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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 2021 年–

Trolling indices for age-1 southern bluefin tuna: update of the grid type trolling index in 2021

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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、2021 年調査データを追加して計算した結果を示す。加入量指数は緯経度 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 57,278 km、ミナミマグロ 1 歳魚群数合計 957 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。2021 年は COVID-19 による一時的な調査方法変更に伴って調査海域が限定されたことから、Esperance 沖のみの指数も求めて指数の一貫性を確認した。求めた加入量指数（TRG）と、オペレーティングモデルで推定した加入量、および日本延縄 4 歳魚と 5 歳魚の標準化した CPUE とは 2016 年級まではトレンドがよく一致していた。しかし TRG では 2016 年級以降の近年の低加入の可能性が示唆されたが OM による加入量推定値とは 2017 年級以降の水準が大きく異なっていた。今後の 4 歳魚と 5 歳魚の CPUE や遺伝標識といった情報追加に伴って加入量水準を注意深く検証していく必要がある。

Summary

From the trolling catch data of the 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

the results calculated by adding the 2021 survey data. The recruitment index is the number of age-1 SBT per trolling search distance on the grid by latitude and longitude 0.1 degrees, date, hour, and area. The data obtained from the total search distance of about 57,278 km and the total number of age-1 SBT schools of 957 were standardized by delta log-normal GLM because there were many zero catch data. In the 2021 survey, the survey area was limited due to a temporarily change of the survey method due to COVID-19, so the index was confirmed to be consistent by calculating an index only off Esperance. Until 2016 year class, the trends of the obtained recruitment index (TRG), the recruitment estimated by the operating model, and the standardized CPUEs of Japanese longline for age-4 and age-5 SBT were in good agreement. It was suggested that there is a possibility of low recruitments in recent years after the 2016 year class, but the level after the 2017 year class is different from the estimated recruitment by the operating model, so careful examination is warranted to the recruitment level along with information accumulated, including age-4 and age-5 CPUEs and the gene tagging.

Introduction

Trolling survey for southern bluefin tuna (*Thunnus maccoyii* SBT) aims to provide a recruitment index of the stock at age-1. The survey has been carried out in the southern coast of Western Australia from 2006 to 2020, except 2015. It has provided an index named the piston-line trolling index (TRP) which have been reported to CCSBT (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, 2020, Tsuda and Itoh 2017, 2018, 2019). In addition, the trolling survey operated trolling in other areas of the piston line. The large area was also surveyed with trolling operation in the acoustic survey which carried out between 1996 and 2006. Using these data, a standardization of the trolling survey index (TRG) was developed in 2014 (Itoh and Takahashi 2014).

The survey was conducted in 2021, but the survey area was limited to off Esperance due to the influence of COVID-19. Therefore, no surveys on the piston-line was conducted. We present the updated TRG in this document. Since the survey area is different from the conventional one, we also created a TRG (TRG_esp) limited to the area off Esperance, and evaluated the difference between the two indices. Also, as in the past, differences with other recruitment indices are examined.

Materials and methods

1. Grid-type Trolling Index　TRG

Data came from trolling catch in the acoustic survey between 1996 and 2003, 2005 and 2006, and the trolling survey between 2006 and 2014, and from 2016 and 2020. Details of the survey were described in other papers that submitted every year (e.g. Itoh 2021). 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 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 removed.

Time intervals of a recording of latitude and longitude differed by year. Up to the 2005 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 survey, 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 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 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 generalized liner model (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 (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.

Probability sub-model:

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

error ~ binomial

Positive catch 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 Grid-type Trolling Index. Furthermore, the bootstrap method was applied to obtain a range of the estimate. 1000 datasets were made through stratified sampling by year.

In addition, since 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 limited to the offshore of Esperance (TRG_esp) was calculated. Except 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 probability sub-model and a positive catch sub-model. The model structure used was similar except for the survey.

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.

Positive catch 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 2020 stock assessment based on the reference set operating model (OM), age specific standardized CPUE from all Japanese longline vessels for age-4 and age-5, and the aerial survey index.

Results

1. Grid-type Trolling Index: TRG

Summary of data aggregated by grid is shown in Table 1. It consists of 10,354 records in total that reach about 57,278 km search distance and 957 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 (90.8%).

Distributions of effort, catch and CPUE in 2021 are shown in Fig. 2. Those in previous years are available in previous document (Itoh and Tsuda 2020). Although the longitudinal range in many of previous years extended from 117.5 (west of Albany) to 123.2 (east of Esperance), that in 2021 was limited from 121.5E to 122.2E off Esperance due to the survey design temporarily revised in response to the situation of COVID-19.

Nominal CPUE is shown in Fig. 3. Note that a substantial part of the effort was made up offshore where few SBT caught from 1996 to 2005. It must be underestimated in this period compared to the latter half period.

The selected GLM models for TRG based on the AIC were follows (Table 2):

Probability sub-model:

$$\log(p/(1-p)) \sim \text{year} + \text{month} + \text{area} + \text{offset}(\log(\text{distance})) + \text{error}$$

Positive catch sub-model:

$$\log(\text{catch}) \sim \text{year} + \text{area} + \text{survey} + \text{offset}(\log(\text{distance})) + \text{error}$$

Relationships between the probability of catch and various variables and between positive catch and various variables in terms of least square mean are shown in Fig.4 and Fig. 5, respectively. The estimated values of each variables are shown in Table 3 and Table 4. QQ plot of positive catch sub-model is shown in Fig. 6, 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 5 and Table 6. Indices of both sub-models and point estimation of TRG are shown in Table 7 and Fig. 7.

Table 8 and Figure 8 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 (2017-2021) have returned to relatively low levels, similar to those in 2000-2002. TRG value for 2021 is the third lowest in 24 years.

2. Comparison to other indices

TRG_esp

Trolling index from grid data limited to off Esperance (TRG_esp) was calculated between 2013 and 2021 (Fig. 9). From the full models, following models were selected by AIC.

Probability sub-model:

$$\log(p/(1-p)) \sim \text{year} + \text{offset}(\log(\text{distance})) + \text{error}$$

Positive catch sub-model:

$$\log(\text{catch}) \sim \text{year} + \text{offset}(\log(\text{distance})) + \text{error}$$

Figure 10 shows comparison between TRG and TRG_esp. Two indices are significantly correlated (Pearson's correlation coefficient, $r=0.861$, $p < 0.01$) and general trends are similar to each other. The value in 2021 was the second lowest next to 2019 in both indices. It is suggested that the index derived from the survey area, reduced temporarily in 2021 only off Esperance, represents that from all survey areas.

