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Citation

Sporcic, M. (2018). *Tier 4 Assessments for selected SESSF Species (data to 2017)*. CSIRO Oceans and Atmosphere, Hobart. 25 p.

Acknowledgements

Thanks goes to the CSIRO database team for their preliminary processing of the catch and effort (CPUE) and Catch Disposal Record (CDR) data as received from the Australian Fisheries Management Authority.

Use of this Report

Background

Tier 4 analyses have been performed for the following species and/or species groups: mirror dory east, mirror dory west, eastern deepwater shark, western deepwater shark and blue eye trevalla (Zone 20 - 50).

Due to recent revisions to annual landed catch estimates (see Castillo-Jordán et al. (2018), page 7), the reported annual landed catch in this report differ from those used in previous Tier 4 analyses for all species. In addition, there have been considerable changes to estimated discards based on recent revisions (see Burch et al. 2018, pp 2-4). These estimates are currently being reviewed and therefore were not used in this report for species which include discards as agreed by SERAG (minutes; Assessment meeting 1, 19-21 September 2018). Instead, the accepted discard series was used.

Introduction

Tier 4 Harvest Control Rule

The Tier 4 harvest control rules are the default procedure applied to species which only have catches and CPUE data available; specifically there is no other reliable information on either current biomass levels or current exploitation rates.

Ideally, in line with the notion of being more precautionary in the absence of information, the outcome from these analyses should be more conservative than those available from higher Tier analyses; this is now explicitly implemented by imposing a 15% discount factor on the RBC as a precautionary measure unless there are good reasons for not imposing such a discount on particular species. The application of the discount factor will occur unless RAGs generate explicit advice that alternative equivalent precautionary measures are in place (such as spatial or temporal closures) or that there is evidence of historical stability of the stock at current catch levels (AFMA, 2009).

In essence Tier 4 analyses require, as a minimum, a time series of total catches and of standardized catch rates.

The current Tier 4 analysis and control rule underwent Management Strategy Evaluation (Wayte, 2009, Little et al., 2011a), which demonstrated its advantages over an earlier implementation used in 2007 and 2008. Further work has since demonstrated that as long as there is a limit on increases and decreases to the RBC of no more than 50% then the notion of including a maximum RBC (at 1.25 times the target) is redundant (Little et al., 2011b).

Tier 4 Assumptions

Informative CPUE

There is a linear relationship between catch rates and exploitable biomass; *if there is hyper-stability (catch rates remain stable while stock size changes) or hyper-depletion* *(catch rates decline much faster than stock size changes) then the standard Tier 4 analysis would provide biased results*.

Consistent CPUE Through Time

The character of the estimated catch rates has not changed in significant ways through the period from the start of the reference period to the end of the most recent year; *If there has been significant effort creep altering the catchability, or there have been changes to the fleet that have altered the relative efficiency of the vessels fishing, or the catchability of the species by the fleet has been altered by other changes then the comparability of recent catch rates with the target period may be compromised. Such changes would obviously reduce the responsiveness of the Tier 4 method to change and may generate completely inappropriate management advice. Included in this clause are the effects of targeting or not targeting of deep water or aggregated species. When catch rates are extremely variable through time, such that mean estimates become unreliable measures of stock status, then the Tier 4 approach cannot be validly applied*.

Plausible Target Reference Period

The reference period provides a good estimate of the stock when at a depletion level of 48% unfished spawning biomass; *the Tier 4 method is based on catch rates and thus relates to exploitable biomass and not spawning biomass. As a minimum the reference period will refer to a period when the stock was in an acceptable, productive and sustainable state. But there can be no guarantees that the target aimed for is really* $B_{48\%}$.

Accurate Total Catch History

Accurate estimates are required for all catches from the stock under consideration during the accepted target period, irrespective of what method was used or whether it was retained or discarded. *This assumption is especially vulnerable to being breached when large proportions of catches are discarded. While there is a procedure for adjusting the standardized CPUE for these missed catches the uncertainty over the actual amount of fish killed remains.*

Some Implications of the Assumptions

The outcomes of the Tier 4 analysis should not be regarded with the same confidence as those from Tier 1 assessments. Even though they are termed stock assessments, in actuality they are empirical considerations of catches and CPUE. Any uncertainty in the catch or CPUE time-series is propagated directly through to the outputs of the analysis. For quota species the catches and reported CPUE is usually relatively well founded because of the quota catch disposal records and other compliance requirements. However, where there is a relatively high degree or variable discarding of catches this can lead to much greater levels of uncertainty.

At some point soon the assessments for those species that are conducted using a Tier 4 analysis should be reviewed for their inter-annual consistency and how the fishery has been responding to the management advice derived from the Tier 4 assessments.

