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 2017 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（PTI）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（GTI）で、両調査の全曳縄操業データを利用し、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 52,360 km、ミナミマグロ 1 歳魚群数合計 902 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。20 年間の GTI は、オペレーティングモデルで推定した加入量、日本延縄 4 歳魚の CPUE から推定した加入量とトレンドがよく一致していた。PTI と GTI は相互に似たトレンドだった。PTI と GTI 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 2016 to 2017. One index is the piston-line trolling index (PTI) which have been reported to CCSBT. The other is the grid-type trolling index (GTI) which was developed in 2014. GTI 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 52,260 km total distance searched with 902 schools. GLM of delta-lognormal method was applied for CPUE standardization because of high percentage of zero catch data. Year trend of GTI in 20 years were agreed to those of

recruitment estimates from operating model, age-4 standardized CPUE of Japanese longline. Trends of GTI and PTI were similar to each other. GTI and PTI are expected to contribute to the CCBST stock assessment.

Introduction

Trolling survey for southern bluefin tuna (*Thunnus maccoyii*: SBT) aims to provide recruitment index of the stock at age-1 from 2006 to 2014, 2016 and 2017. It has provided an index named the piston-line trolling index (PTI) 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). 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 (GTI) was developed in 2014 (Itoh and Takahashi 2014). The updated PTI and GTI are provided in this paper.

Materials and methods

1. Piston-line Trolling Index　PTI

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 2016 to 2017, 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). It contains data in total of 182 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 was repeated from 10 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 since its first determination in 2005 (Fig. 2). In 2006, the piston-line was moved eastward to avoid the array of 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 the array of hydrophone for acoustic tags and to bring closer to the bay the vessel spent night. The locations of the piston-line have been same since 2008 to 2017.

The piston-line in 2005 and 2006 had a larger part of offshore than after 2007. We made the distance of the piston-line in offshore same as in 2007 and removed some effort data in 2005 and 2006. There was no SBT catch that removed by this procedure. 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 (PTI) was calculated as catch of age-1 SBT per 100 km search distance. There were five types of catch definition and PTIs 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. PTI 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. PTI 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. PTI 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 were counted as different. PTI from this definition is “TRI_Times.”

(5) Number of age-1 SBT individuals. PTI from this definition is “TRI_ind.”

Confidence intervals of PTI 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 was expected to 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 PTI. Another case was that chose six days randomly, and used data either outward or inward run (it also chose randomly) to calculate PTI.

2. Grid-type Trolling Index GTI

Data were from trolling catch in the acoustic survey between 1996 and 2003, 2005 and 2006, and the trolling survey between 2006 and 2014, 2016 and 2017. The surveys were carried out in the period from December to March, and year was represented in the year at January in this paper.

Searched 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.

Interval of time for latitude and longitude records was different 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. 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. Start and end time of trolling was 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 different in area types. Area types were 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 determined 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 many years.

Shelf edge: A range near 200 m isobath. The range was determined from 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 shelf edge.

Offshore: southern area of 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 give the final estimate of the Grid-type Trolling Index (GTI).

Model of probability sub-model:

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

error ~ binomial

where p is the probability of positive catch.

Model of positive catch sub-model:

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

error ~ gaussian

In this GLM standardization, the explanatory variables followed the methods described in Itoh and Takahashi 2014 were selected. 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, GTI and PTI, were compared to various recruitment indices, including the recruitment estimated in the 2011 CCSBT stock assessment through OM in the scenario of "MP3_2035_3000_inc_base", standardized CPUE (W0.8) for age-4 SBT in Japanese longline, and aerial survey index and commercial aerial spotting index (SAPUE) in the 2016 CCSBT and 2014 CCSBT data exchange, respectively.

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

Results

1. Piston-line Trolling Index: PTI

PTI estimated were shown in Fig. 3 and Table 3 for five types. Figure 4 shows median of the five indices that adjusted to the mean of each series. There was small difference among TRI_20min, TRI_30min and TRI_2km in the period from 2006 to 2008. There was a good agreement in the trends in the period from 2009 and 2014, 2016 and 2017.

Graphs for the independence of data between outward and inward piston-line on the same day are shown in Fig. 5. It was not observed that variance (range between hinges here) of PTI became smaller when pairs of same day piston-line were chosen. It suggests independence of the two datasets of the piston-line on the same day.

2. Grid-type Trolling Index: GTI

Summary of data aggregated by grid is shown in Table 4. It consists of 10,636 records in total that reaches about 52,360 km search distance and 902 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 (91.5%).

Distributions of effort, catch and CPUE are shown Fig. 6 by year. It is noted that substantial efforts were made in other area than the piston-line except 2007. It is also noted that few catch was observed in offshore area in spite of substantial amount of efforts had been made (Table 5).

Nominal CPUE is shown in Fig. 7. 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 compare to later half period.

Relationship between probability of catch and various variables (Fig. 8) and between CPUE and various variables (Fig. 9) were surveyed. The estimated values are shown in Table 6. QQ plot is shown in Fig. 10 and the estimated values are shown in Table 7. LS-means for year trend in each sub-model are shown in Table 8, Table 9 and Fig. 11. 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. Product (GTI) of both sub-models is shown in Table 10 and Fig. 11.

Table 11 and Fig. 12 show standardized GTI with confidence interval calculated through 1000 times bootstrap. Comparing to nominal CPUE in Fig. 9, GTI is similar trend that low level in 2000-2003, increase in 2005-2007 and high level since 2006.

3. Comparison to other indices

Figure 13 shows comparison between recruitment estimated in OM and trolling indices. OM recruitments after 2013 year class (2013YC) would be inappropriate for comparison because these were estimated without Japanese longline CPUE or just predicted from spawning stock biomass. Among 2004YC to 2006YC, PTI showed same large increase from 2004YC to 2005YC. In GTI, the trends were similar from 1995YC to 2005YC expect GTI is higher in 1998YC. Note that trolling indices were not included in OM and independent information from it.

Figure 14 shows comparison between age-4 CPUE in Japanese longline and trolling indices. PTI showed similar trend from 2004YC to 2009YC. GTI also showed similar trend expect GTI is higher in 1998YC. The two indices were less similar after 2006YC but common in the point that both indices were higher than that in the period of low recruitments around 2000YC.

Figure 15 and 17 shows comparison between aerial survey index and trolling indices, and GTI in three year running average, respectively. 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. A negative correlation was observed between GTI and aerial survey index. The trends of them were not similar to each other before in the year between 2008 and 2017 when both series were available (Fig. 19). Note that aerial survey index was not obtained around 2000YC when extremely low recruitment observed.

Figure 16 and 18 show comparison between commercial aerial spotting index (SAPUE) and, and GTI in three year running average, respectively. SAPUE was not similar to PTI, but agreed in the point that both indices in 2000YC or 2001YC were the lowest and were high value after 2005YC.

4. Discussion

The present paper provided updated PTI and GTI. PTI is the trolling index on the piston-line that made the distance in offshore area from shelf edge same. PTI 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.

PTI was separated so far that from the acoustic survey and that from the trolling survey. In the GLM of GTI, the difference of the survey type was not significant. It may be appropriate to combine the two PTIs into one.

Both Trolling indices, PTI and GTI, are based on catch that is the number of school. When we encountered SBT school in the survey, the numbers of fish individuals caught and catch times could increase if we handle 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 were 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 school 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.

PTI 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 hour 36 minutes in average. When school definition is 30 minutes, six schools and PTI = 17.1 becomes upper limit. If catches are repeated less than 30 minutes interval, it results in the number of school caught as 1 and PTI = 2.8, despite there were many catches. However, up to now, PTI 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.

GTI is a comprehensive index that includes not only the piston-line but also all the area surveyed. PTI is derived for 12 years since 2005. GTI could extend the years to 20 years, by adding the period from 1996 to 2003.

The acoustic survey and the trolling survey were not originally designed to obtain GTI. 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 GTI. 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. And it also should consider the effect of ocean environmental factors such as sea surface water temperature on SBT distribution and weather conditions on catch operation in trolling survey for data analysis (see CCSBT-ESC/1708/24).

Year trend of GTI was similar to those in OM recruitment. 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 trend, some were agreed but others were not. Agreement to aerial survey index was not good. It may be attributed that aerial survey did not included around 2000 when extremely low recruitment occurred. SAPUE agreed to GTI in the point that showed low indices in those years.

Recruitment from OM will be estimated in the coming ESC for more recent several years. Age-4 CPUE will be also updated in future. Those new points of recruitment allow further evaluation of GTI accuracy and precision.

Trolling indices and trolling survey design has several subjects to be addressed in terms of SBT ecology. Distribution dynamics of age-1 SBT, which could be different by year, effect on the trolling indices. Study using electronic tagging is desirable. Structure of age-1 fish that consists of two sub-cohorts which spawned in different season may effect on the indices (CCSBT-ESC/1609/26). However, how a targeted local population in a survey represents whole the SBT stock is quite a big proposition, being common to age-4 Japanese longline CPUE and aerial survey index.

Recruitment of OM, based on the widest data including Japanese longline CPUE, seems to be the most reliable estimate. Trolling indices, GTI and PTI, could provide year trends that not inconsistent with OM recruitment. GTI and PTI are expected to contribute to the CCSBT stock assessment.

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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	
Total	182	172	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
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					

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					

Exclude the data not used for PTI. 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
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
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
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
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

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

Year	N_Record	Time_Min	Time_Max	Range			
				South	North	West	East
1996	401	21 Jan. 1996 06:00	13 Feb. 1996 18:00	-35.2	-34.4	118.2	121.7
1997	522	26 Jan. 1997 09:00	26 Feb. 1997 12:00	-35.3	-34.0	117.5	121.8
1998	535	19 Jan. 1998 06:00	24 Feb. 1998 17:00	-35.4	-34.4	117.7	121.8
1999	676	21 Jan. 1999 06:00	14 Mar. 1999 17:00	-35.4	-34.0	118.0	121.8
2000	685	19 Jan. 2000 06:00	14 Mar. 2000 14:00	-35.4	-34.0	117.5	122.5
2001	760	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	439	02 Jan. 2003 13:00	28 Jan. 2003 15:00	-35.3	-33.9	117.9	121.9
2005	888	14 Jan. 2005 06:00	04 Mar. 2005 16:00	-35.3	-33.9	117.5	121.9
2006	907	12 Jan. 2006 06:00	18 Feb. 2006 13:00	-35.4	-34.0	117.5	121.9
2006	204	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	438	25 Jan. 2011 08:00	11 Feb. 2011 10:00	-35.5	-34.1	117.8	121.8
2012	415	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	442	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	369	27 Jan. 2017 06:00	13 Feb. 2017 11:00	-34.9	-33.9	118.8	122.4

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	5,052	1,177	422	3,234	220		62
	2006	3,882	1,210	378	2,253	41		87
Trolling	2006	927	130	182	586	29		28
	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
Total		52,360	15,291	5,659	29,370	1,488	552	902

SBT Catch is the number of school with definition of 30 minutes is necessary for different school.