OM recruitment

Figure 11 shows comparison between recruitment estimated from the 2020 stock assessment based on the reference set operating model (OM) and TRG by year class (YC). 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 ($r=0.58$, $r<0.05$). Historical low levels of OM recruitment in 2000-2002 are captured by TRG 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 5 years (2016-2020YC) 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 2017-2020YC 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 12 and Figure 13 show comparisons between age specific standardized CPUE from all Japanese longline vessels for age-4 and age-5 and TRG. The general trend of TRG is similar to those CPUE indices, which are significantly correlated (W0.8 of age-4, r=0.530, r<0.05; W0.8 of age-5, r=0.672, r<0.01). The low level of TRG in 1999-2001YC and the high level in 2005-2016YC were supported by both CPUE idices. CPUE values in both age-4 and age-5 are not yet available for the most recent four/five years.

Aerial survey

Figure 14 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 2000 year class (YC) when extremely low recruitment observed. The high value in 2013YC in the aerial survey was not supported by the TRG.

Discussion

The present paper provided updated Grid-type trolling index (TRG) of SBT recruitment indices. Piston line trolling index (TRP) was not updated because temporarily limited survey area in 2021. Both trolling indices are based on catch that is the number of schools. When we encountered SBT school in the survey, the numbers of fish individuals caught and catch times could have increased if we handled the trolling line well and/or the vessel moved well to catch up or attract the school. The numbers of fish individuals caught and catch times 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 were affected 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 24 years, by adding the trolling 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 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. On the other hand, as Tsuda and Itoh (2017) showed, weather conditions have a negligible effect on the standardization of TRG.

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. These indices have similar trend with significant correlation up to 2016YC. Those were medium level in the mid-1990s year classes, low level in the 2000YC-2002YC and high level in the 2005-2014YC. The decrease of 2016YC from 2014-2015YC were common in OM recruitment, age-4 CPUE and TRG.

TRG shows the same low level for 2017-2020YC as in 2016YC. OM may overestimate recruitment in these year classes. Because it is suspected that there may be low recent recruitments, careful attention should be paid to future trends along with the addition of longline CPUEs data and other recruitment indicators, including the gene tagging.

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Table 1. 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

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
Total		57,278	18,989	17,873	12,383	8,033	957

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

Table 2. AIC and selected models for two sub-models

	model	AIC	Model
probability sub-model	full	5575.8	pn~year + month + hour + area + survey + offset(log(dist))
	AIC selected	5563.6	pn~year + month + area + offset(log(dist))
positive catch sub-model	full	2054.6	catch~year + month + hour + area + survey + offset(log(dist))
	AIC selected	2032.5	catch~year + area + survey + offset(log(dist))

Table 3. Estimated value by GLM for probability sub-model

	Estimate	Std. Error	z value	Pr (>| z |)	Significance
(Intercept)	-3.51178	0.26088	-13.46146	2.64.E-41	***
fyear1997	0.31546	0.29323	1.07584	2.82.E-01	
fyear1998	0.27882	0.29459	0.94648	3.44.E-01	
fyear1999	0.81405	0.27759	2.93251	3.36.E-03	**
fyear2000	-0.71355	0.33992	-2.09918	3.58.E-02	*
fyear2001	-0.67134	0.33208	-2.02160	4.32.E-02	*
fyear2002	-1.27286	0.41327	-3.07999	2.07.E-03	**
fyear2003	-0.20351	0.32104	-0.63391	5.26.E-01	
fyear2005	0.04202	0.27128	0.15490	8.77.E-01	
fyear2006	0.88757	0.25653	3.45993	5.40.E-04	***
fyear2007	1.27407	0.31982	3.98370	6.79.E-05	***
fyear2008	1.15313	0.30060	3.83609	1.25.E-04	***
fyear2009	0.79317	0.30583	2.59346	9.50.E-03	**
fyear2010	0.99659	0.28927	3.44521	5.71.E-04	***
fyear2011	1.27866	0.28139	4.54416	5.52.E-06	***
fyear2012	0.72159	0.29734	2.42678	1.52.E-02	*
fyear2013	0.87311	0.29035	3.00713	2.64.E-03	**
fyear2014	0.83593	0.28596	2.92323	3.46.E-03	**
fyear2016	1.32885	0.27866	4.76878	1.85.E-06	***
fyear2017	-0.00971	0.32108	-0.03026	9.76.E-01	
fyear2018	-0.06178	0.32037	-0.19285	8.47.E-01	
fyear2019	-0.62170	0.36258	-1.71466	8.64.E-02	
fyear2020	0.58387	0.30645	1.90530	5.67.E-02	
fyear2021	-0.04926	0.35284	-0.13961	8.89.E-01	
fmonth2	-0.07417	0.08955	-0.82825	4.08.E-01	
fmonth3	-0.86080	0.25833	-3.33219	8.62.E-04	***
fmonth12	0.30975	0.32454	0.95443	3.40.E-01	
fareaOffshore	-1.97311	0.14182	-13.91236	5.33.E-44	***
fareaOnShore	-0.47863	0.10501	-4.55790	5.17.E-06	***
fareaShelfedge	-0.74241	0.10796	-6.87653	6.13.E-12	***

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

Table 4. Estimate values by GLM for positive catch sub-model

	Estimate	Std. Error	t value	Pr (>| t |)	Significance
(Intercept)	-0.10122	0.16846	-0.60082	5.48.E-01	
fyear1997	-0.60445	0.19650	-3.07613	2.16.E-03	***
fyear1998	-0.72437	0.19601	-3.69559	2.32.E-04	***
fyear1999	-0.44220	0.18137	-2.43812	1.50.E-02	*
fyear2000	-0.25545	0.23286	-1.09700	2.73.E-01	
fyear2001	-0.72568	0.22721	-3.19383	1.45.E-03	***
fyear2002	-0.71532	0.28522	-2.50795	1.23.E-02	*
fyear2003	-0.28808	0.20371	-1.41418	1.58.E-01	
fyear2005	-0.37528	0.17987	-2.08639	3.72.E-02	*
fyear2006	-0.63207	0.17283	-3.65729	2.70.E-04	***
fyear2007	-0.99858	0.25401	-3.93118	9.10.E-05	***
fyear2008	-0.78463	0.24642	-3.18409	1.50.E-03	***
fyear2009	-1.19328	0.24700	-4.83099	1.59.E-06	***
fyear2010	-1.02018	0.24262	-4.20492	2.87.E-05	***
fyear2011	-0.86854	0.24054	-3.61077	3.22.E-04	***
fyear2012	-1.14813	0.25096	-4.57503	5.42.E-06	***
fyear2013	-1.01915	0.24600	-4.14282	3.75.E-05	***
fyear2014	-1.20690	0.24502	-4.92578	9.98.E-07	***
fyear2016	-1.01906	0.23913	-4.26147	2.24.E-05	***
fyear2017	-1.29178	0.26505	-4.87366	1.29.E-06	***
fyear2018	-0.91079	0.26554	-3.43003	6.31.E-04	***
fyear2019	-1.01977	0.29189	-3.49364	4.99.E-04	***
fyear2020	-1.33317	0.25512	-5.22564	2.15.E-07	***
fyear2021	-1.48387	0.27942	-5.31059	1.37.E-07	***
fareaOffshore	0.00334	0.09491	0.03516	9.72.E-01	
fareaOnShore	-0.01599	0.06500	-0.24595	8.06.E-01	
fareaShelfedge	-0.15650	0.07101	-2.20402	2.78.E-02	*
surveyTR	0.48388	0.15622	3.09737	2.01.E-03	

