ミナミマグロ 1 歳魚の曳縄指数 –グリッドタイプ曳縄指数の更新 2022 年–

Trolling indices for age-1 southern bluefin tuna: update of the grid type trolling index in 2022

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要約

オーストラリア南西岸において実施したミナミマグロ 1 歳魚の科学加入量調査の曳縄漁獲データから、1996 年から現在までの 20 年以上に及ぶ加入量指数を求めた。本文書では、2022 年調査データを追加して計算した結果を、他の加入指標と比較して示す。ピストンライン曳縄指数（TRP）は、既定の調査定線（ピストンライン）上における探索距離 100km 当たりの漁獲をモデルベースの標準化はせずに求める。グリッドタイプ曳縄指数（TRG）は、より広範な海域のデータを使用してデルタログノーマルアプローチで一般化線形モデルで標準化して計算する。TRG を他の指数と（2022 年 OMMP 会合でのリファレンスセットによる OM の加入量推定値、日本延縄船全船による年齢特異的標準化 CPUE の 4 歳魚と 5 歳魚のもの、航空目視指数、及び遺伝子標識の資源豊度推定値）と比較した。2015 年級までは類似したトレンドが見られていたものの、2016 年級以降は差が大きくなり、TRG は他よりも低かった。今後も、最近年の加入状況を科学調査と漁業から得られる全ての情報を駆使して注意深くモニタリングする必要がある。

Summary

From the trolling catch data of the scientific recruitment monitoring surveys for the age-1 southern bluefin tuna (SBT) *Thunnus maccoyii* on the southwestern coast of Australia, the recruitment index for more than 20 years since 1996 to the present was calculated. This document shows updated indices by adding the 2022 survey data, as well as comparison to

various other recruitment indices. The piston-line trolling index (TRP) is derived from catch per 100 km search distance on a pre-determined transect line (called piston-line) without model-based standardization. The grid-type trolling index (TRG) is calculated based on data from wider area and standardized by the generalized linier model with delta lognormal approach. TRG was compared to various indices: the recruitment estimated from the OMMP meeting in 2022 based on the reference set operating model, age specific standardized CPUE from all Japanese longline vessels for age-4 and age-5, the aerial survey index, and the abundance estimates of gene tagging. Although similar trends were seen up to the 2015 year class, the difference was large after the 2016 year class that TRG is lower than others. It is necessary to continue to carefully monitor the status of recruitment in recent years by making full use of various informaion from scientific researches as well as from fisheries.

Introduction

Trolling survey for southern bluefin tuna (*Thunnus maccoyii* SBT) is a scientific research survey which aims to provide recruitment indices of the stock at age-1. The survey has been carried out in the southern coast of Western Australia since 2006, except 2015. It has provided an index named the piston-line trolling index (TRP) which have been reported to CCSBT since 2006 (Itoh and Kurota 2006, Itoh 2007, Itoh and Sakai 2007, 2008, 2009, 2010, Itoh et al. 2011, 2012, 2013, Itoh and Tokuda 2014, Itoh and Tsuda 2016, Tsuda and Itoh 2017, 2018, 2019, Itoh and Tsuda 2020, Itoh 2021). TRP is derived from catch per 100 km search distance on a pre-determined transect line (called piston-line) without model-based standardization. In addition, another recruitment index, the grid-type trolling index (TRG) which used data from wider area and standardized by the generalized linier model (GLM) has developed and has been reported to CCSBT since 2014 (Itoh and Takahashi 2014).

In 2021, while the trolling survey was conducted, the survey area was limited to off Esperance only due to the influence of COVID-19, which resulted in no surveys on the piston-line. We presented the updated TRG and provided a variation of TRG (TRG_esp) limited to the area off Esperance. In 2022, the trolling survey was carried out in full range scale including piston-line, though still under the influence of COVID-19 in some extent. In this document, we provide updated TRP, TRG and TRG_esp, as well as comparison to various other recruitment indices.

Materials and methods

1. Piston-line Trolling Index　TRP

For TRP, data used were the trolling catch data on the piston-line in the acoustic survey in 2005 and 2006 and that in the trolling survey between 2006 and 2014, 2016 to 2020, and 2022. Details of the survey were described in other papers that submitted every year (e.g. Itoh 2022). It contains data in a total of 212 times on the piston-line (Table 1). Data of another 12 times were not included because the line was incomplete due to mainly rough sea conditions. Datasets were separated between the acoustic survey and trolling survey because there were differences in the two surveys, such as survey design, a vessel used especially in size and specification of trolling gears. Trolling operations on the piston-line were repeated from 8 to 20 times per year.

The piston-line was set off Bremer Bay, in the middle of the whole area for the acoustic and trolling surveys (Fig. 1). The exact locations and length of the line have been changed a few times since its first determination in 2005. The offshore part of the piston line, which had caught a small number of fish over the past years, was cut and extended towards the coast in which available to enter for the small vessels used in the trolling survey in 2007. The data in 2005 and 2006 where locate offshore than the 2007 end points were eliminated (no SBT were caught in the eliminated data). The locations of the piston-line have been almost the same since 2008 to the present. Figure 2 shows the piston-line in 2022. Among 13 lines, 4 lines are out of the predetermined position which was carried out on purpose to examine SBT distribution in neighboring areas. These 4 lines were also included in analysis.

The summary of data is shown in Table 2. It reached a total of 546.7 hours in search time and 7,080 km in search distance. The number of age-1 SBT caught was 778 individuals.

TRP was calculated as a catch of age-1 SBT per 100 km search distance. There were five types of catch definition and TRPs 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. TRP 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. TRP 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. TRP 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. TRP from this definition is “TRI_Times.

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

Confidence intervals of TRP were calculated from data sampled 1000 times by bootstrap method, and the results were shown by median, 5% and 95% points.

1. Grid-type Trolling Index　TRG

For TRG, data used were the trolling catch in the acoustic survey between 1996 and 2003, 2005 and 2006, and in the trolling survey between 2006 and 2014, and from 2016 and 2022. While the surveys were carried out from December in some years, the year was referred to that include January in the survey (e.g. the survey extended from December 2008 to January 2009 was referred to be the 2009 survey) in this analysis.

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 four area types (described later). Data west of 117.5E were eliminated.

Time intervals of a recording of latitude and longitude during the surveys differed by year. Up to the 2005 acoustic survey, latitude and longitude were only recorded when any events occurred, including hourly environmental observation, catch, detection of anything in sonar, the arrival of transect reflection point, CTD observation, etc. Then, locations at every one minute were calculated by interpolating two points of records available. Since the 2006 surveys, locations were recorded in a 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 the 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 eliminated. In the trolling survey, all the times of start and end of trolling operations were recorded.

Catch was limited for age-1 SBT (estimated from fork length of 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 apart were from different schools. Other definition of a school (e.g. 20 minutes apart, 2 km apart) can be possible, however, it has already confirmed that it caused little difference in the previous analysis.

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.

shelfedge: 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.

onshelf: the northern area of the shelfedge.

offshore: the southern area of the shelfedge.

The area for each grid was classified as follows. When a part of the shelfedge zone is included in the grid, it is classified as shelfedge, the coastal side is classified as onshelf, and the offshore side is classified as offshore. After that, those whose center position of any lump is included in the grid are classified as lump. Furthermore, in the case of four lumps (Figure of eight Island, Investigator Island, etc.) where the lump is large or the center of the lump is near the edge of the grid, the adjacent grid that is likely to be affected by the lump is also classified as lump. In the 2021 analysis, the number of lumps to be referred to was increased (170), so the data classification was different from the previous data.

Delta log-normal GLM was applied for CPUE standardization because of a high percentage of zero catch observations (Lo et al. 1992, Li and Jiao 2013). The delta model handles zero catch data and positive catch data in two separate sub-models, i.e. one sub-model to estimate the probability of catching SBT age-1 with an assumption of binomial distribution and logit link function (binomial sub-model), and the other to fit the positive catch data with an assumption of lognormal distribution (CPUE sub-model).

Binomial sub-model:

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

error ~ binomial

CPUE sub-model:

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

error ~ gaussian

where p is the probability of positive catch, survey is either acoustic or trolling surveys, explanatory variables of year, month, hour, area and survey are treated as factors.

In this GLM standardization, the explanatory variables for the optimum model were selected based on the AIC using MuMIn package in R software v4.0.5 (R-core team 2012). The MuMIn package calculates the AIC for models of all combinations of the explanatory variables. The lowest AIC model containing the year explanatory variable was selected as the best model. Product of estimates from these two sub-models gives the final estimate of the TRG. Furthermore, the bootstrap method was applied to obtain a range of the estimate. 1000 datasets were made through stratified sampling by year.

Because the survey area in 2021 was limited to the offshore of Esperance due to the survey design temporarily revised in response to the situation of COVID-19, another TRG that limited to the off Esperance (TRG_esp) was calculated. Eliminated data before 2012 when there is little data for this calculation, the area east of longitude 121.4E was used. There are two types of areas, onshelf and lump. As with TRG, we used a delta model consisting of a binomial sub-model and a CPUE sub-model. The model structure used was similar except for the survey.

Binomial sub-model:

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

error ~ binomial

where p is the probability of positive catch.

CPUE sub-model:

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

error ~ gaussian

TRG is compared to TRG_esp. TRG was also compared to various indices: the recruitment estimated from the OMMP meeting in 2022 based on the reference set operating model (OM), age specific standardized CPUE from all Japanese longline vessels for age-4 and age-5, the aerial survey index, and the abundance estimates of gene tagging.

Results

1. Piston-line Trolling Index: TRP

Summary of data on piston-line is shown in Table 2. Figure 3 and Table 3 show the five types of estimated TRP by different school/catch definition. Figure 4 shows the median of the five types of indices that adjusted to the mean of each. The small differences were observed among the five type indices between 2006 and 2010 and there was a 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 the acoustic survey in 2006. The fluctuation in TRI_30min overtime was smaller among the five types of indices. Therefore, the TRI_30min index which was submitted to CCSBT data exchange is used as TRP.

1. Grid-type Trolling Index: TRG

Summary of data aggregated by grid is shown in Table 4. It consists of 10,647 records in total that reach about 58,630 km search distance and 973 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 (90.9%).

Distributions of effort, catch and CPUE in 2022 are shown in Fig. 5. Those in previous years are available in previous document (e.g. Itoh and Tsuda 2020). It covers the area from Esperance to Bremer Bay as usual years, though did not covere west to Albany where have been covered in several years. Probability of catch is different by the area type distinctively, the largest in lump (17%), followed by onshelf and shelfedge, and lowest in offshore (2.8%) (Table 5). In the positive catch, there is small difference in CPUE by area type.

Nominal CPUE is shown in Fig. 6. Note that a substantial part of the effort was made up offshore where few SBT caught from 1996 to 2005 in which to be expected to underestimate compared to the latter half period.

The selected GLM models for TRG based on the AIC were follows (Table 6):

Binomial sub-model:

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

CPUE sub-model:

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

Relationships between the probability of catch and various variables and between CPUE and various variables in terms of least square mean are shown in Fig.7 and Fig. 8, respectively. The estimated values of each variable are shown in Table 7 and Table 8. QQ plot of CPUE sub-model is shown in Fig. 9, which shows good fit in the middle part though lack of fits in both ends. LS-means of year trend in each sub-model are shown in Table 9 and Table 10. Indices of both sub-models and point estimation of TRG are shown in Table 11 and Fig. 10.

