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Review of the time series of input data available for the assessment of southern blue whiting (*Micromesistius australis*) stocks

New Zealand Fisheries Assessment Report 2013/69

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This document compiles the large amount of research carried out on southern blue whiting over the past 20 years into one document. We have included here age and growth biological parameters, time series of relative abundance from acoustic surveys for each of the four main stocks (both from the wide area R.V. *Tangaroa* surveys and the local aggregation industry vessel surveys), CPUE indices for Bounty Platform and Campbell Island Rise, and trawl survey indices for the Auckland Islands Shelf, Campbell Island Rise, and Pukaki Rise, as well as updated time series of length-at-age and catch-at-age.

The main source of information on southern blue whiting stock size remains the acoustic indices from wide area surveys on the Campbell Island Rise and local aggregations surveys on the Bounty Platform. Aggregation surveys for southern blue whiting on the Pukaki Rise have so far been largely unsuccessful with high variability between snapshots and years. Estimates of southern blue whiting abundance from the sub-Antarctic trawl surveys on the Auckland Islands Shelf, Campbell Island Rise, and Pukaki Rise were available, but do not appear to provide an effective source of abundance information for monitoring these fisheries.

The catch on the Bounty Platform in recent years has been dominated by the strong 2002 year class, with no evidence for further recruitment until 2011 when the 2007 year class entered the fishery. On the Campbell Island Rise, there was strong evidence of several year classes of moderate strength, with both acoustic indices and commercial-catch-at-age proportions suggesting strong recruitment in 2006 and 2007; and the acoustic indices suggesting another strong year class in 2009. Very few otoliths were collected from the Pukaki Rise and Auckland Islands in 2011 and so the catch data have not been aged and the length data in recent years are not sufficient to infer when or if strong recruitment has entered those fisheries.

1. INTRODUCTION

Southern blue whiting are almost entirely distributed in sub-Antarctic waters. They are dispersed throughout the Campbell Plateau and Bounty Platform for much of the year, but during August and September they aggregate to spawn near the Campbell Islands, on Pukaki Rise, Bounty Platform, and near the Auckland Islands over depths of 250–600 m (Figure 1). During most years fish in the spawning fishery range between 35–50 cm fork length (FL), although occasionally smaller size classes of males (29–32 cm FL) are observed in the catch.

Commercial fishing has concentrated on the Campbell Island Rise and, to a lesser extent, the Bounty Platform. Stock assessments for southern blue whiting on the Campbell Island Rise and the Bounty Platform have been conducted at approximately biennial intervals using age-structured stock assessment models. Model inputs have included time series of acoustic survey indices, commercial catch-at-age composition data, and in earlier years, CPUE indices.

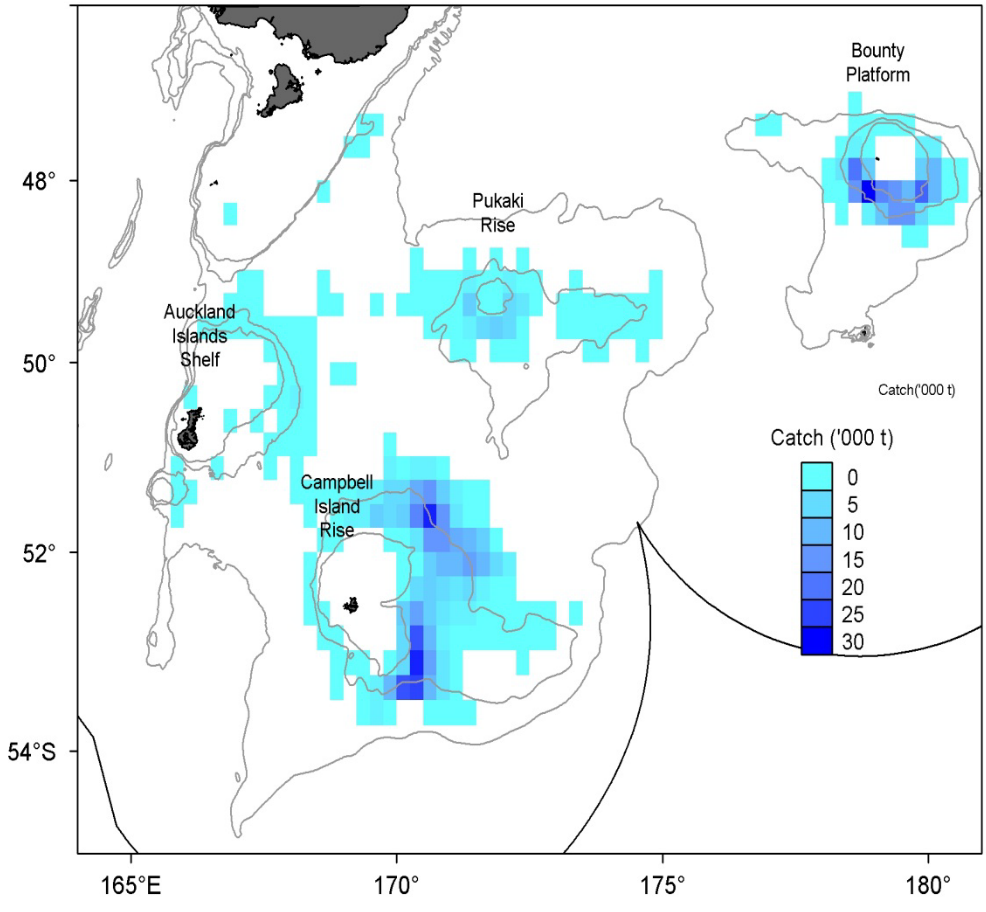

Figure 1: Total cumulative commercial catch of southern blue whiting by location, TCEPR data 1990–2011.

A large amount of research has been carried out on southern blue whiting, including work on stock structure (Hanchet 1998, Hanchet 1999), age and growth (Hanchet & Uozumi 1996), catch-at-age (e.g., Hanchet et al. 2003, Hanchet 2005), acoustic surveys (e.g., O'Driscoll et al. 2009), CPUE analyses (e.g., Hanchet & Blackwell 2003, Hanchet et al. 2005), trawl surveys (Hanchet & Stevenson 2006), and stock assessments (e.g., Dunn & Hanchet 2011a, Dunn & Hanchet 2011b). The objective of this report is to summarise and document the time series of input data which could be used for stock assessment. Further, we revise and update the commercial catch-at-age proportions for the Bounty Platform, Campbell Island Rise, and Pukaki Rise. This report updates the summary provided by Hanchet & Dunn (2010).

This report is in partial fulfilment of the Ministry of Primary Industries Project DEE201002SBWA: To carry out stock assessments of southern blue whiting (*Micromesistius australis*), including estimating biomass and sustainable yields.

2. FISHERY SUMMARY

The data described in this report were based on data extracts from the Ministry of Fisheries Catch-Effort database in November 2011 (REPLOG 8197), the Ministry of Fisheries Observer database in December 2011, and the Ministry of Fisheries Trawl Survey database in March 2012.

2.1 Commercial fisheries

Catch quotas, allocated to individual operators, were introduced for the first time in the 1992–93 fishing year. The catch limit of 32 000 t, with stock-specific sub-limits, was retained for the next three years (Table 1). The stock-specific sub-limits were revised for the 1995–96 fishing year, and the total catch limit increased to 58 000 t in 1996–97 for three years (Table 1). In 1997–98, a separate catch limit of 1640 t was set for the Auckland Islands fishery for the first time.

The southern stocks of southern blue whiting were introduced to the Quota Management System on 1 November 1999 with the following TACCs: Auckland Islands (SBW 6A) 1640 t, Bounty Platform (SBW 6B) 15 400 t, Campbell Island Rise (SBW 6I) 35 460 t, and Pukaki Rise (SBW 6R) 5500 t (Table 1). At the same time, the fishing year was changed to 1 April to 31 March to reflect the timing of the main fishing season. SBW has been managed using a Current Annual Yield (CAY) strategy (Annala et al. 2004), which has contributed to the fluctuating catch limits and TACCs (Table 1). A nominal TACC of 8 t (SBW 1) was set for the rest of the EEZ. Less than 20 t per year has been reported from SBW 1 since 2000–01.

Details of recent stock-specific changes in TACC and catch through time are given in Table 1. Once in the QMS the TACC for the Bounty Platform was gradually reduced to 3500 t by 2003, reflecting a period of poor recruitment to the stock. The TACC remained at that level until 2008 when the strong 2002 year class entered the fishery, and the TACC was increased to 9800 t and then 14 700 t. From 1 April 2011, the TACC for the Bounty Platform stock was reduced to 6860 t. Once in the QMS the TACC for the Campbell Island Rise was gradually reduced to 20 000 t by 2006, reflecting a period of poor to average recruitment to the stock. The TACC remained at that level until 2009 when the strong 2006 year class entered the fishery, and the TACC was increased to 23 000 t in 2010 and then to 29 400 t in 2011. Catch limits for Pukaki Rise and Auckland Islands have remained unchanged since 1997–98.

The southern blue whiting fishery was developed by Soviet vessels during the early 1970s, with early reported landings peaking at almost 50 000 t in 1973 (Table 1). Early reports recorded that southern blue whiting spawned in most years on the Bounty Platform (Shpak 1978) and in some years on the Campbell Plateau (Shpak & Kuchina 1983), and that feeding aggregations could be caught on the Pukaki Rise, southeast of the Campbell Island Rise, and on the Auckland Islands Shelf (Shpak 1978). Some fishing probably took place on each of the grounds, but the proportion of catch from each ground was not accurately recorded before 1978. Hence the amount of catch for each ground cannot accurately be determined before 1978.

Landings were chiefly taken by the Soviet foreign licensed fleet during the 1970s and early 1980s. The entire Campbell Plateau (Campbell Island Rise and Pukaki Rise) was fished year-round between 1978 and 1984, but highest catches were usually made during spawning, typically during September. In some seasons (notably 1979, 1982, and 1983) vessels also targeted spawning fish on the Bounty Platform in August and September (Table 1).

As a result of the increase in hoki quota in 1985 and 1986, the Japanese surimi fleet increased its presence in New Zealand waters and some vessels stayed on after the hoki fishery to fish for southern blue whiting. After that, many of the Japanese and Soviet (replaced later by Ukraine) vessels that fish for hoki on the west coast of the South Island during July and August each year move in late August or early September to the southern blue whiting spawning grounds. Between 1986 and 1989, fishing was confined to the spawning grounds on the northern Campbell Island Rise. From 1990 onwards, vessels also started fishing spawning aggregations on the Bounty Platform, the Pukaki Rise, and the southern Campbell Island Rise. Fishing effort increased markedly between 1990 and 1992, culminating in a catch of over 75 000 t in 1992 (Table 1). The increased catch came mainly from the Bounty Platform. In 1993, a fishery developed for the first time on the Auckland Islands spawning grounds and fishing has continued there at a low level since then. Total annual landings over the past seven years have ranged between 25 000 t and 40 000 t, most of which has been taken from the Campbell Island Rise grounds. However, a strong year class on the Bounty Platform led to a rapid increase in catches there from 2008 to 2010. Relatively large catches also occurred at the Pukaki Rise in the same years.

On the Bounty Platform and Campbell Island Rise the TACC has been almost fully caught in each of the last five years. The total catch also approached the level of the TACC at Pukaki Rise in 2009 and 2010 but fell in 2011. At the Auckland Islands, the catch limits have been under-caught since their introduction. On the Bounty Platform, the amount of fishing effort in any season has depended largely on the timing of the west coast hoki fishery. If there is a delayed hoki season, then the vessels remain longer on the hoki grounds and consequently may miss the peak fishing season on the Bounty Platform. On the Pukaki Rise and Auckland Islands Shelf, operators find it difficult to justify expending time to locate fishable aggregations, given the small allocation available in these areas and the relatively low value of the product.

The fleet has gradually changed from one being dominated by Japanese surimi and Soviet ‘Head and Gut’ vessels to one dominated by vessels from Ukraine and the Dominican Republic which process fish to a dressed product, with the vast majority of the catch taken by midwater trawls. Over the previous five years about 60% of the product was dressed and about 35% was surimi, but these numbers have changed to about 85% and 15% respectively over the past two years.

Table 1: Estimated catches (t) of southern blue whiting for 1971 to 2011–12, and by area for 1978 to 2011–12 (source: QMRs and MHRs; '–' denotes no catch limit in place).