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

Table 5. Year trends of probability sub-model

Year	Mean	Mean-SE	Mean+SE
1996	0.1270	0.0938	0.1602
1997	0.1637	0.1281	0.1993
1998	0.1590	0.1241	0.1939
1999	0.2367	0.1955	0.2778
2000	0.0684	0.0480	0.0887
2001	0.0710	0.0509	0.0911
2002	0.0408	0.0253	0.0563
2003	0.1070	0.0818	0.1323
2005	0.1315	0.1052	0.1578
2006	0.2489	0.2108	0.2871
2007	0.3193	0.2617	0.3769
2008	0.2963	0.2454	0.3473
2009	0.2332	0.1903	0.2762
2010	0.2678	0.2219	0.3138
2011	0.3202	0.2708	0.3695
2012	0.2217	0.1785	0.2650
2013	0.2465	0.2025	0.2905
2014	0.2403	0.1971	0.2834
2016	0.3300	0.2808	0.3791
2017	0.1260	0.0948	0.1572
2018	0.1206	0.0902	0.1511
2019	0.0743	0.0511	0.0974
2020	0.2007	0.1585	0.2429
2021	0.1219	0.0879	0.1560

Table 6. Year trends of positive catch sub-model

Year	Mean	Mean-SE	Mean+SE
1996	2.4010	2.2052	2.5968
1997	1.7966	1.6304	1.9627
1998	1.6767	1.5085	1.8448
1999	1.9588	1.8104	2.1072
2000	2.1456	1.9370	2.3541
2001	1.6753	1.4768	1.8738
2002	1.6857	1.4210	1.9504
2003	2.1129	1.9376	2.2882
2005	2.0257	1.8806	2.1709
2006	1.7689	1.6495	1.8884
2007	1.4024	1.2303	1.5746
2008	1.6164	1.4584	1.7743
2009	1.2077	1.0490	1.3665
2010	1.3808	1.2305	1.5312
2011	1.5325	1.3854	1.6796
2012	1.2529	1.0897	1.4161
2013	1.3819	1.2282	1.5355
2014	1.1941	1.0415	1.3467
2016	1.3820	1.2391	1.5248
2017	1.1092	0.9265	1.2920
2018	1.4902	1.3066	1.6738
2019	1.3812	1.1608	1.6017
2020	1.0678	0.8991	1.2366
2021	0.9172	0.7138	1.1205

Table 7. Point estimates of Grid-type Trolling Index

Year	Prob*Pos	Standardized
1996	0.3049	1.0802
1997	0.2941	1.0417
1998	0.2667	0.9446
1999	0.4636	1.6422
2000	0.1467	0.5196
2001	0.1190	0.4215
2002	0.0687	0.2435
2003	0.2262	0.8013
2005	0.2663	0.9434
2006	0.4404	1.5600
2007	0.4478	1.5863
2008	0.4790	1.6967
2009	0.2817	0.9979
2010	0.3699	1.3102
2011	0.4907	1.7382
2012	0.2778	0.9842
2013	0.3406	1.2066
2014	0.2869	1.0164
2016	0.4560	1.6154
2017	0.1397	0.4950
2018	0.1798	0.6369
2019	0.1026	0.3633
2020	0.2143	0.7591
2021	0.1118	0.3961

Table 8. Grid-type Trolling index with confidence intervals calculated by 1000 times bootstrap

year	5 percentile	25 percentile	Median	75 percentile	95 pecentile
1996	0.892	1.004	1.080	1.159	1.292
1997	0.844	0.957	1.030	1.118	1.246
1998	0.760	0.865	0.938	1.023	1.127
1999	1.417	1.539	1.631	1.742	1.895
2000	0.422	0.477	0.516	0.557	0.616
2001	0.335	0.381	0.420	0.456	0.517
2002	0.195	0.224	0.243	0.263	0.289
2003	0.673	0.747	0.799	0.848	0.936
2004					
2005	0.806	0.885	0.939	0.993	1.074
2006	1.394	1.482	1.555	1.632	1.757
2007	1.396	1.515	1.598	1.674	1.798
2008	1.489	1.611	1.694	1.778	1.897
2009	0.853	0.936	0.999	1.058	1.136
2010	1.138	1.239	1.311	1.372	1.466
2011	1.577	1.677	1.743	1.807	1.912
2012	0.846	0.929	0.986	1.043	1.120
2013	1.051	1.145	1.204	1.271	1.355
2014	0.885	0.963	1.016	1.072	1.144
2015					
2016	1.404	1.532	1.618	1.700	1.829
2017	0.398	0.458	0.495	0.534	0.591
2018	0.523	0.597	0.640	0.683	0.746
2019	0.311	0.341	0.363	0.383	0.419
2020	0.627	0.704	0.760	0.816	0.896
2021	0.313	0.360	0.395	0.432	0.483

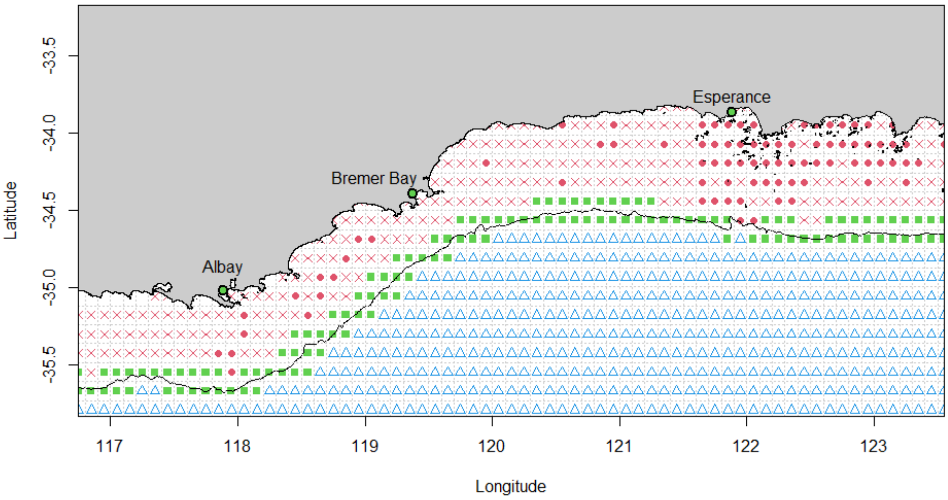

Fig. 1. Map and area classified.

