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Tiger flathead (*Neoplatycephalus richardsoni*) stock assessment based on data up to 2015

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Acknowledgments

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Executive summary

This document updates the 2013 assessment of tiger flathead (*Neoplatycephalus richardsoni*) to provide estimates of stock status in the SESSF at the start of 2017. This assessment was performed using the stock assessment package Stock Synthesis (version SS-V3.24Z). The 2013 stock assessment has been updated with the inclusion of data up to the end of 2015, comprising an additional three years of catch, discard, CPUE, length and age data and ageing error updates. An additional survey point is included from the Fishery Independent Survey and length frequencies have been included from all four years of the Fishery Independent Survey. A range of sensitivities were explored, including splitting the Fishery Independent Survey into two fleets to match the fleet structure in the assessment, and lowering the final year of recruitment estimation from 2012 to 2009.

The base-case assessment estimates that current spawning stock biomass is 43% of unexploited stock biomass (SSB_0). Under the agreed 20:35:40 harvest control rule, the 2017 recommended biological catch (RBC) is 2,971 t, and remains above the long term yield (assuming average recruitment in the future) of 2,765 t. The average RBC over the three year period 2017-2019 is 2,936 t and over the five year period 2017-2021, the average RBC is 2,909 t.

Exploration of model sensitivity showed a variation in spawning biomass from 26% to 51% of SSB_0 when natural mortality was fixed at values of 0.22 and 0.32 respectively. When recruitment is only estimated to 2009, excluding the three above average recruitment estimates in 2010-2012, the spawning biomass was estimated to be 31% of SSB_0. For all other sensitivities explored, the variation in spawning biomass was much narrower, ranging between 39% and 45%.

Changes to the last stock assessment include: separating length frequencies into onboard and port collected components, with a joint selectivity pattern estimated; including FIS length frequencies; weighting length frequencies by shots and trips rather than fish measured; and using a new tuning method. The reduction in spawning biomass compared to the last assessment appear to be largely driven by the new data and the resulting modification to the estimates of recent recruitment, in particular to recruitment in the years 2004, 2006, 2007 and 2009.

1 Introduction

1.1 The fishery

Tiger flathead have been caught commercially in the south eastern region of Australia since the development of the trawl fishery in 1915. They are endemic to Australian waters and are caught mainly on the continental shelf and upper slope waters from northern NSW to Tasmania and through Bass Strait. Historical records (e.g. Fairbridge, 1948; Allen, 1989; Klaer, 2005) show that steam trawlers caught tiger flathead from 1915 to about 1960. A Danish seine trawl fishery developed in the 1930s (Allen, 1989) and continues to the present day. Modern diesel trawling commenced in the 1970s.

1.2 Previous assessments

Prior to 2001, the previous quantitative assessment for tiger flathead was from the late 1980s (Allen, 1989). In that report, the assessment for tiger flathead was conducted based on catch and effort data using a surplus production model. The estimate of Maximum Sustainable Yield, MSY, for NSW and eastern Bass Strait was about 2,500 t.

Between 1989 and 2001, assessments of tiger flathead involved examination of trends in catches, catch rates, and in age and length data, but no quantitative assessments were undertaken. Assessments from 1993 to 2001 can be found in the annual reports of SEFAG (the South East Fishery Assessment Group). For example, the 1993 assessment noted that tiger flathead catches from south-east Tasmanian waters contained higher proportions of larger, older fish than those from eastern Bass Strait. This suggested that tiger flathead resources off Tasmania were either more lightly fished than those in the main fishing areas, or that there was a separate stock with different population characteristics off Tasmania.

During the period 2001-2004, data for tiger flathead were collated, summarized and presented at workshops (see Cui *et al*. (2004) for a detailed summary of these workshops and the analyses presented to them). These workshops led to revisions of the data series, analyses of the data, and to suggestions for revisions to the data sets and research priorities. The 2004 assessment (Cui *et al.*, 2004) used 89 years (1915–2003) of data to estimate the virgin spawning stock biomass and the 2004 spawning stock biomass relative to that in 1915 and provided, for the first time, a complete picture of the dynamics of the tiger flathead fishery.

A number of changes to both the input data and some model structural changes were made and presented in the assessments developed in 2005 (Punt 2005a, Punt 2005b). These assessments considered tiger flathead caught off eastern Tasmania in SEF zone 30 as either separate to, or part of the same stock in zones 10 (E NSW), 20 (E Bass Strait) and 60 (Bass Strait) combined. In the scenario where eastern Tasmanian flathead are part of the same stock, a separate fleet was constructed to account for catches made there. Modifications to estimates of historical catches from Klaer (2005) were incorporated into catch series used in the assessments. Length-frequency data for 1945-1967 and 1971-1984 were obtained, and uncertainty in discard rates was estimated using a bootstrap procedure.

Part of the intention for the 2006 assessment (Klaer, 2006a) was initially to duplicate as far as possible the assessment results from 2005 (Punt, 2005a, Punt 2005b) while implementing the assessment using the Stock Synthesis (SS2) framework. The same assumptions were made about stock structure, i.e. tiger flathead off eastern Tasmania may or may not be the same stock as those off NSW and Victoria. Steepness was treated as an estimable parameter and annual age frequencies were added directly into the model as samples independent to length frequencies. The 2006 Shelf RAG selected the model that treated Tasmanian trawl as a separate fleet fishing the same east coast stock as the most appropriate base case.

The 2009 assessment (Klaer, 2009) moved the model from Stock Synthesis version SS-V2.1.21 (June 2006) to Stock Synthesis version SS-V3.03 (May 2009). Major changes to previous assessments were the use of age-at-length data to estimate growth parameters, correction to discard estimation for steam trawl, allowing selectivity change in 1985 for diesel trawl and 1978 for Danish seine, and estimation of recruitment 3 years prior to the last year (2005) for the 2009 assessment that used data to the end of 2008.

The 2009 assessment was updated in 2010 (Klaer, 2010) using Stock Synthesis version SS-V3.11a, (Methot September 2010). For the 2010 assessment, changes were made to the treatment of discards prior to 1980, an additional growth parameter was estimated and the assumed value for natural mortality, M, was changed from 0.22 to 0.27.

The most recent full quantitative assessment for tiger flathead was performed in 2013 (Day and Klaer, 2013) using Stock Synthesis version SS-V3.24f, (Methot August 2011). Results from three years of the winter fishery independent survey (FIS) were included as an additional abundance index in the 2013 assessment, but no FIS length data were included.

1.3 Modifications to the previous assessments

This assessment uses the current version of Stock Synthesis, version SS-V3.24Z, (Methot 2015).The number of growth parameters estimated and assumptions about mortality and early discarding rates in this assessment are identical to the 2013 assessment (Day and Klaer, 2013). Three growth parameters are estimated (CV, K and l_{min}), natural mortality is assumed to be 0.27 and the discarded catch for steam trawl and for Danish seine prior to 1960 is assumed to be 20% of the retained catch, which translates to a discard ratio (disc/[ret+disc]) of 17%.

An abundance index from the fishery independent survey (FIS) for the winter surveys for four years: 2008, 2010, 2012 and 2014 (Knuckey *et al.*, 2015) was included in the 2013 assessment and this index is retained in this assessment with an additional data point. As the summer FIS was discontinued after 2012, the summer FIS abundance index has not been included in sensitivities in this assessment.

Updates to data used in the previous assessment resulted from improvements in the automatic processing of data and filtering of records. However, some historical length frequency data used in the 2013 assessment are not present in the automatic processing. These length frequencies are included in the current assessment, by using data from the 2013 assessment for the following retained length frequencies:

1. Steam Trawl, Sydney Fish Market – 1953-1958
2. Eastern Trawl, Sydney Fish Market – 1965-1967
3. Danish seine, onboard – 1993-1994

In addition to this historical data, retained for this assessment, there appear to be some changes in the Tasmanian Trawl length frequencies in 2009 and 2010 which may warrant future investigation. Only one shot was recorded from each of the 2009 and 2010 onboard samples, so these length frequencies were excluded, as they were unlikely to be representative. Similarly, the 2009 port length frequency came from less than 100 fish so this length frequency was also excluded. These sample sizes are different to those produced by the 2013 automatic processing, so this may require further investigation.

Discard length frequencies from Danish seine in 1994 and 1995 and eastern trawl from 1994-1996 were excluded in previous assessments as these appear to have unrepresentative distributions. These discard length frequencies were also excluded from the current assessment.

Other substantial changes from the 2013 assessment include:

1. including both port and onboard length frequency data
2. weighting length frequency data by shot or trip numbers rather than numbers of fish measured
3. modifications to the tuning procedures including use of Francis weighting for length and age data
4. inclusion of length frequency data from the fishery independent surveys from 2008, 2010, 2012 and 2014

Previous tiger flathead assessments have applied a lambda of 0.1 to length and age frequency data to down weight the likelihood from these sources relative to the likelihood from the CPUE and survey data. Weighting these frequencies by shot rather than numbers of fish measured, and using the latest protocols including Francis weighting has allowed these lambdas to be returned to 1. If it can be avoided, it is preferable to set the lambdas at 1, rather than make somewhat adhoc decisions to balance the likelihood from different data sources and somewhat arbitrarily down weight length and age data.

Updates to data used in the previous assessment resulted from improvements and corrections in the automatic processing of data and filtering of records. Including both port and onboard length frequencies resulted in additional length frequencies, and weighting these by shot or trip numbers altered the relative weighting between years. When shots or trip were not known (Sydney Fish Market, Kapala or Blackburn data), the number of fish measured was divided by 10 and capped at 200. When the number of trips or shots was available, a cap of 120 trips and 200 shots was used to set an upper limit on the sample size, although the limit on trip numbers was never exceeded.

The data updates produced minor modifications to estimates of discards. An updated estimate of the ageing error matrix constructed from the new ageing data was used. As in the 2013 assessment, age-at-length frequency distributions were only used when the gender was known. The only changes to age-at-length data were the addition of three years of new data from 2013 to 2015. Minor revisions were made to the catch history from 2001 onwards, with minor modifications to recent state catch history and some reallocation of catch between fleets due to misclassification of some vessels. Updates to the preliminary 2012 and assumed 2013 catches were made and new 2014 and 2015 catch data was included, with the 2016 catch data (required to calculate a 2017 RBC) assumed to be the same as the 2015 catch data.

Inclusion of the new data had relatively minor impacts on the estimates of recruitment and the spawning biomass time series. With recruitment estimated up until 2012, this resulted in several of the recruitments estimated from 2004-2009 to be revised down, compared to the 2013 assessment. The general recruitment trend before 2004 was unchanged in the new assessment.

The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be contributing to changes in the assessment outcome was conducted (Day, 2016).

2 Methods

2.1 The data and model inputs

2.1.1 Biological parameters

As male and female tiger flathead have different growth patterns (females are substantially larger), a two-sex model has been used.

The parameters of the Von Bertalanffy growth equation are estimated by sex within the model-fitting procedure from age-at-length data. This approach accounts for the impact of gear selectivity on the age-at-length data collected from the fishery and the impact of ageing error. Three growth parameters are estimated (CV, K and l_{min}), with only one growth parameter fixed (l_{max} = 55.9), with this valued based on the estimate of l_{∞} obtained by Punt(2005a) by fitting von Bertalanffy growth curves to data from SESSF Zones 10 and 20 (NSW and eastern Bass Strait).

Estimates of the rate of natural mortality, M, reported in the literature vary from 0.21 to 0.46 yr^{-1}. This assessment uses a value of 0.27 yr^{-1} as the base-case estimate of M as used in the previous assessment (Day and Klaer, 2013) and as previously agreed to by Shelf RAG. Sensitivity to this value is tested. The steepness of the stock-recruitment relationship, h, is estimated by the model, and for the base case is estimated to be 0.62.

Female tiger flathead become sexually mature at about three years of age, which corresponds to a length of about 30 cm (Klaer, 2010). Maturity is modelled as a logistic function, with 50% maturity at 30 cm. Fecundity-at-length is assumed to be proportional to weight-at-length.

The parameters of the length-weight relationship are the same as those used in the previous assessment a=5.88 x 10^{-6}, b=3.31 (Day and Klaer, 2013), with these parameters originally obtained by fitting von Bertalanffy growth curves to data from SESSF Zones 10 and 20, NSW and eastern Bass Strait (Punt, 2005a).

2.1.2 Fleets

The assessment data for tiger flathead have been separated into five 'fleets', which represent one or more gear, regional, or temporal differences in the fishery. Landings data from eastern Tasmania were separated from the catches from the other regions in the east, because the length compositions of catches from this area indicate that it lands larger fish.

1. Steam trawl – steam trawlers (1915 – 1961)
2. Danish seine – Danish seine from NSW, eastern Victoria and Bass Strait (1929 – 2015)
3. Eastern trawl – diesel otter trawlers from NSW, eastern Victoria and Bass Strait (1971 – 2015)
4. Tasmanian trawl – diesel otter trawlers from eastern Tasmania (1985 – 2015)
5. Fishery Independent Survey – (2008-2014)

2.1.3 Landed catches

A landed catch history for tiger flathead, separated into the four 'fleets', is available for all years from 1915 to 2015 (Table 1, Figure 1 and Figure 2). Landings from the FIS fleet were assumed to be zero, with the actual FIS catch included in the scaling up of logbook catches to landed catches.

Klaer (2005) describes the sources of information used to construct the historical landed catch record for each of the fleets to 1986. Quotas were introduced into the fishery in 1992, and from then onwards, records of landed catches as well as estimated catches from the logbook are available. The landings data give a more accurate measure of the landed catch than do the logbook data, but the logbook data contain more detail. For example, it is usually possible to separate logbook records, but not landing records, by fleet. The logbook catches for each fleet from 1992 onwards have been scaled up by the ratio of landed catches to logbook catches in each year (Thomson, 2002). Prior to 1992, the unscaled logbook catches are used.

In 2007 the quota year was changed from calendar year to the year extending from 1 May to 30 April, however the assessment is based on calendar years. All catches for recent years continue to be those made by calendar year, which may conflict with the fishing year TACs.

Small quantities of tiger flathead are caught in state waters. NSW and Victorian state catches have been added to the eastern trawl fleet, and Tasmanian state catches have been added to the Tasmanian fleet.

In order to calculate the Recommended Biological Catch (RBC) for 2017, it is necessary to estimate the Commonwealth calendar year catch for 2016. The TAC (Table 2) was almost unchanged from 2015 to 2016 and the state catches are unknown for 2016. Hence, assuming that the same ratio of the TAC will be caught in 2016 as in 2015, with the same state catches as 2015, is equivalent to assuming that the catch in 2016 is identical to the 2015 catch. This gives estimated 2016 catches for the eastern fleet, the Tasmanian fleet, and the Danish seine fleet of 1,245 t, 349 t and 1,479 t, respectively.

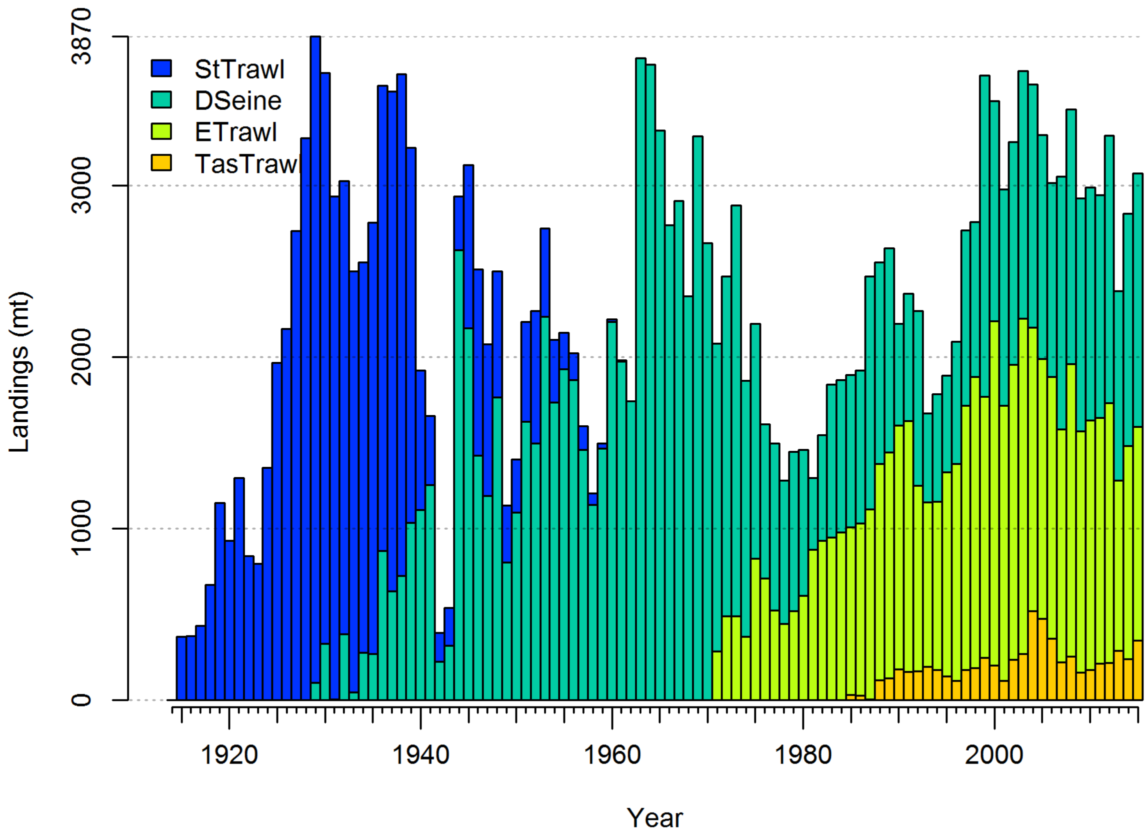


Figure 1. Total landed catch of tiger flathead by fleet (stacked) from 1915-2015.

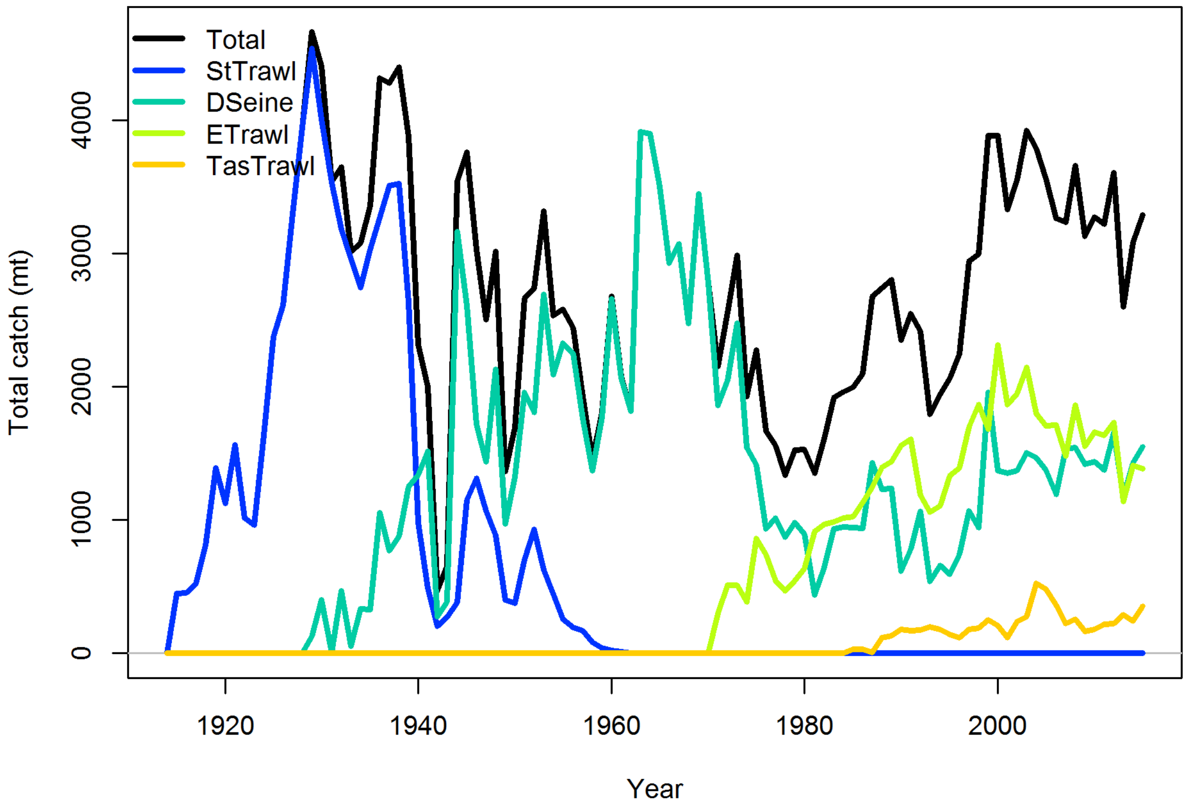


Figure 2. Total landed catch of tiger flathead by fleet from 1915-2015.

Table 1. Total retained catches (tonnes) of tiger flathead per fleet for calendar years from 1915-2016.

Year	Fleet St Trawl	D Seine	E Trawl	Tas Trawl	Year	Fleet St Trawl	D Seine	E Trawl	Tas Trawl	Year	Fleet St Trawl	D Seine	E Trawl	Tas Trawl
1915	371	0	0	0	1951	583	1,625	0	0	1987	0	1,358	1,109	6
1916	373	0	0	0	1952	769	1,499	0	0	1988	0	1,177	1,263	116
1917	432	0	0	0	1953	517	2,235	0	0	1989	0	1,189	1,318	128
1918	671	0	0	0	1954	366	1,737	0	0	1990	0	591	1,425	178
1919	1,151	0	0	0	1955	211	1,932	0	0	1991	0	746	1,461	166
1920	931	0	0	0	1956	157	1,868	0	0	1992	0	1,019	1,080	170
1921	1,297	0	0	0	1957	139	1,459	0	0	1993	0	516	962	194
1922	840	0	0	0	1958	68	1,138	0	0	1994	0	626	982	178
1923	796	0	0	0	1959	32	1,467	0	0	1995	0	564	1,189	139
1924	1,356	0	0	0	1960	15	2,206	0	0	1996	0	711	1,265	114
1925	1,969	0	0	0	1961	9	1,974	0	0	1997	0	1,023	1,542	175
1926	2,167	0	0	0	1962	0	1,742	0	0	1998	0	905	1,700	186
1927	2,735	0	0	0	1963	0	3,745	0	0	1999	0	1,873	1,520	248
1928	3,277	0	0	0	1964	0	3,707	0	0	2000	0	1,286	2,006	203
1929	3,768	102	0	0	1965	0	3,322	0	0	2001	0	1,261	1,602	114
1930	3,329	330	0	0	1966	0	2,769	0	0	2002	0	1,299	1,722	235
1931	2,932	4	0	0	1967	0	2,912	0	0	2003	0	1,447	1,954	270
1932	2,642	385	0	0	1968	0	2,355	0	0	2004	0	1,417	1,654	521
1933	2,456	44	0	0	1969	0	3,289	0	0	2005	0	1,307	1,515	476
1934	2,278	276	0	0	1970	0	2,667	0	0	2006	0	1,133	1,526	359
1935	2,514	270	0	0	1971	0	1,793	286	0	2007	0	1,476	1,357	221
1936	2,712	872	0	0	1972	0	1,981	491	0	2008	0	1,487	1,705	255
1937	2,912	637	0	0	1973	0	2,397	490	0	2009	0	1,356	1,406	163
1938	2,924	725	0	0	1974	0	1,493	369	0	2010	0	1,359	1,456	175
1939	2,185	1,035	0	0	1975	0	1,367	827	0	2011	0	1,300	1,433	214
1940	815	1,108	0	0	1976	0	900	712	0	2012	0	1,562	1,515	217
1941	403	1,255	0	0	1977	0	977	522	0	2,013	0	1,103	995	287
1942	167	225	0	0	1978	0	836	446	0	2,014	0	1,354	1,244	239
1943	223	317	0	0	1979	0	928	520	0	2,015	0	1,479	1,245	349
1944	315	2,624	0	0	1980	0	851	609	0	2016*	0	1,479	1,245	349
1945	953	2,168	0	0	1981	0	418	877	0					
1946	1,088	1,425	0	0	1982	0	615	930	0					
1947	884	1,193	0	0	1983	0	889	950	0					
1948	735	1,767	0	0	1984	0	890	978	0					
1949	330	804	0	0	1985	0	890	978	30					
1950	310	1,095	0	0	1986	0	892	1,005	26					

*2016 catches are estimated

Table 2. Total allowable catch (t) from 1992 to 2016/17.