Fishing year[1]	Bounty Platform (SBW 6B)		Campbell Island Rise (SBW 6I)		Pukaki Rise (SBW 6R)		Auckland Island (SBW 6A)		Total (All areas)	
	Catch	Limit	Catch	Limit	Catch	Limit	Catch	Limit[2]	Catch[3]	Limit
1971	–	–	–	–	–	–	–	–	10 400	–
1972	–	–	–	–	–	–	–	–	25 800	–
1973	–	–	–	–	–	–	–	–	48 500	–
1974	–	–	–	–	–	–	–	–	42 200	–
1975	–	–	–	–	–	–	–	–	2 378	–
1976	–	–	–	–	–	–	–	–	17 089	–
1977	–	–	–	–	–	–	–	–	26 435	–
1978	0	–	6 403	–	79	–	15	–	6 497	–
1978–79	1 211	–	25 305	–	601	–	1 019	–	28 136	–
1979–80	16	–	12 828	–	5 602	–	187	–	18 633	–
1980–81	8	–	5 989	–	2 380	–	89	–	8 466	–
1981–82	8 325	–	7 915	–	1 250	–	105	–	17 595	–
1982–83	3 864	–	12 803	–	7 388	–	184	–	24 239	–
1983–84	348	–	10 777	–	2 150	–	99	–	13 374	–
1984–85	0	–	7 490	–	1 724	–	121	–	9 335	–
1985–86	0	–	15 252	–	552	–	15	–	15 819	–
1986–87	0	–	12 804	–	845	–	61	–	13 710	–
1987–88	18	–	17 422	–	157	–	4	–	17 601	–
1988–89	8	–	26 611	–	1 219	–	1	–	27 839	–
1989–90	4 430	–	16 542	–	1 393	–	2	–	22 367	–
1990–91	10 897	–	21 314	–	4 652	–	7	–	36 870	–
1991–92	58 928	–	14 208	–	3 046	–	73	–	76 255	–
1992–93	11 908	15 000	9 316	11 000	5 341	6 000	1 143	–	27 708	32 000
1993–94	3 877	15 000	11 668	11 000	2 306	6 000	709	–	18 560	32 000
1994–95	6 386	15 000	9 492	11 000	1 158	6 000	441	–	17 477	32 000
1995–96	6 508	8 000	14 959	21 000	772	3 000	40	–	22 279	32 000
1996–97	1 761	20 200	15 685	30 100	1 806	7 700	895	–	20 147	58 000
1997–98	5 647	15 400	24 273	35 460	1 245	5 500	0	1 640	31 165	58 000
1998–00	8 741	15 400	30 386	35 460	1 049	5 500	750	1 640	40 926	58 000
2000–01	3 997	8 000	18 049	20 000	2 864	5 500	19	1 640	24 804	35 148
2001–02	2 262	8 000	29 999	30 000	230	5 500	10	1 640	31 114	45 148
2002–03	7 565	8 000	33 445	30 000	508	5 500	262	1 640	41 795	45 148
2003–04	3 812	3 500	23 718	25 000	163	5 500	116	1 640	27 812	35 648
2004–05	1 477	3 500	19 799	25 000	240	5 500	95	1 640	21 620	35 648
2005–06	3 962	3 500	26 190	25 000	58	5 500	66	1 640	30 278	35 648
2006–07	4 395	3 500	19 763	20 000	1 115	5 500	84	1 640	25 363	30 648
2007–08	3 799	3 500	20 996	20 000	513	5 500	278	1 640	25 587	30 648
2008–09	9 863	9 800	20 483	20 000	1 377	5 500	143	1 640	31 887	36 948
2009–10	15 468	14 700	19 040	20 000	4 853	5 500	174	1 640	39 540	41 848
2010–11	13 913	14 700	20 224	23 000	4 433	5 500	131	1 640	38 708	44 848
2011–12	6 590	6 860	30 840	29 400	677	5 500	65	1 640	38 174	43 408

1. Fishing years defined as 1 April to 30 September for 1978; 1 October to 30 September for 1978–79 to 1997–98; 1 October 1998 to 31 March 2000 for 1998–2000; 1 April to 31 March for 2000–01 to current.
2. Before 1997–98, there were no separate catch limits for Auckland Islands
3. Totals include SBW1 (i.e., all EEZ areas outside QMA 6). SBW 1 has a TACC of 8 t and reported annual catches since 2000–01 have ranged from 1 t in 2007–08 to 21 t in 2008–09.

2.2 Illegal catches

The level of illegal and unreported catch for southern blue whiting has been reported as "thought to be low" (Ministry of Fisheries 2009). However, there have been several instances of area misreporting and illegal discards.

In 2002–03, the operators of one vessel were convicted for area misreporting — the vessel had caught about 204 t of southern blue whiting on the Campbell Island Rise (SBW 6I) and reported this against quota for the Pukaki Rise (SBW 6R); another 480 t caught on the Campbell Island Rise had been reported against quota for the Auckland Islands Shelf (SBW 6A). In addition, in 2004, the operators of a vessel were convicted of dumping southern blue whiting at sea — crew members estimated that between 40 and 310 tonnes were illegally discarded during a two and a half week period of fishing on the Campbell Island Rise (Ministry of Fisheries 2009).

In addition, some catch was alleged to have been misreported between SBW 6R, SBW 6B, and SBW 6I. Ministry of Fisheries noted that in August and September 2002, there was some evidence that a vessel caught 81 t of southern blue whiting in SBW 6R and misreported it as catch from SBW 6B; and also misreported 108 t from SBW 6I as being from SBW 6R. The Ministry of Fisheries noted that in 2004, there was some evidence that 64.5 t of southern blue whiting was caught in SBW 6I and misreported as being caught in SBW 6B (G. Backhouse, Senior Fisheries Investigator, Ministry of Fisheries, pers. comm.).

2.3 Other sources of fishing mortality

Scientific observers have reported discards of undersize fish and accidental losses from torn or burst codends, particularly during the early years of the fishery. Discarding in the southern blue whiting fishery has been estimated by Clark et al. (2000), and Anderson (2004, 2009). Anderson (2004) quantified total annual discard estimates (including estimates of fish lost from the net at the surface) as ranging between 0.4% and 2.0% of the estimated catch for all southern blue whiting fisheries. Anderson (2009) reviewed fish and invertebrate bycatch, and discards in the southern blue whiting fishery based on observer data from 2002 to 2007. He estimated that 0.23% of the catch was discarded from observed vessels. The low levels of discarding occur primarily because the fishery targeted spawning aggregations.

In August 2010, the F.V. *Oyang 70* sank while fishing for southern blue whiting on the Bounty Platform. It was fishing an area between 48° 00’ S and 48° 20’ S, and 179° 20’ E and 180° 00’ E between 15 and 17 August 2010, before sinking on 18 August 2010. The Ministry of Fisheries estimated that it had taken a catch of between 120 t and 190 t that was lost with the vessel (G. Backhouse, Senior Fisheries Investigator, Ministry of Fisheries, pers. comm.).

2.4 The 2011 season

The approximate location of trawls made during the 2011 season (mid-August to mid-October) is shown in Figure 2. Most of the catch was taken by vessels flagged to Ukraine, Dominican Republic, New Zealand, and Japan, and most fishing was carried out on the Bounty Platform and Campbell Island Rise stocks (Table 2).

In 2011, the first vessels arrived on the Bounty Platform on 2 August and gradually worked their way south and east making small to moderate catches. From 10 to 23 August vessels were fishing in the south west and made high catches (typically at least 400 t per day) (Figure 3). Fish were spawning from 20–26 August 2011. Catches were lower after spawning had finished and all vessels had left by 28 August (Figure 4).

In 2011, vessels started fishing the Campbell Island Rise on 16 August and continued fishing until 6 October (Figure 3). As in recent years, the fleet fished the northern and southern spawning aggregations on the Campbell Island Rise ground. Most of the catch at Campbell Island was taken from August 20 to October 1 (Figure 3). Daily proportions spawning (i.e., running ripe) at Campbell Island showed two distinct spawning peaks with the first peak from 12–17 September and the second from 23–29 September (Figure 4).

In 2011, vessels fished the Pukaki Rise between 11 August and 3 October (Figure 3). Most of the catch was taken by vessels in the latter half of the period, but catches remained relatively low at less than 50 t per day (Figure 3). The timing of spawning could not be determined because there were no observers present between 31 August and 14 September (Figure 4).

Five vessels reported catches of southern blue whiting on the Auckland Islands Shelf in 2011, but no targeted fishing was carried out (Table 2) and no fishing was carried out during the spawning season. At the Auckland Islands, the reported daily catches were small and southern blue whiting were taken only as bycatch of fishing for other species.

Comparing daily patterns in the southern blue whiting target catch among regions showed earlier fishing at Bounty Islands, followed by larger, more variable, catches at Campbell Island (Figure 3). Catches at Pukaki Rise were much smaller, but were maintained throughout the 45 days of the fishery (Figure 3). The patterns of effort through time in the two larger fisheries determine the timing of spawning observations, but for both Bounty and Campbell areas, increases in catches preceded the onset of more intensive spawning by ten to twenty days (Figure 4).

Table 2: Number of tows and vessels for vessels targeting southern blue whiting by area, 1990–2011 (source: TCEPR data).

Year	Auckland Islands		Bounty Platform		Campbell Island		Pukaki Rise		Other	
	Tows	Vessels	Tows	Vessels	Tows	Vessels	Tows	Vessels	Tows	Vessels
1990	3	1	263	25	1 030	35	191	32	3	8
1991	1	1	661	31	1 228	33	262	24	3	8
1992	7	2	1 732	49	1 530	47	374	40	13	27
1993	20	4	433	21	423	20	393	23	6	12
1994	43	7	178	9	480	15	81	11	4	4
1995	15	5	155	10	285	12	71	9	6	12
1996	6	3	67	5	474	11	10	4	1	1
1997	18	5	37	5	650	18	46	8	1	2
1998	14	5	118	12	959	24	34	11	3	8
1999	14	3	288	14	790	21	26	7	2	2
2000	1	1	99	6	447	16	57	8	–	–
2001	2	2	32	5	650	14	12	7	1	1
2002	6	2	94	6	862	18	15	5	–	–
2003		–	24	3	599	15	4	3	–	–
2004	1	1	32	3	690	16	3	3	–	–
2005	1	1	100	5	755	17	3	2	–	–
2006	–	–	94	5	521	13	19	1	–	–
2007	–	–	51	4	544	13	20	3	–	–
2008	–	–	200	8	557	14	57	4	–	–
2009	12	2	401	13	627	14	158	9	2	3
2010	–	–	394	13	550	12	170	10	–	–
2011	–	–	175	8	976	14	72	8	–	–

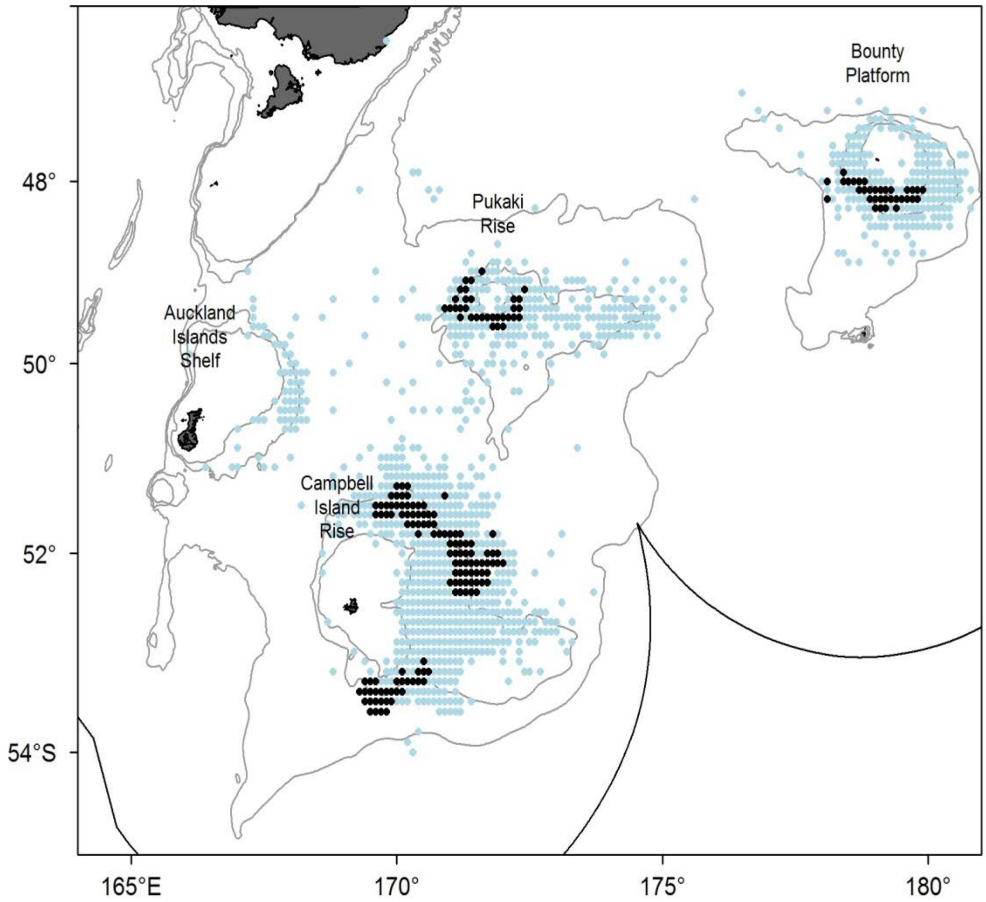

Figure 2: Locations of commercial trawls made during the 2011 season targeting southern blue whiting (late August to early October, black points) and the location of historical target tows 1990–2010 (grey points).

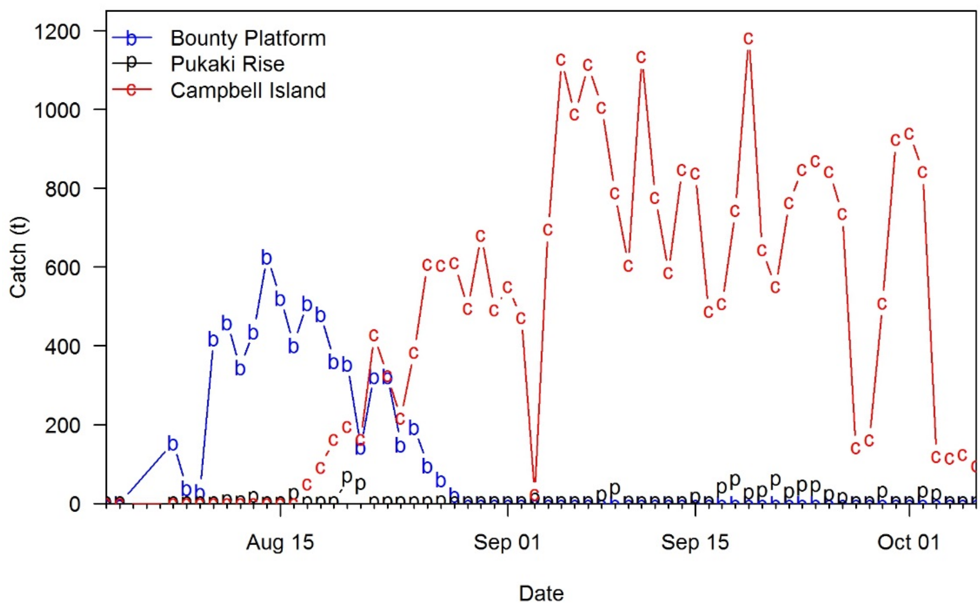

Figure 3: Daily target southern blue whiting catch on the Bounty Platform (blue), Pukaki Rise (black), and Campbell Island Rise (red) in 2011 between July and October.