Table 5. Summary of data by area type

Area	N_records			CPUE	
	All	positive catch	% positive	Mean	SD
Offshore	2,859	27	0.9%	41.6	83.5
Shelfedge	1,612	104	6.5%	43.6	66.2
OnShore	5,753	618	10.7%	23.5	28.8
Lump	365	70	19.2%	31.8	26.3
MaudaReef	161	42	26.1%	39.2	86.0
Total	10,750	861	8.0%		

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

Item	Estimate	Std. Error	z value	Pr (>| z |)	Significance
(Intercept)	-2.31129	0.31198	-7.40840	1.28.E-13	***
fyear1997	0.33101	0.28978	1.14227	2.53.E-01	
fyear1998	0.26243	0.29263	0.89681	3.70.E-01	
fyear1999	0.76938	0.27715	2.77608	5.50.E-03	**
fyear2000	-0.84649	0.34074	-2.48426	1.30.E-02	*
fyear2001	-0.82150	0.33167	-2.47681	1.33.E-02	*
fyear2002	-1.53457	0.41483	-3.69926	2.16.E-04	***
fyear2003	-0.37714	0.31928	-1.18121	2.38.E-01	
fyear2005	-0.04286	0.26806	-0.15987	8.73.E-01	
fyear2006	0.82205	0.25345	3.24347	1.18.E-03	**
fyear2007	1.18156	0.30955	3.81698	1.35.E-04	***
fyear2008	1.09230	0.29455	3.70833	2.09.E-04	***
fyear2009	0.62802	0.30065	2.08885	3.67.E-02	*
fyear2010	0.91774	0.28295	3.24345	1.18.E-03	***
fyear2011	1.08056	0.27622	3.91199	9.15.E-05	***
fyear2012	0.45052	0.29510	1.52668	1.27.E-01	
fyear2013	0.80660	0.28473	2.83287	4.61.E-03	**
fyear2014	0.69135	0.28039	2.46570	1.37.E-02	
fyear2016	1.29769	0.27109	4.78690	1.69.E-06	***
fyear2017	0.08984	0.31098	0.28890	7.73.E-01	
fmonth2	0.00253	0.09185	0.02756	9.78.E-01	
fmonth3	-0.78125	0.25855	-3.02170	2.51.E-03	**
fmonth12	0.29492	0.31886	0.92490	3.55.E-01	
fhour7	-0.22423	0.17087	-1.31229	1.89.E-01	
fhour8	-0.26974	0.17425	-1.54806	1.22.E-01	
fhour9	-0.37779	0.17828	-2.11901	3.41.E-02	*
fhour10	-0.39033	0.17871	-2.18411	2.90.E-02	
fhour11	-0.57372	0.18345	-3.12742	1.76.E-03	**
fhour12	-0.42132	0.17817	-2.36469	1.80.E-02	*
fhour13	-0.55499	0.18349	-3.02458	2.49.E-03	**
fhour14	-0.19284	0.17514	-1.10106	2.71.E-01	
fhour15	-0.39684	0.19005	-2.08810	3.68.E-02	
fhour16	-0.34008	0.20167	-1.68637	9.17.E-02	
fhour17	-0.73891	0.25042	-2.95071	3.17.E-03	**
fhour18	-1.45002	0.73218	-1.98042	4.77.E-02	*
fareaMaudaReef	-0.34997	0.24768	-1.41301	1.58.E-01	
fareaOffshore	-3.78613	0.25012	-15.13695	9.24.E-52	***
fareaOnShore	-1.37514	0.15744	-8.73449	2.45.E-18	***
fareaShelfedge	-1.57391	0.18482	-8.51569	1.66.E-17	***

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

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

Item	Estimate	Std. Error	t value	Pr (>| t |)	Significance
(Intercept)	-0.55996	0.19967	-2.80449	5.17.E-03	**
fyear1997	0.07939	0.19193	0.41363	6.79.E-01	
fyear1998	0.03755	0.18909	0.19858	8.43.E-01	
fyear1999	-0.03183	0.18054	-0.17632	8.60.E-01	
fyear2000	0.37021	0.24057	1.53887	1.24.E-01	
fyear2001	-0.33478	0.26718	-1.25303	2.11.E-01	
fyear2002	0.03583	0.34774	0.10302	9.18.E-01	
fyear2003	0.39300	0.19906	1.97432	4.87.E-02	*
fyear2005	0.15070	0.17566	0.85791	3.91.E-01	
fyear2006	0.14303	0.16279	0.87862	3.80.E-01	
fyear2007	0.07585	0.19047	0.39825	6.91.E-01	
fyear2008	0.52109	0.18341	2.84112	4.62.E-03	**
fyear2009	0.07824	0.18483	0.42331	6.72.E-01	
fyear2010	0.15618	0.18014	0.86697	3.86.E-01	
fyear2011	0.43352	0.17780	2.43826	1.50.E-02	*
fyear2012	0.00026	0.19172	0.00134	9.99.E-01	
fyear2013	0.25755	0.18531	1.38981	1.65.E-01	
fyear2014	0.01821	0.18278	0.09963	9.21.E-01	
fyear2016	0.24580	0.17673	1.39078	1.65.E-01	
fyear2017	0.11898	0.25118	0.47368	6.36.E-01	
fhour7	0.03192	0.10931	0.29202	7.70.E-01	
fhour8	-0.01827	0.11185	-0.16332	8.70.E-01	
fhour9	-0.01517	0.11718	-0.12943	8.97.E-01	
fhour10	0.07108	0.11522	0.61694	5.37.E-01	
fhour11	-0.18982	0.12227	-1.55248	1.21.E-01	
fhour12	-0.12527	0.11694	-1.07121	2.84.E-01	
fhour13	0.14079	0.11942	1.17894	2.39.E-01	
fhour14	0.05379	0.11351	0.47384	6.36.E-01	
fhour15	0.03212	0.12212	0.26305	7.93.E-01	
fhour16	-0.09117	0.13161	-0.69270	4.89.E-01	
fhour17	-0.06607	0.16211	-0.40755	6.84.E-01	
fhour18	0.03610	0.50187	0.07194	9.43.E-01	
fareaMaudaReef	-0.04561	0.14694	-0.31037	7.56.E-01	
fareaOffshore	0.03405	0.16679	0.20413	8.38.E-01	
fareaOnShore	-0.35238	0.10054	-3.50478	4.85.E-04	***
fareaShelfedge	0.29275	0.12234	2.39298	1.70.E-02	**

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	-2.0029	0.3940	0.1189	0.1078	0.1300
1997	-1.6719	0.3669	0.1582	0.1398	0.1765
1998	-1.7405	0.3681	0.1493	0.1329	0.1657
1999	-1.2335	0.3446	0.2256	0.1905	0.2606
2000	-2.8494	0.4052	0.0547	0.0523	0.0571
2001	-2.8244	0.3920	0.0560	0.0536	0.0585
2002	-3.5375	0.4687	0.0283	0.0275	0.0290
2003	-2.3800	0.3725	0.0847	0.0794	0.0901
2005	-2.0458	0.3437	0.1145	0.1055	0.1235
2006	-1.1809	0.3327	0.2349	0.1982	0.2716
2007	-0.8213	0.3805	0.3055	0.2345	0.3765
2008	-0.9106	0.3659	0.2869	0.2267	0.3471
2009	-1.3749	0.3588	0.2018	0.1726	0.2311
2010	-1.0852	0.3547	0.2525	0.2073	0.2978
2011	-0.9223	0.3527	0.2845	0.2274	0.3416
2012	-1.5524	0.3670	0.1747	0.1523	0.1972
2013	-1.1963	0.3574	0.2321	0.1936	0.2707
2014	-1.3115	0.3568	0.2122	0.1801	0.2444
2016	-0.7052	0.3496	0.3307	0.2542	0.4071
2017	-1.9131	0.3844	0.1286	0.1159	0.1414

Table 9. Year trends of positive catch sub-model

	Original		Converted		
Year	Mean	SE	Mean	Mean-SE	Mean+SE
1996	1.7450	0.2619	5.7261	5.2022	6.2499
1997	1.8131	0.2500	6.1297	5.6298	6.6296
1998	1.7858	0.2457	5.9645	5.4732	6.4558
1999	1.7316	0.2338	5.6497	5.1820	6.1174
2000	2.1572	0.2831	8.6466	8.0805	9.2127
2001	1.4690	0.3057	4.3449	3.7335	4.9563
2002	1.7889	0.3852	5.9827	5.2123	6.7531
2003	2.0299	0.2518	7.6136	7.1100	8.1172
2005	1.9172	0.2298	6.8020	6.3424	7.2616
2006	1.9008	0.2220	6.6912	6.2473	7.1351
2007	1.8431	0.2471	6.3161	5.8219	6.8103
2008	2.2863	0.2398	9.8382	9.3585	10.3179
2009	1.8126	0.2388	6.1267	5.6491	6.6042
2010	1.9221	0.2363	6.8350	6.3624	7.3075
2011	2.1794	0.2348	8.8409	8.3714	9.3105
2012	1.7482	0.2446	5.7441	5.2548	6.2333
2013	2.0166	0.2403	7.5128	7.0321	7.9934
2014	1.7644	0.2383	5.8379	5.3614	6.3144
2016	1.9926	0.2337	7.3348	6.8674	7.8022
2017	1.8635	0.2992	6.4466	5.8481	7.0451

Table 10. Point estimates of Grid-type Trolling Index

Year	Prob*Pos	Standardized
1996	0.6624	0.5447
1997	0.9540	0.7845
1998	0.8633	0.7099
1999	1.2173	1.0010
2000	0.4414	0.3630
2001	0.2233	0.1836
2002	0.1632	0.1342
2003	0.6991	0.5749
2005	0.7415	0.6098
2006	1.5099	1.2416
2007	1.8360	1.5097
2008	2.6913	2.2130
2009	1.2160	0.9999
2010	1.6447	1.3524
2011	2.4450	2.0105
2012	0.9738	0.8007
2013	1.6732	1.3758
2014	1.2041	0.9901
2016	2.3555	1.9369
2017	0.8072	0.6638

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	0.353	0.453	0.539	0.618	0.733
1997	0.584	0.701	0.781	0.859	0.988
1998	0.513	0.624	0.704	0.782	0.903
1999	0.808	0.915	1.005	1.103	1.249
2000	0.227	0.295	0.352	0.407	0.499
2001	0.114	0.151	0.177	0.203	0.247
2002	0.062	0.099	0.129	0.163	0.204
2003	0.403	0.491	0.561	0.633	0.749
2004					
2005	0.473	0.548	0.608	0.663	0.748
2006	1.076	1.178	1.248	1.323	1.434
2007	1.187	1.373	1.513	1.659	1.902
2008	1.779	2.031	2.210	2.403	2.680
2009	0.743	0.890	0.991	1.107	1.269
2010	1.092	1.233	1.341	1.467	1.633
2011	1.664	1.870	2.012	2.185	2.406
2012	0.597	0.717	0.791	0.880	0.991
2013	1.082	1.248	1.360	1.469	1.641
2014	0.789	0.903	0.989	1.076	1.191
2015					
2016	1.639	1.828	1.950	2.086	2.286
2017	0.465	0.566	0.651	0.733	0.849

Table 12. Correlation between trolling indices and other indices

Var1	Var2	N	df	cor	t	P.val	sign.
OM	TR	11	9	0.3992	1.3061	0.2239	
OM	GTI	20	18	0.5411	2.7302	0.0137	**
JP_age4	TR	8	6	-0.4921	-1.3848	0.2154	
JP_age4	GTI	17	15	0.5319	2.4326	0.0280	**
ASI	TR	8	6	-0.4590	-1.2654	0.2526	
ASI	GTI	13	11	-0.0607	-0.2017	0.8439	
ASI	GTI_3yr	9	7	0.3163	0.8820	0.4070	
SAPUE	TR	7	5	-0.1408	-0.3180	0.7634	
SAPUE	GTI	11	9	0.3504	1.1222	0.2908	
SAPUE	GTI_3yr	9	7	0.6358	2.1792	0.0657	

cor: Pearson's correlation

sign.: significance; *** 0.001, **<0.01 and * <0.05.