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

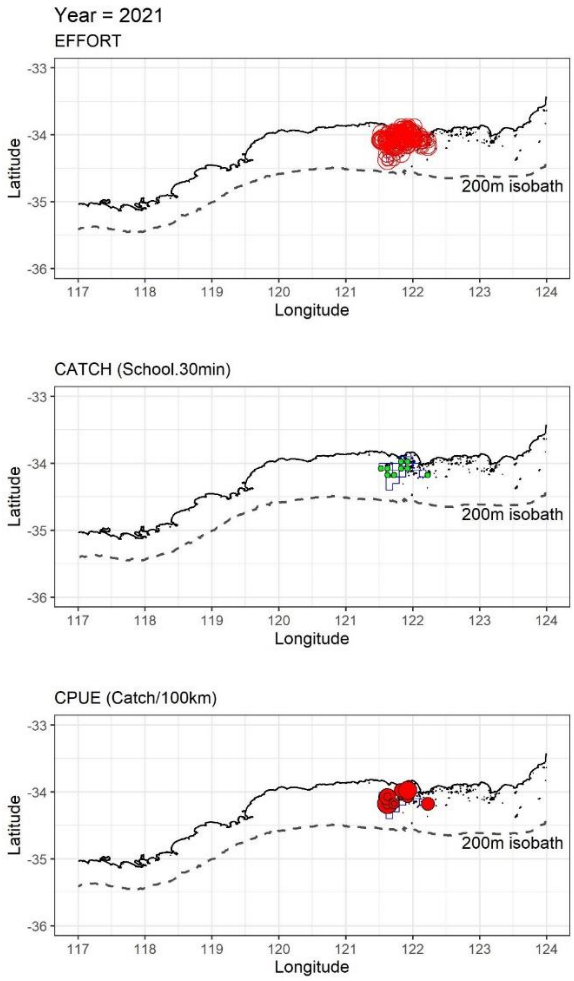

Fig. 2. Distributions of effort, age-1 SBT catch and CPUE in 2021

Blue line is the trajectory of the vessel while trolling.

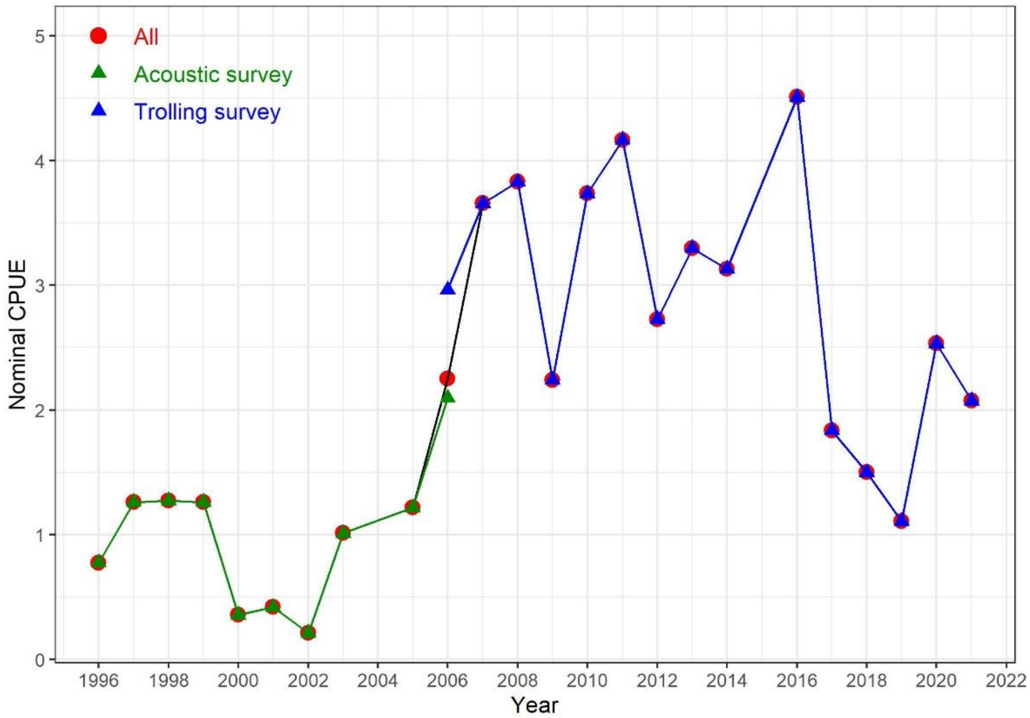

Fig. 3. Nominal CPUE of TRG.