Table 12 and Figure 11 show TRG with confidence interval calculated through 1000 times bootstrap. TRG showed considerable low levels in 2000-2002, then increase in 2005-2008 and relatively high level in 2006-2016 with fluctuation from year to year. TRG values in recent years (2017-2022) have returned to relatively low levels, similar to those in 2000-2002. TRG value for 2022 is slightly larger than that in 2021, while the median is 55 % of the mean over 25 years.

2. Comparison to other indices

We compared TRG with other recruitmen indices. In the comparison, the year of birth was arranged in cohort and expressed in year class (YC).

<u>TRG_esp</u>

Trolling index from grid data limited to off Esperance (TRG_esp) was calculated between 2013 and 2022 (Fig. 12). From the full models, following models were selected by AIC.

Binomial sub-model:

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

CPUE sub-model:

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

Figure 13 shows comparison between TRG and TRG_esp. Two indices are significantly correlated (Pearson's correlation coefficient, $r=0.852$, $p < 0.01$) and general trends are similar to each other. It is suggested that the index derived from the survey area, reduced temporarily in 2021 only off Esperance, represents that from all survey areas.

TRP

Figure 14 shows comparison between TRG and TRP. Two indices are significantly correlated (Pearson's correlation coefficient, $r=0.923$, $p < 0.001$).

OM recruitment

Figure 15 shows comparison between recruitment estimated from the OMMP meeting in 2022 based on the reference set operating model (OM) and TRG by year class. The recruitment from OM has a large uncertainty in years of future projection or years based on few observed data in most recent years. The general trend of TRG is similar to that of OM recruitment between 1995 and 2016, which is significantly correlated ($r=0.56$, $p<0.05$). TRG captured the historical low levels of OM recruitment in 2000-2002 and TRG has been relatively high levels after 2005YC as same as in OM's. TRG captured increase/decrease change in OM recruitment well (e.g. 2004-2005YC and 2008-2011YC), while failed in a few years (e.g. 1998YC, 2007YC). TRG in the most recent 6 years (2016-2021YC) has been much lower than those average in 2010-2015YC. The recruitment of OM was low in 2016YC which agreed to TRG decrease. However, the recruitment of OM in 2017-2021YC were estimated to be as high as the 2010-2015YC, which is inconsistent with TRG.

Age-4 and age-5 all vessel CPUE of Japanese longline

Figure 16 and Figure 17 show comparisons between age specific standardized CPUE from all Japanese longline vessels for age-4 and age-5, respectably, and TRG. The general trend of TRG is similar to those CPUE indices, which is significantly correlated in age-5 (W0.8 of age-4, $r=0.335$, $p>0.05$; W0.8 of age-5, $r=0.613$, $p<0.01$). The low level of TRG in 1999-2001YC and the high level in 2005-2016YC were supported by both CPUE idices. Large differences are observed in the most recent years, that although TRG dropped from 2015YC to 2016-2021YC, age-4 CPUE of 2017YC is higher than 2015YC and the highest since 1995. Age-5 CPUE of 2016YC is the same level of the 2015YC.

Aerial survey

Figure 18 shows comparison between aerial survey index and TRG. 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 TRG and the aerial survey index were not similar to each other over time ($r=-0.20$, $p>0.05$). Note that the aerial survey index was not obtained around 2000YC when extremely low recruitment observed. The high value in 2013YC in the aerial survey was not supported by the TRG.

Gene tagging

Figure 19 shows comparison between age-2 abundance estimates from the gene tagging and TRG. Only three YC estimates from gene tagging are correspond to TRG. The trends of both TRG and the gene tagging estimates were not similar to each other over time ($r=-0.37$, $p>0.05$).

5 main indices

Figure 20 shows trends of five main indices (TRG, OM, age-4 W0.8, age-5 W0.8, gene tagging). The trend of TRG year class was similar to those of recruitment from OM and age-4 and age-5 standardized CPUEs of Japanese longline up to 2015YC. Those were medium level in the mid-1990s year classes, low level in the 2000YC-2002YC and high level in the 2005-2014YC.

The trend is different after 2016YC. TRG is as low to 2021YC. Information on recruitment from Japanese longline CPUE is available in 2016YC and 2017YC as age-4 or 5, which are high. In gene tagging, 2017YC is suggested to be higher than 2015YC and 2016YC. Of the recruitment estimates from OM, 2016YC and 2017YC estimated based on the observed values are at the same level as 2005-2015.

Discussion

The present paper provided updated Piston line trolling index (TRP) and Grid-type trolling index (TRG) of SBT recruitment indices. 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 fish school. The numbers of fish individuals caught and catch times were decreased when a 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 can be depends on such crew skills of trolling. The number of schools was selected as a catch to avoid the influence of crew skill. However, the definition of catch as a school for index means to set an assumption that the probability distribution of the size of school (the number of individuals per school) is the same every year.

TRG is a comprehensive index that includes not only on the piston-line but also all the area surveyed. TRG enabled to extend the years to as long as 25 years, by adding the trolling data in the acoustic survey from 1996 to 2003. The acoustic survey and the trolling survey were not originally designed to obtain TRG. However, because the acoustic survey was well designed to cruise randomly in the research area for sonar detection, the trolling catch operated simultaneously in the 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 the larger area since 2008 intending development of TRG. 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 a high percentage of zero observation was used. Area type was highly significant in the binomial 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. On the other hand, as Tsuda and Itoh (2017) showed, weather conditions have a negligible effect on the standardization of TRG.

In the comparison among the main indices (Fgi. 20), although similar trends were seen up to 2015YC, the difference was large after the 2016YC. It is noted that the OM recruitment estimation includes data on Japanese longline CPUE (though different CPUE series to be used this document) and gene tagging, which are not independent of each other. On the other hand, TRG is not used for the recruitment calculation by OM and is an independent index. At present TRG provides six index points from 2016YC to 2021YC, though only 1-2 points have been obtained from other sources. When limited to the 2017YC, the high CPUE of the 2017YC in age-4 was widely recognized in Japanese longline fishing grounds, which appears to be a strong signal at least suggesting that it is not a weak chohort. Status of other year classes are totally unknown except from TRG. It is necessary to continue to carefully monitor the status of recruitment in recent years by making full use of various informaion from scientific researches as well as from fisheries.

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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	
2019	8	8	
2020	10	10	
2022	15	13	2
Total	224	212	12

Table 2. Summary data of the 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	43:17	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	38:16	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	28:37	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	38:24	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	27:50	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	26:52	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	29:22	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	33:17	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	40:07	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	36:43	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	38:45	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	36:42	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	24:07	349.2				6	6	6	6	19					
2018	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	21:27	311.1				0	0	0	0	0					
2019	min	2:37	34.8	2019/2/3	5:55	8:40	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	4:10	36.2	2019/2/11	13:14	17:21	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	mean	3:00	35.5	2019/2/5	8:29	11:29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	total	24:00	284.2				0	0	0	0	0					
2020	min	2:23	34.1	2020/2/1	6:17	9:15	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	2:58	36.7	2020/2/11	13:41	16:22	2	2	2	2	8	5.86	5.86	5.86	5.86	22.76
	mean	2:37	35.1	2020/2/6	9:05	12:33	0.60	0.60	0.60	0.70	2.00	1.72	1.72	1.72	2.01	5.75
	total	26:11	351.3				6	6	6	7	20					
2022	min	1:48	30.5	2022/2/13	6:38	9:00	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	max	4:44	36.1	2022/2/20	16:14	18:08	1	1	1	2	5	3.11	3.11	3.11	5.54	13.85
	mean	2:30	33.9	2022/2/16	1:23	3:54	0.31	0.31	0.31	0.38	1.00	0.90	0.90	0.90	1.11	2.89
	total	32:37	441.2				4	4	4	5	13					

A part of data not used for TRP has already excluded.

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	2.279	3.373	4.867	6.854	8.597
	Trolling	2007	2.826	4.244	6.149	8.186	10.487
	Trolling	2008	3.161	3.979	4.929	5.920	6.672
	Trolling	2009	1.134	2.310	3.837	5.519	7.904
	Trolling	2010	1.045	1.843	2.884	3.953	4.931
	Trolling	2011	1.699	4.598	6.333	8.346	9.972
	Trolling	2012	0.414	0.811	1.622	2.440	3.275
	Trolling	2013	2.580	3.478	4.346	5.180	5.641
	Trolling	2014	1.226	2.247	3.257	4.294	5.271
		2015					
	Trolling	2016	1.450	2.845	4.349	5.796	6.984
	Trolling	2017	0.000	0.836	1.702	2.826	3.470
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
	Trolling	2020	0.000	0.849	1.723	2.850	4.059
	Trolling	2021					
	Trolling	2022	0.000	0.239	0.896	1.547	2.067
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	1.968	3.127	4.297	5.429	6.294
	Trolling	2007	1.524	2.796	4.461	6.660	9.465
	Trolling	2008	3.119	3.989	4.894	5.880	6.631
	Trolling	2009	1.141	2.280	3.582	5.079	6.788
	Trolling	2010	0.534	1.584	2.623	3.650	4.721
	Trolling	2011	1.957	3.416	5.085	6.791	9.192
	Trolling	2012	0.397	0.811	1.618	2.432	3.269
	Trolling	2013	2.379	2.841	3.697	4.562	5.027
	Trolling	2014	1.225	2.030	2.859	3.690	4.335
	Trolling	2015					
	Trolling	2016	1.440	2.679	4.046	5.333	7.091
		2017	0.279	0.839	1.711	2.848	4.017
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
	Trolling	2020	0.000	0.842	1.718	2.623	4.066
	Trolling	2021					
	Trolling	2022	0.000	0.239	0.887	1.559	2.036
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	2.314	3.421	5.151	6.952	8.815
	Trolling	2007	2.825	4.978	7.591	10.118	12.226
	Trolling	2008	3.532	4.565	5.450	6.482	7.502
	Trolling	2009	1.154	2.300	3.819	5.584	7.080
	Trolling	2010	0.793	2.098	3.413	4.753	6.888
	Trolling	2011	3.127	4.604	6.656	9.284	11.686
	Trolling	2012	0.596	1.007	1.835	2.828	3.873
	Trolling	2013	2.619	3.693	4.780	5.851	6.704
	Trolling	2014	1.627	2.643	3.862	5.298	7.278
	Trolling	2015					
	Trolling	2016	1.640	3.130	4.561	5.832	6.821
		2017	0.000	0.849	1.709	2.819	4.036
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
	Trolling	2020	0.000	0.586	1.723	2.620	3.763
	Trolling	2021					
	Trolling	2022	0.000	0.239	0.899	1.562	2.243
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	3.394	5.484	9.628	13.706	17.193
	Trolling	2007	2.939	6.440	9.719	13.388	15.746
	Trolling	2008	3.721	4.818	6.050	7.295	8.442
	Trolling	2009	1.451	2.882	4.903	7.331	11.517
	Trolling	2010	1.039	3.109	6.070	9.891	15.019
	Trolling	2011	2.903	5.700	9.007	13.378	16.874
	Trolling	2012	0.397	1.005	1.824	2.837	3.669
	Trolling	2013	4.116	6.261	9.959	15.029	18.748
	Trolling	2014	1.846	3.031	4.697	7.126	9.059
	Trolling	2015					
	Trolling	2016	2.073	3.493	4.956	6.589	8.206
		2017	0.270	0.836	1.709	2.835	3.460
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
	Trolling	2020	0.277	0.863	1.997	3.185	4.927
	Trolling	2021					
	Trolling	2022	0.000	0.426	1.110	1.976	3.032
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	5.616	11.017	18.836	27.063	35.499
	Trolling	2007	8.904	14.059	22.285	31.846	41.926
	Trolling	2008	7.960	10.538	13.522	16.220	17.449
	Trolling	2009	1.852	5.726	10.456	16.452	22.357
	Trolling	2010	2.574	5.028	9.551	14.879	18.782
	Trolling	2011	5.347	9.269	18.249	28.709	42.850
	Trolling	2012	0.404	1.206	2.622	4.513	5.788
	Trolling	2013	9.448	14.846	20.892	27.582	35.290
	Trolling	2014	2.421	4.138	6.661	9.600	12.271
	Trolling	2015					
	Trolling	2016	3.515	6.612	10.276	14.342	18.443
		2017	0.000	2.471	5.353	8.595	11.456
	Trolling	2018	0.000	0.000	0.000	0.000	0.000
	Trolling	2019	0.000	0.000	0.000	0.000	0.000
	Trolling	2020	0.277	2.003	5.521	9.489	13.765
	Trolling	2021					
	Trolling	2022	0.000	0.922	2.892	5.180	7.660

