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Reconsideration of estimation of catch at size for young Pacific bluefin tuna caught by Japanese small pelagic fish purse seine fisheries

Kazuhiro Oshima, Mikihiko Kai, Sigehide Iwata and Yukio Takeuchi

National Research Institute of Far Seas Fisheries
5-7-1 Orido, Shimizuku, Shizuoka, 424-8633, Japan

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Introduction

Length measurements of young Pacific bluefin tuna (PBF) caught by Japanese small pelagic fish purse seine fishery have been conducted at Fukuoka fish market since 2002. Oshima and Takeuchi (2010) estimated catch at size of PBF landings caught by this fishery using length measurement data. They made the length frequency distributions by market size categories assuming the length frequency of fish within each size category did not vary between years or seasons. With some reservations on representativeness of the length frequency distributions within the market size categories, the ISC PBF Working Group (WG) accepted the results, because of relative consistency observed in the length distributions within each category for most years. The WG, however, recommended for the estimation of catch at size from this fishery: 1) to derive length compositions without data substitution, and 2) to derive length compositions with data substitution and identifying the substitution (Anonymous 2011). In this paper, we reviewed the assumption of no seasonal and between year variations in size frequencies of fish in each market size categories and investigated possibility of improving substitution procedures.

Materials and methods

Description of fishery

Japanese small pelagic fish purse seine fishery is assigned into Fleet 2 in the Stock Synthesis 3 (SS3) model for PBF and includes offshore and coastal fisheries harvesting young PBF at ages 0 and 1, in contrast to Japanese tuna purse seine, which catch larger PBF and is assigned to Fleet 3. The offshore fishery accounts for 98.8% on an average of annual landings in weight of Japanese small pelagic fish purse seine fishery since 2000. Average of 81% of PBF landings caught by the offshore fishery is made at the markets in Kyusyu region, especially at Fukuoka fish market located at the northern Kyusyu region (Fig. 1). Consequently, if accurate length frequencies can be estimated for landings in Kyusyu region through adequate sampling, they will represent well the PBF catch at size by this fishery.

Fish landed are sorted into market size categories (called hereafter as box-categories) according to body weight and put into separate boxes. The box-categories are classified roughly into two groups: one-fish-per-box; multi-fish-per-box (Fig. 2). In the market, PBF larger than 6 kg in body weight are recorded by weight classes of 0.5 kg intervals and individually put into boxes (one-fish-per-box). The notation of weight is by the lower limit. For example, the weight classes of 8.0 kg and 8.5 kg include fish of 8.0-8.4 kg and 8.5-8.9 kg, respectively. With regard to the multi-fish-per-box group, fish less than 6 kg are sorted by similar fork length and placed in boxes of a standard dimension (35 cm x 60 cm x 12 cm). The criteria for category-sorting are based on relative body lengths to the box. Hence, number of fish per box indicates size of fish, i.e. more fish per box

corresponds to smaller fish. On an average, 85.9% of landing in number is constituted by fish sorted into multi-fish-per-box group (Fig. 3). Ratio of PBF sorted into one-fish-per-box group tends to increase in the 4th quarter with growth of PBF.

Data

As described in Oshima and Takeuchi (2011), summary reports published by a wholesale firm "*Nishinihon Uoichi*" provide daily number of boxes of by box-category and by landing ports in the entire Kyusyu region. The summary reports were available for two periods between the 3rd quarter 1991 and the 3rd quarter 1995 and between the 1st quarter 2003 and the 4th quarter 2011. In addition, monthly number of boxes by box-category at all ports in Kyusyu region was available from 1997 through 2002.

In the summary reports, numbers of boxes are either recorded by each box-category or sometimes of several box categories aggregated (e.g. 50 boxes for 3-5-fish-per-box). When accumulated categories were reported, the number of boxes was allocated equally to all the box-categories involved (i.e. the total number of boxes was split evenly among the categories) (see Table 1). The numbers of boxes by the box-category were not available from the 4th quarter 1995 through the 4th quarter 1996.

Since 2002, length measurements have been conducted in Fukuoka market. Fukuoka market is one of the major markets, accounting for 62.6 – 76.5% (2007 – 2009) of landing in weight of PBF caught by this fishery in Kyusyu Island. Fork lengths by 1 cm interval with the records of box category are recorded. The length data obtained from 2002 through 2011 were used in this study.

Quarterly numbers of fish measured by the box-category are listed in Table 1 with quarterly landings in number and their proportion of total quarterly landing in number. Frequent market size categories the landing of which occurred in more than 20 quarters were 1-, 3-, 4-, 5-, 6-, 8-, 10- and 12-fish-per-box. The length measurement for PBF in the one-fish-per-box group started in the 4th quarter of 2007. The length measurements of fish in this group were conducted in 47.1-53.3% of fish in each quarter when PBF of the one-fish-per-box group were unloaded (Table 2). Quarterly number of fish measured by the box-category showed statistically significant increase in proportion to quarterly catch in number by the box-category (R^2=0.423, $p<0.001$) (Fig. 4).

Estimation method of catch at size applied in the previous study

Estimation method of catch at size of overall landings applied by Oshima and Takeuchi (2011) was as follows. The length frequencies of PBF landings were made for each box-category by date of length measurements. Subsequently, daily length frequencies by the box-category were simply combined regardless to the year or quarter, to get a standard frequency for each category. The weight classes of 0.5 kg intervals for fish under 11.0 kg of one-fish-per-box group were combined into weight classes of 1 kg intervals. For example, the weight class of 6.0 kg includes non-combined weight class of 6.0 kg and 6.5 kg. In addition, the weight classes of 11.0 kg to 19.9 kg were combined into a single weight class due to very little sample size from these classes. Fish over 20 kg were ignored, because of rare landing. Yearly and quarterly catch at size of PBF unloaded

at the markets in Kyusyu region were estimated by raising the standard length frequencies for each box-category by the yearly and quarterly landing in number in the corresponding category. It should be noted that the size samples collected at Fukuoka market was raised to the total catch by this fishery in the entire Kyushu Region in this study. This is well justified the predominant importance of Fukuoka market for this fishery as previously noted.

Reconsideration of procedure for estimation of catch at size

As shown in Table 1, the length measurements were carried out frequently, although during the period between 2005 and 2010, the sampling efforts were less. The coverage rates defined as <number of quarters where length measurements were made for a box-category > over <the total number of quarters where PBF of the corresponding box-category were landed>, ranged from 25.0% to 48.6% for major box-categories. This means that the substituted length frequency data accounted for more than 50% of quarters. Therefore, if no substitutions were made for as suggested by the ISC-PBFWG, catch at size would represent only less than a half of the catches.

In order to explore appropriate procedures of data substitution, length data were analyzed regarding spatio-temporal changes in the length distribution within each box category. Generalized linear model (GLM) was conducted to clarify differences of mean length among possible effects, such as years, seasons and box categories and consequently to identify effects (with magnitude of variation of mean length within effects) for creation of length frequency data to be used for data substitutions by pooling in terms of the identified effects with more variation. Oshima and Takeuchi (2011) pointed out that the lengths of PBF landing sorted into multi-fish-per-box group increased within each box category, in 2008 and 2009. Hence, it was possible that the criteria of category-sorting at the landing port might have changed historically. Effect of period was incorporated in the GLM analysis applied only to the multi-fish-per-box group. The GLM model is as follows:

$$\text{Length} = \text{Intercept} + \text{Period} + \text{Year} + \text{Quarter} + \text{Box category} + \text{Error} \quad (1)$$

Where length, response variable; Period, Year, Quarter and Box-category, main effects of period, year, quarter and box-category as categorical variables; Error, error term with N(0, σ^2). The GLM model applied to the one-fish-per-box group corresponds to the model where the period effect was eliminated and the box-category effect was replaced by the weight class effect in Eq. 1. Consequently, full model consisted of effects of period, year, quarter and box-category for the multi-fish-per-box group and effects of year, quarter weight class for the one-fish-per-box group. Deviances were calculated for the full model and the reduced model where the main effect was eliminated one by one. The magnitude of variation of mean length within stratum (=effects) was evaluated with differences in deviance between the full model and the reduced model. The effect involving more large variation of mean length was considered as preferable effect where the length frequencies were combined when data substitution.

The catch at size during the periods between 2002 and 2011 when the length measurements were implemented was estimated through the procedures, which are

described in the following section. As for the substitution for catches prior to 2002, procedures are explained in the section "Catch at size before 2002". The length frequencies by the box category derived from small sample (< 10 fish) was not used. Uniform length frequency (combined regardless year and quarter as done in the previous studies) was applied to the 2-fish-per-box category where the proportion of catch was always less than 1 % of the total catch in number. The box-categories containing more than 13 individuals and over per box were combined into single market size category because of low sampling coverage from this class as well as proportion of fish of this categories in the catch. The number of boxes 7-, 9- and 11-fish-per-box categories was very scarce and no sampling has been done, during the periods between 2002 and 2011. Thereby, their numbers of boxes were divided into halves, each of which was added to the neighboring box-categories.