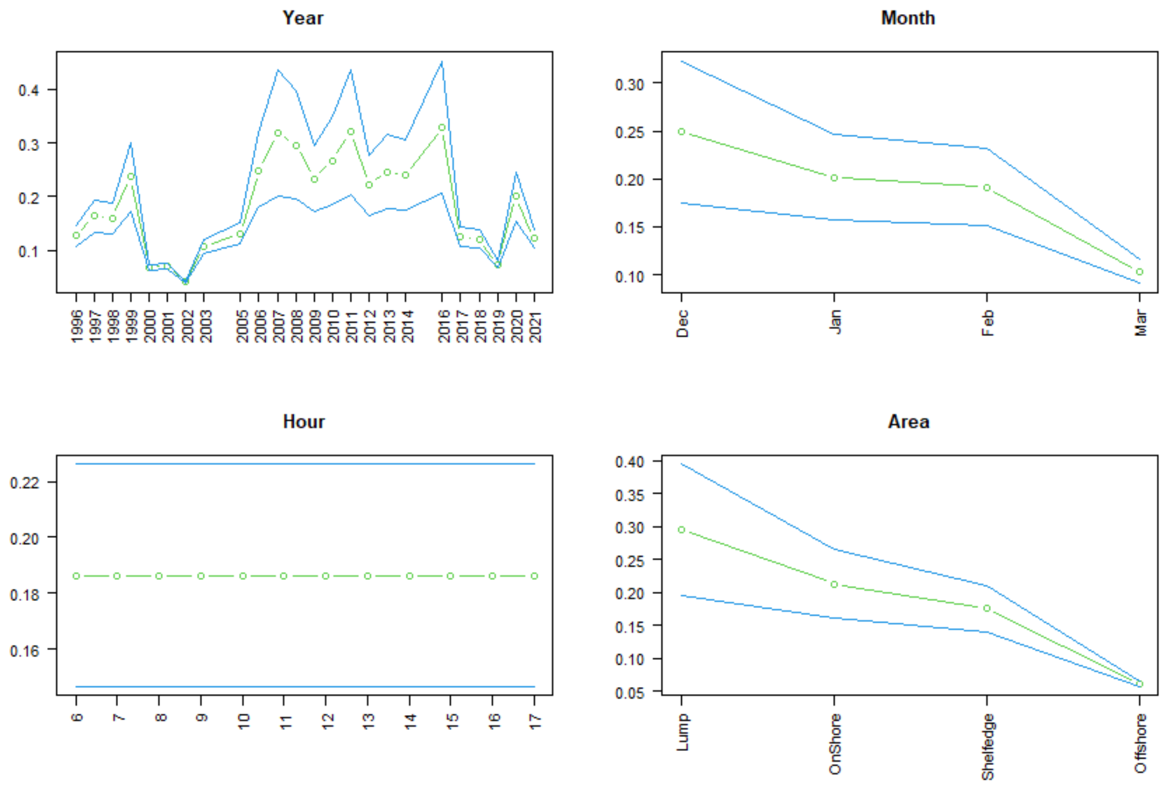

Fig. 4. Least square means of variables in probability of catch model.

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.

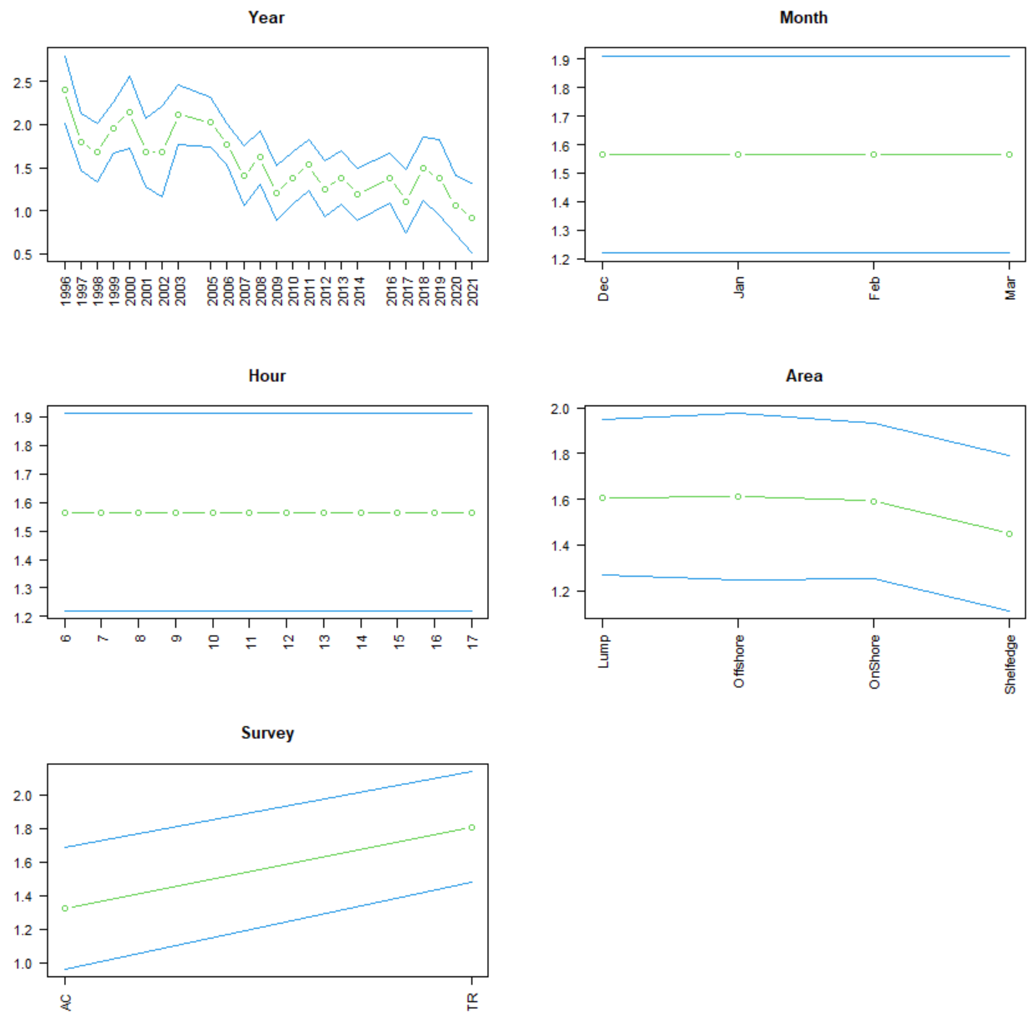

Fig. 5. Least square means of variables in catch in the positive catch dataset.

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.

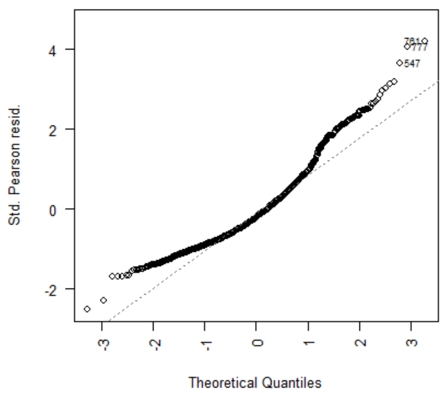

Fig. 6. QQ plot of GLM for positive catch sub-model.

