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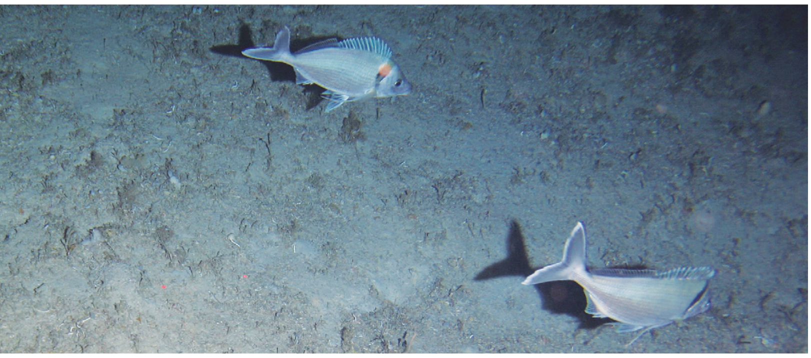
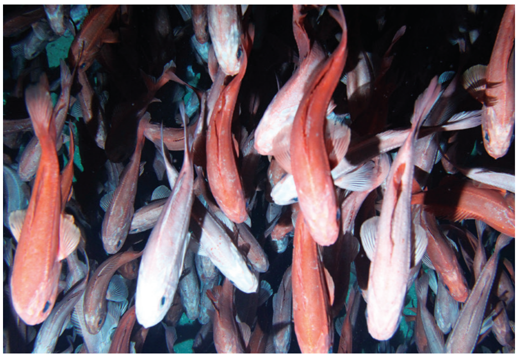
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014

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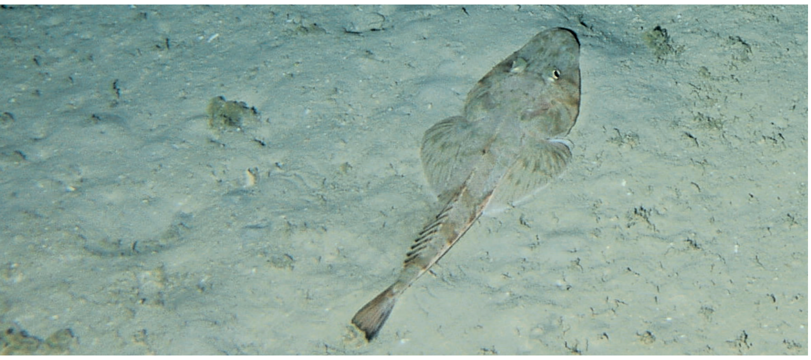
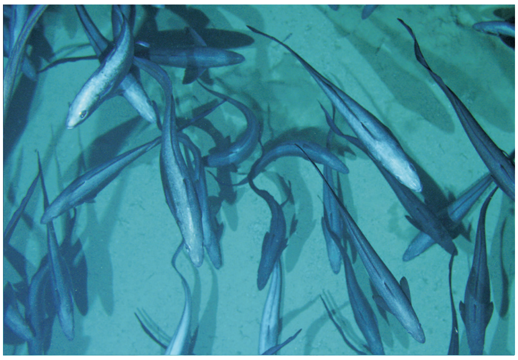


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Cover photographs

Front cover, jackass morwong, orange roughy, blue grenadier, and flathead.

Report structure

Part 1 of this report describes the Tier 1 assessments of 2014. Part 2 describes the Tier 3 and Tier 4 assessments, catch rate standardisations and other general work contributing to the assessment and management of SESSF stocks in 2014.

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014

Part 1: Tier 1 assessments

G.N. Tuck
June 2015
Report 2013/0010

Australian Fisheries Management Authority

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014
Part 1

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6. Development of a base-case Tier 1 assessment of redfish *Centroberyx affinis* based on data up to 2013

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6.1 Summary

This paper presents the data and results from a preliminary assessment developed to assist the establishment of a 2014 base-case assessment of eastern redfish *Centroberyx affinis* in the Southern and Eastern Scalefish and Shark Fishery (SESSF). For the first time, the assessment uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS). The assessment includes data up to the end of the 2013 calendar year. Data include annual landings, catch rates, discard rates, and length/age compositions. The main purpose of this document is to initiate discussion regarding the data to be used and the assumptions to be included in the base-case model structure. This is especially pertinent to the catch time-series, and assumptions regarding discard rates and discarding behaviour.

Tentative results from the preliminary assessment conclude that the redfish spawning biomass in 2014 is considerably less than the unexploited spawning stock biomass. However, at this point, focus should be on obtaining an agreed set of data and model structures for the base-case model, which currently has many strong and influential assumptions, especially about early catches and discard rates.

6.2 Introduction

An integrated analysis model, implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Methot, 2011; Methot and Wetzel, 2013. V3.24f), was applied to the eastern redfish stock of the SESSF, with data from 1975 to the 2013 calendar year (length and age data; age-error, catch rate series; landings and discard rates). The model fits directly to length frequencies (by sex where possible) and conditional age-at-length data.

Previous assessment models for eastern redfish are those of Chesson (1995), Thomson (2002) and Klaer (2005). The first comprehensive assessment of redfish was carried out in 1993 (Chesson, 1995). This assessment concluded that stock biomass was low in the late 1980s (less than 20% of that in 1969) but increases in catch and CPUE from 1990 to 1993, especially of small fish, suggested an increase in recruitment. A yield per recruit analysis based on growth and mortality rates indicated that better yields and value could be obtained if fish were caught at a greater size and age (Redfish FAR, 2002). No further comprehensive assessments of redfish were undertaken until April 1997 when a workshop (Rowling, 1997) was held in Cronulla to discuss the research findings for redfish which had accumulated since 1993. This led to the formation of the Redfish Assessment Group (RAG) in November 1997. The RAG was charged with developing an authoritative stock assessment for redfish, which first required the development of acceptable data sets to describe the true catch level and size composition throughout the history of the fishery (to account for the significant discarding which had always been a characteristic of this fishery) (Redfish FAR, 2002).

