	17.2	37.7	1.0	0.0	69.2	1.0	0.0	4.5	0.0	0.0	2.0	12.0	0.0
SD report	2003	0.0	36.2	5.7	0.0	0.0	0.0	13.4	0.0	3.9	63.8	53.8	30.3	6.0	9.1	11.5	13.4	0.0	7.3	0.0	0.0	0.0	0.0	0.0	30.6	0.0	0.0	124.2	0.0	0.0	2.0	11.9	0.8
	2004	108.3	61.9	7.8	1.0	0.0	0.0	2.0	0.0	3.1	155.8	95.1	84.5	22.5	5.0	15.8	0.0	0.0	12.8	0.0	0.0	0.0	0.0	0.0	19.8	0.0	0.0	84.6	0.0	0.0	3.0	12.9	0.8
	2005	247.7	34.9	12.3	1.6	0.0	0.0	47.6	0.0	28.6	123.9	231.8	146.1	57.2	50.8	109.6	0.0	0.0	63.5	0.0	0.0	0.0	0.0	0.0	166.7	0.0	0.0	330.3	0.0	0.0	4.8	49.2	4.8
	2006	141.0	54.2	0.0	0.0	0.0	0.0	17.4	0.0	11.9	100.9	174.6	192.0	24.9	19.5	39.1	18.4	0.0	7.6	0.0	0.0	3.3	0.0	0.0	24.9	0.0	0.0	48.8	0.0	0.0	1.1	3.3	0.0
	2007	149.2	57.4	0.0	0.0	0.0	0.0	18.4	0.0	12.6	106.7	184.7	203.1	26.4	20.7	41.3	19.5	0.0	8.0	0.0	0.0	3.4	0.0	0.0	26.4	0.0	0.0	51.6	0.0	0.0	1.1	3.4	0.0
	2008	367.5	252.3	0.0	0.0	0.0	0.0	42.6	0.0	32.3	399.7	42.6	327.1	46.1	26.5	24.2	109.4	0.0	13.8	0.0	0.0	19.6	0.0	0.0	36.9	0.0	0.0	81.8	0.0	0.0	5.8	8.1	0.0
	2009	307.2	256.5	42.9	0.0	0.0	0.0	18.7	0.0	5.5	383.1	15.4	178.4	49.5	7.7	17.6	110.1	11.0	4.4	0.0	87.0	19.8	0.0	0.0	45.1	0.0	0.0	90.3	0.0	0.0	1.1	19.8	0.0
	2010	171.0	119.5	11.0	0.0	0.0	0.0	41.7	0.0	12.1	261.0	66.9	179.8	81.1	28.5	29.6	99.8	8.8	11.0	0.0	54.8	19.7	0.0	0.0	28.5	0.0	0.0	59.2	0.0	0.0	2.2	9.9	0.0
	2011	68.7	160.8	38.8	0.0	0.0	0.0	27.7	0.0	45.5	290.5	65.4	122.0	47.7	22.2	42.1	36.6	2.2	14.4	0.0	35.5	7.8	0.0	0.0	33.3	0.0	0.0	75.4	0.0	0.0	0.0	10.0	0.0
	2012	83.8	112.8	44.7	0.0	0.0	0.0	12.3	0.0	29.0	260.2	129.5	166.4	61.4	14.5	23.5	67.0	3.4	15.6	0.0	55.8	16.8	0.0	0.0	36.9	0.0	0.0	118.4	0.0	0.0	1.1	16.8	0.0
Strata		P	P	A	A	A	A	A	A	P	P	P	P	A	A	P	A	A	P	A	A	P	A	P	A	A	A	A	A	A	A	P	A

Table 3 Total number of size sampling data by year, prefecture and quality (measured by weight, length or both) and the minimum strata of spcae information (Prefecture or Area).