Year	TAC Agreed
1992	3000
1993	3000
1994	3500
1995	3500
1996	3500
1997	3500
1998	3500
1999	3500
2000	3500
2001	3500
2002	3500
2003	3500
2004	3500
2005	3150
2006	3000
2007	3015
2008-09	2850
2009-10	2850
2010-11	2750
2011-12	2750
2012-13	2750
2013-14	2750
2014-15	2878
2015-16	2860
2016-17	2882

2.1.4 Discard rates

Information on the discarding rate of tiger flathead was available from the PIRVic-run Integrated Scientific Monitoring Program (ISMP) for 1992-2006. From 2007 the ISMP was run by AFMA. The discard data are summarised in Table 3. Generally, discards of tiger flathead were in the order of 8% for Danish seine, 10% for eastern trawl and 1% for Tasmanian trawl.

There is limited information on discarding for the early steam trawl fleet (1915-61) and the early Danish seine fleet (1929-67). However, it is known that total discards for all species from steam trawl in the 1920s was in the order of 20% of the retained catch (Klaer, 2001). As there is no way to determine the species catch composition of the discards, Shelf RAG made the decision to apply this ratio to tiger flathead, which translates to a discard fraction of 17%. For the base-case, all steam trawl (1915-1961) and early Danish seine (1929-1960) were assigned a constant discard fraction of 17% to apply equally to all selected fish (Figure 3). The discard fraction for Danish seine from 1961 to present was set using recent observed discard ratios since 1994. Recent observations were used to estimate discard fractions for the east coast and Tasmanian diesel trawl fleets.

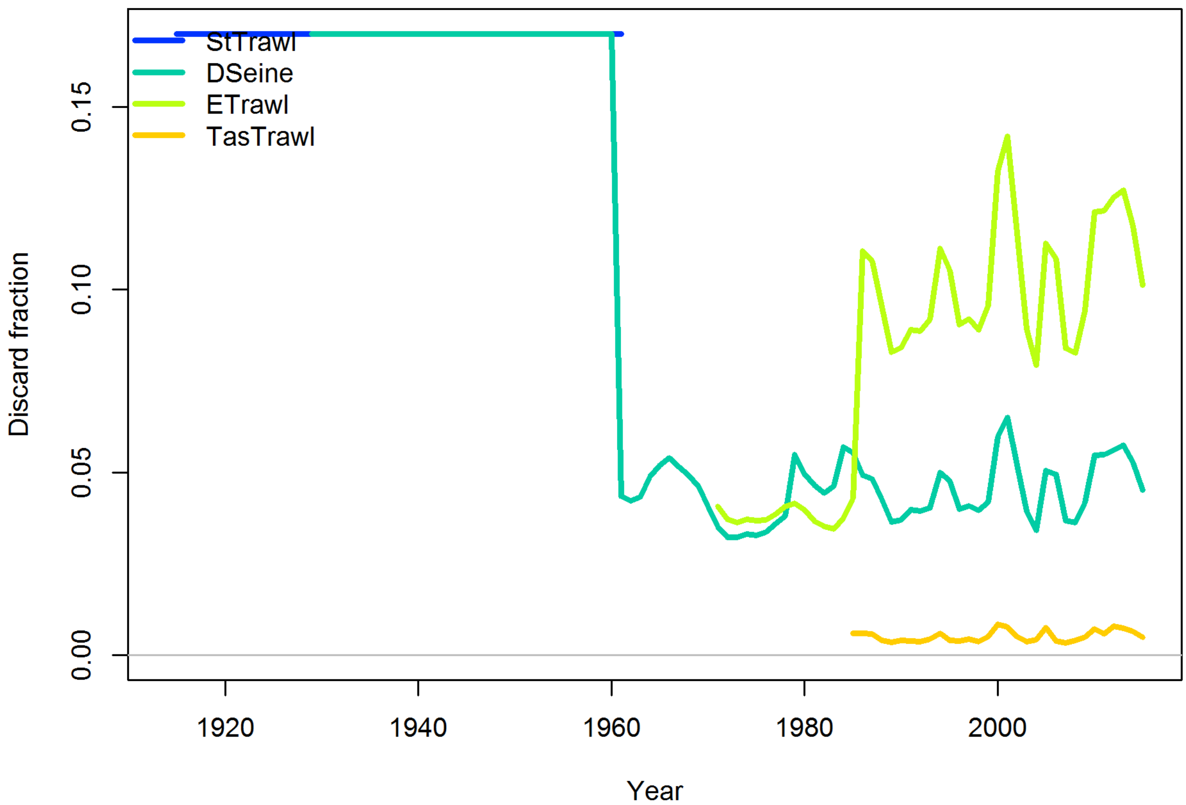


Figure 3. Model estimates of discard fractions per fleet.

Table 3. Proportion of catch discarded by fleet, with sample sizes.

Year	Fleet					
	D Seine	n	E Trawl	n	Tas Trawl	n
1992			0.087868	11		
1993			0.101798	195		
1994	0.040297	79	0.129968	267	0.081380	18
1995	0.123334	44	0.127717	129		
1996			0.122627	240		
1997			0.031345	383	0.000956	10
1998	0.053599	23	0.118566	246	0.000245	27
1999	0.015437	34	0.199701	382	0.002363	48
2000	0.071560	27	0.114977	395		
2001	0.006871	41	0.075192	457		
2002	0.112531	30	0.067438	385	0.006729	8
2003	0.014414	113	0.072940	470	0.005699	10
2004	0.001241	39	0.099207	387		
2005	0.049008	61	0.105351	461	0.001489	16
2006	0.023315	125	0.132521	369	0.000582	59
2007	0.106470	47	0.030259	106		
2008	0.030943	37	0.020926	214		
2009	0.136644	32	0.113514	200	0.052681	8
2010	0.151653	75	0.117542	171	0.029486	20
2011	0.255459	124	0.141128	140	0.002131	22
2012	0.069183	70	0.095674	127	0.009509	27
2013	0.041523	102	0.118683	128	0.016985	22
2014	0.170019	109	0.106842	128	0.006047	36
2015	0.045976	72	0.148704	231	0.003959	49

2.1.5 Catch rate indices

A standardised catch rate (CPUE) index is available for the historical steam trawl fleet for the years 1919-23, 1937-42, and 1952-57 (Klaer, 2006b; Table 4). An unstandardised catch rate index for early Danish seine has been used in tiger flathead assessments since Cui *et al.* (2004) (Table 5).

Catch and effort information from the SEF1 logbook database from the period 1986-2015 were standardised using GLM analysis to obtain indices of relative abundance for recent Danish seine, eastern and Tasmanian trawl fleets (Sporcic and Haddon, 2016; Table 6).

Abundance indices from the Fishery Independent Survey from 2008-2014 were also used, with either zones 10, 20 and 30 combined, or separated into zones 10 and 20, to match the eastern trawl fleet, and zone 30, to match the Tasmanian trawl fleet (Table 7).

Table 4. Standardised catch rates for the steam trawl fleet (Klaer 2006b).

Year	Value	CV
1919	1.618	0.31
1920	1.732	0.31
1921	1.806	0.31
1922	1.758	0.31
1923	1.646	0.31
1937	0.635	0.31
1938	0.749	0.31
1939	0.723	0.31
1940	0.611	0.31
1941	0.618	0.31
1942	0.401	0.31
1952	0.262	0.31
1953	0.208	0.31
1954	0.232	0.31
1955	0.219	0.31
1956	0.208	0.31
1957	0.169	0.31

Table 5. Unstandardised catch rates for the early Danish seine fleet.

Year	Value	CV
1950	38.7	0.33
1951	27.6	0.33
1952	31.8	0.33
1953	52.0	0.33
1954	34.4	0.33
1955	47.4	0.33
1956	46.5	0.33
1957	32.1	0.33
1958	22.5	0.33
1959	28.7	0.33
1960	43.6	0.33
1965	38.2	0.33
1966	41.5	0.33
1967	62.5	0.33
1968	61.2	0.33
1969	77.8	0.33
1970	67.1	0.33
1971	69.9	0.33
1972	114.0	0.33
1973	88.0	0.33
1974	58.1	0.33
1975	56.6	0.33
1976	41.9	0.33
1977	55.5	0.33
1978	51.9	0.33

Table 6. Standardised catch rates for the Danish seine, Eastern and Tasmanian diesel trawl fleets from 1986-2015.

Year	Fleet D Seine	CV	E Trawl	CV	Tas Trawl	CV
1986*	1.0947	0.0226	0.7877	0.0166	0.9491	0.1587
1987	1.6044	0.0224	1.0463	0.0157	0.6198	0.1888
1988	1.7212	0.0222	1.1251	0.0155	0.9453	0.1693
1989	1.6220	0.0226	1.1337	0.0156	0.6935	0.1627
1990	1.0619	0.0240	1.3771	0.0164	0.7211	0.1648
1991	1.3400	0.0242	1.2851	0.0166	0.7154	0.1602
1992	1.3756	0.0222	1.0215	0.0173	0.6389	0.1648
1993	0.8305	0.0227	1.0317	0.0164	0.6095	0.1562
1994	0.7199	0.0218	0.7564	0.0158	0.6493	0.1573
1995	0.7671	0.0231	0.7945	0.0158	0.6922	0.1575
1996	0.7235	0.0217	0.7093	0.0156	0.6303	0.1573
1997	0.9375	0.0214	0.7080	0.0160	0.8179	0.1562
1998	0.7929	0.0209	0.7531	0.0160	0.9458	0.1567
1999	1.1942	0.0213	0.9077	0.0158	1.0199	0.1569
2000	0.8323	0.0222	0.9992	0.0153	0.8539	0.1581
2001	0.7881	0.0221	0.9655	0.0155	0.7411	0.1551
2002	0.8893	0.0219	1.0556	0.0155	1.3840	0.1542
2003	0.9534	0.0217	1.0394	0.0153	1.4364	0.1536
2004	0.9239	0.0222	0.9038	0.0155	1.8854	0.1532
2005	0.9777	0.0226	0.7814	0.0159	1.6647	0.1537
2006	0.9379	0.0239	0.9421	0.0164	1.3593	0.1546
2007	1.1678	0.0238	1.1485	0.0181	1.1231	0.1561
2008	1.0327	0.0234	1.2151	0.0175	1.0002	0.1559
2009	1.0518	0.0239	1.1181	0.0182	1.0080	0.1575
2010	0.9450	0.0235	1.0767	0.0178	1.0175	0.1584
2011	0.8876	0.0229	1.0592	0.0179	0.9416	0.1575
2012	0.8473	0.0228	1.1652	0.0178	1.1783	0.1567
2013	0.6376	0.0228	0.8862	0.0186	1.1522	0.1561
2014	0.6716	0.0225	1.0355	0.0180	1.3544	0.1566
2015	0.6704	0.0225	1.1716	0.0181	1.2521	0.1551

* CV values for 1986 were set to the average of all other years

Table 7. Abundance indices for the fishery independent survey: combined (zones 10, 20 and 30); with eastern trawl fleet (zones 10 and 20); and Tasmanian trawl fleet (zone 30).

Year	FIS Z 10, 20, 30	CV	FIS East Z 10, 20	CV	FIST Tas Z 30	CV
2008	93.06	0.11	141.65	0.13	81.6400	0.1900
2010	91.06	0.12	104.18	0.13	112.7200	0.2000
2012	152.36	0.11	176.39	0.12	123.0900	0.2000
2014	97.22	0.10	114.39	0.12	102.06	0.18

2.1.6 Age composition data

An estimate of the standard deviation of age reading error was calculated by Andre Punt (pers. comm., 2016) from data supplied by Kyne Krusic-Golub of Fish Ageing Services (Table 8).

Age-at-length measurements, based on sectioned otoliths, provided by Fish Ageing Services, were available for the years 1998, 2000-2015 for the Danish seine fleet; 1998-2002, 2004-2015 for the eastern diesel trawl fleet; and 1999, 2000, 2002, 2005-2008, 2010 and 2012 for the Tasmanian diesel trawl fleet (Table 9). Years for which the total number of fish aged was less than 10 were not used. No age information was available for the earlier fleets.

Table 8. Standard deviation of age reading error (A Punt pers. comm. 2016).

Age	sd
0.5	0.245117
1.5	0.271087
2.5	0.296930
3.5	0.322645
4.5	0.348233
5.5	0.373695
6.5	0.399031
7.5	0.424243
8.5	0.449330
9.5	0.474293
10.5	0.499133
11.5	0.523850
12.5	0.548446
13.5	0.572920
14.5	0.597273
15.5	0.621507
16.5	0.645621
17.5	0.669615
18.5	0.693492
19.5	0.717251
20.5	0.740892

2.1.7 Length composition data

Length composition information for the onboard retained components of catches is available for: the Danish seine fleet 1993-1994, 1998-2007 and 2009-2015; the eastern trawl fleet from 1977, 1993, 1996-2015; and the Tasmanian trawl fleet for 1998-2006, 2008, 2010-2015 along with the numbers of fish measured and numbers of shots in each year (Table 10). Length composition information from port data is available for: the steam trawl fleet from 1945-1958; the Danish seine fleet from 1945-1967, 1992 and 1994-2015; the eastern trawl fleet from 1965-1967, 1969-2015; and the Tasmanian trawl fleet for 1999-2000, 2002-2006, 2009-2013 and 2015, along with the numbers of fish measured and numbers of trips in each year (Table 11 and Table 12). Length composition information from the ISMP for the discarded components of catches is available for: the Danish seine fleet 1998-2003, 2006-2007 and 2011-2015; and the eastern trawl fleet from 1992-2006 and 2008-2015; along with the numbers of fish measured and numbers of shots in each year (Table 13). In line with current standard practice in the SESSF, both port and onboard length frequencies are used when they are available.

Table 9. Number of age-length otolith samples included in the base case assessment by fleet 1998-2015.

Year	Fleet D Seine	E Trawl	Tas Trawl	Total
1998	101	211		312
1999		169	46	215
2000	192	521	56	769
2001	30	180		210
2002	558	588	149	1,295
2003	102			102
2004	174	152		326
2005	603	268	11	882
2006	312	64	141	517
2007	159	302	8	469
2008	363	277	66	706
2009	596	698		1,294
2010	259	444	88	791
2011	715	410		1,125
2012	336	813	131	1,280
2013	299	434	65	798
2014	573	461	162	1,196
2015	394	735	23	1,152

Table 10. Number of onboard retained lengths and number of shots for length frequencies included in the base case assessment by fleet 1977-2015.

Year	Fleet	# fish		Fleet	# shots	
	D Seine	E Trawl	Tas Trawl	D Seine	E Trawl	Tas Trawl
1977		2,136			200	
1993	356	1,347		4	17	
1994	1,950			20		
1996		494			7	
1997		6,797			191	
1998	1,706	9,364	959	30	139	8
1999	1,765	18,771	3,066	26	259	26
2000	707	21,686	492	15	235	5
2001	238	21,952	383	3	213	4
2002	332	17,229	477	8	181	4
2003	4,158	18,187	399	72	201	3
2004	3,595	11,836	562	26	122	5
2005	5,353	18,745	1,692	38	176	10
2006	13,202	12,137	4,588	103	107	34
2007	1,593	1,243		9	35	
2008		1,482	101		45	6
2009	672	1,374		11	32	
2010	678	1,909	239	28	68	9
2011	1,303	1,881	334	52	74	11
2012	1,821	2,226	348	49	72	8
2013	2,479	1,880	410	66	45	10
2014	2,064	1,999	972	73	44	21
2015	1,925	4,393	741	40	110	20

Table 11. Number of port retained lengths and number of trips used for length frequencies included in the base case assessment by fleet 1945-1991.

Year	Fleet	# fish		Fleet	# trips	
	St Trawl	D Seine	E Trawl	St Trawl	D Seine	E Trawl
1945	5,076	21,735		200	200	
1946	10,916	26,475		200	200	
1947	15,488	20,287		200	200	
1948	11,973	20,721		200	200	
1949	10,863	23,316		200	200	
1950	18,057	16,640		200	200	
1951	25,843	21,423		200	200	
1952	32,188	28,941		200	200	
1953	14,880	16,264		200	200	
1954	13,167	26,263		200	200	
1955	2,313	9,966		200	200	
1956	343	14,878		34	200	
1957	150	15,283		15	200	
1958	149	17,291		15	200	
1959		20,354			200	
1960		25,334			200	
1961		18,623			200	
1962		20,255			200	
1963		15,988			200	
1964		17,882			200	
1965		17,861	14,310		200	200
1966		19,101	23,222		200	200
1967		7,233	11,798		200	200
1969			96			10
1970			187			19
1971			610			61
1972			1,223			122
1973			435			44
1974			5,590			200
1975			11,684			200
1976			14,881			200
1977			18,017			200
1978			16,335			200
1979			12,189			200
1980			8,757			200
1981			6,184			200
1982			5,893			200
1983			5,140			200
1984			6,702			200
1985			2,633			200
1986			12,513			200
1987			8,154			200
1988			6,274			200
1989			3,999			200
1990			1,398			140
1991			4,040			200

Table 12. Number of port retained lengths and number of trips used for length frequencies included in the base case assessment by fleet 1992-2015.

Year	Fleet	# fish		Fleet	# trips	
	D Seine	E Trawl	Tas Trawl	D Seine	E Trawl	Tas Trawl
1992	1,442	873		13	5	
1993		502			3	
1994	292	156		3	1	
1995	1,566	1,418		20	10	
1996	3,760	2,520		31	16	
1997	11,857	5,106		115	26	
1998	11,346	11,302		112	84	
1999	5,079	12,747	519	22	94	3
2000	3,566	6,698	362	20	53	2
2001	5,690	11,087		35	88	
2002	3,569	6,208	5,201	32	35	27
2003	1,896	4,686	649	11	35	6
2004	4,280	10,247	1,520	38	71	7
2005	3,542	13,035	769	12	74	3
2006	1,375	13,029	1,323	5	116	6
2007	505	3,024		3	20	
2008	435	132		3	1	
2009	428	735	87	7	7	1
2010	751	2,107	64	15	17	1
2011	1,066	1,061	204	35	24	6
2012	884	771	188	32	22	4
2013	1,055	885	185	41	26	3
2014	1,691	1,288		52	22	
2015	2,401	1,099	232	54	19	3

Table 13. Number of discarded lengths and number of shots included in the base case assessment by fleet 1992-2015.

Year	Fleet	# fish	Fleet	# shots
	D Seine	E Trawl	D Seine	E Trawl
1992		131		7
1993		896		45
1997		139		55
1998	126	2,155	21	94
1999	104	3,988	7	151
2000	110	2,890	5	93
2002	235	2,834	11	89
2003	102	2,622	7	89
2004		3,098		56
2005		1,478		31
2006	119	2,116	10	30
2007	218		1	
2008		99		12
2009		376		19
2010		175		24
2011	132	546	4	48
2012	212	388	15	35
2013	125	477	10	23
2014	254	700	29	18
2015	175	1,504	14	60

2.1.8 Fishery Independent Survey (FIS) estimates

Abundance indices for tiger flathead for the FIS surveys conducted in 2008, 2010, 2012 and 2014 are provided in Knuckey et al. (2015). As well as the standard tiger flathead FIS abundance indices (covering SESSF zones 10, 20 and 30 only), indices from the FIS were re-estimated for the eastern fleet (SESSF zones 10 and 20) and the Tasmanian fleet (SESSF zone 30) with coefficients of variation calculated for each fleet (Table 14). The length composition data from the FIS are included in this assessment and this allows the selectivity of the various partitions of the FIS fleet to be estimated within the assessment. Small numbers of tiger flathead are caught in the FIS from zones 40 and 50, but this data is excluded from the calculation of the FIS abundance indices and is excluded from the assessment.

Table 14. FIS derived abundance indices for tiger flathead with corresponding coefficient of variation (cv) for a single FIS fleet, and for split FIS fleets.

Year	FIS		FIS East		FIST Tas	
	Z 10, 20, 30	CV	Z 10, 20	CV	Z 30	CV
2008	93.06	0.11	141.65	0.13	81.6400	0.19
2010	91.06	0.12	104.18	0.13	112.7200	0.20
2012	152.36	0.11	176.39	0.12	123.0900	0.20
2014	97.22	0.10	114.39	0.12	102.0600	0.18

The number of length measurements and the number of shots with tiger flathead from each year of the FIS are listed in Table 15. These are also separated into a single FIS fleet (zones 10, 20 and 30) and into two FIS fleets: eastern FIS (zones 10 and 20) and Tasmanian FIS (zone 30 only).

Table 15. Number of FIS length measurements and number of shots containing tiger flathead by fleet and year.

Year	FIS	(10,20,30)	FIS East	(10,20)	FIST Tas	(30)
	# fish	# shots	# fish	# shots	# fish	# shots
2008	5222	65	3952	47	1270	18
2010	8298	101	6426	75	1872	26
2012	6494	88	5397	71	1097	17
2014	3991	44	3403	39	588	5

2.1.9 Input data summary

The data used in this assessment is summarised in Figure 4, indicating which years the various data types were available.