Results

Changes in length distribution by market size category

Lengths of PBF sorted into multi-fish-per-box group ranged approximately from 40 cm to 80 cm (Fig. 5). Generally, obvious inter-annual or seasonal variations in length frequency distribution within each box-category were not observed until the 4th quarter in 2008. However, during the period after the 4th quarter of 2008, sudden increases in length were observed in the following quarters: the 4th quarter of 2008 for the 3-, 4- and 5-fish per box categories; the 2nd quarter of 2009 for the 10- and 12-fish-per-box categories; and the 3rd quarter of 2009 for the 8-fish-per-box category. After sudden increases in length, lengths tended to vary among quarters. There were no marked changes in lengths in the 6-fish-per-box category. This might be caused by absence of length measurement data for this category in 2009. As for the one-fish-per-box category, no significant increase or decrease in lengths was observed.

GLM analysis

Based on yearly and quarterly changes in lengths in multi-fish-per-box group, two levels were set in the period effect according to yearly and quarterly changes in the length frequency in each box category. That is, breakpoint was empirically set at interspaces between the 3rd quarter and the 4th quarter in 2008 for the 3-, 4- and 5-fish-per-box categories and between the 4th quarter of 2008 and the 1st quarter of 2009 for the 6-, 8-, 10- and 12-fish-per-box categories.

Results of the GLM analysis are summarized in Table 3. At the model for the multi-fish-per-box group, the market size category was the most important effect for variations in mean lengths, because deviance of the reduced model where the box-category effect was eliminated was the largest. In the same way, the second and third most important effects were the year and period effects. There was small difference in deviance between the full model and the reduced model where the quarter effect was eliminated.

The main effects for the full model to be applied the one-fish-per-box group were selected using AIC. Significance of the quarter effect, however, was even with that of the year effect, because there was not so much of difference in deviance between the reduced

models where these two effects were eliminated one by one.

Data substitution procedure

The GLM analysis for the multi-fish-per-box group supported keeping stratum of the box-category throughout creation of the catch at size. Data substitution procedures (Procedure 1) adopted in this study are summarized in Table 4 and explained below by step.

Procedure 1

Step 1. As for the multi-fish-per-box group; the length frequencies were combined for year/quarter/box-category stratum. This year-quarter-box-category specific length frequency was raised to the total landing in the matching box-category, as recommended by the WG for the previous study (Oshima and Takeuchi 2011).

Step 2. For fish which lacks matching size data during the above Step 1; following the results from the GLM analysis, quarterly length frequencies were combined for each year with keeping stratum of box-category, because difference in deviance between the full model and the reduced model where the year effect was eliminated was the second largest. This year-box-category specific length frequency was used to substitute the size data for the catch which lacks size information in Step 1.

Step 3. The fish still lacks matching size data even in Step 2; year-box-category specific length frequencies are combined for all the years, i.e. one single length frequency for each box-category. However those were made separately for two periods described in the previous section “GLM analysis”. Subsequently, these standard combined length compositions were used for the catch which had no matching size data.

Procedure 2

The uniform (standard) length frequency for each box-category was created combined for year-quarter but individually for each box-category and this was used for all the catches i.e. the same data substitution procedure applied in the previous study (Oshima and Takeuchi 2011).

Procedure 3

Step 1. This procedure is added to the list of data substitution procedure as sensitivity test to inspect effect of data substitution. The length frequencies combined for year stratum (year-box-category specific length frequency) were raise to the total landing in the matching box-category.

Step 2. For fish which lacks matching size data during the above Step 1; the period-box-category length frequencies were used to substitute the size data for the catch which lacks size information in Step 1.

Procedure 4

This procedure is also for the sensitivity test as well as Procedure 3. The period-box-category specific length frequency categories were raised to the total

landing in number in the matching box-category.

The raised length frequencies obtained through the procedures described above for each box-category were aggregated by year and quarter to create total catch at size on yearly and quarterly basis.

As for the one-fish-per-box group, year and quarter had just small effects on the change in lengths in each weight class shown in Table 3b. Therefore, uniform length compositions were made for each weight class and used for estimating the catch at size.

Catch at size from 2002 through 2011

The catch at size with Procedure 1 were different from those obtained by Procedure 2, which were used in the previous study by Oshima and Takeuchi (2011) (Fig. 6). Generally, changes are note in the location of the modal length: the modal length by Procedures 1 being larger than by Procedures 2. The lengths in each box category increased apparently from the 4th quarter of 2008, might have related to the increments of modal lengths estimated through Procedures 1. The increments of modal lengths were 2 to 6 cm, corresponding to 1-3 length-bin differences for the fish smaller than 58 cm in the SS3 model for PBF.

Procedures 3 and 4 were tested by applying to particular quarters, as shown in Fig. 7, since those quarters were better sampled and less substitution made (see Table 1). Application of Procedures 3 and 4 resulted in catch at size close to those derived from Procedure 1. There were, however, slightly prominent differences in length at modal length class in the 2nd quarter of 2005, the 4th quarter of 2008 and the 2nd quarter of 2009. In the 2nd quarter of 2005, modes were at 52 cm, 46 cm and 48 cm in length in catch at size by Procedures 1, 3 and 4, respectively. The maximal difference among the modal lengths was 6 cm, which was equal to 3 length-bin difference in the SS3 model.

Catch at size before 2002

There was no acute discrepancy of the length frequency distributions between Procedures 1, 2 and 3. It was concluded that data substitution manner in Procedures 3 and 4 provides relatively reliable catch at size for PBF landings. Therefore, Procedure 4 was applied for the estimation of catch at size for data before 2002 when there was no length measurement data were available and hence Procedure 1 is not applicable.

The frequent box-categories the landing of which occurred in more than 20 quarters from 1991 through 2001 except for 1996 were 1-, 3-, 4-, 5-, 6-, 8-, 10- and 12-fish-per-box (Table 5). Although, the occurrence of landing for the 2-fish-per-box category also frequent with 22 quarters, total landing in number of this category from 1991 through 2001 was much smaller than those in other frequent categories. The length frequency distributions of catch at size from the 3rd quarter of 1991 through 2001 were estimated through Procedure 4 (Fig. 8).

Discussion

As shown in Table 1, the length measurement data for the frequent box-category were

absent from more than 50% of quarters with PBF unloading occurred from 2002 through 2011. Hence, if the data substitution is not applied, the catch at size would be quite incomplete.

In this paper, four different data substitution procedures were analyzed based on temporal changes in length composition by the box category. The following procedures were adopted: Procedure 1, for the period between 2002 and 2011; Procedure 4, for the period between 1991 and 2001. The catch at size estimated in this study is expected to become more reliable than previous study's ones. The GLM analysis indicated that the year effect was more important for the differences of the mean lengths within each box-category than the period effect. As shown in Fig. 7, the catch at size estimated by Procedure 4 (only with period and box-category specific strata), produced quite similar results of those by Procedure 1. It was concluded that application of Procedure 4 itself was reasonable for the estimation of catch at size before 2002. There was, however, no length measurement data before 2002, thereby the change in lengths within each box category could not have been examined even if the criteria of category-sorting for PBF landings at the market was had been changed. There are two options for the estimation of catch at size before 2002: the first one involves application of substitution procedures 4 to the landings; and another to prepare no size data. Conventional size data for Fleet 2 in the SS3 model for PBF were provided and used in past analysis for the period between the 1st quarter of 1997 and the 2nd quarter of 2008. The size data from 1997 through 2001 will be lost from the analysis if we adopt the second option above. The difference in the modal length between catch at size and frequencies of actual samples is expected to fall within 4-6 cm as illustrated in Fig. 6, if the lengths in the market size category were not dramatically changed before 2002. In addition, the size data from 1991 through 1995 can be added to the input data for the SS3 model if application of Procedure 4 is approved, thereby information on size of a strong year class of 1994 will become available (As previously explained, there are no catch data by the box category for 1996 and hence the data would be missing for that year, no matter what the procedures were applied). For these reasons, it is highly recommended that the catch at size before 2002 are estimated through Procedure 4 for use in the next stock assessment.

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References cited

Anonymous. 2011. Report of the Pacific bluefin tuna Working Group Workshop. ISC Plenary. July, 2011. San Francisco, U.S.A. 34pp.

Oshima, K. and Takeuchi, Y. 2011. Approaches for estimation of catch at age of young Pacific bluefin tuna caught by Japanese small purse seine fisheries. ISC/11-1/PBFWG/07.

