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ミナミマグロ 1 歳魚の曳縄指数
– ピストンライン指数とグリッドタイプ曳縄指数の更新 –

Trolling indices for age-1 southern Bluefin tuna: update of the piston line index and the grid type trolling index

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要約

オーストラリア南西岸にて、2006 年から 2014 年、2016 から 2018 年に行われた曳縄調査および 1996 年から 2006 年に行われた音響調査の曳縄漁獲データから、ミナミマグロ 1 歳魚の 2 種類の資源量指数を求めた。一つは従来から報告しているピストンライン指数（TRI-P）である。もう一つは 2014 年に開発したグリッドベースの曳縄指数（TRI-G）で、両調査の全曳縄操業データを利用した、緯経度 0.1 度、日付、時間、海域別のグリッドにおける曳縄探索距離当たりのミナミマグロ 1 歳魚の群数である。探索合計距離約 54,159 km、ミナミマグロ 1 歳魚群数合計 928 群から求めたデータは、ゼロキャッチが多かったことから GLM のデルタログノーマルによる標準化をした。21 年間の TRI-G は、オペレーティングモデルで推定した加入量、日本延縄 CPUE から推定した加入量とトレンドがよく一致していた。TRI-P と TRI-G は CCSBT における資源評価に貢献できるものと考えられる。

Summary

Two recruitment indices of age-1 southern bluefin tuna *Thunnus maccoyii* was developed using trolling catch data in two surveys in the southwestern coast of Australia, the acoustic survey from 1996 to 2006 and the trolling survey from 2006 to 2014, and from 2016 to 2018. One index is the piston-line trolling index (TRI-P) which have been reported to CCSBT. The other is the grid-type trolling index (TRI-G) which was developed in 2014. TRI-G utilizes all of the trolling data that aggregated the trolling effort and the number of southern bluefin tuna schools caught by date, hour, area type, and 0.1 degrees square in latitude and longitude. Dataset included about 54,159 km total distance searched with 928 schools. GLM of delta-lognormal method was applied for CPUE standardization because of high percentage of zero catch data. Year trends of TRI-G in 21 years were agreed to those of recruitment estimates from the operating model and from standardized CPUE of Japanese longline. Trends of TRI-G

and TRI-P were similar to each other. TRI-G and TRI-P are expected to contribute to the CCBST stock assessment.

Introduction

Trolling survey for southern bluefin tuna (*Thunnus maccoyii*: SBT) aims to provide a recruitment index of the stock at age-1 from 2006 to 2014, and from 2016 and 2018. It has provided an index named the piston-line trolling index (TRI-P[1]) which have been reported to CCSBT (Itoh and Kurota 2006, Itoh 2007, Itoh and Sakai 2007, 2008, 2009, 2010, Itoh et al. 2011, 2012a, 2013, Itoh and Tokuda 2014, Itoh and Tsuda 2016, 2017). In addition, trolling survey operated trolling in other area of the piston line. Large area was also surveyed with trolling operation in the acoustic survey between 1996 and 2006. Using these data, a standardization of the trolling survey index (TRI-G) was developed in 2014 (Itoh and Takahashi 2014). The updated TRI-P and TRI-G are provided in this paper.

Materials and methods

1. Piston-line Trolling Index　TRI-P

Trolling catch data on the piston-line in the acoustic survey in 2005 and 2006 and in the trolling survey between 2006 and 2014, and from 2016 to 2018, were used for analysis. Details of the survey were described in other papers that submitted every year (e.g. Itoh et al. 2013, 2016, Tsuda and Itoh 2017, 2018). It contains data in total of 191 times on the piston-line (Table 1). Data of another ten times were not included because the line was abandoned due to mainly rough sea conditions. Datasets were separated between the acoustic survey and trolling survey because there were differences in the two surveys for survey design, vessel used especially in size and specification of trolling gears. Trolling operations on the piston-line were repeated from 9 to 20 times per year.

The piston-line was set off Bremer Bay, in the middle of the whole area for acoustic and trolling surveys (Fig. 1). The exact locations have been changed a few times since its first determination in 2005 (Fig. 2). In 2006, the piston-line was moved eastward to avoid the array of a hydrophone for acoustic tags deployed in the acoustic tagging research project on SBT (Fujioka et al. 2010). In 2007, the piston-line was cut its offshore portion where few fish had caught in previous years and extended toward coast. The small vessels used for the trolling survey allowed operation in closer area to the coast, while the large vessel used for the acoustic survey lasted up to 2006 could not. In 2008, the piston-line was moved west in order to avoid

[1] TRI-P and TRI-G are previously called the piston-line trolling index (PTI) and the grid-type trolling index (GTI), respectively. New designations of TRI-P and TRI-G are used to avoid confusion with gene tagging (GT) in CCSBT.

the array of a hydrophone for acoustic tags and to bring closer to the bay the vessel spent at night. The locations of the piston-line have been same since 2008 to 2018.

The piston-line in 2005 and 2006 had a larger part of offshore than after 2007. We made adjustment that the distance of the piston-line in offshore is same as that in 2007 and removed some effort data in 2005 and 2006. There was no SBT catch that removed by this adjustment. No correction was made on the coastal portion of the 2005 and 2006 piston-line.

The summary of data after correction was made for location of offshore point of the piston-line, as well as several records on time was shown in Table 2. It reached a total of 441.6 hours in search time and 5,693 km in search distance. The number of SBT caught was 745 individuals.

Piston line trolling index (TRI-P) was calculated as catch of age-1 SBT per 100 km search distance. There were five types of catch definition and TRI-Ps were calculated for each of them.

(1) School of age-1 SBT. A catch of age-1 SBT that apart from 2 km in distance from last catch of age-1 SBT is defined as a different school. TRI-P from this definition is "TRI_2km."

(2) School of age-1 SBT. A catch of age-1 SBT that apart from 20 minutes in time from last catch of age-1 SBT is defined as a different school. TRI-P from this definition is "TRI_20min."

(3) School of age-1 SBT. A catch of age-1 SBT that apart from 30 minutes in time from last catch of age-1 SBT is defined as a different school. TRI-P from this definition is "TRI_30min."

(4) Number of times age-1 SBT caught. All the catches even it was likely to be from the same school was counted as different. TRI-P from this definition is "TRI_Times."

(5) Number of age-1 SBT individuals. TRI-P from this definition is "TRI_ind."

Confidence intervals of TRI-P were calculated from data sampled 1000 times by bootstrap method, and the results were shown by box plots or median, 5% and 95% points.

Usually, piston-line was surveyed two times per day. It was evaluated whether the two datasets of the same day, outward run and inward run, can be assumed to be independent. If two datasets in the same date were strongly correlated, the variance between them would be small. So, limit the data in a year for both outward and inward runs were operated in the same day. Chose data randomly with 1000 times bootstrap in following two cases and compared the

variability of estimates. One case was that for example, it was three days, chose three days randomly and used data in both outward and inward runs of these days to calculate TRI-P. Another case was that chose six days randomly and used data either outward or inward run (it also chose randomly) to calculate TRI-P.

2. Grid-type Trolling Index　TRI-G

Data were from trolling catch in the acoustic survey between 1996 and 2003, 2005 and 2006, and the trolling survey between 2006 and 2014, and from 2016 and 2018. The surveys were carried out in the period from December to March, and year was represented in the year at January in this paper.

Search distance of trolling, catch of age-1 SBT and CPUE (catch/100km searched) were aggregated by survey type (acoustic survey / trolling survey), year, month, day, hour, longitude (0.1 degree), latitude (0.1 degree) and five area types (described later). Data west of 117.5E were removed.

Time intervals of recording of latitude and longitude differed by year. Up to 2005, latitude and longitude were only recorded when any events occurred, including hourly environmental observation, catch, detection of anything in sonar, arrival of transect reflection point, CTD observation, etc. Then, locations at every one minute were calculated by interpolating two points available. Since 2006, locations were recorded in short interval such as 10 or 15 seconds by GPS logger devises and mean locations by one minute were used for analysis.

In the acoustic survey, it was planned that trolling was operated in daytime from 6 AM to 6 PM. Actual times of start and end of trolling were not recorded. Some records of catch before 6 AM and after 6 PM were removed. In the trolling survey, all the times of start and end of trolling operations were recorded.

Catch was limited for age-1 SBT (40-63 cmFL) in the analysis. Catch was defined as a fish school and schools were defined as that successive catches more than 30 minutes were from different schools.

In the research area, SBT distribution was distinctly different by area type which categorized as follows (Fig. 1).

Lump: Small seamounts or small islands. Its center position was measured on nautical charts. A range of effect of each of lumps was assumed by observing contour of depth and SBT catch locations. Lumps specified for analysis were "BaldIs27", "lumpA40", "lumpB36", "lumpC35", "lumpD48", "lumpE5", "lumpF50", "lumpG35", "lumpH49", "BBeast50", "BBeast16", "Investigator Island", "West Group (Figure of Eight) ". The figures came from depth of its summit.

Mauda Reef: A large lump off Albany. It was treated separately because it was very large in size and surveyed in many years.

Shelf edge: A range near 200 m isobath. The range was determined from observing SBT catch records that 3.0 km toward inshore and 0.5 km toward offshore. Two People Canyon off Albany, a large sea canyon, was included in shelf edge.

On shelf: northern area of the shelf edge.

Offshore: southern area of the shelf edge.

Delta model was applied for CPUE standardization because of high percentage of zero observations (Lo et al. 1992, Li and Jiao 2013). The delta model handles zero data and positive catch data in two separate sub-models, i.e. one sub-model to estimate the probability of catching SBT age-1 (probability sub-model) with an assumption of binomial distribution and logit link function, and the other to fit the positive catch data (positive catch sub-model) with an assumption of lognormal distribution. Product of estimates from these two sub-models gives the final estimate of the Grid-type Trolling Index (TRI-G). In this GLM standardization, the explanatory variables were selected through a stepwise approach based on the AIC.

AIC selected probability sub-model:

log(p/(1-p)) ~ year + month + area + offset(log(distance)) + error

error ~ binomial

where p is the probability of positive catch.

AIC selected of positive catch sub-model:

log(catch) ~ year + area + offset(log(distance)) + error

error ~ gaussian

The program codes were corrected from previous one in a few points, including for the standardization model and LS-mean calculation. Bootstrap method was applied to obtain a range of estimate. 1000 datasets were made through stratified sampling by year.

The trolling indices, TRI-P (piston-line indices from acoustic survey (TRI-P(acoustic)) and trolling survey(TRI-P(troll)) and TRI-G, were compared to various recruitment indices: recruitment estimated from the 2017 stock assessment based on the reference set operating model (OM), recruitment indices from CPUE age-4 and 5 (CCSBT-OMMP/1806/09), and aerial survey index in the 2017 data exchange, respectively.

R software (version 3.3.0) was used for analysis (R-core team 2012).

Results

1. Piston-line Trolling Index: TRI-P

Figure 3 and Table 3 show the five types of estimated TRI-P by different school/catch definition. Figure 4 shows the median of the five types indices that adjusted to the mean of each. Since no age-1 SBT in 2018 trolling survey was caught on the piston line (CCSBT/1809/26), Trolling Index of Piston-line (TRI-P) in 2018 became zero. The small differences were observed among the five type indices between 2006 and 2010 and there was large difference between school indices (TRI_20min, 30min and 2km) and catch indices (TRI_times and ind.) in 2013. The relative index of TRI_30min was consistent with the index from acoustic survey in 2006. The fluctuation in TRI_30min over time was smaller among the five types of indices. Therefore, the TRI_30min index was submitted to CCSBT data exchange as trolling index of piston-line.

2. Grid-type Trolling Index: TRI-G

Summary of data aggregated by grid is shown in Table 4. It consists of 11,008 records in total that reach about 54,159 km search distance and 928 SBT age-1 schools. One record with anomalously high CPUE (>2000) with a short distance was removed for analysis. Quite a large part of data was zero catch (91.6%).

Distributions of effort catch and CPUE are shown by year (Fig. 5). It is noted that substantial efforts were made in other area than the piston-line except 2007. It is also noted that few catches were observed in offshore area despite substantial amount of efforts had been made (Table 5).

Nominal CPUE is shown in Fig. 6. Note that a substantial part of effort was made up offshore where few SBT caught from 1996 to 2005. It must be underestimated in this period compared to later half period.

Relationship between probability of catch and various variables and between CPUE and various variables are shown in Fig.7 and 8, respectively. The estimated values are shown in Table 6 and 7. QQ plot is shown in Fig. 9. LS-means for year trend in each sub-model are shown in Table 8 and Table 9. Year trend of the probability sub-model was transformed with logit function and that of the positive catch sub-model was transformed with exponential function. Indices of both sub-models and point estimation of standardized Grid-type Trolling Index (TRI-G) are shown in Table 10 and Fig. 10.

Table 11 and Fig. 12 show standardized TRI-G with confidence interval calculated through

1000 times bootstrap. TRI-G showed considerable low levels in 2000-2003, then increase in 2005-2008 and relatively high level in 2006-2016 with large fluctuation from year to year. Recent two years (2017-2018) were back to relatively low levels near the values in 2003.