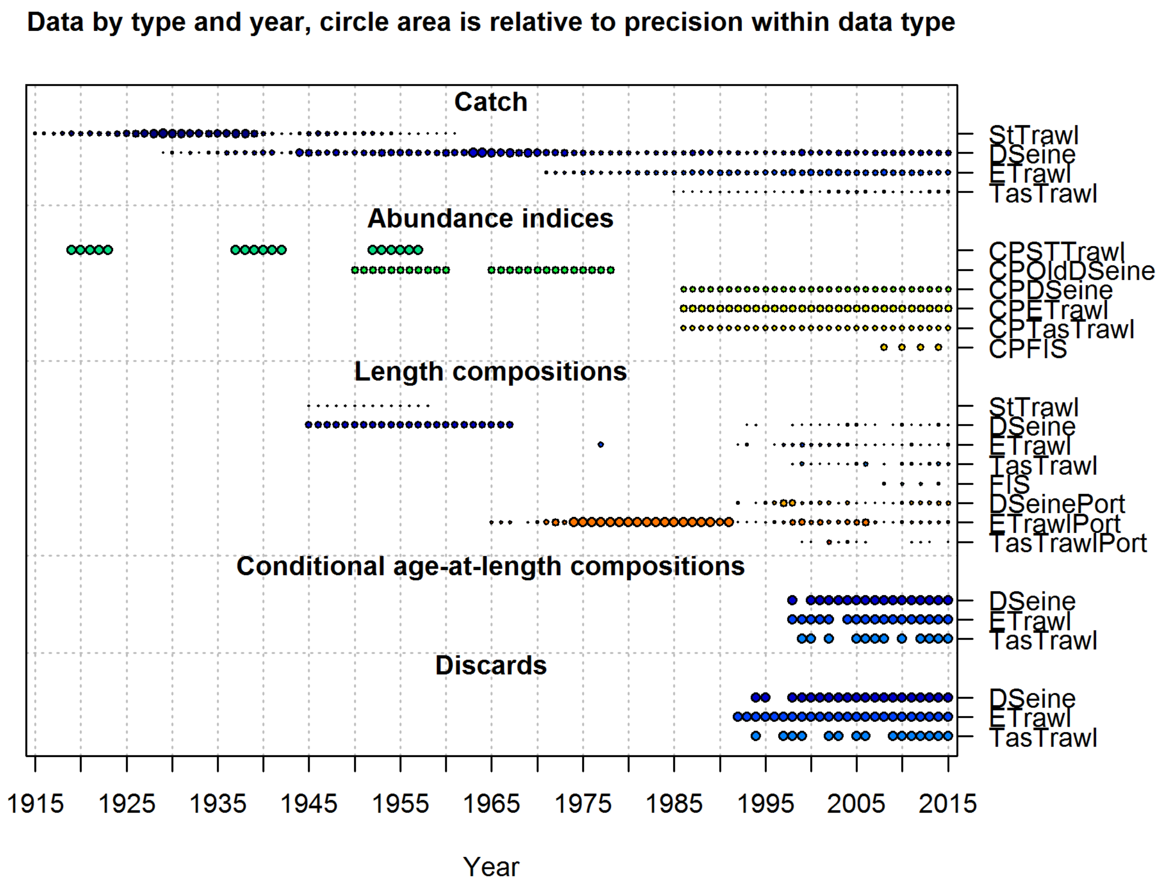


Figure 4. Summary of input data used for the tiger flathead assessment.

2.2 Stock assessment method

2.2.1 Population dynamics model and parameter estimation

A two-sex stock assessment for tiger flathead was conducted using the software package Stock Synthesis version SS-V3.24Z, (Methot, 2015). Stock Synthesis is a statistical age- and length-structured model which allows multiple fishing fleets and can be fitted simultaneously to the range of data available for tiger flathead. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are given fully in the SS technical description (Methot, 2005) and are not reproduced here. Some key features of the population dynamics model underlying Stock Synthesis which are pertinent to this assessment are discussed below.

A single stock of tiger flathead is assumed to occur from zone 10 off Sydney, through zone 20 (eastern Bass Strait), zone 60 (Bass Strait) and zone 30 (eastern Tasmania). The stock is assumed to be unexploited at the start of 1915 when the steam trawl fishery commenced. Catches prior to this are thought to have been minimal. The assessment models the impact of four fishing fleets on the tiger flathead population. The input CVs of the catch rate indices for the pre-1986 fleets were set to fixed values which are largely arbitrary due to the process of iterative reweighting. For the post-1986 fleets, the standard errors calculated from the catch-rate standardisation are used in the model (Haddon, 2013). Iterative reweighting is used to adjust the standard errors so their average equals those estimated by the model.

Selectivity is assumed to vary among fleets, but the selectivity pattern for each fleet is modelled as time-invariant except for two changes. The selectivity for Danish seine is allowed to change in 1978, and eastern diesel trawl in 1985. Selectivity is modelled as a function of length. Separate logistic functions are used for the selectivity ogives for each fleet. The two parameters of the selectivity function for each fleet are estimated within the assessment. Retention is also defined as a logistic function of length, and the inflection and slope of this function are estimated for those fleets where discard information is available (Danish seine, eastern trawl and Tasmanian trawl).

The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The natural mortality for the base-case analysis is fixed to 0.27 yr^{-1} as in the previous assessment (Day and Klaer, 2013).

Recruitment is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis is estimated at 0.62. Deviations from the average recruitment at a given spawning biomass (recruitment deviations) are estimated for 1915 to 2012. The value of the parameter determining the magnitude of the process error in annual recruitment, σ_R , was set equal to 0.4, which is greater than the amount of error estimated by the model.

A plus-group is modelled at age 20. Growth of tiger flathead is assumed to be time-invariant, that is there has been no change over time in the mean size-at-age, with the distribution of size-at-age determined from fitting the growth curve within the assessment using the age-at-length data. Differences in growth by gender are modelled.

2.2.2 Relative data weighting

Iterative reweighting of input and output CVs or input and effective sample sizes is an imperfect but objective method for ensuring that the expected variation is comparable to the input. This makes the model internally consistent, although some argue against this approach, particularly if it is believed that the input variance is well measured and potentially accurate. It is not necessarily good to down weight a data series just because the model does not fit it, if in fact, that series is reliably measured. On the other hand, most of the indices we deal with in fisheries underestimate the true variance by only reporting measurement and not process error.

Data series with a large number of individual measurements such as length or weight frequencies tend to swamp the combined likelihood value with poor fits to noisy data when fitting is highly partitioned by area, time or fishing method. These misfits to small samples mean that simple series such as a single CPUE might be almost completely ignored in the fitting process. This model behaviour is not optimal, because we know, for example, that the CPUE values are in fact derived from a very large number of observations. If there is reason to believe that the length and age data are noisy at the level fitted, it has been recommended in similar circumstances (e.g. see sablefish: Schirripa 2007, pacific sardine: Hill *et. al* 2005) that the length and age data be down weighted to allow the model to better fit other data sources.

Previous tiger flathead assessments dealt with this issue by capping length frequency sample sizes at 200 and reducing both the age and length components of the total likelihood by a factor of 10 for the base case. This procedure was modified in this assessment to avoid making arbitrary changes to particular likelihood components, through using trip and shot numbers, where available, instead of numbers of fish measured and by adopting the Francis weighting method for age and length composition data.

Shot or trip number is not available for all data, especially for some of the early length frequency data, which often had very large sample sizes (numbers of fish measured). To balance sample sizes for numbers of fish measured, these cases were divided by 10 and capped at 200. The number of trips were also capped at 120 and the number of shots capped at 200. Samples with less than 100 fish measured per year were excluded.

The sample sizes for the recent fleets are also individually tuned so that the input sample size is equal to the effective sample size calculated by the model.

2.2.3 Tuning procedure

The tuning procedure used (Andre Punt pers comm.) was to:

1. Set the coefficients of variation to 0.1 for all CPUE and index fleets. This encourages an initial good fit to the abundance indices.
2. Simultaneously tune the sample size multipliers for the length frequencies using Francis weights and the age-at-length frequencies using Francis B. Iterate to convergence.
3. Adjust the recruitment bias ramp.
4. Tune to σ_R with a lower bound of 0.4 – replace with with the RMSE and iterate to convergence (and adjust the bias ramp if required).
5. Tune the CPUE and FIS abundance indices using the variance adjustment factors and iterate to convergence, checking bias ramp and length frequencies.
6. Perform a single tuning to the Francis A method on age-at-length data (no iteration).
7. Re-tune CPUE and check recruitment bias ramp.

2.2.4 Calculating the RBC

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith *et al*.2008) and has been used as a basis for providing advice on TACs in the SESSF quota management system for fishing years 2006-2016. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to one of four Tier levels depending on the basis used for assessing stock status or exploitation level for that stock. Tiger flathead is classified as a Tier 1 stock as it has an agreed quantitative stock assessment.

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. Since 2005 various values have been used for the target and the breakpoint in the rule. In 2009, AFMA directed that the 20:40:40 (B_{lim}: B_{MSY}: F_{targ}) form of the rule is used up to where fishing mortality reaches F_{48}. Once this point is reached, the fishing mortality is set at F_{48}. Day (2008) determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} respectively, this form of the rule is equivalent to a 20:35:48 (B_{lim}: Inflection point: F_{targ}) strategy.

Previously, a preliminary economic analysis was used as a basis for using a 20:35:41 rule for tiger flathead (Klaer 2010). As steepness is an estimated parameter in the tiger flathead assessment, it is one of the few SESSF stocks where an MSY estimate may be taken from the base-case stock assessment. SESSFRAG in 2010 determined that a tiger flathead RBC may be calculated using a rule that incorporates application of the default 1.2 multiplier to the MSY depletion level to determine a minimum value for an MEY depletion level. It was also agreed at SESSFRAG that if this level was below 40% of B_0, that the 40% level be used to generate an RBC to maintain the biological precaution implicit in the 40% level. As with the 2013 assessment, SERAG agreed that the default RBC for tiger flathead is calculated under the 20:35:40 strategy.

2.2.5 Sensitivity tests and alternative models

A number of tests were used to examine the sensitivity of the results of the model to some of the assumptions and data inputs:

1. M = 0.22 yr^{-1}.
2. M = 0.32 yr^{-1}.
3. 50% maturity at 27cm.
4. 50% maturity at 33 cm.
5. σ_R set to 0.35.
6. σ_R set to 0.45.
7. Double the weighting on the length composition data.
8. Halve the weighting on the length composition data.
9. Double the weighting on the age-at-length data.
10. Halve the weighting on the age-at-length data.
11. Double the weighting on the survey (CPUE) data.
12. Halve the weighting on the survey (CPUE) data.
13. Fix steepness (h) at 0.75 and estimate natural mortality (M).
14. Estimate recruitment only until 2009 (exclude the 2010, 2011 and 2012 recruitment estimates). This assumes average recruitment from 2010-2012, lower recruitment than estimated in these years in the base case.
15. Split the fishery independent survey (FIS) data into two fleets, to match the eastern and Tasmanian trawl fleets (one in SESSF zones 10 and 20 and another in SESSF zone 30 only). This included splitting both the FIS abundance index and the FIS length frequency data.

The results of the sensitivity tests are summarized by the following quantities (Table 19Table 19):

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2017}: the female spawning biomass at the start of 2017.

3. SSB_{2017}/SSB_0: the female spawning biomass depletion level at the start of 2017.
4. Steepness: the estimated steepness of the stock-recruitment relationship.
5. SSB_{MSY}/SSB_0: the female spawning biomass depletion level at maximum sustainable yield (MSY).
6. RBC_{2017}: the recommended biological catch (RBC) for 2017.
7. RBC_{2017-9}: the mean RBC over the three years from 2017-2019.
8. $RBC_{2017-21}$: the mean RBC over the five years from 2017-2021.
9. $RBC_{longterm}$: the longterm RBC.

The RBC values are calculated for tuned models only, which are the base case and the final sensitivity where the FIS is split into two fleets (sensitivity 15). While SERAG requested a single FIS fleet, when the length frequencies were separated between Zone 30 and Zones 10 and 20, it was clear that larger fish are being caught off Eastern Tasmania (Zone 30). This same reason is used to separate the commercial fleets. As this seems a plausible alternative model, this sensitivity was also fully tuned with RBCs reported

It is possible that the Eastern Tasmanian part of the stock could have different growth to the rest of the stock, and this option could be explored in future assessments. The current assessment assumes a single growth curve for the whole stock, an assumption also made in previous assessments.

3 Results and discussion

3.1 The base-case analysis

3.1.1 Parameter estimates

Figure 5 shows the estimated growth curve for female and male tiger flathead. All growth parameters are estimated by the model except for l_{max} (parameter values are listed in Table 16).

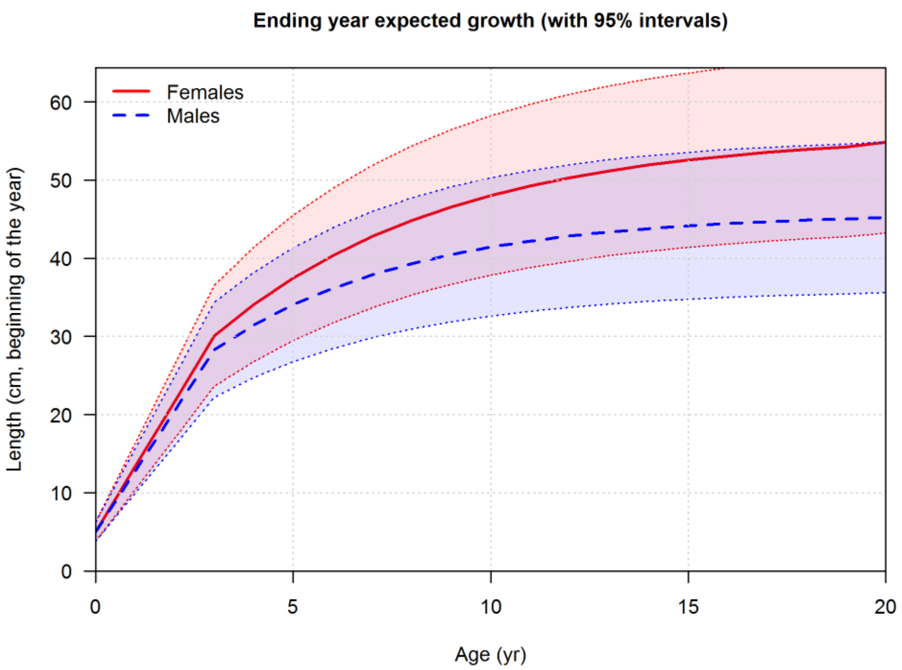


Figure 5. The model-estimated growth curves.

Table 16. Summary of parameters of the base case model.

Feature	Details	
Fleets	Steam trawl	Fixed discard rate of 17%
	Danish seine	Fixed discard rate of 17% to 1960, fitted thereafter
		Selectivity change in 1978 from early to modern Danish seine
	East coast trawl	Selectivity change in 1985 from early to modern diesel trawl
	Tasmanian trawl	Diesel trawl in Zone 30
Natural mortality *M*	fixed	0.27
Steepness *h*	estimated	0.62
σ_R in	fixed	0.40
Recruitment devs	estimated	1915-2012, bias adjustment ramps 1928-1943 and 20015
CV growth	estimated	0.106
Growth *K*	estimated	Female 0.168
Growth l_{min}	estimated	Female age 2 29.73
Growth l_{max}	fixed	Female 55.9

Selectivity is assumed to be logistic for all fleets. The parameters that define the selectivity function are the length at 50% selection and the spread (the difference between length at 50% and length at 95% selection). Figure 6 shows the selectivity and retention functions for each od the commercial fleets. Figure 7 shows the selectivity for the combined FIS fleet (zones 10, 20 and 30) and Figure 8 shows the selectivity for the two FIS fleets when they are split into an eastern fleet (zones 10 and 20) and a Tasmanian fleet (Zone 30). The difference in the selectivity patterns when the FIS fleet is split suggests different characteristics in the fish caught by the FIS in Zone 30 from fish caught by the FIS in zones 10 and 20, reflecting similar pattern as is seen in the commercial trawl data in these regions.

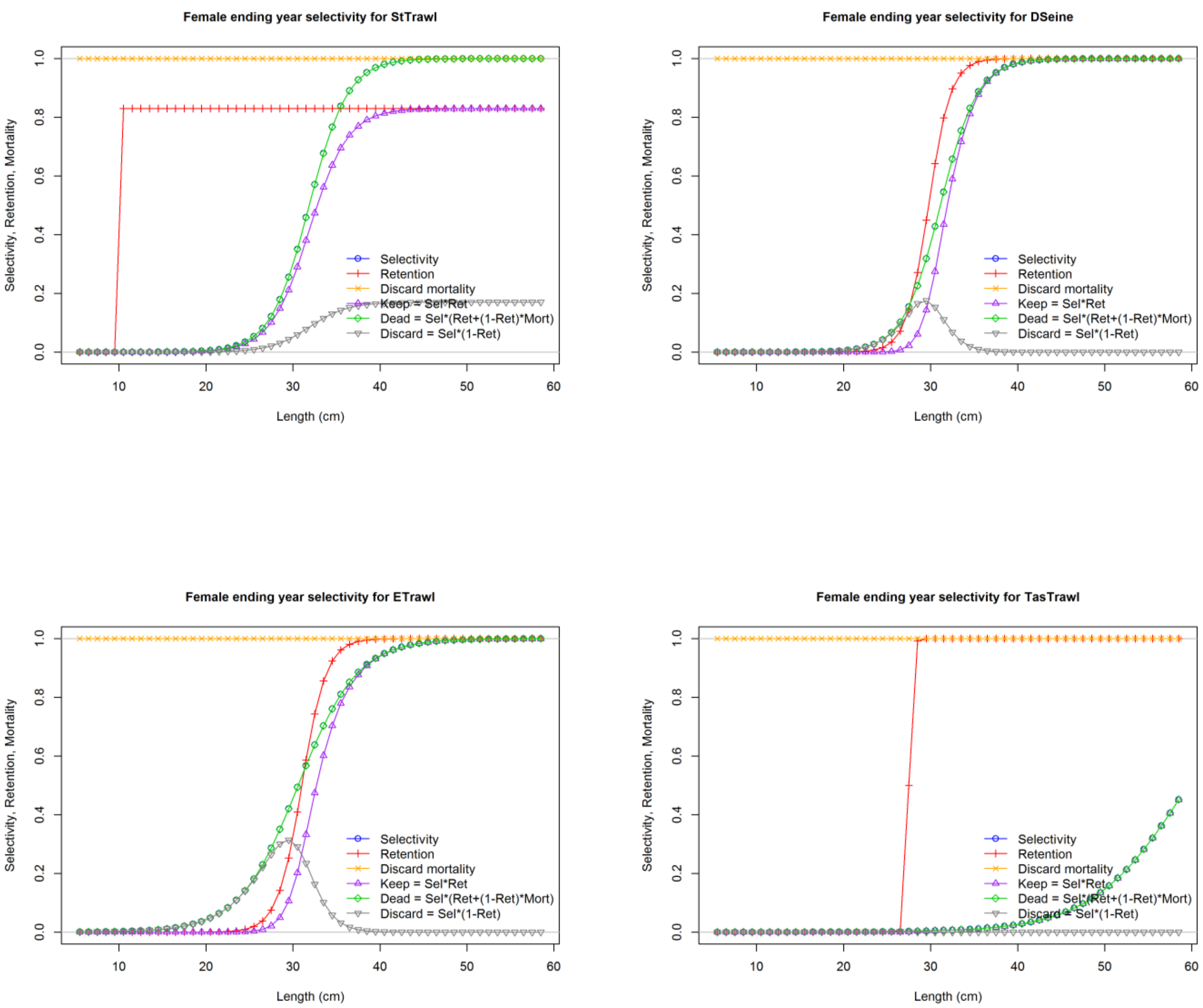


Figure 6. Selectivity (blue/green) and retention (red) functions for the four commercial fleets.

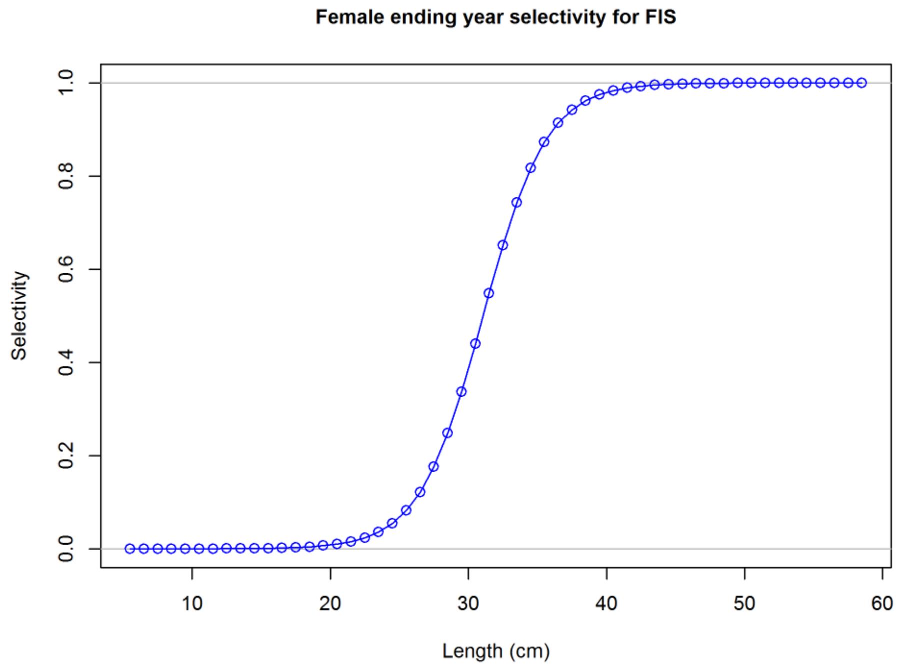


Figure 7. Selectivity for the single FIS fleet.

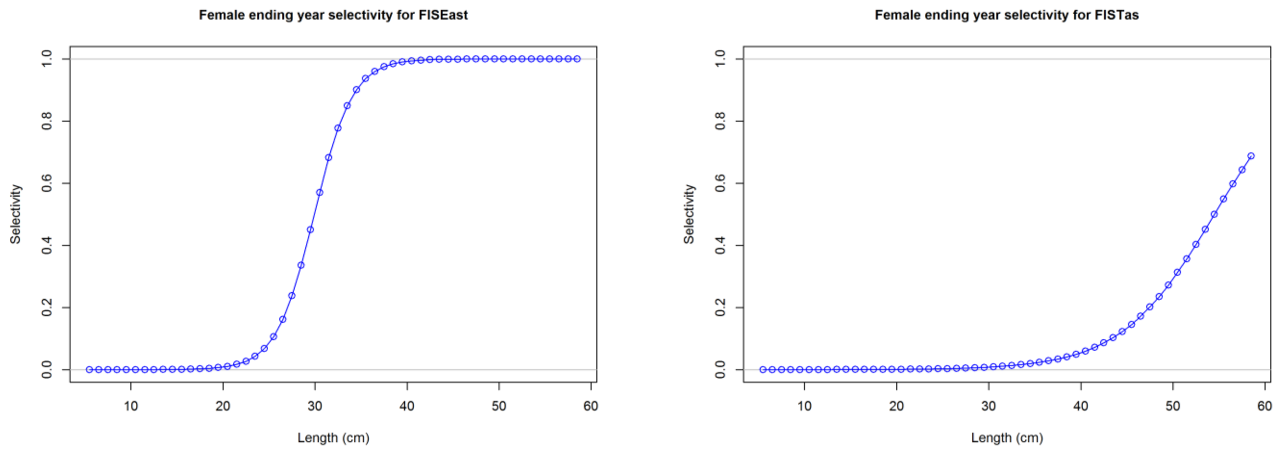


Figure 8. Selectivity for the eastern (left) and Tasmanian (right) FIS fleets when the FIS length frequencies are separated into zones.