Table 1 Summary of quarterly landing in number by box-category, its proportion to total quarterly catch in number and number of fish measured by box-category, denoted as Number, % and N, respectively. The second last row indicates number of quarters when PBF sorted into corresponding box-category was landed and when length measurement was carried out. The last row shows ratio of number of quarters with length measurement for total number of quarters with landing of PBF. Cells shaded or colored in gray indicate quarters or years when there is no length measurement data, respectively.

Year	Quarter	Market size category																																	
		1			2			3			4			5			6			7			8			9			10		
		Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N			
		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%				
2002	1	2,400	17.9								160	1.2		325	2.4		1,350	10.0					2,600	19.3					850	6.3				
	2							75	0.0		8,840	1.7		450	0.1		148,590	28.8					154,600	29.9					135,350	26.2				
	3										1,380	0.4		1,275	0.4		128,940	38.1					134,240	39.6					70,050	20.7				
	4				320	0.2	68	186,225	88.2	1282	22,380	10.6	720	100	0.0	30	390	0.2	72				80	0.0	32				250	0.1	140			
2003	1	400	2.0		83	0.4		73	0.4		208	1.0		121	0.6		436	2.2		48	0.2		2,486	12.4					10,443	52.2				
	2	4,690	1.1		102	0.0	6	1,148	0.3	36	4,245	1.0	52	1,828	0.4	20	22,710	5.2	132				182,324	41.9	191	504	0.1		194,754	44.8	100			
	3	4,030	1.6					624	0.2		1,375	0.5		460	0.2		49,428	19.5	184				153,551	60.5	288				44,193	17.4	150			
	4	117,840	53.2		771	0.3	2	17,070	7.7	135	4,933	2.2	81	918	0.4	30	27,962	12.6	186				44,909	20.3	86				7,294	3.3				
2004	1	590	5.2							30	578	5.1	16	2,375	21.1	30	4,027	35.7	60				3,181	28.2	64				516	4.6	20			
	2	12,170	6.0					3,794	1.9	15	32,145	15.7	180	44,165	21.6	210	26,898	13.2	168				56,751	27.8	247				28,392	13.9	120			
	3																																		
	4	17,290	2.9					10	0.0	9	223	0.0	12	4,487	0.8	55	43,493	7.3	119	147	0.0		63,098	10.6	136				88,955	15.0	199			
2005	1										88	0.0		1,472	0.3		14,719	3.1					58,333	12.4					121,559	25.9				
	2							1,585	0.3		8,641	1.9		1,770	0.4	20	73,808	15.8	30				215,067	46.1	24				143,440	30.7	85			
	3	1,500	0.3					15	0.0		13,128	2.2		80,384	13.8		243,207	41.6					219,691	37.6					26,303	4.5				
	4	118,460	48.7		1,287	0.5		1,815	0.7	30	1,857	0.8		914	0.4		12,773	5.3	60				69,650	28.6	85	272	0.1		20,031	8.2	80			
2006	1	320	1.2								147	0.5		183	0.7		220	0.8											1,000	3.7				
	2	81,545	17.0					1,014	0.2		15,505	3.2		12,096	2.5		38,311	8.0					167,641	34.9					162,812	33.9				
	3	3,370	16.9					570	2.9		1,227	6.2		1,521	7.6		2,465	12.4					8,073	40.5					2,692	13.5				
	4	136,147	35.8		377	0.1		2,526	0.7	21	668	0.2		19	0.0		14,344	3.8	30	652	0.2		88,375	23.2	96				137,305	36.1	80			
2007	1	16,694	34.1					18	0.0		387	0.8		7,017	14.3		11,264	23.0					7,436	15.2					2,697	5.5				
	2	8,745	3.1					133	0.0		789	0.3		10,414	3.7		44,130	15.8	30				131,145	47.1	32				82,110	29.5	40			
	3							30	0.2		60	0.4		2,338	13.7		6,505	38.1					5,713	33.4					2,442	14.3				
	4	70,470	69.8	676				69	0.1	60							92	0.1					11,938	11.8	16				14,000	13.9				
2008	1	4,600	9.4								57	0.1		96	0.2		10,154	20.6					22,366	45.5					11,582	23.5				
	2	11,426	2.3								230	0.0		9,137	1.8		59,418	11.8					179,720	35.8					222,582	44.4				
	3	1,350	0.2					1,965	0.3	29	29,020	4.1	32	89,800	12.8		136,590	19.5	60				332,320	47.5	64				108,410	15.5	60			
	4	20,260	6.3	200				14,959	4.7	31	162,582	50.8	32	29,170	9.1	25	6,587	2.1					17,843	5.6					27,197	8.5	30			
2009	1	11,765	15.4	108				53	0.1		517	0.7		8,366	11.0		15,277	20.0		153	0.2		21,071	27.6					17,725	23.2				
	2	838	0.2	82							20	0.0		5,904	1.2		23,748	4.9					83,479	17.1					254,511	52.3	90			
	3	500	0.3	67				170	0.1		4,793	2.6		48,967	26.1	30	38,190	20.4					62,987	33.6	16				28,233	15.1	90			
	4	2,100	33.9					81	1.3		869	14.0		486	7.8		43	0.7					857	13.8					1,071	17.3				
2010	1	1,280	1.1	30									64	75	0.1	60	10,700	9.1	120				67,227	57.4	60				37,783	32.3				
	2	4,110	2.5	135				405	0.2		8,700	5.4		19,913	12.3		26,385	16.3					74,900	46.2	4				27,675	17.1	51			
	3	20	0.3					675	10.9		2,873	46.3		1,992	32.1		650	10.5																
	4	1,600	20.5																				300	3.8					2,675	34.3				
2011	1	1,200	35.5																				592	17.5					1,040	30.8				
	2													752	0.1	36	46,526	7.5	462				218,196	35.0	272				327,107	52.4	192			
	3													583	0.8		8,750	12.7					29,787	43.1					28,817	41.7				
	4	148,990	66.1	917	577	0.3		21,495	9.5	48	5,950	2.6	30	521	0.2	5	10,605	4.7	90				21,900	9.7	90				13,300	5.9	60			
Sum		806,700	8.5	2,215	3,517	0.0	76	256,597	2.7	1,726	334,576	3.5	1,219	390,392	4.1	551	1,309,684	13.8	1,803	1,000	0.0		2,914,426	30.7	1,803	775	0.0		2,407,145	25.4	1,587			
No. of quarter		31		8	7		3	26		12	33		10	36		12	37		15	4		0	37		18	2		0	38		17			
%		25.8			42.9			46.2			30.3			33.3			40.5			0.0			48.6						44.7					

Table 1 cont.

Year	Quarter	Market size category																																		Sum	
		11			12			13			14			15			16			17			18			19			20			21				
		Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch	N
		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	
2002	1				5,760	42.8																														13,445	
	2				68,760	13.3																														516,665	
	3				2,880	0.9																														338,765	
	4				1,320	0.6																														211,065	2,344
2003	1	152	0.8		1,362	6.8		2,915	14.6		620	3.1		208	1.0		443	2.2																		19,998	
	2				5,802	1.3		2,382	0.5	13	1,568	0.4	14	9,161	2.1	30							3,848	0.9	18			19								435,064	631
	3																																			253,662	622
	4																																			221,697	520
2004	1																																			11,268	220
	2																																			204,315	940
	3																																				
	4				53,001	8.9	72	272	0.0		152,023	25.6		86,347	14.5		29,557	5.0	34	24,821	4.2		1,884	0.3		25,056	4.2					3,297	0.6		593,962	636
2005	1				135,383	28.8		7,439	1.6		12,017	2.6		66,442	14.1		25,619	5.5		7,296	1.6		12,480	2.7		6,273	1.3		440	0.1						469,561	
	2				21,513	4.6	36	150	0.0		161	0.0		173	0.0		184	0.0																		466,491	195
	3																																			584,228	
	4	5,200	2.1		362	0.1	24	7,452	3.1					905	0.4	29	2,253	0.9																		243,230	308
2006	1				9,000	33.4		9,750	36.2					2,850	10.6		3,040	11.3											200	0.7		210	0.8			26,920	
	2				1,622	0.3																														480,545	
	3																																			19,918	
	4				279	0.1																														380,694	227
2007	1				1,573	3.2					1,553	3.2					323	0.7																		48,962	
	2				1,102	0.4																														278,566	102
	3																																			17,088	
	4				4,431	4.4																														101,001	752
2008	1							329	0.7																											49,184	
	2	451	0.1		18,697	3.7																														501,660	
	3				360	0.1																														699,815	245
	4	7,052	2.2		24,975	7.8		1,017	0.3		740	0.2		2,901	0.9	15	580	0.2		788	0.2	17	1,617	0.5		551	0.2		580	0.2		609	0.2		320,007	350
2009	1				1,447	1.9																														76,374	108
	2				110,045	22.6	96	435	0.1		562	0.1					1,316	0.3		1,398	0.3		1,480	0.3		1,562	0.3		1,645	0.3						486,943	268
	3				3,420	1.8	108																													187,260	311
	4				686	11.1																														6,193	
2010	1																																			117,065	334
	2																																			162,088	190
	3																																			6,210	
	4				2,730	35.0		488	6.3	30																											7,793	30
2011	1				168	5.0		182	5.4		196	5.8																								3,378	
	2				26,996	4.3	94	2,540	0.4		631	0.1		676	0.1		240	0.0		256	0.0																623,919	1,056
	3				1,200	1.7																														69,137	
	4				2,040	0.9	7																														225,378	1,247
Sum		12,855	0.1		506,912	5.3	437	35,351	0.4	43	170,071	1.8	14	169,664	1.8	74	63,555	0.7	34	34,559	0.4	17	21,308	0.2	18	33,442	0.4	19	2,864	0.0		4,115	0.0		9,479,509	11,636
No. of quarter		4		0	28		7	13		2	10		1	9		3	10		1	5		1	5		1	4		1	4		0	3		0	39	22
%					25.0			15.4			10.0			33.3			10.0			20.0			20.0			25.0									56.4	