Mirror Dory East Discard

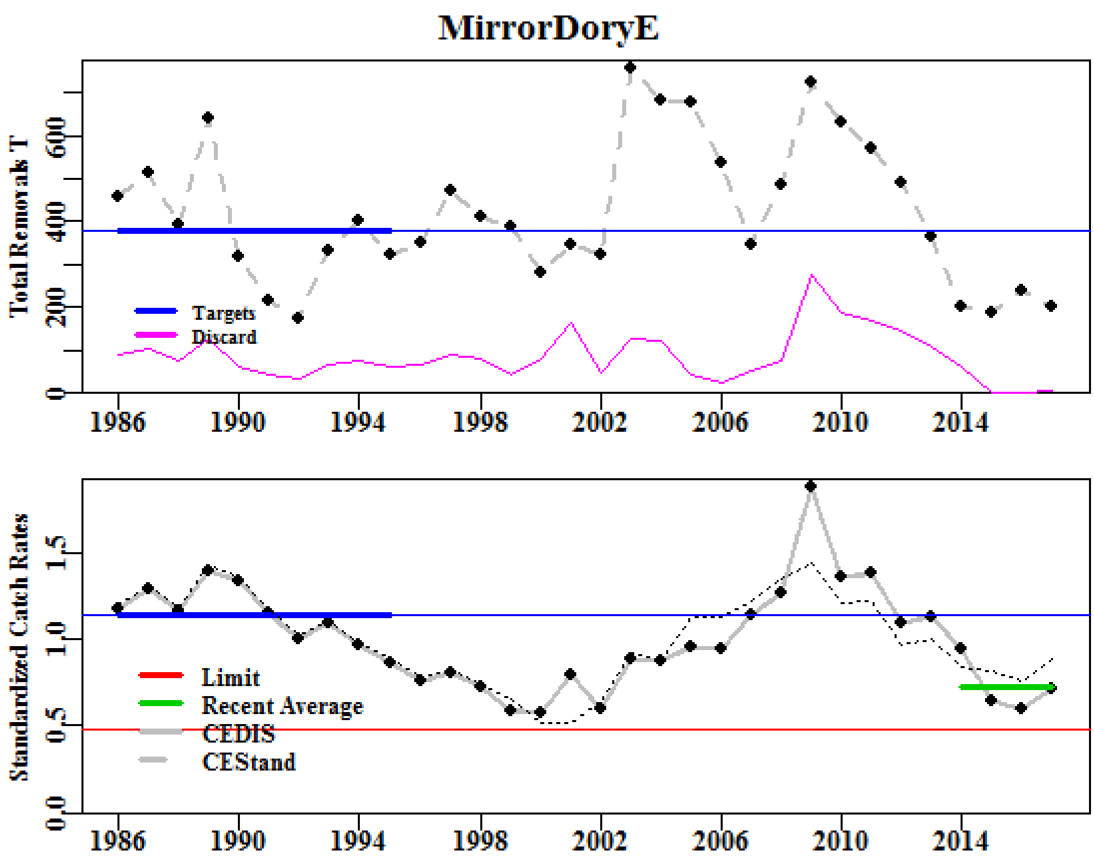

Figure 1: Mirror Dory 10 - 30 Discard. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represents the reference period for catches, catch rates, and the recent average catch rate. The thin black dotted line is the unmodified standardized CPUE before the inclusion of discards.

Table 1: Mirror Dory 10 - 30 Discard RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value		Parameter	Value
Reference_Years	1986 - 1995	|	Scaling	0.3723
CE_Target	1.1408	|	Last Year's TAC	235
CE_Limit	0.4753	|	Ctarg	377.051
CE_Recent	0.723	|	RBC	140.378
Wt_Discard	7.086	|	-	-

Table 2: Mirror Dory 10 - 30 Discard data for the Tier 4 calculations. Total (t) is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CE is the standardized catch rate (Sporcic and Haddon, 2018a). GeoMean is the geometric mean catch rates. Discards (D) are estimates from 1998 to present. The ratio of discards to catch over the 1998 - 2006 period was used to estimate the discards between 1986 and 1997. TAC refers to the Total Allowable Catch (t).

Year	Catch (C)	Discards	Total	(D/C)+1	CE	DiscCE	TAC	State
1986	368	91.091	459.076	1.248	1.1982	1.1748	-	0.000
1987	414	102.375	515.946	1.248	1.3086	1.2831	-	0.000
1988	313	77.539	390.776	1.248	1.1832	1.1601	-	0.000
1989	514	127.170	640.906	1.248	1.4209	1.3932	-	0.000
1990	254	62.969	317.349	1.248	1.3546	1.3282	-	0.000
1991	171	42.318	213.272	1.248	1.1750	1.1521	-	0.000
1992	140	34.765	175.206	1.248	1.0219	1.0020	-	0.000
1993	267	66.116	333.207	1.248	1.1081	1.0865	800	0.000
1994	304	75.158	400.287	1.248	0.9811	0.9620	800	21.509
1995	243	60.097	324.483	1.248	0.8838	0.8666	800	21.609
1996	262	64.963	348.875	1.248	0.7751	0.7600	800	21.477
1997	361	89.460	472.447	1.248	0.8227	0.8066	800	21.590
1998	303	79.350	409.636	1.262	0.7330	0.7268	800	27.041
1999	310	42.255	389.673	1.136	0.6482	0.5788	800	36.959
2000	190	81.131	281.973	1.428	0.5122	0.5748	800	11.174
2001	173	164.476	347.647	1.952	0.5125	0.7862	800	10.399
2002	257	45.720	324.683	1.178	0.6427	0.5949	640	21.701
2003	563	124.887	756.542	1.222	0.9222	0.8855	576	68.462
2004	452	122.544	680.661	1.271	0.8755	0.8748	576	106.415
2005	557	44.291	675.235	1.079	1.1224	0.9522	700	73.457
2006	427	23.351	535.355	1.055	1.1291	0.9360	634	85.429
2007	265	50.836	344.076	1.192	1.2151	1.1385	788	28.716
2008	390	75.461	487.896	1.193	1.3502	1.2663	634	22.090
2009	416	274.025	725.525	1.658	1.4348	1.8698	718	35.112
2010	430	187.155	628.674	1.436	1.2021	1.3565	718	12.019
2011	391	170.552	568.040	1.436	1.2191	1.3756	718	6.091
2012	339	147.835	492.729	1.436	0.9633	1.0870	718	5.630
2013	249	108.442	362.938	1.436	1.0005	1.1290	1077	5.632
2014	138	60.090	199.778	1.436	0.8364	0.9438	808	1.787
2015	184	1.112	187.175	1.006	0.8165	0.6456	437	1.790
2016	230	1.623	237.621	1.007	0.7520	0.5952	325	5.717
2017	189	4.685	199.545	1.025	0.8789	0.7079	235	5.718

Discussion

While recent catches have stabilized at a low level, the most recent standardized CPUE has increased. Previously, CPUE has followed catches and so the CPUE may be expected to increase in coming years. Usually, the Mirror Dory East fishery is assessed using the Tier 4 method that includes discards in the catches and CPUE (see the Methods Appendix and the next analysis). However, for the past three years the discards of Mirror Dory in the east have been small (see Table 2). Such low estimated discards has the potential to distort the analysis (especially given the recent years' discards are weighted more heavily). It was decided by SERAG (see minutes 2018 Assessment Meeting 1, 19-21 September 2018) that the Tier 4 analysis to include discards.