		1	2	3	4	6	8	12	14	15	16	17	22	24	30	31	32	35	38	39	46
Number of weight alone	1994	0	1559	0	0	0	0	0	0	0	0	0	0	0	1	13	0	0	0	0	3
	1995	2	17860	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
	1996	0	4652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
	1997	0	1302	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
	1998	0	2604	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
	1999	141	6442	0	0	0	0	0	0	21	2	0	0	0	47	0	0	0	0	0	0
	2000	229	5739	0	0	0	0	0	0	4	0	0	0	0	51	0	35	0	0	0	0
	2001	2840	7679	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0
	2002	2965	4036	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	2003	390	11094	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2004	127	4295	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2005	1409	13254	0	0	0	0	0	0	1431	0	0	0	0	0	0	0	0	0	0	0
	2006	137	12162	0	0	0	0	0	0	479	0	0	0	0	0	0	0	0	0	0	0
	2007	75	11428	0	0	0	0	0	0	733	0	0	0	0	0	0	0	0	0	0	0
	2008	288	19277	0	0	0	0	0	0	3633	4	0	0	0	0	0	0	0	0	0	0
	2009	877	7670	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
	2010	62	0	0	0	0	0	0	0	2576	0	7	0	0	0	0	0	0	0	0	0
	2011	169	2	0	0	0	0	0	0	1609	0	0	0	0	0	0	0	0	0	0	0
	2012	129	3	0	0	0	0	0	0	2843	1	334	0	0	0	0	0	0	0	0	1
	2013	158	0	0	0	0	0	0	0	1522	33	81	0	0	0	0	0	0	0	0	1
Number of length alone	1994	40	0	316	702	134	0	0	0	0	1552	0	0	0	4	0	0	0	0	0	0
	1995	61	0	1929	2321	0	0	0	0	0	709	0	0	0	47	0	0	0	0	0	1
	1996	18	0	1028	1637	0	0	0	0	0	183	0	0	0	3	0	0	0	0	0	0
	1997	0	0	670	1186	0	0	0	99	0	420	0	0	0	118	0	0	0	0	0	0
	1998	0	0	763	1080	0	0	0	2	0	1327	0	0	58	0	0	1	0	0	0	0
	1999	0	0	0	1037	0	0	0	0	0	1922	0	0	2	34	0	0	0	0	0	0
	2000	0	0	0	3299	0	0	0	1	0	2014	0	0	0	7	0	0	0	0	0	0
	2001	0	0	0	997	0	13	0	15	0	756	0	0	59	0	0	0	0	0	0	0
	2002	0	0	0	2498	0	0	0	4	0	527	0	0	0	0	0	0	0	0	0	0
	2003	0	0	0	1254	0	0	0	38	0	1026	0	0	53	0	0	0	0	0	0	0
	2004	0	0	0	845	0	0	0	21	0	1423	0	0	88	11	0	0	0	0	0	0
	2005	0	0	0	0	0	0	0	0	0	1384	0	0	894	9	0	0	0	0	0	0
	2006	0	0	0	228	0	0	0	3	0	1943	0	0	177	87	0	0	0	0	0	0
	2007	0	0	15	0	0	0	0	305	0	1340	0	0	206	0	0	0	0	0	0	0
	2008	0	0	0	168	0	0	0	89	0	929	0	0	198	0	0	0	265	0	0	0
	2009	0	0	1	177	0	0	0	41	0	432	0	0	24	0	0	0	163	0	0	0
	2010	0	0	0	105	0	0	6	73	0	1895	593	0	162	0	0	0	0	0	0	0
	2011	0	0	0	0	0	0	0	197	0	37	38	0	161	0	0	0	0	0	0	2
	2012	0	0	0	242	0	0	0	18	0	2207	563	0	49	0	0	0	0	0	0	0
	2013	0	0	86	116	0	0	0	3	0	1310	568	0	14	0	0	0	0	0	0	0
Number of both length and weight	1994	212	0	119	158	1	0	0	15	759	236	0	0	0	4	0	0	33	3	0	10
	1995	209	0	191	87	0	0	0	16	3283	275	0	0	0	3	0	0	181	0	0	42
	1996	48	0	136	297	4	0	0	2	1426	82	0	0	0	1	0	0	75	3	0	12
	1997	34	0	86	216	44	0	0	184	1185	61	0	0	4	11	0	0	30	2	0	33
	1998	0	0	157	157	1	0	0	47	521	367	0	0	0	6	0	11	17	2	0	0
	1999	0	0	1010	118	0	0	0	50	834	233	0	0	0	1	0	0	0	0	0	0
	2000	119	0	1698	369	0	0	0	25	973	145	0	0	12	11	0	0	20	0	0	0
	2001	146	0	1096	251	0	0	0	40	908	98	0	4	14	9	0	0	55	1	0	0
	2002	157	0	1083	509	0	0	0	16	451	0	0	0	0	0	0	0	15	23	0	0
	2003	72	0	900	240	0	0	0	11	565	0	0	0	10	0	11	0	36	4	0	0
	2004	4	2	610	809	0	0	0	1	881	1	0	0	49	1	0	0	46	0	0	0
	2005	0	19	1018	1419	0	0	0	3	1481	15	0	0	67	12	0	0	149	148	47	0
	2006	4	63	2551	836	0	0	0	3	972	44	0	0	17	0	0	0	114	20	0	0
	2007	0	35	1425	1252	0	0	0	4	943	112	0	0	20	7	0	0	86	0	0	0
	2008	12	116	2686	2028	0	0	0	36	873	286	0	0	2	0	0	0	354	0	0	0
	2009	9	0	2125	1279	0	0	0	0	633	185	0	0	1	0	0	0	360	0	0	55
	2010	2	192	1119	1026	0	0	0	1	357	286	162	0	10	0	0	0	290	0	0	9
	2011	5	197	399	148	0	0	0	22	757	53	38	0	15	0	0	0	470	0	0	9
	2012	61	1362	2346	1295	0	0	0	43	527	358	341	0	15	25	0	0	778	9	0	424
	2013	32	486	1054	1413	0	0	0	91	302	456	624	0	0	21	0	0	538	0	1	371
Total number		11243	133530	26617	31799	184	13	6	1520	33491	26672	3349	4	2381	531	24	55	4075	215	48	1028
Strata		-	-	P	P	A	A	A	P	P	P	P	A	P	P	A	A	P	P	A	P

Table 4 Senarios for sensitivity analysis.

Secario	Observation	Cover rate(%)
1	0	0
2	5	50
3	10	50

Table 5 The result of combination between prefectures and AIC value by steps. Step 9 was selected for the area stratification in this study.

Steps	1	2	3	4	5	6	7	8	9	10	11	12
3 Iwate	1	1	1	1	1	1	1	2	2	2	2	2
4 Miyagi	2	2	2	2	2	2	2	2	2	2	2	2
14 Kanagawa	3	3	3	3	3	3	3	3	4	8	10	12
24 Mie	4	4	4	4	4	4	4	4	4	8	10	12
30 Wakayama	5	5	5	5	6	8	8	8	8	8	10	12
38 Ehime	6	6	6	6	6	8	8	8	8	8	10	12
46 Kagoshima	7	8	8	8	8	8	8	8	8	8	10	12
35 Yamaguchi	8	8	8	8	8	8	8	8	8	8	10	12
17 Ishikawa	9	9	10	10	10	10	10	10	10	10	10	12
16 Toyama	10	10	10	10	10	10	10	10	10	10	10	12
15 Nigata	11	11	11	12	12	12	12	12	12	12	12	12
6 Yamagata	12	12	12	12	12	12	12	12	12	12	12	12
AIC	791888	791949	792077	792928	793992	794788	794788	796209	802884	821928	839964	1134500

Table 6 AIC values of GLM for the determination of appropriate order of pooling. Model name and its explanatory variables are shown in increasing order according to AIC value.