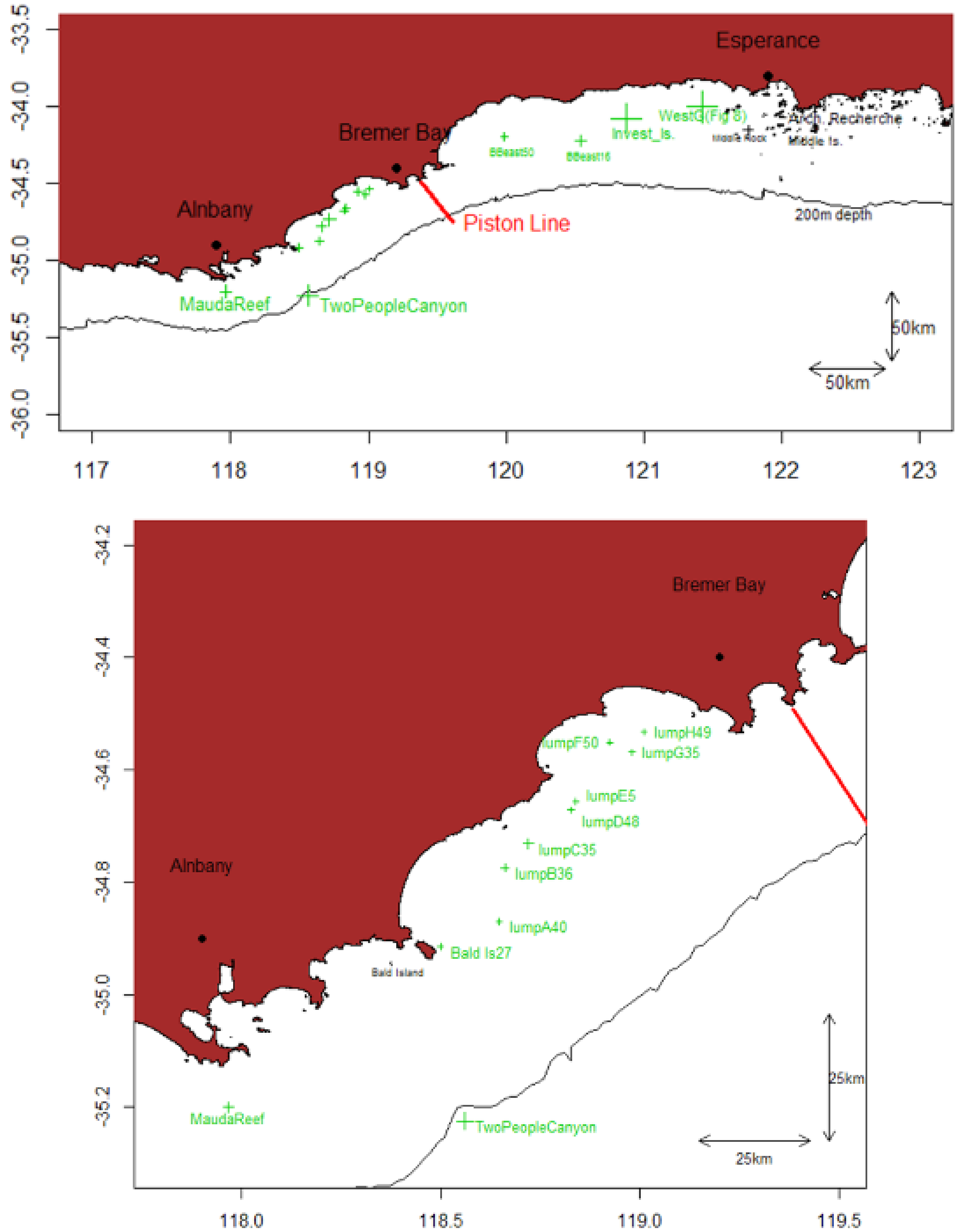


Fig. 1. Map and relating places

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

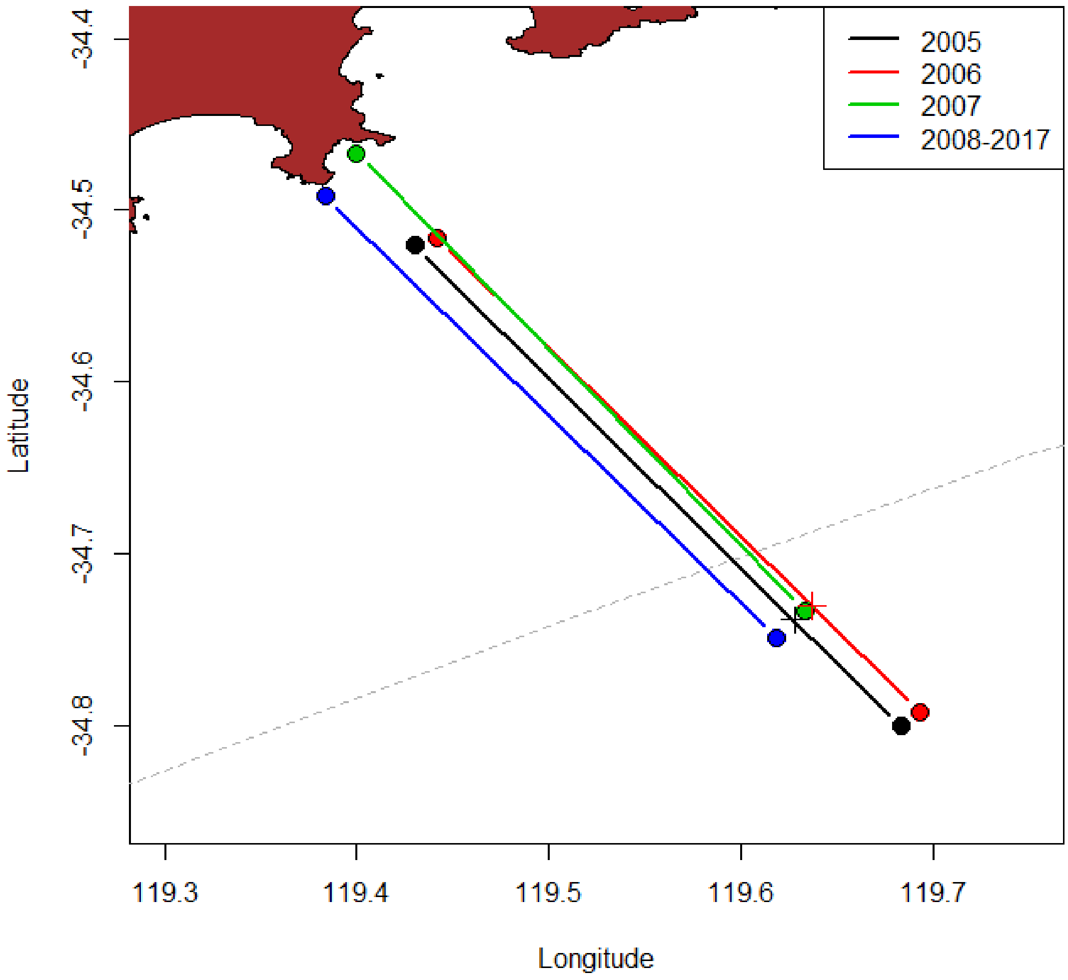


Fig. 2. Locations of piston-line

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.

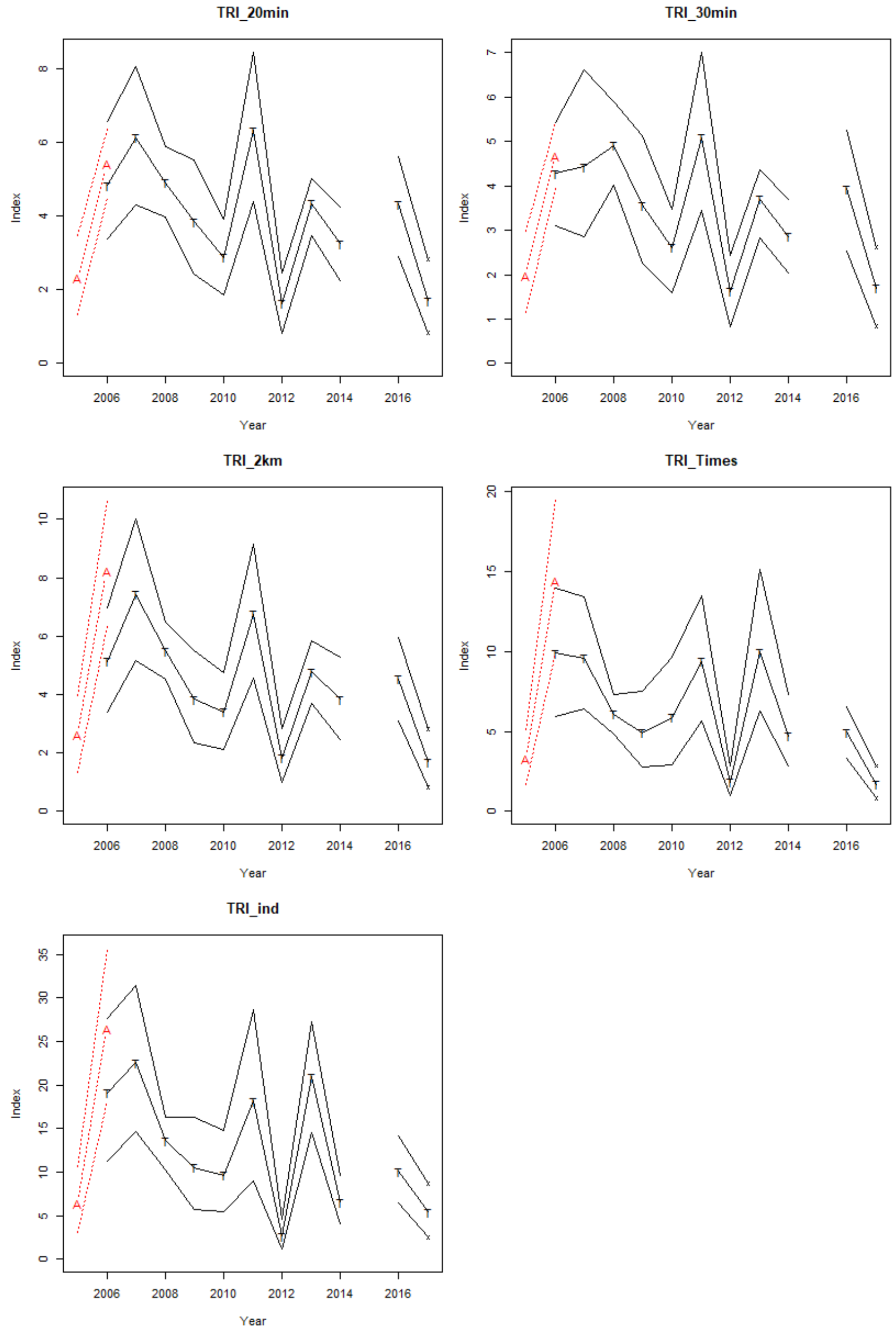


Fig. 3. Five types of piston-line trolling index

Showing median, 5 and 95 percentiles. A in red was from the acoustic survey and T in black was from the trolling survey.