Mirror Dory West

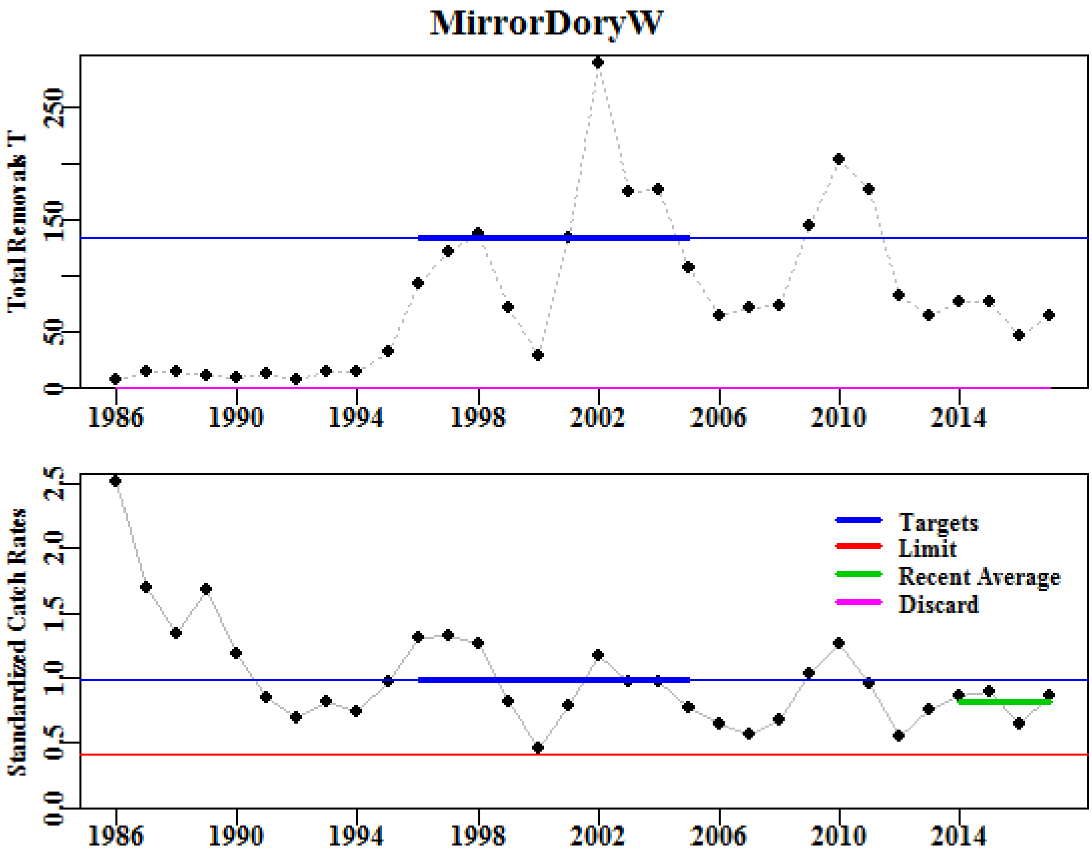

Figure 2: Mirror Dory 40 - 50. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represents the reference period for catches, catch rates, and the recent average catch rate.

Table 3: Mirror Dory 40 - 50 RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value		Parameter	Value
Reference_Years	1996 - 2005	|	Scaling	0.7114
CE_Target	0.9841	|	Last Year's TAC	235
CE_Limit	0.41	|	Ctarg	133.2
CE_Recent	0.8184	|	RBC	94.76
Wt_Discard	0	|	-	-

Table 4: Mirror Dory 40 - 50 data for the Tier 4 calculations. Total (t) is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CE is the standardized catch rate (Sporcic and Haddon, 2018a). GeoMean is the geometric mean catch rates. TAC refers to the Total Allowable Catch (t).

Year	Catch	Discards	Total	State	CE	GeoMean	TAC
1986	7	0	7.400		2.5065	1.7250	-
1987	16	0	15.500		1.6902	1.6740	-
1988	15	0	15.000		1.3418	1.7250	-
1989	11	0	11.100		1.6776	2.1006	-
1990	10	0	10.000		1.1809	1.7574	-
1991	13	0	12.800		0.8390	0.8254	-
1992	8	0	8.300	0.000	0.6899	0.6770	-
1993	15	0	14.753	0.000	0.8078	0.7790	800
1994	15	0	15.205	0.361	0.7446	0.6863	800
1995	31	0	31.613	0.765	0.9718	0.7141	800
1996	93	0	93.729	0.238	1.3141	1.0851	800
1997	120	0	120.546	0.350	1.3306	1.1361	800
1998	136	0	136.609	0.214	1.2597	1.2752	800
1999	72	0	72.108	0.220	0.8197	0.7883	800
2000	28	0	28.218	0.214	0.4551	0.3663	800
2001	134	0	134.192	0.215	0.7886	0.6538	800
2002	288	0	288.377	0.216	1.1661	1.1500	640
2003	175	0	175.424	0.274	0.9702	0.9599	576
2004	176	0	176.171	0.024	0.9700	0.9413	576
2005	107	0	106.623	0.039	0.7665	0.7048	700
2006	65	0	64.656	0.005	0.6387	0.7280	634
2007	71	0	71.395	0.005	0.5728	0.6631	788
2008	74	0	74.136	0.014	0.6743	0.7466	634
2009	145	0	144.954	0.000	1.0286	0.9274	718
2010	203	0	203.435	0.000	1.2548	1.2288	718
2011	177	0	177.026	0.001	0.9542	1.0109	718
2012	82	0	82.141	0.000	0.5584	0.7837	1077
2013	65	0	65.203	0.002	0.7540	0.9645	1077
2014	77	0	76.908	0.001	0.8673	0.9089	808
2015	77	0	77.321	0.002	0.8885	0.8068	437
2016	47	0	46.569	0.002	0.6516	0.7651	325
2017	65	0	64.549	0.002	0.8662	0.7419	235

Discussion

The increases and decreases in catches and CPUE in the western SESSF zones occur more rapidly than in the eastern zones. With the fishery only beginning to report significant catches from about 1996 onwards the reference period used is relatively recent. Nevertheless there are now eight years between the reference period and the start of the most recent four years used to denote the current state of the fishery. CPUE in recent years is not as depressed in relative terms as on the east (Zone 10-30).