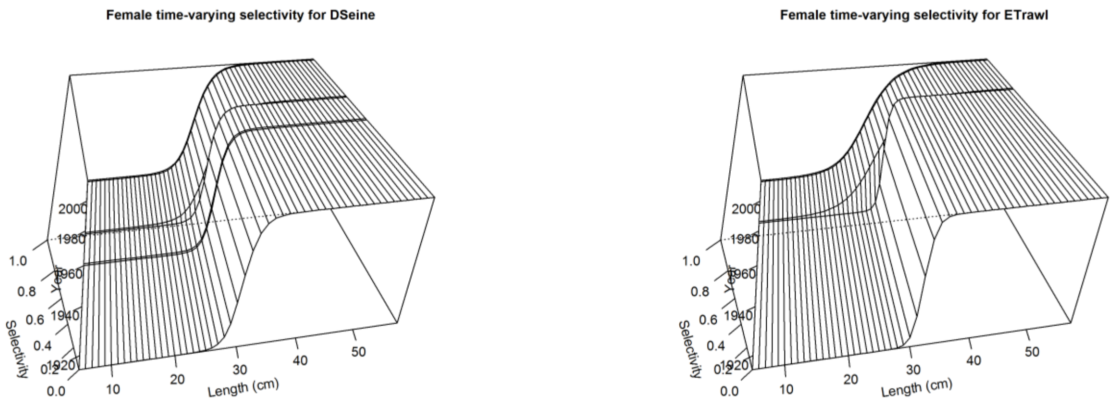


Figure 9. Time variation in selectivity for Danish seine and eastern diesel trawl.

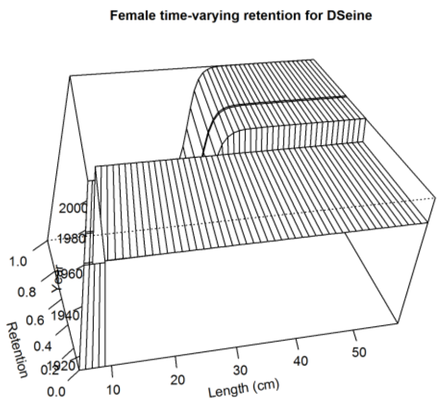


Figure 10. Time variation in retention for Danish seine.

3.1.2 Fits to the data

The fits to the catch rate indices (Figure 11) are variable in quality. The catch rate indices for the steam trawl fleet shows a considerable decline from 1915 to 1950, consistent with overexploitation during that time (see Fairbridge 1948, Klaer 2006b). The early Danish seine index from 1950 to 1978 was relatively flat or increasing over that period. Recent abundance indices from 1986 to present also show reasonably flat trends. The Tasmanian trawl fleet index is the worst fit for the recent indices, but the catch contribution by that fleet is also the smallest. The fit to the single FIS fleet is adequate, but the relatively high 2012 abundance estimate relative to the others makes it difficult to achieve a better fit to these data points.

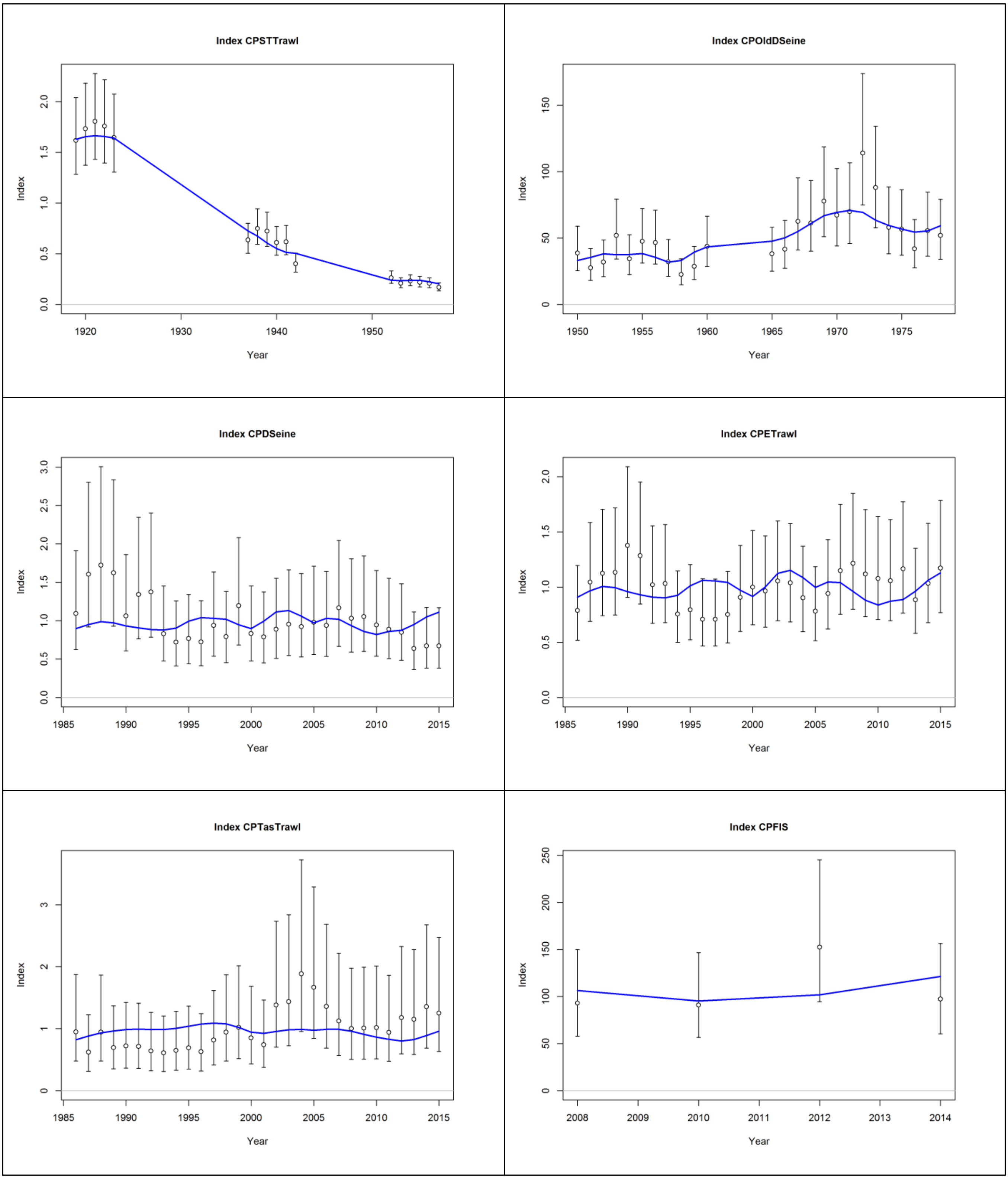


Figure 11. Observed (circles) and model-estimated (lines) catch rates vs year, with approx 95% asymptotic intervals.

The fits to the FIS abundance indices when this index is separated into and eastern (zones 10 and 20) and Tasmanian (zone 30) fleet are shown in Figure 12. As with the fits to the single FIS abundance index, variability between years and inconsistent patterns between the two regions makes it difficult to achieve any better fit to these data points, and the fits do not appear to be much better than for the single FIS fleet (Figure 11).

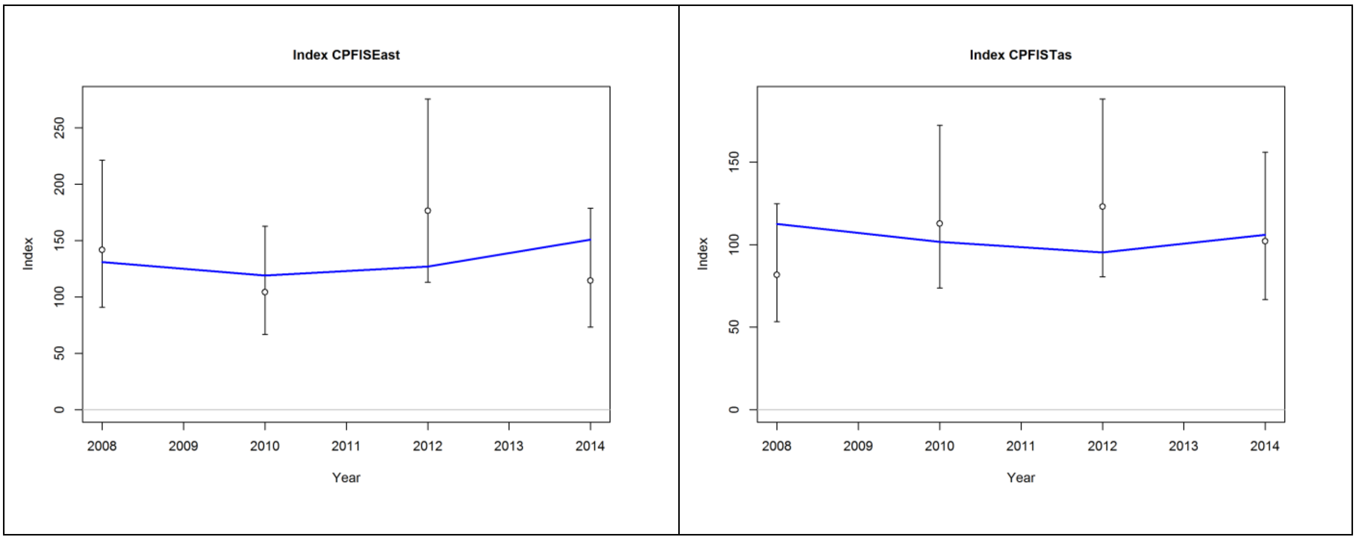


Figure 12. Observed (circles) and model-estimated (lines) catch rates vs year, with approx 95% asymptotic intervals for the FIS abundance index separated into Eastern (zones 10 and 20) and Tasmanian (zone 30) fleets.

The fits to the discard fractions (Figure 13) are reasonable given the variability in the data, with some very low data points (less than 1%) and others up to 20% for Danish seine and eastern trawl and up to 8% for Tasmanian trawl. The fits to the discard fractions for the Eastern trawl and Danish seine fleets are considerably better than in the 2013 assessment.

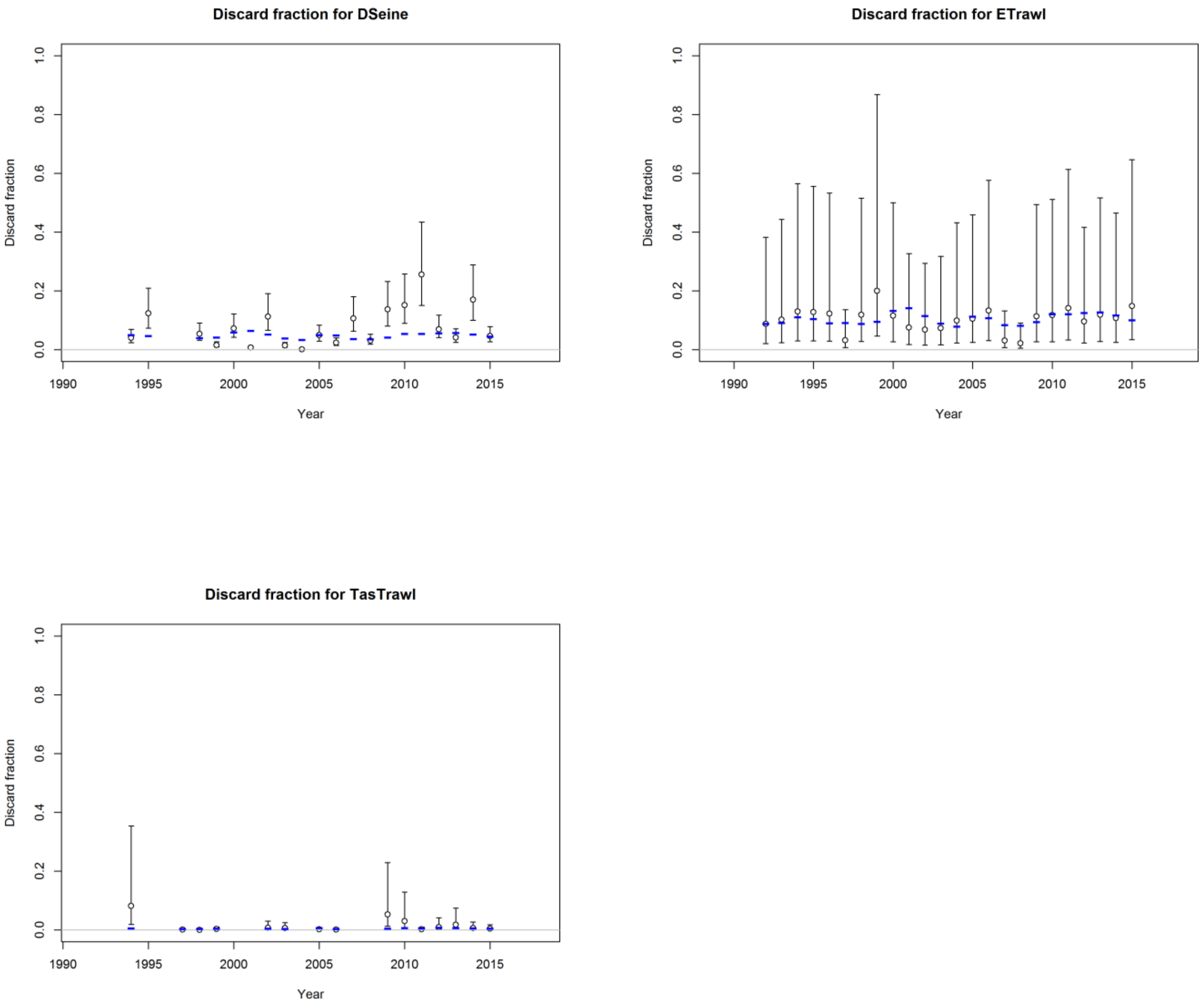


Figure 13. Observed (circles) and model-estimated (blue lines) discard estimates versus year, with approximate 95% asymptotic intervals.

The base-case model is able to mimic the retained length-frequency distributions adequately (Figure 14 and Appendix A), with the exception of the Tasmanian trawl fleet, for which the actual sample sizes are relatively small. The fits to the historical steam trawl and early Danish seine fleets are better than those for the more recent data (except for steam trawl in 1957 and 1958). The number of fish measured for the historical data is generally very high, which leads to smoother observed distributions. The fits to the discarded length compositions are variable (Figure 15 and Appendix A). This is not surprising, as the observed discard length frequencies are quite variable from year to year, and actual sample sizes are small in comparison to the retained length frequencies.

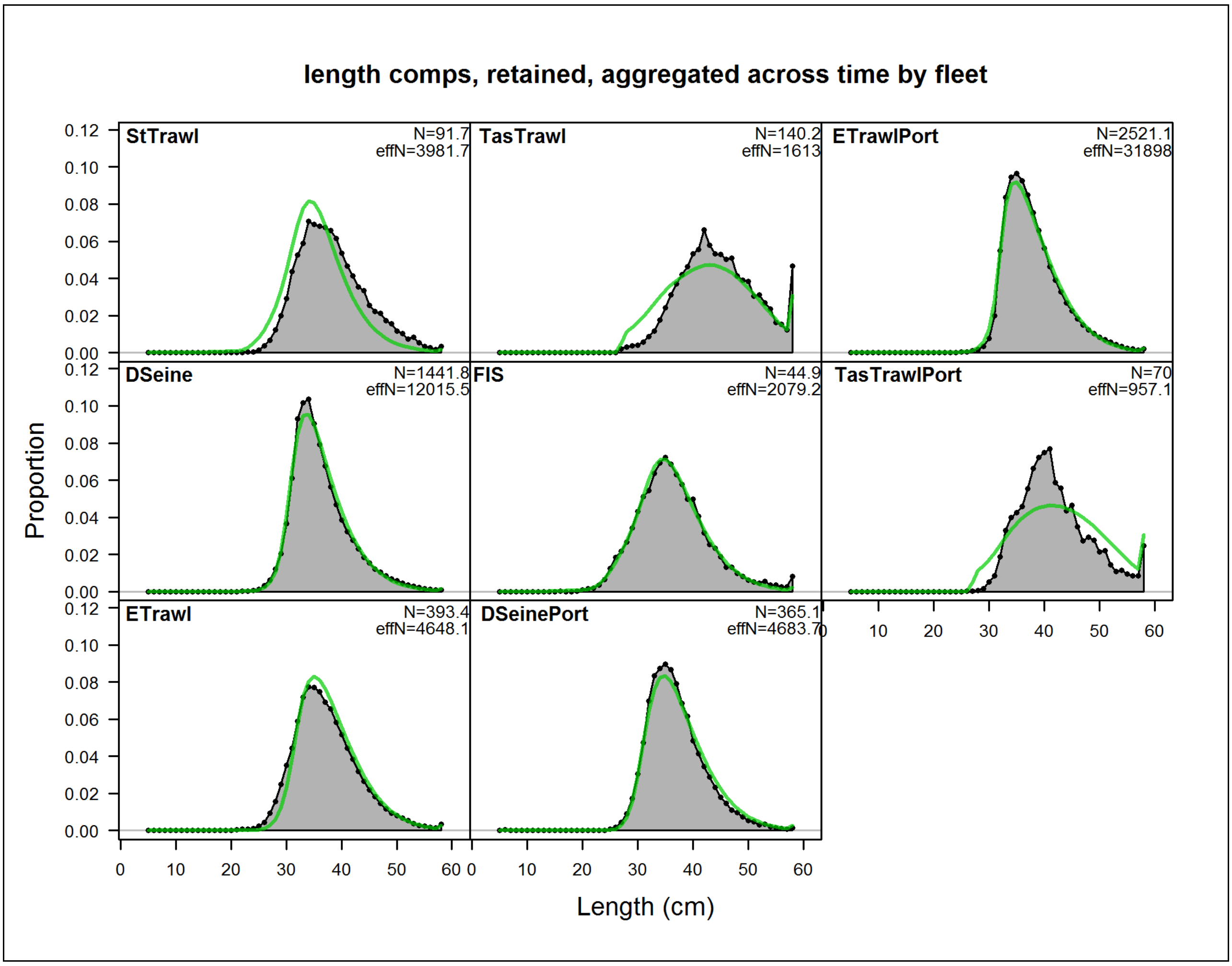


Figure 14. Fits to retained length compositions by fleet, separated by port and onboard samples, aggregated across all years. Observed data are grey and the fitted value is the green line.

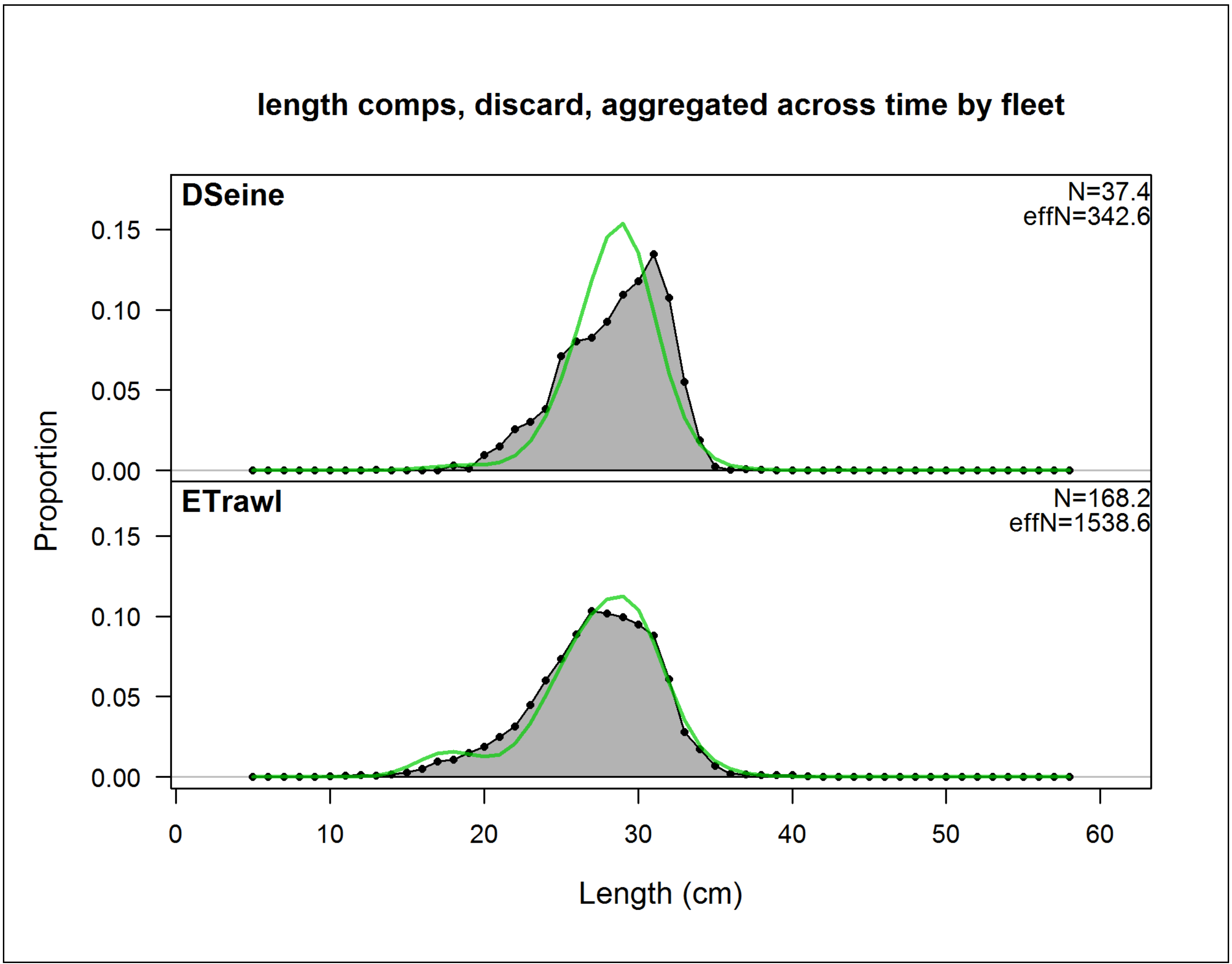


Figure 15. Fits to discarded length compositions by fleet, aggregated across all years. Observed data are grey and the fitted value is the green line.

The implied fits to the age composition data are shown in Appendix B. The age compositions were not fitted to directly, as age-at-length data were used. However, the model is capable of outputting the implied fits to these data for years where length frequency data are also available, even though they are not included directly in the assessment. The model mimics the observed age data reasonably well for all three recent fleets.