3. Comparison to other indices

OM recruitment

Figure 12 shows comparison between recruitment estimated from the 2017 stock assessment based on the reference set operating model (OM) and TRI-G by year class (YC). The general trend of TRI-G is similar to that of OM recruitment. Historical low levels in 1999-2001 are caught by TRI-G and relatively high levels after 2005YC. The relative values of TRI-G in 2004-2010YC were higher than the recruitment by OM. In detail, the year fluctuations of TRI-G were consistent well with that of OM recruitment except for some years such as at 1998YC, 2006-2008YC, 2013YC and 2015-2016YC. Hence, a high value in 2013YC estimated by OM was not captured by the TRI-G.

Aerial survey

Figure 13 shows comparison between aerial survey index and TRI-G. Aerial survey index is a mix of age-2, age-3 and age-4. In the figure, age-3 was assumed to assign a year class of the aerial survey index. The trends of both TRI-G and the aerial survey index were not similar to each other over time. Note that aerial survey index was not obtained around 2000YC when extremely low recruitment observed. The high value in 2013YC in aerial survey was not captured by the TRI-G.

Recruitment indices from age-4 and 5 CPUE

Figure 14 shows comparison between recruitment indices from age-4 and age-5 CPUE in Japanese longline (CCSBT-OMMP/1806/09) and TRI-G. The low level of TRI-G in 1999-2001 YC and the high level after 2005YC were supported by both CPUEs. TRI-G has a yearly difference with the age-4 CPUE. On the other hands, the increase and decrease of both TRI-G and age-5 CPUE were very similar. Especially in 2008-2012 YC when the CPUE data available recently, they almost agreed. Additionally, the fluctuations of TRI-G differed from that of CPUEs such as 2006-2007YC and 2011-2012YC in age-4 CPUE and 2006-2007YC in age-5 CPUE.

4. Discussion

The present paper provided updated Piston-line trolling index (TRI-P) and Grid-type trolling index (TRI-G). Both Trolling indices are based on catch that is the number of schools.

When we encountered SBT school in the survey, the numbers of fish individuals caught and catch times could have increased if we handled the trolling line well and/or the vessel moved well to catch up or attract the school. The numbers of fish individuals caught and catch times was decreased when suspended fishing operation such as several trolling lines was tangled at one catch and we needed some time to solve the tangling. The numbers of fish individuals or catch time were affected such crew skills of trolling. The number of schools was selected as catch to avoid the influence of crew skill. However, definition of catch as school for index means to set an assumption that the probability distribution of the size of school (the number of individuals per school) is same every year.

There were various types of school definition. We explored three definitions; two subsequent catches are from different schools if 20 minutes apart, 30 minutes apart, and 2 km apart. Definition by time may be inappropriate because it is affected by crew skill on trolling gear and definition by distance seems more appropriate. Detail location data in every 10 seconds have been available since 2006 by using GPS data logger. However, because detail location records were not available in the period from 1996 to 2005, the 30 minutes definition was chosen to keep the consistency. Fortunately, no large difference was observed among trends of index in different catch definition.

TRI-P has a potential problem that it has an upper limit because the piston-line has a determined distance. At present, the trolling survey operates the piston-line with about 34 km in 2 hours 36 minutes on average. When school definition is 30 minutes, six schools and TRI-P = 17.1 becomes upper limit. If catches were repeated less than 30 minutes interval, it would result in the number of schools caught as 1 and TRI-P = 2.8, despite there have been many catches. However, up to now, TRI-P trends were similar among various types of catches, including 30 minutes, catch times and number of individuals, and suggests such an extreme situation did not occur.

TRI-P was nominal value indices that not standardized like as using GLM. It does not need standardization because the survey itself was standardized that the vessel used, specification of trolling gears and survey methods have been identical for eleven years and survey was carried out in almost same area and season. TRI-P was separated so far that from the acoustic survey (TRI-P(acoustic)) and that from the trolling survey (TRI-P(troll)). In the GLM of TRI-G, the difference of the survey type was not significant. It may be appropriate to combine the two TRI-Ps into one.

TRI-G is a comprehensive index that includes not only the piston-line but also all the area surveyed. TRI-P is derived for 12 years since 2005. TRI-G enabled to extend the years to as long as 21 years, by adding the trolling in acoustic survey from 1996 to 2003. The acoustic survey and the trolling survey were not originally designed to obtain TRI-G. However, because

the acoustic survey was well designed to cruise randomly in the research area for sonar detection, the trolling catch operated simultaneously in daytime is expected to be a random sampling in the area. While the survey area was concentrated on the piston-line in 2006 and 2007, the trolling survey was also operated in larger area since 2008 intending development of TRI-G. When trolling was operated on a lump, we tried to operate trolling also in the area out of the lump so that collect data to evaluate the SBT distribution difference in area types.

In GLM standardization, the delta method which frequently used for data with high percentage of zero observation was used. Area type was highly significant in the probability sub-model. It is well known the effect of sea bottom topography, such as lumps, on SBT distribution (Hobday and Campbell 2009). It should fully consider the effect of lumps and islands on SBT distribution for survey design. Tsuda and Itoh (2017) showed weather conditions have negligible effect on the standardization of TRI-G (CCSBT-ESC/1708/24). However, ocean environmental conditions might affect on the distribution and residence time of SBT in survey area. Therefore, it should consider incorporating environmental variables such as sea surface temperature and chlorophyll into the standardization of the model.

Trend of TRI-G was similar to that recruitment from OM and age-4 and 5 CPUE of Japanese longline. The correlation was depending on broader scale agreement that medium level in year classes in the mid-1990s, low level in the 2000YC-2002YC and high level since 2005YC. In detail, TRI-G agreed very well with age-5 CPUE between 2008-2012YC that age-5 CPUE data available at this time. However, some differences were observed among OM, the longline CPUE and TRI-G in recent year class, especially in 2006-2007YC and 2011YC. It is necessary to investigate the cause of differences in those year class. Also, by investigating the differences, it will be possible to further improvement in the standardization of the TRI-G and CPUE series. The trends of both TRI-G and the aerial survey index were not similar to each other over time. Especially the high recruitment in 2013 YC from aerial survey index is not supported by TRI-G.

TRI-P and TRI-G in recent two years (2017 and 2018) indicate the low recruitment level in 2017YC and 2018YC. Now, we cannot verify those low recruitments because the information are limited. Therefore, it is necessary to carefully monitor the recruitment information such as estimation of age-2 abundance by gene tagging and age-4 and 5 CPUE in the next few years.

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Table 1. Number of times piston-line surveyed

Year	Total	Used for index	Incomplete and not used for index
Acoustic Survey			
2005	21	20	1
2006	22	18	4
Trolling Survey			
2006	16	12	4
2007	14	14	
2008	10	10	
2009	11	10	1
2010	11	11	
2011	12	12	
2012	14	14	
2013	13	13	
2014	14	14	
2016	14	14	
2017	10	10	
2018	9	9	
Total	191	181	10

Table 2. Summary data on piston-line survey

Acoustic survey

Year	Value	Search hours	Search distance (km)	Date	Start time	End time	sch20min	sch30min	sch2km	hit.times	number SBT	Index sch20min	Index sch30min	Index sch2km	Index hit.times	Index numbser SBT
2005	min	1:57	30.3	2005/1/15	5:45	8:10	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:26	30.3	2005/2/15	12:23	14:23	2	2	3	5	11	6.61	6.61	9.92	6.53	6.36
	mean	2:09	30.3	2005/1/30	8:38	10:47	0.70	0.60	0.80	1.00	2.00	2.31	1.98	2.64	3.31	6.61
	total	1.804	605.0				14	12	16	20	40					
2006	min	1:52	29.7	2006/1/15	6:11	8:14	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:50	29.7	2006/2/13	14:54	16:50	3	2	6	12	27	10.11	6.74	20.22	40.43	90.97
	mean	2:07	29.7	2006/1/27	10:13	12:21	1.61	1.39	2.50	4.33	7.89	5.43	4.68	8.42	4.60	6.58
	total	1.595	534.2				29	25	45	78	142					

Trolling survey

Year	Value	Search hours	Search distance (km)	Date	Start time	End time	sch20min	sch30min	sch2km	hit.times	number SBT	Index sch20min	Index sch30min	Index sch2km	Index hit.times	Index numbser SBT
2006	min	2:08	26.8	2006/1/23	5:15	7:30	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:47	29.8	2006/1/30	11:07	17:45	4	3	4	7	16	13.77	11.52	13.77	23.58	61.42
	mean	2:24	28.6	2006/1/26	8:26	11:59	1.42	1.25	1.58	3	6	4.98	4.41	5.59	9.66	21.54
	total	1.193	349.2				15	13	17	26	62					
2007	min	2:14	28.7	2007/1/22	6:46	9:46	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:15	36.1	2007/1/28	11:31	18:18	5	5.1.43	6	7	21	16.63	16.63	18.11	23.49	69.83
	mean	2:44	32.5	2007/1/25	8:53	13:41	1.93	20	2.36	3	7	6.13	4.55	7.51	9.84	22.53
	total	1.600	455.0				27		33	43	98					
2008	min	2:32	31.6	2008/1/21	6:55	9:53	1	1	1	1	1	2.81	2.81	2.81	2.81	2.89
	max	3:14	35.9	2008/1/31	14:26	18:05	3	3	3	3	7	8.61	8.61	8.61	8.89	19.72
	mean	2:47	34.6	2008/1/25	9:22	13:37	1.70	1.70	1.90	2.10	4.70	4.92	4.92	5.49	6.07	13.52
	total	1.160	346.4				17	17	19	21	47					
2009	min	2:16	30.7	2009/1/18	6:23	8:46	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:55	35.9	2009/1/28	12:06	17:04	3	3	3	5	114	9.76	9.76	9.76	14.59	32.11
	mean	2:41	34.3	2009/1/21	8:19	12:28	1.30	1.20	1.30	1.70	3.70	3.87	3.58	3.87	5.02	10.86
	total	1.120	343.2				13	12	13	17	37					
2010	min	2:27	33.7	2010/1/20	5:22	8:02	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:04	36.3	2010/1/31	13:32	16:06	2	2	3	8	11	5.93	5.93	8.69	23.72	31.85
	mean	2:40	34.7	2010/1/26	8:17	11:57	1.00	0.91	1.18	2.09	3.36	2.88	2.62	3.41	6.10	9.77
	total	1.224	381.5				11	10	13	23	37					
2011	min	2:20	27.6	2011/1/26	5:28	8:28	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:20	35.3	2011/2/8/	10:32	17:46	4	4	6	10	18	14.47	14.47	18.00	30.01	65.12
	mean	2:46	33.6	2001/1/31	7:41	12:22	2.08	1.67	2.25	3.08	5.92	6.33	5.11	6.77	9.37	18.52
	total	1.387	402.8				25	20	27	37	71					
2012	min	2:31	33.8	2012/1/25	5:21	5:21	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:27	36.2	2012/2/7	13:27	13:27	2	2	2	2	5	5.77	5.77	5.77	5.77	14.42
	mean	2:52	35.3	2012/1/31	7:50	7:50	0.57	0.57	0.64	0.64	0.93	1.63	1.63	1.83	1.83	2.66
	total	1.672	493.6				8	8	9	9	13					
2013	min	2:38	33.8	2013/1/19	5:56	5:56	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:21	36.0	2013/1/31	12:21	12:21	2	2	3	13	18	5.69	5.69	8.42	37.72	52.23
	mean	2:49	35.2	2013/1/24	8:34	8:34	1.54	1.31	1.69	3.62	7.38	4.34	3.70	4.78	10.26	20.95
	total	1.530	458.0				20	17	22	47	96					
2014	min	2:30	34.3	2014/1/26	6:04	8:55	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	3:04	35.7	2014/2/7	11:54	14:29	3	2	4	7	7	8.41	5.83	11.21	19.62	20.23
	mean	2:46	35.0	2014/1/31	1:53	5:23	1.14	1.00	1.36	1.71	2.36	3.26	2.86	3.88	4.88	6.74
	total	1.615	490.0				16	14	19	24	33					
2016	min	2:22	33.1	2016/1/27	5:40	8:09	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:53	35.2	2016/2/8	12:30	16:54	3	3	3	3	9	8.74	8.74	8.74	8.74	25.60
	mean	2:37	34.6	2016/2/2	8:14	11:40	1.50	1.36	1.57	1.71	3.57	4.33	3.92	4.54	4.95	10.26
	total	1.529	484.5				21	19	22	24	50					
2017	min	2:12	33.4	2017/1/31	6:22	9:12	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:35	37.0	2017/2/7	9:05	11:40	2	2	2	2	5	5.76	5.76	5.76	5.76	14.96
	mean	2:24	34.9	2017/2/2	3:48	7:08	0.60	0.60	0.60	0.60	1.90	1.71	1.71	1.71	1.71	5.44
	total	1.005	349.2				6	6	6	6	19					
2017	min	2:16	33.2	2018/2/4	6:15	9:16	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:35	35.4	2018/2/12	14:53	17:12	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	mean	2:23	34.6	2018/2/7	10:59	13:33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	total	0.894	311.1				0	0	0	0	0					

Exclude the data not used for TRI-P. Unit of total search hours is day.