Eastern Deepwater Shark

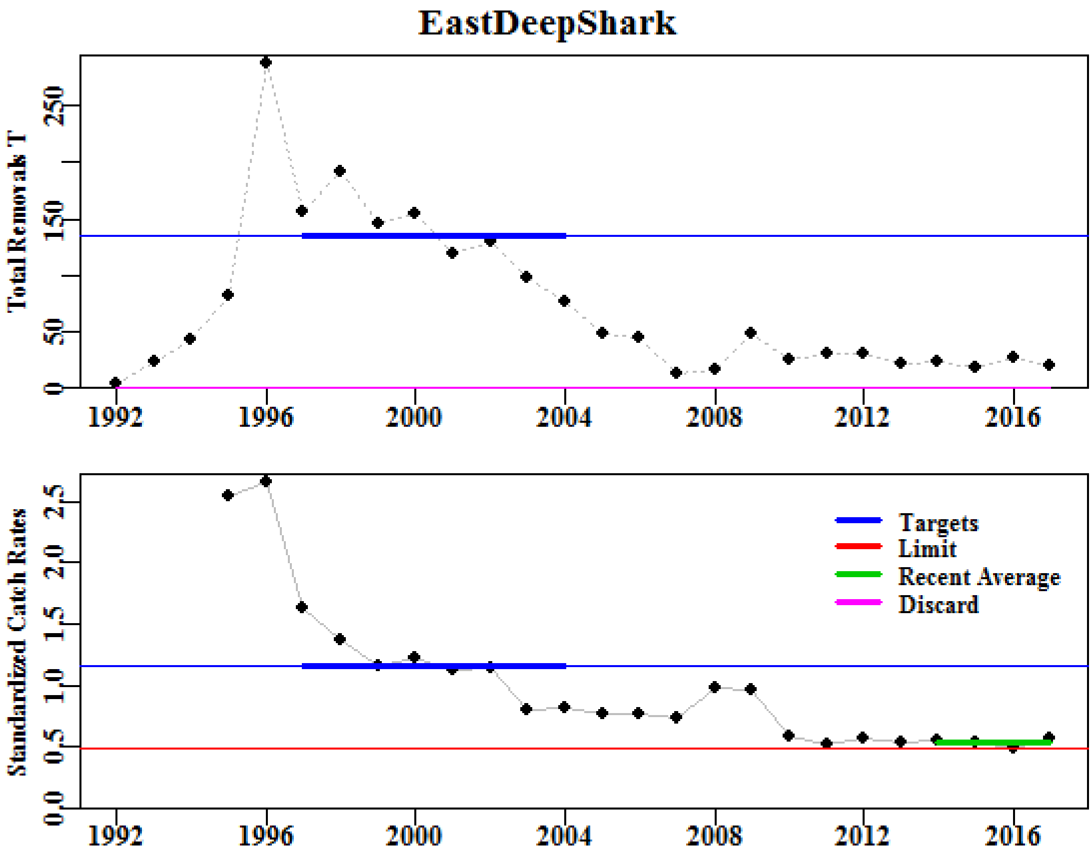

Figure 3: Eastern Deepwater Shark. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represents the reference period for catches, catch rates, and the recent average catch rate.

Table 5: Eastern Deepwater Shark RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value		Parameter	Value
Reference_Years	1997 - 2004	|	Scaling	0.0743
CE_Target	1.1592	|	Last Year's TAC	47
CE_Limit	0.483	|	Ctarg	134.443
CE_Recent	0.5332	|	RBC	9.993
Wt_Discard	0	|	-	-

Table 6: Eastern Deepwater Shark data for the Tier 4 calculations. Total (t) is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CE is the standardized catch rate (Sporcic and Haddon, 2018a). GeoMean is the geometric mean catch rates. TAC refers to the Total Allowable Catch (t).

Year	Catch	Discards	Total	State	CE	GeoMean	TAC
1992	4	0	4.232	0			-
1993	23	0	22.950	0			-
1994	43	0	42.750	0			-
1995	82	0	82.247	0	2.5450	4.7268	-
1996	288	0	287.778	0	2.6525	2.5186	-
1997	157	0	157.159	0	1.6361	1.3790	-
1998	192	0	192.378	0	1.3747	1.1839	-
1999	147	0	146.646	0	1.1579	0.9711	-
2000	154	0	154.416	0	1.2259	1.2127	-
2001	119	0	119.493	0	1.1293	1.1063	-
2002	130	0	130.456	0	1.1450	1.0819	-
2003	98	0	97.858	0	0.7970	0.8292	-
2004	77	0	77.136	0	0.8075	0.7738	-
2005	47	0	47.427	0	0.7704	0.8602	92
2006	45	0	45.358	0	0.7674	0.7228	92
2007	13	0	13.119	0	0.7296	0.2838	21
2008	17	0	16.590	0	0.9746	0.5631	50
2009	48	0	47.514	0	0.9569	0.8048	75
2010	26	0	25.668	0	0.5852	0.4789	85
2011	31	0	30.619	0	0.5148	0.4745	85
2012	30	0	30.179	0	0.5673	0.4722	85
2013	21	0	21.278	0	0.5297	0.4545	85
2014	23	0	23.021	0	0.5460	0.4212	47
2015	18	0	18.343	0	0.5298	0.5188	47
2016	26	0	26.216	0	0.4928	0.5964	47
2017	21	0	20.548	0	0.5644	0.5654	47

Discussion

The catch and effort database currently only has data for a limited number of the many species listed under the basket species in AFMA (2017). However, the listing omits important reporting codes (see Haddon and Sporcic, 2017) such as the ‘Pearl Shark’ (a combination of *Deania calcea* and *quadrispinosa* = 37020905) and the ‘Black Shark - (roughskin)’ (*Centroscymnus* spp. = 37020906). Even less specific are the codes ‘dogfishes’ (37020000) and ‘Shark Other’ (37990003), which were the primary reporting categories prior to 1995, which is the start year for the deepwater shark CPUE analyses, although those codes have been almost negligible since about 2003. The main species in the logbooks currently is still the ‘Pearl Shark’ code (37020905) which is specifically not included in the Management Arrangements booklet (AFMA, 2017). In previous years these composite codes for the logbooks were used in the standardizations and it would appear that they are accounted for in the catch disposal records as the end-of-season total catches can only be approximated by the log-books if the composite codes are included. For these reasons the standardizations were conducted including the composite codes and the CPUE document (Sporcic and Haddon, 2018a) should be inspected for details of these analyses. The current listing of deepwater shark species includes a number of *Etmopterus* species which have only recently been described beyond *Etmpoterus* A, B, C, D, and E. Given the difficulty in identifying such species it would appear ambitious to expect untrained commercial fishers to be able to identity these new species rather than use a generic 'Pearl' shark category. It is recommended that such details be clarified in future management arrangement booklets.

By contrast to previous Tier 4 analyses, catches in this analysis are based on open areas only. Catches of deepwater sharks in the east dropped rapidly in 2007 following the onset of the deepwater closure (Figure 3; Table 6). There was a temporary increase in 2009 when the 700 m boundary was revised to open a few parts of the closure, but catches remain low and are only increasing slowly. Given that the preferred depth of these target species can be greater than 700 m, the advent of the closure may have contributed greatly to the decline in CPUE apparent in the analysis (Figure 3; Table 6).