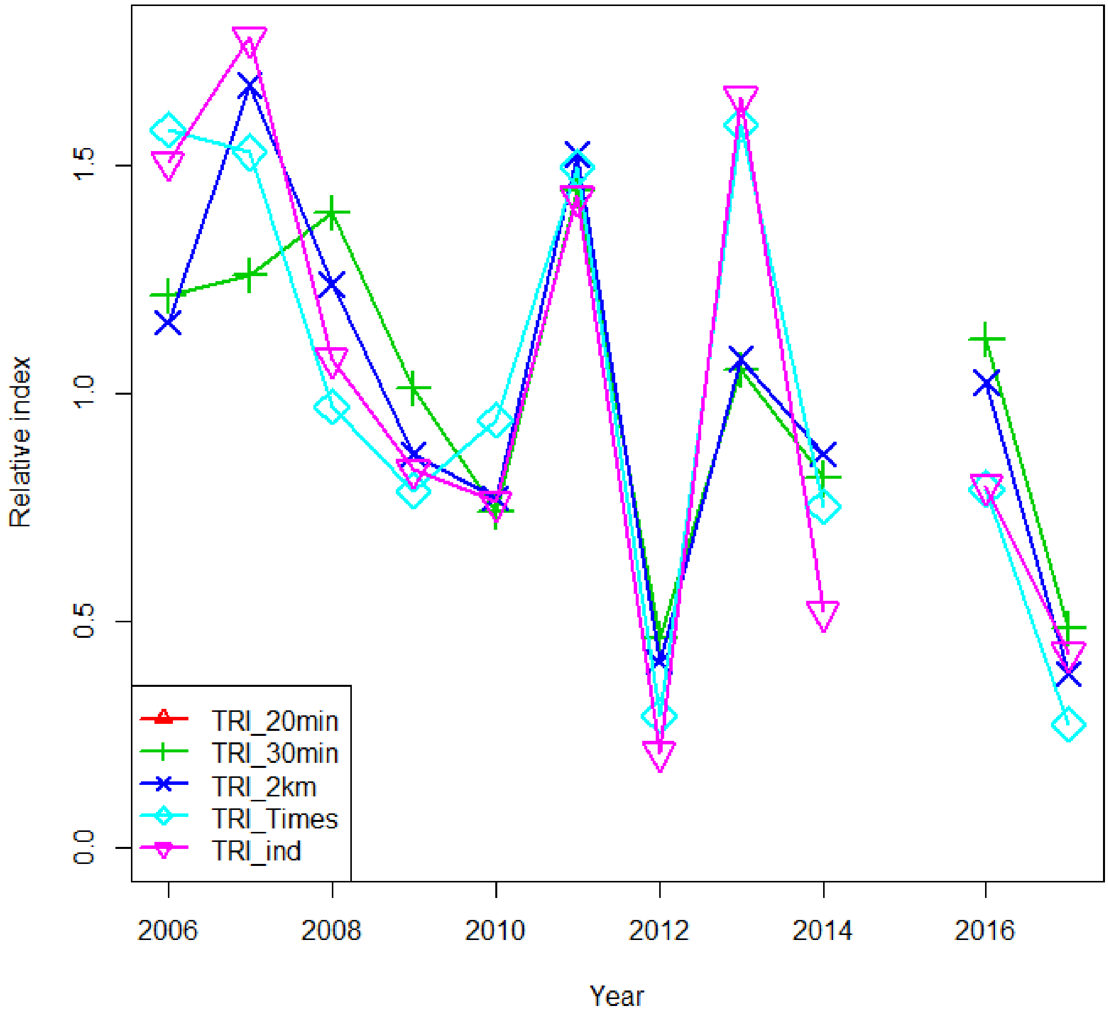


Fig. 4. Comparison of median from five types of piston-line trolling index

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

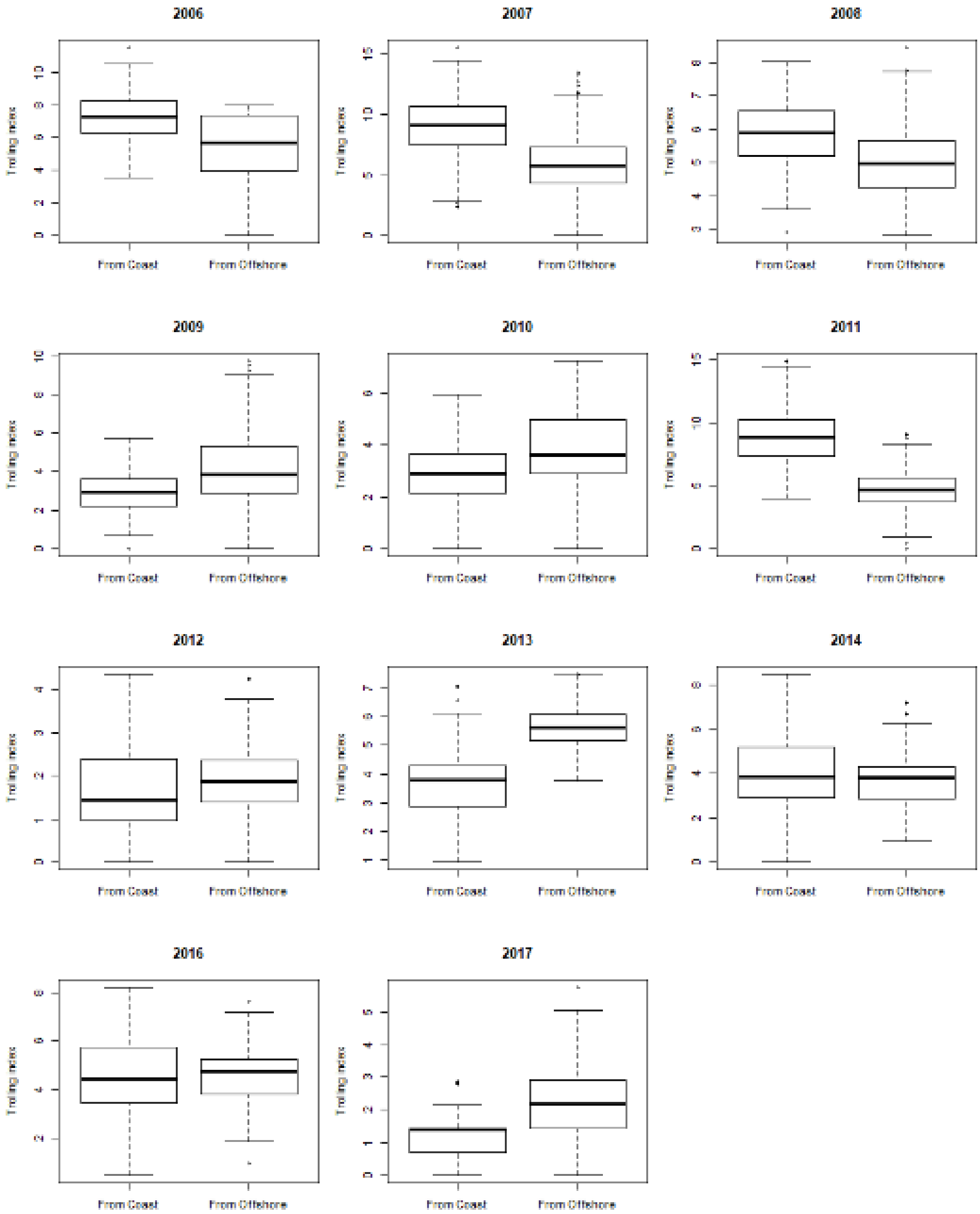


Fig. 5. Examination of independence of data between outward and inward piston-line on the same day by the piston-line trolling index

On each panel, left hand side is the index based on data in both outward and inward surveys of a day. Right hand side is the index based only on either of them. Catch is school with definition of 2 km is necessary for different school. Data in the trolling survey were used. Estimates were simulated by 1000 times bootstrapping.

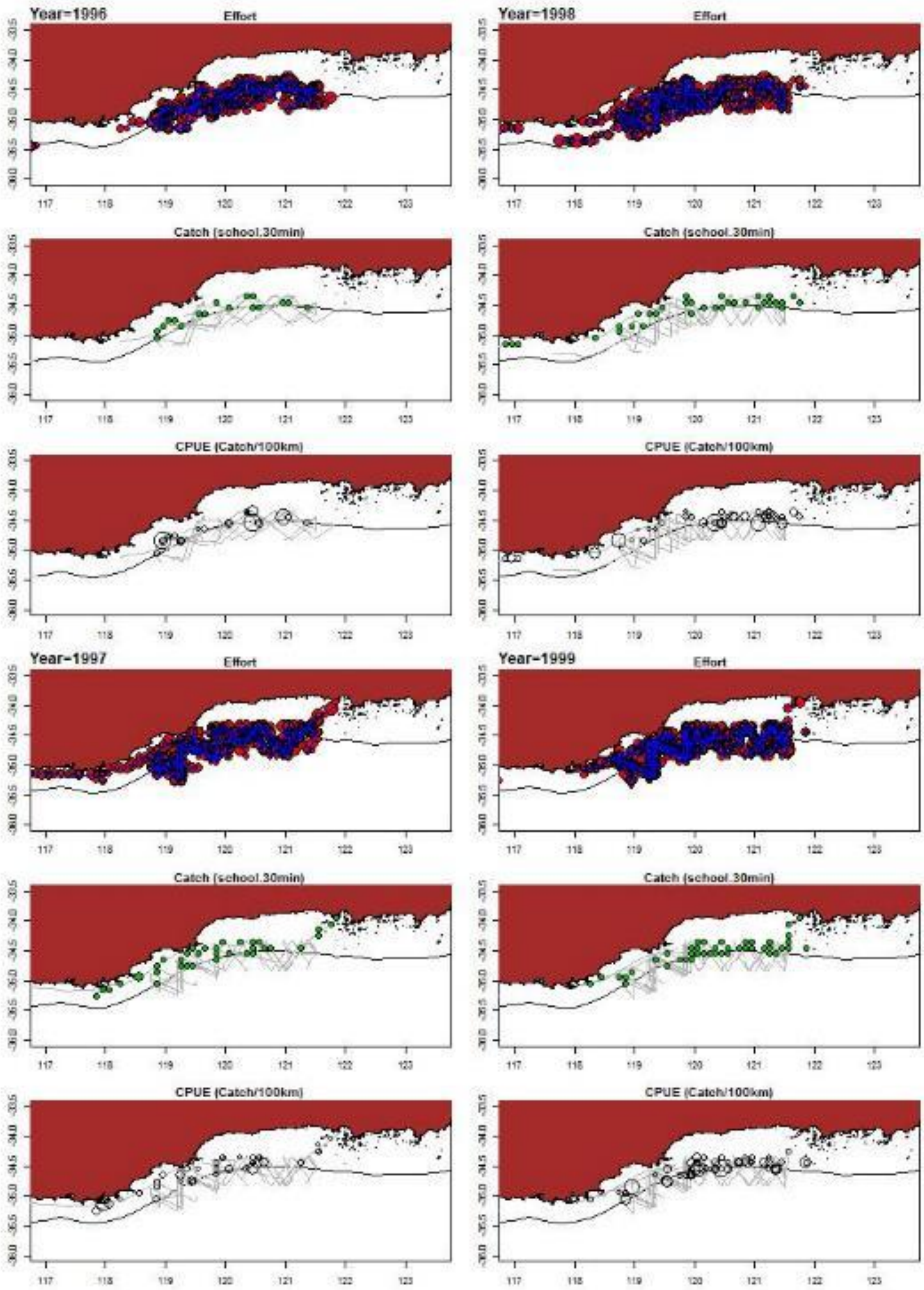


Fig. 6. Distributions of effort, SBT age-1 catch and CPUE by year

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.