Table 3. Piston-line Trolling Index value

index	Survey	Year	Minimum	5%	Median	95%	Maximum
sch20min	Acoustic	2005	0.496	1.322	2.314	3.471	4.297
	Acoustic	2006	3.369	4.493	5.429	6.364	7.113
	Trolling	2006	1.994	3.380	4.841	6.562	8.552
	Trolling	2007	2.783	4.320	6.139	8.052	10.486
	Trolling	2008	2.860	3.980	4.918	5.898	6.893
	Trolling	2009	1.407	2.422	3.851	5.530	7.301
	Trolling	2010	1.044	1.858	2.881	3.923	4.713
	Trolling	2011	2.661	4.400	6.334	8.467	10.226
	Trolling	2012	0.202	0.816	1.625	2.448	3.298
	Trolling	2013	2.405	3.480	4.344	5.010	5.633
	Trolling	2014	1.226	2.242	3.257	4.260	5.452
	Trolling	2015					
	Trolling	2016	1.653	2.915	4.337	5.625	7.026
	Trolling	2017	0.270	0.829	1.702	2.829	3.730
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
sch30min	Acoustic	2005	0.331	1.157	1.983	2.975	3.801
	Acoustic	2006	3.182	3.931	4.680	5.429	5.990
	Trolling	2006	2.007	3.111	4.278	5.422	6.388
	Trolling	2007	1.299	2.859	4.434	6.624	9.066
	Trolling	2008	3.130	4.013	4.917	5.900	6.665
	Trolling	2009	1.408	2.271	3.559	5.125	6.240
	Trolling	2010	0.787	1.587	2.612	3.466	4.409
	Trolling	2011	2.668	3.444	5.088	7.019	8.749
	Trolling	2012	0.397	0.815	1.622	2.429	2.872
	Trolling	2013	2.364	2.835	3.703	4.370	5.007
	Trolling	2014	1.220	2.051	2.863	3.683	4.493
	Trolling	2015					
	Trolling	2016	1.430	2.536	3.936	5.245	6.624
	Trolling	2017	0.000	0.836	1.705	2.614	3.727
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
sch2km	Acoustic	2005	0.331	1.322	2.644	3.967	5.289
	Acoustic	2006	5.054	6.364	8.236	10.670	13.478
	Trolling	2006	2.258	3.418	5.130	6.977	8.554
	Trolling	2007	3.252	5.151	7.438	10.010	12.207
	Trolling	2008	3.205	4.533	5.499	6.464	7.416
	Trolling	2009	1.136	2.333	3.848	5.486	7.415
	Trolling	2010	1.068	2.111	3.415	4.770	6.299
	Trolling	2011	3.107	4.578	6.761	9.146	12.101
	Trolling	2012	0.397	0.998	1.822	2.820	3.682
	Trolling	2013	2.392	3.696	4.773	5.845	6.704
	Trolling	2014	1.627	2.467	3.840	5.274	6.689
	Trolling	2015					
	Trolling	2016	1.865	3.084	4.543	5.970	7.005
	Trolling	2017	0.279	0.836	1.702	2.829	3.485
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
hit.times	Acoustic	2005	0.331	1.653	3.306	5.124	7.107
	Acoustic	2006	7.488	9.921	14.414	19.468	25.083
	Trolling	2006	3.108	5.921	9.881	13.977	19.143
	Trolling	2007	3.063	6.389	9.570	13.416	17.369
	Trolling	2008	3.694	4.834	6.072	7.303	8.129
	Trolling	2009	1.165	2.806	4.923	7.525	10.268
	Trolling	2010	1.285	2.913	5.887	9.644	16.670
	Trolling	2011	3.852	5.663	9.361	13.445	20.655
	Trolling	2012	0.202	1.012	1.826	2.838	3.673
	Trolling	2013	4.324	6.302	9.944	15.108	20.039
	Trolling	2014	1.427	2.876	4.701	7.269	9.705
	Trolling	2015					
	Trolling	2016	1.660	3.333	4.944	6.554	7.812
	Trolling	2017	0.270	0.827	1.702	2.838	3.738
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
number SBT	Acoustic	2005	0.661	3.140	6.446	10.578	15.371
	Acoustic	2006	12.355	18.157	26.394	35.753	52.039
	Trolling	2006	5.244	11.229	19.130	27.656	36.582
	Trolling	2007	9.262	14.724	22.597	31.452	45.399
	Trolling	2008	6.847	10.212	13.633	16.266	17.869
	Trolling	2009	1.451	5.693	10.562	16.280	22.297
	Trolling	2010	2.082	5.442	9.658	14.759	18.829
	Trolling	2011	5.046	9.043	18.174	28.688	38.160
	Trolling	2012	0.402	1.201	2.661	4.563	6.987
	Trolling	2013	8.219	14.533	20.929	27.232	35.221
	Trolling	2014	2.052	4.088	6.600	9.602	12.823
	Trolling	2015					
	Trolling	2016	3.310	6.536	10.115	14.118	18.222
	Trolling	2017	0.000	2.544	5.445	8.720	12.378
	Trolling	2018	0.000	0.000	0.000	0.000	0.000

Table 4. Summary of data for Grid-type Trolling Index (TRI-G)

Survey	Year	N_Record	Time_Min	Time_Max	Range			
					South	North	West	East
Acoustic	1996	400	21 Jan. 1996 06:00	13 Feb. 1996 18:00	-35.2	-34.4	118.2	121.7
	1997	508	26 Jan. 1997 09:00	26 Feb. 1997 12:00	-35.3	-34.0	117.5	121.8
	1998	525	19 Jan. 1998 06:00	24 Feb. 1998 17:00	-35.4	-34.4	117.7	121.8
	1999	663	21 Jan. 1999 06:00	14 Mar. 1999 17:00	-35.4	-34.0	118.0	121.8
	2000	677	19 Jan. 2000 06:00	14 Mar. 2000 14:00	-35.4	-34.0	117.5	122.5
	2001	748	22 Jan. 2001 06:00	14 Mar. 2001 16:00	-35.4	-33.9	117.5	121.9
	2002	712	25 Dec. 2001 08:00	14 Mar. 2002 15:00	-35.4	-33.9	117.5	121.9
	2003	440	02 Jan. 2003 13:00	28 Jan. 2003 15:00	-35.3	-33.9	117.9	121.9
	2005	887	14 Jan. 2005 06:00	04 Mar. 2005 16:00	-35.3	-33.9	117.5	121.9
	2006	905	12 Jan. 2006 06:00	18 Feb. 2006 13:00	-35.4	-34.0	117.5	121.9
Trolling	2006	203	22 Jan. 2006 08:00	31 Jan. 2006 15:00	-34.8	-34.1	119.3	121.3
	2007	216	21 Jan. 2007 10:00	29 Jan. 2007 07:00	-34.8	-34.1	119.3	121.3
	2008	395	03 Dec. 2007 10:00	01 Feb. 2008 08:00	-35.5	-34.1	117.5	121.3
	2009	348	17 Jan. 2009 09:00	29 Jan. 2009 07:00	-35.5	-34.1	117.7	121.3
	2010	425	19 Jan. 2010 08:00	04 Feb. 2010 17:00	-35.5	-34.1	117.7	123.4
	2011	437	25 Jan. 2011 08:00	11 Feb. 2011 10:00	-35.5	-34.1	117.8	121.8
	2012	414	24 Jan. 2012 08:00	10 Feb. 2012 11:00	-35.5	-34.0	117.9	121.9
	2013	443	19 Jan. 2013 05:00	04 Feb. 2013 12:00	-35.5	-33.9	117.9	122.1
	2014	441	25 Jan. 2014 08:00	11 Feb. 2014 10:00	-35.4	-34.0	117.6	123.2
	2016	416	26 Jan. 2016 08:00	12 Feb. 2016 12:00	-35.5	-34.0	117.7	122.3
	2017	370	27 Jan. 2017 06:00	13 Feb. 2017 11:00	-34.9	-33.9	118.8	122.4
	2018	435	31 Jan. 2018 06:00	17 Feb. 2018 11:00	-34.9	-33.9	118.8	122.3

Survey	Year	Distance searched						SBT Catch
		Total	Offshore	Shelfedge	On Shore	Lump	Mauda Reef	
Acoustic	1996	2,786	1,339	463	985			24
	1997	3,206	1,399	406	1,395		6	42
	1998	3,255	1,479	326	1,450			37
	1999	3,979	1,843	354	1,781	1		58
	2000	4,048	1,762	293	1,861	128	4	17
	2001	4,388	1,614	400	2,145	230		20
	2002	4,287	1,542	458	2,022	263	2	21
	2003	2,363	582	304	1,405	64	8	17
	2005	5,051	1,177	422	3,234	219		62
	2006	3,882	1,210	378	2,253	41		87
Trolling	2006	919	130	182	577	29		27
	2007	915	59	215	635	6		35
	2008	1,393	137	143	1,033	25	55	48
	2009	1,171	112	191	798	25	44	37
	2010	1,549	159	198	1,051	35	106	58
	2011	1,469	141	190	1,043	58	38	64
	2012	1,443	132	163	929	119	100	39
	2013	1,592	138	160	1,164	29	101	57
	2014	1,646	91	153	1,266	80	56	52
	2016	1,530	161	185	1,111	42	31	70
	2017	1,478	85	76	1,224	92		29
	2018	1,809	280	82	1,410	37		27
Total		54,159	15,571	5,741	30,771	1,523	552	928

SBT Catch is the number of school with definition of 30 minutes is necessary to be a different school from last catch.

Table 5. Summary of data by area type

Area	N_records			CPUE	
	All	positive catch	% positive	Mean	SD
Lump	372	74	19.9%	33.6	27.9
Mauda Reef	160	41	25.6%	26.1	18.2
On shore	6,028	633	10.5%	22.9	22.5
Shelf edge	1,646	103	6.3%	36.6	24.7
Off shore	2,910	30	1.0%	25.5	15.8
Total	11,116	881	7.9%		

Table 6. Estimated value by GLM for probability sub-model

	Estimate	Std. Error	z value	Pr (>| z |)	Significance
(Intercept)	-2.67231	0.28071	-9.52001	0.00.E+00	***
fyear1997	0.34123	0.28879	1.18159	2.37.E-01	
fyear1998	0.28074	0.29169	0.96244	3.36.E-01	
fyear1999	0.78865	0.27596	2.85780	4.27.E-03	**
fyear2000	-0.84005	0.33993	-2.47125	1.35.E-02	*
fyear2001	-0.81679	0.33092	-2.46821	1.36.E-02	*
fyear2002	-1.50804	0.41414	-3.64139	2.71.E-04	***
fyear2003	-0.38315	0.32129	-1.19254	2.33.E-01	
fyear2005	-0.01647	0.26710	-0.06167	9.51.E-01	
fyear2006	0.84484	0.25283	3.34150	8.33.E-04	***
fyear2007	1.20438	0.30879	3.90033	9.61.E-05	***
fyear2008	1.06105	0.29482	3.59896	3.20.E-04	***
fyear2009	0.70307	0.29965	2.34628	1.90.E-02	*
fyear2010	0.94920	0.28258	3.35909	7.82.E-04	***
fyear2011	1.15119	0.27500	4.18618	2.84.E-05	***
fyear2012	0.49589	0.29421	1.68551	9.19.E-02	
fyear2013	0.86069	0.28369	3.03391	2.41.E-03	**
fyear2014	0.75251	0.27934	2.69388	7.06.E-03	**
fyear2016	1.31805	0.27053	4.87210	1.10.E-06	***
fyear2017	0.12650	0.31028	0.40770	6.83.E-01	
fyear2018	0.01395	0.31311	0.04456	9.64.E-01	
fmonth2	-0.00093	0.09118	-0.01015	9.92.E-01	
fmonth3	-0.78111	0.25798	-3.02775	2.46.E-03	**
fmonth12	0.08393	0.33270	0.25226	8.01.E-01	
fareaMaudaReef	-0.34731	0.24447	-1.42067	1.55.E-01	
fareaOffshore	-3.72685	0.23975	-15.54476	0.00.E+00	***
fareaOnShore	-1.40193	0.15282	-9.17373	0.00.E+00	***
fareaShelfedge	-1.64624	0.18183	-9.05358	0.00.E+00	***

Significances are *** < 0.001, ** < 0.01 and * < 0.05.