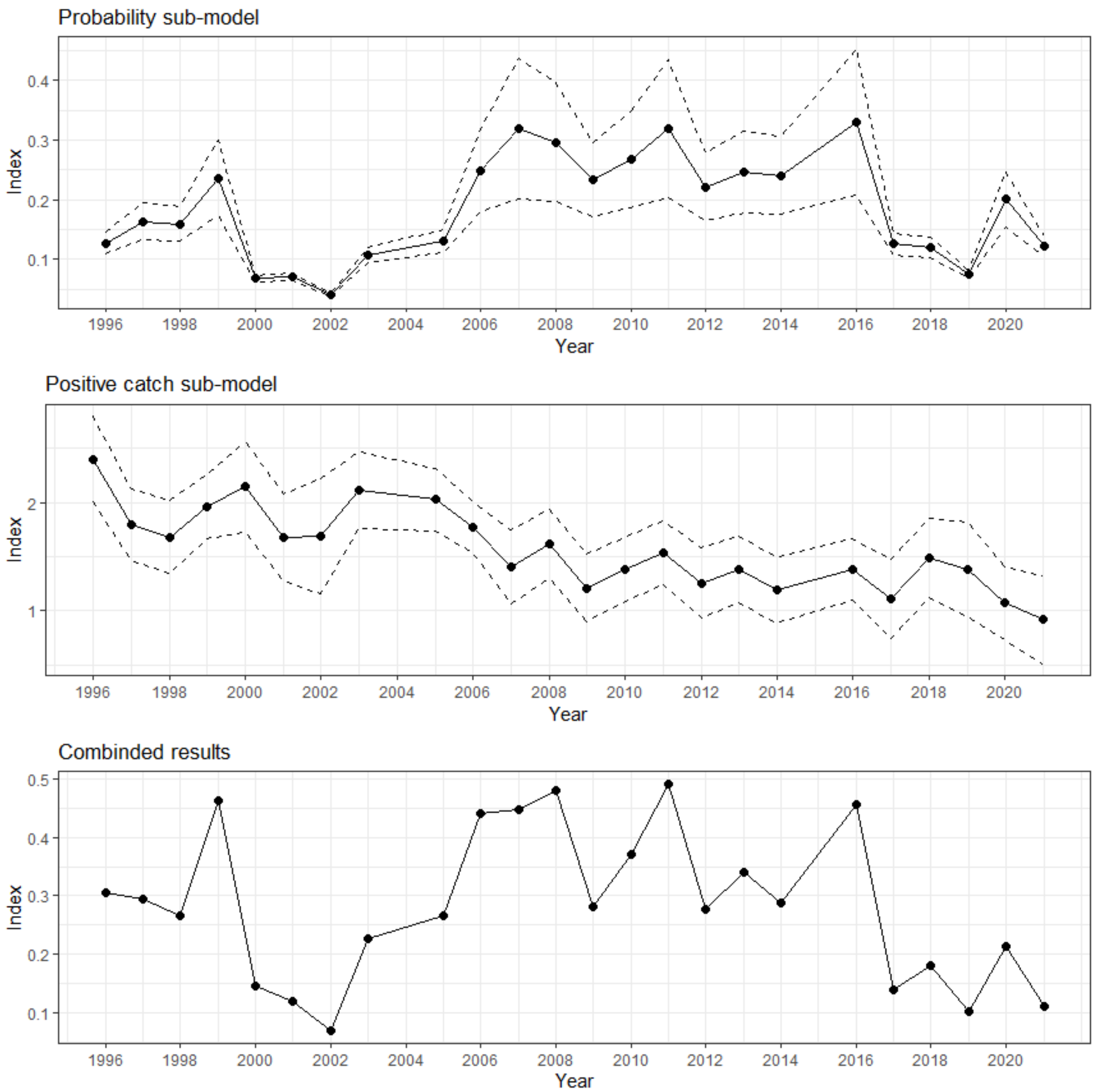

Fig. 7. Probability sub-model, positive catch sub-model, and combined index from two sub-models (point estimation standardized TRG).

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

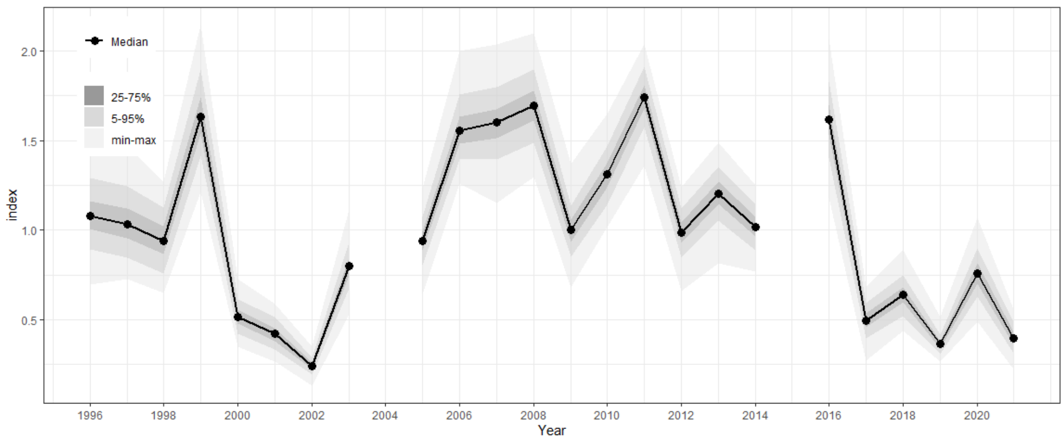

Fig. 8. TRG with confidence intervals.

Estimate was simulated with 1000 times bootstrapping.

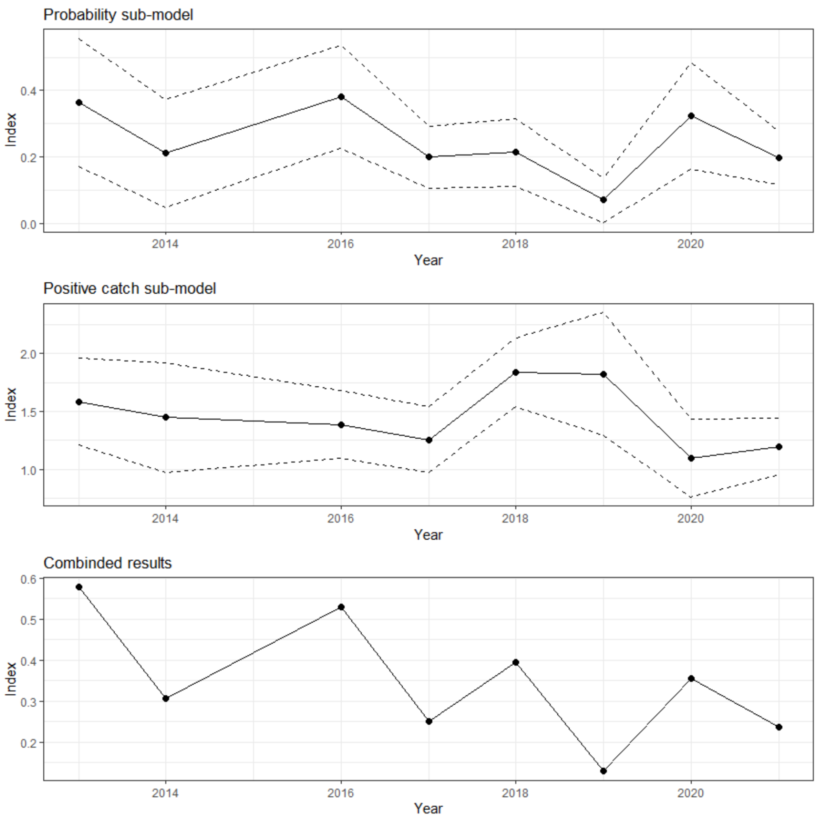

Fig. 9. TRG off Esperance only (TRG_esp) with confidence intervals.