Table 4. Data summary for Grid-type Trolling Index (TRG)

Survey	Year	N_Record	Time_Min	Time_Max	Range			
					South	North	West	East
Acoustic	1996	385	21 Jan. 1996 06:00	13 Feb. 1996 17:00	-35.2	-34.4	118.2	121.7
	1997	459	26 Jan. 1997 09:00	26 Feb. 1997 12:00	-35.3	-34.0	117.5	121.8
	1998	469	19 Jan. 1998 06:00	24 Feb. 1998 17:00	-35.4	-34.4	117.7	121.7
	1999	596	21 Jan. 1999 06:00	14 Mar. 1999 17:00	-35.4	-34.0	118.0	121.8
	2000	626	19 Jan. 2000 06:00	14 Mar. 2000 14:00	-35.4	-34.0	117.5	122.5
	2001	686	22 Jan. 2001 06:00	14 Mar. 2001 16:00	-35.4	-33.9	117.5	121.9
	2002	578	22 Jan. 2002 06:00	14 Mar. 2002 15:00	-35.4	-33.9	117.5	121.9
	2003	463	25 Dec. 2002 08:00	28 Jan. 2003 15:00	-35.3	-33.9	117.9	121.9
	2005	806	14 Jan. 2005 06:00	04 Mar. 2005 16:00	-35.3	-33.9	117.5	121.9
	2006	756	12 Jan. 2006 06:00	18 Feb. 2006 13:00	-35.4	-34.0	117.5	121.9
Trolling	2006	180	22 Jan. 2006 08:00	31 Jan. 2006 15:00	-34.8	-34.1	119.3	121.3
	2007	181	21 Jan. 2007 10:00	29 Jan. 2007 07:00	-34.8	-34.1	119.3	121.3
	2008	294	20 Jan. 2008 09:00	01 Feb. 2008 08:00	-35.5	-34.1	117.6	121.3
	2009	317	03 Dec. 2008 10:00	29 Jan. 2009 07:00	-35.5	-34.1	117.5	121.3
	2010	334	19 Jan. 2010 08:00	04 Feb. 2010 17:00	-35.5	-34.1	117.7	123.4
	2011	334	25 Jan. 2011 08:00	11 Feb. 2011 10:00	-35.5	-34.1	117.8	121.8
	2012	332	24 Jan. 2012 08:00	10 Feb. 2012 11:00	-35.5	-34.0	117.9	121.9
	2013	354	19 Jan. 2013 06:00	04 Feb. 2013 12:00	-35.5	-33.9	117.9	122.1
	2014	360	25 Jan. 2014 08:00	11 Feb. 2014 10:00	-35.4	-34.0	117.6	123.2
	2016	344	26 Jan. 2016 08:00	12 Feb. 2016 12:00	-35.5	-34.0	117.7	122.3
	2017	321	27 Jan. 2017 06:00	13 Feb. 2017 11:00	-34.9	-33.9	118.8	122.4
	2018	382	31 Jan. 2018 06:00	17 Feb. 2018 13:00	-34.9	-33.9	118.8	122.3
	2019	325	31 Jan. 2019 07:00	18 Feb. 2019 12:00	-35.5	-34.0	117.7	122.5
	2020	299	30 Jan. 2020 07:00	15 Feb. 2020 10:00	-35.3	-34.0	117.8	122.2
	2021	173	03 Feb. 2021 06:00	20 Feb. 2021 14:00	-34.4	-33.9	121.5	122.2
	2022	293	31 Jan. 2022 06:00	26 Feb. 2022 15:00	-34.9	-33.9	119.3	122.2

Survey	Year	Distance searched (km)					SBT Catch
		Total	Offshore	Shelfedge	On Shore	Lump	
Acoustic	1996	2,765	1,498	1,192	75		21
	1997	3,134	1,589	1,019	438	88	38
	1998	3,214	1,657	1,184	324	49	34
	1999	3,961	2,080	1,317	493	71	56
	2000	4,049	1,906	1,375	685	82	17
	2001	4,388	1,809	1,125	954	501	20
	2002	3,783	1,699	1,055	815	214	9
	2003	2,865	854	1,220	649	143	29
	2005	5,054	1,418	1,624	1,348	665	62
	2006	3,884	1,380	1,584	817	103	84
Trolling	2006	911	237	380	252	42	27
	2007	903	192	401	300	9	33
	2008	1,149	213	426	350	161	44
	2009	1,402	245	516	382	258	41
	2010	1,499	262	470	304	464	56
	2011	1,392	261	473	334	325	58
	2012	1,394	214	405	465	311	38
	2013	1,516	226	401	471	419	50
	2014	1,597	176	437	542	442	50
	2016	1,508	258	365	436	448	68
	2017	1,471	131	194	465	681	27
	2018	1,734	319	279	587	549	26
	2019	1,445	155	167	354	769	16
	2020	1,342	212	265	395	470	34
	2021	916			147	769	19
	2022	1,352	296	263	368	426	16
Total		58,630	19,285	18,136	12,751	8,459	973

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

Table 5. Summary data by area type

Area	N_records	Catch		CPUE	
	All	positive catch	% positive	Mean	SD
Lump	1,616	274	17.0%	26.4	45.3
On shore	2,525	284	11.2%	27.2	32.0
Shelf edge	3,158	320	10.1%	24.2	24.8
Off shore	3,348	95	2.8%	27.7	32.1
Total	10,647	973	9.1%		

Table 6. AIC and selected models for two sub-models

	model	AIC	Model
Binomial sub-model	full	5689.3	pn~year + month + hour + area + survey + offset(log(dist))
	AIC selected	5676.2	pn~year + month + area + offset(log(dist))
CPUE sub-model	full	2092.4	catch~year + month + hour + area + survey + offset(log(dist))
	AIC selected	2070.5	catch~year + area + survey + offset(log(dist))

Table 7. Estimated value by GLM for binomial sub-model

	Estimate	Std. Error	z value	Pr (>| z |)	Significance
(Intercept)	-3.51254	0.26006	-13.50669	1.43.E-41	***
fyear1997	0.31387	0.29328	1.07022	2.85.E-01	
fyear1998	0.27639	0.29464	0.93806	3.48.E-01	
fyear1999	0.81187	0.27766	2.92400	3.46.E-03	**
fyear2000	-0.71741	0.33997	-2.11022	3.48.E-02	*
fyear2001	-0.67325	0.33211	-2.02720	4.26.E-02	*
fyear2002	-1.27650	0.41329	-3.08861	2.01.E-03	**
fyear2003	-0.21267	0.32098	-0.66257	5.08.E-01	
fyear2005	0.03699	0.27124	0.13638	8.92.E-01	
fyear2006	0.88078	0.25652	3.43351	5.96.E-04	***
fyear2007	1.26348	0.31978	3.95108	7.78.E-05	***
fyear2008	1.14396	0.30044	3.80768	1.40.E-04	***
fyear2009	0.78479	0.30564	2.56772	1.02.E-02	*
fyear2010	0.99205	0.28906	3.43205	5.99.E-04	***
fyear2011	1.27557	0.28132	4.53419	5.78.E-06	***
fyear2012	0.71704	0.29727	2.41207	1.59.E-02	*
fyear2013	0.86653	0.29015	2.98647	2.82.E-03	**
fyear2014	0.83183	0.28586	2.90991	3.62.E-03	**
fyear2016	1.32598	0.27857	4.75992	1.94.E-06	***
fyear2017	-0.01138	0.32087	-0.03547	9.72.E-01	
fyear2018	-0.06293	0.32028	-0.19648	8.44.E-01	
fyear2019	-0.61974	0.36240	-1.71009	8.72.E-02	
fyear2020	0.58283	0.30634	1.90257	5.71.E-02	
fyear2021	-0.04436	0.35258	-0.12582	9.00.E-01	
fyear2022	-0.31340	0.36190	-0.86598	3.87.E-01	
fmonth2	-0.08083	0.08893	-0.90889	3.63.E-01	
fmonth3	-0.86659	0.25822	-3.35606	7.91.E-04	***
fmonth12	0.31044	0.32451	0.95664	3.39.E-01	
fareaOffshore	-1.97414	0.14086	-14.01449	1.27.E-44	***
fareaOnShore	-0.45773	0.10343	-4.42536	9.63.E-06	***
fareaShelfedge	-0.73545	0.10677	-6.88843	5.64.E-12	***