Table 2 Summary of quarterly landing in number by weight class in the one-fish-per-box group, its proportion to total quarterly catch in number and number of fish measured by weight class, denoted as Number, % and N, respectively. The second last row indicates number of quarters when PBF sorted into corresponding weight class was landed and when length measurement was carried out. The last row shows ratio of number of quarters with length measurement for total number of quarters with landing of PBF. Shaded cells indicate quarters when there is no length measurement data.

Year	Quarter	Weight class																Sum			Quarterly catch in number
		6.0, 6.5kg			7.0, 7.5kg			8.0, 8.5kg			9.0, 9.5kg			10.0, 10.5kg			11.0−19.5kg						
		Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	Catch		N	
		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		Number	%		
2007	1	429	0.9		443	0.9		1,156	2.4		3,516	7.2		3,643	7.4		7,193	14.7		16,379	33.5		48,962
	2	180	0.1		202	0.1		340	0.1		1,297	0.5		2,049	0.7		3,594	1.3		7,663	2.8		278,566
	3																						17,088
	4	14,603	14.5	129	14,739	14.6	160	10,871	10.8	114	10,598	10.5	184	6,643	6.6	74	12,396	12.3	15	69,850	69.2	676	101,001
2008	1	75	0.2		126	0.3		450	0.9		450	0.9		245	0.5		994	2.0		2,338	4.8		49,184
	2	698	0.1		784	0.2		850	0.2		863	0.2		946	0.2		4,507	0.9		8,649	1.7		501,660
	3							13	0.0		25	0.0		25	0.0		1,282	0.2		1,346	0.2		699,815
	4	4,052	1.3	9	3,792	1.2	69	4,302	1.3	68	3,711	1.2	34	1,996	0.6	15	2,407	0.8	5	20,260	6.3	200	320,007
2009	1	625	0.8	6	930	1.2	11	1,329	1.7	25	1,321	1.7	21	844	1.1	15	3,605	4.7	30	8,655	11.3	108	76,374
	2	34	0.0	5	52	0.0	12	55	0.0	23	55	0.0	25	55	0.0	11	110	0.0	6	360	0.1	82	486,943
	3	8	0.0	6	8	0.0	7	8	0.0	8	8	0.0	7	8	0.0	5	458	0.2	34	500	0.3	67	187,260
	4	388	6.3		388	6.3		388	6.3		388	6.3		388	6.3		162	2.6		2,100	33.9		6,193
2010	1	143	0.1	2	148	0.1	4	148	0.1	13	148	0.1	5	148	0.1	5	528	0.5	1	1,265	1.1	30	117,065
	2	352	0.2	18	378	0.2	30	613	0.4	35	613	0.4	29	399	0.2	14	1,554	1.0	9	3,909	2.4	135	162,088
	3													4	0.1		16	0.3		20	0.3		6,210
	4	141	1.8		141	1.8		141	1.8		141	1.8		141	1.8		865	11.1		1,572	20.2		7,793
2011	1	50	1.5		50	1.5		50	1.5		50	1.5		50	1.5		452	13.4		702	20.8		3,378
	2																						623,919
	3																						69,137
	4	29,649	13.2	161	30,429	13.5	228	30,549	13.6	214	30,134	13.4	192	21,909	9.7	109	6,321	2.8	13	148,990	66.1	917	225,378
Sum		51,428	1.3	336	52,611	1.3	521	51,261	1.3	500	53,318	1.3	497	39,494	1.0	248	46,446	1.2	113	294,559	7.4	2,215	3,988,018
No. of quarter		15		8	15		8	16		8	16		8	17		8	17		8	18	17	9	
%		53.3			53.3			50.0			50.0			47.1			47.1			50.0			

Table 3 Deviance and Akaike Information Criterion (AIC) for full model and reduced models from GLM analysis applied for multi-fish-per-box group (a) and one-fish-per-box group (b)

(a) Multi-fish-per-box group.

Model	Df	Deviance	AIC
Full model		59,441	41,777
Reduced model			
-(Quarter)	3	60,204	41,883
-(Period)	1	61,306	42,046
-(Year)	9	63,125	42,287
-(box-category)	6	279,088	55,354

(b) One-fish-per-box group

Model	Df	Deviance	AIC
Full model		6375.6	7799.3
Reduced model			
-(Quarter)	1	6477.6	7827.9
-(Year)	3	6537.6	7841.7
-(Weight class)	4	21483.3	10133.4

Table 4 Type of box-category-specific length frequencies by step used for data substitutions of Procedures 1-4.

Procedure	Type of box-category specific length frequency		
	Step 1	Step 2	Step 3
1	Year-quarter specific	Year specific	Period specific
2	Uniform		
3	Year specific	Period specific	
4	Period specific		

Table 5　Quarterly landing in number by box-category and its proportion to total quarterly catch, denoted as Number and %, respectively.　The last row indicates number of quarters when PBF sorted into corresponding market size category was landed.