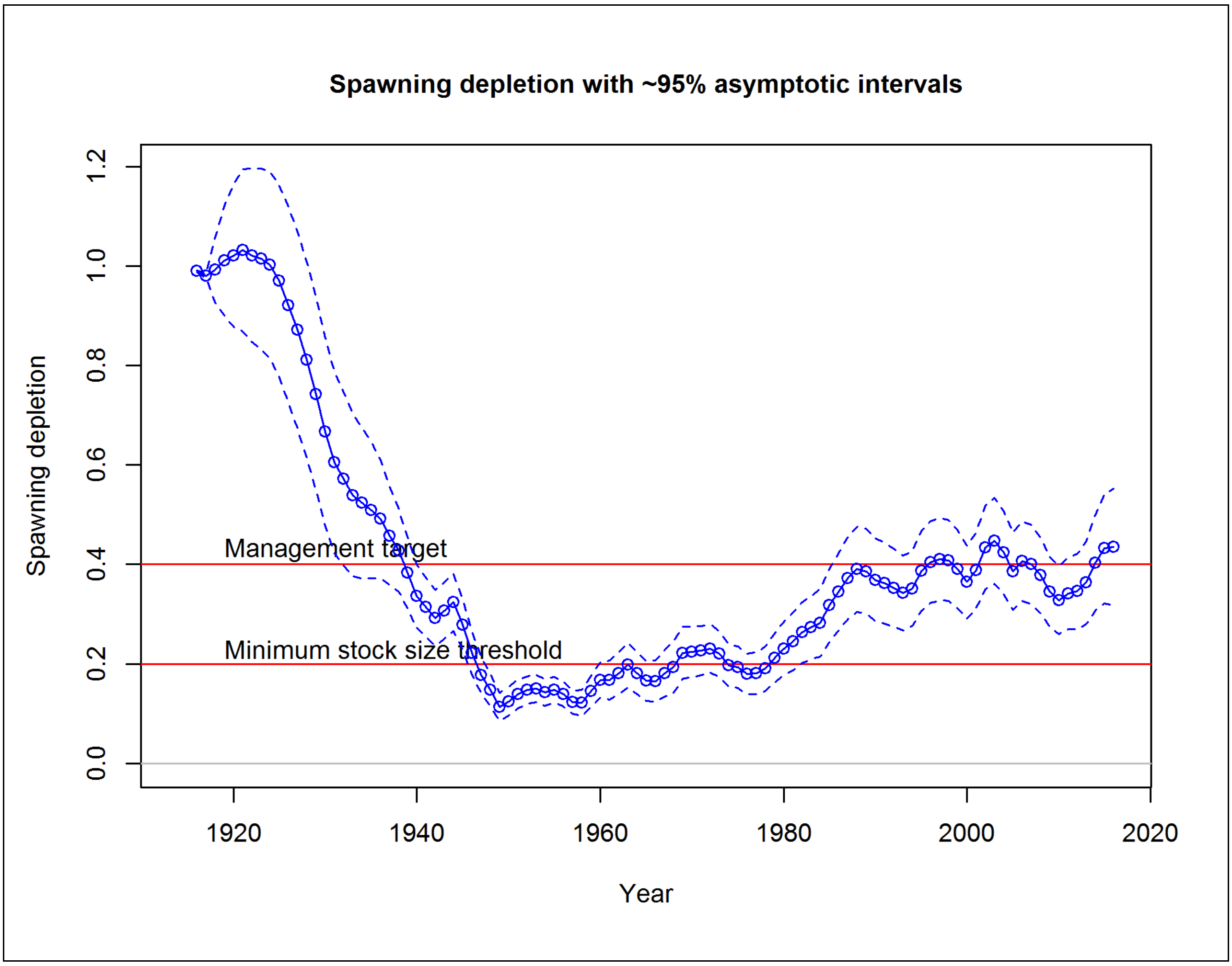


Figure 16. Time-trajectory of spawning biomass depletion (with approximate 95% asymptotic intervals) corresponding to the MPD estimates for the base-case analysis for tiger flathead.

3.1.3 Assessment outcomes

Figure 16 shows the trajectory of spawning stock depletion. The stock declines substantially from the beginning of the fishery in 1915 to 1950, fluctuates near the minimum threshold of 20% SSB_0 during the 1950s, 1960s and 1970s, before an increase to near 40% SSB_0 by the 1990. This increase in the 1980s was driven by a combination of favourable recruitments (Figure 17) and total landings of less than 2,000t in the late 1970s and early 1980s. The stock has fluctuated near 40% SSB_0 since around 1990 with a slight increase in the last few years.

Figure 17. Recruitment estimation for the base case analysis. Top left : Time-trajectories of estimated recruitment numbers; top right : time trajectory of estimated recruitment deviations; bottom left : time-trajectories of estimated recruitment numbers with approximate 95% asymptotic intervals; bottom right: the standard errors of recruitment deviation estimates.

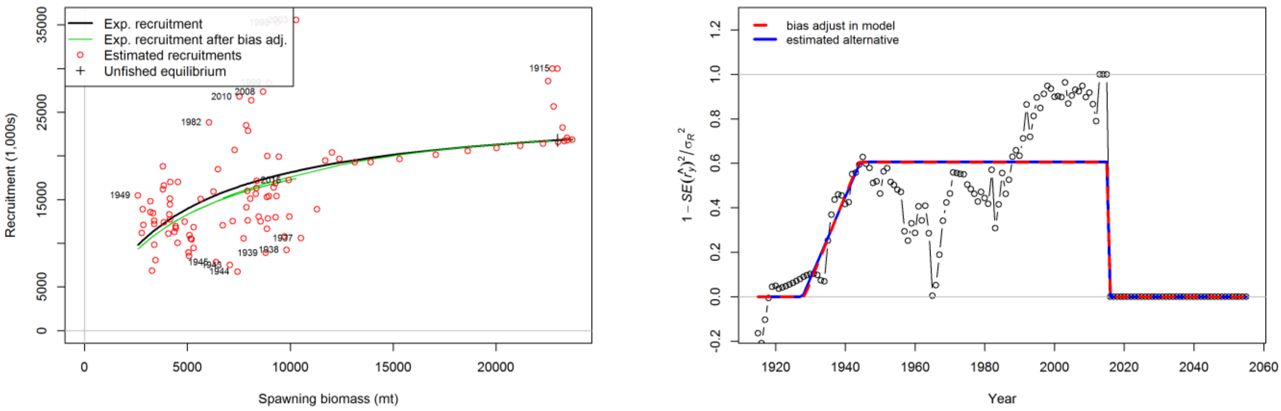


Figure 18. Recruitment estimation for the base case analysis. Left: the stock-recruit curve and estimated recruitments; right: bias adjustment.

The time-trajectories of recruitment and recruitment deviation are shown in Figure 17. Estimates of recruitments since about 1940 are generally variable, but periods of above and below average recruitment levels appear for periods of up to 12 years. Long-term regular cycles are not evident however. Recruitment in the past 15 years has been highly variable, with both average or above average recruitment for the last 6 estimated years of recruitment. The variability in estimated recent recruitment is likely to be a result of the model attempting to fit the increased quantity of data in recent years, particularly the age data.

The base-case assessment estimates that current spawning stock biomass is 43% of unexploited stock biomass (SSB_0). The 2017 recommended biological catch (RBC) under the 20:35:40 harvest control rule is 2,971 t (Table 17) and the long term yield (assuming average recruitment in the future) is 2,765 t (Table 19). Averaging the RBC over the three year period 2017-2019, the average RBC is 2,936 t (Table 17) and over the five year period 2017-2021, the average RBC is 2,909 t (Table 19). The RBCs for each individual year from 2017-2021 are listed in Table 17 for both the base case and for the sensitivity with two FIS fleets.

Table 17. Yearly projected RBCs (tonnes) across all fleets under the 20:35:40 harvest control rules: assuming average recruitment from 2013 (base case, column 2); and for the sensitivity when the FIS has two fleets (sensitivity 15, column 3), assuming average recruitment from 2013.

RBCs Year	Base 1 FIS	Sens 15 2 FIS
2017	2,971	2,929
2018	2,934	2,900
2019	2,903	2,876
2020	2,879	2,857
2021	2,860	2,841

3.1.4 Discard estimates

Model estimates for discards for the period 2017-21 with the 20:35:40 Harvest Control Rule are listed in Table 18 for the base case, with a range of 163 to 167 t, and for the sensitivity with two FIS fleets, with a range of 159 to 163 t.

Table 18. Yearly projected discards (tonnes) across all fleets under the 20:35:40 harvest control rules with catches set to the calculated RBC for each year from 2017 to 2021: assuming average recruitment from 2013 (base case, column 2); and for the sensitivity when the FIS has two fleets (sensitivity 15, column 3), assuming average recruitment from 2013.

Discards	Base	Sens 15
Year	1 FIS	2 FIS
2017	163	159
2018	164	160
2019	166	162
2020	167	163
2021	167	163

3.1.5 Sensitivity tests and alternative models

Results of the sensitivity tests are shown in Table 19. The results are very sensitive to the assumed value for natural mortality (*M*). Much of this variability is due to the estimated current depletion level, which can be as low as 26% SSB_0 when *M* is 0.22. For all other standard sensitivities, there is much less variability in current depletion. The one exception to this result for a non-standard sensitivity is when recruitment is only estimated to 2009, and not estimated in 2010, 2011 and 2012.

Unweighted likelihood components for the base case and differences for the sensitivities reveal several points (Table 20). The overall likelihood is not improved for a smaller value of *M*, in contrast to the results from Day and Klaer (2013), but in line with earlier results in Klaer (2010). Steepness and *M* are highly correlated, and it is normally not possible to estimate both of these parameters. The base-case is essentially uninformative about the value of *M*, which needs to be sourced independently of the stock assessment if steepness is estimated, but these results suggests that *M* should not be reduced.

In contrast to the 2013 assessment, none of the sensitivities show an overall improvement to the fit, which suggests the model is remarkably stable and well balanced.

In addition to the standard sensitivities, (cases 1-13 in Table 19), two additional sensitivities were investigated.

The last three estimated recruitment events (2010-2012) were all above average. Recruitment events at the end of the tie series can often be modified with the addition of future data, which may be more informative, so it is useful to explore the possible effect of lower recruitment over this time period. If these recruitment events are assumed to be average, which reduces all three of these recruitment events, the depletion in 2017 would be 31%, and the fits to the discards and age compositions would be worse (Table 20). This suggests that the age and discard data support these good recent recruitment events.

Splitting the FIS into two fleets, made very little difference to the depletion estimate, improved the fit to the surveys slightly and resulted in poorer fits to the length frequency data. None of these results are surprising. The influence of the FIS data is relatively small given the quantity of other data in the assessment, so structural changes to this fleet are unlikely to have much impact. Separating the length frequencies allowed the larger fish caught in zone 30 to have a little more influence, and not surprisingly, these were subsequently harder to fit.

Exploration of model sensitivity showed a variation in spawning biomass from 26% to 51% of SSB_0 when natural mortality was fixed at values of 0.22 and 0.32 respectively. When recruitment is only estimated to 2009, excluding the above average recruitment estimates in 2010, 2011 and 2012, the spawning biomass was estimated to be 31% of SSB_0. For all other sensitivities explored, the variation in spawning biomass was much narrower, ranging between 39% and 45%.

For the base-case (20:35:40 Harvest Control Rule with recruitment estimated to 2012), SSB_{MSY} is estimated to be 31% of SSB_0. If the standard MEY proxy multiplier of 1.2 is applied to this MSY estimate, the SSB_{MEY} estimate for the base case is 37% of SSB_0. This proxy for SSB_{MEY} is rounded up to 40% of SSB_0 by agreement at SESSFRAG, with a 20:35:40 Harvest Control Rule used for tiger flathead.

Table 19. Summary of results for the base-case and sensitivity tests. Recommended biological catches (RBCs) are only shown for tuned models (cases 0 & 17).

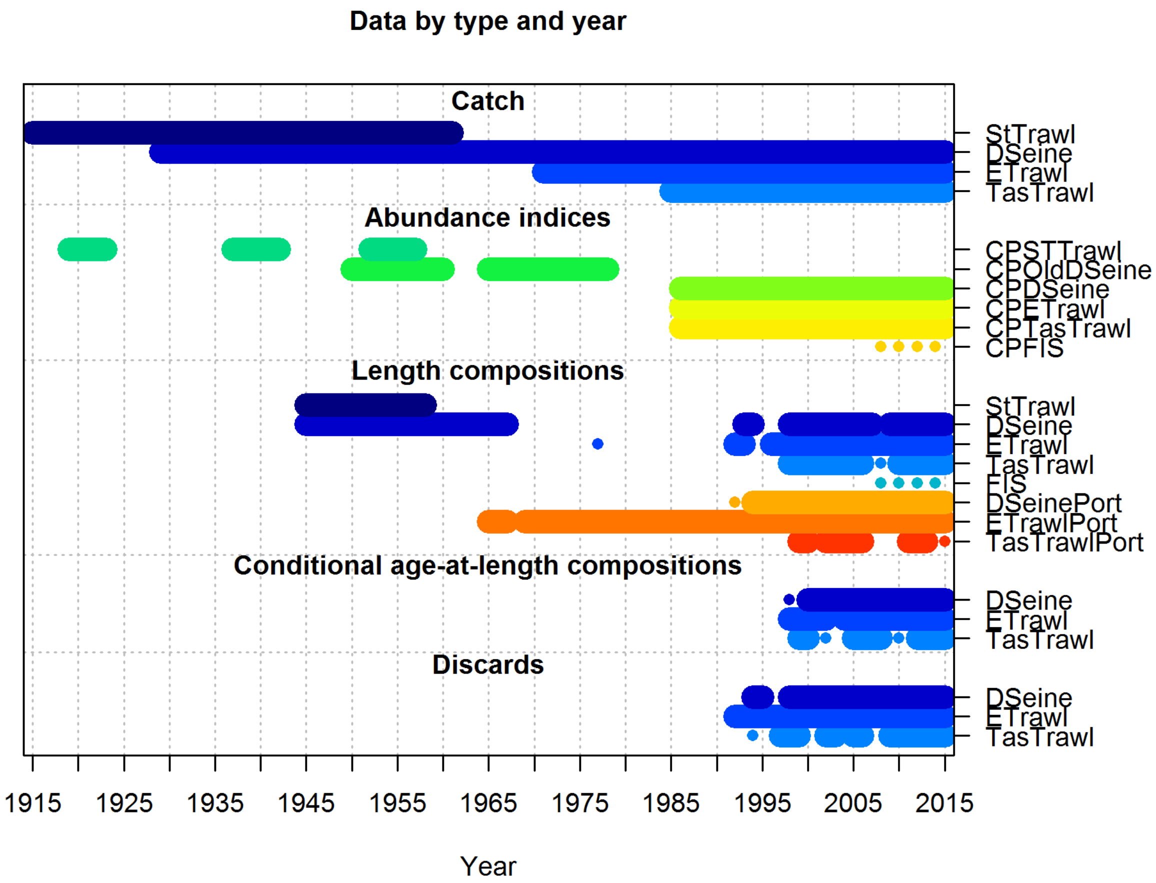
Case		SSB_0	SSB_{2017}	SSB_{2017}/SSB_0	Steepness	SSB_{MSY}/SSB_0	RBC_{2017}	$RBC_{2017\text{-}9}$	$RBC_{2017\text{-}21}$	$RBC_{longterm}$
0	base case 20:35:40 *M* 0.27	22,987	9,972	0.43	0.62	0.31	2,971	2,936	2,909	2,765
1	*M* 0.22	22,041	5,728	0.26	0.75	0.27				
2	*M* 0.32	25,095	12,898	0.51	0.50	0.35				
3	50% maturity at 27cm	24,182	10,661	0.44	0.60	0.32				
4	50% maturity at 33cm	21,333	9,032	0.42	0.64	0.30				
5	σ_R = 0.35	22,795	9,799	0.43	0.61	0.31				
6	σ_R = 0.45	23,151	10,092	0.44	0.62	0.31				
7	wt x 2 length comp	23,271	9,815	0.42	0.61	0.31				
8	wt x 0.5 length comp	22,619	9,993	0.44	0.63	0.30				
9	wt x 2 age comp	23,126	9,717	0.42	0.61	0.31				
10	wt x 0.5 age comp	22,838	10,187	0.45	0.63	0.31				
11	wt x 2 CPUE	22,653	10,067	0.44	0.63	0.31				
12	wt x 0.5 CPUE	22,803	9,531	0.42	0.62	0.31				
13	estimate *M* (0.232), *h* 0.75	21,592	8,413	0.39	0.75	0.26				
14	recruitment est to 2009	22,705	7,032	0.31	0.61	0.31				
15	Two FIS fleets	23,100	9,877	0.43	0.61	0.31	2,929	2,901	2,880	2,766

Table 20. Summary of likelihood components for the base-case and sensitivity tests. Likelihood components are unweighted, and cases 1-17 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

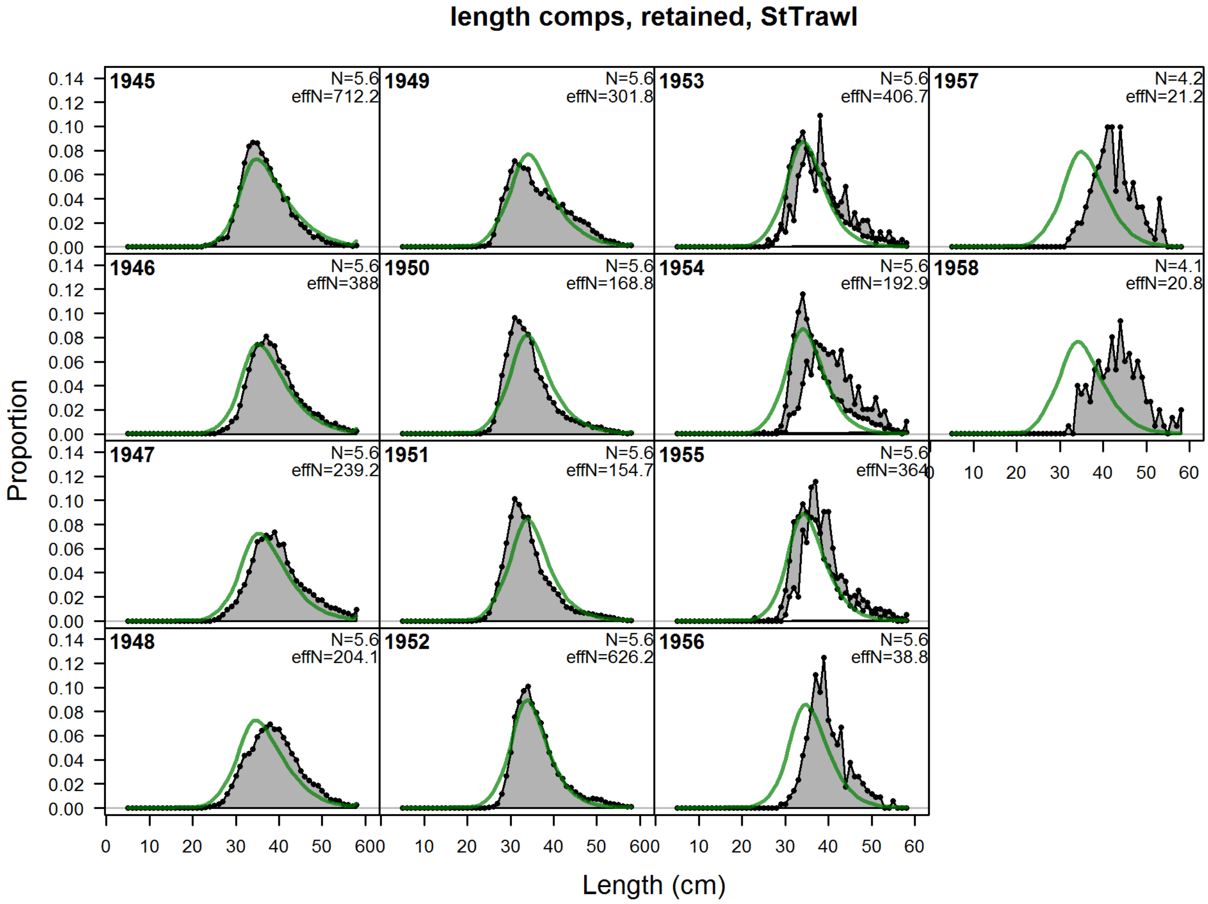
Case		Likelihood TOTAL	Survey	Discard	Length comp	Age comp	Recruitment	Parm_priors
0	base case 20:35:40 M 0.27	2834.33	-129.41	187.76	404.01	2383.26	-14.30	2.94
1	M 0.22	9.85	11.72	-1.52	-1.43	1.68	-1.79	-0.07
2	M 0.32	0.57	-2.03	0.55	-0.09	0.04	1.56	0.43
3	50% maturity at 27cm	6.80	-0.03	-0.01	-0.01	0.00	-0.21	7.07
4	50% maturity at 33cm	7.35	0.04	0.01	0.02	0.00	0.29	6.99
5	σ_R = 0.35	2.22	1.69	0.63	1.72	0.06	-1.89	0.00
6	σ_R = 0.45	-1.00	-1.23	-0.46	-1.30	-0.01	2.00	0.00
7	wt x 2 length comp	4.55	1.08	5.08	-10.10	3.36	5.11	0.02
8	wt x 0.5 length comp	2.77	0.14	-2.77	9.90	-1.34	-3.13	-0.02
9	wt x 2 age comp	3.65	3.85	5.59	2.83	-9.10	0.45	0.02
10	wt x 0.5 age comp	4.20	-2.36	-6.63	-1.38	14.24	0.34	-0.02
11	wt x 2 CPUE	4.38	-10.22	4.50	0.95	4.32	4.84	-0.02
12	wt x 0.5 CPUE	3.70	12.78	-3.44	-0.10	-2.19	-3.34	0.00
13	estimate M (0.232), h 0.75	0.75	1.65	-0.53	0.36	-0.02	-0.60	-0.07
14	recruitment est to 2009	13.00	0.79	5.68	1.19	7.44	-2.20	0.01
15	Two FIS fleets	12.13	-4.43	1.34	13.48	-0.61	-0.14	0.17

Appendix A

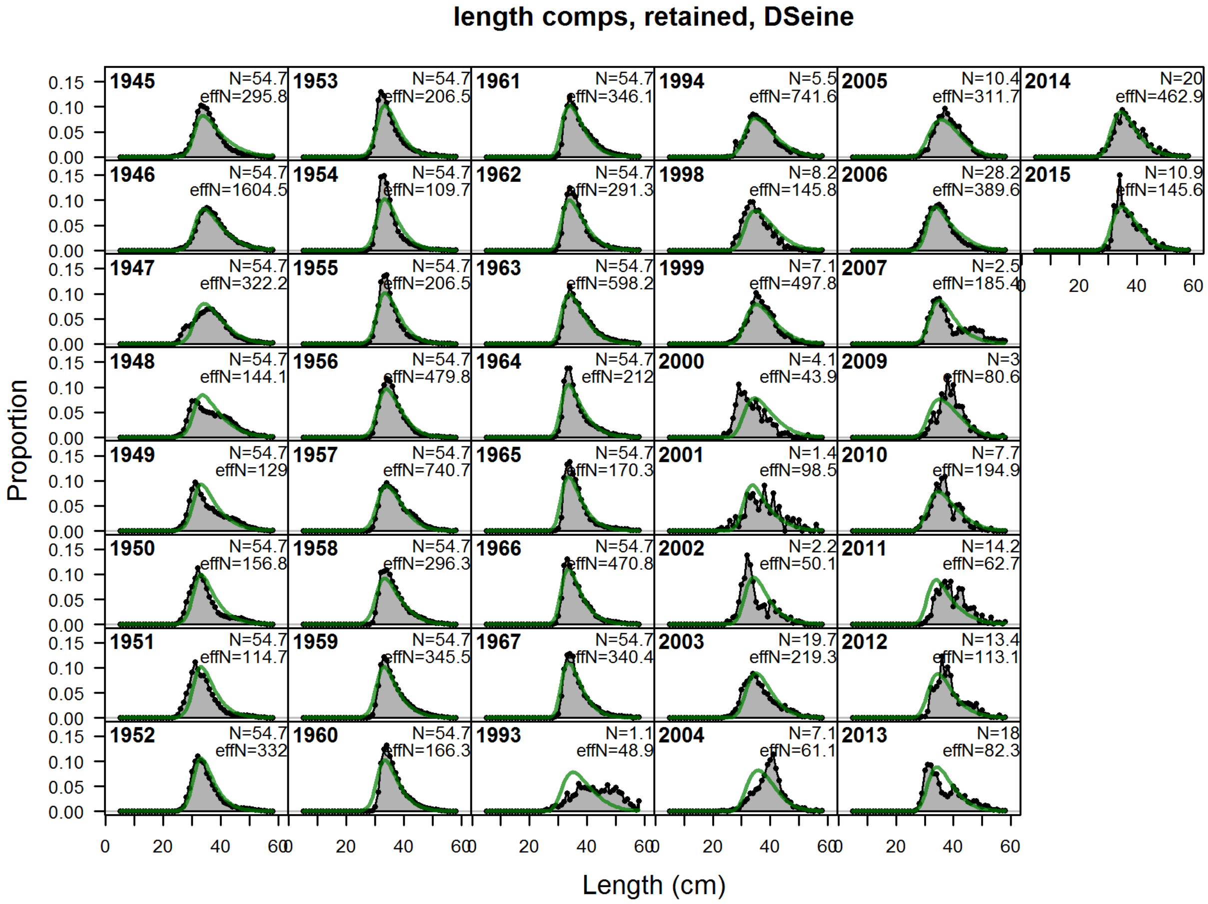
A.1 Data source summary and fits to length composition data