Thomson (2002) used an integrated assessment (ADMB) to assess stock status of redfish using data up 2001. The model of Thomson (2002) showed a considerable decline in stock biomass for both northern and southern regions (~25% of initial biomass in 2001). However, there were concerns regarding fits to catch at length data; namely a consistent tendency to over-estimate the proportion of large fishes in the catches since 1995 and to under-estimate them prior to 1995. Klaer (2005) focussed on the effect of changes in mesh selectivity on the future stock status of redfish, using the assessment platform Coleraine (Hilborn et al. 2000). Klaer (2005) largely used the biological parameters, catch and discard rate information provided by Thomson (2002), with updates of recent catch rate, catch and discard estimates to 2004. Results for the northern and southern regions, under the nominated base-case parameter set, showed stock status of less than 20% of initial biomass.

This paper presents the first assessment for redfish to be implemented using SS. The use of SS allows the implementation of a model very similar to that used in previous assessments, but additionally presents an opportunity to improve the estimation of length-based selectivity. SS can be fitted simultaneously to several data sources and types of information available for redfish. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, is outlined fully in the SS user manual (Methot, 2005; 2011) and is not reproduced here.

6.3 The fishery

The history of the redfish fishery is well documented in previous reports (eg Rowling 1999; Wise and Thomson, 2002). Redfish (also known as nannygai) occur throughout southern Australia and in New Zealand (Rowling, 1994). It is well established that redfish are a slow growing species which may live more than 35 years (Kalish, 1995; Wise and Thomson, 2002). Tagging studies (Rowling, 1990) suggested a single unit stock of redfish off NSW, however studies of mean length at age suggest differences in growth rates between the ‘northern’ and ‘southern’ sectors of the fishery off eastern Australia (Morison and Rowling, 2001). The redfish assessments of Thomson (2002) and Klaer (2005) have assumed that the fishery exploits two separate populations, with the boundary between these ‘stocks’ being 36ºS (just north of Montague Island). The assessments presented in this paper also assume northern and southern stocks, split at 36ºS.

The 2002 redfish fishery assessment report (Redfish FAR, 2002) states that the breeding biology of redfish remains poorly documented. They are reported to mature between five and seven years of age, with spawning thought to occur on continental shelf grounds in late summer and autumn throughout much of the range of the species. Juveniles commonly occur in the larger coastal bays and nearshore reefs, while adults have historically been more abundant in deeper continental shelf and upper slope waters.

The following text is taken from Wise and Thomson (2002) and provides a brief summary of the fishery to 2002.

> The earliest catches of redfish were made by the steam trawler fleet which began operating in 1915, however most redfish were discarded at sea as these boats principally targeted tiger flathead (Houston 1955). Expansion of the steam trawl fishery continued until 1929. The late 1950s and early 1960s were characterised by small, incidental redfish catches as steam trawlers were displaced by Danish seiners as the main units in the fishery. During the 1960s the Danish seine fleet began converting to otter trawling. Modern diesel powered trawlers were predominant in many ports by the mid 1970s, and Danish seiners had all but disappeared from the fishery by the early 1980’s. During the 1970s trawling extended to the upper continental slope (to depths of 600 m), mainly targeting gemfish (*Rexea solandri*). Large incidental catches of redfish were taken on upper slope grounds while targeting gemfish. These fish were generally larger than those taken on continental shelf grounds and had a higher market acceptance.

> Some large targeted catches of redfish were taken by fishers returning from unsuccessful gemfish targeting, and in the periods either side of the main gemfish catching season. However, a very significant proportion of the redfish catch continued to be discarded at sea due to oversupply of the market. Redfish consignments to the Sydney Fish Markets increased to 2400 t in 1980 as effort levels increased and markets gradually improved. Landings fluctuated between 1500 t and 2000 t per year until 1985. Despite continuing high effort levels, recorded landings of redfish declined to less than 1000 t in 1989. Landings increased again in the early 1990s reaching a peak of just over 2000 t in 1993.
>
> Individual transferable quotas (ITQs) were introduced in 1992 with the total allowable catch (TAC) for redfish of 600 t reflecting concern over the decline in catches in the late 1980s and the indications from early stock assessments (Rowling, 1993). However, the implementation of quota management coincided with a substantial increase in the availability of redfish, which resulted in calls for the TAC to be increased. Enforcement of the TAC was compromised as some redfish caught in Commonwealth waters were reported as coming from State waters to avoid being counted against quota (in fact in 1993 when the TAC was 600 t the actual landings of redfish were around 2000 t). In recognition of the increased availability of redfish, the TAC was increased to 1000 t in 1994 and to 1700 t in 1995. The "state waters" loophole was reduced in 1994 with the imposition by NSW of a 100 kg trip limit for redfish caught in waters south of Barranjoey Point.
>
> Discarding and high-grading have been features of the fishery for redfish since its inception. The rate of discarding is known to have varied over time but only since 1993 have actual data been available from observers participating in Scientific Monitoring Programs and the NSW Bycatch Study (Liggins, 1996). Between 1993 and 1995 overall discard rates were estimated to be around 50% by weight, but this rate declined to less than 10% during 1997.

Discard practices seem also to be influenced by the availability of surimi markets, with discarding generally lower during the periods the processors operated. Discard rates may have been as high as 80% in some years, but unfortunately no estimates of the quantities, size or age composition of the discarded fish exist prior to 1993 (Rowling, 1999). As stated by Hall (2001), the lack of these data will result in considerable imprecision in estimates of the pristine biomass prior to 1993.

Rowling (1999) documents historical estimates of discard rates and catches since 1960. Rowling (1999; Appendix 2) also describes the factors considered when determining the rate of discarding and the size composition of the catch. These factors were used to determine periods of operational change that influenced discarding practices when structuring the current SS assessment's retention function. Thomson (2002) provides updated catch and discard values for the northern and southern regions, as determined and agreed by the redfish RAG and more precisely in recent years from AFMA data. Discard rates prior to 1998 (north) and 1992 (south) are those estimated by the RAG and after these dates from ISMP observer data. Catch, discard, catch rate and length/age composition data have all been updated to the end of 2013 in this assessment. These data are described in the sections that follow.