Table 7. Estimate values by GLM for positive catch sub-model

	Estimate	Std. Error	t value	Pr (>| t |)	Significance
(Intercept)	-0.47071	0.16609	-2.83413	4.70.E-03	**
fyear1997	-0.11612	0.17817	-0.65171	5.15.E-01	
fyear1998	0.03401	0.17963	0.18934	8.50.E-01	
fyear1999	0.15090	0.16607	0.90864	3.64.E-01	
fyear2000	0.18765	0.21685	0.86538	3.87.E-01	
fyear2001	-0.21857	0.20763	-1.05266	2.93.E-01	
fyear2002	0.13939	0.26456	0.52690	5.98.E-01	
fyear2003	0.34351	0.19160	1.79287	7.33.E-02	
fyear2005	0.17063	0.16472	1.03587	3.01.E-01	
fyear2006	0.13329	0.15392	0.86596	3.87.E-01	
fyear2007	0.04260	0.18092	0.23545	8.14.E-01	
fyear2008	0.40972	0.17441	2.34914	1.90.E-02	*
fyear2009	0.07315	0.17508	0.41779	6.76.E-01	
fyear2010	0.14041	0.16874	0.83215	4.06.E-01	
fyear2011	0.35146	0.16648	2.11109	3.51.E-02	*
fyear2012	-0.03040	0.17975	-0.16914	8.66.E-01	
fyear2013	0.21128	0.17097	1.23577	2.17.E-01	
fyear2014	-0.00445	0.17041	-0.02612	9.79.E-01	
fyear2016	0.07997	0.16301	0.49061	6.24.E-01	
fyear2017	-0.05694	0.19084	-0.29837	7.65.E-01	
fyear2018	0.28255	0.19419	1.45503	1.46.E-01	
fareaMaudaReef	-0.15365	0.13575	-1.13186	2.58.E-01	
fareaOffshore	-0.21513	0.14922	-1.44163	1.50.E-01	
fareaOnShore	-0.40158	0.08733	-4.59863	4.90.E-06	***
fareaShelfedge	0.15393	0.11074	1.38998	1.65.E-01	

Significances are *** < 0.001, ** < 0.01 and * < 0.05

Table 8. Year trends of probability sub-model

	Original		Converted		
Year	Mean	SE	Mean	Mean-SE	Mean+SE
1996	-1.9687	0.3349	0.1169	0.0398	0.1940
1997	-1.6275	0.3033	0.1563	0.0792	0.2335
1998	-1.6880	0.3048	0.1470	0.0714	0.2227
1999	-1.1801	0.2775	0.2229	0.1499	0.2959
2000	-2.8088	0.3479	0.0536	0.0012	0.1060
2001	-2.7855	0.3330	0.0547	0.0040	0.1055
2002	-3.4768	0.4182	0.0274	-0.0125	0.0673
2003	-2.3519	0.3144	0.0806	0.0210	0.1402
2005	-1.9852	0.2755	0.1141	0.0517	0.1766
2006	-1.1239	0.2619	0.2315	0.1634	0.2997
2007	-0.7643	0.3190	0.3033	0.2293	0.3772
2008	-0.9077	0.3029	0.2769	0.2008	0.3530
2009	-1.2657	0.2939	0.2043	0.1283	0.2803
2010	-1.0195	0.2891	0.2457	0.1733	0.3182
2011	-0.8175	0.2858	0.2820	0.2161	0.3479
2012	-1.4728	0.3028	0.1720	0.0953	0.2487
2013	-1.1080	0.2913	0.2294	0.1554	0.3034
2014	-1.2162	0.2906	0.2092	0.1352	0.2831
2016	-0.6507	0.2824	0.3178	0.2594	0.3762
2017	-1.8422	0.3231	0.1259	0.0510	0.2008
2018	-1.9548	0.3291	0.1142	0.0407	0.1876

Table 9. Year trends of positive catch sub-model

	Original		Converted		
Year	Mean	SE	Mean	Mean-SE	Mean+SE
1996	3.0105	0.1637	2.0064	1.0177	2.9950
1997	2.8855	0.1385	1.7928	1.0763	2.5092
1998	3.0443	0.1398	2.0709	1.1897	2.9521
1999	3.1616	0.1205	2.3538	1.4569	3.2508
2000	3.1997	0.1821	2.5035	1.0446	3.9624
2001	2.7935	0.1711	1.5935	0.8318	2.3553
2002	3.1517	0.2367	2.2557	0.5731	3.9384
2003	3.3436	0.1524	2.8502	1.3974	4.3031
2005	3.1818	0.1172	2.3713	1.4871	3.2554
2006	3.1436	0.1031	2.3061	1.5589	3.0534
2007	3.0439	0.1411	2.0901	1.1921	2.9880
2008	3.4121	0.1314	3.0180	1.6646	4.3714
2009	3.0826	0.1325	2.1613	1.2784	3.0442
2010	3.1384	0.1221	2.2627	1.3959	3.1295
2011	3.3559	0.1208	2.8123	1.6723	3.9522
2012	2.9802	0.1351	1.9404	1.1593	2.7216
2013	3.2145	0.1253	2.4295	1.4513	3.4076
2014	3.0055	0.1249	1.9786	1.2359	2.7213
2016	3.0852	0.1163	2.1590	1.3842	2.9337
2017	2.9421	0.1535	1.8740	1.0274	2.7205
2018	3.2696	0.1556	2.5956	1.2750	3.9162

Table 10. Point estimates of Grid-type Trolling Index

Year	Prob*Pos	Standardized
1996	0.2345	0.5832
1997	0.2803	0.6970
1998	0.3045	0.7571
1999	0.5248	1.3049
2000	0.1342	0.3336
2001	0.0872	0.2169
2002	0.0619	0.1539
2003	0.2297	0.5711
2005	0.2707	0.6731
2006	0.5339	1.3277
2007	0.6338	1.5761
2008	0.8356	2.0780
2009	0.4415	1.0978
2010	0.5561	1.3828
2011	0.7930	1.9719
2012	0.3337	0.8299
2013	0.5573	1.3860
2014	0.4139	1.0293
2016	0.6862	1.7063
2017	0.2359	0.5866
2018	0.2963	0.7368

Table 11. Grid-type Trolling index with confidence intervals calculated by 1000 times bootstrap

year	5 percentile	25 percentile	Median	75 percentile	95 pecentile
1996	0.347	0.470	0.582	0.686	0.873
1997	0.481	0.584	0.668	0.758	0.898
1998	0.511	0.631	0.737	0.863	1.037
1999	0.930	1.127	1.280	1.435	1.672
2000	0.183	0.255	0.313	0.379	0.489
2001	0.137	0.176	0.212	0.258	0.325
2002	0.062	0.115	0.160	0.202	0.281
2003	0.374	0.488	0.571	0.658	0.798
2004					
2005	0.512	0.601	0.666	0.738	0.853
2006	1.065	1.193	1.287	1.402	1.556
2007	1.122	1.339	1.515	1.711	1.993
2008	1.476	1.775	1.991	2.240	2.581
2009	0.780	0.947	1.077	1.221	1.431
2010	1.087	1.248	1.390	1.528	1.769
2011	1.595	1.837	2.030	2.209	2.512
2012	0.606	0.750	0.836	0.944	1.096
2013	1.078	1.269	1.407	1.571	1.809
2014	0.827	0.950	1.051	1.151	1.309
2015					
2016	1.361	1.569	1.714	1.855	2.082
2017	0.383	0.501	0.583	0.665	0.823
2018	0.483	0.624	0.751	0.874	1.057

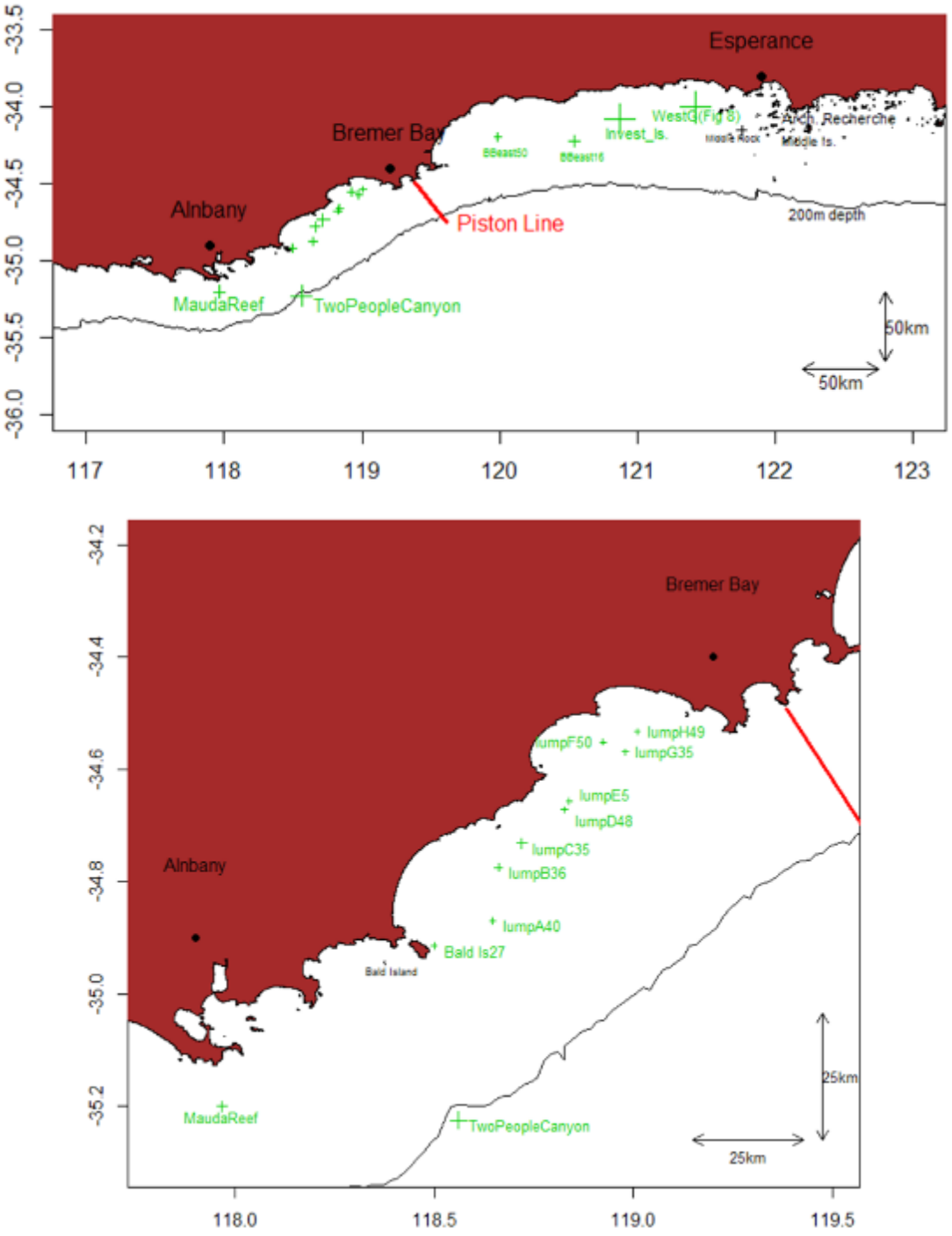

Fig. 1. Map and relating places.

Lower panel is an enlargement of a part of upper panel. Size in cross mark reflects determined range of effect of the lump.

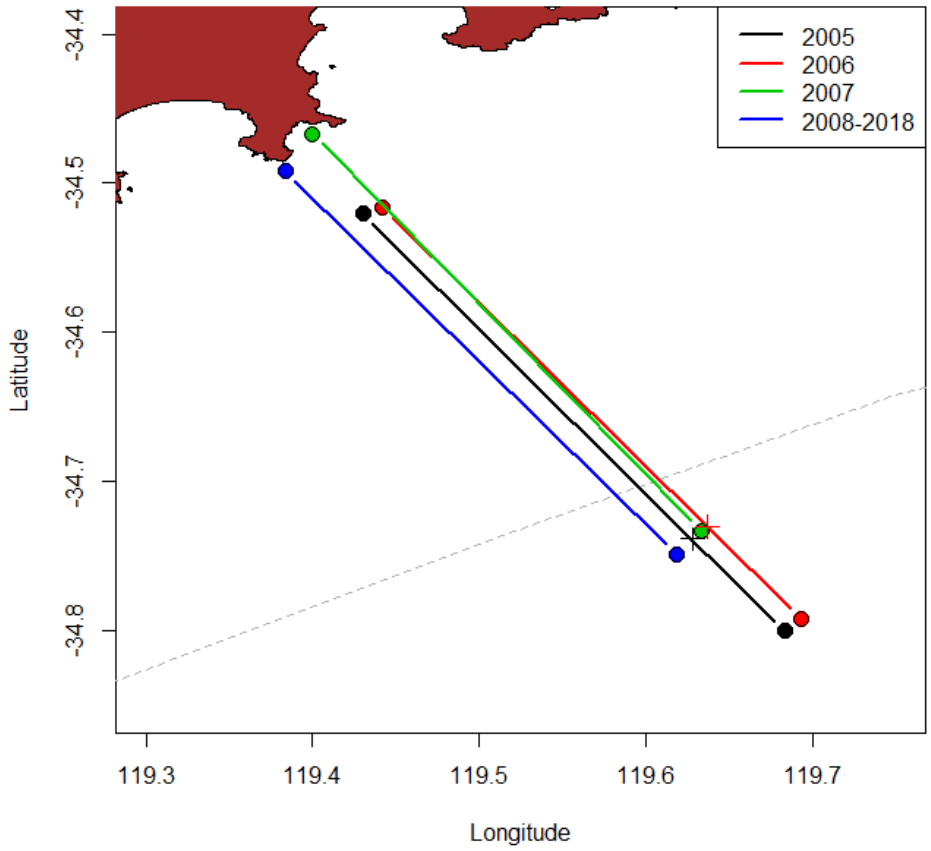

Fig. 2. Locations of piston-line.

Circles denote each ends of piston-line surveyed. Cross marks are the offshore point of the 2005 and 2006 piston lines that adjusted to the 2007 piston-line.