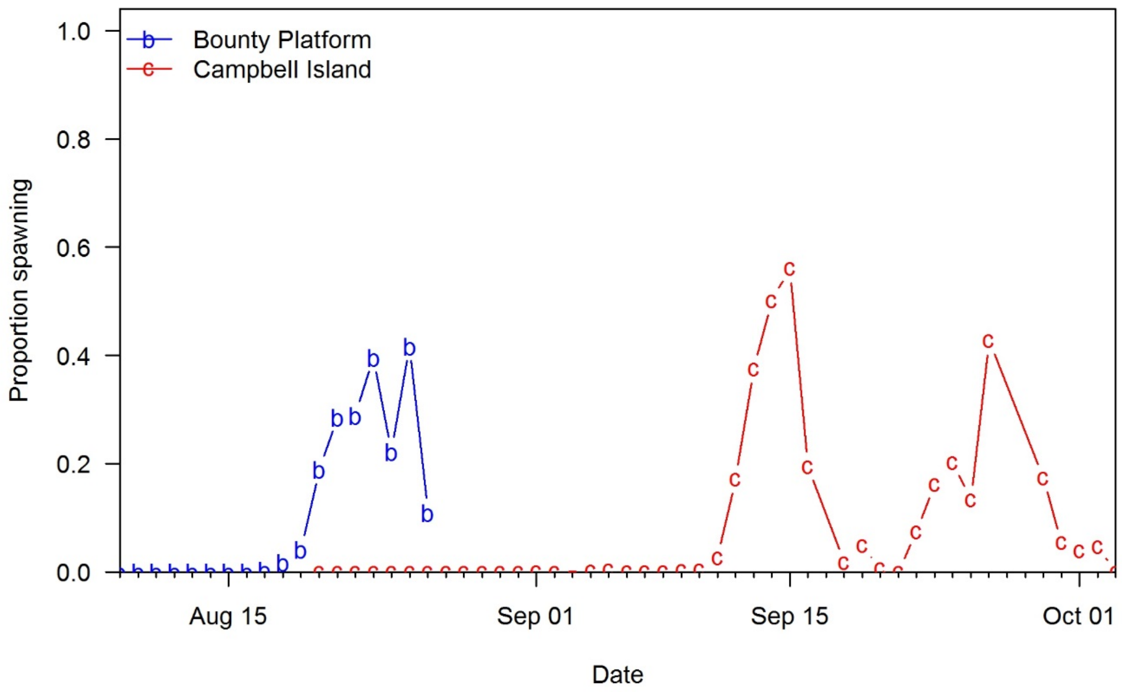

Figure 4: Daily proportion of females spawning (proportions at stage 4) for target southern blue whiting tows on the Bounty Platform (blue) and Campbell Island Rise (red) in 2011 between July and October. Note: No data available for the Pukaki Rise in 2011.

3. BIOLOGY

3.1 Stock structure

Stock structure of southern blue whiting was reviewed by Hanchet (1998, 1999) who examined data on distribution and abundance, reproduction, growth, and morphometrics. There appear to be four main spawning grounds: Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise. There are also consistent differences in the size and age distributions of fish, in the recruitment strength, and in the timing of spawning, between these four areas. Multiple discriminant analysis of data collected in October 1989 and 1990 showed that fish from Bounty Platform, Pukaki Rise, and Campbell Island Rise could be distinguished on the basis of their morphometric measurements. This constitutes strong evidence that fish in these areas spawn on the grounds to which they first recruit. There have been no genetic studies, but given the close proximity of the areas, it is unlikely that there would be detectable genetic differences in the fish among these four areas.

For stock assessment purposes, it is assumed that there are four biological stocks of southern blue whiting with fidelity within stocks: the Bounty Platform stock, the Pukaki Rise stock, the Auckland Islands stock, and the Campbell Island Rise stock. Southern blue whiting are also managed as four separate administrative stocks.

3.2 Biological parameters

3.2.1 Age and growth

Early growth has been well documented with fish reaching a length of about 20 cm FL after one year and 30 cm FL after two years Hanchet & Uozumi (1996). Growth slows after five years and virtually ceases after ten years. Ages have been validated up to at least 15 years by following strong year classes, but ring counts from otoliths suggest that individual fish may reach 25 years (Hanchet & Uozumi 1996).

Mean length at age estimates for each area (based directly on the annual age-length key) were presented by Hanchet et al. (2003). These estimates have been recalculated using catch-at-age software (Bull & Dunn 2002). In this approach the raw age-length key data are scaled up so that the mean length at age for the plus group is based on the scaled LF distribution of fish in the plus group. The results are presented in Figure 5 and Figure 6 for the Campbell Island Rise and the Bounty Platform respectively. Note that the revised mean lengths in the plus group are typically slightly (1–2 cm) smaller than the original lengths calculated directly from the age-length key given by Hanchet et al. (2003).

An important feature of the biology of southern blue whiting is very high recruitment variability and associated density dependent growth (Hanchet et al. 2003). For example, the very strong 1991 year class on the Campbell Island Rise grew at a much slower rate (smaller length and weight at age) than previous year classes (see Figure 5 and Table 3). A similar large reduction in growth rate occurred on the Bounty Platform with the strong 2002 year class (Figure 6). The subsequent two year classes grew at a similar slow rate. For this reason, mean length at age is used as a year specific matrix of lengths at age rather than a vector of length at age based on the von Bertalanffy growth parameters.

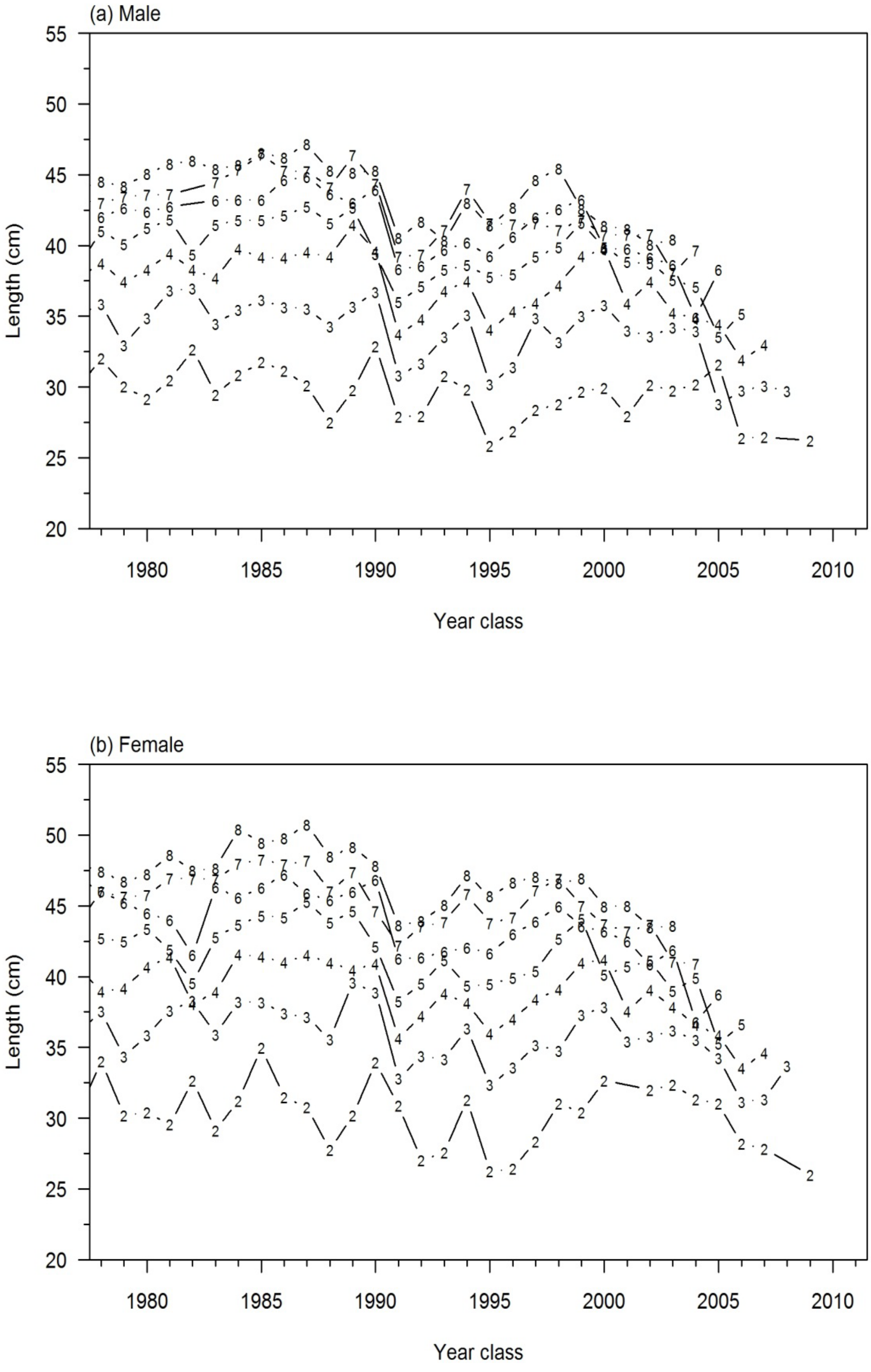

Figure 5: Estimated mean length-at-age (ages 2–8) for the Campbell Island stock by sex and year class, 1978–2009.

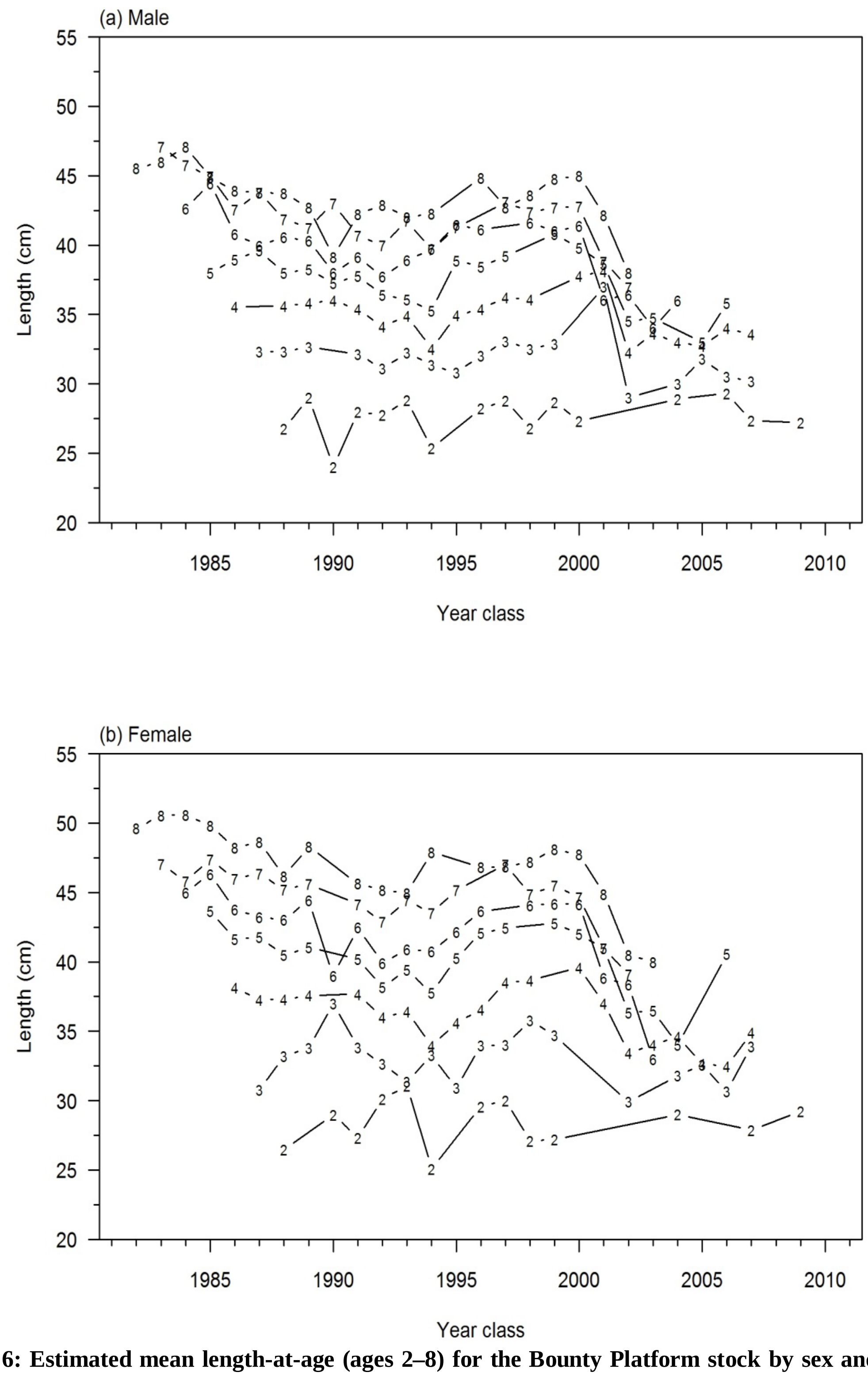

Figure 6: Estimated mean length-at-age (ages 2–8) for the Bounty Platform stock by sex and year class, 1990–2009.

3.2.2 Spawning and length and age at maturity

Southern blue whiting are highly synchronised batch spawners. Four spawning areas have been identified, on Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise. The Campbell Island Rise has two separate spawning grounds to the north and south. Fish appear to recruit first to the southern ground but thereafter spawn on the northern ground. Spawning on Bounty Platform begins in mid-August and finishes by mid-September. Spawning begins 3–4 weeks later in the other areas, finishing in late September/early October. Spawning appears to mainly occur at night, in mid-water, over depths of 400–500 m on Campbell Island Rise but shallower elsewhere.