Several authors have expressed concerns regarding growth over-fishing of redfish (Rowling, 1999, 2001; Wise, 2002; Knuckey, 2010). As stated by Knuckey (2010) "If we track the biomass of a cohort of fish as they grow, we find that it reaches a maximum at a certain age when the improved yield from growth is matched by the reduced yield from mortality. Growth overfishing occurs when large numbers of small fish are taken at a size or age before this maximum is reached". Knuckey finds that growth overfishing of redfish is occurring in the trawl fishery using current codend configurations. Analyses showed that the optimum yield per recruit is obtained when redfish are between 18 to 22 cm fork length. Due to the selectivity of standard 90mm diamond codends (50% selectivity at ~13cm), a large proportion of redfish are captured below the size of optimum yield.

6.4 Data

The data inputs to the assessment come from multiple sources: length and age-at-length data from the trawl fishery, updated cpue series (Sporcic and Haddon, 2014), the annual total mass landed and discard rates, and age-reading error. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and data sources were split at 36˚S (and east of 147˚E) to delineate the northern and southern regions.

6.4.1 *Catch and discard rates*

The catch tonnage for redfish has been estimated in the past based on a combination of sources, including Sydney Fish Market (SFM) data (to 1986), NSW and Victorian landings and the SEF logbook data (Table 28 of Rowling (1994); Appendix 1 of Rowling (1999); Table 1 of Thomson (2002); Table 1 of Klaer (2005)). The estimated annual tonnages of landings, discard rates and cpue are provided in Table 6.1. The landings from the SEF1 logbook data (over years available) were used to apportion catches to the northern and southern regions (Table 6.2). These proportions were then applied to the landings (CDRs) for the corresponding year to give the total tonnage caught in each region. For years in which the logbook was greater than the landings, the logbook data were used (1992-1994). For years in which there were no CDRs but logbook data did exist, the average of years 1992 to 1996 was used for the ratio of landings to logbook catches.

State data exist for years 1984 to 2012 for NSW and 1978 to 2005 for Vic (zero catch from 2006 in Victoria). For NSW, it appears that the state data have been recorded in the logbook until perhaps 1997 (Figure 6.1). Therefore, for the northern region, state data were only added into the Commonwealth catch after 1997 (Table 6.2).

Discard rates prior to 1998 in the north and 1992 in the south are those estimated by the redfish RAG (Thomson, 2002). Discard rates after these dates were estimated from on-board data which gives the weight of the retained and discarded component of those shots that were monitored (Thomson and Klaer, 2011). Rowling (1999) provides considerable detail on how the historical discard rates were estimated and the factors that influenced discard practices. Redfish discarding was discussed at a redfish workshop held in Cronulla in April 1997 and at various open redfish assessment group meetings during late 1997 and early 1998. The resulting discard rates are documented in Rowling (1999) and also listed in the last redfish assessment group (Thomson, 2002) and Shelf RAG (Klaer, 2005) assessments of redfish. Here we update the discard estimates by the addition of on-board estimates through to 2013 (Table 6.1).

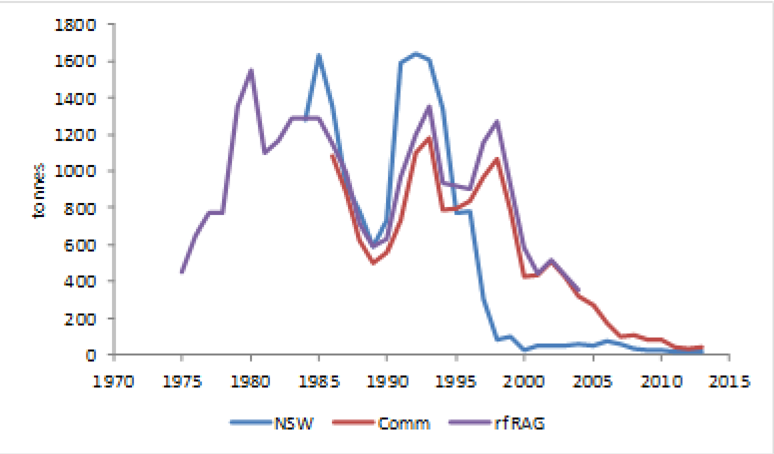

Figure 6.1.The time series of catches for the north from NSW, Commonwealth and that estimated by the various redfish assessment groups (rf RAG) and supplemented by AFMA data (Klaer, 2005).

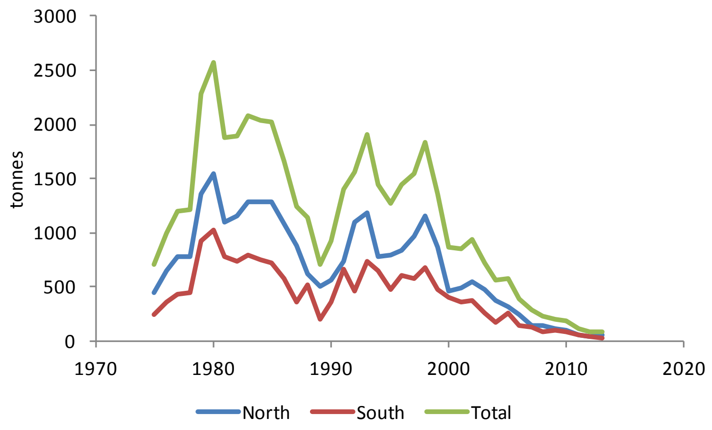

Figure 6.2 The annual catch series (tonnes) for the northern and southern redfish regions and the combined total catch.

The SS assessment model allows an estimation of the probably of retention (which is 1 – P(discard)) as a function of length in order to estimate the annual discard rate and any information on discard length composition. It is apparent that the redfish fishery has undergone numerous changes that may have influenced the behaviour of discarding; these changes are documented in Rowling (1999; Appendix 2). In consultation with K. Rowling (pers. comm.), the following discarding periods have been identified:

1975 – 1985. Market driven discarding

1975 – 1985. Discards largely across all size ranges, but with more small fish discarded

1986 – 2000. Surimi markets period

1986 – 1992. Surimi market. Discarding rates lower, mainly small fish.

1993 – 1995. Quantity of fish sent to surimi market declined, Geelong surimi market closes; consequent increase in discarding.