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

Table 8. Estimate values by GLM for CPUE sub-model

	Estimate	Std. Error	t value	Pr (>| t |)	Significance
(Intercept)	-0.11831	0.16866	-0.70146	4.83.E-01	
fyear1997	-0.60356	0.19699	-3.06395	2.25.E-03	**
fyear1998	-0.72371	0.19652	-3.68262	2.44.E-04	***
fyear1999	-0.44113	0.18184	-2.42596	1.55.E-02	*
fyear2000	-0.25397	0.23344	-1.08792	2.77.E-01	
fyear2001	-0.71927	0.22773	-3.15843	1.64.E-03	**
fyear2002	-0.71205	0.28592	-2.49036	1.29.E-02	*
fyear2003	-0.28475	0.20422	-1.39433	1.64.E-01	
fyear2005	-0.37193	0.18032	-2.06256	3.94.E-02	*
fyear2006	-0.63171	0.17327	-3.64581	2.81.E-04	***
fyear2007	-0.99838	0.25467	-3.92024	9.50.E-05	***
fyear2008	-0.78213	0.24705	-3.16588	1.60.E-03	**
fyear2009	-1.19052	0.24763	-4.80761	1.78.E-06	***
fyear2010	-1.01369	0.24322	-4.16784	3.36.E-05	***
fyear2011	-0.86366	0.24114	-3.58152	3.59.E-04	***
fyear2012	-1.14055	0.25157	-4.53379	6.56.E-06	***
fyear2013	-1.01323	0.24659	-4.10893	4.33.E-05	***
fyear2014	-1.20247	0.24561	-4.89587	1.15.E-06	***
fyear2016	-1.01312	0.23972	-4.22628	2.61.E-05	***
fyear2017	-1.28220	0.26567	-4.82625	1.63.E-06	***
fyear2018	-0.90168	0.26617	-3.38763	7.35.E-04	***
fyear2019	-1.00453	0.29254	-3.43380	6.22.E-04	***
fyear2020	-1.32404	0.25573	-5.17758	2.76.E-07	***
fyear2021	-1.46932	0.28004	-5.24688	1.92.E-07	***
fyear2022	-0.85600	0.28935	-2.95838	3.17.E-03	**
fareaOffshore	0.01786	0.09486	0.18825	8.51.E-01	
fareaOnShore	0.00182	0.06429	0.02825	9.77.E-01	
fareaShelfedge	-0.13898	0.07057	-1.96941	4.92.E-02	*
surveyTR	0.48454	0.15663	3.09352	2.04.E-03	**

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

Table 9. Year trends of binomial sub-model

Year	Mean	Mean-SE	Mean+SE
1996	0.1275	0.0942	0.1607
1997	0.1641	0.1284	0.1997
1998	0.1593	0.1244	0.1942
1999	0.2370	0.1959	0.2782
2000	0.0684	0.0481	0.0887
2001	0.0712	0.0510	0.0913
2002	0.0408	0.0253	0.0563
2003	0.1066	0.0815	0.1318
2005	0.1314	0.1052	0.1577
2006	0.2486	0.2105	0.2866
2007	0.3181	0.2607	0.3755
2008	0.2954	0.2446	0.3463
2009	0.2326	0.1898	0.2755
2010	0.2678	0.2219	0.3137
2011	0.3204	0.2711	0.3697
2012	0.2217	0.1785	0.2650
2013	0.2462	0.2023	0.2901
2014	0.2403	0.1972	0.2834
2016	0.3303	0.2812	0.3794
2017	0.1263	0.0951	0.1575
2018	0.1210	0.0905	0.1515
2019	0.0747	0.0514	0.0979
2020	0.2012	0.1590	0.2434
2021	0.1229	0.0886	0.1571
2022	0.0978	0.0683	0.1273

Table 10. Year trends of CPUE sub-model

Converted			
Year	Mean	Mean-SE	Mean+SE
1996	2.3967	2.2005	2.5929
1997	1.7932	1.6267	1.9597
1998	1.6730	1.5045	1.8415
1999	1.9556	1.8069	2.1043
2000	2.1428	1.9337	2.3518
2001	1.6774	1.4785	1.8764
2002	1.6847	1.4194	1.9500
2003	2.1120	1.9363	2.2877
2005	2.0248	1.8793	2.1703
2006	1.7650	1.6454	1.8846
2007	1.3983	1.2259	1.5708
2008	1.6146	1.4563	1.7729
2009	1.2062	1.0471	1.3653
2010	1.3830	1.2324	1.5337
2011	1.5331	1.3856	1.6805
2012	1.2562	1.0926	1.4197
2013	1.3835	1.2295	1.5375
2014	1.1942	1.0414	1.3471
2016	1.3836	1.2405	1.5267
2017	1.1145	0.9314	1.2976
2018	1.4950	1.3110	1.6791
2019	1.3922	1.1713	1.6131
2020	1.0727	0.9036	1.2417
2021	0.9274	0.7237	1.1311
2022	1.5407	1.3226	1.7588

Table 11. Point estimates of Grid-type Trolling Index

Year	Prob*Pos	Standardized
1996	0.3055	1.1025
1997	0.2942	1.0616
1998	0.2665	0.9618
1999	0.4636	1.6728
2000	0.1466	0.5290
2001	0.1194	0.4309
2002	0.0688	0.2481
2003	0.2252	0.8127
2005	0.2661	0.9603
2006	0.4387	1.5832
2007	0.4448	1.6052
2008	0.4770	1.7214
2009	0.2806	1.0125
2010	0.3704	1.3367
2011	0.4913	1.7728
2012	0.2785	1.0052
2013	0.3405	1.2289
2014	0.2870	1.0358
2016	0.4570	1.6490
2017	0.1407	0.5079
2018	0.1809	0.6527
2019	0.1040	0.3752
2020	0.2158	0.7788
2021	0.1140	0.4112
2022	0.1507	0.5437

Table 12. Grid-type Trolling index with confidence intervals calculated by 1000 times bootstrap

year	5 percentile	25 percentile	Median	75 percentile	95 pecentile
1996	0.895	1.011	1.092	1.186	1.313
1997	0.873	0.986	1.062	1.135	1.267
1998	0.771	0.877	0.953	1.033	1.157
1999	1.402	1.554	1.658	1.778	1.924
2000	0.434	0.488	0.526	0.569	0.633
2001	0.346	0.392	0.430	0.471	0.532
2002	0.200	0.227	0.246	0.268	0.299
2003	0.678	0.755	0.809	0.869	0.950
2004					
2005	0.823	0.899	0.955	1.013	1.106
2006	1.404	1.502	1.578	1.658	1.771
2007	1.389	1.526	1.610	1.690	1.802
2008	1.520	1.638	1.721	1.816	1.937
2009	0.864	0.958	1.013	1.071	1.152
2010	1.174	1.265	1.337	1.403	1.494
2011	1.602	1.712	1.780	1.851	1.938
2012	0.863	0.947	1.009	1.072	1.155
2013	1.055	1.160	1.230	1.296	1.387
2014	0.903	0.985	1.039	1.087	1.159
2015					
2016	1.442	1.574	1.652	1.734	1.861
2017	0.405	0.462	0.503	0.546	0.611
2018	0.544	0.610	0.655	0.700	0.764
2019	0.323	0.353	0.375	0.398	0.428
2020	0.639	0.718	0.779	0.835	0.916
2021	0.322	0.375	0.416	0.452	0.504
2022	0.424	0.501	0.551	0.596	0.673

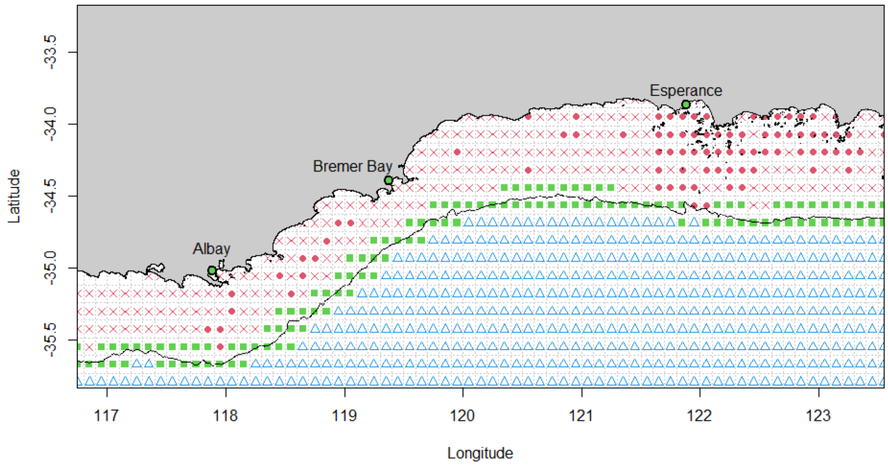

Fig. 1. Map and area classified.

Red cross denotes on-shore, red solid circle denotes lump, green solid square denotes shelf-edge, and open blue triangle denotes offshore.

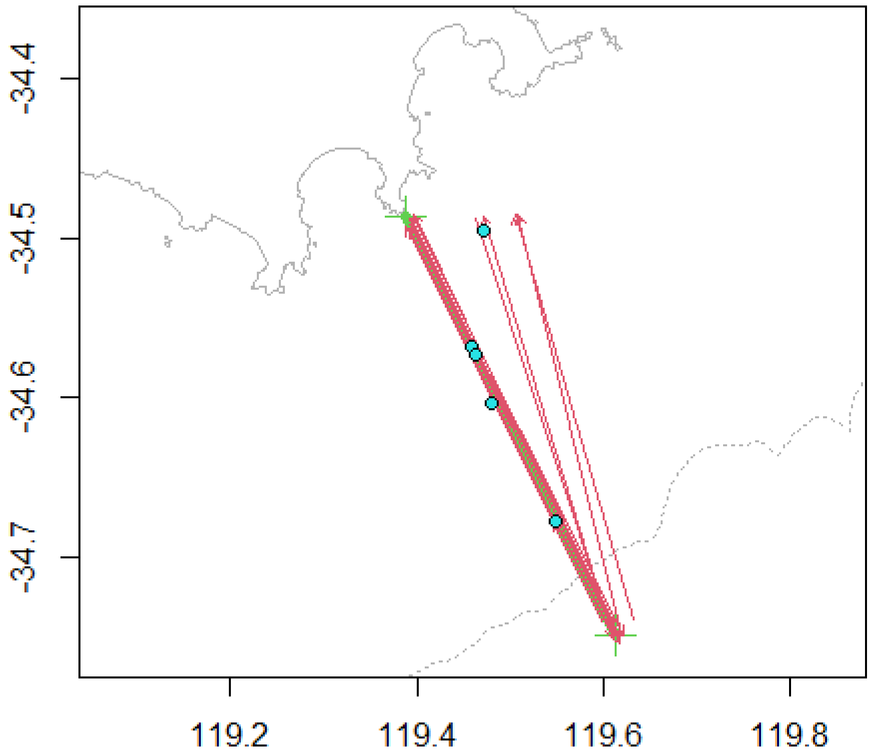

Fig. 2. Locations of the piston-line off Bremer Bay in the 2022 survey.

Green cross marks are defined end points of the piston line. Red arrow denotes each of piston line and direction. Circles denote location of age-1 SBT caught.