Year	Quarter	Market size category																												Sum
		1		2		3		4		5		6		8		10		12		13		14		17		18		20		21		
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	
1991	3	95	0.1	20	0.0	7,830	10.1	4,440	5.7	1,900	2.5	47,400	61.3	10,000	12.9	5,400	7.0	240	0.3													77,325
	4	448,102	63.8	724	0.1	15,182	2.2	1,392	0.2	739	0.1	132,527	18.9	92,339	13.1	11,345	1.6															702,349
1992	1	38,581	78.9	20	0.0	188	0.4	1,390	2.8	88	0.2	6,855	14.0	1,800	3.7																	48,921
	2	58,815	24.7	988	0.4	117,507	49.3	60,790	25.5			392	0.2																			238,492
	3	13,495	77.2	51	0.3	3,746	21.4	184	1.1																							17,476
	4	290	8.8			150	4.5					960	29.1	1,600	48.5	300	9.1															3,300
1993	1	31,118	79.8	120	0.3	283	0.7	2,992	7.7	1,658	4.3	1,970	5.1	768	2.0	67	0.2															38,976
	2	11,314	12.3	75	0.1	10,560	11.5	31,085	33.8	11,456	12.4	16,079	17.5	2,709	2.9											1,083	1.2	6,019	6.5	1,685	1.8	92,067
	3			51	0.2	1,183	5.7	10,875	52.4	4,548	21.9	4,002	19.3	81	0.4																	20,740
	4	95	8.9	3	0.3	5	0.5	7	0.6			300	28.0	560	52.3	100	9.3															1,070
1994	1	1,570	37.4					120	2.9	1,550	36.9	960	22.9																			4,200
	2	3,743	2.6			376	0.3	5,692	3.9	30,241	21.0	90,256	62.6	13,845	9.6																	144,154
	3	40	1.5			484	18.3	46	1.7							2,073	78.4															2,643
	4					339	0.6	392	0.7	1,268	2.1	21,644	36.0	30,033	49.9	5,851	9.7	624	1.0													60,150
1995	1					16	0.0	803	0.4	5,367	2.4	23,420	10.5	102,489	46.1	80,052	36.0	651	0.3			7,896	3.6	830	0.4	879	0.4					222,402
	2							370	0.3	109	0.1	13,276	9.5	81,420	58.2	40,394	28.9	261	0.2	1,979	1.4	2,131	1.5									139,940
	3					2,000	0.3	49,250	7.5	126	0.0	260,698	39.8	243,503	37.1	99,934	15.2															655,509
1997	1	47,060	29.9			375	0.2	560	0.4	2,750	1.7	30,240	19.2	50,160	31.9	7,900	5.0	18,180	11.6													157,225
	2	1,625	0.6	20	0.0	12,360	4.9	116,480	46.4	34,950	13.9	31,320	12.5	28,880	11.5	10,700	4.3	14,520	5.8													250,855
	3	5,435	0.8	60	0.0	45,450	7.1	104,320	16.3	88,375	13.8	287,850	45.0	89,520	14.0	1,150	0.2	18,084	2.8													640,244
	4	32,750	9.4	6,760	1.9	238,800	68.6	36,560	10.5			720	0.2	7,440	2.1	2,750	0.8	22,320	6.4													348,100
1998	1	41,660	62.7	210	0.3	840	1.3	1,160	1.7	1,075	1.6	16,470	24.8	880	1.3	750	1.1	3,420	5.1													66,465
	2	15,980	17.1	30	0.0	1,470	1.6	28,300	30.3	2,800	3.0	31,890	34.1	11,000	11.8			1,980	2.1													93,450
	3	490	0.6	160	0.2	2,745	3.4	38,680	48.6	10,950	13.8	23,940	30.1	200	0.3			2,460	3.1													79,625
	4	92,015	42.5	40	0.0	720	0.3	20,900	9.6	41,175	19.0	44,730	20.6	15,640	7.2	950	0.4	540	0.2													216,710
1999	1	18,240	37.0			210	0.4	40	0.1	350	0.7	3,240	6.6	20,360	41.3	3,600	7.3	3,240	6.6													49,280
	2	950	0.5	40	0.0	5,070	2.7	3,420	1.8	35,175	19.0	114,090	61.6	24,200	13.1			2,400	1.3													185,345
	3			60	0.0	12,780	3.4	113,000	30.4	150,000	40.4	76,770	20.7	6,960	1.9			12,060	3.2													371,630
	4	51,325	15.7	10	0.0	210	0.1	80	0.0	24,550	7.5	42,960	13.1	33,080	10.1	9,900	3.0	165,360	50.5													327,475
2000	1	43,343	38.0	50	0.0	690	0.6	220	0.2	1,075	0.9	3,690	3.2	15,040	13.2	31,200	27.3	18,780	16.5													114,088
	2	3,270	0.5			11,895	1.7	22,980	3.2	300	0.0	80,460	11.3	426,440	59.7	150,050	21.0	18,360	2.6													713,755
	3	4,620	0.7			12,225	1.8	235,300	34.3	48,675	7.1	178,950	26.1	192,360	28.0	13,000	1.9	840	0.1													685,970
	4	690	0.2			48,345	16.9	75,940	26.6	6,075	2.1	31,050	10.9	38,720	13.6	28,900	10.1	55,680	19.5													285,400
2001	1	11,830	2.4	70	0.0	270	0.1	2,680	0.5	150	0.0	1,740	0.3	32,040	6.4	329,600	65.6	123,792	24.7													502,172
	2	380	0.1			60	0.0	560	0.1	225	0.0	95,784	13.0	329,752	44.8	247,450	33.7	61,140	8.3													735,351
	3	1,630	4.3	40	0.1	75	0.2	860	2.2	4,175	10.9	21,420	55.9	9,840	25.7	250	0.7															38,290
	4	690	1.3			15	0.0	40	0.1	25	0.0	30,420	55.7	10,640	19.5	900	1.6	11,880	21.8													54,610
Sum		981,242	11.7	9,603	0.1	554,453	6.6	971,907	11.6	511,899	6.1	1,768,474	21.1	1,924,298	22.9	1,084,565	12.9	556,811	6.6	1,979	0.0	10,027	0.1	830	0.0	1,962	0.0	6,019	0.1	1,685	0.0	8,385,755
No. of quarters		31		22		35		36		31		35		33		26		23		1		2		1		2		1		1		37

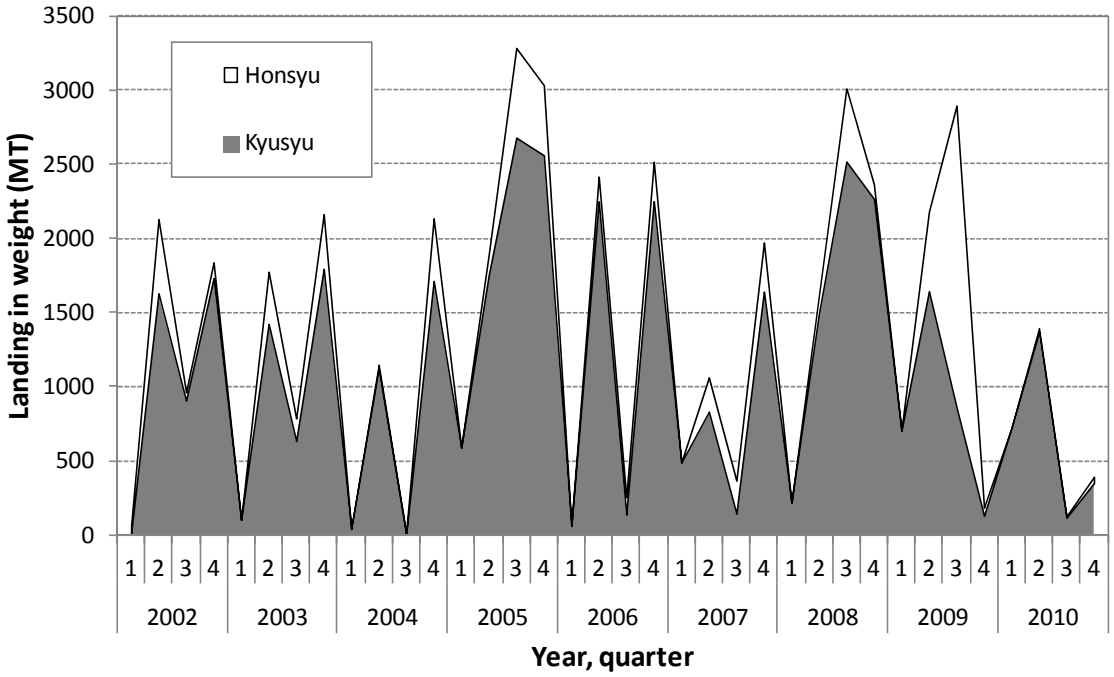


Fig. 1 Yearly and quarterly landing in weight of PBF.

(a) Multi-fish-per-box (b) One-fish-per-box

Fig. 2 Pictures of PBF landings in multi-fish-per-box (a) and one-fish-per-box (b). In the right picture, lateral figures of box show individual body weight.

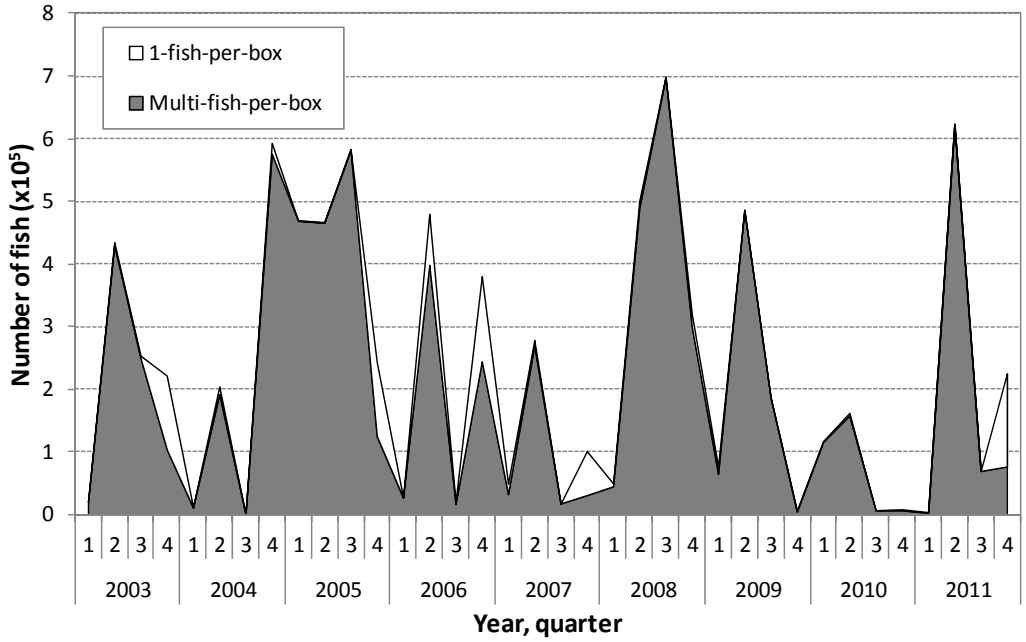


Fig. 3 Landing in number of PBF by box-category unloaded at the markets in Kyusyu region.