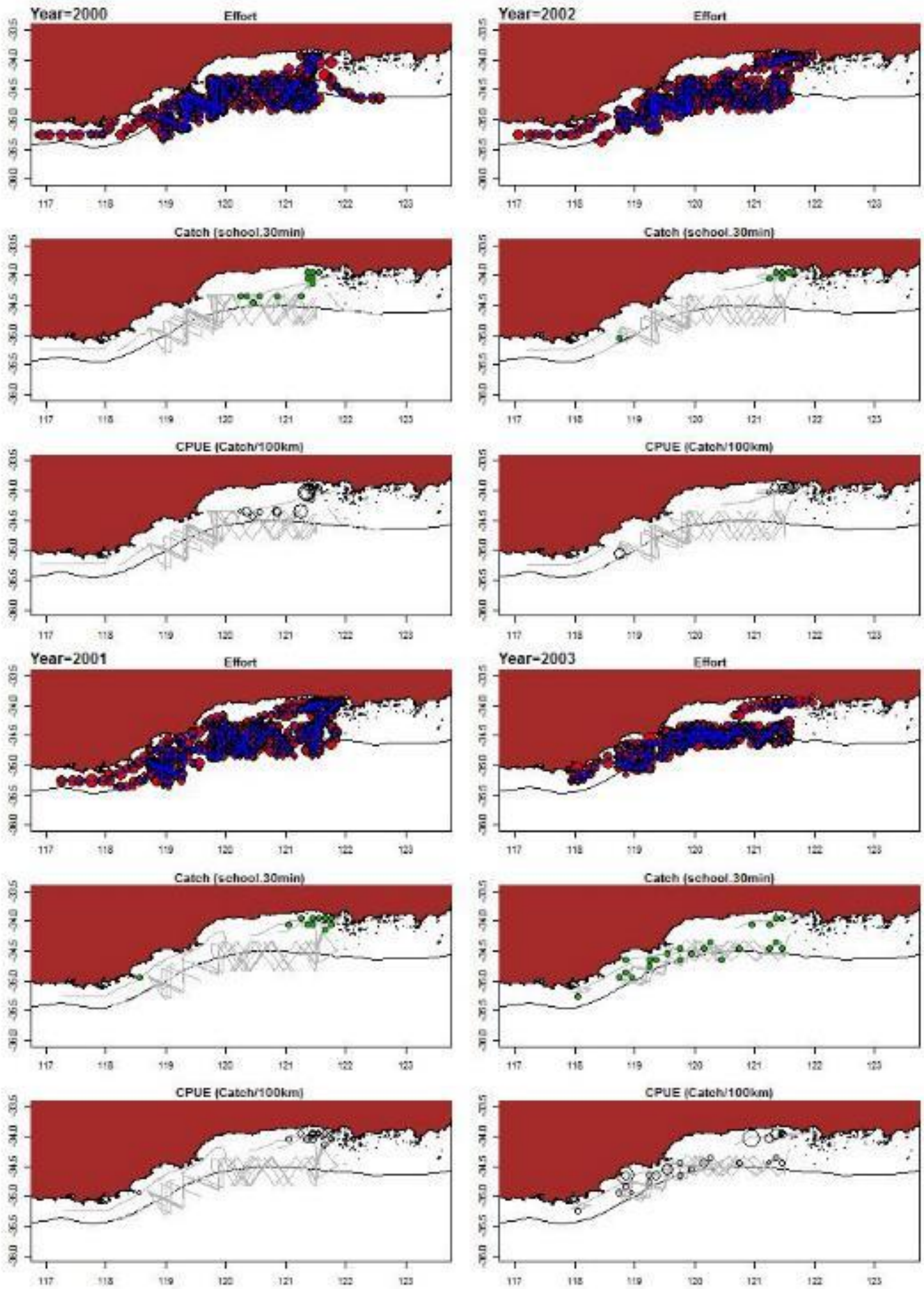

Year=2000
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2001
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2002
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2003
Effort
Catch (school.30min)
CPUE (Catch/100km)

Fig. 6. (cont'd)

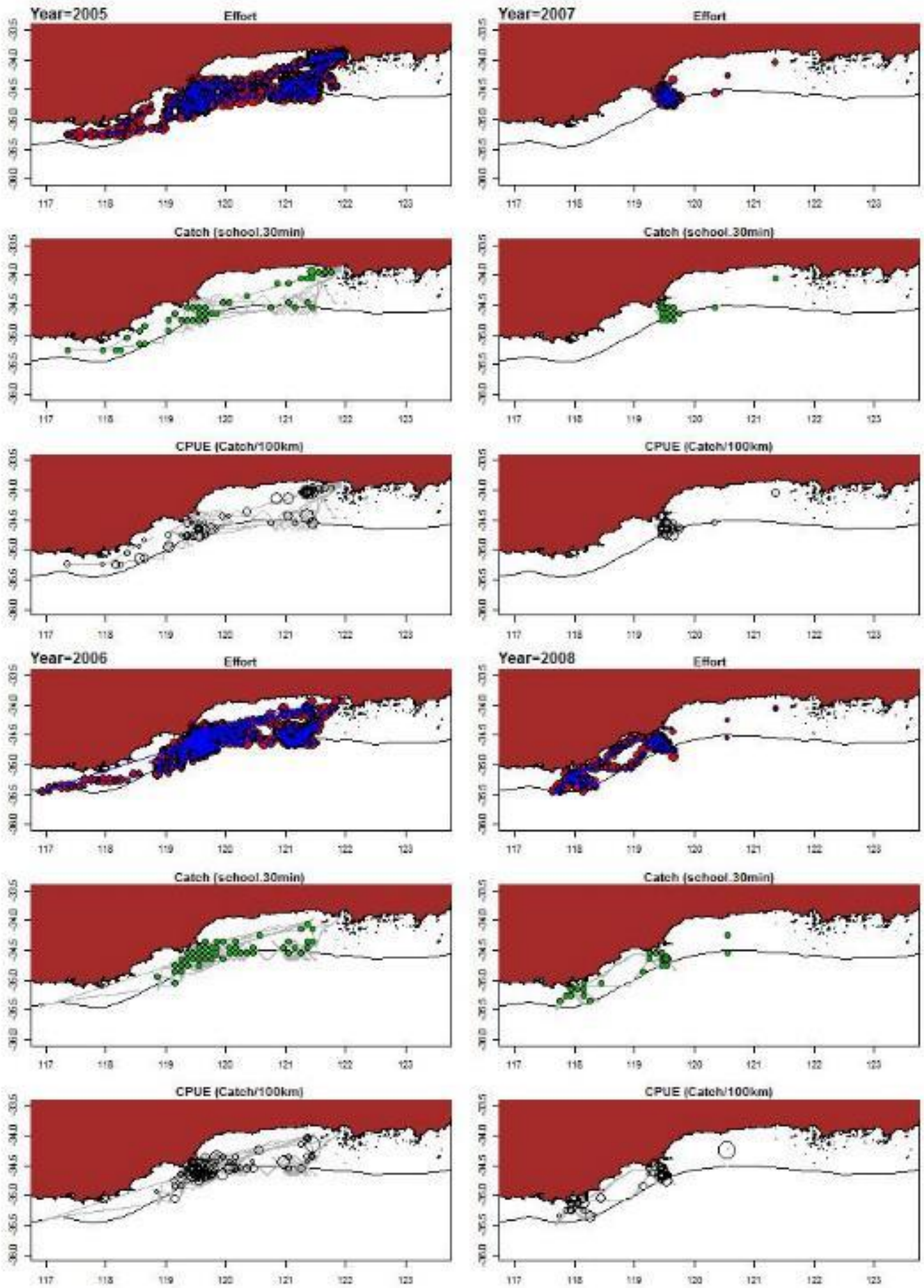

Year=2005
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2006
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2007
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2008
Effort
Catch (school.30min)
CPUE (Catch/100km)

Fig. 6. (cont'd)

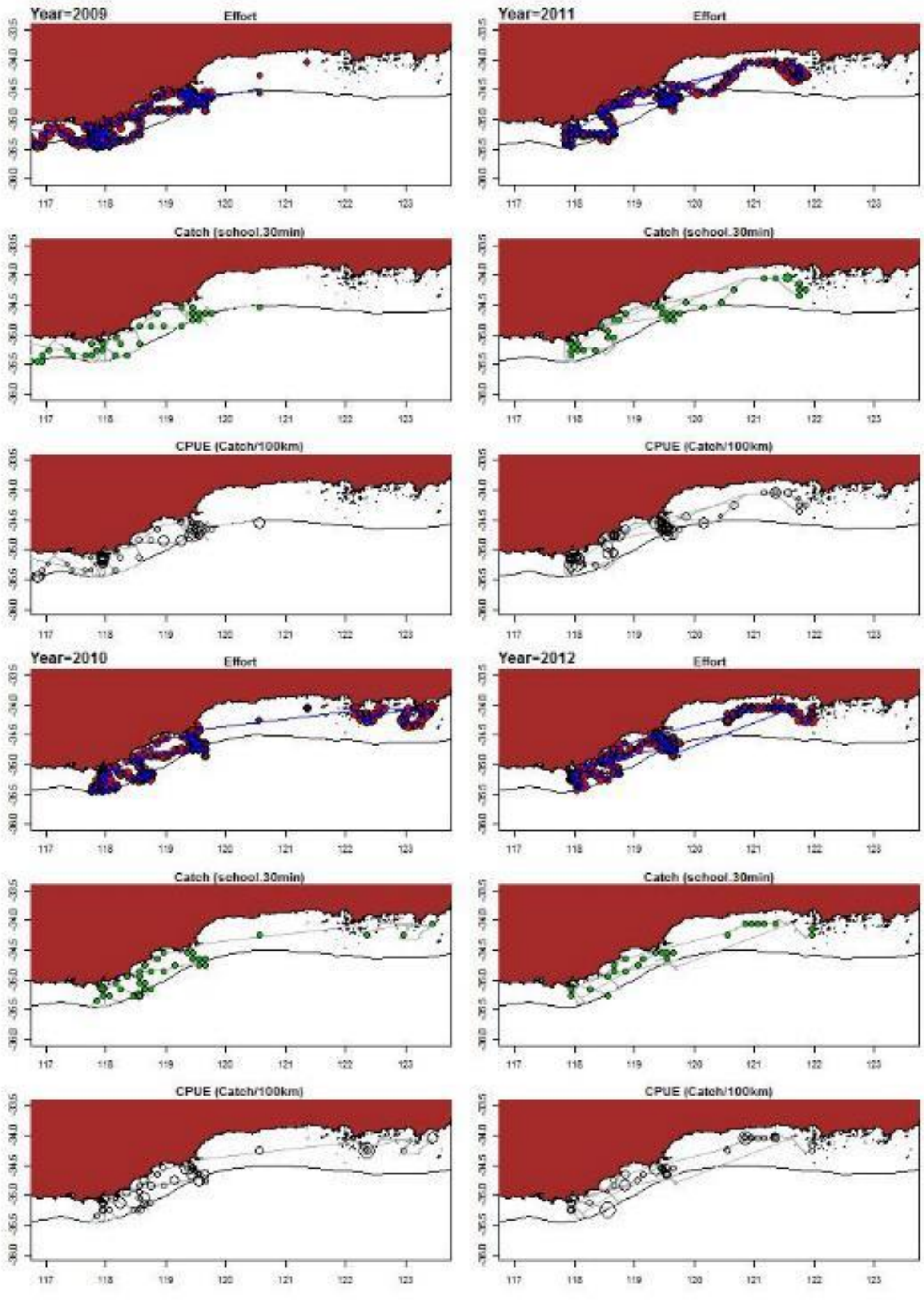

Year=2009
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2011
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2010
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2012
Effort
Catch (school.30min)
CPUE (Catch/100km)
117
118
119
120
121
122
123

Fig. 6. (cont'd)