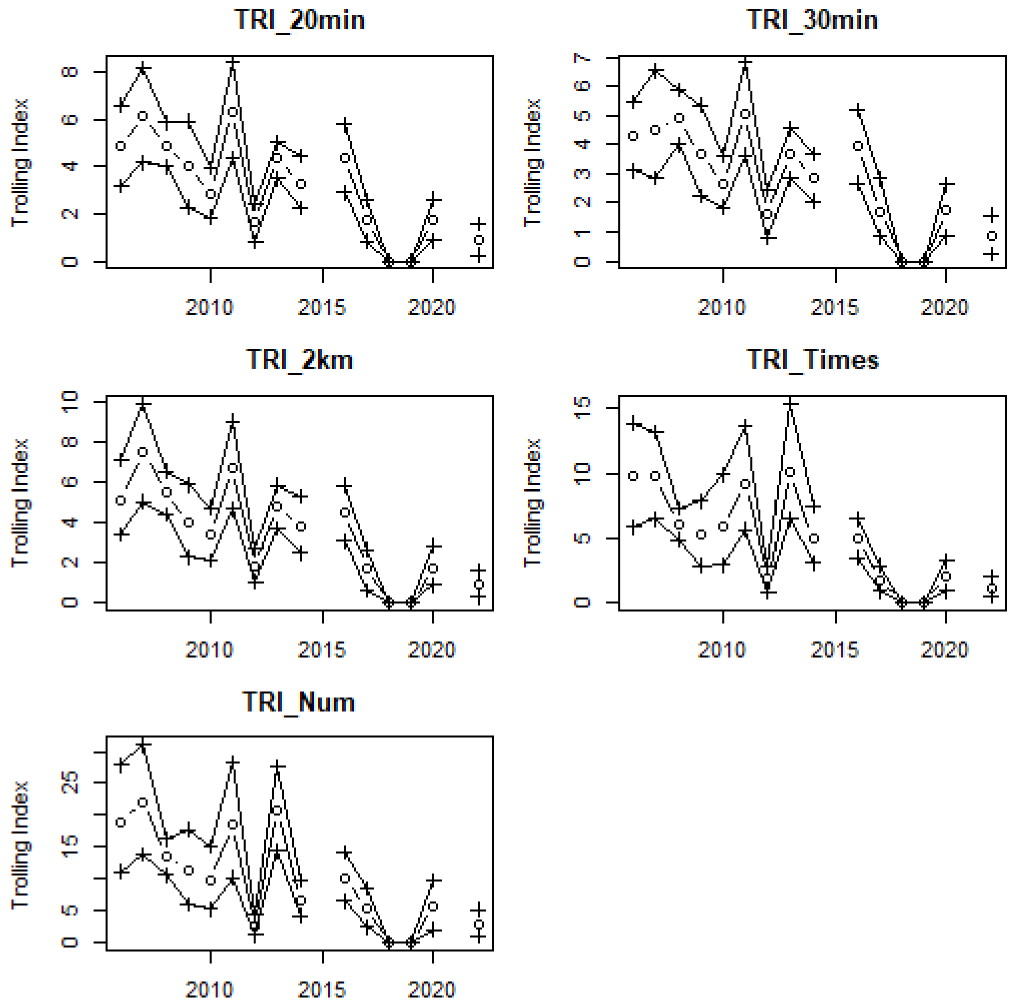

Fig. 3. Five types of the piston-line trolling index by different school/catch definition.

Showing median, 5 and 95 percentiles.

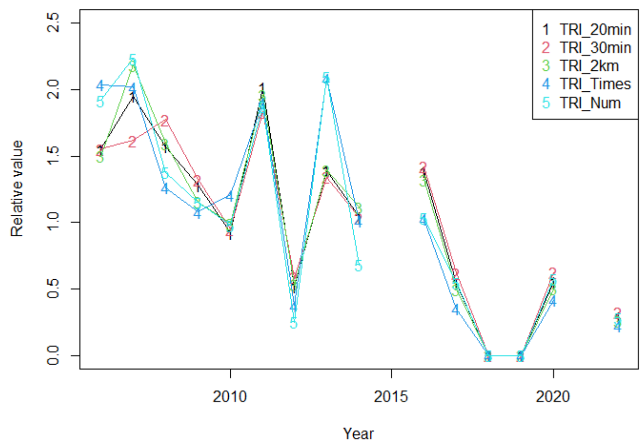

Fig. 4. Comparison of the median from five types of piston-line trolling index by different school/catch definition.

Standardized with the mean of each index.

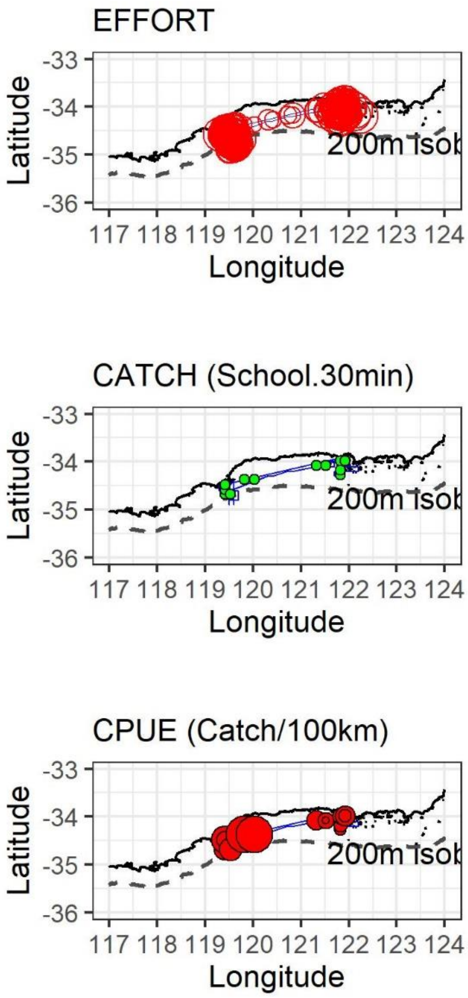

Fig. 5. Distributions of effort, age-1 SBT catch and CPUE in the 2022 survey

Blue line is the trajectory of the vessel while trolling.

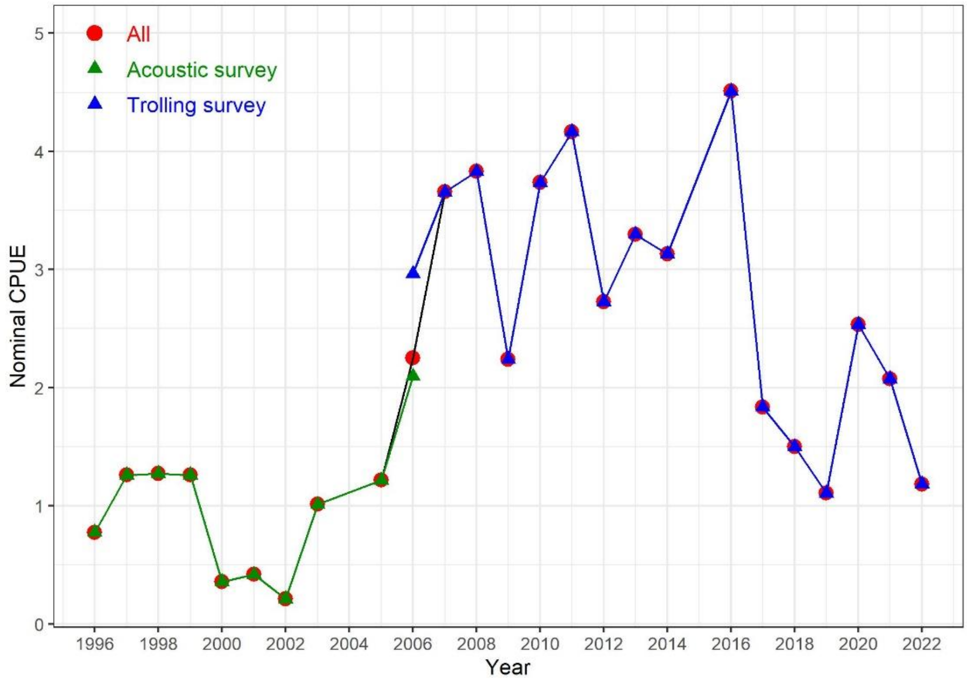

Fig. 6. Nominal CPUE of TRG.

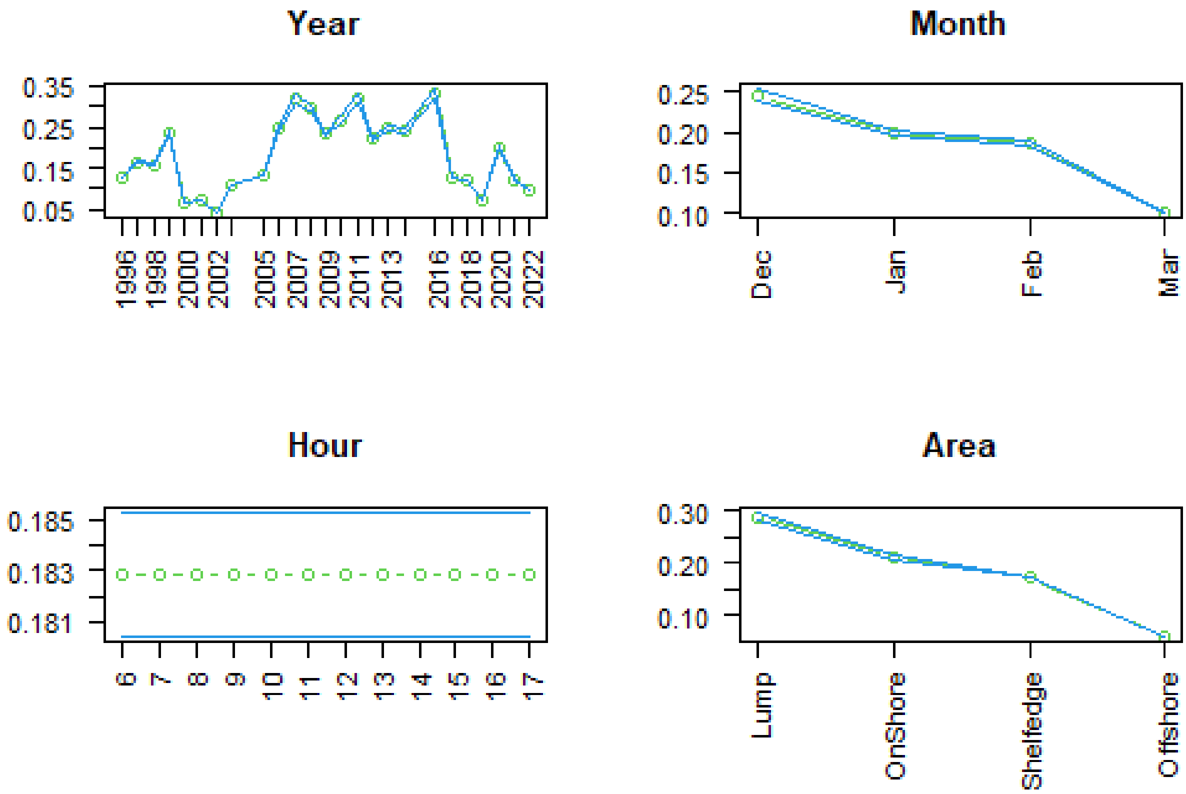

Fig. 7. Least square means of variables in binomial sub-model.

Green is mean and blue is mean±SD. Catch was defined as schools with a definition of 30 minutes is necessary for a different school. Note that hour term was not selected in the optimal model formula.