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

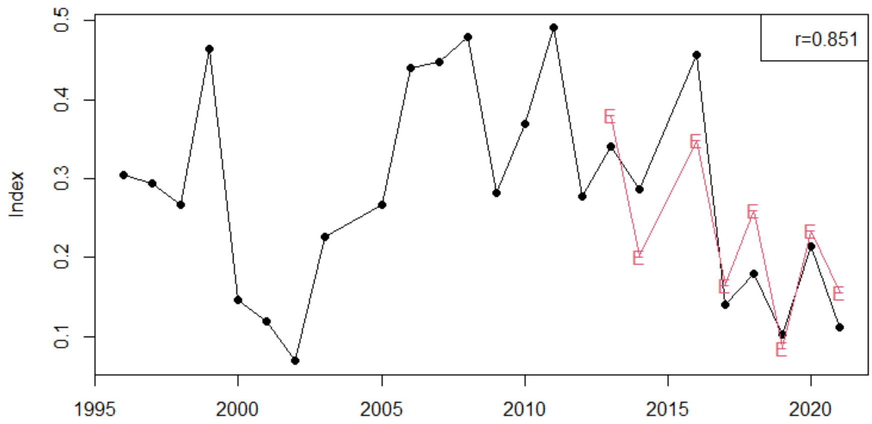

Fig. 10. Comparison between TRG and TRG_esp where data are limited off Esperance only.
Values of TRG_esp are standardized to the mean of TRG between 2013 and 2021. Pearson's correlation r is 0.851 ($p<0.01$).

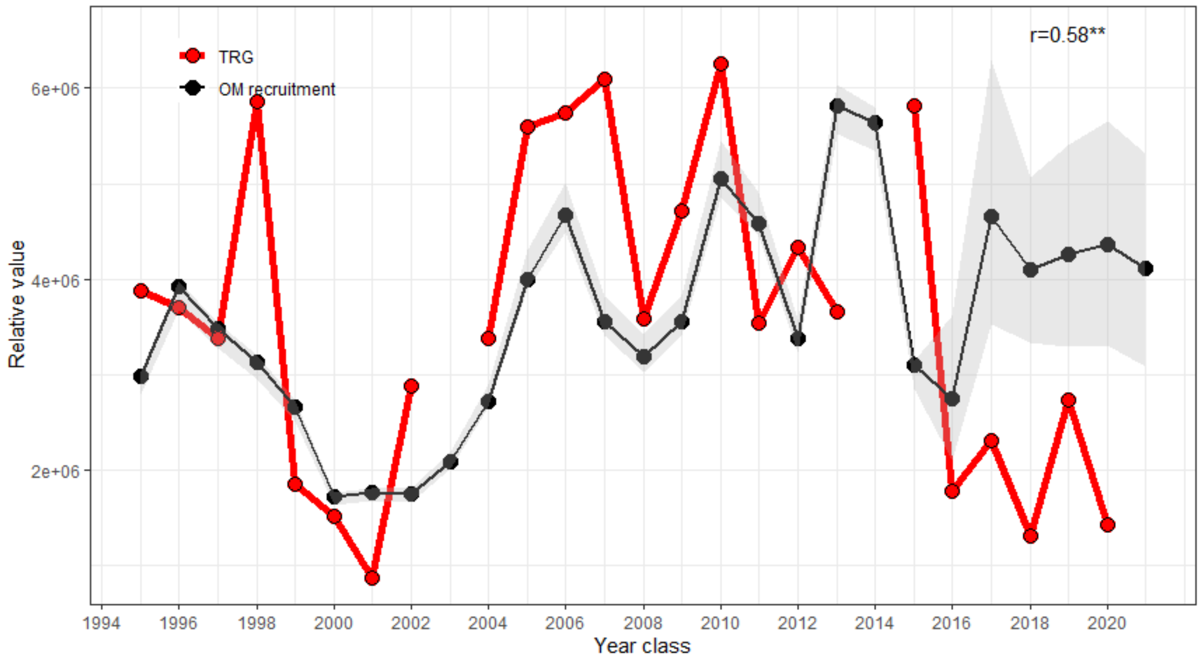

Fig. 11. Comparison between OM recruitment from the 2020 stock assessment and TRG by year class (cohort).
Range of OM recruitment is 25-75 percentiles. Pearson's correlation r was calculated from data up to the 2016 year class.