Model	AIC	Explanatory variables
M3	-21727	Brand/Month/Area
M2	-18896	Brand/Quarter/Prefecture
M6	-17247	Brand/Quarter/Area
M1	-17058	SML/Month/Prefecture
M5	-16463	SML/Month/Area
M4	-11740	SML/Quarter/Prefecture
M7	-10847	SML/Quarter/Area

Table 7 Percentage (%) of estimated catch amount of length frequency against to total RJB catch amount by scenario and estimation step.

Step	Strata	Percentage (%)		
		Senario 1	Senario 2	Senario 3
1	Brand/Month/Prefecture	2.55	2.25	2.09
2	Brand/Month/Area	2.60	2.30	2.13
3	Brand/Quarter/Prefecture	2.68	2.57	2.40
4	Brand/Quarter/Area	2.78	2.60	2.43
5	SML/Month/Prefecture	79.54	74.97	73.83
6	SML/Month/Area	90.34	85.37	84.27
7	SML/Quarter/Prefecture	93.02	90.59	87.85
8	SML/Quarter/Area	95.58	93.69	91.04

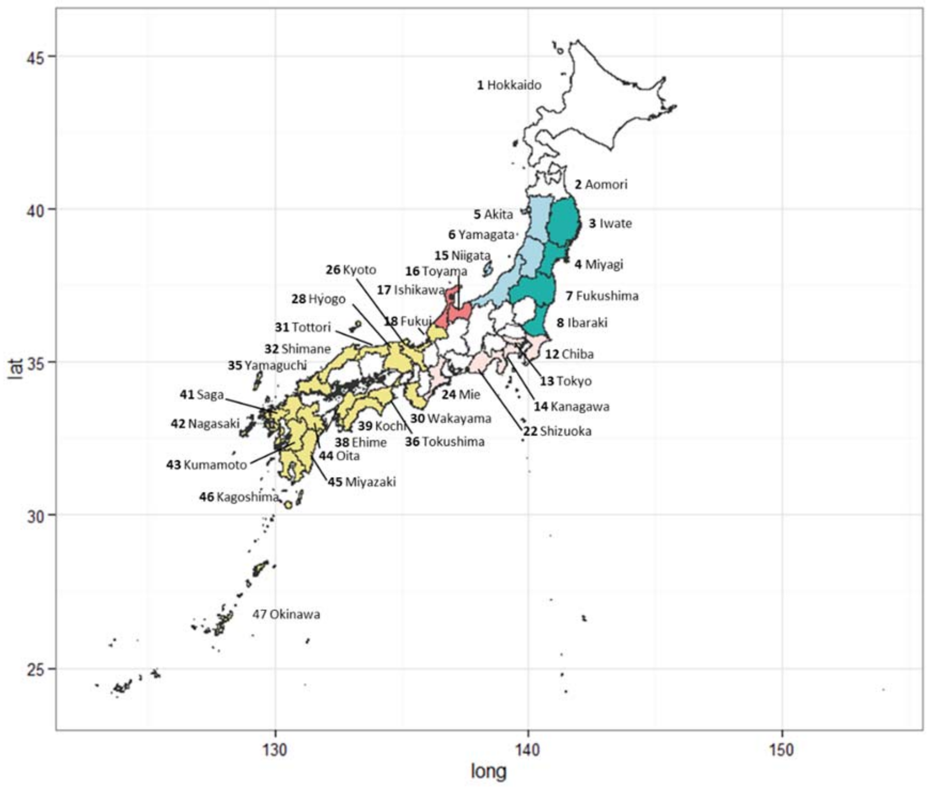

Fig. 1. Map of prefectures and prefecture numbers referred to Tables 2-3. Five kind of colors indicates the area stratification in this study.

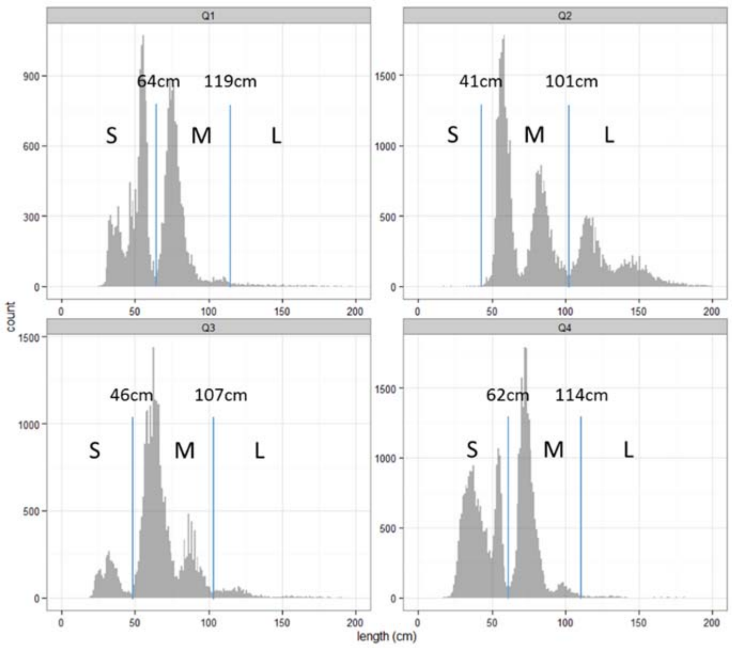

Fig. 2 Quarterly size frequency of raw size data for PBF caught by set-net during 1994-2013. Blue line and number indicates the boundary for size class.