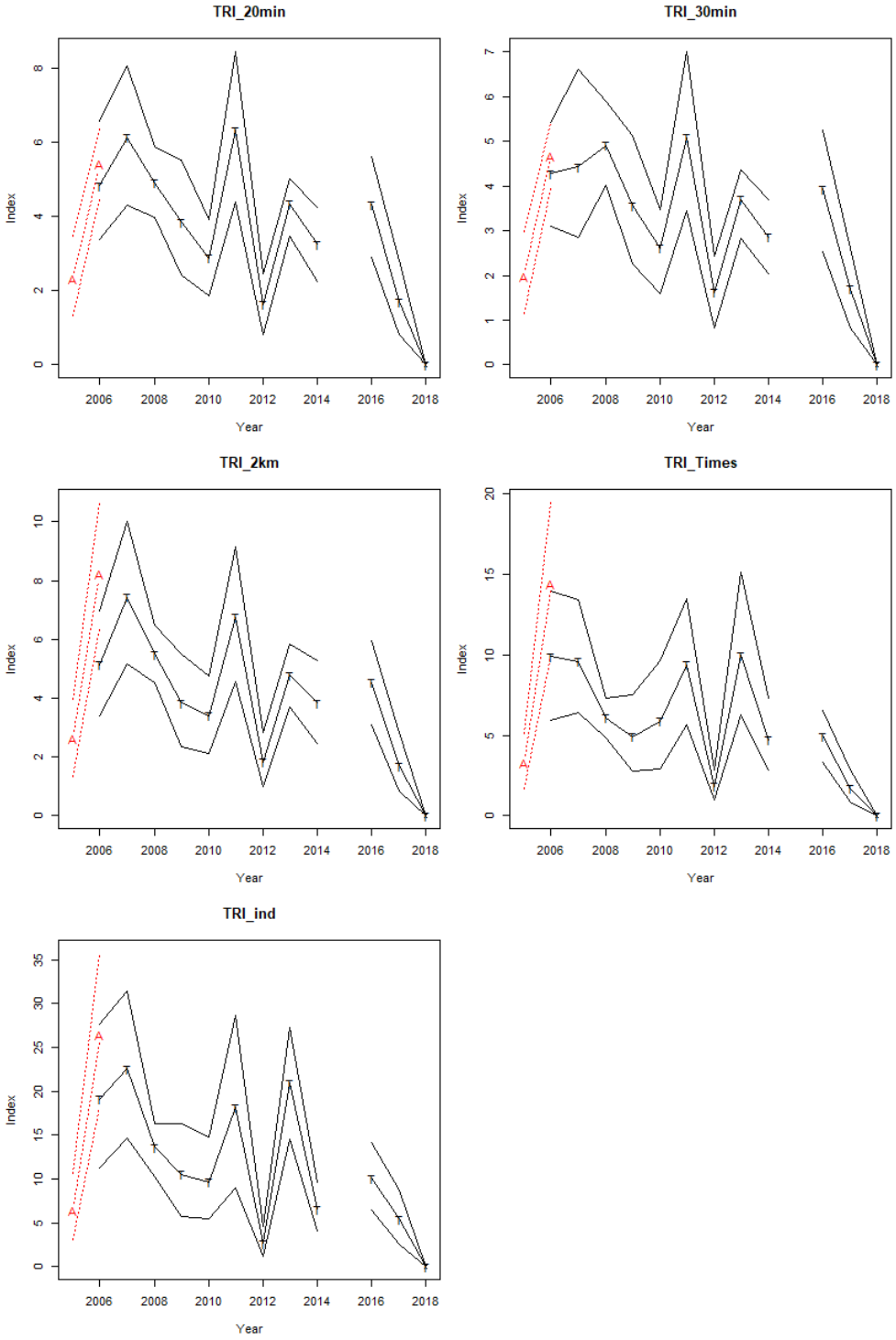

Fig. 3. Five types of piston-line trolling index by different school/catch definition. Showing median, 5 and 95 percentiles. A in red was from the acoustic survey and T in black was from the trolling survey.

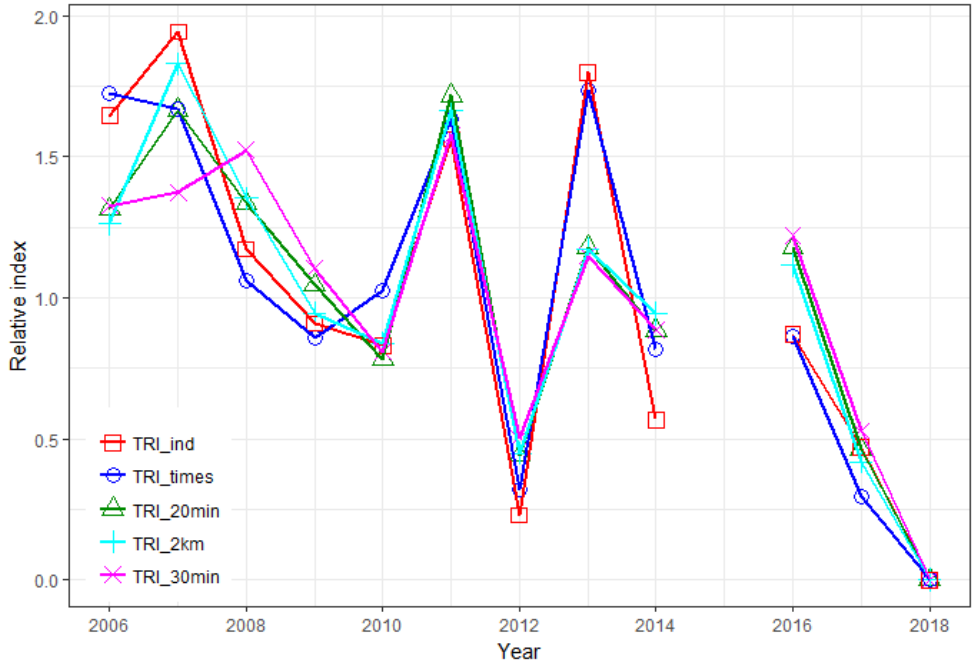

Fig. 4. Comparison of median from five types of piston-line trolling index by different school/catch definition.

Standardized with the mean of each index. Only shows that from the trolling survey.

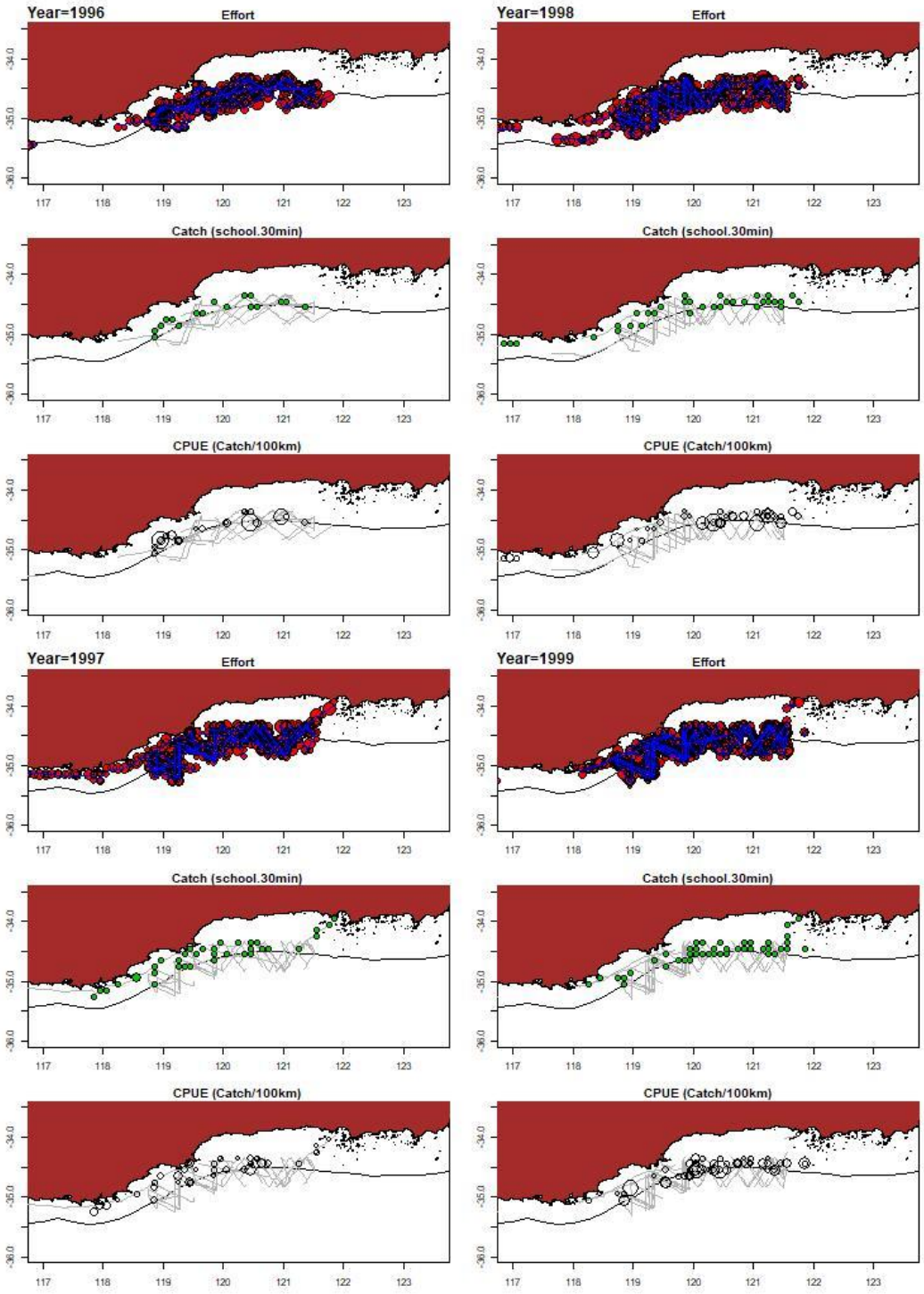

Fig. 5. Distributions of effort, SBT age-1 catch and CPUE by year

Blue line is trajectory of the vessel while trolling. Some points of anomalously high CPUE with little effort were not shown. Isobath of 200 m is drawn.

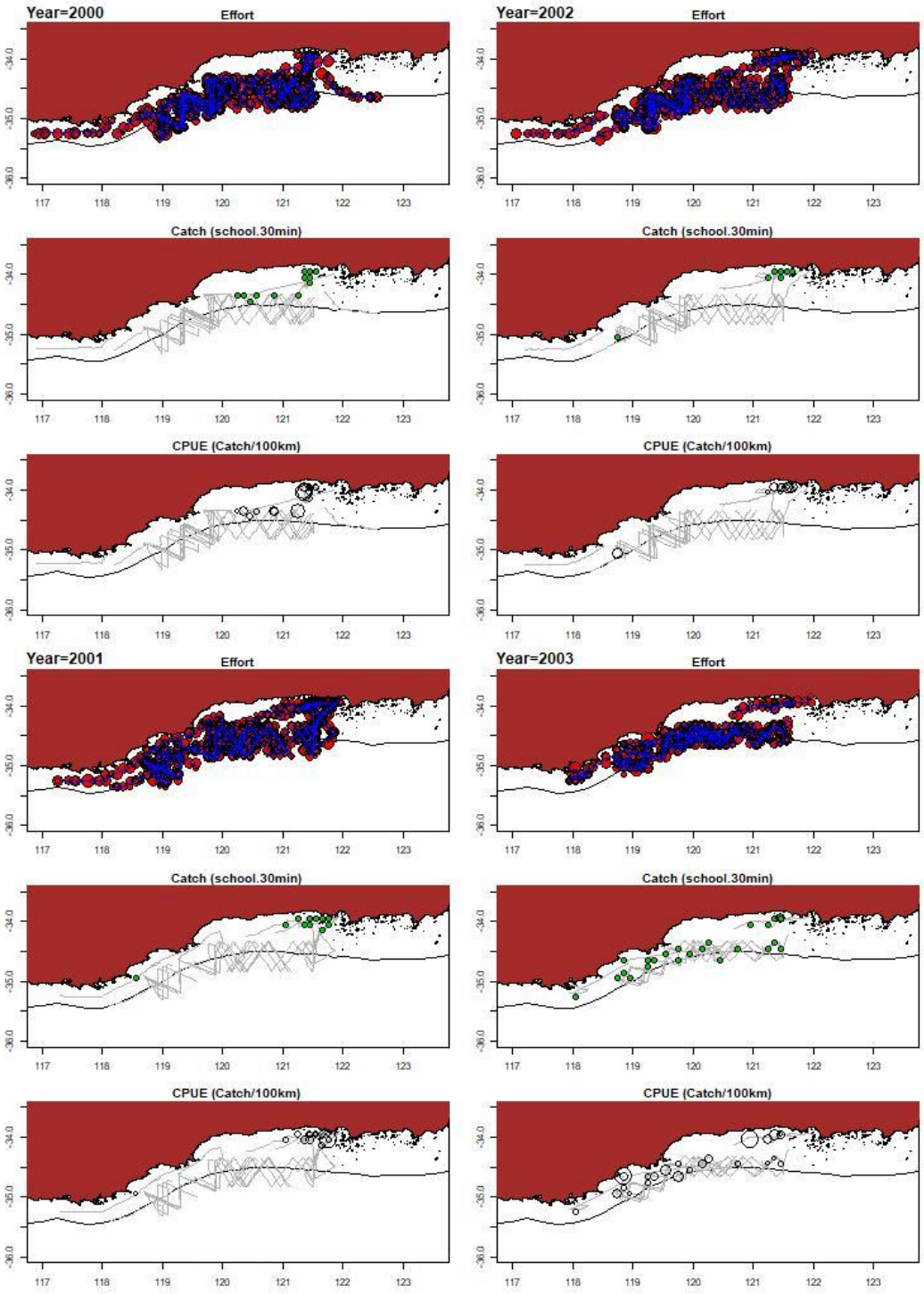
Year=2000
Effort
Year=2002
Effort
Catch (school.30min)
Catch (school.30min)
CPUE (Catch/100km)
CPUE (Catch/100km)
Year=2001
Effort
Year=2003
Effort
Catch (school.30min)
Catch (school.30min)
CPUE (Catch/100km)
CPUE (Catch/100km)
-34.0
-35.0
-36.0
117
118
119
120
121
122
123