1996 – 2000. Discarding declined ‘as redfish became less available’. Close of Hacker surimi processor in 2000.

2001 – 2013. Size based discarding period

2001 – 2013. Assume mostly small fish discarded

These changes in discarding behaviour have influenced the large variations in discard rates observed (Table 6.1), as well as the catches, catch rates and discard length composition. The model retention function has been allowed to vary according to each of these identified discard periods.

6.4.2 *Catch rates*

Sporcic and Haddon (2014) provides the updated catch rate series for redfish (Table 6.1; Figure 6.3). After substantial increases in catch rate in the early and late 1990s, the catch rate has continued to decline since then, and is now less than 15% of levels in 1986. The most recent year in the series has shown a small increase, which may correspond to the apparent large influx of young fish noticeable in the 2013 age data.

Note that since 2010, the redfish Tier 4 assessment, which is based upon catch rates, has used a split reference period, covering the years 1986 to 1990 and 1999 to 2003. The intervening period is not considered representative of the fishery because it involved large trawlers catching large quantities of redfish for surimi markets.

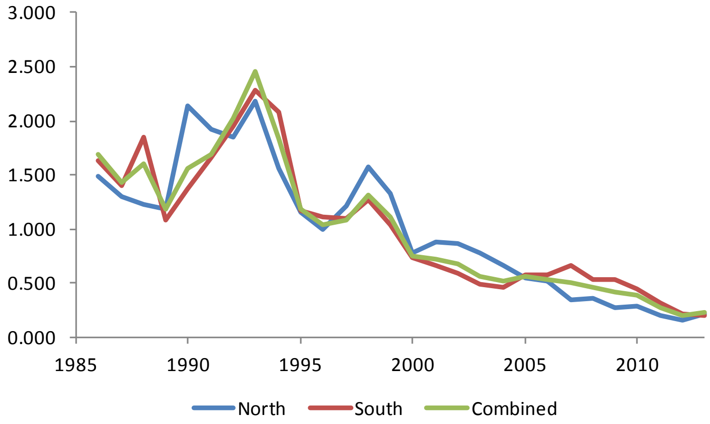

Figure 6.3. The annual catch rate series for the northern and southern redfish regions and the combined region.

Table 6.1. Estimated landings, discard rates and cpue (Sporcic and Haddon, 2014) for the northern and southern redfish regions by calendar year.

Year	Landings		Discard Rates		CPUE	
	North	South	North	South	North	South
1975	452	249	0.4	0.4		
1976	645	355	0.4	0.4		
1977	774	426	0.4	0.4		
1978	774	446	0.4	0.4		
1979	1355	920	0.4	0.4		
1980	1548	1030	0.3	0.3		
1981	1097	787	0.2	0.2		
1982	1161	731	0.2	0.2		
1983	1290	794	0.2	0.2		
1984	1290	750	0.2	0.2		
1985	1290	727	0.2	0.2		
1986	1079	584	0.2	0.2	1.495	1.638
1987	885	360	0.1	0.2	1.293	1.407
1988	624	521	0.1	0.2	1.231	1.854
1989	499	205	0.1	0.2	1.186	1.079
1990	560	364	0.1	0.1	2.141	1.371
1991	732	662	0.1	0.1	1.921	1.656
1992	1096	466	0.1	0.1	1.846	1.945
1993	1179	730	0.14	0.580	2.177	2.283
1994	785	657	0.44	0.540	1.561	2.080
1995	795	473	0.40	0.758	1.159	1.174
1996	839	606	0.25	0.279	0.994	1.114
1997	969	576	0.02	0.062	1.206	1.091
1998	1150	685	0.054	0.432	1.581	1.266
1999	872	480	0.001	0.101	1.330	1.039
2000	457	406	0.030	0.212	0.780	0.730
2001	490	357	0.233	0.539	0.876	0.668
2002	553	378	0.483	0.684	0.869	0.592
2003	472	254	0.242	0.440	0.780	0.486
2004	378	178	0.448	0.291	0.667	0.459
2005	320	259	0.221	0.216	0.554	0.579
2006	248	149	0.012	0.059	0.516	0.575
2007	151	133	0.405		0.341	0.658
2008	138	93	0.034		0.358	0.538
2009	109	98	0.198	0.496	0.271	0.540
2010	102	86	0.198	0.041	0.283	0.450
2011	55	61	0.179	0.123	0.205	0.312
2012	47	39	0.086	0.023	0.164	0.213
2013	52	28	0.224	0.282	0.215	0.204

Table 6.2. Logbook and CDR landings for the northern and southern redfish regions by calendar year and adjustments made to account for logbooks being less than landings and State data. Shaded values for the North explain the origin of values used in the catch series for the assessment. [1] estimated value taken as the tonnage from 2012.

Year	Logbook		CDR	Multiplier	Adjusted Comm Catch		State Catch		RAG agreed values (<2005)		Catch for assessment	
	North	South		CDR/Log bk	North	South	NSW	Vic	North	South	North	South
1975									452	249	452	249
1976									645	355	645	355
1977									774	426	774	426
1978								20	774	426	774	446
1979								175	1355	745	1355	920
1980								178	1548	852	1548	1030
1981								184	1097	603	1097	787
1982								92	1161	639	1161	731
1983								84	1290	710	1290	794
1984							1277	40	1290	710	1290	750
1985	90	39		1.019	91	40	1628	17	1290	710	1290	727
1986	1059	568		1.019	1079	578	1350	6	1145	555	1079	584
1987	869	346		1.019	885	352	923	8	993	407	885	360
1988	612	485		1.019	624	494	779	26	713	487	624	521
1989	490	194		1.019	499	198	589	7	589	211	499	205
1990	550	354		1.019	560	360	728	4	631	369	560	364
1991	719	629		1.019	732	640	1592	22	970	630	732	662
1992	1096	463	829	1.000	1096	463	1636	2	1193	607	1096	466
1993	1179	705	538	1.000	1179	705	1606	25	1351	749	1179	730
1994	785	645	699	1.000	785	645	1332	12	938	662	785	657
1995	783	445	1246	1.014	795	451	767	22	921	479	795	473
1996	774	551	1436	1.084	839	597	776	8	903	597	839	606
1997	864	513	1544	1.120	969	575	304	<1	1155	581	969	576
1998	939	603	1752	1.136	1067	685	83	<1	1266	638	1150	685
1999	684	422	1258	1.137	778	480	95	<1	920	486	872	480
2000	385	364	836	1.117	430	406	27	<1	582	253	457	406
2001	403	329	795	1.085	438	357	52	<1	440	354	490	357
2002	457	341	885	1.109	507	378	47	<1	520	360	553	378
2003	364	218	678	1.165	424	254	49	<1	436	241	472	254
2004	297	165	498	1.079	320	178	58	<1	352	186	378	178
2005	241	229	532	1.134	273	259	47	<1			320	259
2006	166	145	321	1.033	172	149	76				248	149
2007	89	123	230	1.087	97	133	54				151	133
2008	98	84	201	1.103	108	93	29				138	93
2009	73	86	182	1.149	84	98	25				109	98
2010	73	78	166	1.098	80	86	22				102	86