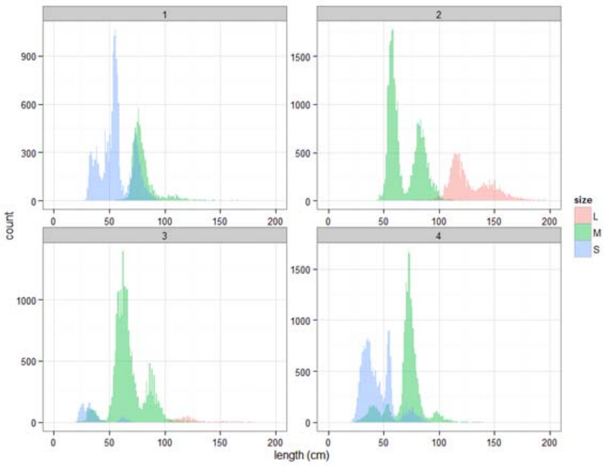

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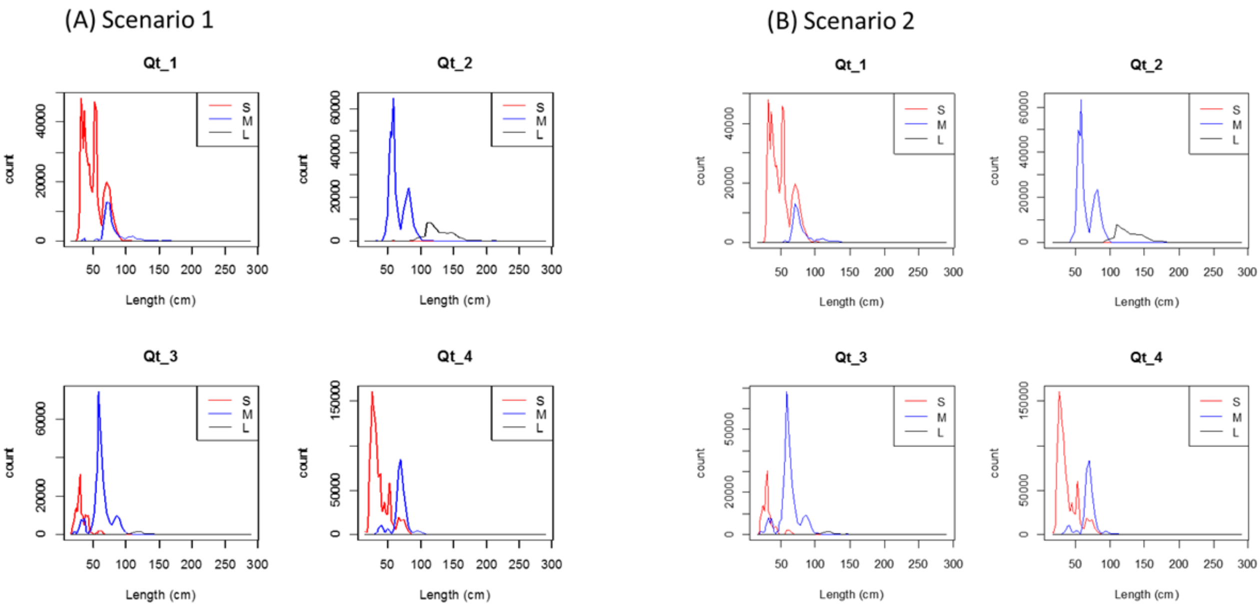
Fig 3. Quarterly size frequency of raw size data for PBF caught by set-net during 1994-2013 by estimated size class



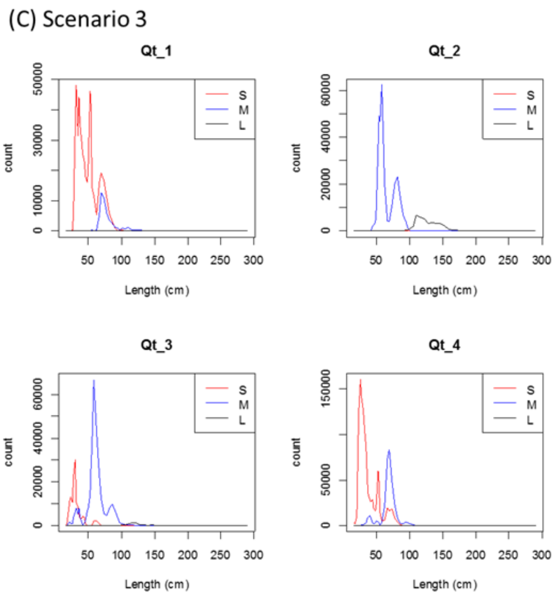


Fig 4. Quarterly size frequency of estimated catch at size by scenario.