Fig. 5. (cont'd)

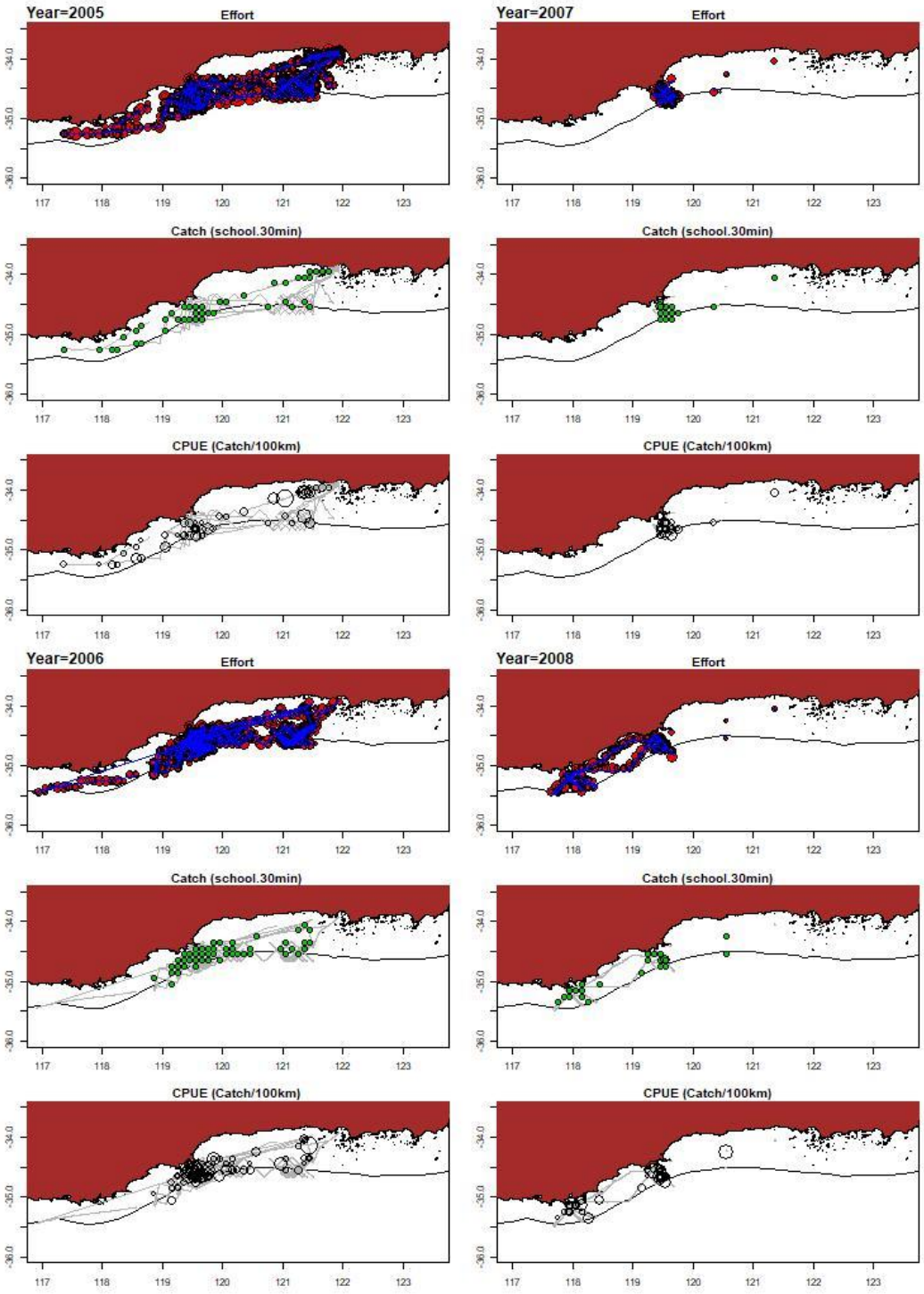
Year=2005
Effort
Year=2007
Effort
Catch (school.30min)
Catch (school.30min)
CPUE (Catch/100km)
CPUE (Catch/100km)
Year=2006
Effort
Year=2008
Effort
Catch (school.30min)
Catch (school.30min)
CPUE (Catch/100km)
CPUE (Catch/100km)
-34.0
-35.0
-36.0
117
118
119
120
121
122
123

Fig. 5. (cont'd)

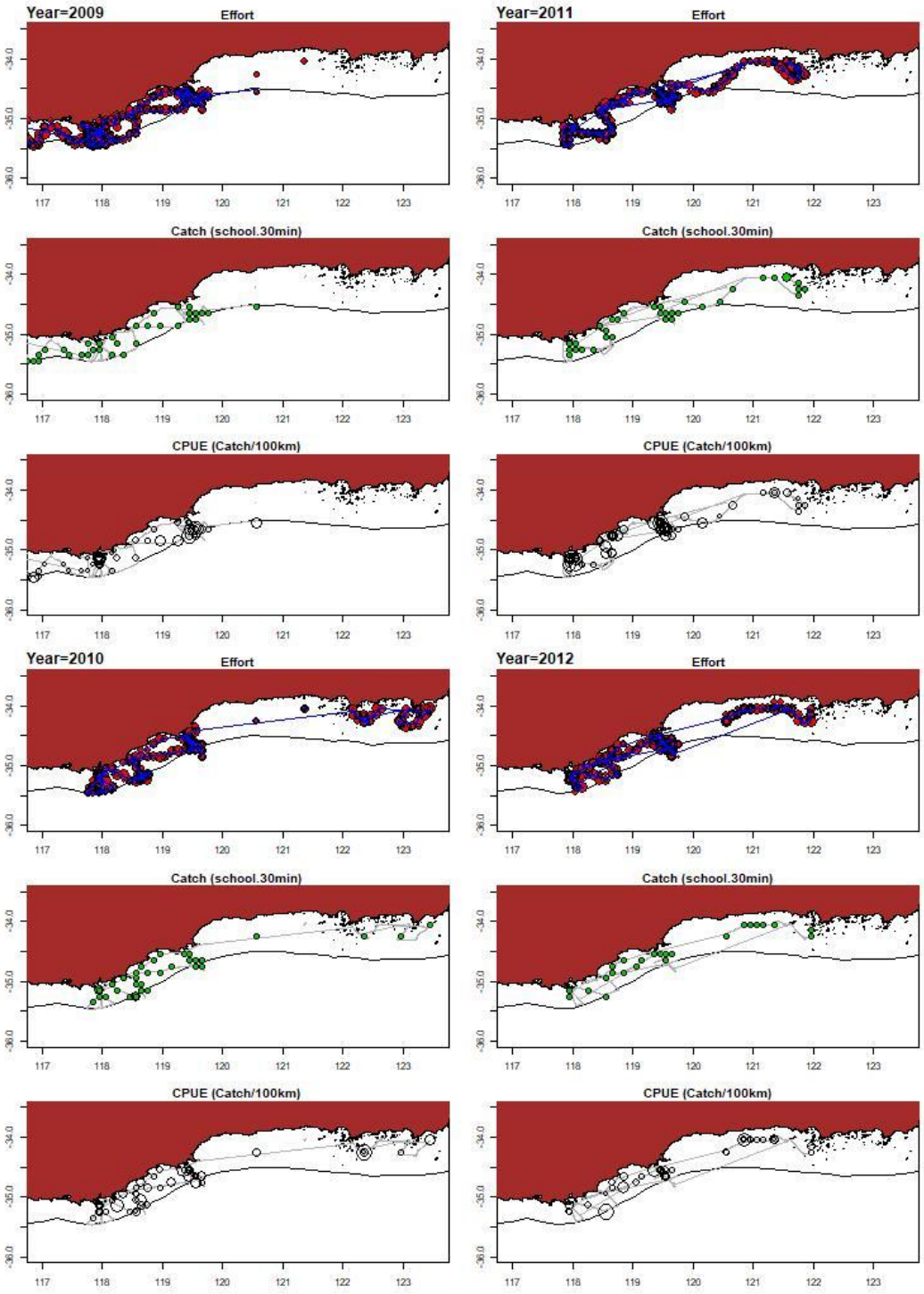
Year=2009
Effort
Year=2011
Effort
Catch (school.30min)
Catch (school.30min)
CPUE (Catch/100km)
CPUE (Catch/100km)
Year=2010
Effort
Year=2012
Effort
Catch (school.30min)
Catch (school.30min)
CPUE (Catch/100km)
CPUE (Catch/100km)
-34.0
-35.0
-36.0
117
118
119
120
121
122
123

Fig. 5. (cont'd)

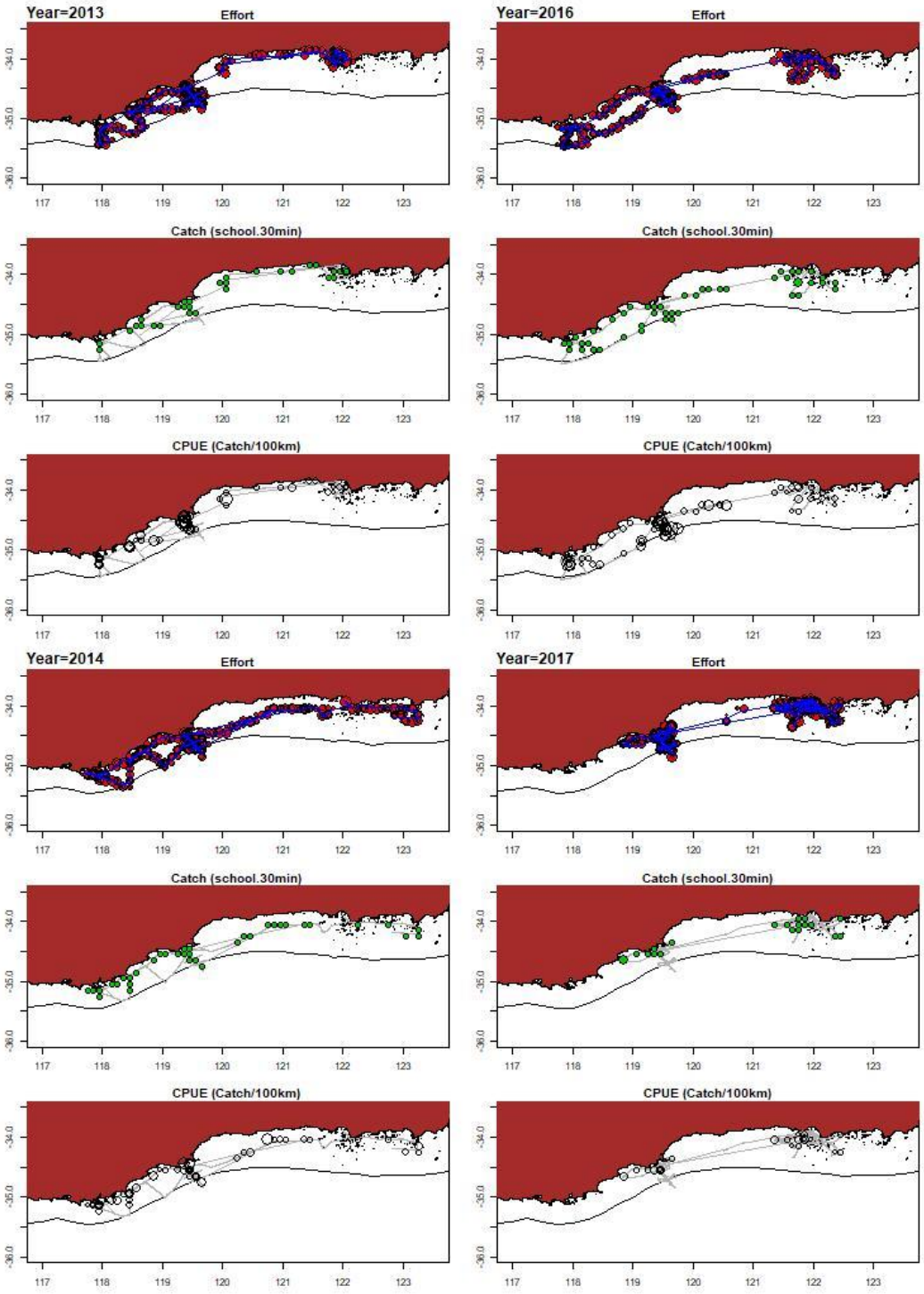
Year=2013
Effort
Year=2016
Effort
Catch (school.30min)
Catch (school.30min)
CPUE (Catch/100km)
CPUE (Catch/100km)
Year=2014
Effort
Year=2017
Effort
Catch (school.30min)
Catch (school.30min)
CPUE (Catch/100km)
CPUE (Catch/100km)
-34.0
-35.0
-36.0
117
118
119
120
121
122
123