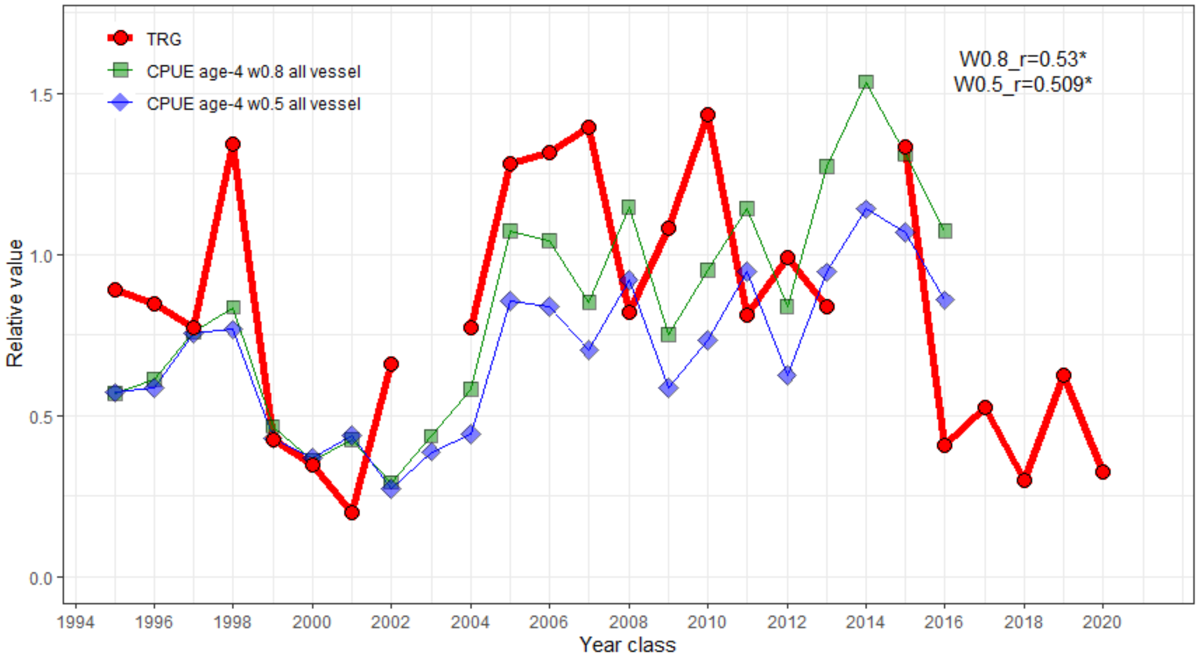

Fig. 12. Comparison between the age-4 all vessel CPUEs (w0.5 and w0.8) of Japanese longline and TRG by year class (cohort).
r is Pearson's correlation.

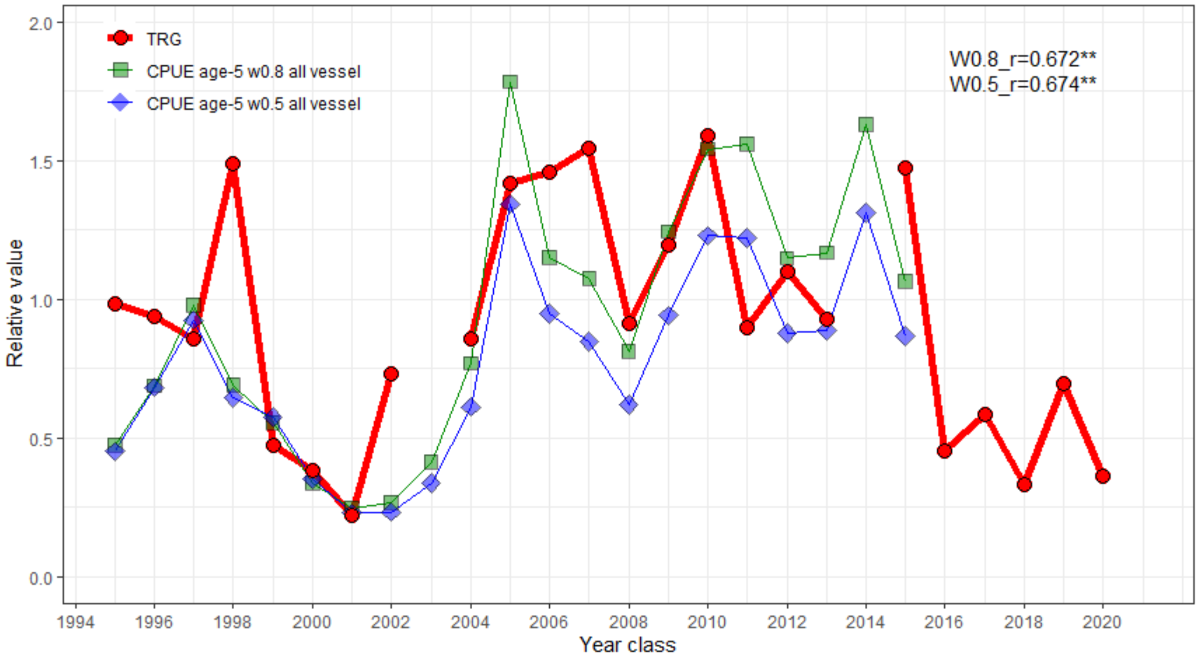

Fig. 13. Comparison between the age-5 all vessel CPUEs (w0.5 and w0.8) of Japanese longline and TRG by year class (cohort).
r is Pearson's correlation.

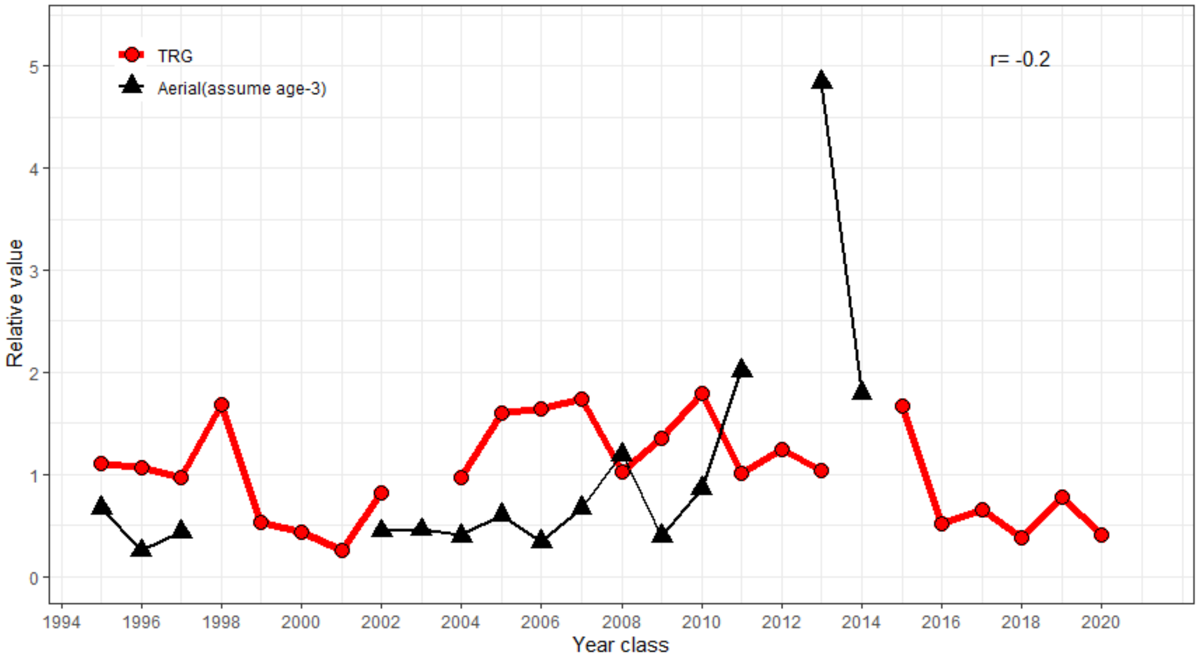

Fig. 14. Comparison between aerial survey index and TRG by year class (cohort).

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