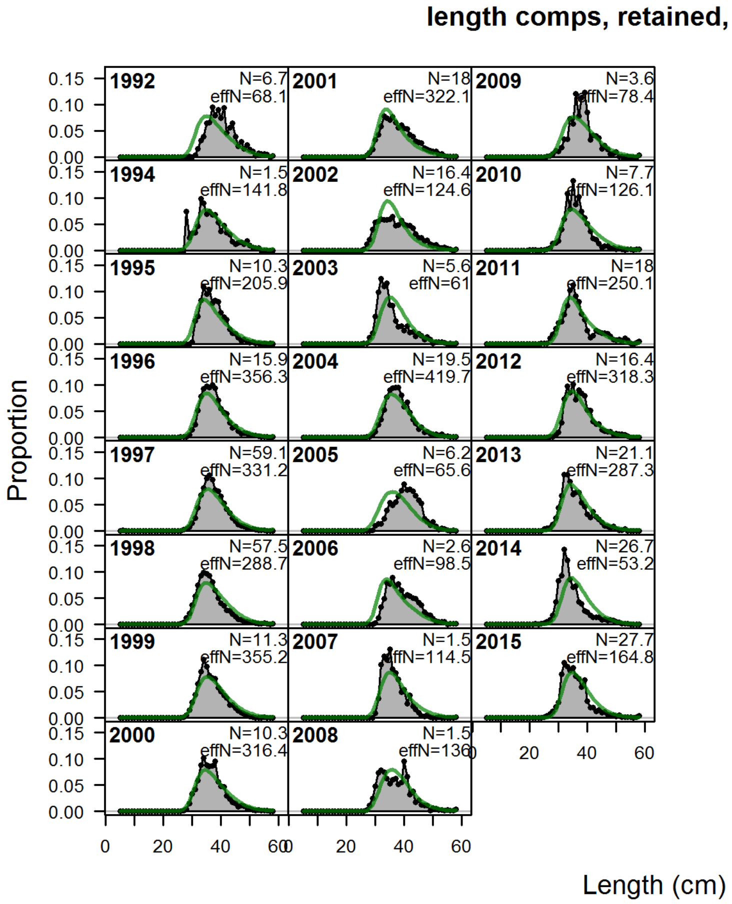
Apx Figure A.1 Summary of data sources for tiger flathead stock assessment.



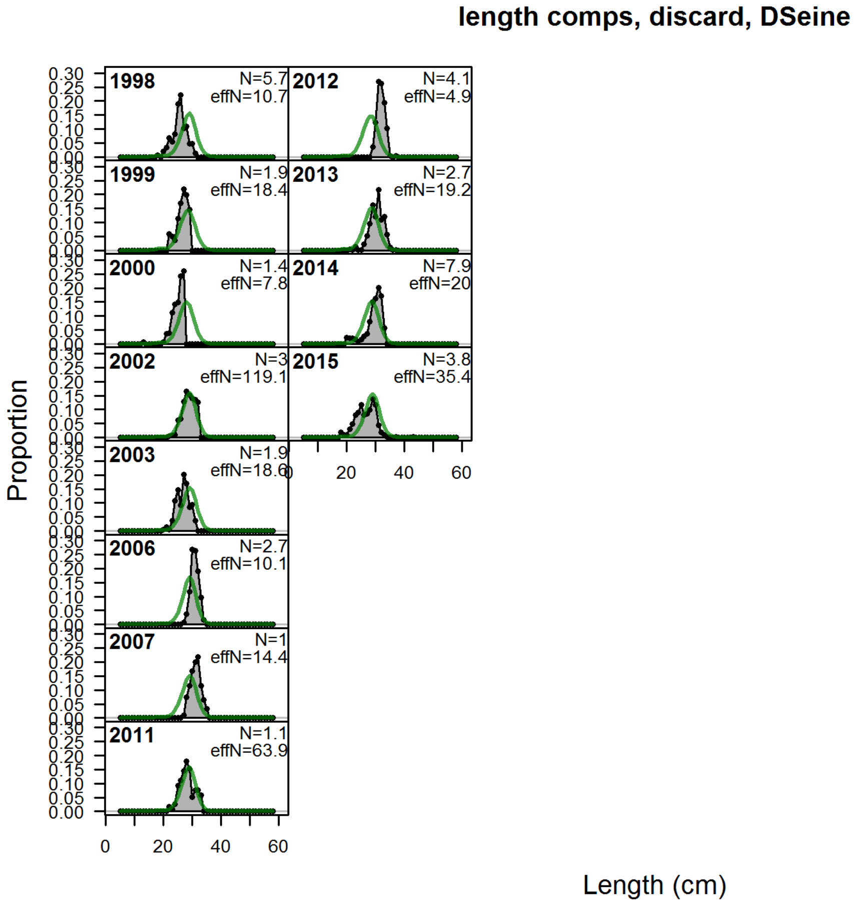
Apx Figure A.2 Tiger flathead length composition fits: steam trawl retained.



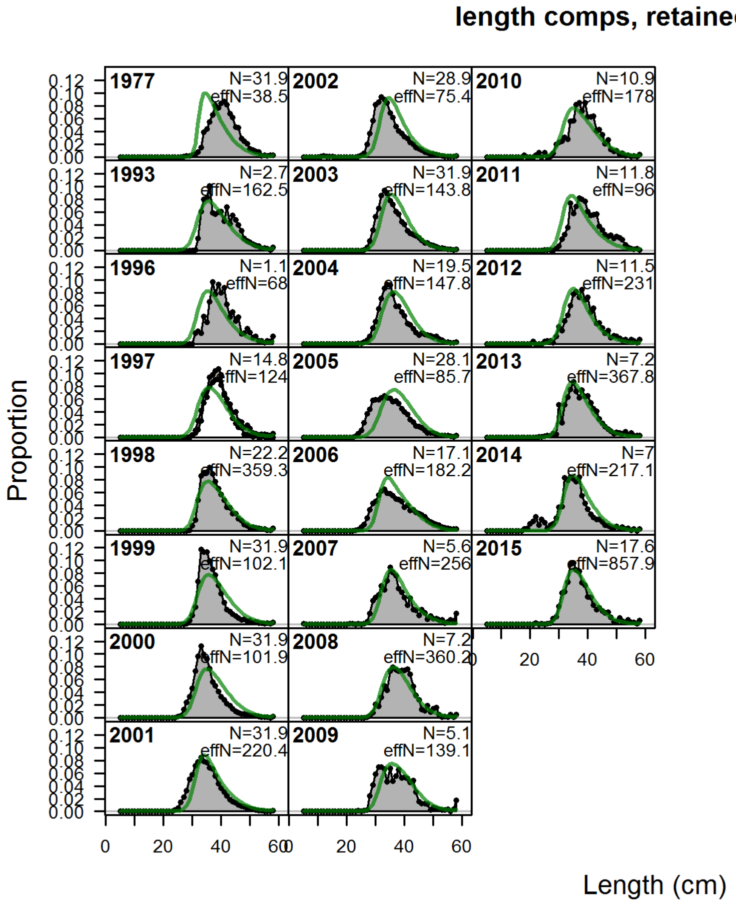
Apx Figure A.3 Tiger flathead length composition fits: Danish seine retained onboard.



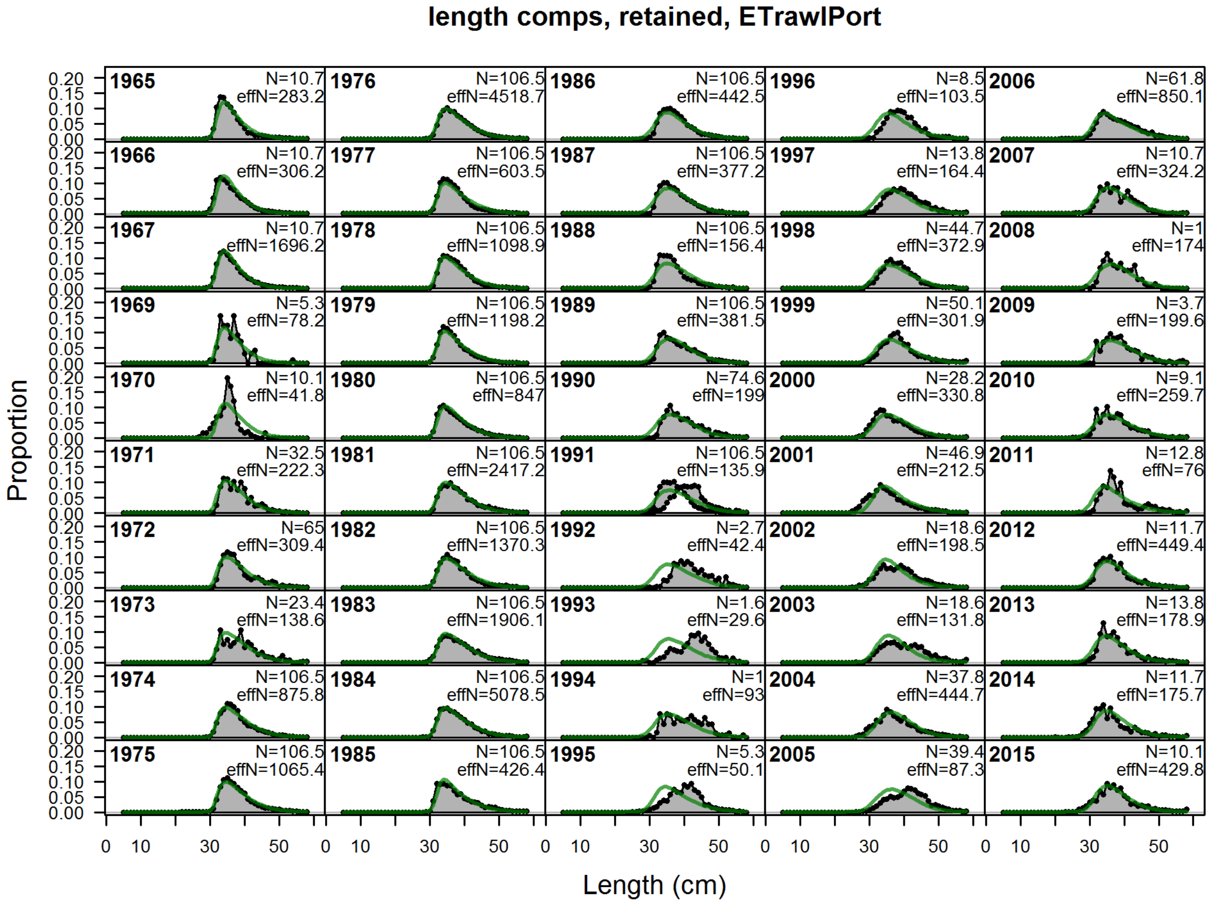
Apx Figure A.4 Tiger flathead length composition fits: Danish seine retained port.



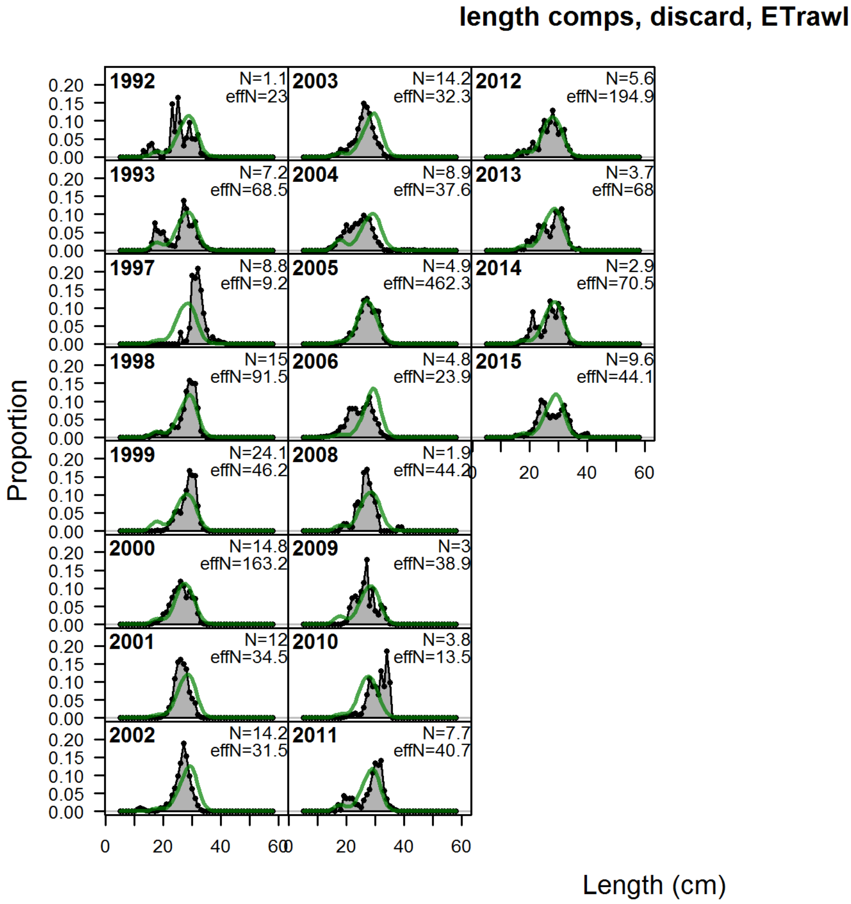
Apx Figure A.5 Tiger flathead length composition fits: Danish seine discarded.



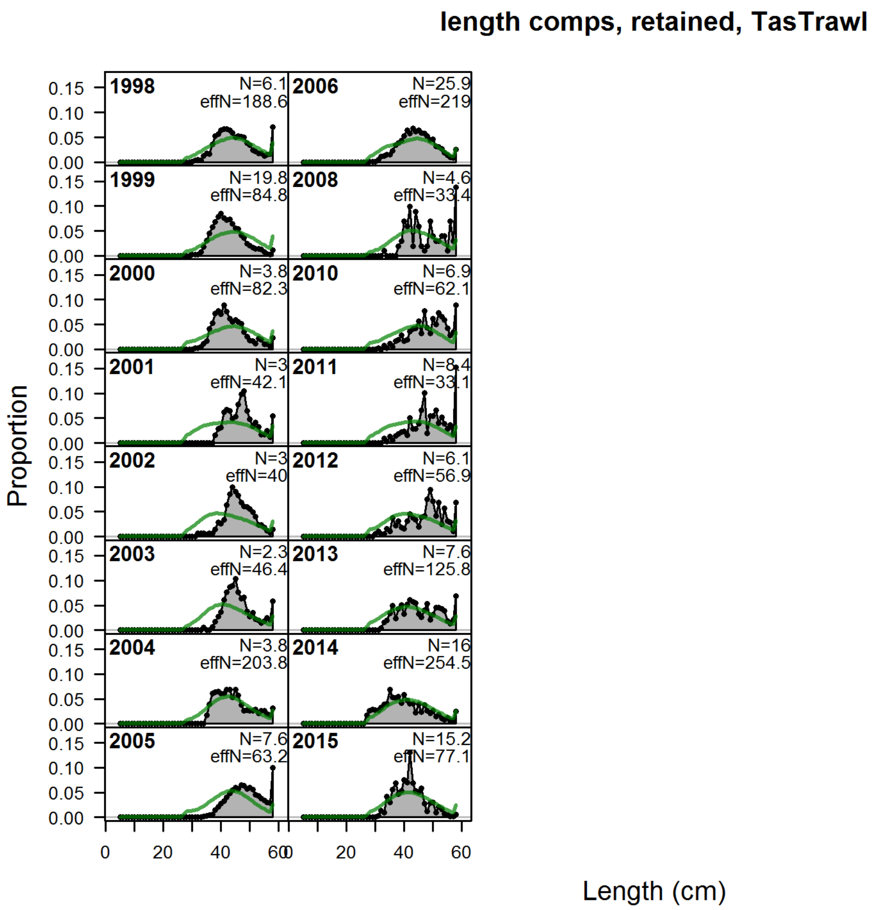
Apx Figure A.6 Tiger flathead length composition fits: eastern trawl retained onboard.



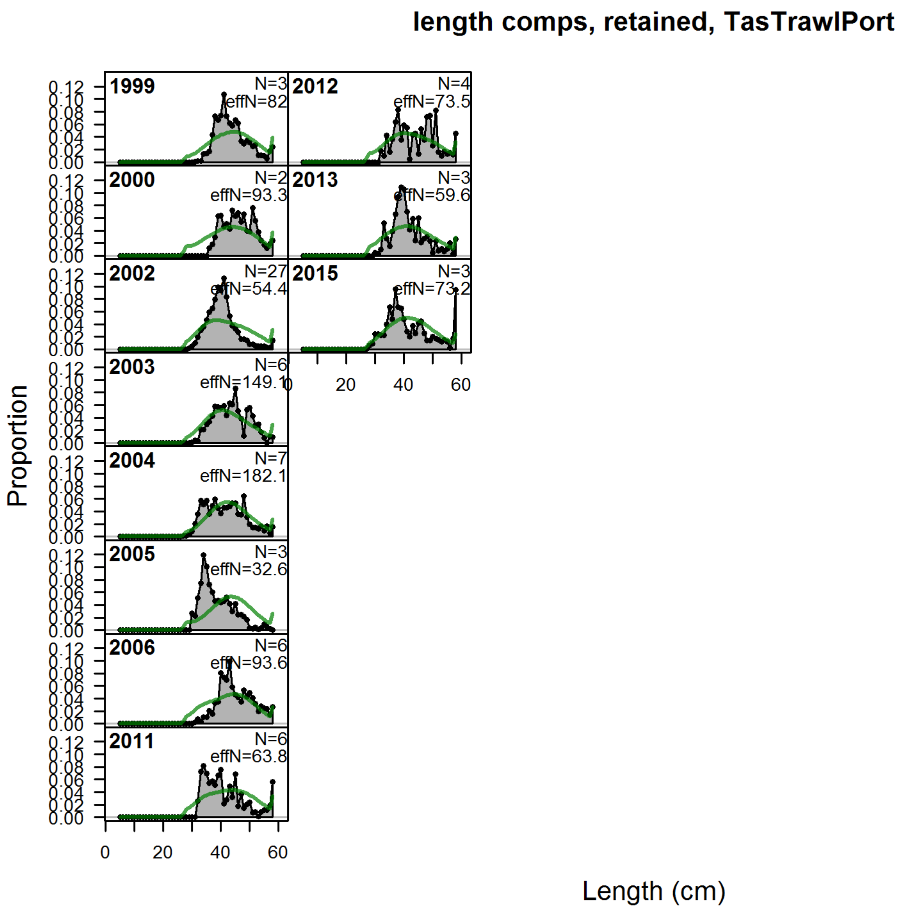
Apx Figure A.7 Tiger flathead length composition fits: eastern trawl retained port .



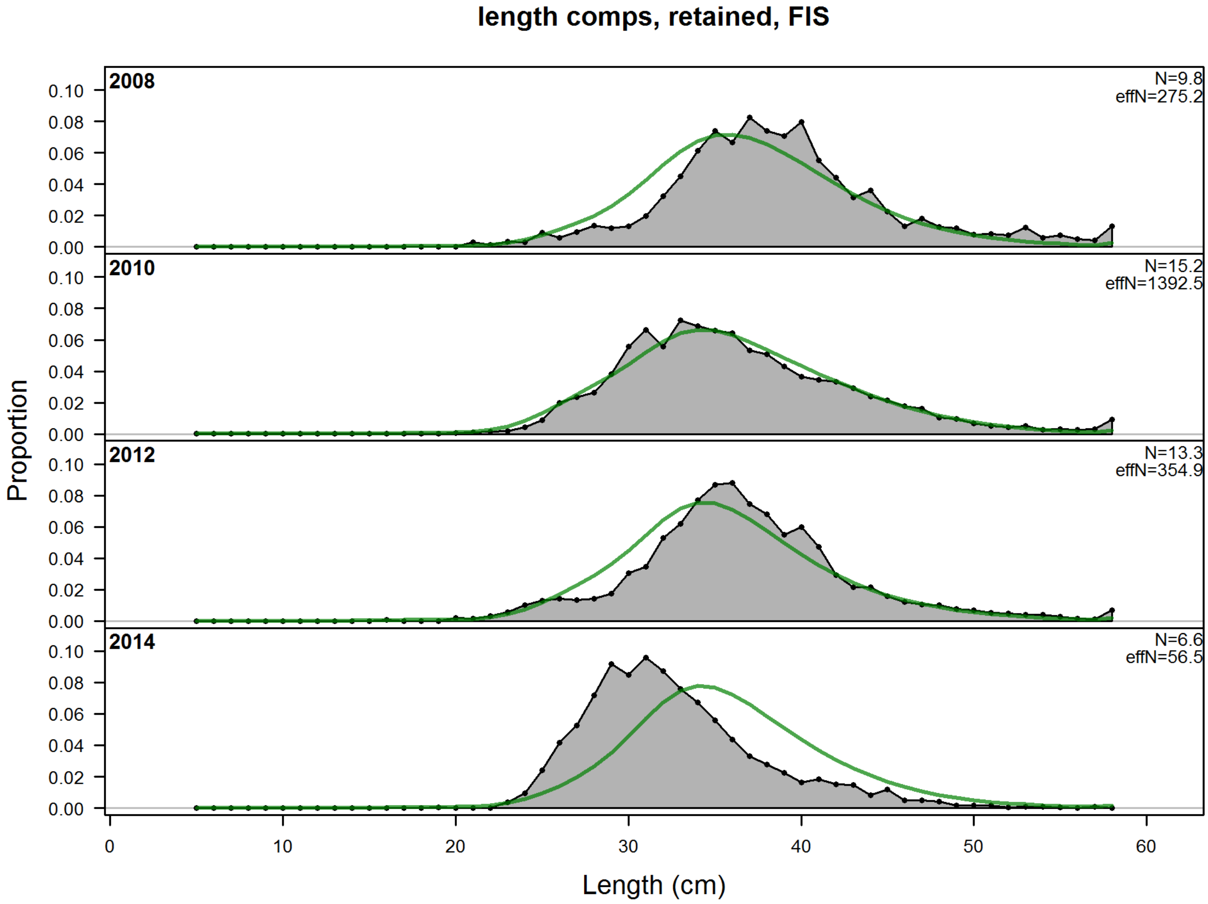
Apx Figure A.8 Tiger flathead length composition fits: eastern trawl discarded.