The age and length of maturity, and recruitment to the fishery, varies between areas and between years. In some years a small proportion of males mature at age 2, but the majority do not mature until age 3 or 4, usually at a length of 33–40 cm FL. The majority of females also mature at age 3 or 4 at a length of 35–42 cm FL. Ageing studies have shown that this species has very high recruitment variability (Hanchet et al. 2003).

3.2.3 Natural mortality

Natural mortality (*M*) was estimated using the equation $\log_e(100)$/maximum age, where maximum age is the age to which 1% of the population survives in an unexploited stock (see Table 4). Using a maximum age of 22 years, M was estimated as 0.21 y^{-1}, and a value of 0.2 y^{-1} has been assumed in assessments. Recent Campbell Island stock assessments have estimated *M* within the model. MCMC estimates of 0.18–0.22 have been obtained from recent assessments of the Campbell island stock when M was estimated in the model (e.g., Dunn & Hanchet 2011b).

Table 3: Overall mean weight and the mean weight for strong year classes (1991 and 1992) at age for southern blue whiting on the Campbell Island Rise (from Hanchet & Dunn, 2010).

Weight (g)	Age (y)									
	2	3	4	5	6	7	8	9	10	11
Overall mean	170	292	420	513	599	661	716	771	794	835
Strong year class	110	220	315	400	485	550	600	680	710	780

Table 4: Estimates of biological parameters estimated for the Campbell Island Rise stock, and assumed for all stocks.

Estimate	Parameter	Male	Female	Source
Natural mortality (y^{-1})	*M*	0.2	0.2	Hanchet (1992)
Weight = a (length)^b	*a*	0.00515	0.00407	
Weight in g, length in cm fork length	*b*	3.092	3.152	Hanchet (1991)

4. RESEARCH SURVEYS AND OTHER ESTIMATES OF ABUNDANCE

4.1 Acoustic research surveys

A programme to estimate southern blue whiting spawning stock biomass on each fishing ground using acoustic techniques began in 1993. The Bounty Platform, Pukaki Rise, and Campbell Island Rise were each surveyed annually between 1993 and 1995. After the first three annual surveys it was decided to survey these areas less regularly. The Bounty Platform grounds were surveyed in 1997, 1999, and most recently in 2001. The Pukaki area was surveyed in 1997 and 2000. The only on-going series of research surveys is on the Campbell Island Rise grounds, which have been surveyed in 1998, 2000, 2002, 2004, 2006, 2009, and 2011. All these surveys have been carried out from R.V. *Tangaroa* using towed transducers and have been wide-area surveys intended to survey spawning southern blue whiting and pre-recruits. The results of these surveys have been the main input into southern blue whiting stock assessments for the last decade (e.g., Dunn & Hanchet 2011a, Dunn & Hanchet 2011b). Various spatial designs for acoustic surveys of southern blue whiting were investigated using simulation studies by Dunn & Hanchet (1998) and Dunn et al. (2001), whilst Hanchet et al. (2000a) examined diel variation in southern blue whiting density estimates.

The primary objective of the surveys has been to estimate the biomass of the adult spawning stock. A secondary objective has been to provide estimates of pre-recruit fish in each of the areas and so the surveys have been extended into shallower water where the younger fish live. When adult southern blue whiting are actively spawning, the marks are easily identified because they are very dense and have characteristic features (Hanchet et al. 2000b, McClatchie et al. 2000, O'Driscoll 2011b). However, the pre-spawning and post-spawning adult marks are somewhat more diffuse and the adult fish distribution at this time often overlaps with the pre-recruits. The original analysis separated southern blue whiting marks into categories of adult, immature (mainly 2 and 3 years old) and juvenile (mainly 1 year old). However, in some areas and years the marks classified as adults also contained some immature 2 and 3 year old fish, whilst juveniles were often a mix of 1 and 2 year old fish. This problem was addressed by Hanchet et al. (2000b) who carried out a re-analysis of the early R.V. *Tangaroa* acoustic survey and decomposed the estimates into age 1, 2, 3, and 4+ fish. These decomposed estimates were further reanalysed by Grimes et al. (2007) who: (i) incorporated the new target strength-fish length relationship of Dunford & Macaulay (2006), (ii) used the new sound absorption coefficient of Doonan et al. (2003), (iii) included corrections and changes to strata areas, and (iv) estimated c.v.s of the decomposed estimates by age. More recently, estimates of biomass of the southern blue whiting categories were recalculated along similar lines (i.e. revising (i)-(iii) above) (NIWA Unpublished Data).

Pedersen et al. (2011) carried out target strength work on the closely-related blue whiting (*Micromesistius poutassou*) and estimated a target strength that was much higher than that which is being used for *M. australis*. If the target strengths from *M. poutassou* were similar to *M. australis*, then estimates of southern blue whiting biomass from the acoustic surveys presented here would be about half of the value reported.

4.1.1 Auckland Islands

A single survey of the Auckland Islands Shelf was carried out in 1995 using R.V. *Tangaroa*. This provided a spawning stock biomass estimate of 7800 t (c.v. 0.34).

4.1.2 Bounty Platform

Two time series of acoustic indices are available for the Bounty Platform stock. The first was a wide-area time series of aged 2, 3, and 4+ southern blue whiting using the R.V. *Tangaroa* for the period 1993 to 2001 (Table 5 and Table 6).

A time series of aggregation or local area acoustic surveys using industry vessels (usually from only one vessel in each year) was initiated in 2004 and has continued in most years to 2011 (Table 7). These surveys have had mixed levels of success. Acoustic data collected in 2005 could not be used because of acoustic interference from the scanning sonar used by the vessel for searching for fish marks and inadequate survey design. There was also concern that the surveys in 2006 and 2009 did not sample the entire aggregation because on several transects the fish marks extended beyond the area being surveyed (O'Driscoll 2011c). Surveys in 2010 and 2011 were thought to have had reasonably good coverage, and to have surveyed the aggregations successfully (O'Driscoll 2011a, O'Driscoll et al. 2012).

Table 5: R.V. *Tangaroa* juvenile, immature, sub-adult, and adult acoustic biomass estimates for the Bounty Platform using revised target strength and sound absorption coefficient, 1993–2001 (NIWA Unpublished Data).

Year	Juvenile		Immature		Sub-adult		Adult	
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
1993	18 024	0.27	20 607	0.33			61 177	0.58
1994	305	0.80	24 039	0.27			40 769	0.25
1995	160 790	0.37	0				34 246	0.24
1997	336	0.67	12 526	0.54			61 316	0.37
1999	1 682	0.59	1 009	0.37			42 466	0.75
2001[1]	–	0.00	6 328	0.28	2 305	0.12	21 883	0.35

1. In 2001 an additional category of 'sub-adults' was used.

Table 6: R.V. *Tangaroa* age 1, 2, 3 and 4+ acoustic biomass estimates for the Bounty Platform using revised target strength and sound absorption coefficient, 1993–2001 (Grimes et al. 2007).

Year	Age 1		Age 2		Age 3		Age 4+	
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
1993	29 057	0.23	11 347	0.25	777	0.37	47 087	0.64
1994	299	0.81	9 082	0.28	36 445	0.25	20 844	0.25
1995	155 460	0.37	7 108	0.32	7 874	0.34	23 480	0.24
1997	5 054	0.39	7 274	0.36	30 668	0.41	31 929	0.32
1999	993	0.57	1 134	0.33	5618	0.62	34 194	0.73
2001	379	0.16	4 669	0.23	7 261	0.19	16 396	0.36

Table 7: The local area acoustic biomass estimates for the Bounty Platform with revised target strength and sound absorption coefficient, 2004–2011.

Year	Biomass	c.v.	Source
2004	13 473	0.69	(O'Driscoll 2011c)
2005 [1]	–	–	(O'Driscoll 2011c)
2006	21 765	0.12	(O'Driscoll 2011c)
2007	159 589	0.19	(O'Driscoll 2011c)
2008	144 187	0.34	(O'Driscoll 2011c)
2009	28 242	0.24	(O'Driscoll 2011c)
2010	27 782	0.36	(O'Driscoll 2011a)
2011	35 597	0.28	(O'Driscoll 2012)

1. In 2005, a local area aggregation survey was carried out, but the acoustic data could not be used because of acoustic interference from the scanning sonar used by the vessel.

4.1.3 Campbell Island Rise

As of 2011, ten acoustic surveys of the Campbell Island Rise spawning grounds have been completed using the R.V. *Tangaroa*, and results of recent surveys were reported by Hanchet et al. (2002, 2003), O'Driscoll et al. (2005), O'Driscoll et al. (2007), Gauthier et al. (2011), and O'Driscoll et al. (2012) and are summarised in Tables 8 and 9.

The first industry survey of the Campbell stock was carried out from F.V. *Aoraki* in September 2003 (O'Driscoll & Hanchet 2004). This demonstrated that industry vessels with hull-mounted acoustic systems could also be used to collect acoustic data on southern blue whiting in good weather (less than 25 knots of wind). However, surveys from industry vessels on the Campbell Island grounds in subsequent years (e.g., O'Driscoll et al. 2006), have not been successful and have not provided estimates useful for assessment.

Table 8: R.V. *Tangaroa* juvenile, immature, and adult acoustic biomass estimates for the Campbell Island Rise using revised target strength and sound absorption coefficient, 1993–2011 (O'Driscoll et al. 2012).

Year	Juvenile		Immature		Adult		Total
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass
1993	0	–	129 380	0.25	28 649	0.24	158 029
1994	0	–	26 280	0.38	180 439	0.34	206 719
1995	0	–	48 844	0.29	123 124	0.30	171 968
1998	2 103	0.45	26 987	0.20	171 199	0.14	200 289
2000	2 468	0.39	6 074	0.24	138 196	0.17	146 738
2002	13 228	0.39	681	0.76	116 178	0.68	130 087
2004	3 090	0.67	16 833	0.16	79 074	0.35	98 997
2006	2 200	0.38	10 892	0.24	81 628	0.32	94 720
2009	0	–	98 098	0.28	204 539	0.27	302 637
2011	0	–	64 605	0.17	118 122	0.22	182 727

Table 9: R.V. *Tangaroa* age 1, 2, 3 and 4+ acoustic biomass estimates for the Campbell Island Rise using the revised target strength and sound absorption coefficient, 1993–2011 (O'Driscoll et al. 2012).

Year	Age 1		Age 2		Age 3		Age 4+		Total
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass
1993	206	1.76	107 192	0.28	13 396	0.23	16 784	0.25	137 578
1994	699	0.57	19 634	0.29	168 006	0.32	23 213	0.28	211 552
1995	0	–	17 269	0.27	27 952	0.21	124 892	0.25	170 113
1998	8 678	0.25	20 895	0.15	35 579	0.12	139 388	0.18	204 540
2000	2 443	0.38	15 606	0.16	8 785	0.16	110 931	0.17	137 765
2002	13 436	0.38	4 609	0.65	10 632	0.64	103 422	0.68	132 099
2004	3 144	0.65	24 380	0.15	36 683	0.30	39 007	0.39	103 214
2006	2 230	0.32	27 933	0.23	10 199	0.34	56 206	0.32	96 568
2009	0	–	110 250	0.22	115 944	0.26	92 598	0.27	318 792
2011	0	–	61 512	0.17	1 668	0.22	116 396	0.22	179 576

4.1.4 Pukaki Rise

A total of five acoustic surveys of the Pukaki Rise spawning grounds were completed using the R.V. *Tangaroa* between 1993 and 2000 (Table 10, Table 11).

Large aggregations of spawning southern blue whiting were detected by vessels fishing on the Pukaki Rise in 2009 (O'Driscoll 2011c), and some vessels opportunistically collected acoustic data on these aggregations. The acoustic biomass estimates from the snapshots at the Pukaki Rise in 2009 ranged from 400 t (c.v. 29%) to 24 000 t (c.v. 38%) (Table 12). The latter estimate was of a similar magnitude to the abundance of sub-adult and adult southern blue whiting estimated from previous wide-area acoustic surveys of the area (Table 10).

Acoustic surveys on Pukaki Rise in September 2010, using the industry vessels *Professor Alexandrov* and *Meridian 1*, were reported by O'Driscoll (2011c) (Table 12). The estimated acoustic biomass from the survey by *Meridian 1* was 2211 t (c.v. 17%). Acoustic data collected from the *Professor Alexandrov* were of lower quality due to acoustic noise from bubble aeration. In addition, the coverage was less extensive and the vessel's echo sounder had not been scientifically calibrated. Hence, the data from the *Professor Alexandrov* were not used in the estimate of biomass for that year. O'Driscoll (2011b) re-iterated the problems with trying to use aggregation-based surveys on the Pukaki Rise and recommended the use of wide-area surveys instead.

Table 10: R.V. *Tangaroa* juvenile, immature, sub-adult, and adult acoustic biomass estimates for the Pukaki Rise using revised target strength and sound absorption coefficient, 1993–2000 (NIWA Unpublished Data).

Year	Juvenile		Immature		Sub-adult		Adult	
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
1993	0	–	31 406	0.25			42 817	0.32
1994	0	–	544	1.00	7 488	0.48	43 094	0.69
1995	0	–	0	–			10 936	0.18
1997	0	–	4 104	0.12			27 576	0.34
2000	0	–	5 760	0.62	16 695	0.74	12 341	0.37

Table 11: R.V. *Tangaroa* age 1, 2, 3 and 4+ acoustic biomass estimates for the Pukaki Rise using revised target strength and sound absorption coefficient, 1993–2000 (Grimes et al. 2007).

Year	Age 1		Age 2		Age 3		Age 4+	
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
1993	1 055	0.18	41 966	0.16	9 206	0.31	18 822	0.30
1994	23	0.80	1 978	0.38	8 910	0.32	27 124	0.40
1995	0	–	144	0.18	884	0.18	8 382	0.18
1997	41	0.12	4 442	0.13	890	0.29	22 696	0.32
2000	102	0.63	10 183	0.42	5 584	0.57	16 277	0.50

Table 12: Local area acoustic biomass estimates for the Pukaki Rise, 2009-2010.