Western Deepwater Shark

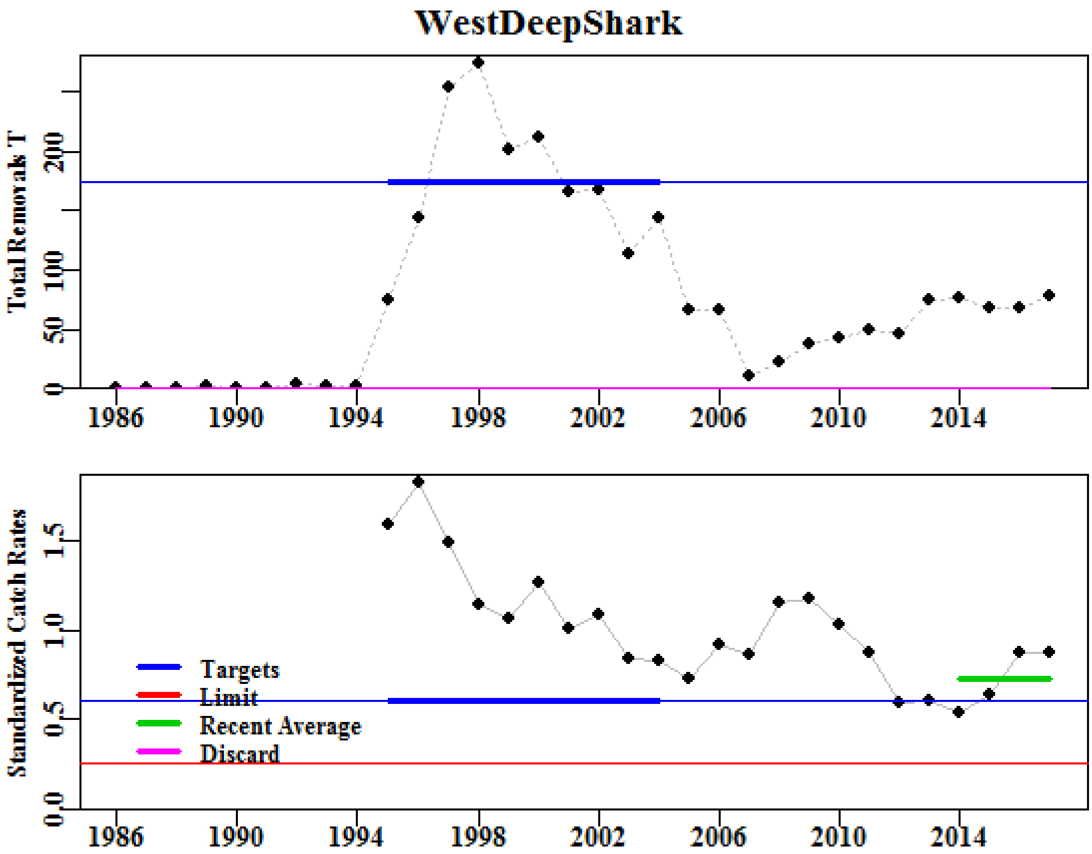

Figure 4: Western Deepater Shark. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represents the reference period for catches, catch rates, and the recent average catch rate.

Table 7: Western Deepater Shark RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value	Parameter	Value
Reference_Years	1995 - 2004	Scaling	1.3442
CE_Target	0.6073	Last Year’s TAC	215
CE_Limit	0.253	Ctarg	174.849
CE_Recent	0.7292	RBC	235.036
Wt_Discard	0	-	-

Table 8: Western Deepater Shark data for the Tier 4 calculations. Total (t) is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CE is the standardized catch rate (Sporcic and Haddon, 2018a). GeoMean is the geometric mean catch rates. TAC refers to the Total Allowable Catch (t).

Year	Catch	Discards	Total	State	CE	GeoMean	TAC
1986	0.970	0	0.970	0			-
1987	0.545	0	0.545	0			-
1988	0.105	0	0.105	0			-
1989	1.490	0	1.490	0			-
1990	0.000	0	0.000	0			-
1991	0.480	0	0.480	0			-
1992	3.780	0	3.780	0			-
1993	1.995	0	1.995	0			-
1994	1.552	0	1.552	0			-
1995	75.219	0	75.219	0	1.5918	1.4865	-
1996	143.247	0	143.247	0	1.8222	1.6110	-
1997	253.317	0	253.317	0	1.4908	1.4905	-
1998	273.775	0	273.775	0	1.1480	1.1530	-
1999	201.927	0	201.927	0	1.0615	1.0124	-
2000	210.835	0	210.835	0	1.2627	1.2695	-
2001	165.234	0	165.234	0	1.0079	1.0365	-
2002	167.357	0	167.357	0	1.0901	1.2093	-
2003	113.102	0	113.102	0	0.8407	0.7995	-
2004	144.482	0	144.482	0	0.8300	0.8999	-
2005	66.806	0	66.806	0	0.7222	0.8115	108
2006	65.480	0	65.480	0	0.9179	0.9361	108
2007	10.261	0	10.261	0	0.8644	0.7633	10
2008	22.257	0	22.257	0	1.1553	1.0285	50
2009	37.634	0	37.634	0	1.1731	1.0526	63
2010	42.093	0	42.093	0	1.0267	1.0044	95
2011	49.623	0	49.623	0	0.8750	0.8838	143
2012	45.989	0	45.989	0	0.5968	0.6307	215
2013	75.439	0	75.439	0	0.6061	0.6147	215
2014	76.399	0	76.399	0	0.5405	0.5584	215
2015	67.885	0	67.885	0	0.6318	0.6910	215
2016	67.135	0	67.135	0	0.8702	1.0084	215
2017	78.757	0	78.757	0	0.8744	1.0486	215

Discussion

The western deepwater sharks have similar issues to the eastern deepwater sharks regarding the codes used to report their catches. Thus the primary species code used relates to 'Pearl Shark' (a combination of *Deania calcea* and *quadrispinosa* = 37020905) followed by the platypus shark (which, unlike the Pearl Shark, is on the Management Arrangements list). The Platypus shark is *Deania quadrispinosa*, which is included as one of the components of the 'Pearl Shark', which suggests that the reliability of the species identities may not be high (which is no insult to the commercial fishers as taxonomically separating these species is not always straightforward). When currently management does not require the separation of inshore and offshore Ocean Perch it would be oddly inconsistent to expect fishers to separate at least 18 different species of Lantern sharks.

By contrast to previous Tier 4 analyses, catches in this analysis are based on open areas only.