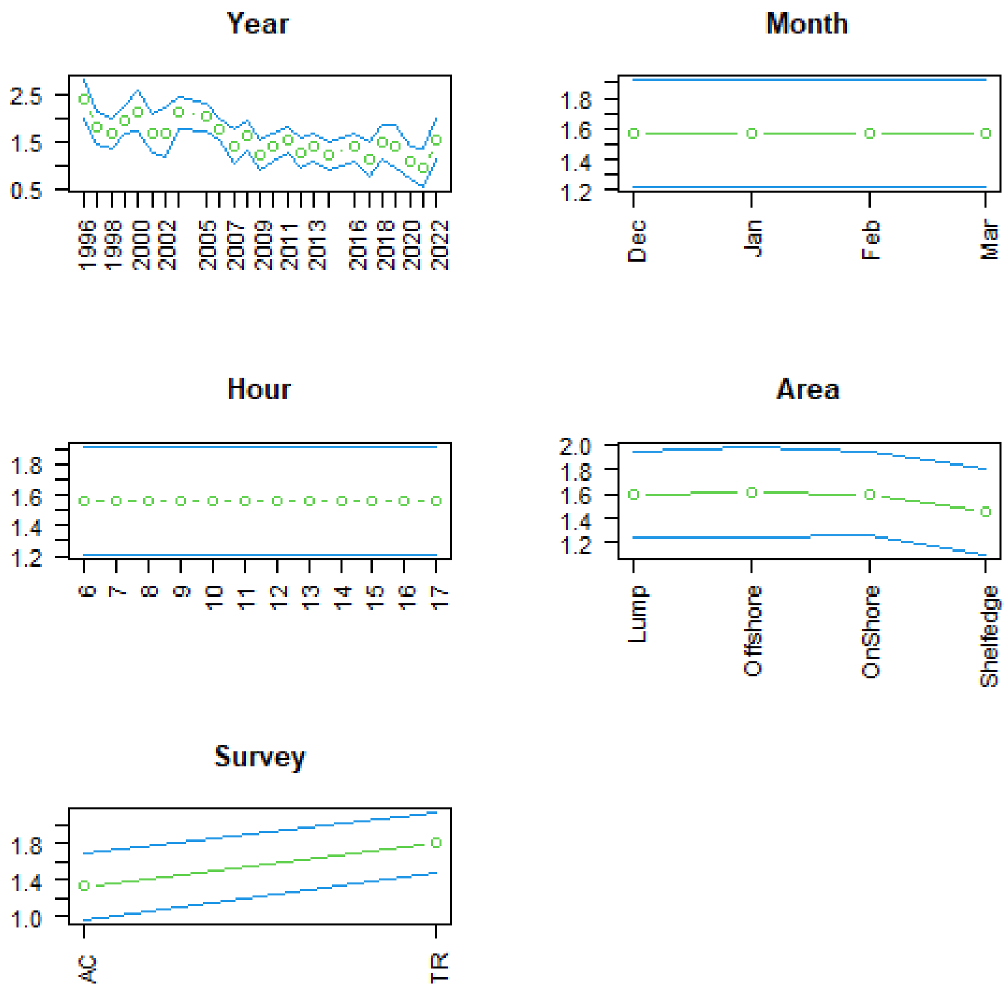

Fig. 8. Least square means of variables in catch in the CPUE sub-model.

Green is mean and blue is mean ± +SD. Catch was defined as schools with a definition of 30 minutes is necessary for a different school. Note that month and hour terms were not selected in the optimal model formula.

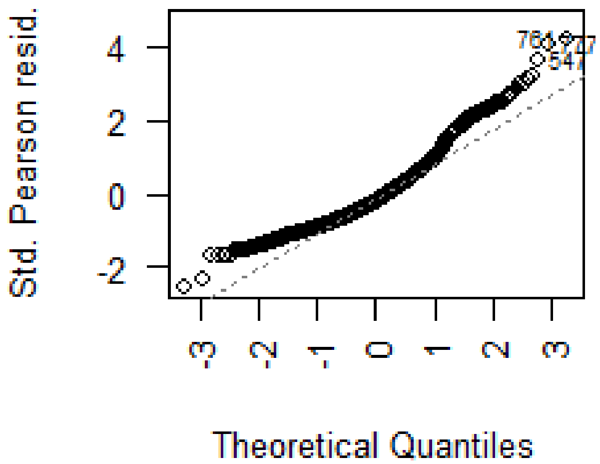

Fig. 9. QQ plot of GLM for CPUE sub-model.

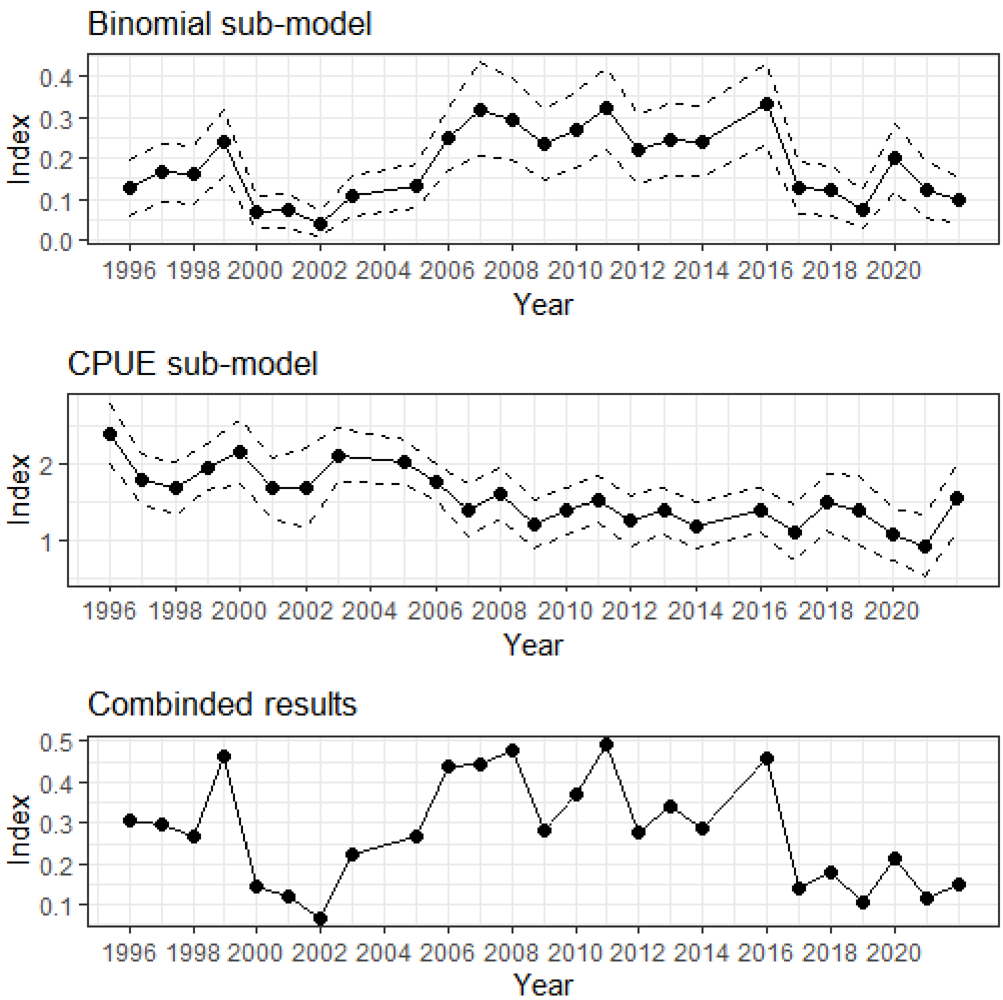

Fig. 10. Binomial sub-model, CPUE sub-model, and combined index from two sub-models (point estimation standardized TRG).

Upper panel shows the year trend from the binomial sub-model. Mean±1SD. The middle panel shows the year trend form the CPUE sub-model. Mean±1SD. Lower panel shows TRG which is a product of two sub-models.

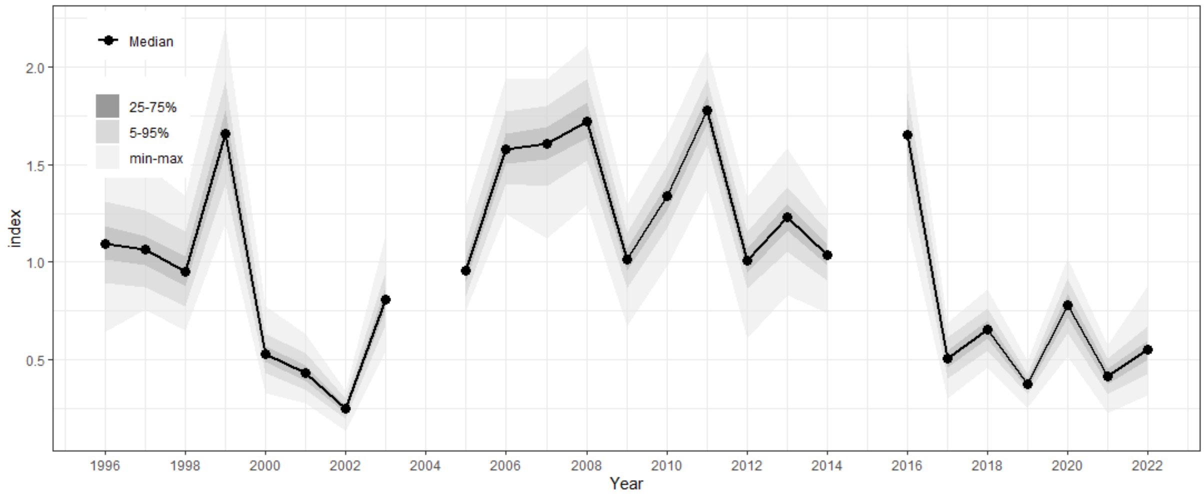

Fig. 11. TRG with confidence intervals.

Estimate was simulated with 1000 times bootstrapping.

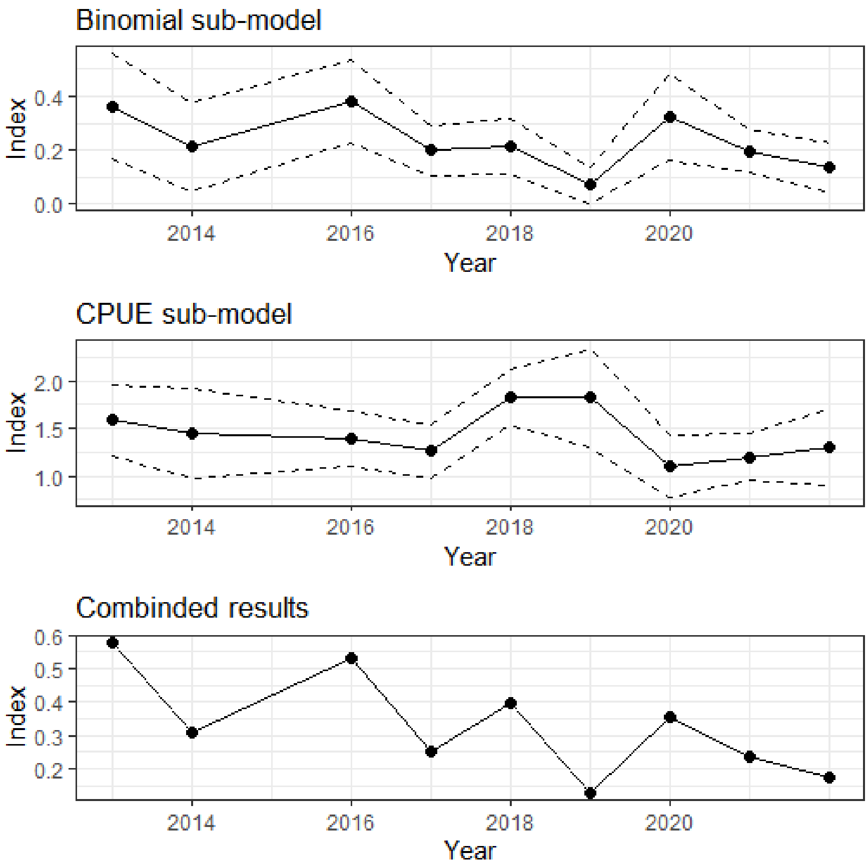

Fig. 12. TRG off Esperance only (TRG_esp) with confidence intervals.