Year	Vessel	No. transects	Area (km^2)	Biomass (t)	c.v.	Source
2009	*Meridian 1*	4	50	397	0.29	(O'Driscoll 2011c)
2009	*Meridian 1*	5	283	19 954	0.30	(O'Driscoll 2011c)
2009	*Meridian 1*	6	83	13 196	0.46	(O'Driscoll 2011c)
2009	*Buryachenko*	6	60	4 980	0.12	(O'Driscoll 2011c)
2009	*Buryachenko*	7	117	16 672	0.26	(O'Driscoll 2011c)
2009	*Buryachenko*	6	19	23 881	0.38	(O'Driscoll 2011c)
2010	*Meridian 1*	10	364	2 211	0.17	(O'Driscoll 2011c)

4.2 Trawl research surveys

Trawl surveys of the sub-Antarctic targeting hoki, hake, and ling have been carried out using R.V. *Tangaroa* since 1991 (e.g., O'Driscoll & Bagley 2009). Although SBW are not a target species of this survey, they are often caught in moderate numbers, particularly on the Pukaki Rise and Campbell Island Rise, and it was considered possible that the surveys could be used to monitor their abundance. Hanchet & Stevenson (2006) reanalysed biomass estimates and scaled length frequency distributions for southern blue whiting from the Sub-Antarctic summer and autumn survey series for each of three sub-areas, Pukaki Rise, Campbell Island Rise, and Auckland Island Shelf. They defined the three areas as follows: Pukaki Rise (strata 11, 12); Campbell Island Rise (10, 13, 14, 15, and 9S); Auckland Island Shelf (3, 4, 5, 6, 7, 8, 9N) (Figure 7).

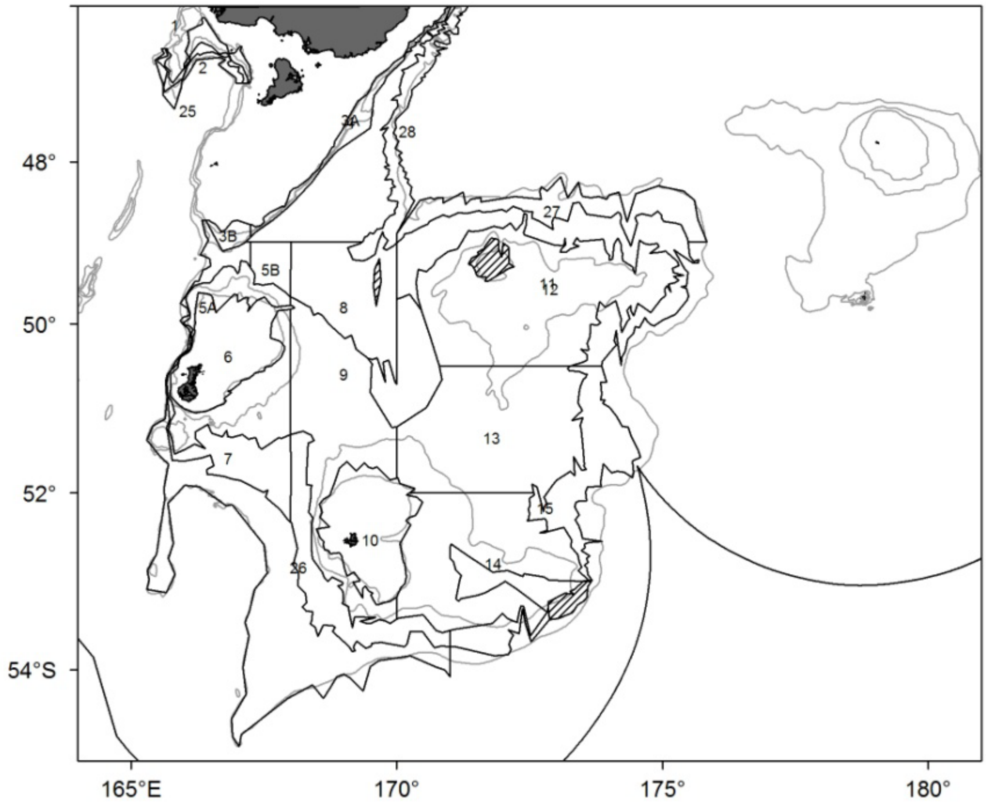

Figure 7: Survey area and stratum boundaries used for R.V. *Tangaroa* sub-Antarctic trawl surveys since 1996. Stratum 9 was split into 9N and 9S at 51ºS for this analysis.

4.2.1 Auckland Island Shelf

The c.v.s of the biomass estimates for the Auckland Islands Shelf were typically 55–80%, making them too imprecise for monitoring abundance (Table 13). There was little consistency in biomass estimates between the summer and autumn series and between adjacent surveys. Hanchet & Stevenson (2006) concluded that because of the erratic biomass estimates and very high c.v.s, it is extremely unlikely that the trawl survey indices were monitoring abundance on the Auckland Islands Shelf.

Table 13: R.V. *Tangaroa* trawl survey biomass estimates, c.v.s, and number of stations (N) for selected strata for the Auckland Islands Shelf (data for 1991–2005 from Hanchet & Stevenson (2006), data for 2006 onwards N. Bagley, NIWA, pers. comm.).

Year	Summer				Autumn				
	Trip	Biomass (t)	c.v.	N	Year	Trip	Biomass (t)	c.v.	N
1991	TAN9105	565	0.75	58	1992	TAN9211	125	0.98	60
1992	TAN9204	40	0.31	31	1993	TAN9310	3 458	0.60	51
1993	TAN9304	159	0.89	44	1996	TAN9605	447	0.33	40
2000	TAN0012	135	0.61	38	1998	TAN9805	746	0.69	25
2001	TAN0118	527	0.68	36					
2002	TAN0219	68	0.76	38					
2003	TAN0317	281	0.85	27					
2004	TAN0414	28	0.69	30					
2005	TAN0515	3 972	0.39	98					
2006	TAN0617	1 146	0.81	40					
2007	TAN0714	1 686	0.45	41					
2008	TAN0813	275	0.55	36					
2009	TAN0911	1 432	0.60	39					
2011	TAN1117	3 628	0.61	45					

4.2.2 Campbell Island Rise

The c.v.s of the biomass estimates for the Campbell Island Rise were mostly between 25 and 40%, making them only marginally useful for monitoring abundance (Table 14). There was some consistency in biomass estimates between the summer and autumn series and also between adjacent surveys. However, Hanchet & Stevenson (2006) noted that although the trend in the trawl survey abundance indices on the Campbell Island Rise was generally similar to estimates of biomass from the population model, the trawl survey underestimated biomass at low stock sizes and overestimated biomass at high stock sizes. Hanchet & Stevenson (2006) suggested that increasing the number of trawl stations would improve the precision of the surveys, but they could not determine if this would also remove this bias.

Dunn & Hanchet (2011a) included observations of biomass from the sub-Antarctic trawl survey and the associated age frequencies in an assessment model for the Campbell Island Rise. They drew a similar conclusion to Hanchet & Stevenson (2006), with the fits suggesting some consistency in the pattern of biomass estimates between the summer series, but the observations underestimating biomass at low stock sizes and overestimating biomass at high stock sizes.

Table 14: R.V. *Tangaroa* trawl survey biomass estimates, c.v.s, and number of stations (N) for selected strata for the Campbell Island Rise (data for 1991–2005 from Hanchet & Stevenson (2006), data for 2006 onwards N. Bagley, NIWA, pers. comm.).

Year	Summer				Autumn				
	Trip	Biomass (t)	c.v.	N	Year	Trip	Biomass (t)	c.v.	N
1991	TAN9105	2 328	0.53	52	1992	TAN9211	5 013	0.31	54
1992	TAN9204	5 942	0.58	39	1993	TAN9310	2 472	0.25	52
1993	TAN9304	1 714	0.29	34	1996[1]	TAN9605	31 203	0.36	19
2000	TAN0012	10 738	0.14	23	1998	TAN9805	10 321	0.37	17
2001	TAN0118	6 393	0.40	23					
2002	TAN0219	3 198	0.45	21					
2003	TAN0317	1 047	0.56	19					
2004	TAN0414	778	0.26	21					
2005	TAN0515	1 502	0.27	17					
2006	TAN0617	4 729	0.73	16					
2007	TAN0714	2 631	0.53	19					
2008	TAN0813	5 870	0.29	17					
2009	TAN0911	4 884	0.31	15					
2011	TAN1117	1 610	0.25	15					

1. Only one station for TAN9605 was in stratum 0009S. This was supplemented with a second station taken from 0009N to allow the stratum biomass and variance to be calculated. The contribution of stratum 0009S to the total biomass was approximately 64 t, and hence the impact of this adjustment was negligible.

4.2.3 Pukaki Rise

The c.v.s of the biomass estimates for the Pukaki Rise were quite variable between years but mainly in the range 20–45%, making them only marginally useful for monitoring abundance (Table 15). There was some consistency in biomass estimates between the summer and autumn series and also between adjacent surveys.

Hanchet & Stevenson (2006) concluded that given the reduction in station density over time and poor agreement of the indices with either modelled biomass or catch history, it was unlikely that the trawl survey indices were monitoring abundance on the Pukaki Rise. After reviewing the work, The Middle Depths Working Group recommended that the number of stations in the core Pukaki Rise stratum be increased slightly during the surveys and this has been undertaken in some recent surveys, where time allowed (e.g., O'Driscoll & Bagley 2009). Recent biomass estimates have fluctuated considerably and the conclusions of Hanchet & Stevenson (2006) remain valid.

Table 15: R.V. *Tangaroa* trawl survey biomass estimates, c.v.s, and number of stations (N) for selected strata for the Pukaki Rise (data for 1991–2005 from Hanchet & Stevenson (2006), data for 2006 onwards N. Bagley, NIWA, pers. comm.).

Year	Summer				Autumn				
	Trip	Biomass (t)	c.v.	N	Year	Trip	Biomass (t)	c.v.	N
1991	TAN9105	3 037	0.31	30	1992	TAN9211	2 368	0.31	29
1992	TAN9204	2 894	0.60	17	1993	TAN9310	3 550	0.24	20
1993	TAN9304	3 684	0.44	16	1996	TAN9605	13 698	0.65	15
2000	TAN0012	6 659	0.33	10	1998	TAN9805	11 102	0.31	10
2001	TAN0118	2 995	0.26	14					
2002	TAN0219	3 251	0.63	12					
2003	TAN0317	1 731	0.35	12					
2004	TAN0414	2 537	0.47	10					
2005	TAN0515	1 109	0.18	10					
2006	TAN0617	911	0.43	10					
2007	TAN0714	3 747	0.28	12					
2008	TAN0813	9 078	0.14	14					
2009	TAN0911	45 657	0.85	12					
2011	TAN1117	2 106	0.21	12					

4.3 CPUE analyses

Standardised CPUE analyses were carried out for the southern blue whiting spawning fisheries on the Campbell Island Rise from 1986 to 2002, and on the Bounty Platform from 1990 to 2002 by Hanchet & Blackwell (2003). Indices were calculated using lognormal linear models of catch-per-tow, catch-per-hour, and catch per day for all vessels, and catch-per-tow for subsets of vessels based on processing type (surimi or dressed), and by relative experience in each fishery. The authors summarised the data and the method of calculating the indices, and then compared the CPUE indices with the results of recent stock assessments.

4.3.1 Bounty Platform

The Bounty Platform analysis was based on a data set of 3288 non-zero records from 1990 to 2002 (Hanchet & Blackwell 2003). The CPUE indices fluctuated considerably, peaking in 1992, 1996–1998, and again in 2002 (Table 16). The indices were similar between most of the CPUE models until 1997, but after 1997 they became more erratic between years and inconsistent amongst vessel subsets. The authors noted that there were other problems with the model assumptions, and that the model structure may be inadequate to reliably determine the indices and their standard errors. Trends in CPUE for the Bounty Platform fishery were consistent with trends in biomass from the 2002 NIWA assessment model of Hanchet (2002), apart from the first two years and last two years. The lower indices in the first two years may be due to fishers developing the new fishery, whilst the higher indices in the last two years are suggestive of hyper-stability. The CPUE indices were rejected as indices of abundance by the Middle Depths Working Group and have not been used for stock assessments.

Table 16: Relative year effects and standard errors (s.e.) for the all vessels, catch per tow model, 1990 to 2002 for the Bounty Platform fishery (Hanchet & Blackwell 2003).

Year	Standardised CPUE	
	Index	s.e.
1990	1.00	–
1991	1.20	0.12
1992	1.69	0.15
1993	0.89	0.10
1994	0.35	0.06
1995	0.57	0.09
1996	1.06	0.20
1997	0.98	0.25
1998	1.06	0.16
1999	0.68	0.08
2000	0.75	0.12
2001	0.98	0.25
2002	1.52	0.24

4.3.2 Campbell Island Rise

The original Campbell Island Rise analysis was based on 11 853 non-zero records from 1986 to 2002. CPUE indices decreased slowly to a minimum in 1992, increased to a peak in 1996, followed by a slight decline to 2002 (Hanchet & Blackwell 2003). This trend was consistent among alternative measures of effort and among subsets of surimi and dressed vessels. *Vessel* was the most important variable, together with *day in season*, *end time of tow*, and *sub-area*. Model diagnostics indicate a poor fit to the data, and the models were unable to fit very high or very low catch rates.

The trends in CPUE for the Campbell Island Rise fishery were consistent with the trends in the 2003 assessment model (Hanchet & Blackwell 2003). They followed the increase from 1993 to 1996 associated with the strong 1991 year class, and then followed the decline in relative abundance as this year class was fished down. Exploratory stock assessment model runs including the CPUE indices gave very similar results to those excluding the CPUE indices. The authors concluded that the CPUE indices for the Campbell Island Rise were monitoring the stock abundance and could be used in future stock assessments. However, they also cautioned that there can be considerable variability in the CPUE indices for individual years, and several years' data may be necessary before any trends become apparent.