2011	33	52	99	1.156	38	61	16	55	61
2012	30	34	73	1.139	34	39	14	47	39
2013	36	26	66	1.078	39	28	14[1]	52	28

6.4.3 *Length frequencies and age data*

Length and age data have been included in the model as length frequency data and conditional age-at-length data by year and sex (when available). Age composition data is included in diagnostic plots but is not used directly within the fitting procedure. Catch length frequency data were obtained from NSW records of fish measured at the Sydney Fish Markets to 1998 in the north and 1991 in the south. After these dates length frequencies were obtained from ISMP on-board measurements. Figures of the observed length and age data are shown in later figures with the corresponding model predicted values.

6.4.4 *Age-reading error*

Standard deviations for aging error by reader have been estimated, producing the age-reading error matrix of Table 6.4 (A.E. Punt, pers. comm.).

Table 6.3.The standard deviation of age reading error.

Age	St Dev	Age	St Dev
0	0.167	20	0.98
1	0.167	21	1.00
2	0.237	22	1.02
3	0.304	23	1.04
4	0.366	24	1.06
5	0.424	25	1.07
6	0.479	26	1.09
7	0.531	27	1.10
8	0.579	28	1.12
9	0.625	29	1.13
10	0.668	30	1.14
11	0.708	31	1.15
12	0.746	32	1.17
13	0.781	33	1.18
14	0.815	34	1.19
15	0.846	35	1.19
16	0.876	36	1.20
17	0.903	37	1.21
18	0.930	38	1.22
19	0.954	39	1.23
		40	1.23

6.4.5 *Fishery independent survey (FIS) estimates*

Abundance indices for redfish over surveys in 2008, 2010 and 2012 are provided in Knuckey et al. (2013) and summarised in Table 6.4. Indices from the FIS were not used in the preliminary assessments.

Table 6.4. Abundance indices of redfish in the summer and winter surveys with corresponding cv.

	2008	2010	2012
Summer	3.43	10.35	3.76
c.v.	0.79	0.64	0.5
Winter	14.37	26.89	1.14
c.v.	0.23	0.23	0.31

6.4.6 *Kapala data*

Abundance indices from the Kapala research cruises for redfish provide estimates of 115 for 1976/77 and 4.8 for 1996/97, a decline of 24:1. Previous modelling attempted to include these abundance indices but the model was unsuccssful in providing reasonable fits (Thomson, 2002). Length frequncy of redfish from the Kapala research cruises are provided in Figure 6.3. These length frequencies have not been included in any previous assessment models. Sample sizes for the south are small (n=1548 for 1977 and n=210 for 1997) compared to the north (n=54526 for 1977 and n=4991 for 1997). Data from the Kapala have not been included in the preliminary model presented here.

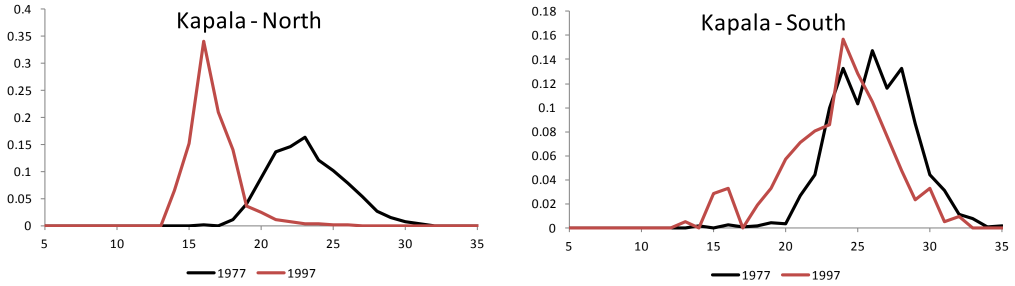

Figure 6.4. The Kapala length frequencies for the northern and southern redfish regions.

6.4.7 *Biological parameters*

The preliminary assessment assumes that length at 50% maturity of 19cm for females in the north and 18cm in the south (Thomson, 2002). Natural mortality is assumed to be 0.10y^{-1}. Redfish natural mortality is generally assumed to be in the 0.05 and 0.15 y^{-1} range (SEFAG, 2000). Morison and Rowling (2001) calculated natural mortality values between 0.07 and 0.11 y^{-1}. Steepness is assumed to be 0.75. Parameters for the length weight relationship were taken from Klaer (2005; also used by Thomson, 2002). The Redfish FAR (2002) states that studies of mean length at age suggest differences in growth rates between the northern and southern regions of the fishery off eastern Australia (Morison and Rowling, 2001). As a consequence two assessments are considered here: a northern assessment and a southern assessment, split at 36˚S. The von Bertalanffy growth parameter *k* for the north is 0.24 while for the south it is 0.2 (Thomson, 2002). These values are fixed in the preliminary assessment; other growth parameters, including those by sex, are estimated.

6.5 Analytic approach

6.5.1 The population dynamics model

The 2014 assessment of eastern redfish uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.24f, NOAA 2011). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

The base–case model includes the following key features:

(a) Two regions are considered separately: north and south, split at 36˚S and east of 147˚E.