Upper panel shows the year trend from the binomial sub-model. Mean±1SD. The middle panel shows the year trend form the CPUE sub-model. Mean±1SD. Lower panel shows TRG which is a product of two sub-models.

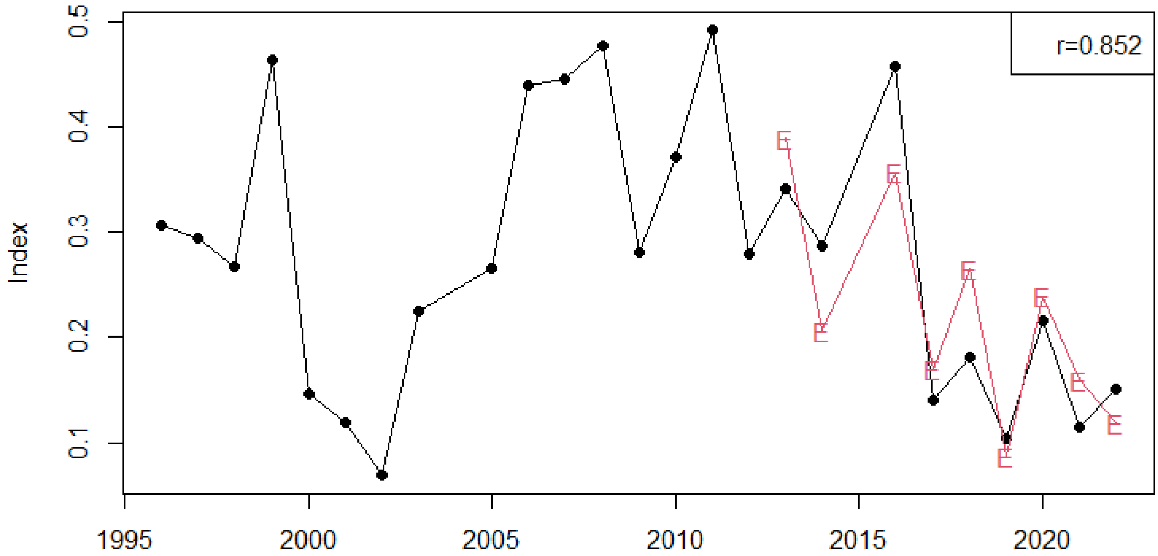

Fig. 13. Comparison between TRG and TRG_esp where data are limited off Esperance only.

Values of TRG_esp are standardized to the mean of TRG between 2013 and 2022. Pearson's correlation *r* is 0.852 (p<0.01).

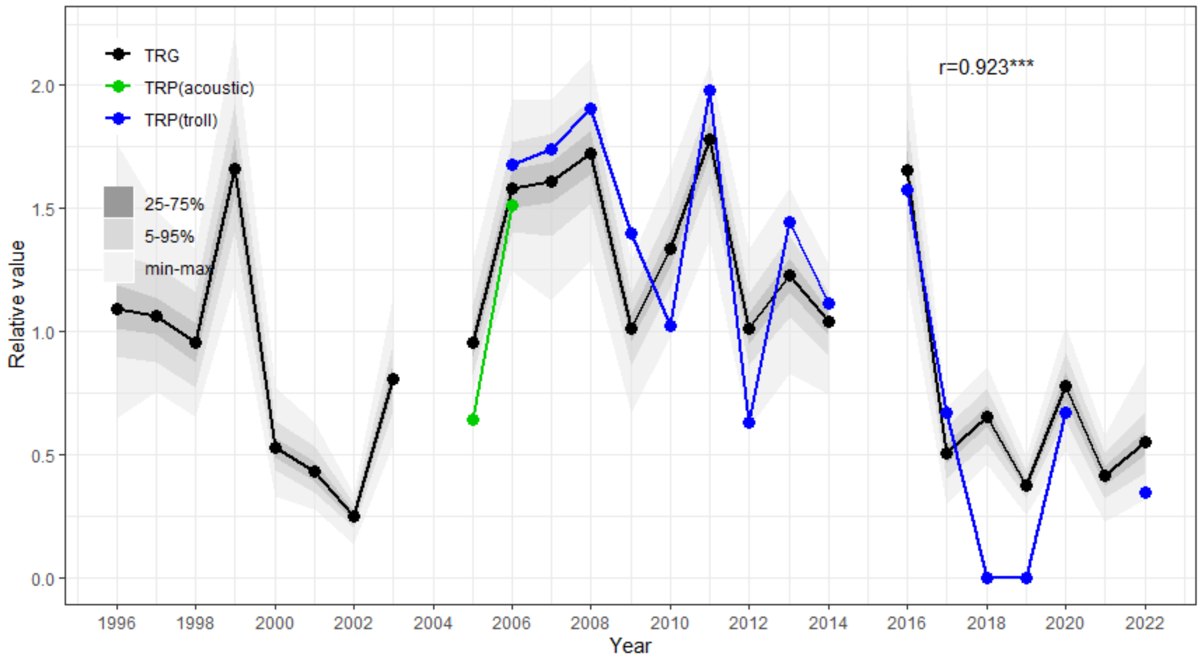

Fig. 14. Comparison between TRG and TRP.

r is Pearson's correlation.

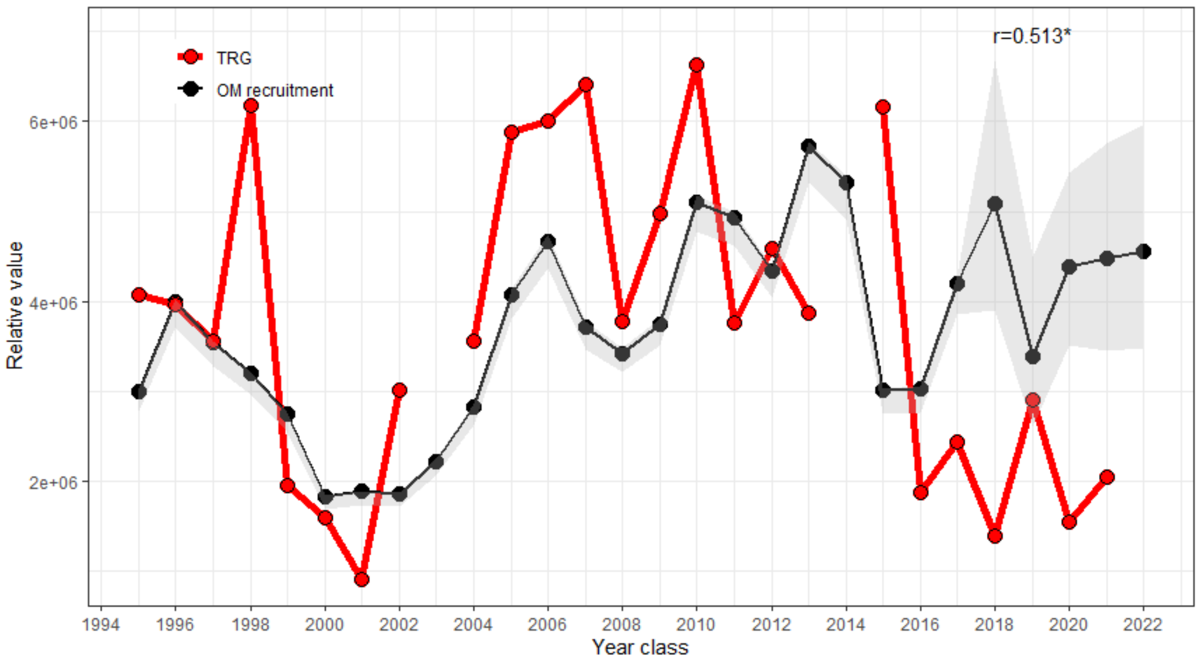

Fig. 15. Comparison between OM recruitment calculated in 2022 and TRG by year class (cohort).
OM recruitment is derived from the base21.s file. Range of OM recruitment is 25-75 percentiles. Pearson's correlation *r* was calculated from data up to the 2017 year class.

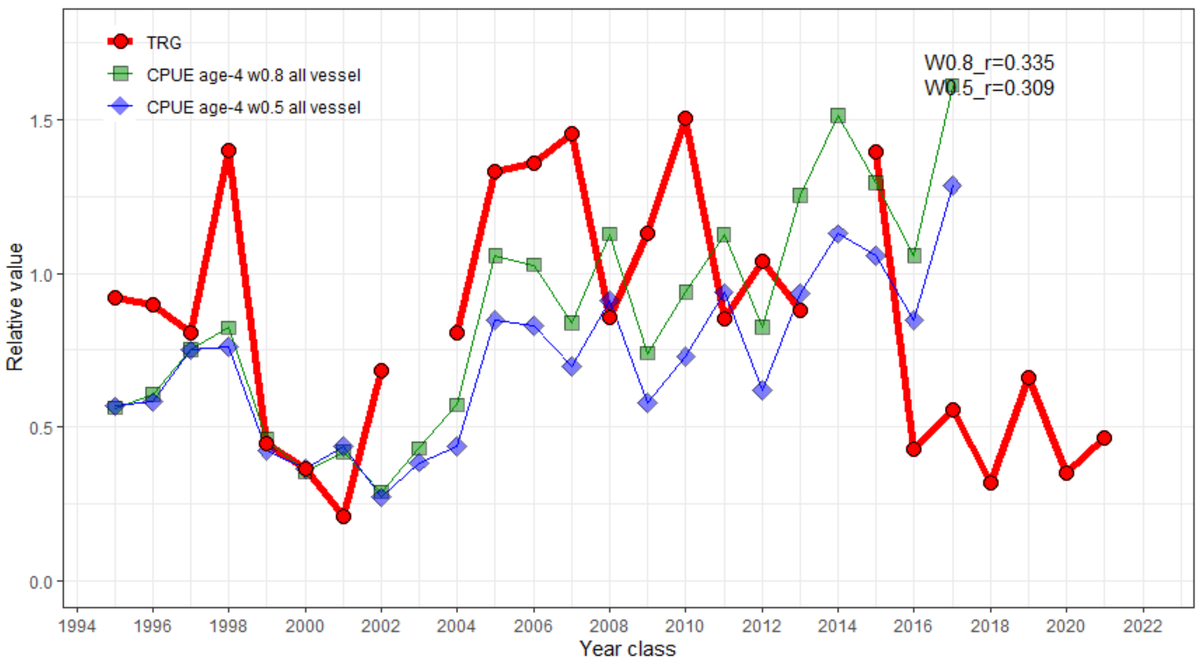

Fig. 16. Comparison between the age-4 all vessel CPUEs (w0.5 and w0.8) of Japanese longline and TRG by year class (cohort).
r is Pearson's correlation.