The standardised CPUE analysis (Table 17) was updated to 2005 by (Hanchet et al. 2006). They found that there was some divergence in the CPUE indices between the various models in the years 2002 to 2005. The Working Group was unable to agree on which indices were monitoring abundance. As such the CPUE indices were rejected as indices of abundance by the Middle Depths Working Group and have not been used for stock assessments.

Table 17: Relative year effects and standard errors (s.e.) for the all vessels catch per hour and catch per tow standardised CPUE models, and raw mean CPUE for the Campbell Island fishery, 1986 to 2005 (source: Hanchet et al. 2006).

Year	Catch per hour model			Catch per tow model		
	Year index	s.e.	CPUE (t/hr)	Year index	s.e.	CPUE (t/tow)
1986	1.00	–	9.7	1.00	–	14.9
1987	0.79	0.06	7.7	0.91	0.06	15.4
1988	0.59	0.05	6.7	0.88	0.06	19.9
1989	0.68	0.07	8.7	1.40	0.12	27.2
1990	0.52	0.05	7	1.04	0.09	17.7
1991	0.44	0.05	7.2	1.31	0.13	18.3
1992	0.29	0.03	4.3	0.60	0.06	11.7
1993	0.69	0.09	9.4	1.05	0.13	24
1994	0.69	0.10	9.2	1.19	0.14	25.8
1995	0.93	0.14	11.3	1.26	0.17	46.2
1996	1.88	0.27	14	2.34	0.29	42
1997	1.67	0.23	10.3	2.34	0.29	32.1
1998	1.17	0.15	11.5	1.79	0.21	28.3
1999	1.91	0.26	17.3	2.57	0.30	36
2000	1.23	0.17	10.8	1.87	0.23	32.7
2001	1.00	0.13	11.1	1.77	0.21	36.1
2002	1.02	0.14	11.1	1.88	0.22	33.2
2003	0.82	0.11	10.3	2.11	0.25	36.6
2004	0.92	0.12	12.1	1.95	0.23	28.9
2005	0.95	0.13	13.5	2.51	0.30	33.6

5. LENGTH AND AGE COMPOSITION OF THE FISHERY

5.1 Methods

Historical time series of catch-at-age data are available for each of the stocks, and these form an important input into the southern blue whiting stock assessments. A summary of the number of length measurements and otoliths read, on which these catch-at-age estimates were based, is tabulated for each area, in Tables 18–22. The raw LF data were examined graphically for variability in length composition by time of season and/or locality within each of the main areas, and divided into appropriate strata. The length frequency data for each tow were first scaled up to the catch from that tow, and these were then scaled up to the catch for each of the strata, and then the strata were combined to form a single length frequency for that area/year combination.

Age-length keys were year and area specific. In most years and areas (except Auckland Islands), 400–500 otoliths were read for each area/year combination. Before 2002, the catch-at-age was estimated by combining the scaled length frequency data with the age-length key using the old NIWA catch-at-age software. Catch-at-age data for each stock were reanalysed in 2002 using the new NIWA catch-at-age software (Bull & Dunn 2002). The revised catch-at-age series for the Bounty Platform and Campbell Island Rise were summarised by Hanchet (2005) and Hanchet et al. (2003) respectively. The updated software revised the calculation algorithms as well as producing c.v.s that incorporate the variance from both the length-frequency data and the age-length key using bootstrapping. Some of the age-length keys used for the analysis were also slightly modified during that re-analysis. Where necessary, 'proxy' ages were assumed for those length intervals with no corresponding age — typically only smaller fish lengths (less than about 30 cm) that were assigned age 1 or 2 depending on their size. We therefore ensured that an age was available for every length interval below 50 cm for males and 52 cm for females, for which length frequency observations were available. Any larger fish were put into an 'unassigned' category, which were placed in the plus group at age 11 for modelling.

5.2 Auckland Islands

The Auckland Islands has been fished only sporadically since 1990 (Table 18). Some targeting of aggregations of southern blue whiting during the spawning season occurred between 1993 and 1998, but since then most of the southern blue whiting catch has been taken as bycatch of fisheries targeting hoki, hake, ling, and squid during other months of the year (Hanchet & Dunn 2009). Almost 86% of the catch but only 37% of the tows have been made in the months July to October.

Small numbers of fish were measured in most years from a small amount of effort around the Auckland Islands (Figure 8, Table 18), but few otoliths were collected and these have not been read. Catch-at-age data are available only for 1993 to 1998 (Figure 9). The catch at that time was dominated by the strong 1991 year class.

Table 18: Total number of tows and TCEPR estimated catch of southern blue whiting (including non-target), observed tows and estimated catch (including non-target), number of measured and aged males and females, Auckland Islands 1990–2011 (source: TCEPR and Observer data, 1990–2011).

Year			Catch				Observed		Measured		Aged
	Vessels	Tows	t	Vessels	Tows	t	%t	Male	Female	Male	Female
1990	7	90	0	0	0	0	0.0	0	0	0	0
1991	6	126	5	0	0	0	0.0	0	0	0	0
1992	11	88	73	0	0	0	0.0	0	0	0	0
1993	5	82	1 133	2	5	457	40.4	495	264	28	37
1994	12	310	1 056	1	7	324	30.6	601	563	57	79
1995	5	15	408	4	10	345	84.4	732	974	46	94
1996	3	6	54	0	0	0	0.0	0	0	0	0
1997	7	54	935	3	11	517	55.4	1 019	827	126	114
1998	11	120	520	1	6	238	45.8	649	550	80	38
1999	10	172	214	0	0	0	0.0	0	0	0	0
2000	11	273	7	0	0	0	0.0	0	0	0	0
2001	9	218	0	0	0	0	0.0	0	0	0	0
2002	15	496	45	2	3	3	6.0	100	89	20	25
2003	14	462	14	0	0	0	0.0	0	0	0	0
2004	11	312	27	1	1	4	16.7	12	28	0	0
2005	13	445	43	0	0	0	0.0	0	0	0	0
2006	12	225	35	0	0	0	0.0	0	0	0	0
2007	11	488	240	2	5	4	1.8	107	77	0	0
2008	7	186	67	1	11	16	24.4	307	220	0	0
2009	8	293	93	0	0	0	0.0	0	0	0	0
2010	9	256	39	1	3	5	13.5	175	175	0	0
2011	6	185	28	1	1	1	2.0	9	11	0	0

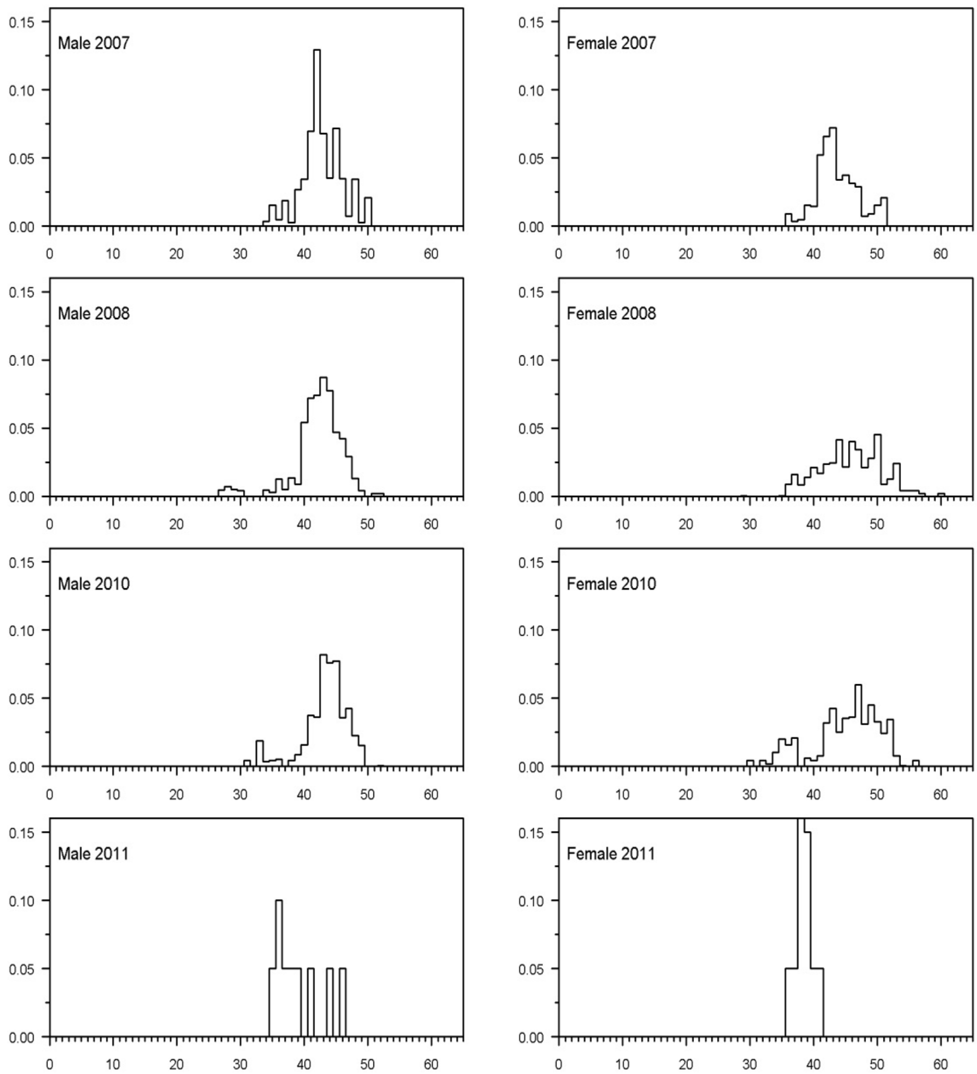

Figure 8: Commercial catch proportions-at-length for the Auckland Islands stock by sex, 2007–2011.

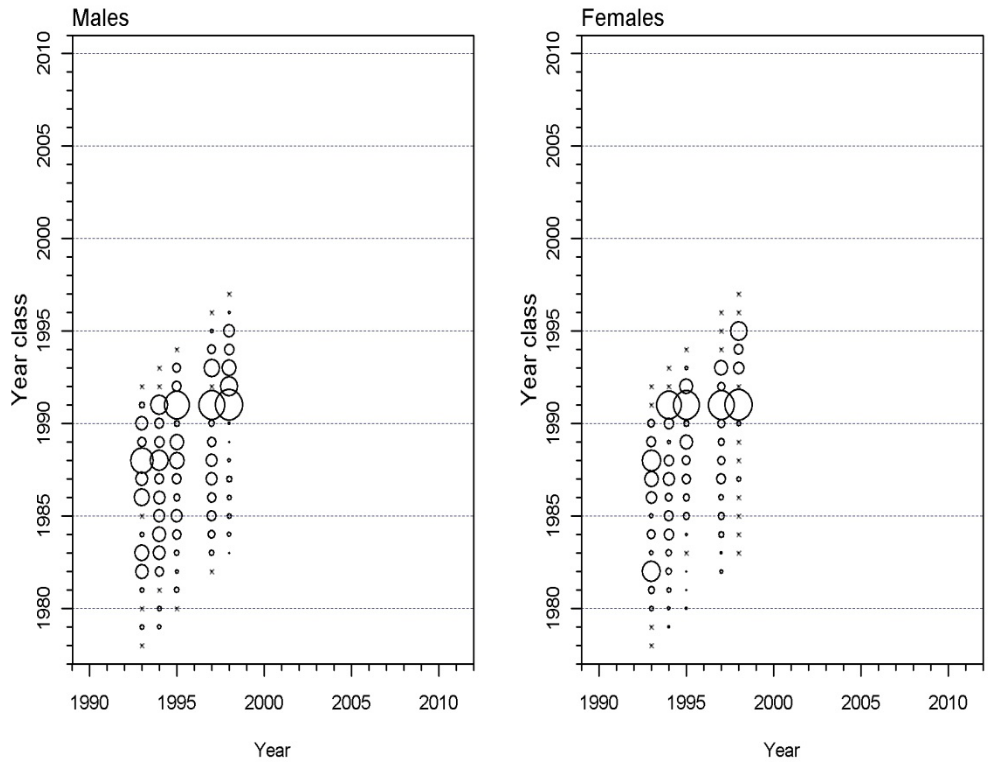

Figure 9: Commercial catch proportions-at-age for the Auckland Islands stock by sex and year class, 1990–2011. Symbol area is proportional to the proportions-at-age within the sampling year.

5.3 Bounty Platform

The Bounty Platform has been fished consistently since 1990 (Table 19), and in each year all of the catch and almost all of the tows have been made between July and October. Catch-at-age data are available for almost the entire period 1990 to 2011, although the numbers of fish measured and aged were low in some years and missing in 2003 (Table 19). Examination of the raw data showed that the length composition was relatively constant through the season and across the area and so in most years all the length frequency data were placed into a single stratum. The catch in recent years has been dominated by a single mode of fish (the 2002 year class), which can be tracked from 2005, when it first entered the fishery at about 30 cm as 3 year olds, to 2010, when it completely dominated the fishery as 8 year olds (Figure 10). This year class was estimated to be particularly strong (Hanchet & Dunn 2009). In 2011, a second year class was apparent in the length and age frequency (the 2007 year class), with a mode at about 35 cm. Previously, the catch over the 20 year period has been dominated by several other strong year classes — in particular those from 1986, 1988, 1991, 1992, and 1994 (Figure 11).

Table 19: Total number of tows and TCEPR estimated catch of southern blue whiting (including non-target), observed tows and estimated catch (including non-target), number of measured and aged males and females, Bounty Platform, 1990–2011 (source: TCEPR and Observer data, 1990–2011).