(A) Scenario 1

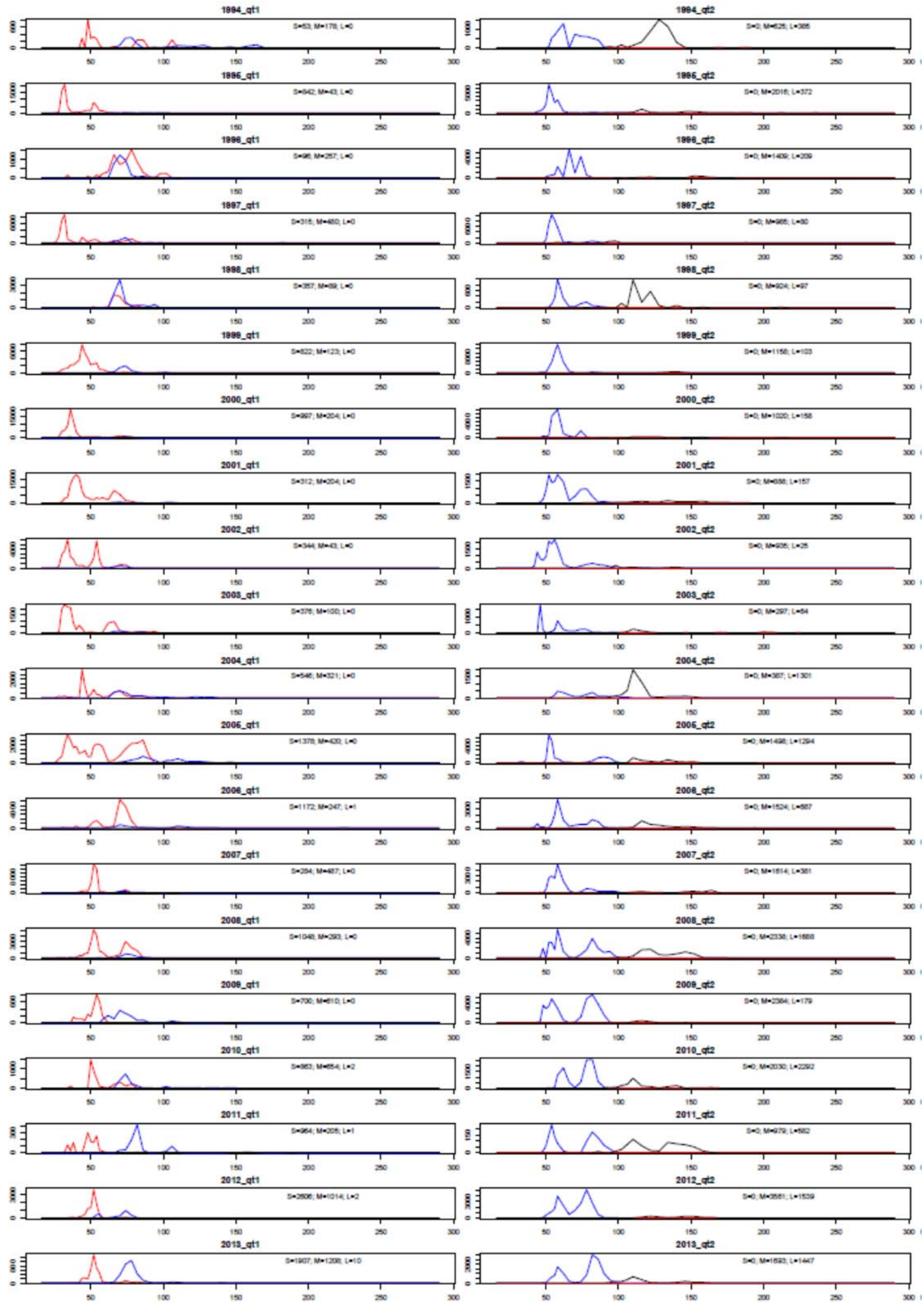


Fig.5. Estimated catch at size by quarter, year and size class.