(b) The selectivity pattern for the trawl fleet was assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment. A trend in selectivity centred on 1995 was considered to account for the shift in mean length from larger to smaller fish.

(c) Redfish within each region consist of a single stock within the area of the fishery.

(d) The model accounts for males and females separately.

(e) The initial and final years are 1975 and 2013. Previous modelling (Thomson, 2002; Klaer, 2005) has begun models in 1975 due to the generally perceived poorer quality of data prior to this year. Allowing pre-1975 exploitation of the stock will be considered in future iterations of the model.

(f) The CVs of the CPUE indices for the non-spawning fleet were initially set at a low value to encourage a fit to the abundance data, before being re-tuned to the model-estimated standard errors after tuning to length and age data. The Francis method (Francis, 2011) has not been used here but will be in future iterations of the model.

(g) Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. A retention function was estimated for each ‘block’ period: namely 1975-1985; 1986-1992; 1993 -1996; 1997 – 2000; 2001 – 2013. This attempts to account for the changing discarding behaviour throughout the fishery (Rowling, 1999).

(h) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M is 0.1 y^{-1}.

(i) Recruitment to the stock 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 set to 0.75.

(j) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is initially set to 0.6 and re-tuned in the preliminary model.

(k) The population plus-group is modelled at age 40 years, as is the maximum age for observations.

(l) Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with the parameters of the growth function being estimated separately for females and males inside the assessment model, except for the k parameter which is fixed at 0.24 (north) and 0.2 (south).

(m) Retained and discard length sample sizes were capped at 200 and required to have a minimum of 100 samples to be included. Reducing the sample size to a maximum of 200 is because the appropriate sample size for length frequency data is probably more related to the number of shots sampled, rather than the number of fish measured. The length frequency data is given too much weight relative to other data sources if the number of fish measured were used. Length, age, σ_r, and cpue data were tuned.

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 6.5.

Table 6.5. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	Description	Value
M	Natural mortality	0.1
σ_r	Initial c.v. for the recruitment residuals	0.6
h	“steepness” of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	40 years
a	allometric length-weight equations	0.0577 g^{-1}.cm
b	allometric length-weight equations	2.77
l_m	Female length at 50% maturity	19cm
k	Von Bertalanffy growth parameter	0.24 (n) 0.2 (s)

6.5.2 *Alternative models*

A key uncertainty in the assessment of redfish relates to the early catch and discarding practices (Rowling, 1999; Hall, 2001). Years from 1975 - 1985 are generally assumed to be a period of large discarding due to a lack of markets, with the discard size composition matching that of the landed catch (Rowling, 1999; Appendix 2). However, as has been stated by Thomson (2002), it is unlikely that that when skippers did choose to land redfish that they landed small fish as well as large fish. After 1985 discarding is assumed to have changed from being market-driven to being size based, and influenced by the surimi markets. In order to model the situation where the size of the discard and retained catch are similar, but with a larger proportion of small fish discarded, two methods are considered here:

1) Scenario 1 (S1). Use model derived discard rates to fit to estimates over the period 1975-1985. Include a logistic retention function with a cap less than 1.0 (i.e. larger fish do not reach full retention and can be discarded).

2) Scenario 2 (S2). Add the estimated mass of discards into the retained mass (see new landings values in Table 6.2). Retention is 1.0 across all lengths for 1975-1985. Do not allow selection of small fish through the selectivity function. In this case, model derived discard rates over 1975 – 1985 are not fit to the corresponding estimates in Table 6.1. This is the method that was adopted by Thomson (2002).

Table 6.6. Landings (tonnes) assumed under scenario (S2) where the estimated discard mass is added into the estimated retained mass for years 1975 - 1985. Discard rates used to calculate the discard mass are in Table 6.1.

Year	Landings	
	North	South
1975	753	415
1976	1075	592
1977	1290	710
1978	1290	744
1979	2258	1534
1980	2211	1471
1981	1371	983
1982	1451	914
1983	1613	993
1984	1613	937
1985	1613	909

6.6 Results and discussion

6.6.1 The base case stock assessment

6.6.1.1 Parameter estimates

The weight-length relationships, maturity-at-length and growth are shown in the Appendices pages 1-3 for each of the regions and model scenarios. Selectivity and the retention functions are shown on pages 4-8 (Figure 6.5). Selectivity is allowed to vary with time and is logistic for the trawl fleet. Retention has multiple ‘time-blocks’ to account for the varying discarding behaviours documented. Retention during the years of the surimi markets (1986 – 2000) can be seen to have been much higher than at other times (less discarding), as a much broader range of size classes are retained and sold to surimi processors. Selectivity tends to move from larger sized fish to much smaller fish. This pattern of decreasing mean length has been noted in previous assessments (Rowling, 1999; Thomson, 2002) and may be related to a gradual movement away from deeper waters where larger fish were caught, to more shallow depths (K. Rowling, pers. comm.).

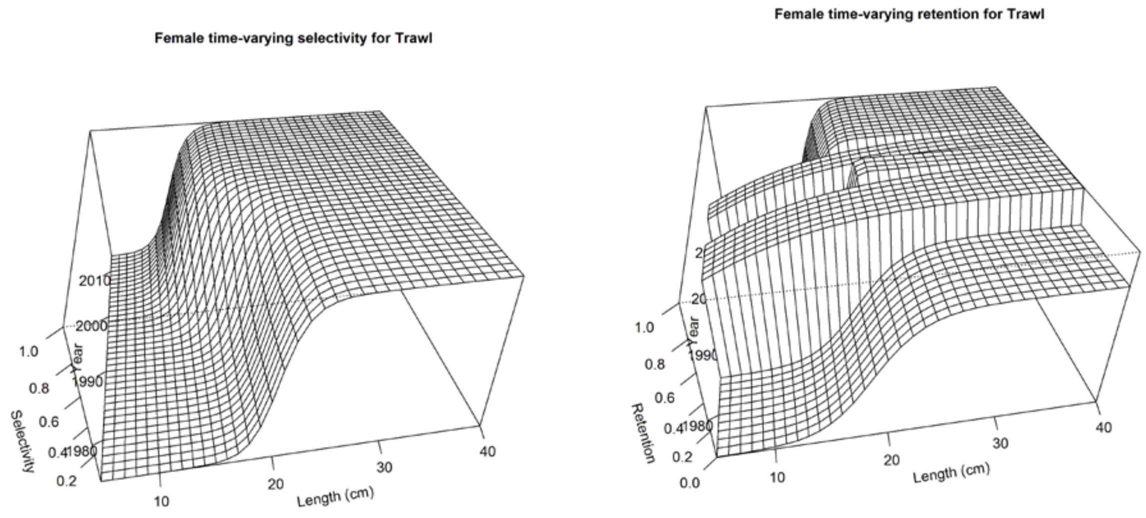

Figure 6.5.The estimated selectivity (left) and retention (right) functions for the northern redfish regions under scenario 1 where discarding over 1975 – 1985 is estimated.