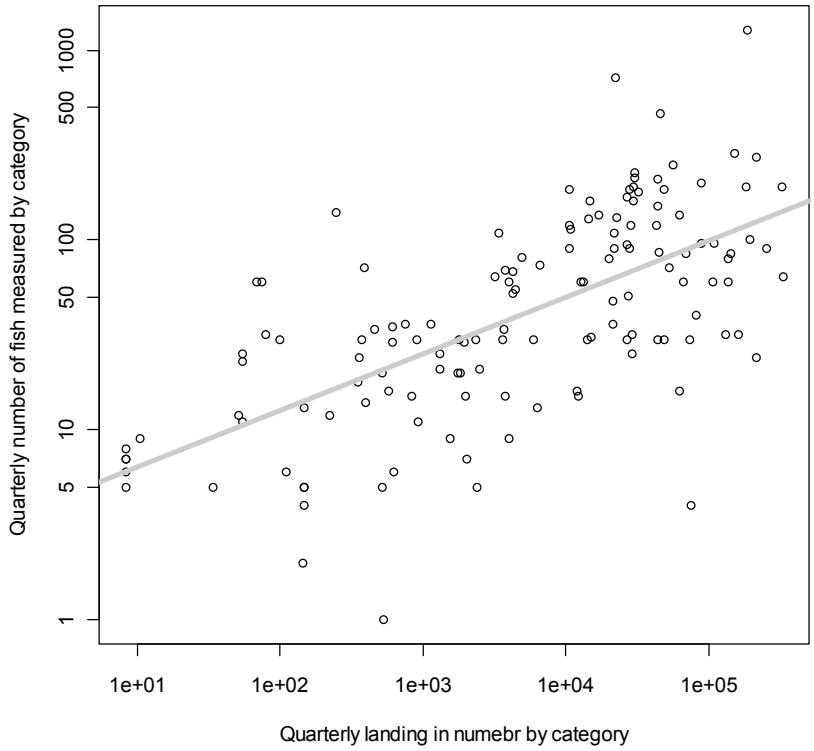


Fig. 4 Plot of quarterly number of fish measured by box-category against correspondent quarterly catch in number. X- and Y-axes are logarithmic axes. Gray thick line indicates regression line.

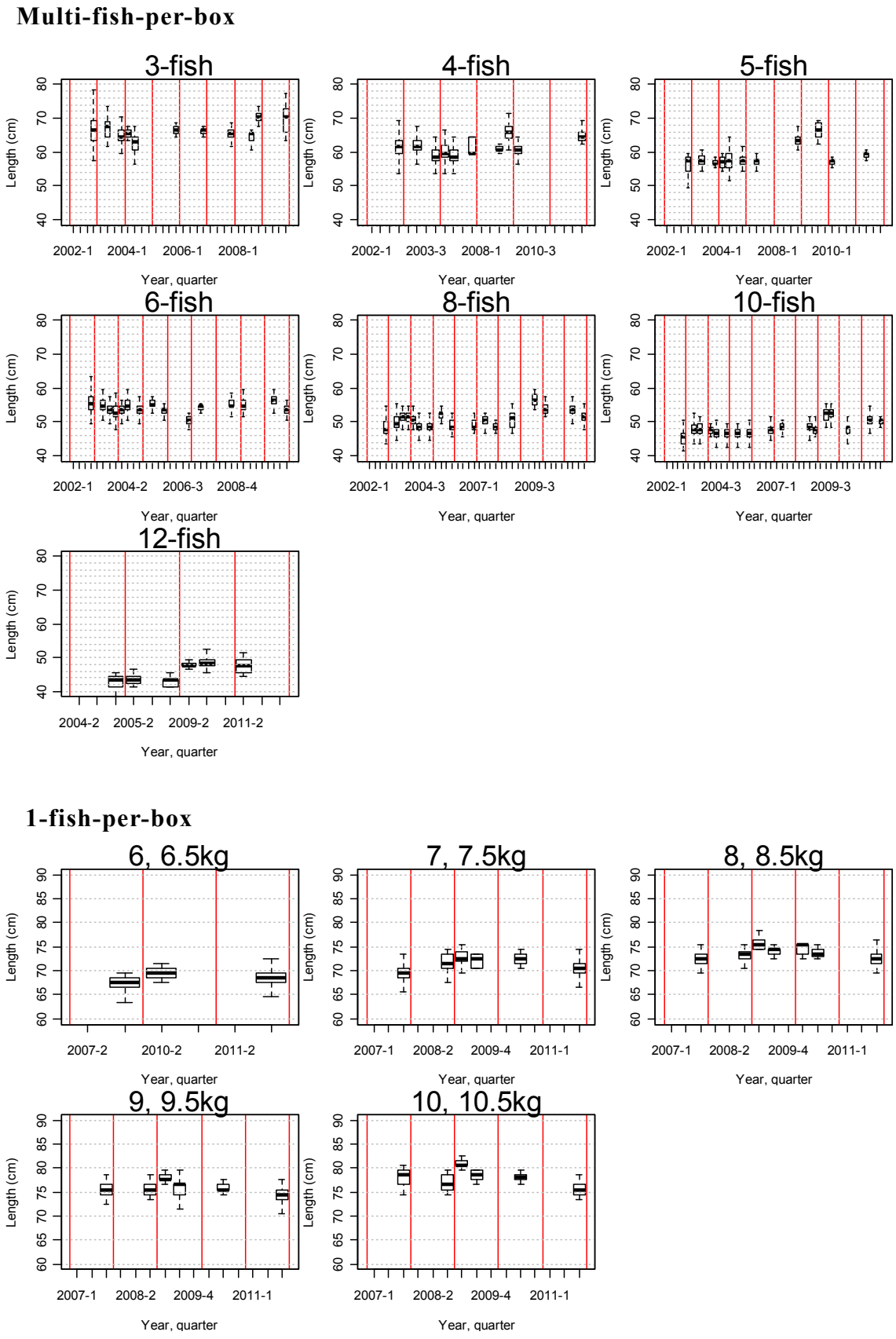


Fig. 5 Boxplots of length by quarter of PBF landings in each market size category. Vertical red lines indicate breakpoints between years.