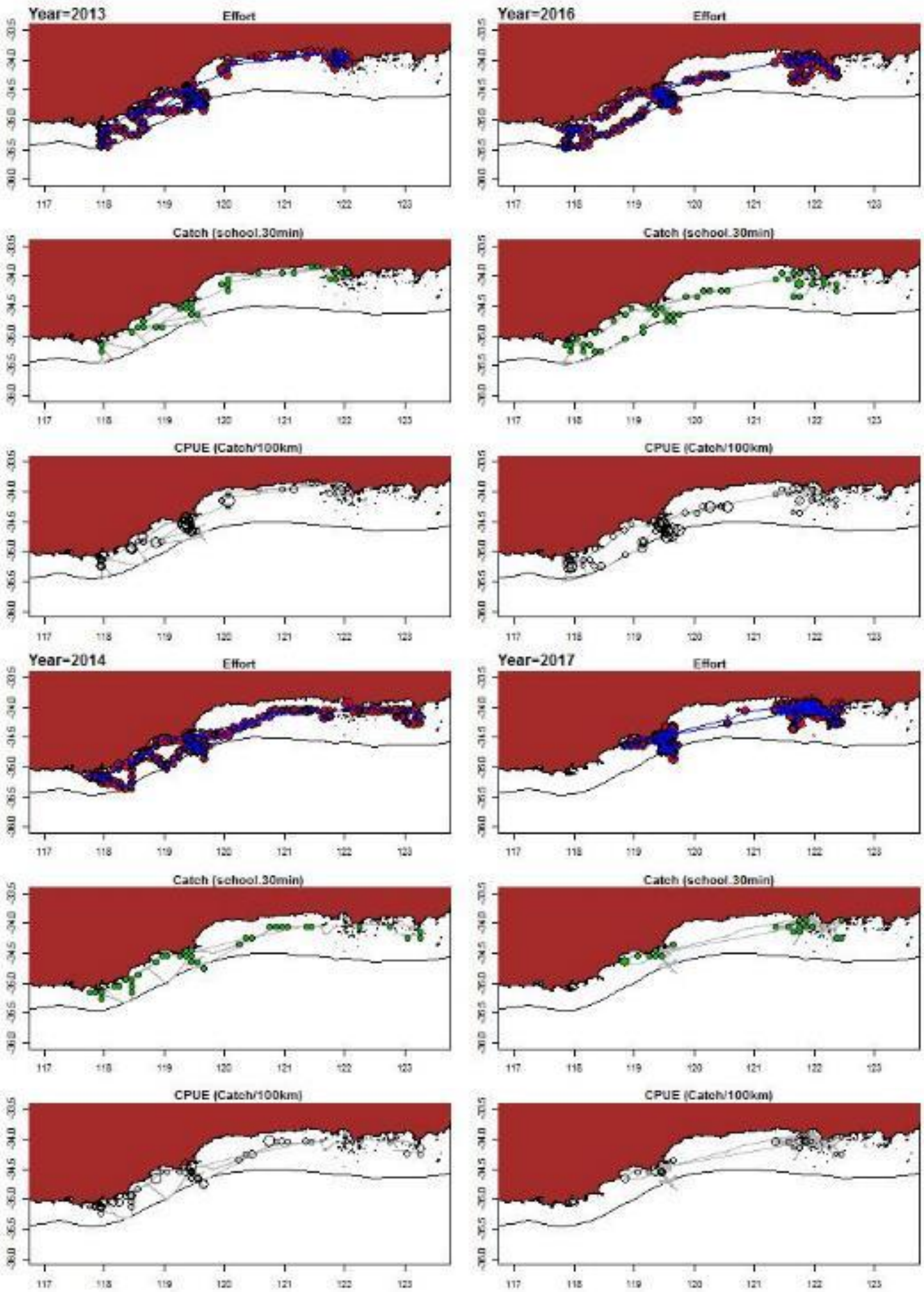

Year=2013
Effort
Catch (school.30min)
CPUE (Catch/100km)
Year=2014
Year=2016
Year=2017

Fig. 6. (cont'd)