Blue Eye Non-Trawl

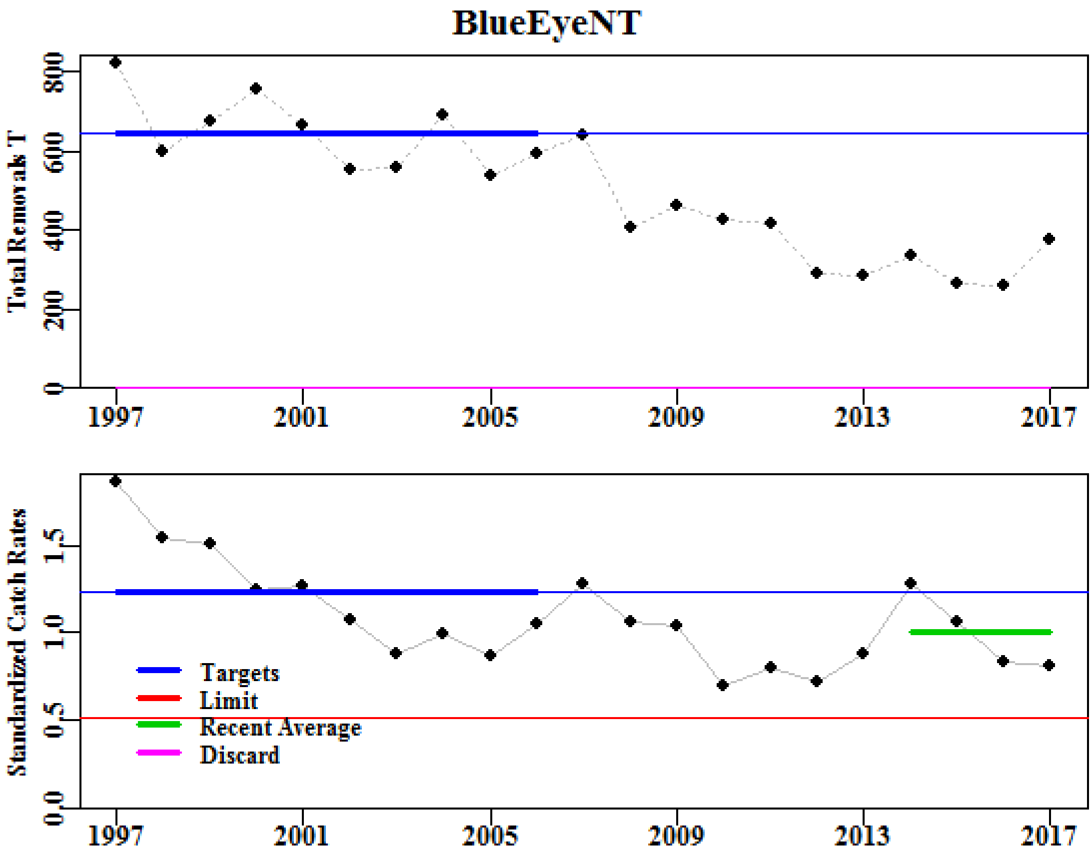

Figure 5: Blue-Eye. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represents the reference period for catches, catch rates, and the recent average catch rate.

Table 9: Blue-Eye RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value		Parameter	Value
Reference_Years	1997 - 2006	|	Scaling	0.6799
CE_Target	1.2288	|	Last Year's TAC	458
CE_Limit	0.512	|	Ctarg	645.263
CE_Recent	0.9994	|	RBC	438.697
Wt_Discard	0	|	-	-

Table 10: Blue-Eye data for the Tier 4 calculations. Total (t) is the sum of Discards, State (Vic, Tas and NSW), Non Trawl and SEF2 catches. All values in Tonnes. CE is the standardized catch rate (Sporcic and Haddon, 2018a). GeoMean is the geometric mean catch rates. TAC refers to the Total Allowable Catch (t).

Year	Catch	Discards	Total	State	CE	GeoMean	TAC
1997	202	0	821.654	620.141	1.8588		125
1998	474	0	597.101	123.012	1.5397		630
1999	544	0	676.578	132.608	1.5036		630
2000	658	0	757.291	98.983	1.2457		630
2001	575	0	662.430	87.133	1.2633		630
2002	453	0	555.398	102.362	1.0782		630
2003	508	0	559.752	51.704	0.8813		690
2004	627	0	691.737	64.538	0.9970		621
2005	483	0	538.353	55.638	0.8661		621
2006	548	0	592.332	44.095	1.0545		560
2007	585	0	638.553	53.102	1.2832		785
2008	373	0	408.359	34.980	1.0579		560
2009	428	0	463.579	35.090	1.0410		560
2010	383	0	426.149	43.287	0.7002		428
2011	376	0	418.651	42.377	0.8042		326
2012	259	0	290.136	31.317	0.7236		388
2013	264	0	285.982	22.135	0.8756		388
2014	318	0	337.104	18.619	1.2849		335
2015	236	0	263.983	27.591	1.0634		335
2016	242	0	257.269	15.708	0.8379		410
2017	360	0	375.817	15.708	0.8112		458

Discussion

This analysis (unlike the previous Tier 4 analysis), is based on landed catch corresponding to Zones 20 - 50, i.e., it excludes areas corresponding to seamounts. A separate seamount (Tier 5) analysis was conducted for this species.

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Appendix: Methods

Tier 4 Harvest Control Rule

The data required are time series of catches and catch rates. The analyses have been conducted on total catches across the entire SESSF (including State catches, SEF2 landing records, and any discards). For some species, where there is only a single stock and a single primary fishing method, analyses are presented using standardized CPUE data (Haddon, 2014). For other species, there may be multiple stocks or areas or multiple methods and selecting which time series of catch rates to use in the analyses is not always straightforward. In those cases, the standardized time series for the method now accounting for the majority of current catch was used.

All 2010 data relating to catches and discards, from both State waters and SEF2 data sets, were provided by AFMA, with initial processing by N. Klaer and J. Upston of CSIRO. All catch rate data were derived from the standard commercial catch and effort database processed by the data services Team at CSIRO Hobart.