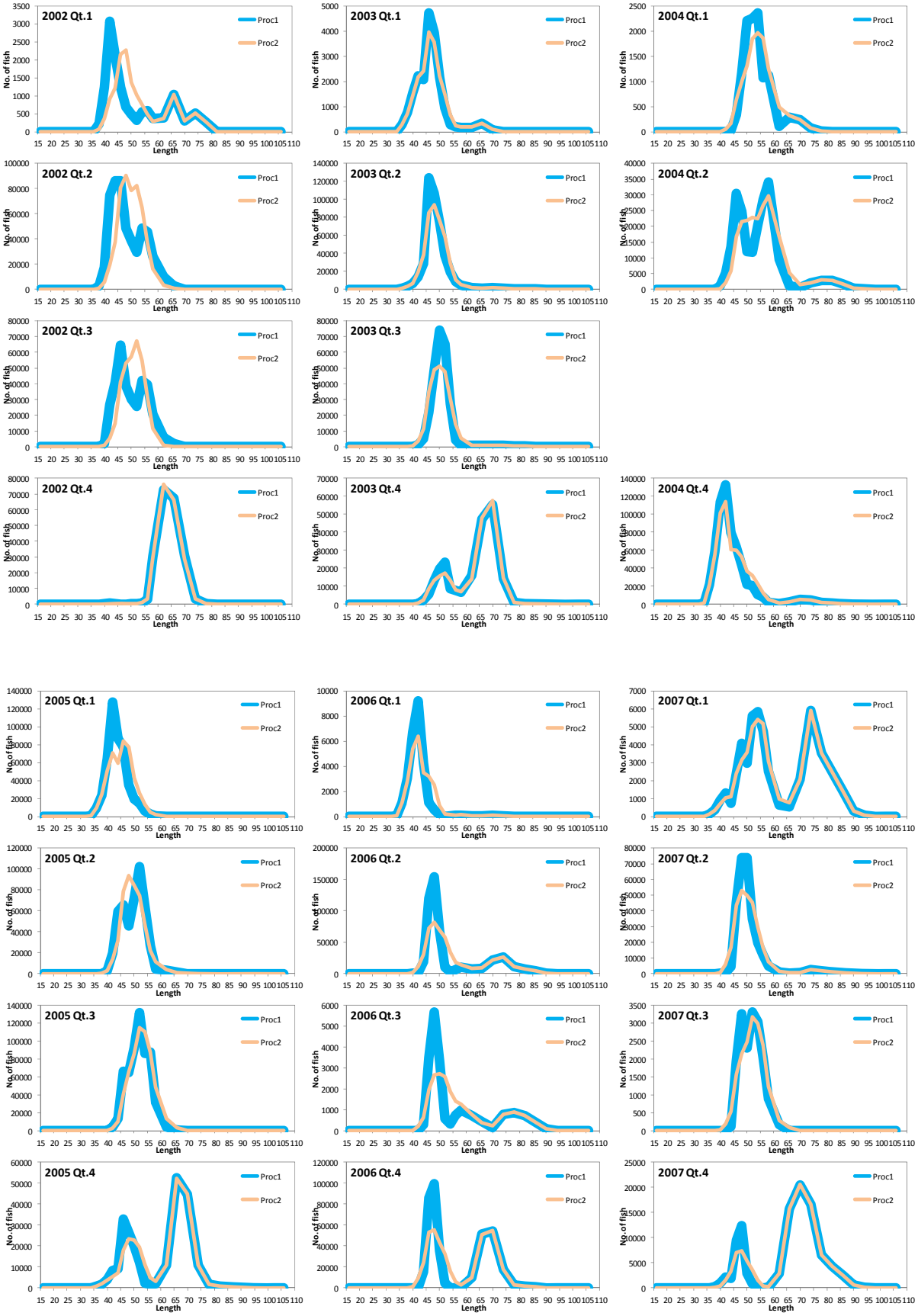


Fig. 6 Quarterly catches at size of PBF unloaded in Kyusyu region from 2002 through 2011 estimated through Procedures 1 and 2. Blue and orange lines indicate the frequency distributions derived from Procedures 1 and 2, respectively.

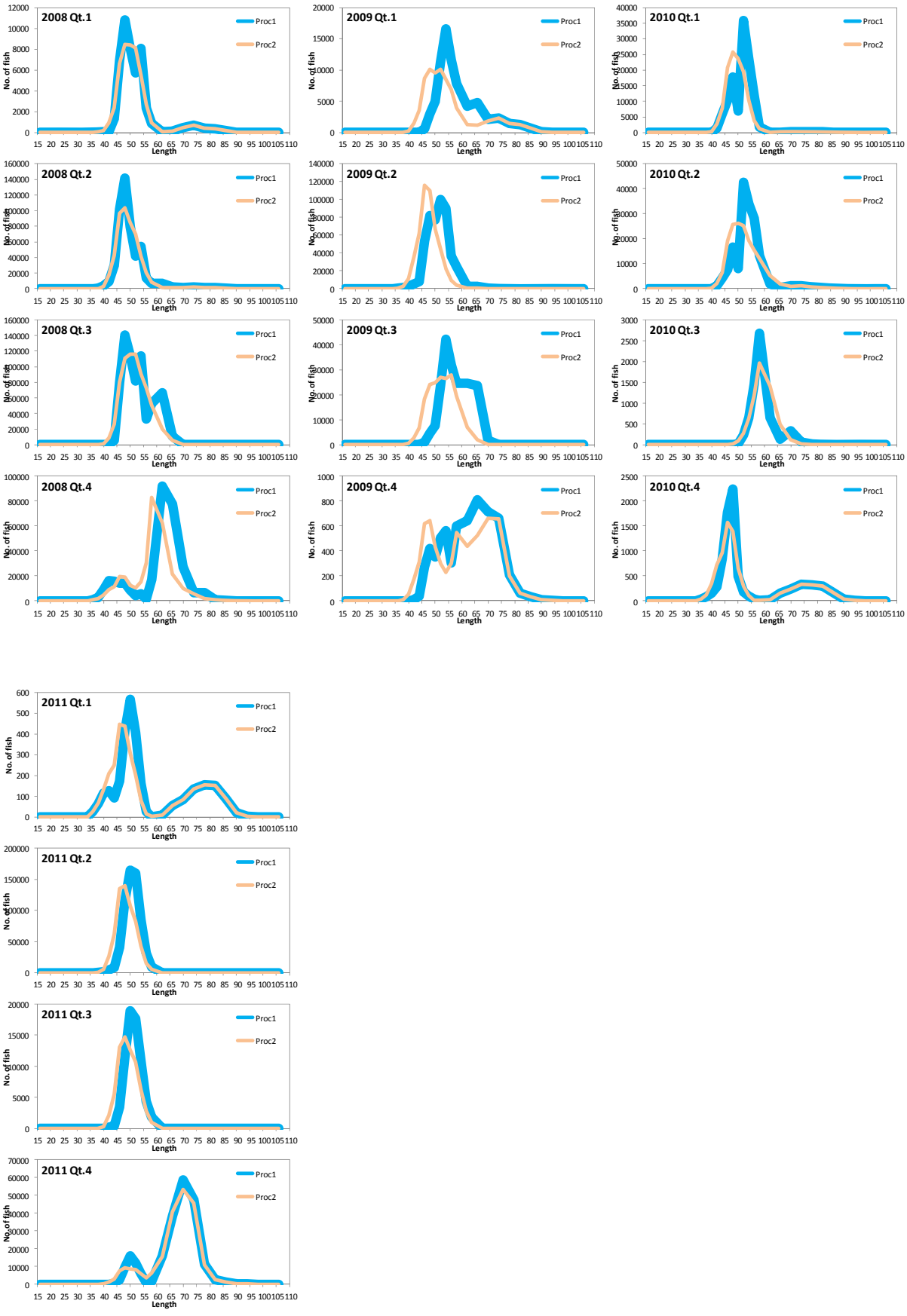

2008 Qt.1
2009 Qt.1
2010 Qt.1
2008 Qt.2
2009 Qt.2
2010 Qt.2
2008 Qt.3
2009 Qt.3
2010 Qt.3
2008 Qt.4
2009 Qt.4
2010 Qt.4
2011 Qt.1
2011 Qt.2
2011 Qt.3
2011 Qt.4
Proc1
Proc2
No. of fish
Length

Fig. 6 Cont.

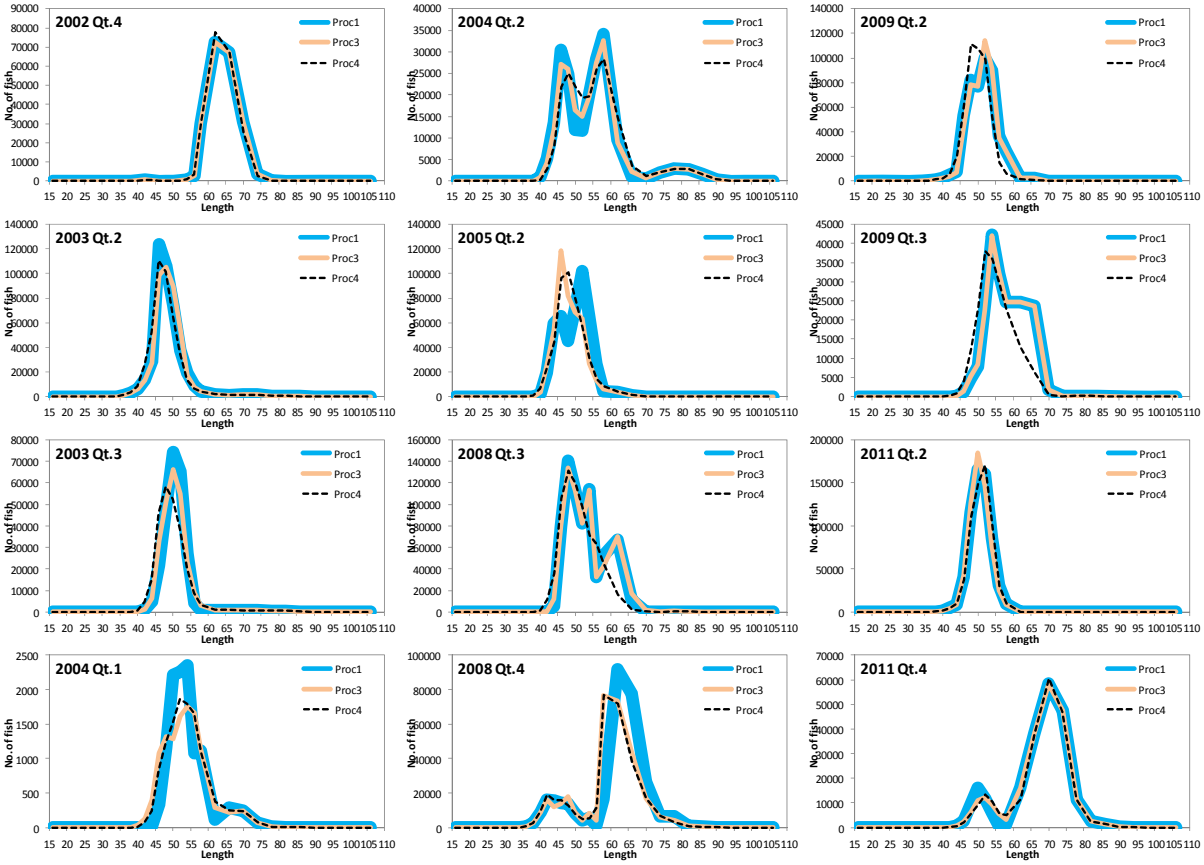


Fig. 7 Comparison of catches at size estimated through Procedures 1, 3 and 4 in the quarters when there were low data substitutions.