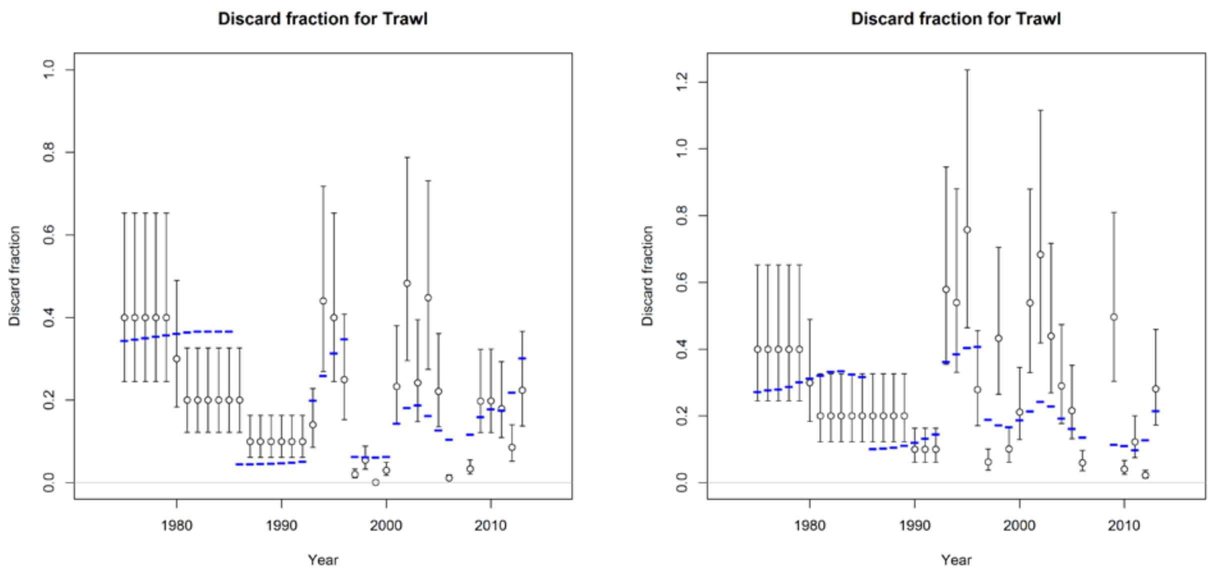

Figure 6.6. The fit to the discard rate data for the northern region (left) and southern region (right) under scenario 1 where discarding over 1975 – 1985 is estimated; blue dashes are the model fitted estimates.

6.6.2 *Fits to the data*

The fit of the model to the discard rates shows some correspondence as the model attempts to fit to the various changes in discarding over time, however, discard rates are highly variable and predicted discard rates appear biased low in many years (Appendices). Figure 6.7 shows the model fit to the catch rate series showing little difference between the model scenarios with both providing acceptable fits, especially after 1995. Appendix p17 show that the model fits intersect most of the 95% confidence intervals for the catch rate data.

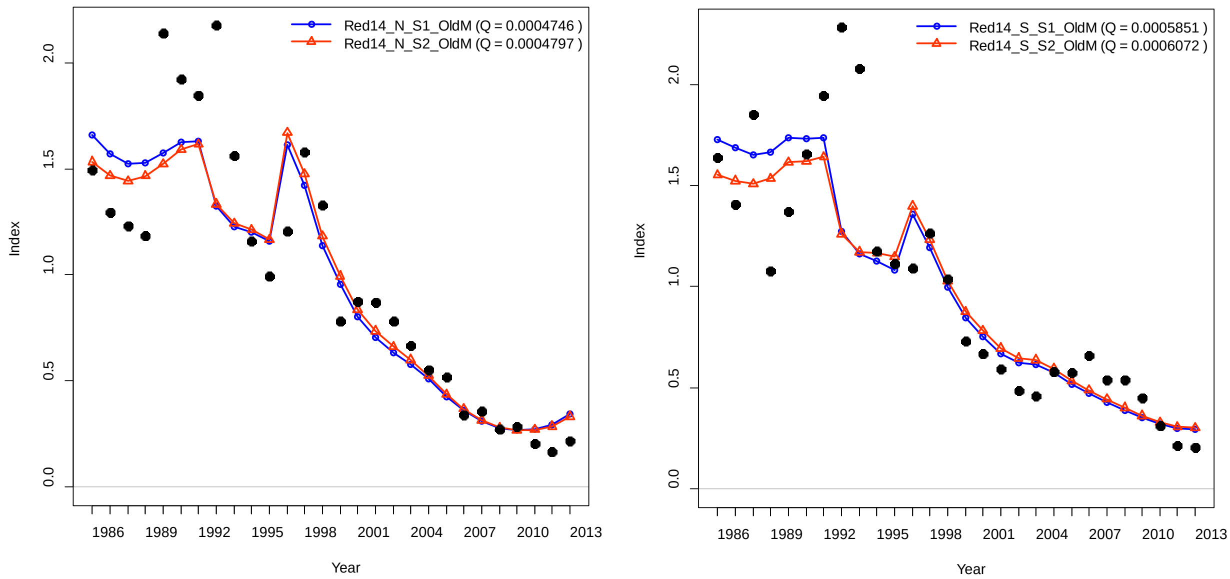

Figure 6.7. The fit to the annual catch rate series for the northern region (left) and southern region (right). Blue = scenario 1, Red = scenario 2.