Standard analyses were set up in the statistical software, R Core Team (2018), which provided the tables and graphs required for the Tier 4 analyses. The data and results for each analysis are presented for transparency. The Tier 4 harvest control rule formulation essentially uses a ratio of current catch rates with respect to the selected limit and target reference points to calculate a scaling factor for the current year. This scaling factor is applied to the target catch to generate an RBC. To generate a TAC, known discards and State catches are first removed and then, if applicable, the 15% discount is applied. The TAC calculations are conducted by AFMA. This report focusses on providing the estimates of the Recommended Biological Catches.

$$\text{Scaling Factor } = SF_t = \max\left(0, \frac{\overline{CPUE} - CPUE_{\text{lim}}}{CPUE_{\text{targ}} - CPUE_{\text{lim}}}\right)$$

$$RBC = C_{\text{targ}} \times SF_t$$

If new data becomes available, for example, more State data has become available this year, or other large changes occur in the catch rates then the RBC could undergo large changes. Such changes are constrained by the following limits:

$$\begin{array}{ll} RBC_y = 1.5RBC_{y-1} & RBC_y > 1.5RBC_{y-1} \\ RBC_y = 0.5RBC_{y-1} & RBC_y < 0.5RBC_{y-1} \end{array}$$

where

1. RBC_y is the RBC in year *y*,
2. $CPUE_{\text{targ}}$ is the target CPUE for the species,
3. $CPUE_{\text{lim}}$ is the limit CPUE for the species = 0.4 * $CPUE_{\text{targ}}$,
4. $\overline{CPUE}$ is the average CPUE over the past *m* years; *m* tends to be the most recent four years,

5. C_{targ} is a catch target derived from a period of historical catch that has been identified as a desirable target in terms of CPUE, catches and status of the fishery, e.g. 1986 – 1995. This is an average of the total removals for the selected reference period, including any discards.

$$C_{\text{targ}} = \frac{\sum_{y=yr1} \; yr2 L_y}{(yr2 - yr1 + 1)}$$

where L_y represents the landings in year *y*.

$$CPUE_{\text{targ}} = \frac{\sum_{y=yr1}^{yr2} CPUE_y}{(yr2 - yr1 + 1)}$$

where $CPUE_y$ is the catch rate in year *y*, *yr2* and *yr1* represent the last and the first years in the reference period respectively.

Percent discards are estimated from ISMP observations from 1998 to the current year. Discards for earlier years, prior to ISMP sampling, are generally estimated by taking the overall average percent discard from 1998 to the 2006 and applying that discard rate to the reported landings for the earlier years. The year 2006 was selected as the final year as discarding practices altered at about that time following the structural adjustment and the introduction of the Harvest Strategy Policy. For Eastern Gemfish the average discard rate was determined for 1998-2002 to allow for the non-target nature of the fishery following 2002. The calculation of the earlier discards is done so that the total catches can be estimated even though only the landed catches are available. To calculate the discards for a given year we used:

$$D_y = \frac{C_y \overline{D}_{98-06}}{\left(1 - \overline{D}_{98-06}\right)}$$

Discard proportions for the projected year for which the RBC is being calculated are taken as a weighted mean of the previous four years:

$D_{\text{CUR}} = (1.0\ D_{y\text{-}1} + 0.5\ D_{y\text{-}2} + 0.25\ D_{y\text{-}3} + 0.125\ D_{y\text{-}4})/1.875$

where D_{CUR} is the estimated discard rate for the coming year *y*, $D_{y\text{-}1}$ is the discards rate in year *y-1*. The discard rate in year *y* is the ratio of discards to the sum of landed catches plus those discards (this can vary between 0 – 100%):

$$D_y = \frac{Discard_y}{\left(Catches_y + Discard_y\right)}$$

For each species, reference years were selected by the RAGs to generate estimates of target catches and target catch rates. In addition, a decision was required as to whether the fishery could be considered as fully developed or otherwise. Where a fishery was not con-sidered to be fully developed the target catch rate, $CPUE_{\text{targ}}$, was divided by two as a proxy for expected changes to catch rates as the fishery develops and the resource stock size declines towards the target of 48% unfished biomass.

Plots are given of the total removals illustrating the target catch level. In addition, the standard-ized catch rates are illustrated with the target catch rate and the limit catch rate. Finally, where the data are available, plots are given of the Total removals contrasted with State removals, and of discards and non-trawl catches.

The Inclusion of Discards

Some species, especially redfish (*Centroberyx affinis*) and inshore Ocean Perch (*Helicolenus percoides*), have experienced high levels of discarding but the reported catch rates relate only to the estimated landed weights. In those species where discarding makes up a significant proportion of the catch (in some years more redfish were discarded than landed and more inshore ocean perch tend to be discarded than landed) it is reasonable to ask how the discards would have affected catch rates. This is an important question because standardized commercial catch rates are used in Australian stock assessments as an index of relative abundance (Haddon, 2014); if ignoring discards leads to a consistent bias this could affect the outcome of the assessments and thus, the assessments should become aware of the effects of discards.

Catch rates are used in assessments as an index of relative abundance through time and it is the trends exhibited by the catch rates that are important rather than their absolute values. If the discard levels are relatively constant through time and evenly distributed amongst the fleet, then their inclusion would not be expected to influence the trends in catch rates except to add noise. In all cases the discard rates are estimates based on sub-sampling the fleet of vessels. That the estimates are uncertain can be seen simply by considering the summary data tables in this document; where discards rates are not low they are very variable between years. Redfish provide an extreme where in 1998 the estimate was 2324 t, which was nearly 56 % of the total catch, while in 1999 discards estimated at only 69 t, making up on about 5 % of the total catch. So in those cases where discard levels are low, adding discards to the estimation of catch rates is not expected to alter outcomes.

For those species, such as redfish and ocean perch, where discard rates are much higher it was decided to include those estimated catches to determine their effect on the outcome of the Tier 4 analyses. In 2010 it was concluded that while the inclusion of discards contributed a great deal of noise to the analyses, for those species where discarding made up significant proportions of the overall catch the discard augmented catch rates should be examined each year as a sensitivity analysis to contrast with the outcome from the un-augmented catch rates (Haddon, 2010).

Analyses Including Discards

Discard rates cannot simply be added to known catches on the way to calculating catch rates. The standardized catch rates are estimated from individual catch and effort records but the estimates of discards are summary estimates for each fishery. While a method for incrementing the standardized catch rates has been developed it should be noted that this ignores all complications relating to unknown aspects of discarding behaviour (is the discard rate constant across all catch sizes, across all vessels, across all areas? etc). This means that including discard catches into the annual catch rate estimates introduces an unknown amount of uncertainty into the analysis. It should also be noted that the discard estimates are highly variable from year to year and derive from relatively small samples of all trips contributing to catches.

The method developed was to find the multiplier needed to adjust ratio mean catch rates and apply that to the standardized catch rates (Haddon, 2010). The ratio mean catch rates require the annual sum of catches for the fishery along with the sum of effort and ratio means calculated for each year. The discard estimates from the fishery can be added to the catch totals and new ratio means calculated and compared. The multiplier needed to make the same changes to the ratio mean catch rates can then be developed and applied to the standardized catch rates.