Fig. 5. (cont'd)

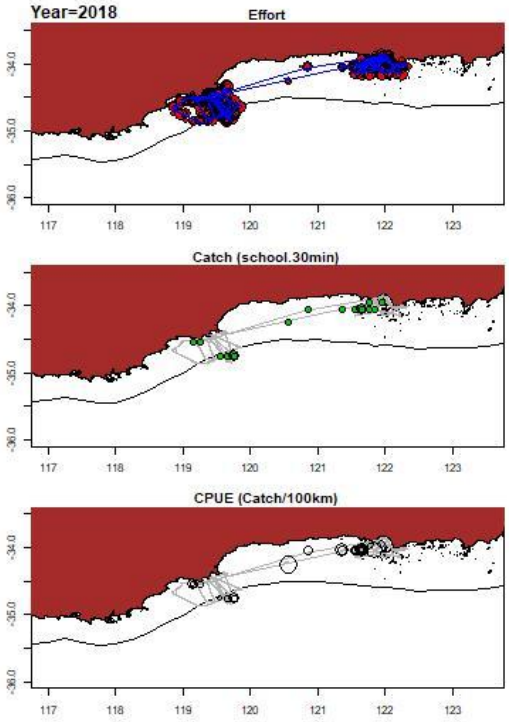
Year=2018
Effort
Catch (school.30min)
CPUE (Catch/100km)
-34.0
-35.0
-36.0
117
118
119
120
121
122
123

Fig. 5. (cont'd)

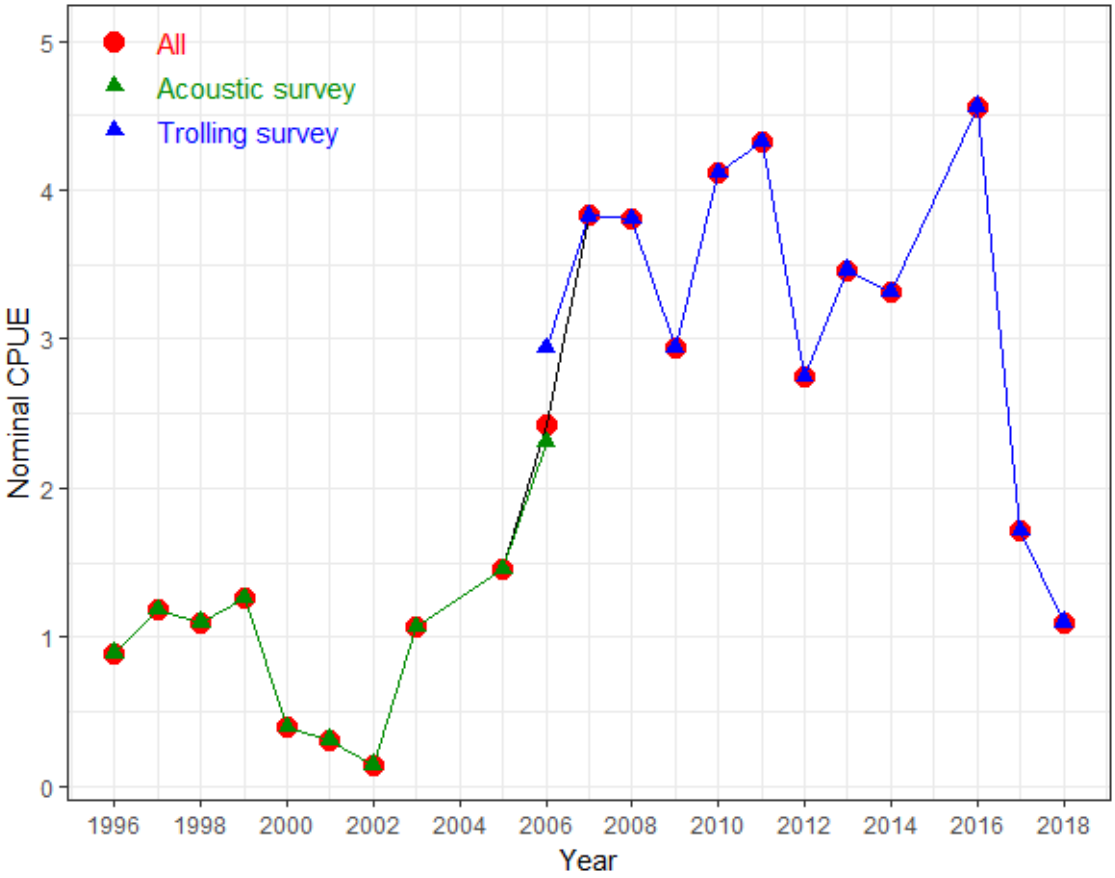

Fig. 6. Nominal CPUE of TRI-G.

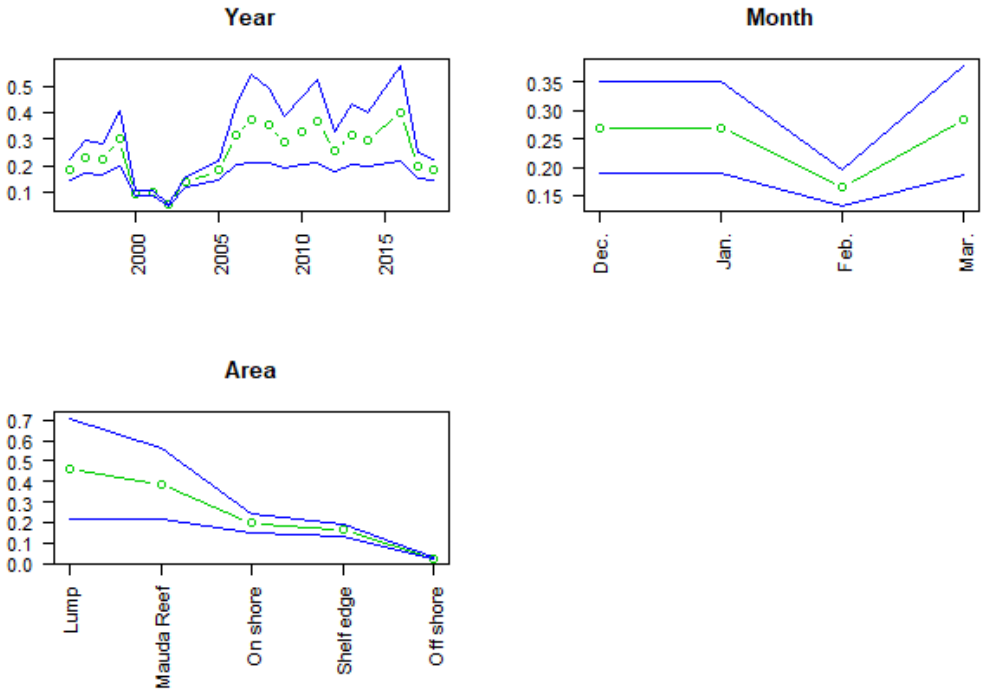

Fig. 7. Probability of catch for variables that were selected by AIC.

Green is mean and blue is mean+SD. Catch was defined as school with definition of 30 minutes is necessary for different school.

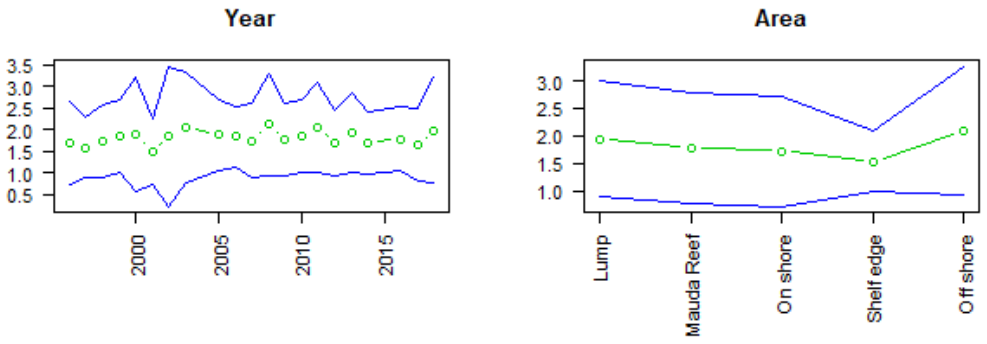

Fig. 8. Catch in positive catch for variables that were selected by AIC.

Green is mean and blue is mean+SD. Catch was defined as school with definition of 30 minutes is necessary for different school.

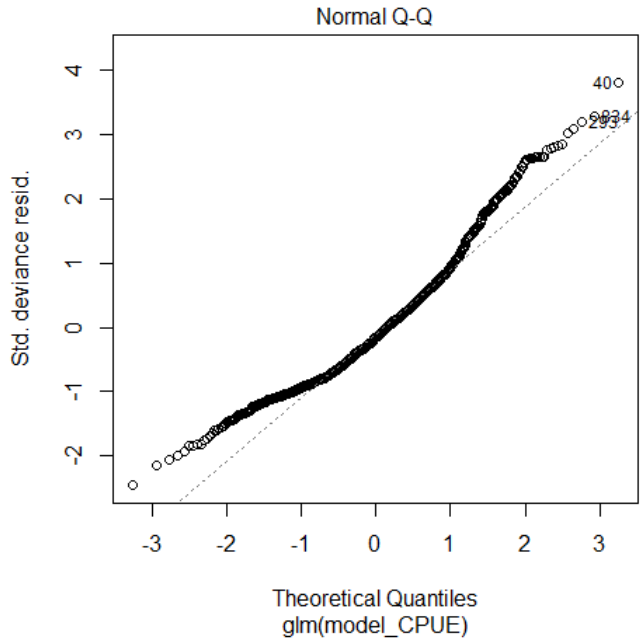

Fig. 9. QQ plot of GLM for positive catch sub-model.

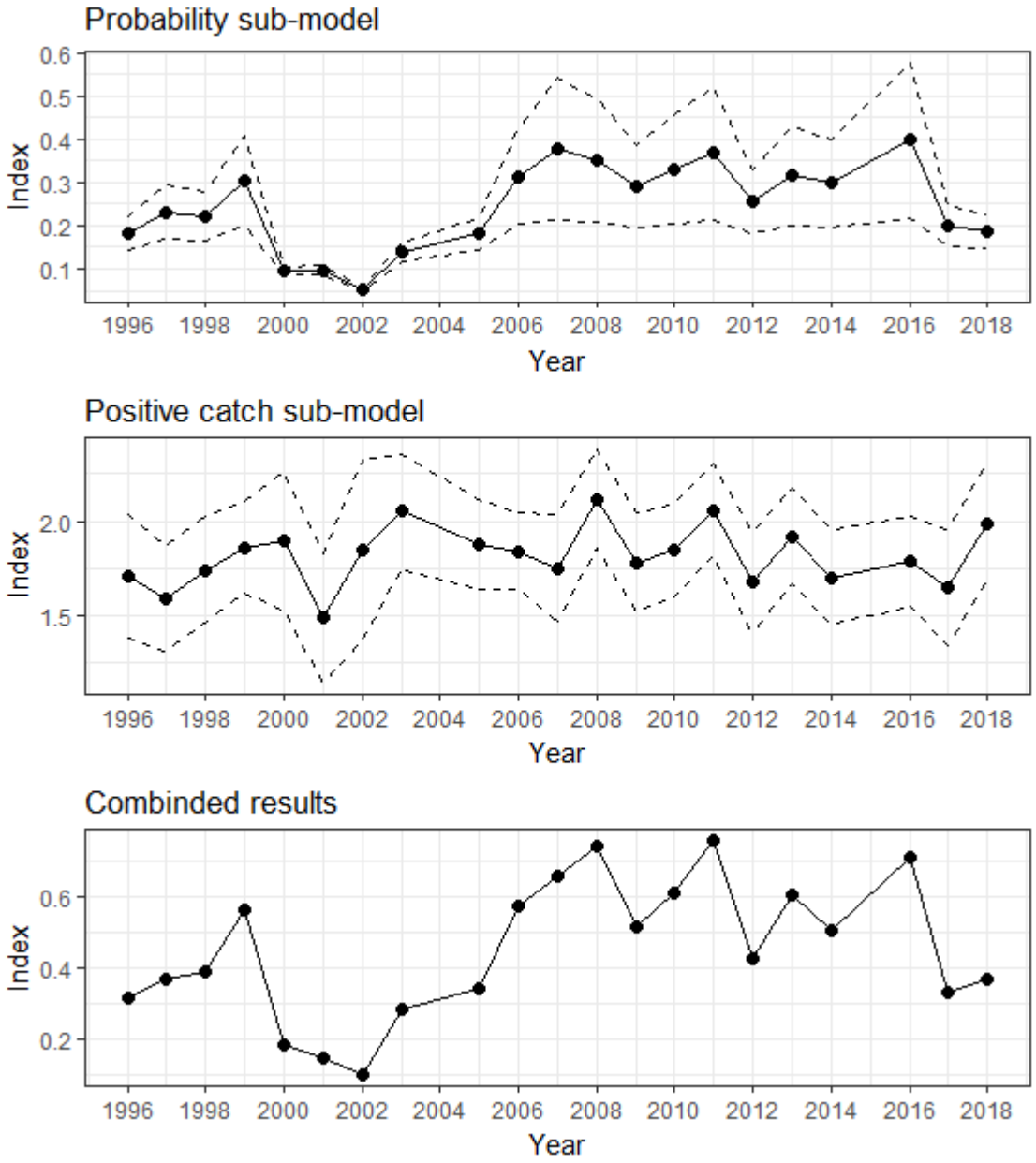

Fig. 10. The probability sub-model, the positive catch sub-model, and combined index from two sub-model (point estimation standardized TRI-G).