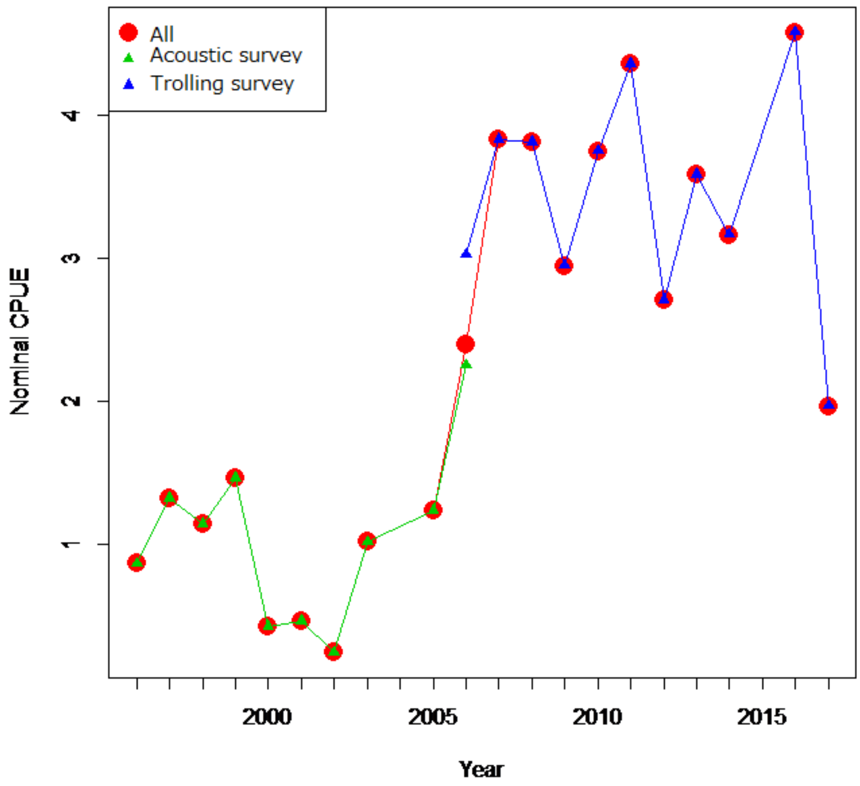


Fig. 7. Nominal CPUE of Grid-type Trolling Index

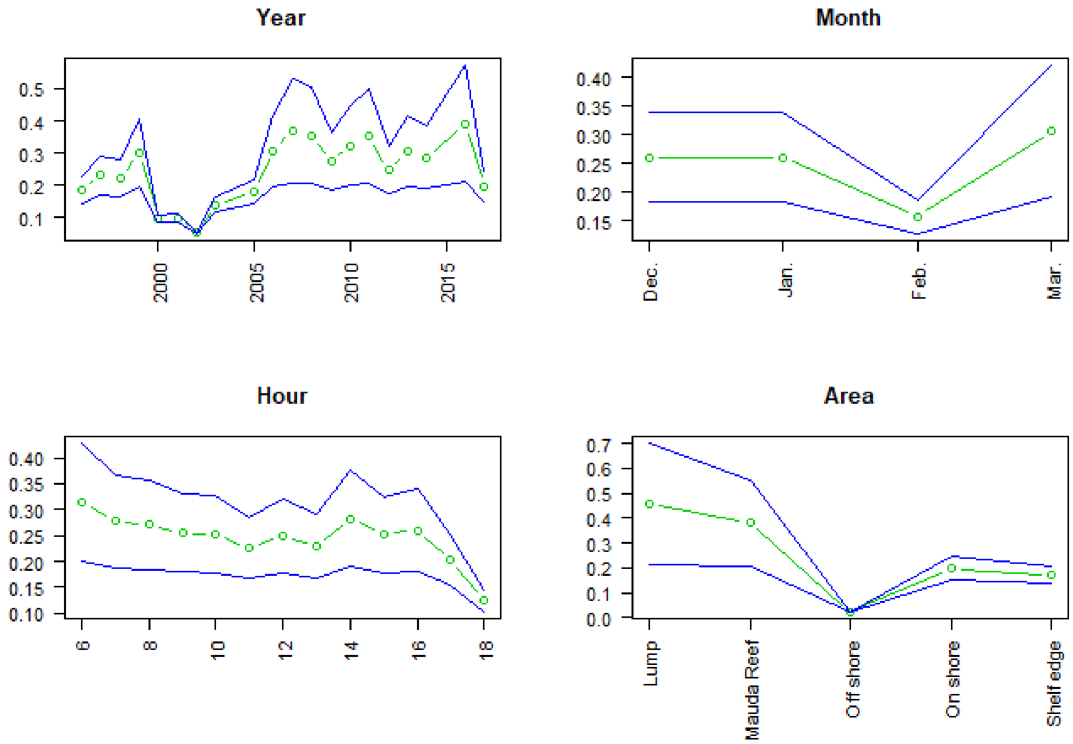


Fig. 8. Probability of catch for variables that were selected by AIC in 2014

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

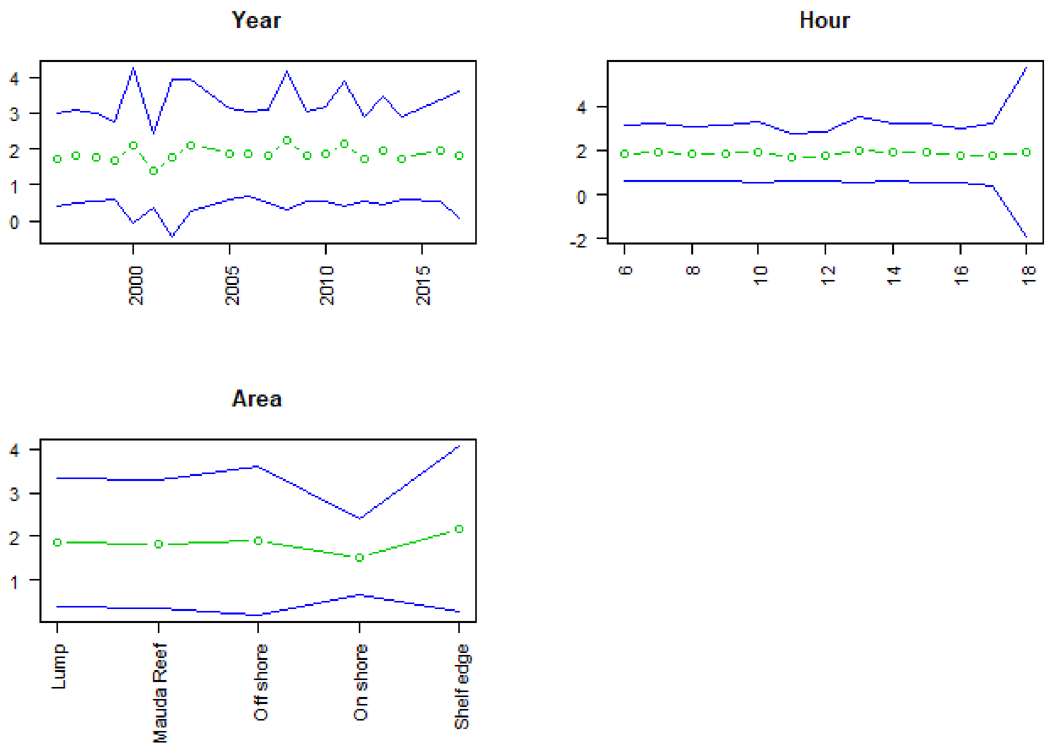


Fig. 9. CATCH in positive catch for variables that were selected by AIC in 2014

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

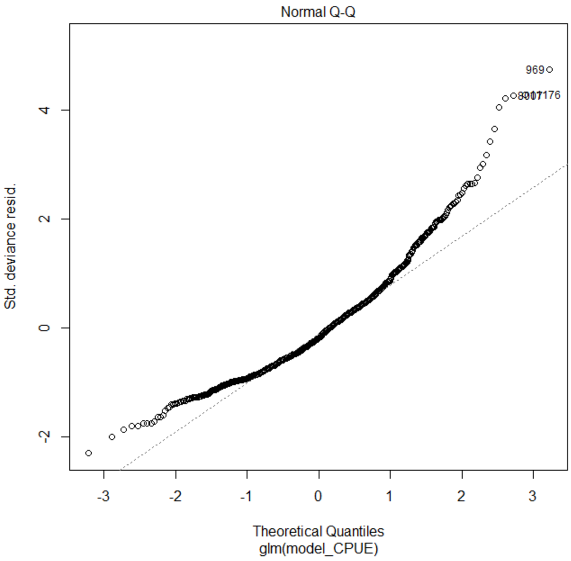


Fig. 10. QQ plot of GLM for positive catch sub-model

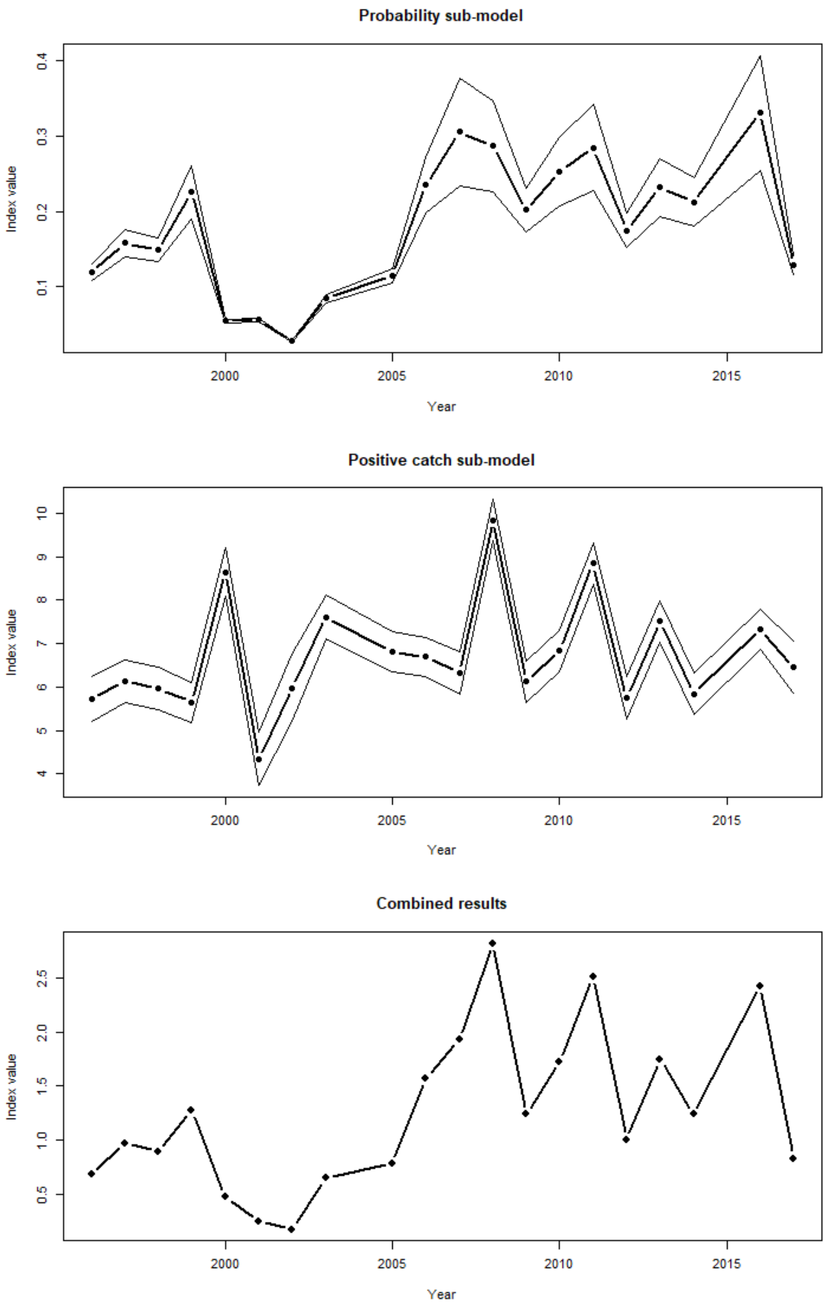


Fig. 11. Grid-type Trolling Index

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

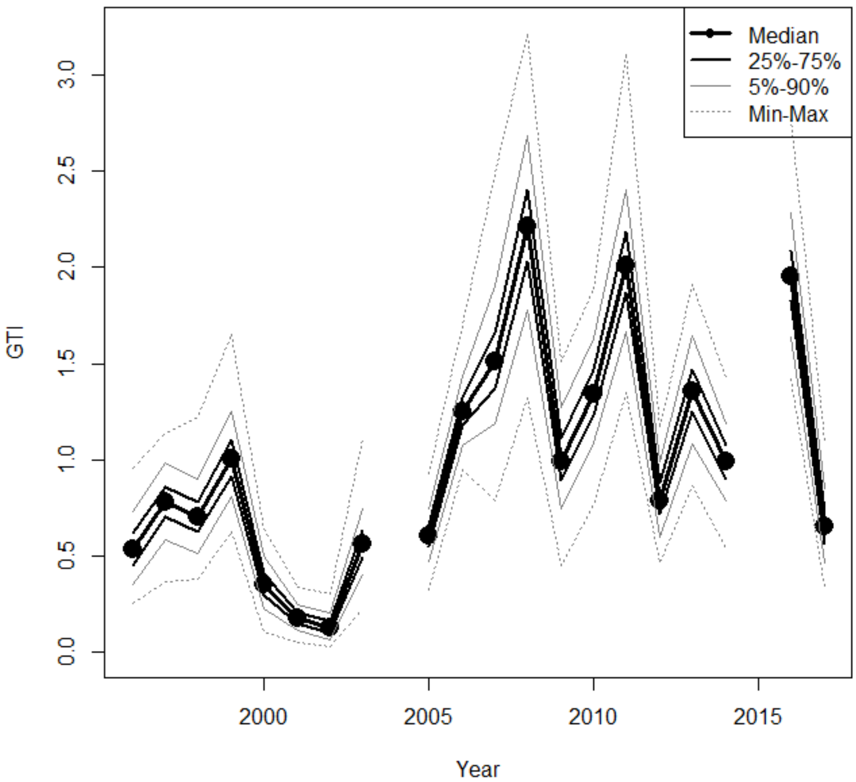
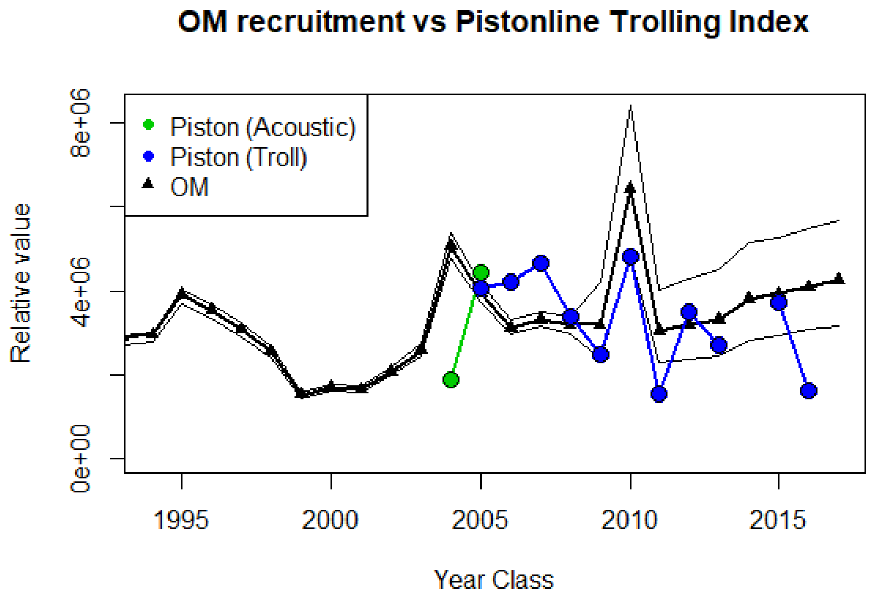


Fig. 12. Grid-type Trolling Index with confidence intervals

Estimate was simulated with 1000 times bootstrapping.



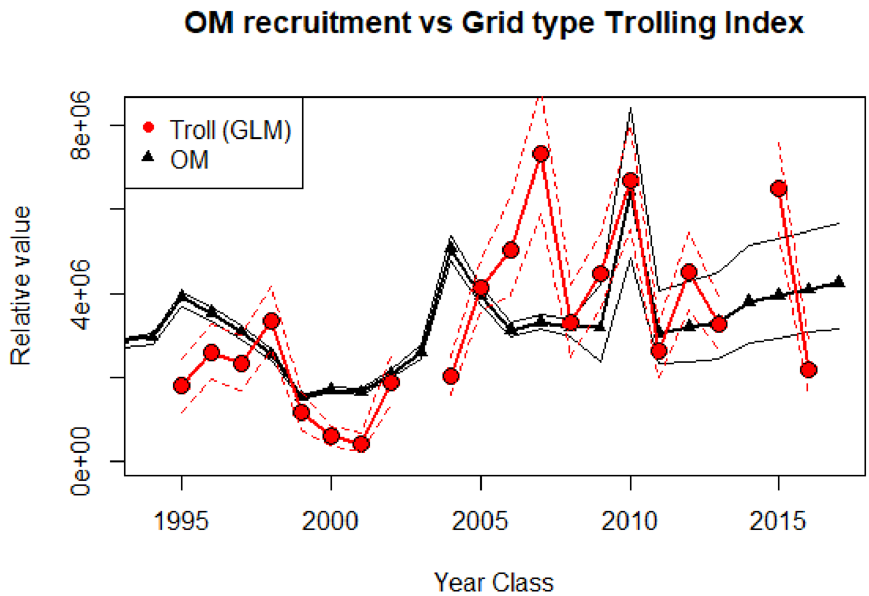
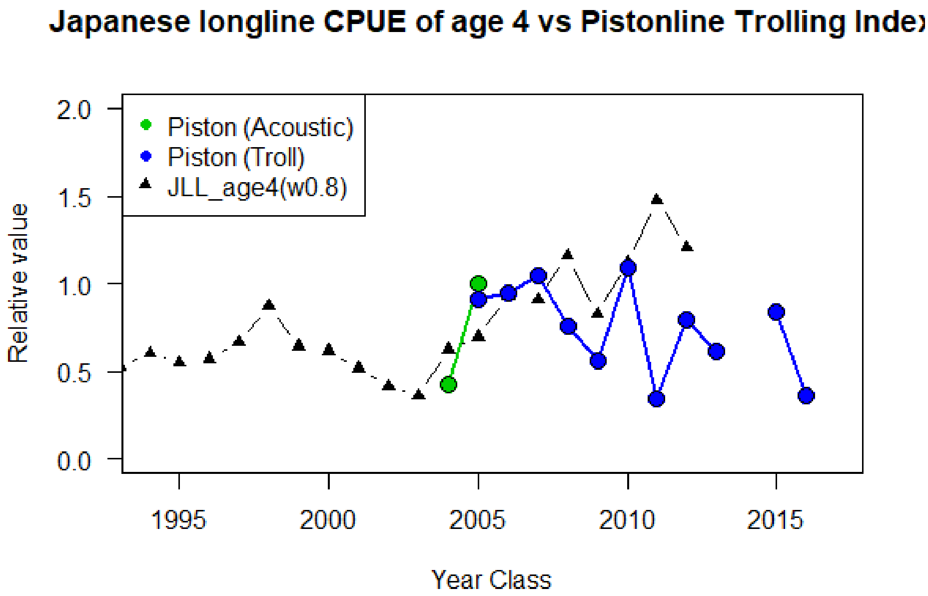


Fig. 13. Comparison between OM recruitment and trolling indices

Upper panel shows PTI and lower panel shows GTI. Range of OM recruitment is 25-75 percentiles.



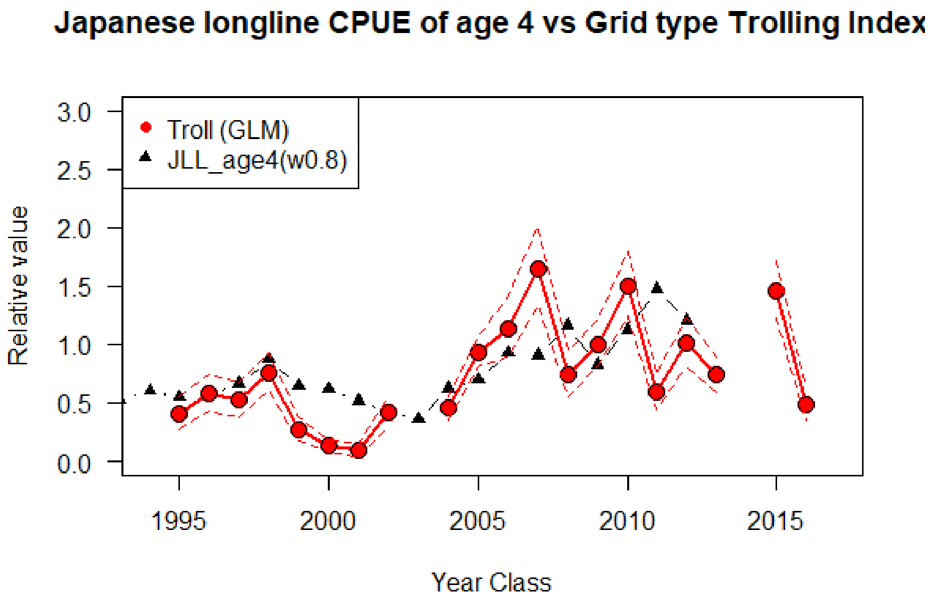


Fig. 14. Comparison between age^4 standardized CPUE (W0.8) of Japanese longline and trolling indices

Upper panel shows PTI and lower panel shows GTI.