(A) Scenario 1

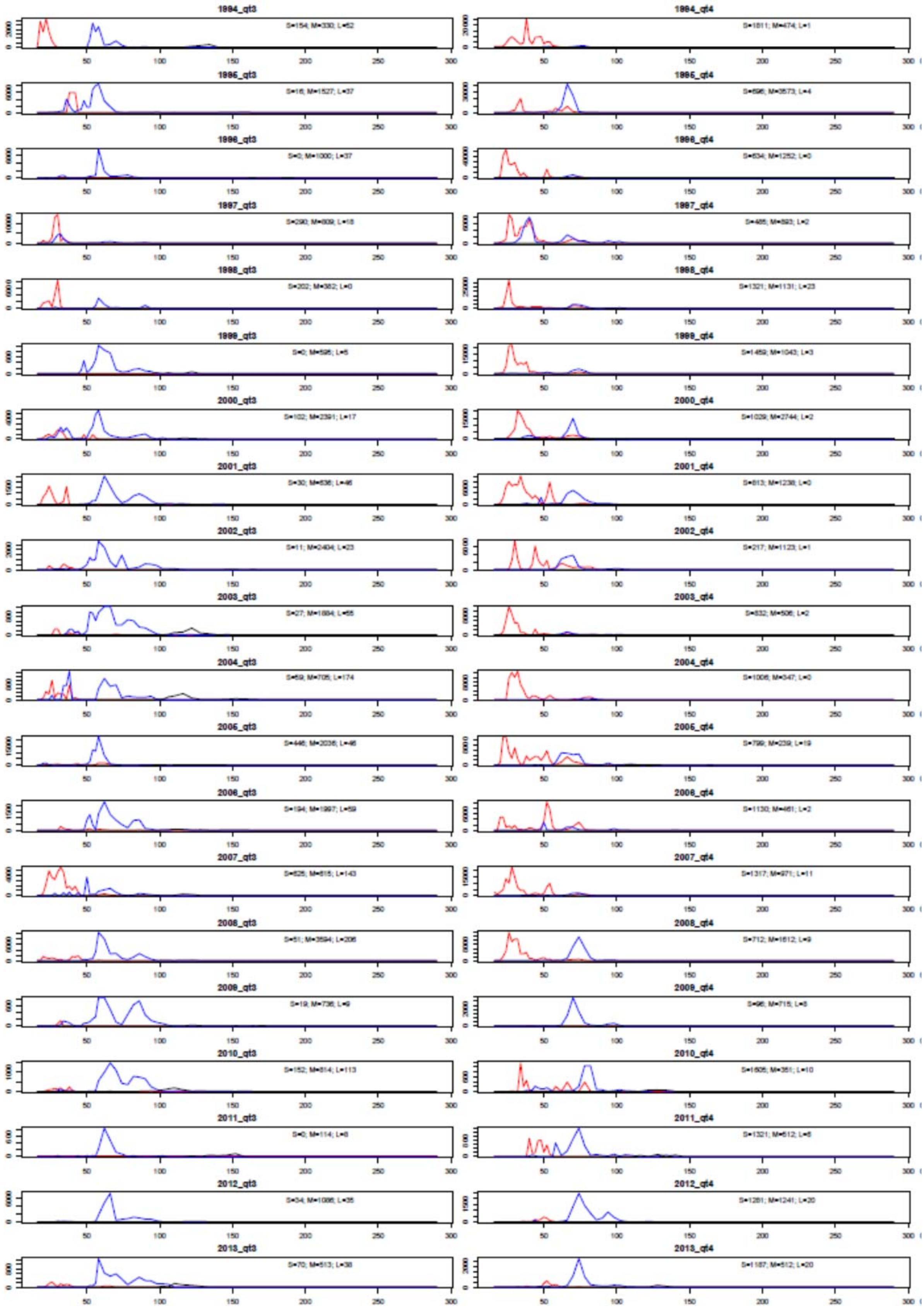


Fig.5. Continued.

(B) Scenario 2

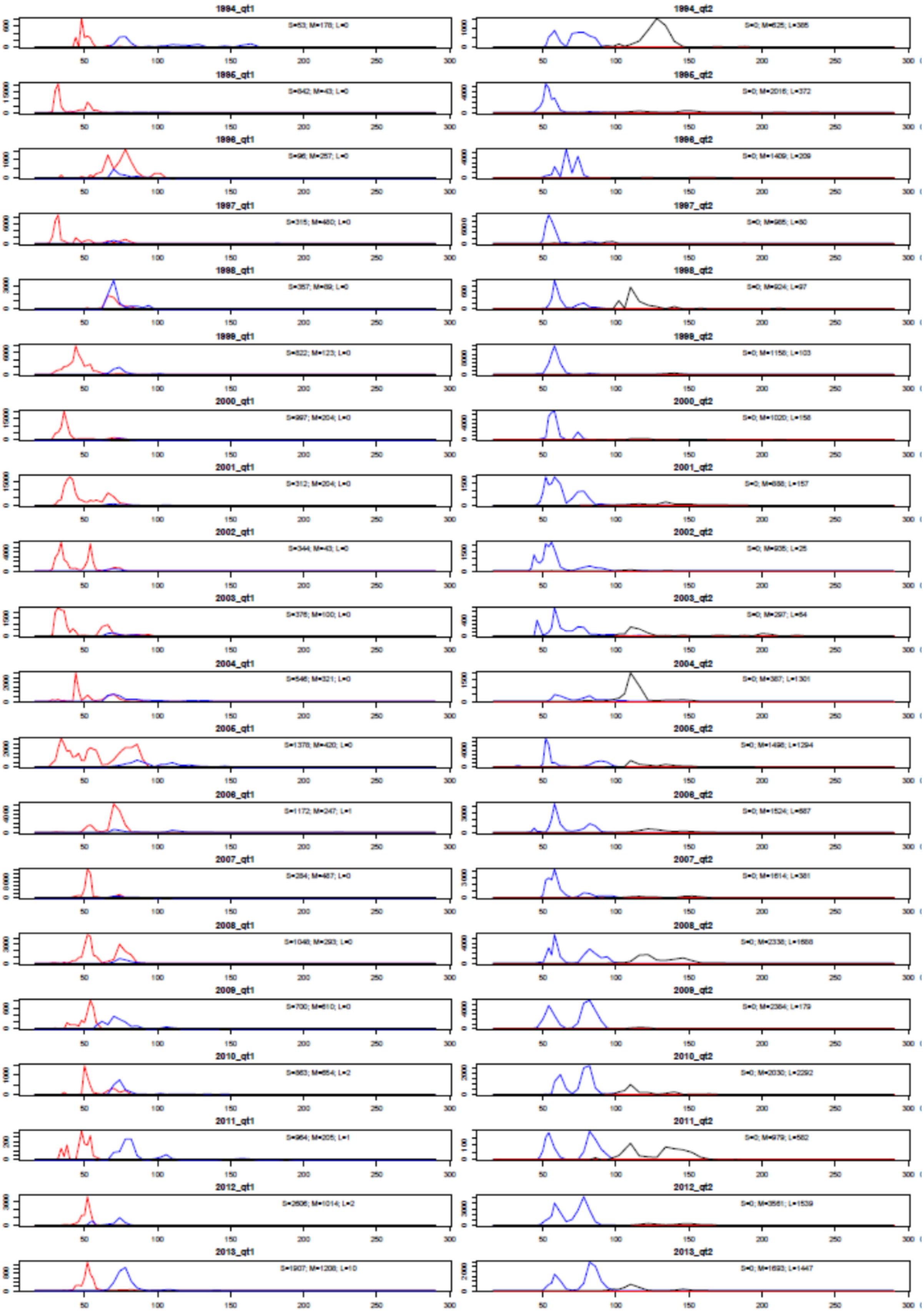


Fig.5. Continued.