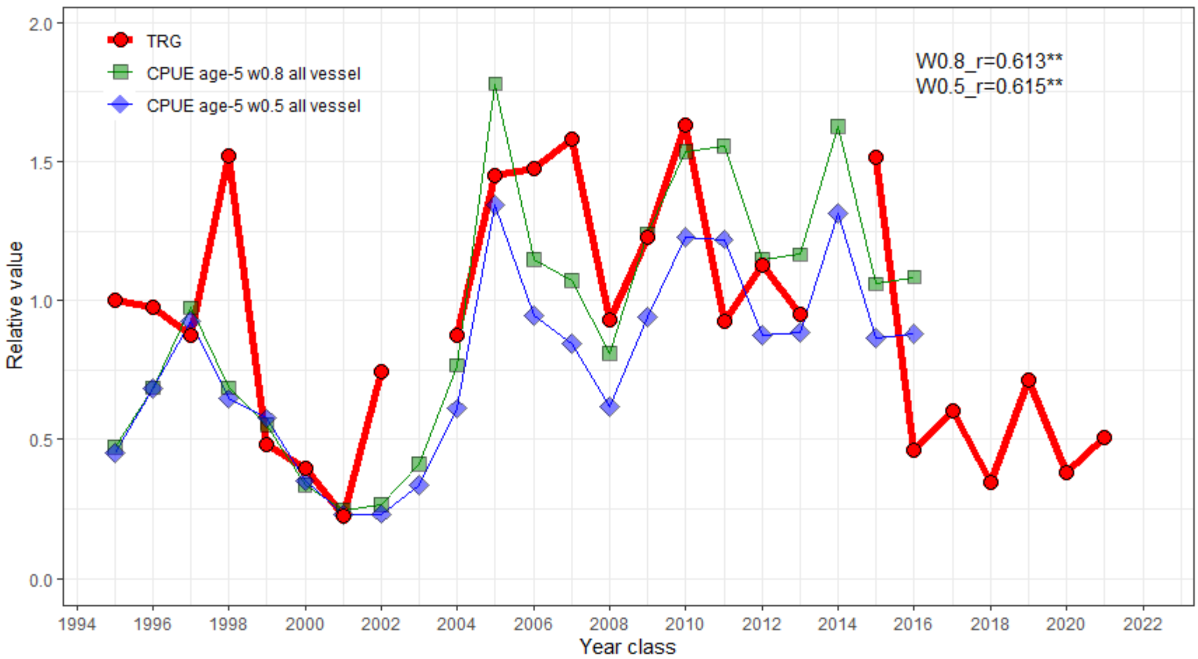

Fig. 17. Comparison between the age-5 all vessel CPUEs (w0.5 and w0.8) of Japanese longline and TRG by year class (cohort).

r is Pearson's correlation.

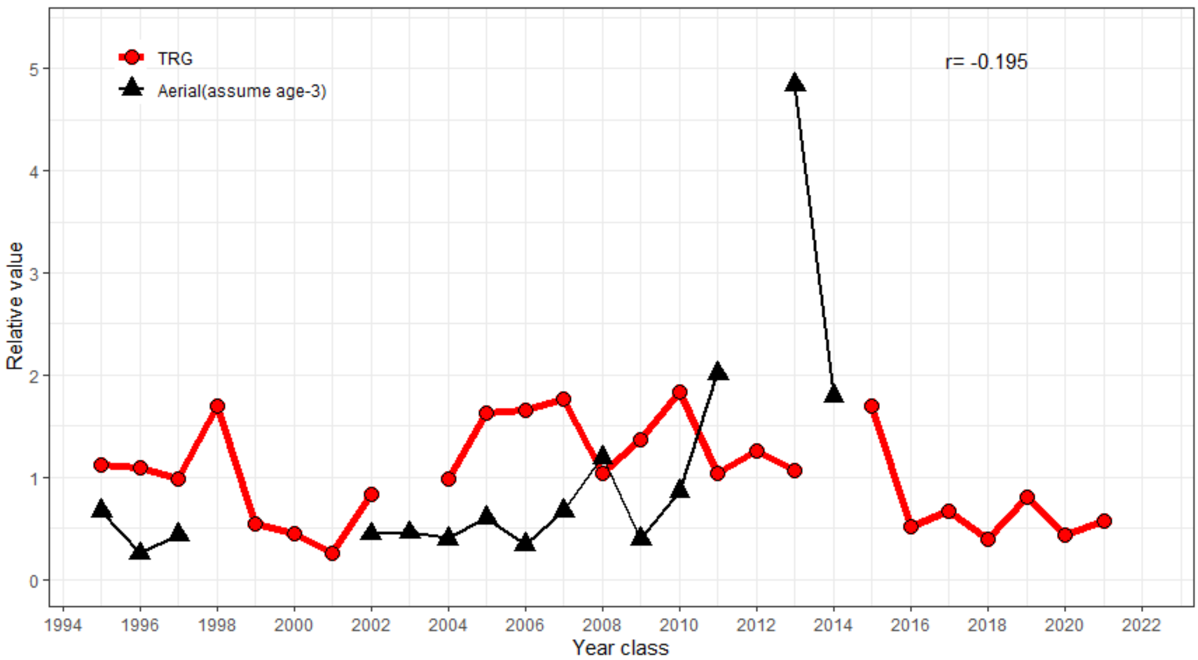

Fig. 18. Comparison between aerial survey index and TRG by year class (cohort).

Assigned year class for aerial survey assuming age-3 fish observed. r is Pearson's correlation.

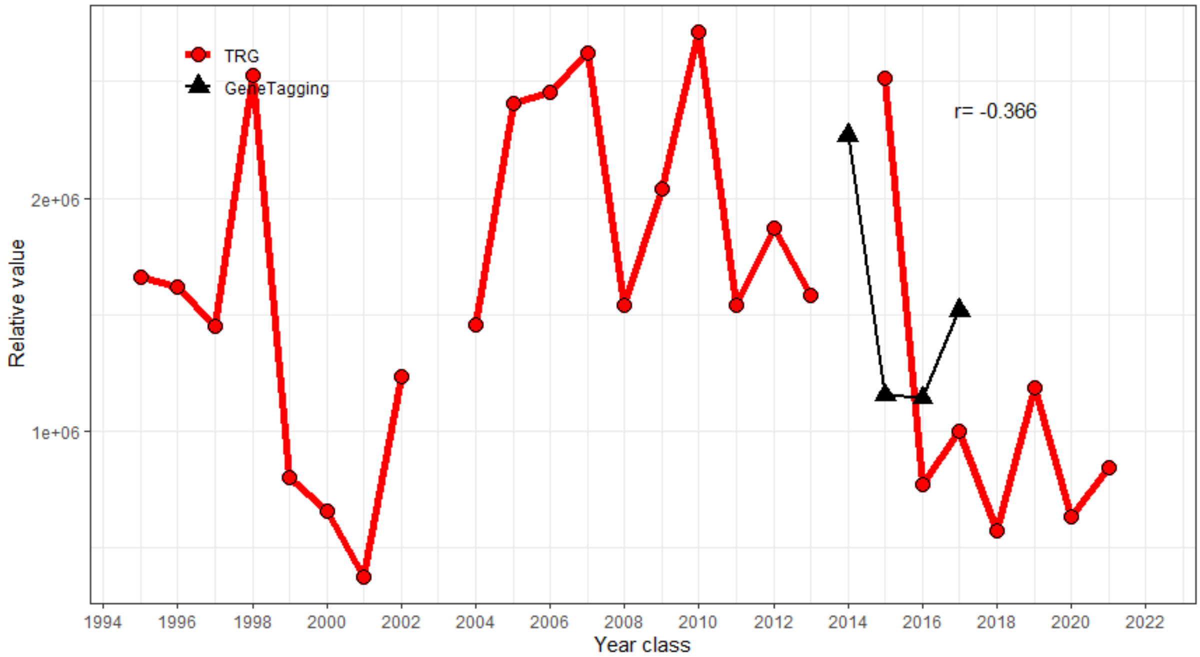

Fig. 19. Comparison between the gene tagging estimates for age-2 abundance and TRG by year class (cohort).

r is Pearson's correlation.

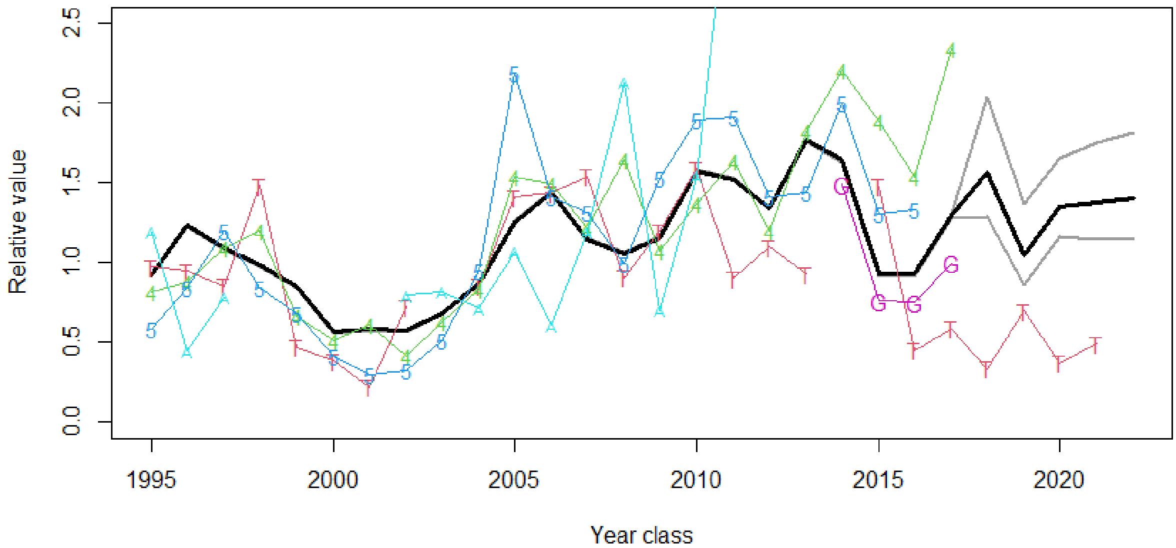

Fig. 20. Various recruitment indices by year class (cohort).

It shows the OM recruitment (thick black line. Grey lines are upper and lower values), the age-4 CPUE (w0.8) of all the Japanese longline ("4" in green), the age-5 CPUE (w0.8) of all the Japanese longline ("5" in blue), the aerial survey index ("A" in pale blue, the values in the 2011, 2013 and 2014 year classes are placed upper out range of the panel. Assuming to be age-3 fish.), gene tagging estimated value of age-2 abundance ("G" in purple), and TRG ("T" in red). Values were standardized to the mean between 1995 and 2010 of each series, except the gene tagging which were to the mean between 2014 and 2017.