The ratio mean is simply the sum of all catches divided by the sum of effort

$$\hat{I}_{R,t} = \frac{\sum C_t}{\sum E_t}$$

where $\hat{I}_{R,t}$ is the ratio mean catch rate for year *t*, $\sum C_t$ is the sum of landed catches in year *t*, and $\sum E_t$ is the sum of effort (as hours trawled) in year *t*. If $\sum D_t$ is the sum of discards in year *t* then the discard incremented ratio mean catch rate would be:

$$\hat{I}_{D,t} = \frac{\sum C_t + \sum D_t}{\sum E_t}$$

The same values of $\hat{I}_{D,t}$ can also be obtained using the following multiplier:

$$\hat{I}_{D,t} = [(\sum D_t / \sum C_t) + 1] \times I_t$$

where I_t is the catch rate estimate to be modified by the inclusion of discards. If this is the ratio mean then the augmented catch rates would be identical to the first equation dealing with $\sum D_t$. In practice, the catch rates used with the multiplier are the standardized catch rates (e.g. Haddon, 2014).

The Limitations of Including Discards

The discard rates are estimated as the proportion of the total catch (= landed catch plus discards), which means that discard proportions greater than 0.5 imply that more fish are discarded than landed. To calculate the discarded catches from a discard rate and the landed catches we use:

$$D_t = \left(\frac{C_t}{1 - P_t}\right) - C_t$$

where D_t is the discarded catches in year *t*, C_t is the total landed catches in year *t*, and P_t is the proportion of discards in year *t*. Because the divisor is $1 - P_t$ as P_t tends to 1.0 the divisor becomes very small and hence acts as a multiplier on total landed catch C_t. The effect of this is that when P_t is estimated to be above 0.5 the multiplying effect in the calculation of discards becomes grossly exaggerated (Figure 8).

It is recommended that once discard proportions are estimated to be above 0.5 or 0.6 then attention needs to be paid to whether or not the inclusion of discards into the CPUE and the calculation of the RBC can be considered valid. In such cases, for example Inshore Ocean Perch, the Tier 4 analysis may need to be rejected and some alternative adopted.

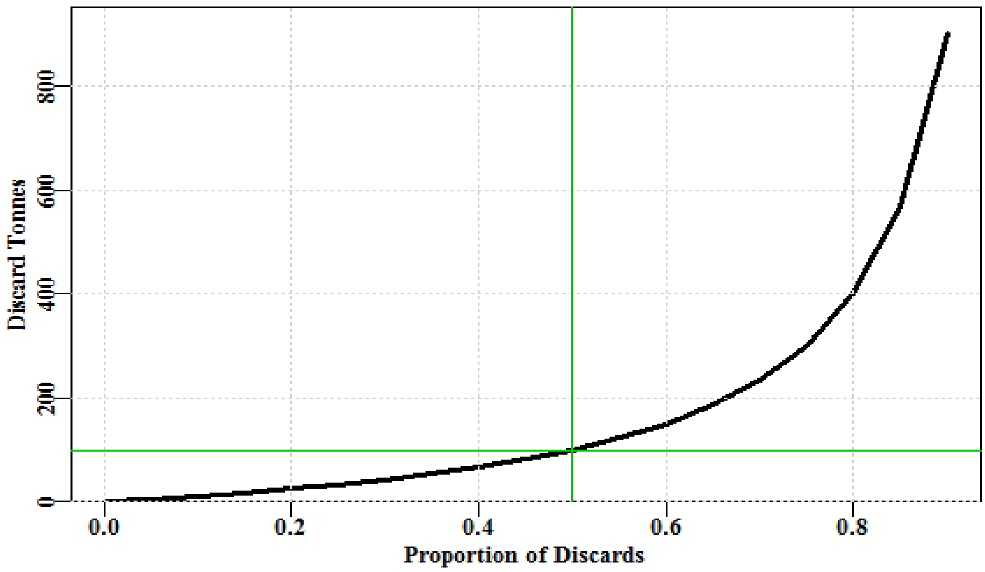

Figure 6: The influence of the proportion discarded on estimates of discarded catches. As the proportion of discards approaches 1.0 the multiplying effect in the estimation of discard amounts becomes greatly amplified.

Selection of Reference Periods

The Tier 4 requires a reference period to be selected in order to establish target and limit levels of catch rates and associated target levels of catch that are deemed by the RAG to act as a proxy for the desired state for the fishery. These act as a proxy for the Harvest Strategy Policy reference points of 48% and 20% unfished spawning biomass. The original Tier 4 rule that used a linear regression of the last four year's catch rates to determine whether catches increase or decrease was not able to rebuild a resource towards a desired target level and the current approach was developed so as to be able to manage a fishery towards a target and away from a limit.

The essence of the Tier 4 control rule is that it sets a RAG agreed target catch rate, which has an associated target catch. An estimate of current catch rates (usually the average of the last four years) is compared with the target and a multiplier is estimated which is to be applied to the target catch to generate the recommended biological catch.

To select a reference period requires a time series of comparable catch rates. For this reason the use of standardized catch rates should be an improvement over using, for example, the ob-served arithmetic or geometric mean catch rates. Catch rate data is available in the SESSF for all targeted species from 1986 - 2011, although it needs to be noted that the character of the fishery has changed markedly during that period. Little et al. (2009) provide a discussion on how reference periods might be selected. They proposed a default ten year period of 1986 – 1995, stating: "We have assumed that the average CPUE from 1986 to 1995 corresponds to that which would be attained if the stock were at the level that provides the maximum economic yield, B_{MEY}. The limit CPUE is 40% of this CPUE." (Little et al., 2009, p 234).

For each species, reference years were selected by the RAGs to generate estimates of target catches and target catch rates. In addition, a decision was required as to whether the fishery could be considered as fully developed or otherwise during the reference period or not. Where a fishery was not considered to be fully developed the target catch rate, CPUE targ, was divided by two as a proxy for expected changes to catch rates as the fishery develops and the resource stock size declines towards the assumed proxy target for 48% unfished biomass.

Little et al. (2009) proposed three rules used to estimate the CPUE target:

1. The CPUE target for stocks fully exploited at or prior to 1986 is based on the average CPUE from 1986-1995.
2. Where fishing exploitation up to 1986 is thought to be minimal, the CPUE determined in step 1 is halved (to provide a catch rate proxy for B_{MEY}).
3. Where fishing exploitation after 1986 is low, the first year in which catches are above 100t signifies the start of the 10 year period for which CPUE targeted is calculated.