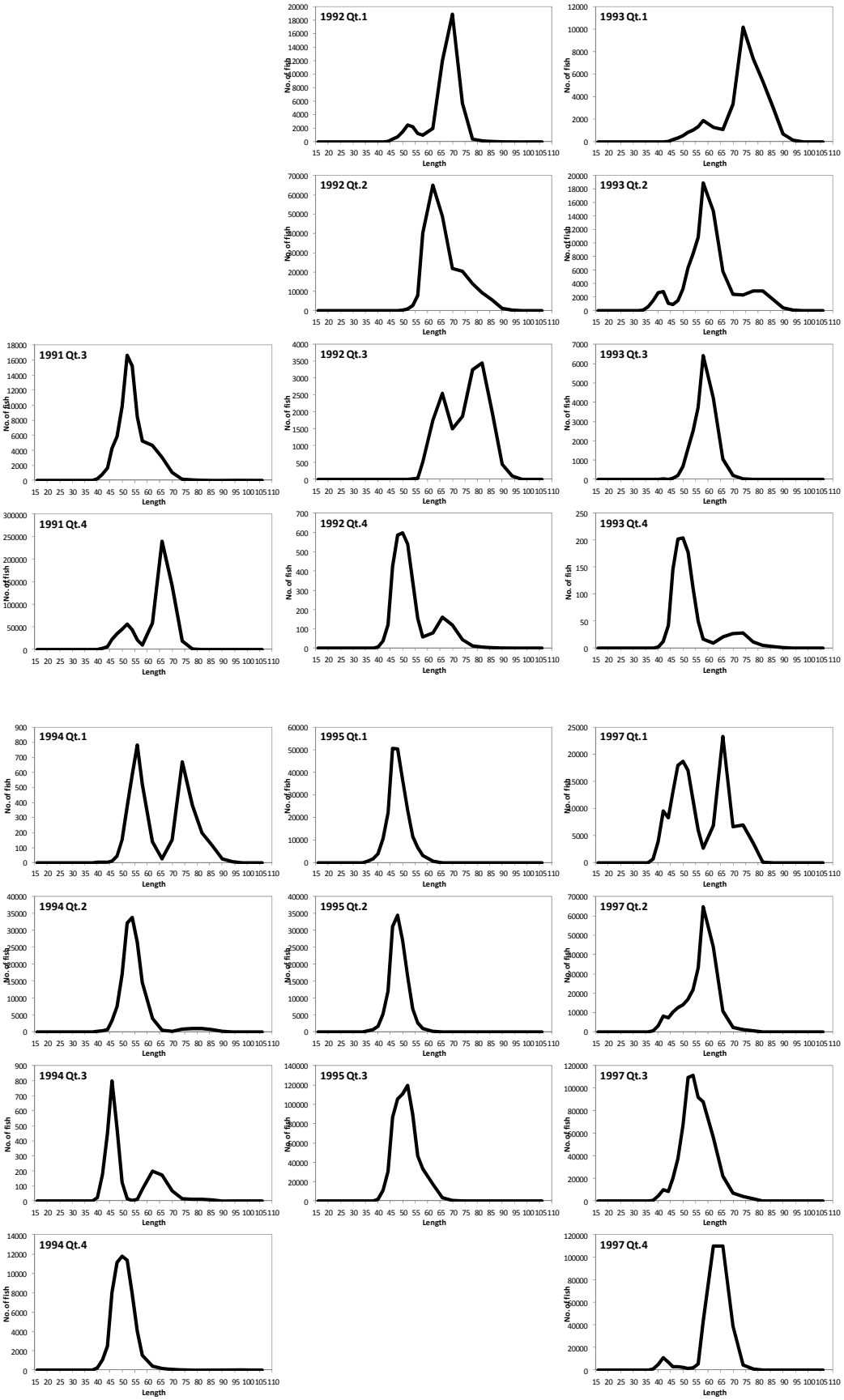
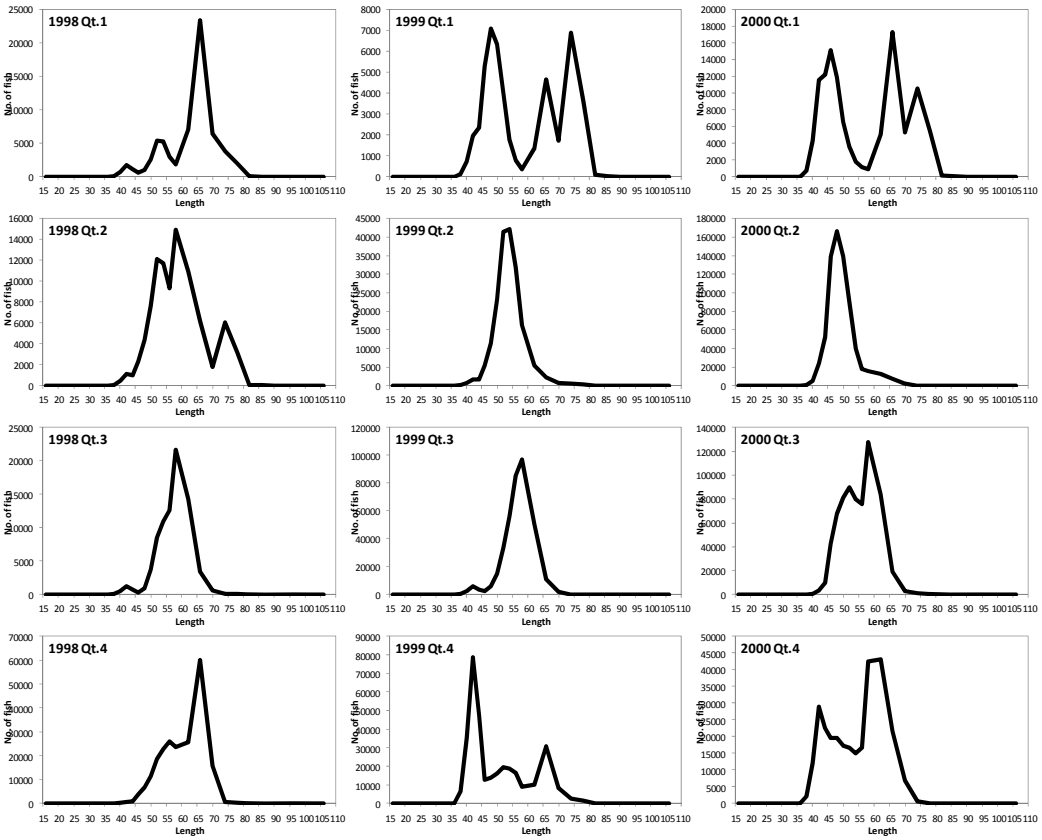


Fig. 8 Quarterly catch at size of PBF unloaded in Kyusyu region from 1991 through the 3rd quarter of 1995 and from 1997 through 2001 estimated through Procedure 4.


1998 Qt.1
1999 Qt.1
2000 Qt.1
1998 Qt.2
1999 Qt.2
2000 Qt.2
1998 Qt.3
1999 Qt.3
2000 Qt.3
1998 Qt.4
1999 Qt.4
2000 Qt.4
No. of fish
Length

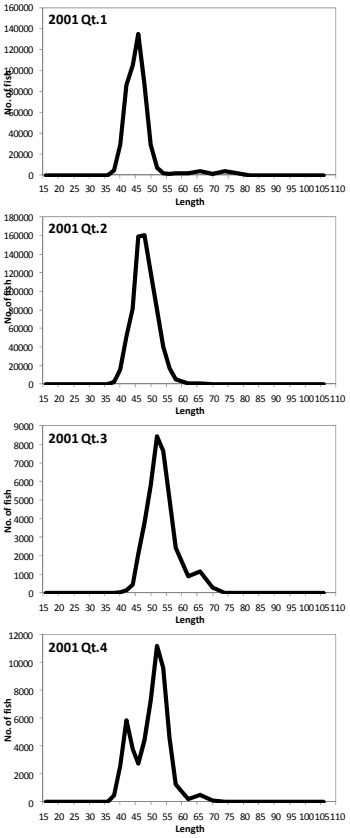

2001 Qt.1
2001 Qt.2
2001 Qt.3
2001 Qt.4
No. of fish
Length

Fig. 8 Cont.