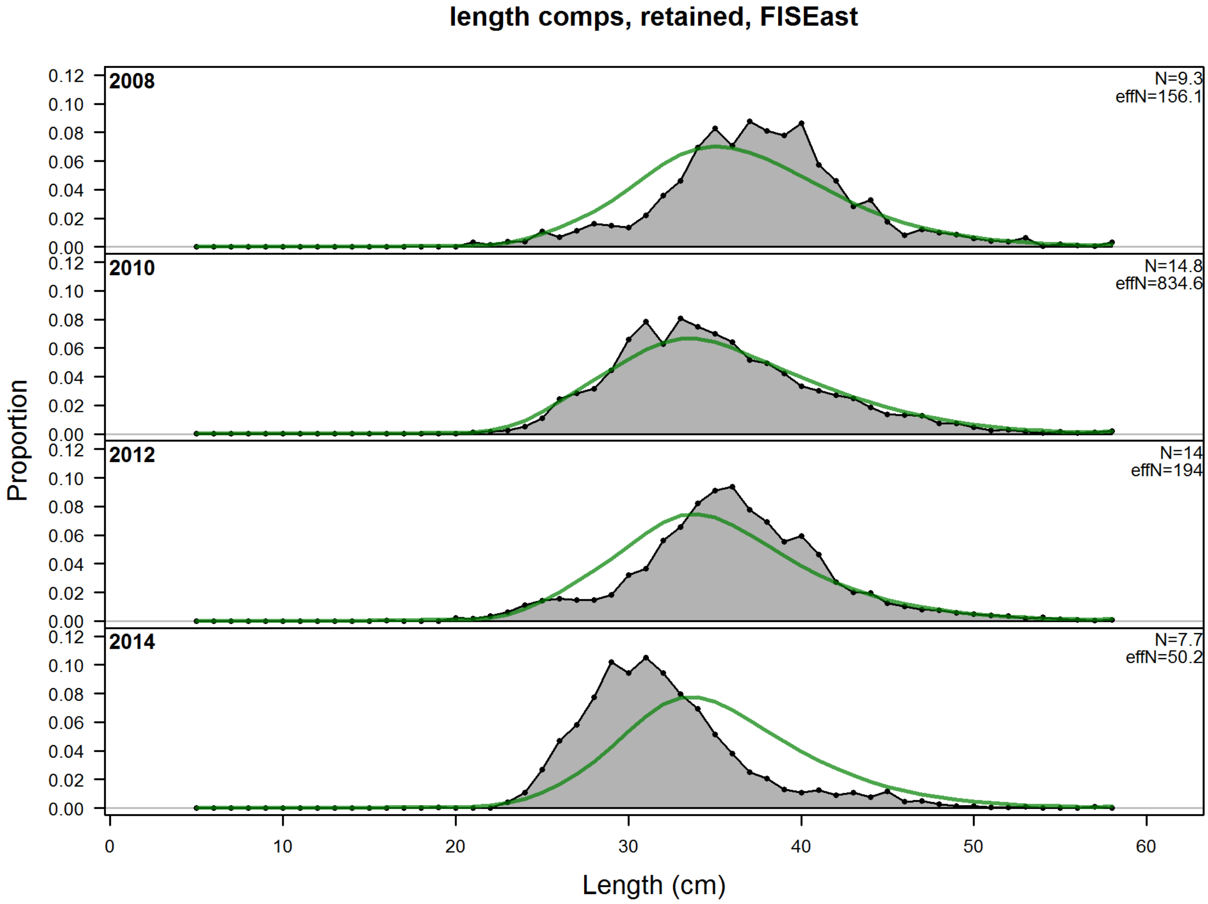
Apx Figure A.9 Tiger flathead length composition fits: Tasmanian trawl retained onboard.



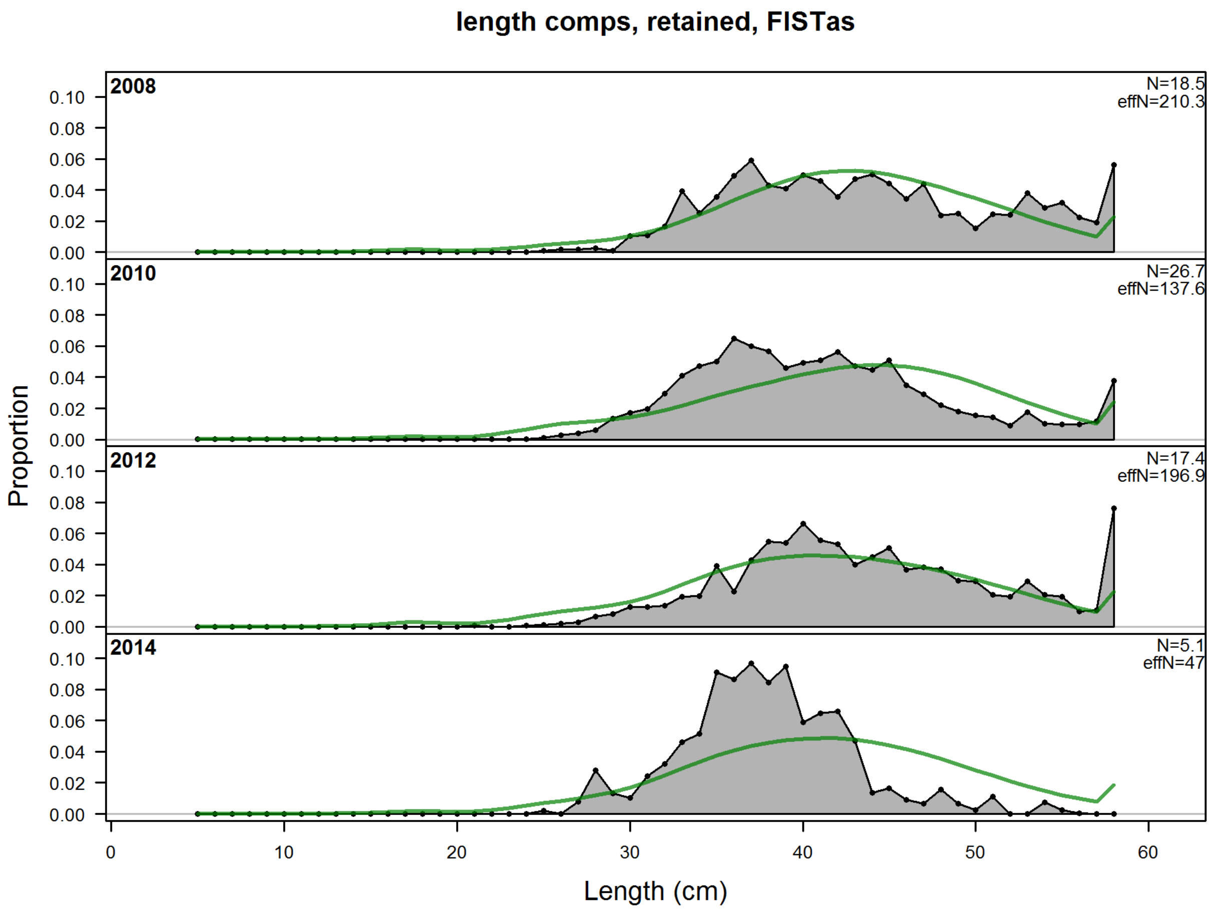
Apx Figure A.10 Tiger flathead length composition fits: Tasmanian trawl retained port.



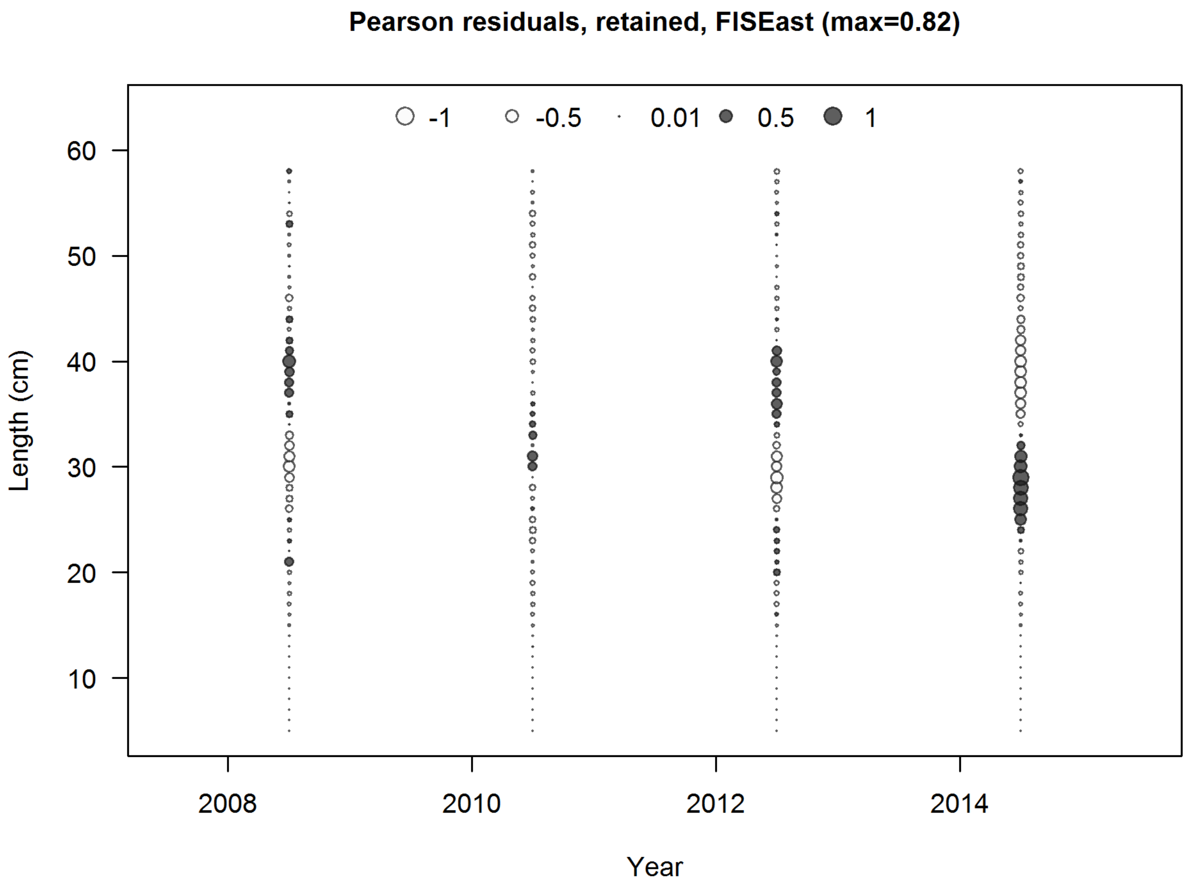
Apx Figure A.11 Tiger flathead length composition fits: FIS (zones 10, 20 and 30).



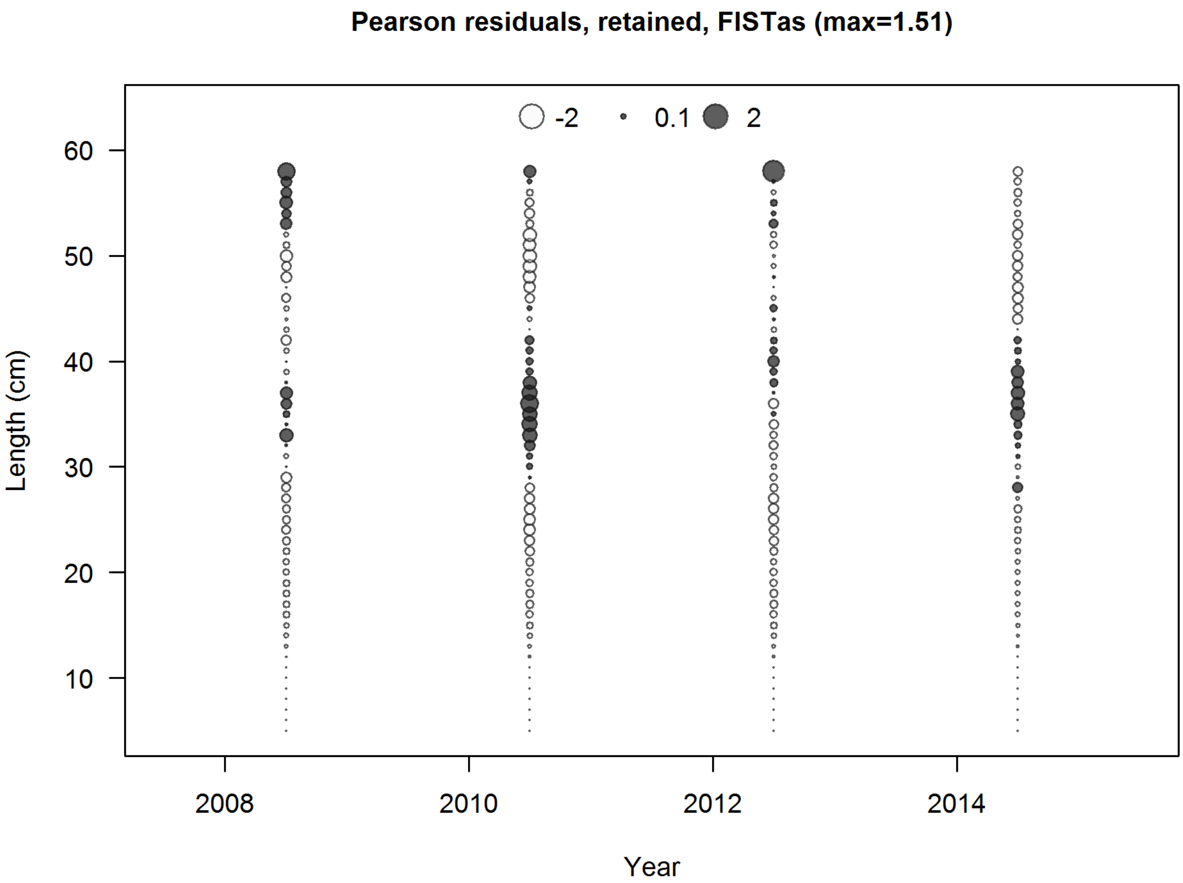
Apx Figure A.12 Tiger flathead length composition fits: Eastern FIS (zones 10 and 20).



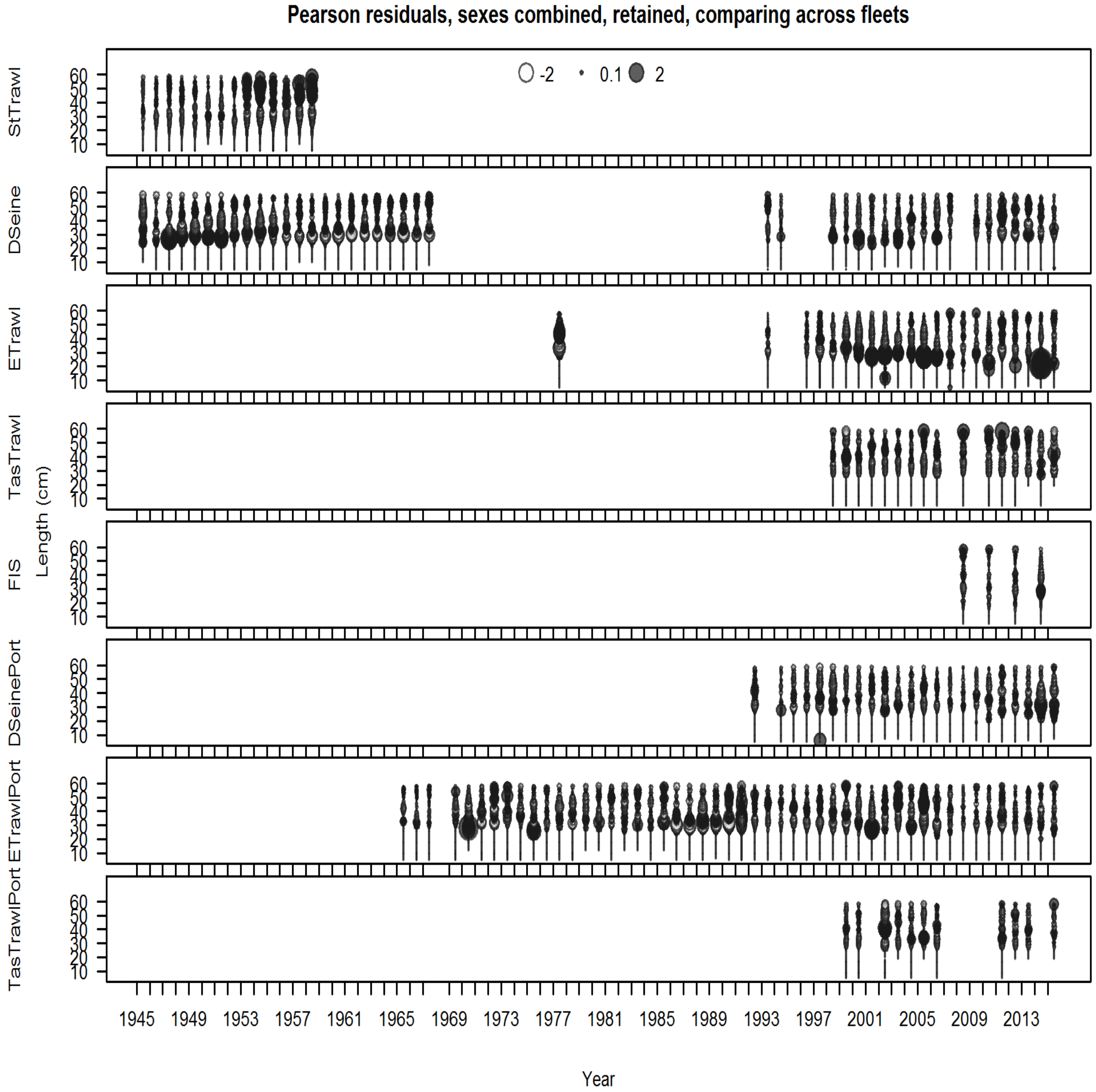
Apx Figure A.13 Tiger flathead length composition fits: Tasmanian FIS (zone 30 only).



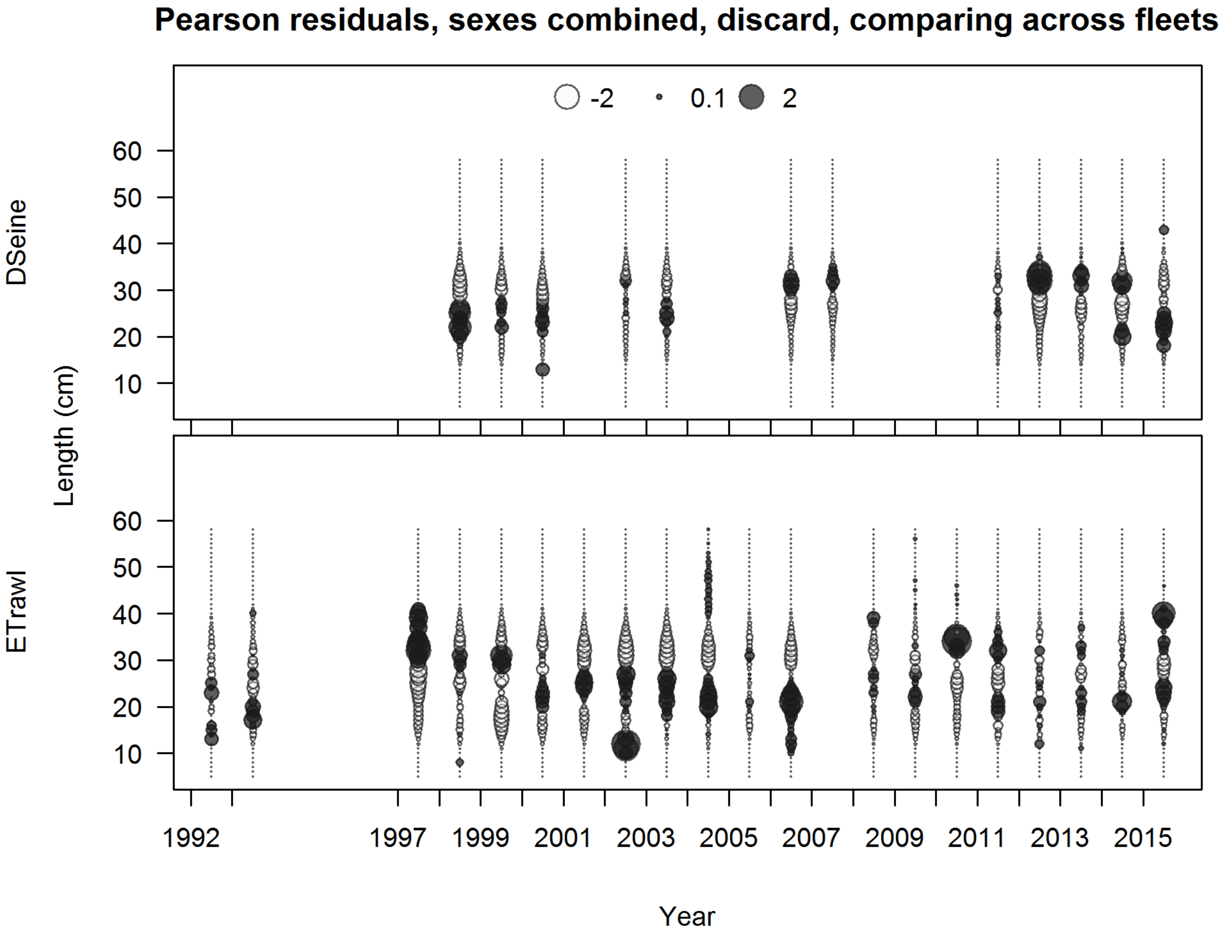
Apx Figure A.14 Tiger flathead length composition fits: Eastern FIS (zones 10 and 20).