(B) Scenario 2

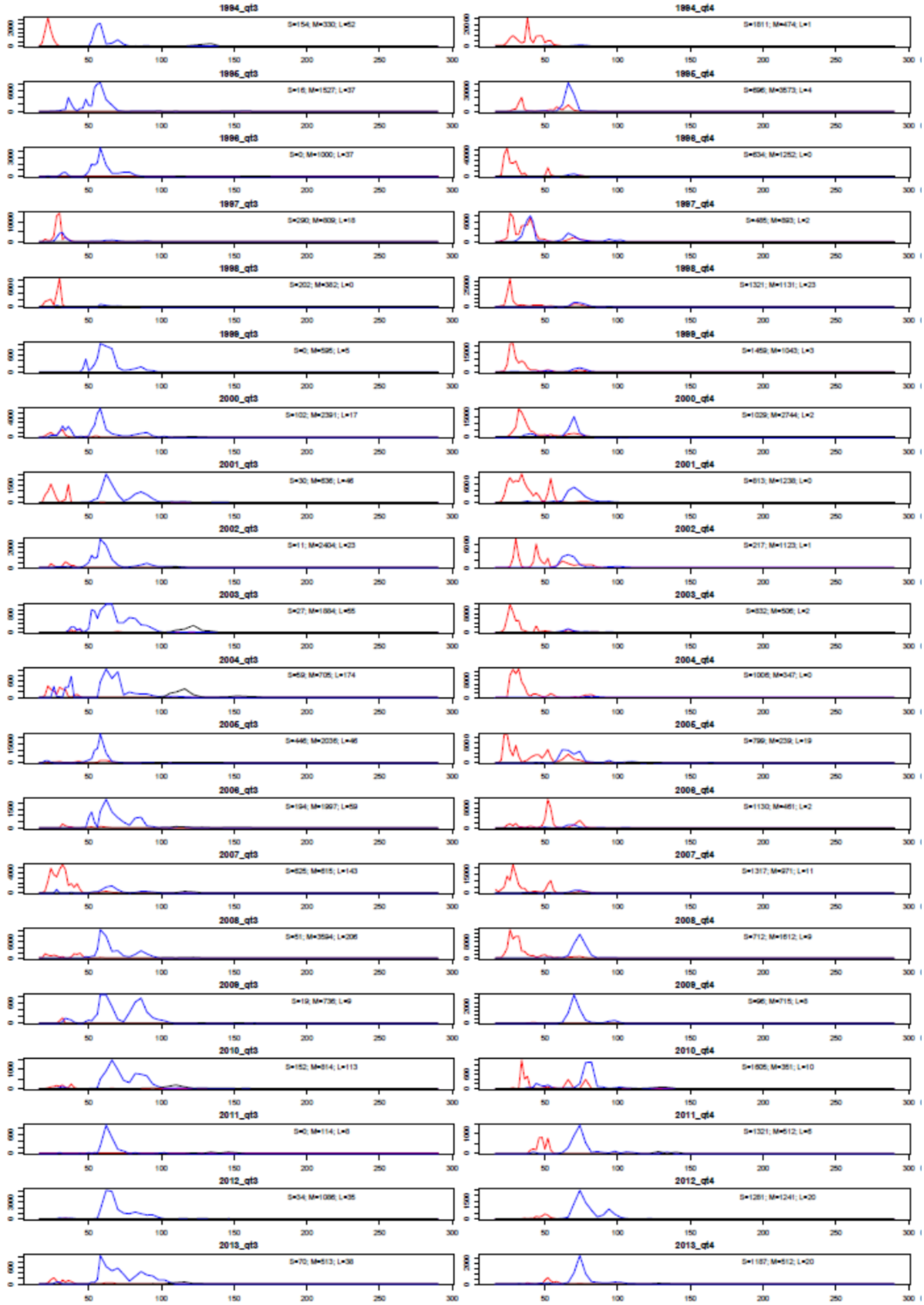


Fig.5. Continued.