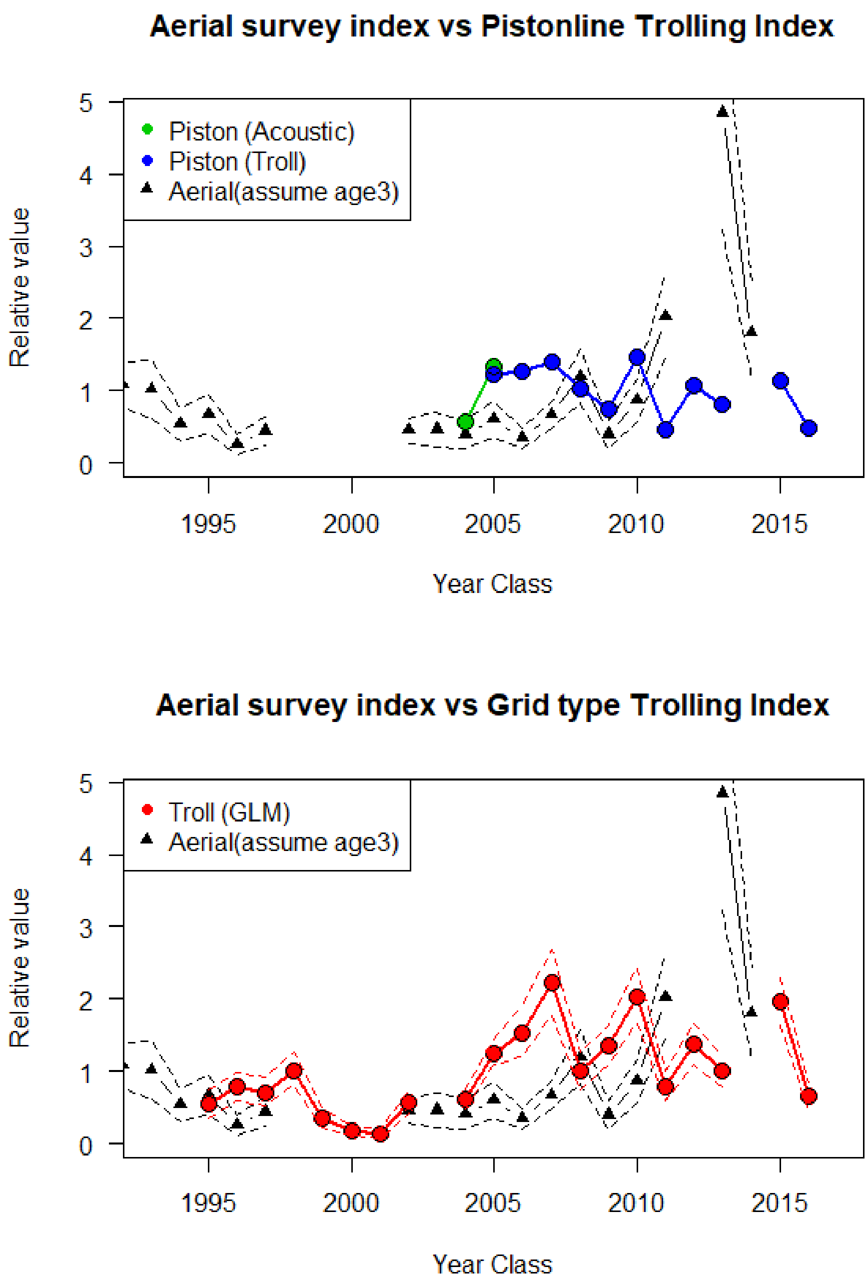
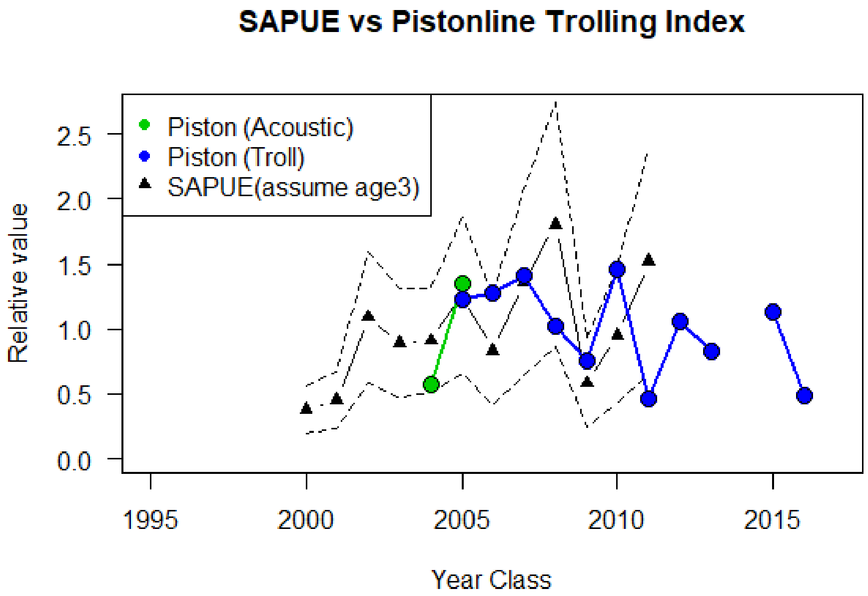


Fig. 15. Comparison between aerial survey index trolling indices
Upper panel shows PTI and lower panel shows GTI. Assigned year class for aerial survey assuming age-3 fish observed. Range of aerial index is ±1SE.



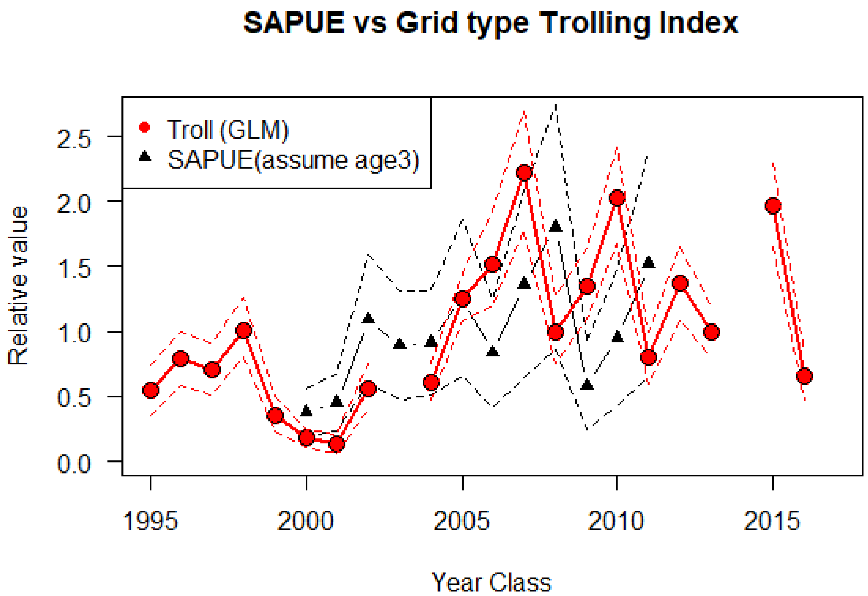


Fig. 16. Comparison between SAPUE and trolling indices

Upper panel shows PTI and lower panel shows GTI. Assigned year class for SAPUE assuming age-3 fish observed. Range of SAPUE is ±2SE.

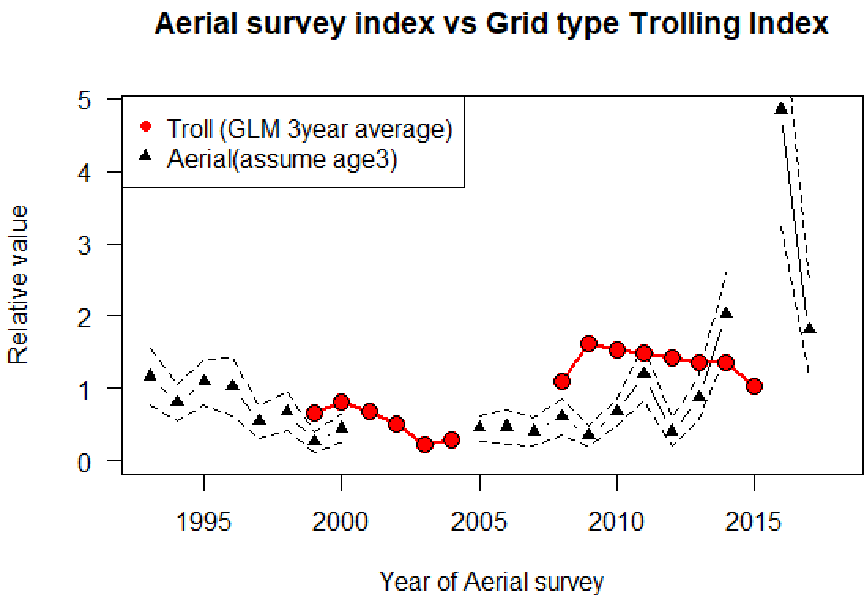


Fig. 17. Comparison between aerial survey index and grid-type trolling index in three years running average

Range of aerial index is ±2SE. Trolling index was plotted two years later of it operated assuming that SAPUE for age 3 and trolling survey for age 1.

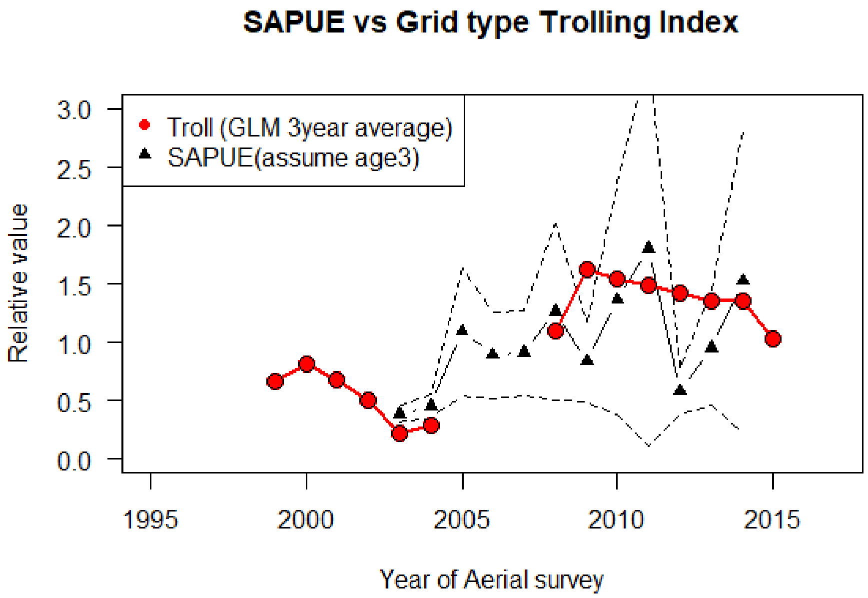


Fig. 18. Comparison between SAPUE and grid-type trolling index in three years running average

Range of aerial index is ±2SE. Trolling index was plotted two years later of it operated assuming that SAPUE for age 3 and trolling survey for age 1.