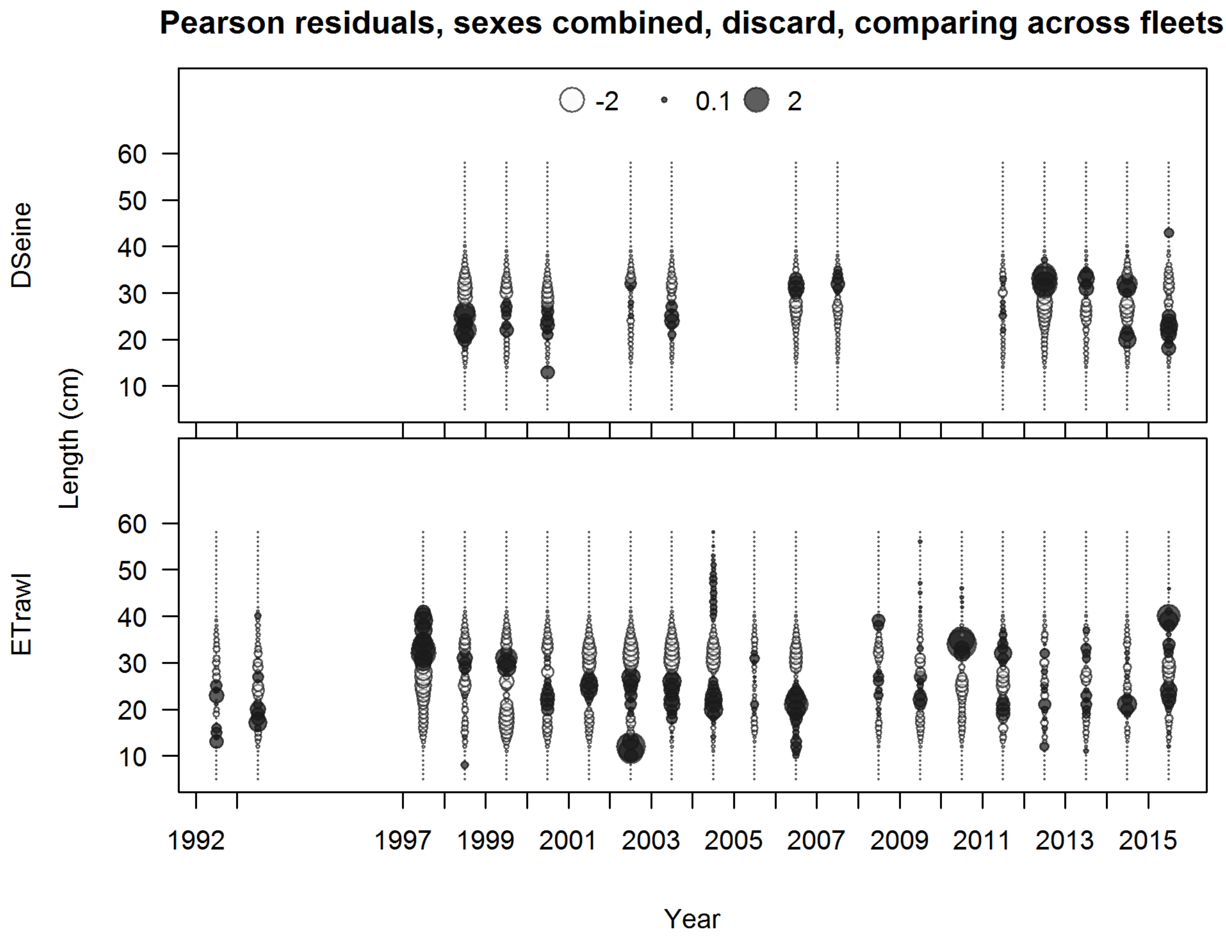
Apx Figure A.15 Tiger flathead length composition fits: Tasmanian FIS (zone 30 ony).



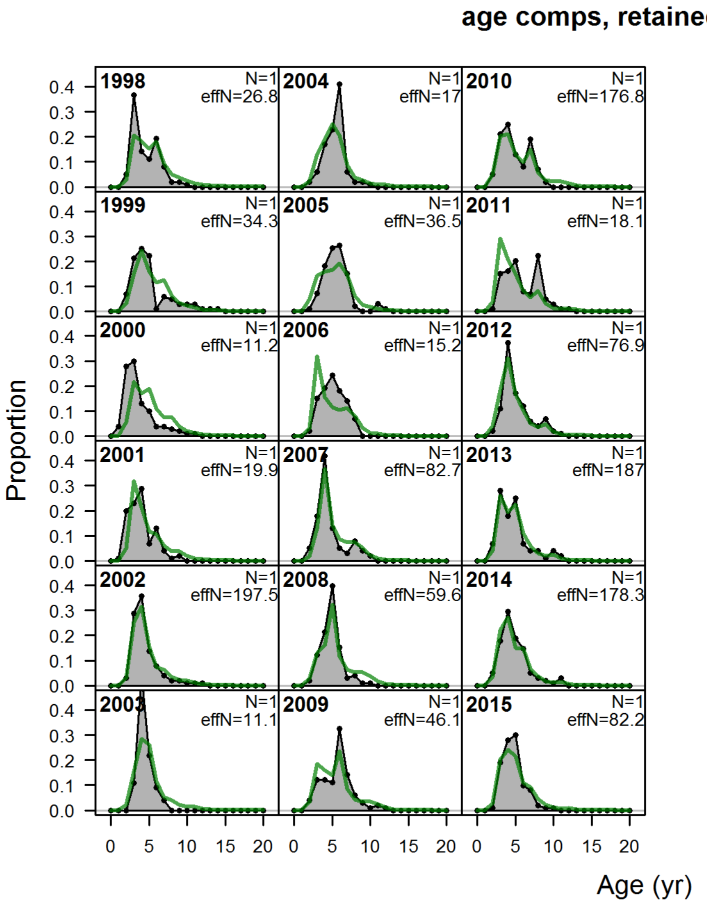
Apx Figure A.16 Residuals from the annual length compositions (retained) for tiger flathead displayed by year and fleet.



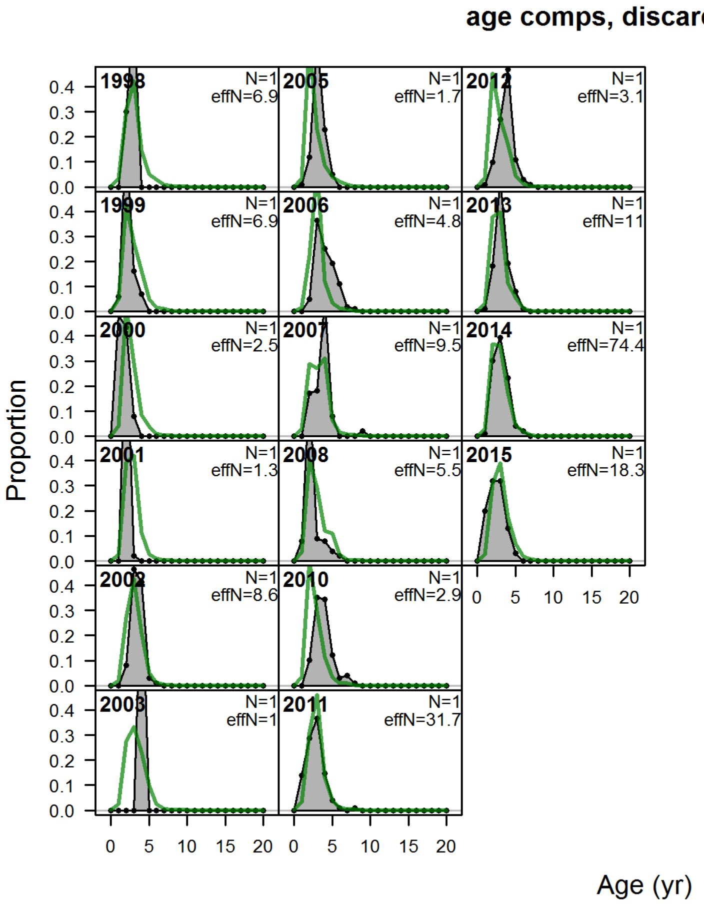
Apx Figure A.17 Residuals from the annual length compositions (discarded) for tiger flathead displayed by year and fleet.



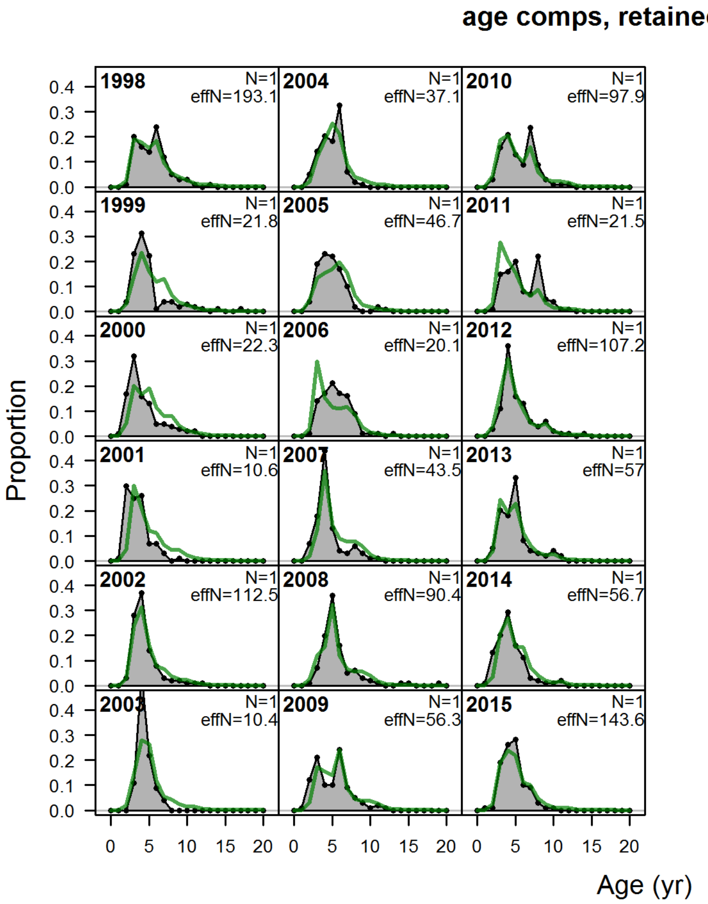
Apx Figure A.18 Residuals from the annual length compositions (discarded) for tiger flathead displayed by year and fleet.



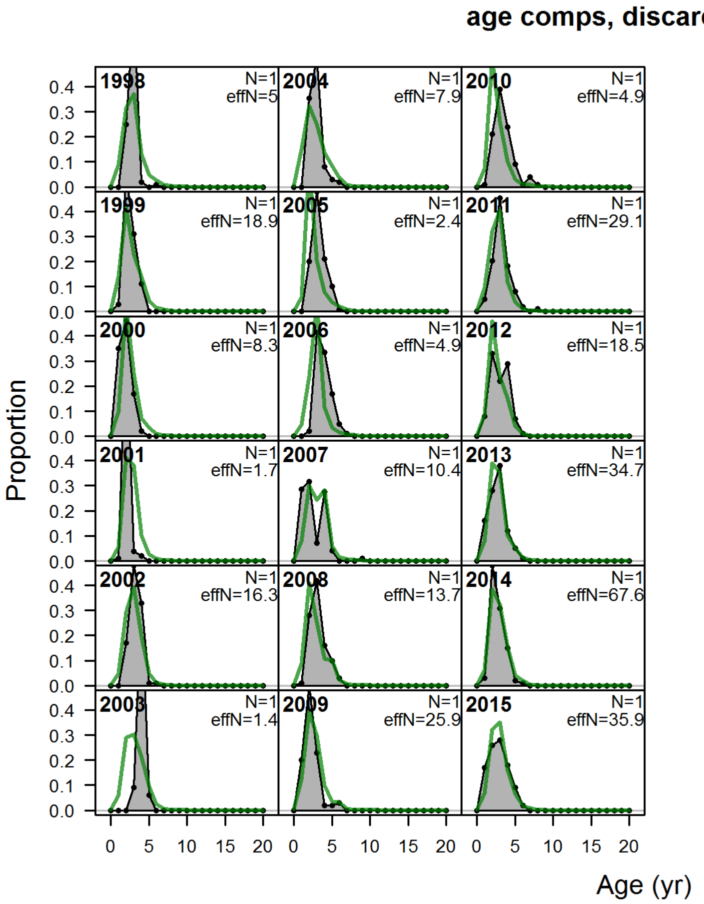
Apx Figure A.19 Implied fits to age compositions for tiger flathead Danish seine (retained).



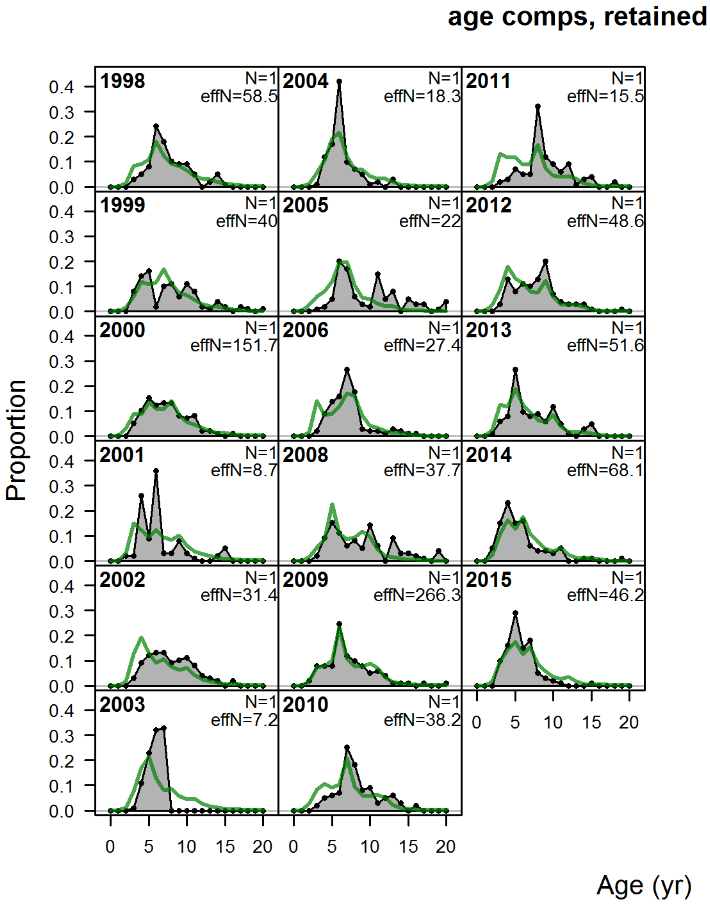
Apx Figure A.20 Implied fits to age compositions for tiger flathead Danish seine (discarded).



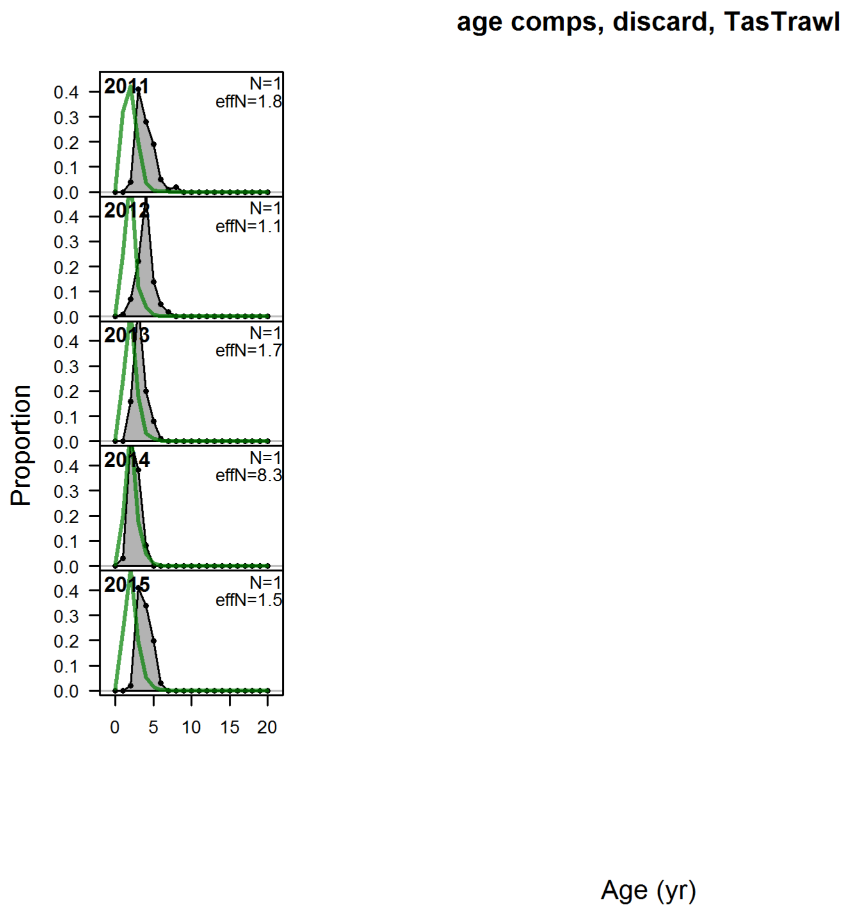
Apx Figure A.21 Implied fits to age compositions for tiger flathead eastern trawl (retained).



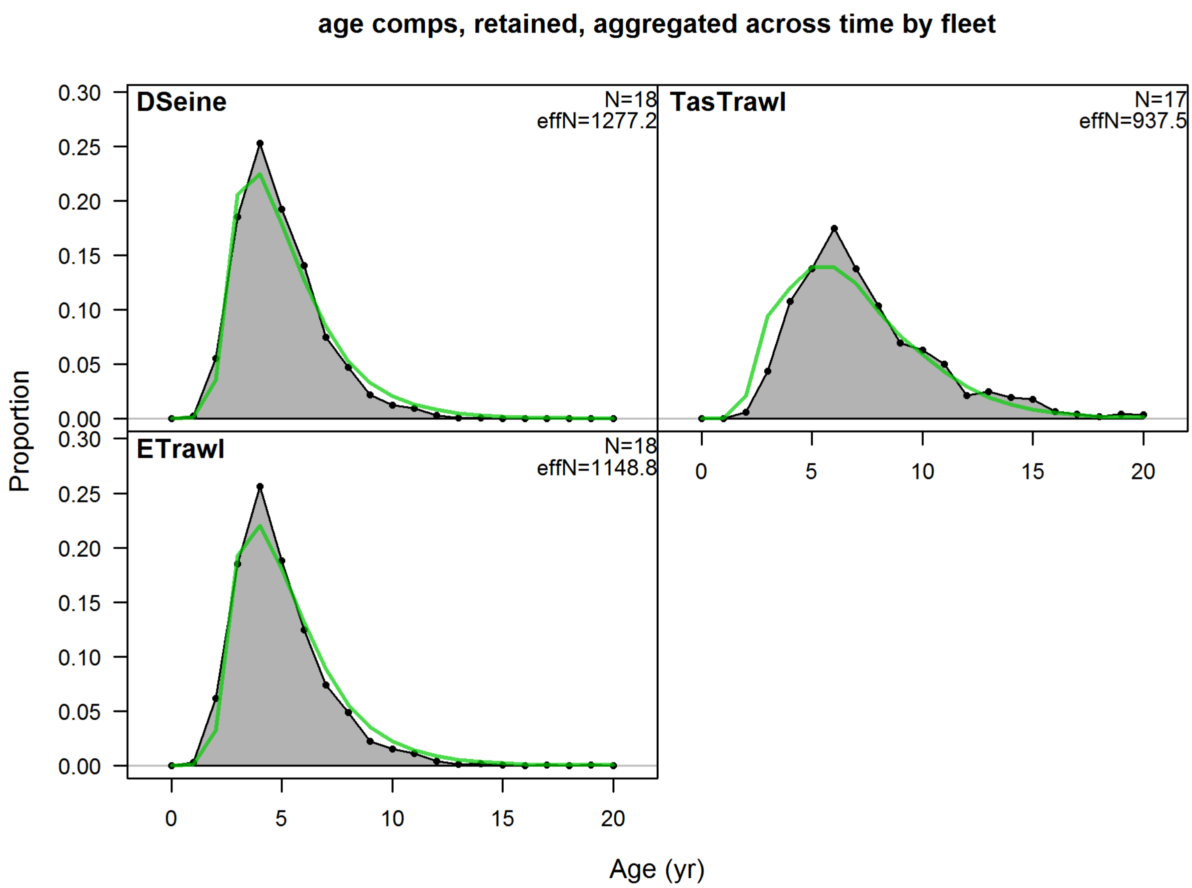
Apx Figure A.22 Implied fits to age compositions for tiger flathead eastern trawl (discarded).



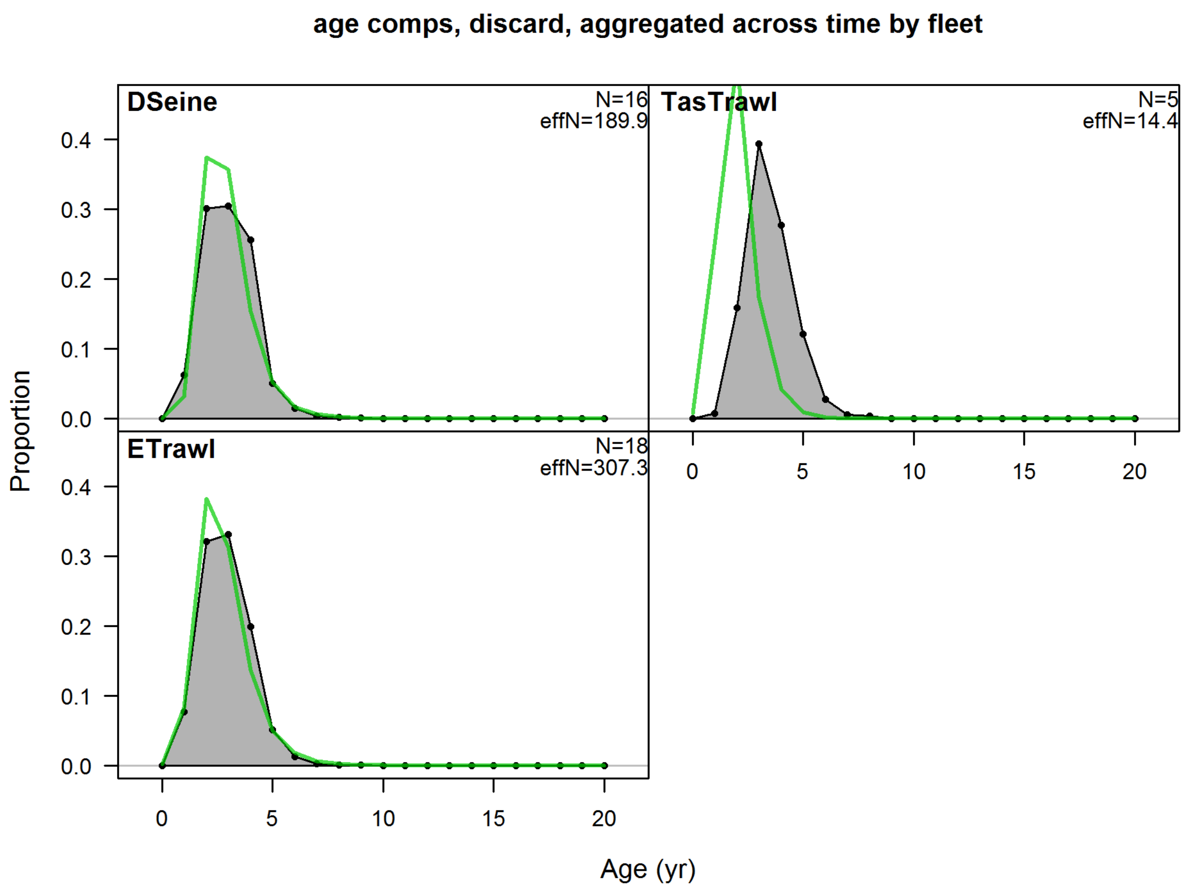
Apx Figure A.23 Implied fits to age compositions for tiger flathead Tasmanian trawl (retained).



Apx Figure A.24 Implied fits to age compositions for tiger flathead Tasmanian trawl (discarded).



Apx Figure A.25 Implied fits to age compositions for tiger flathead aggregated across time by fleet (retained).



Apx Figure A.26 Implied fits to age compositions for tiger flathead aggregated across time by fleet (discarded).

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