(C) Scenario 3

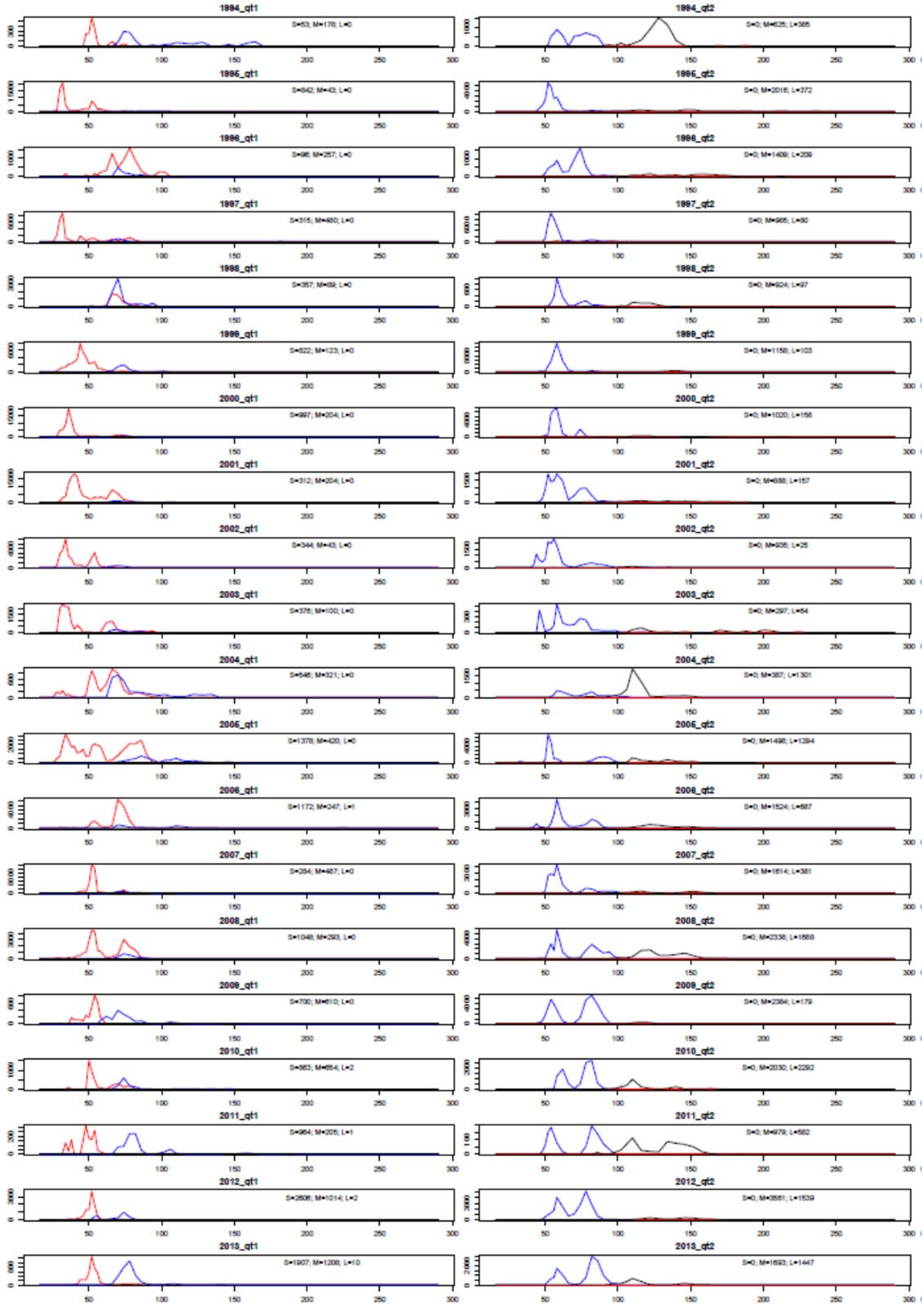


Fig.5. Continued.

(C) Scenario 3

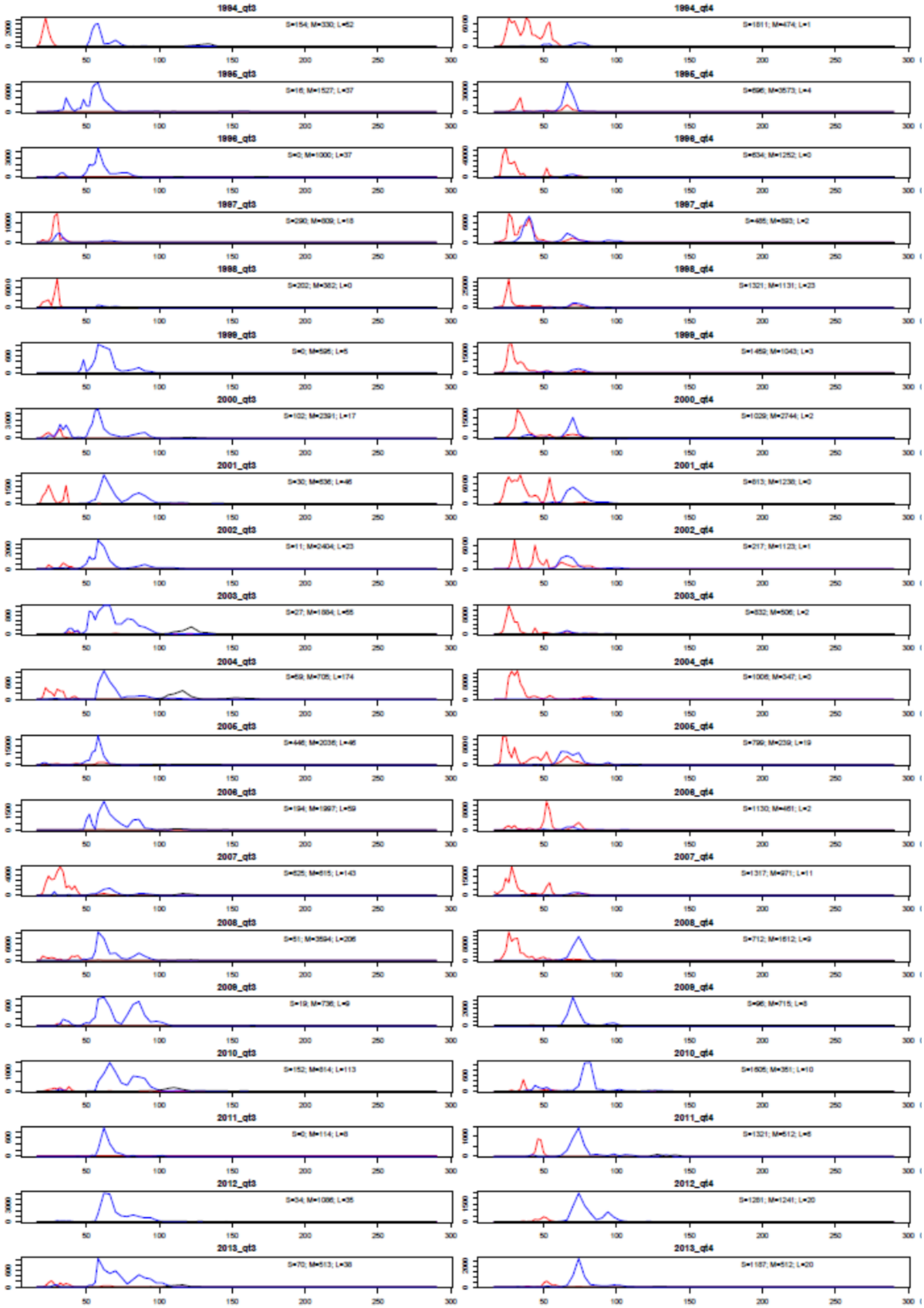


Fig.5. Continued.