Upper panel shows year trend from the probability sub-model. Mean+1SD. Middle panel shows year trend form the positive catch sub-model. Mean+1SD. Lower panel shows TRI-G which is product of above two year trends.

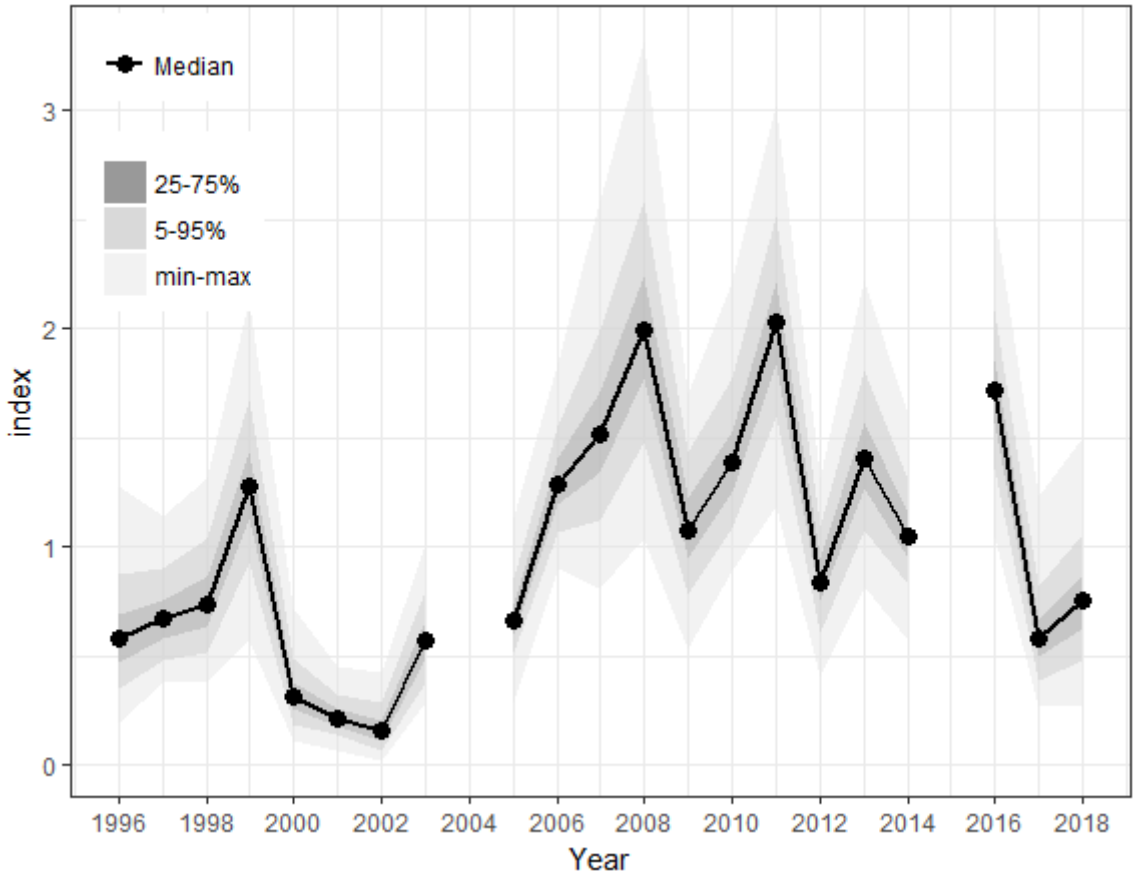

Fig. 11. TRI-G with confidence intervals.

Estimate was simulated with 1000 times bootstrapping.

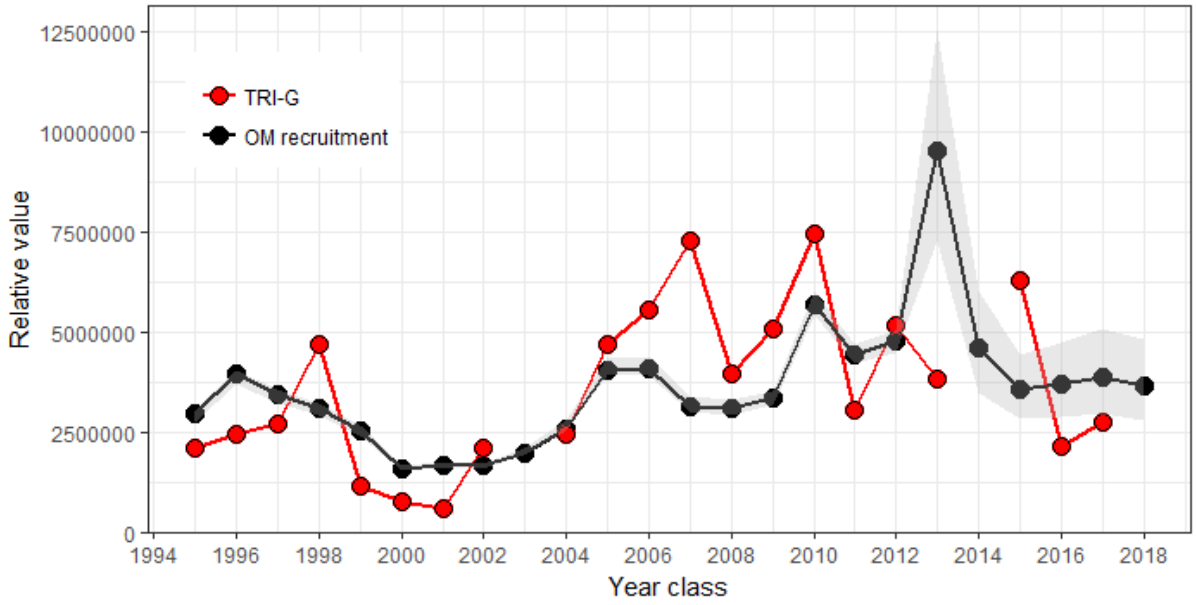

Fig. 12. Comparison between OM recruitment from the 2017 stock assessment and TRI-G by year class (cohort).

TRI-P(acoustic) and TRI-P(troll) indicate the piston-line trolling index from the acoustic survey and trolling survey. TRI-G indicates grid-type trolling index. Range of OM recruitment is 25-75 percentiles.

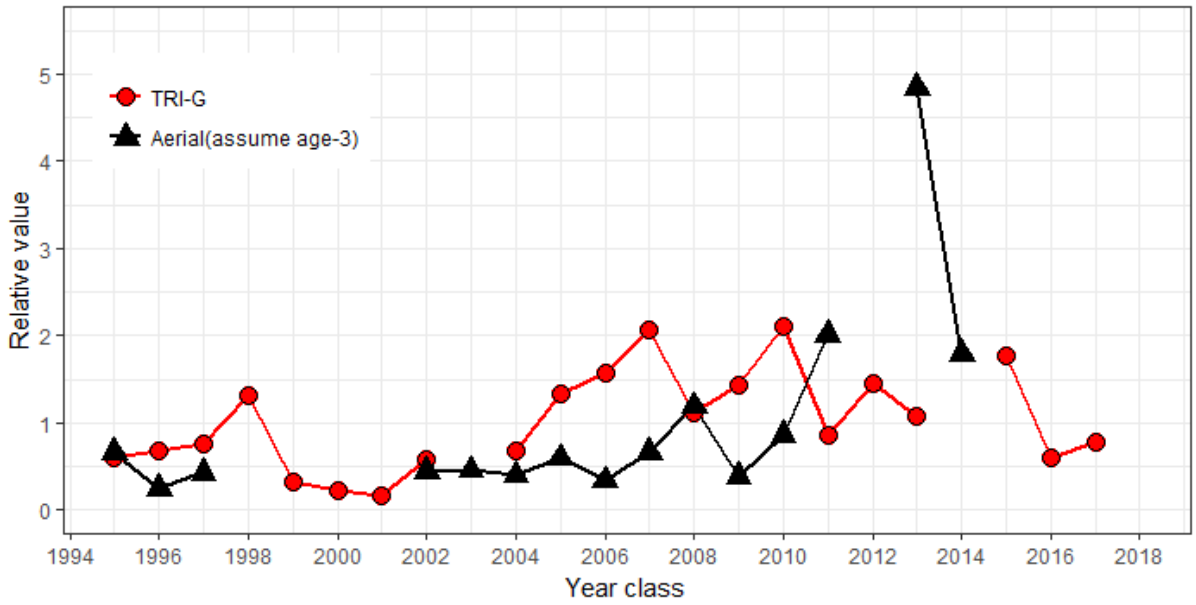

Fig. 13. Comparison between aerial survey index and TRI-G by year class (cohort).

Assigned year class for aerial survey assuming age-3 fish observed.

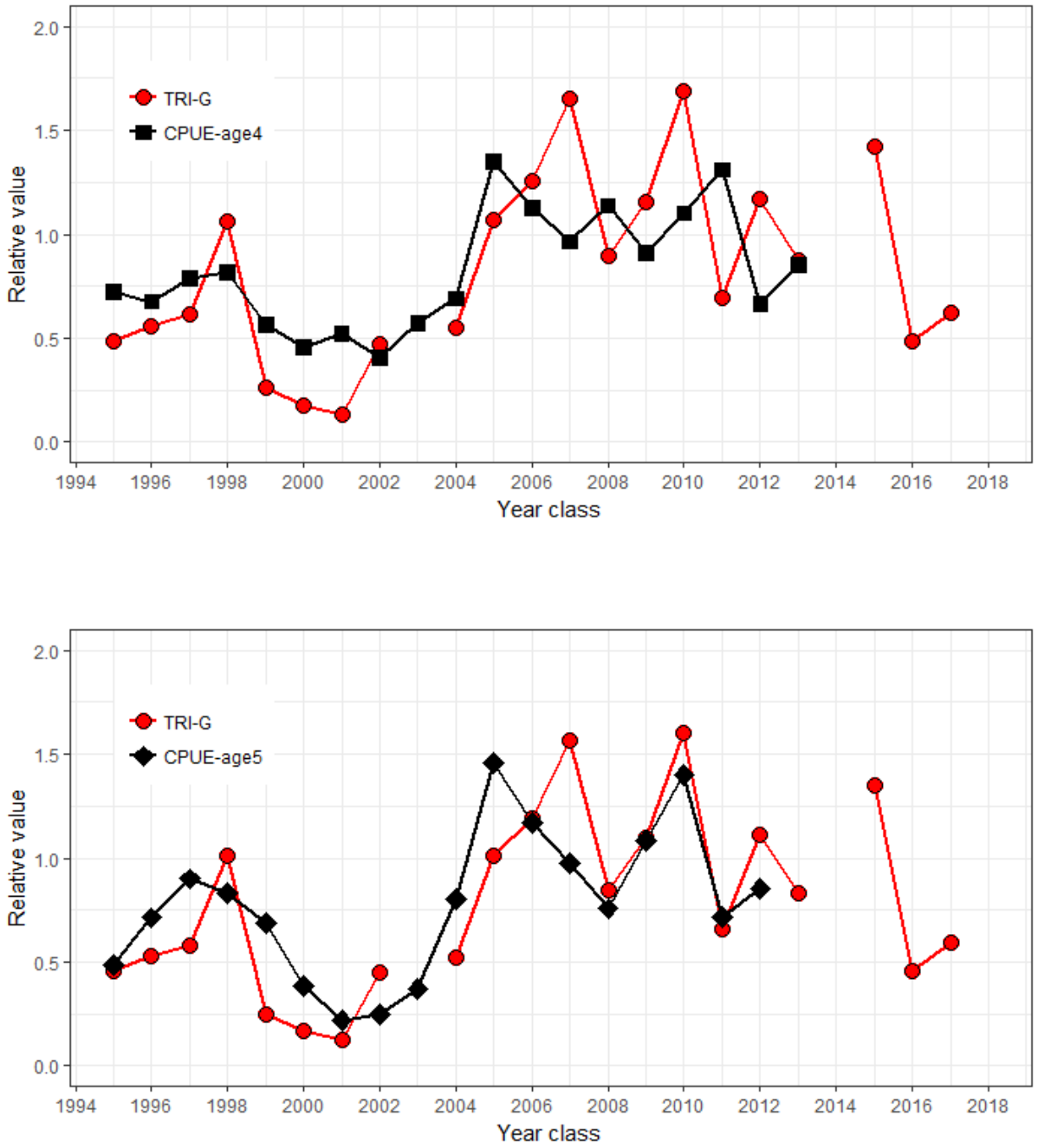

Fig. 14. Comparison between the age-4 and 5 standardized CPUE of Japanese longline and TRI-G by year class (cohort).

Upper panel shows age-4 CPUE and lower panel shows age-5 CPUE.