Year	Catch			Observed				Measured		Aged	
	Vessels	Tows	t	Vessels	Tows	t	%t	Male	Female	Male	Female
1990	26	269	4 438	5	23	391	8.8	2 569	1 690	135	118
1991	31	662	11 185	3	16	458	4.1	1 613	1 140	85	56
1992	49	1 732	58 696	10	161	10 086	17.2	12 726	12 189	318	282
1993	21	433	11 788	6	72	5 037	42.7	4 901	7 065	213	319
1994	9	202	3 877	4	40	2 836	73.1	4 202	3 126	255	253
1995	10	156	6 473	5	65	5 816	89.9	5 992	4 299	215	189
1996	5	67	5 113	2	22	2 511	49.1	2 171	2 465	201	280
1997	5	37	2 043	3	8	689	33.7	692	884	151	293
1998	12	119	5 824	6	69	5 627	96.6	7 574	6 743	211	261
1999	14	289	10 573	5	73	4 765	45.1	6 145	6 217	195	383
2000	6	99	3 851	3	27	2 716	70.5	1 858	3 323	110	288
2001	5	32	1 554	2	12	1 060	68.2	836	1 133	218	283
2002	8	182	6 209	1	8	1 116	18.0	590	671	62	87
2003	3	24	3 603	0	0	0	0.0	0	0	0	0
2004	4	234	1 478	1	3	379	25.7	202	292	80	111
2005	8	284	3 769	4	40	2 818	74.8	3 212	3 256	159	261
2006	6	145	4 256	3	62	3 375	79.3	5 658	4 231	232	268
2007	5	103	3 602	3	27	3 458	96.0	2 118	2 124	110	190
2008	9	209	9 582	5	91	6 489	67.7	6 085	9 713	130	276
2009	14	426	14 958	4	104	5 269	35.2	7 637	8 526	130	292
2010	14	601	13 783	4	57	3 810	27.6	4 918	3 836	194	204
2011	9	241	6 468	4	49	3 876	59.9	4 121	4 205	143	203

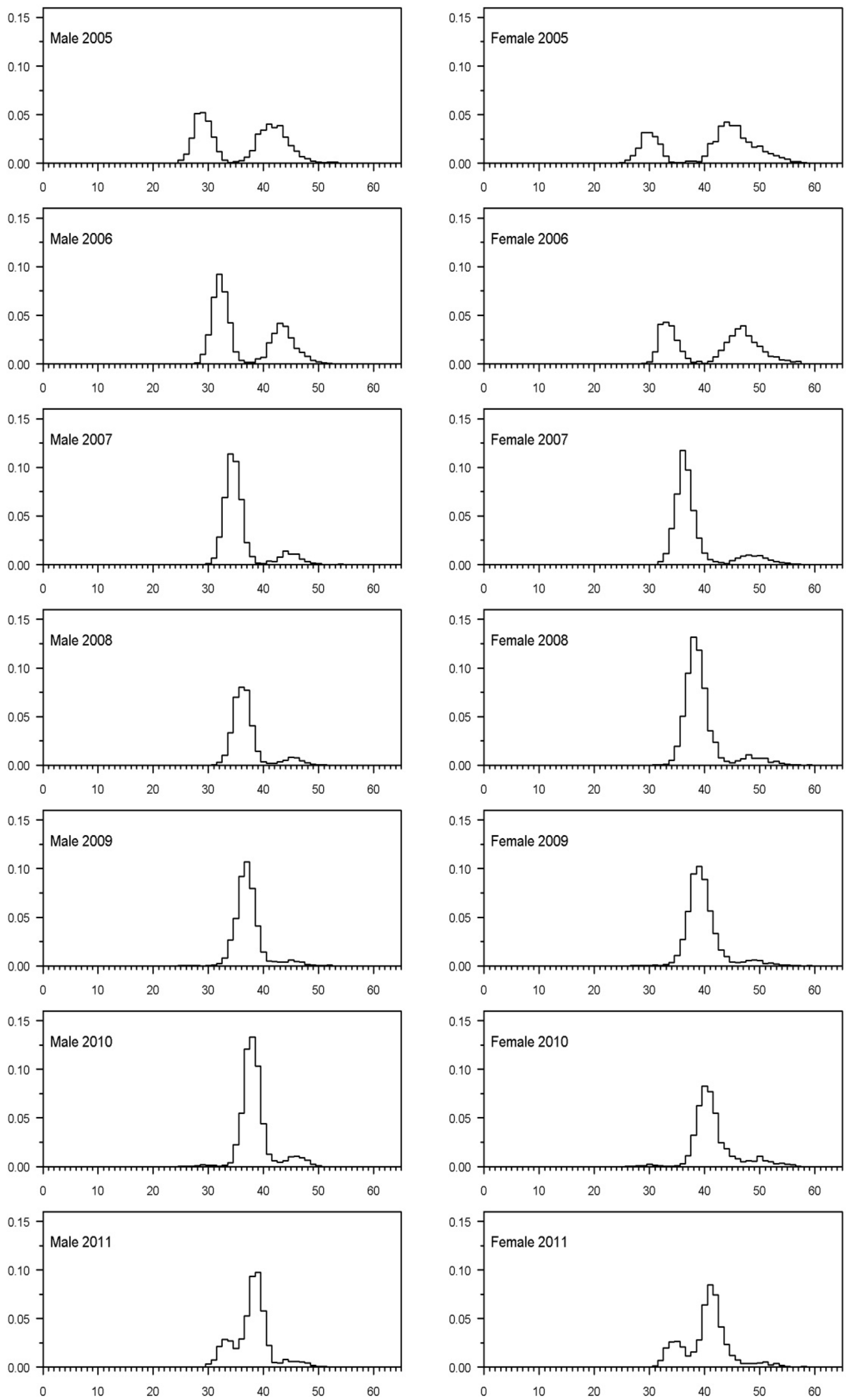

Figure 10: Commercial catch proportions-at-length for the Bounty Platform stock by sex, 2005–2011.

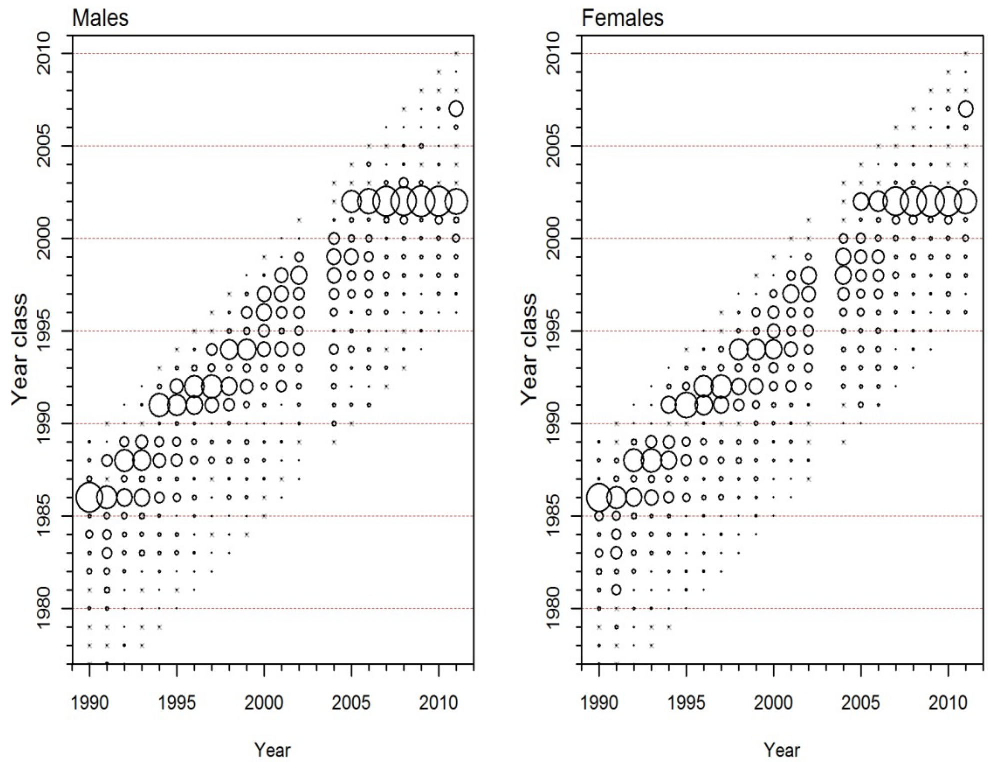

Figure 11: Commercial catch proportions-at-age for the Bounty Platform stock by sex and year class, 1990–2011. Symbol area proportional to the proportions-at-age within the sampling year.

5.4 Campbell Island Rise

The Campbell Island Rise has been fished since 1979, although we have restricted much of the data presented here to that collected since 1990 (Table 20). Almost all of the catch and the tows during these years have been made in the months July to October.

Catch-at-age data are presented for the period since 1990, although the numbers of fish measured and aged were low in some years (Table 20). Examination of the raw data showed that the length composition was often different between the northern and southern Campbell Island Rise. Therefore, the analysis was carried out by dividing the area into two strata (at 52º 30’S) for each year. The commercial catch at Campbell Island is currently dominated by a single mode of fish at about 35 cm, which comprises the 2006 and 2007 year classes (Figure 12 and Figure 13). Previously, the catch over the 20 year period has been dominated by several other strong year classes – in particular those from 1988, 1991, and 2001 (Figure 13).

Data for the numbers-at-age (and c.v.s) from 1979 to 1989 are described in Hanchet et al. (2003). But as these data came from single vessels fishing during the spawning season, they are probably less reliable than the more recent data.

Table 20: Total number of tows and TCEPR estimated catch of southern blue whiting (including non-target), observed tows and estimated catch (including non-target), number of measured males and females, Campbell Island Rise, 1990–2011 (source: TCEPR and Observer data, 1990–2011).

Year	Catch			Observed				Measured		Aged	
	Vessels	Tows	t	Vessels	Tows	t	%t	Male	Female	Male	Female
1990	36	1 079	16 559	7	94	2 508	15.1	10 459	7 677	346	282
1991	35	1 242	21 934	3	52	1 107	5.0	3 852	4 864	281	413
1992	48	1 533	13 454	10	121	1 911	14.2	9 839	8 287	330	287
1993	20	423	8 757	5	55	2 722	31.1	4 456	4 623	247	321
1994	15	480	11 405	4	80	5 622	49.3	8 458	4 717	416	346
1995	12	285	9 989	5	76	7 726	77.3	5 807	7 301	212	358
1996	11	474	16 744	4	97	5 406	32.3	7 802	10 270	182	347
1997	18	650	19 145	6	185	9 476	49.5	16 756	16 254	239	255
1998	24	960	24 162	8	254	12 740	52.7	26 603	23 237	259	361
1999	21	790	27 206	9	175	11 308	41.6	15 024	15 522	227	190
2000	18	556	14 470	10	168	9 695	67.0	15 098	14 289	210	289
2001	16	919	24 410	10	321	19 144	78.4	27 994	25 500	135	270
2002	20	1 013	29 148	7	185	9 863	33.8	15 990	16 212	178	319
2003	16	636	22 695	5	124	2 922	12.9	9 259	10 979	236	383
2004	16	726	19 513	7	132	7 263	37.2	12 083	11 958	276	439
2005	17	757	25 200	6	187	9 041	35.9	14 184	18 757	147	262
2006	13	524	18 905	4	110	7 653	40.5	11 779	7 700	206	294
2007	13	549	20 437	6	119	8 345	40.8	10 291	11 504	182	234
2008	14	557	19 723	6	171	9 658	49.0	15 112	14 513	225	252
2009	14	629	18 299	3	53	3 145	17.2	4 506	3 856	123	311
2010	13	553	19 415	7	175	8 460	43.6	14 406	13 810	214	260
2011	14	976	29 204	8	246	9 739	33.3	18 600	23 340	208	254

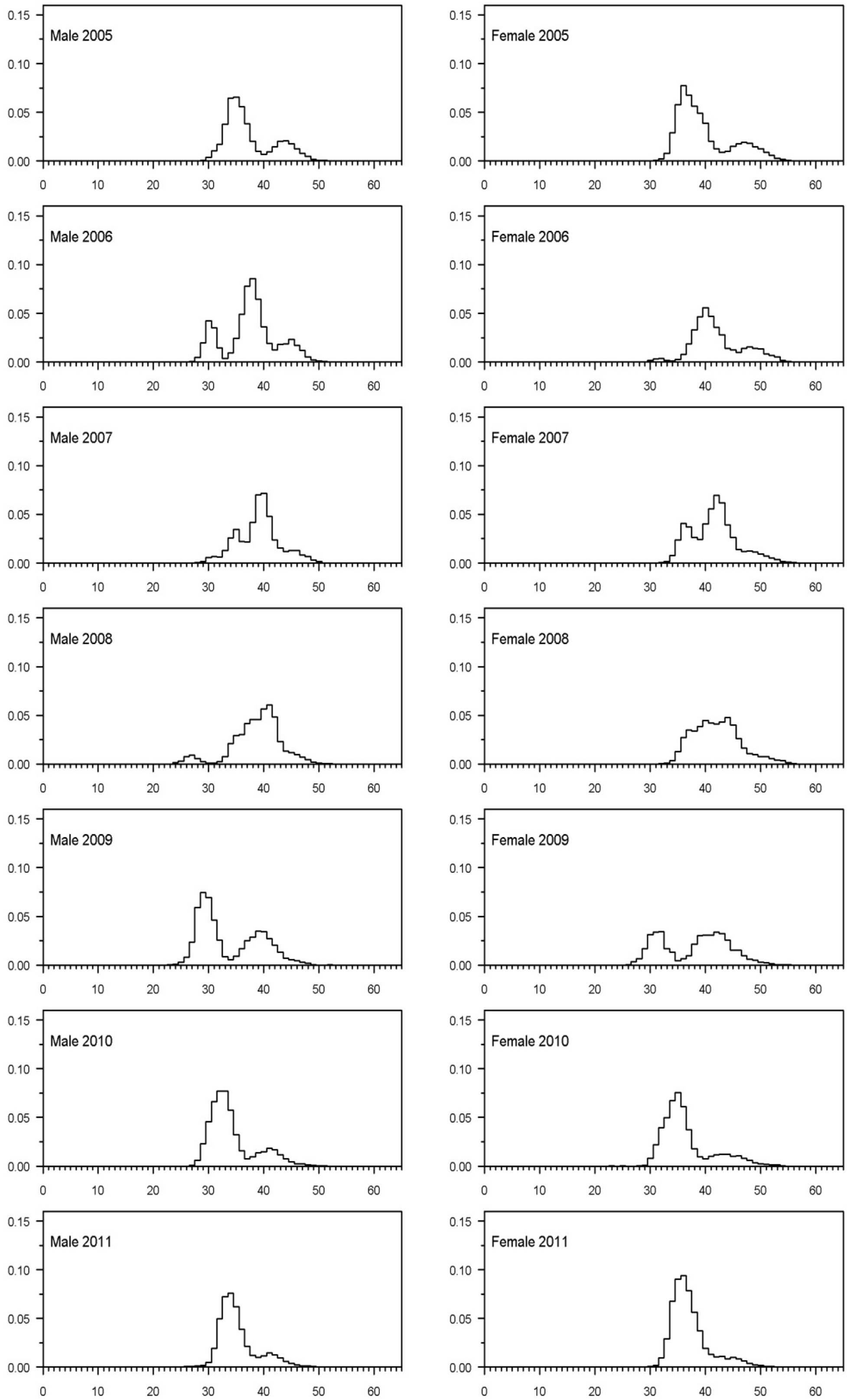

Figure 12: Commercial catch proportions at length for the Campbell Island Rise stock by sex, 2005–2011.