The model is able to replicate the implied age-composition data reasonably well, particularly where the samples were from the separate sexes in the retained catch (Appendices p24-32). Age compositions from 2012 and 2013 seem to suggest that a relatively large recruitment may have moved into the available stock. This is also evident in the model estimates of recruitment for both regions. Length composition data are not as well estimated by the model, with early years showing an over-estimation of small fish, and later years showing a much narrower distribution of observed lengths compared to the model estimates (Appendices p18-19). Length fits for the southern region are particularly poor from 1988 onward. The length composition data for this stock appear to vary markedly from one year to the next; making model fitting difficult (e.g. 1997, 1998).

6.6.3 *Assessment outcomes*

The estimated time series of recruitment under the preliminary assessment models S1 and S2 for both regions show periods of strong recruitment, amongst a general declining trend (Appendices p11; Figure 6.8). The model estimates a recent large recruitment for both northern and southern regions, which is also evident in the age composition data for 2013.

The trajectories of spawning biomass (Figure 6.8) and spawning biomass relative to the un-exploited level (Appendices p9-10) show a general declining trend of stock status since 1975. Models for both regions show stock status moving below the limit reference point of 20% in 1999, with current stock status well below the limit (Appendices p10).

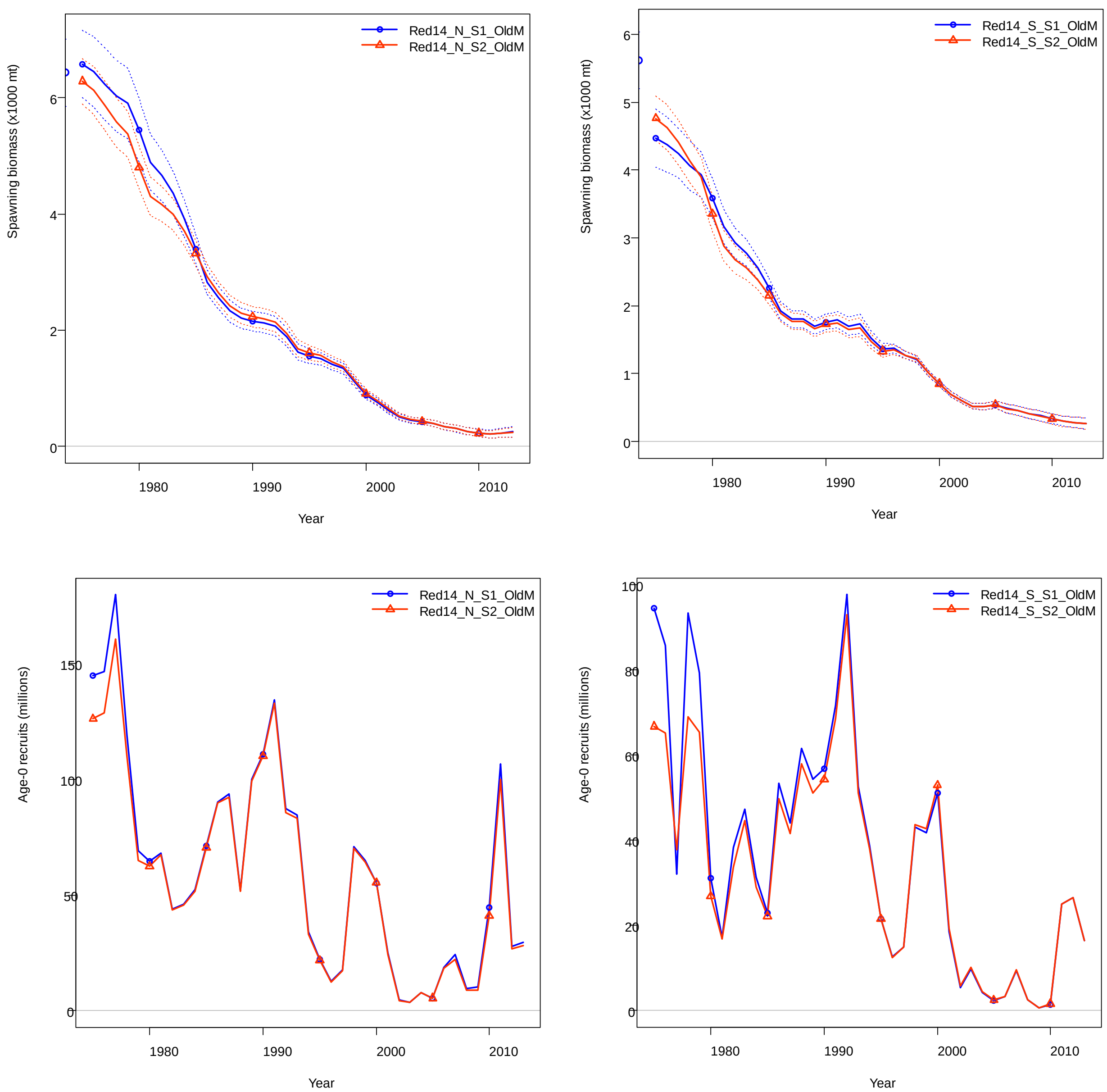

Figure 6.8.The annual time-series of female spawning biomass (top) and recruitment (bottom) for the northern (left) and southern (right) redfish regions. Blue = scenario 1, Red = scenario 2.

6.6.4 *Development towards the 2014 base-case*

1) Are the assumptions behind the catch time-series appropriate?
2) Are the time-block set-ups appropriate for retention and selectivity? Which of scenario S1 or S2 is favoured for years 1975 - 1985?
3) How should selectivity be refined to deal with the residual pattern in length fits?
4) Ensure composition data are included where appropriate and available
5) Consider Francis (2011) tuning method
6) Are assumptions about growth appropriate with respect to the different regions?
7) Should any of the current fixed parameters be estimated? M, growth
8) What sensitivities should be considered, e.g. with respect to historical discard rates, tuning methods, alternative parameters?
9) Should Kapala data be included?
10) What, if any, attention should be provided to FIS abundance indices?
11) Should the composition data from 2007 – 2009 be included?
12) Should a 'combined regions' model be considered?

6.7 Acknowledgements

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