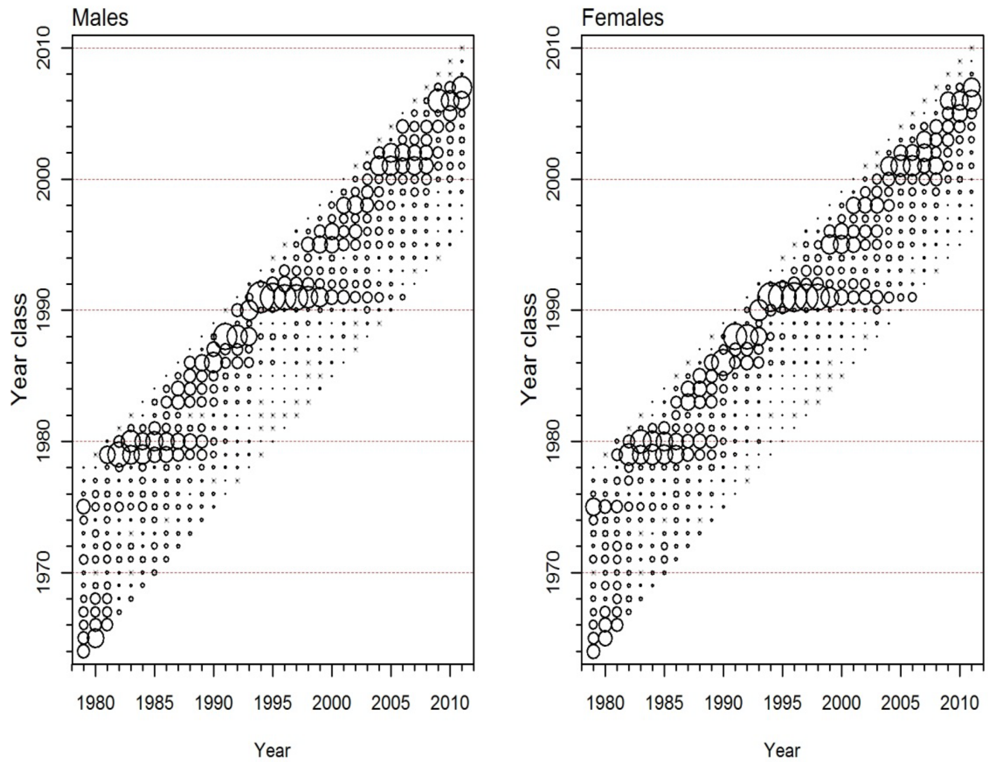

Figure 13: Commercial catch proportions-at-age for the Campbell Island Rise stock by sex and year class, 1979–2011. Symbol area proportional to the proportions-at-age within the sampling year.

5.5 Pukaki Rise

The Pukaki Rise has been fished only sporadically since 1990 with most of the catch taken between 1991 and 1993 and again in 2009 and 2010 (Table 21). While almost all of the catch has been made in the months July to October, less than half of the effort that recorded at least some southern blue whiting catch occurs during this period. The remaining effort has typically targeted hoki and other middle depth species (Hanchet & Dunn 2009), with small amounts of southern blue whiting bycatch.

Catch-at-age data are available for the period 1989 to 2000 and again for 2007, 2009, and 2010, although the numbers of fish measured and aged were low in some years (Table 21). Examination of the raw data showed that the length composition was relatively constant through the season and across the area and so the length frequency data were analysed as a single stratum. The catch in 2010 was dominated by two main modes: a mode of larger fish comprising the 2003–2005 year classes and a mode of smaller fish comprising the 2006 year class (Figure 14). The catch over the 20 year period has been dominated by several other moderate year classes – in particular those from 1985, 1986, 1990, and 1991 (Figure 15).

Table 21: Total number of tows and TCEPR estimated catch of southern blue whiting (including non-target), observed tows and estimated catch (including non-target), number of measured males and females, Pukaki Rise 1990–2011 (source: TCEPR and Observer data, 1990–2011).

Year	Catch			Observed				Measured		Aged	
	Vessels	Tows	t	Vessels	Tows	t	%t	Male	Female	Male	Female
1990	35	464	1 295	6	20	204	15.7	2 624	1 050	182	197
1991	27	512	4 697	4	24	771	16.4	1 983	2 265	191	282
1992	44	614	2 866	5	23	227	7.9	1 611	1 391	233	243
1993	23	396	5 341	6	43	2 004	37.5	3 496	3 237	234	345
1994	14	195	1 918	4	22	1 191	62.1	1 831	1 940	222	188
1995	10	82	1 364	4	12	725	53.2	885	1 136	240	274
1996	5	11	299	1	1	112	37.5	72	113	0	0
1997	11	118	2 109	4	24	1 609	76.3	1 720	2 312	184	305
1998	15	115	1 219	7	18	1 248	102.4	1 686	1 756	174	168
1999	10	67	955	0	0	0	0.0	0	0	0	0
2000	15	131	2 402	3	15	1 475	61.4	1 236	1 703	172	229
2001	15	68	284	1	2	45	15.9	153	157	0	0
2002	13	207	111	0	0	0	0.0	0	0	0	0
2003	12	113	19	0	0	0	0.0	0	0	0	0
2004	11	178	53	0	0	0	0.0	0	0	0	0
2005	11	83	44	1	1	4	8.3	85	69	0	0
2006	8	47	1 048	0	0	0	0.0	0	0	0	0
2007	12	200	391	1	4	103	26.4	382	287	39	48
2008	8	113	1 306	1	1	4	0.3	63	117	0	0
2009	16	393	4 777	4	48	1 078	22.6	3 016	3 953	164	261
2010	14	470	4 168	4	51	1 505	36.1	3 319	4 085	170	235
2011	10	444	625	4	4	50	7.9	243	282	0	0

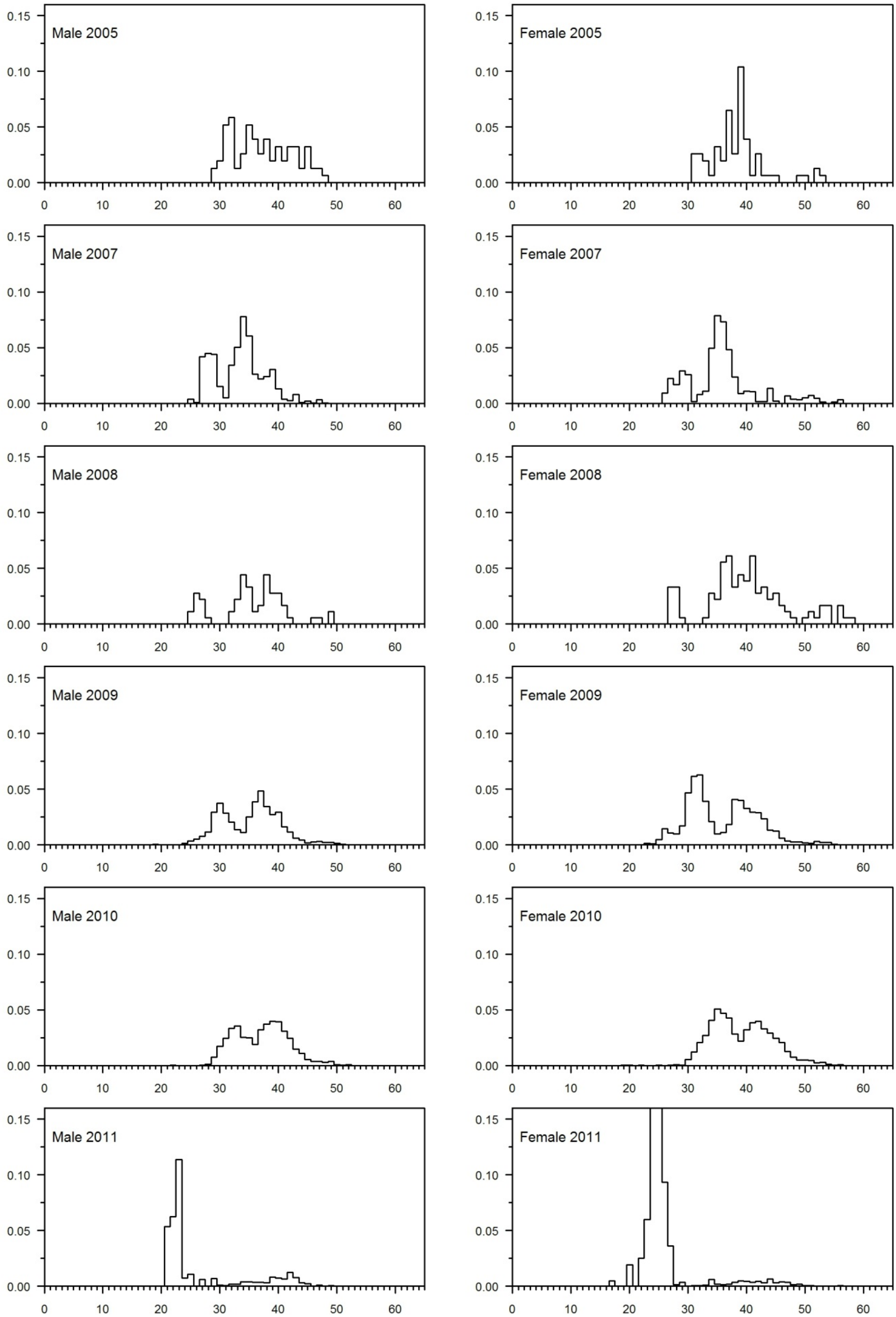

Figure 14: Commercial catch proportions at length for the Pukaki Rise stock by sex, 2007–2011.

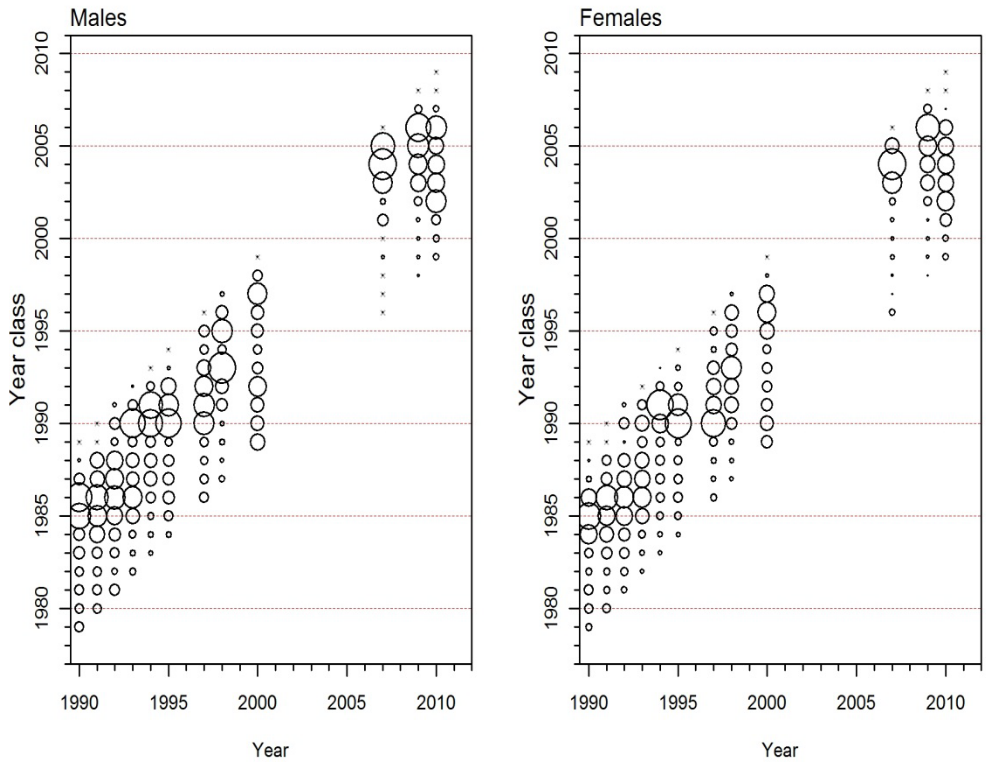

Figure 15: Commercial catch proportions at age for the Pukaki Rise stock by sex and year class, 1990–2011. Symbol area proportional to the proportions-at-age within the sampling year.

5.6 Other areas (SBW1)

The remaining catch has been taken as bycatch of fisheries for hoki and other middle depths species from the Snares Shelf and southern Chatham Rise. Some large catches reported from this area between 1990 and 1996 are likely to be errors in the TCEPR database (Table 22). Most of the catch has been made in the months July to October, but less than half of the effort was made during this period.

Table 22: Total number of tows and TCEPR estimated catch of southern blue whiting (including non-target), observed tows and estimated catch (including non-target), numbers of measured and aged males and females, SBW1 1990–2011 (source: TCEPR and Observer data, 1990–2011).

Year	Catch			Observed			Measured		Aged	
	Vessels	Tows	t	Vessels	Tows	t	Male	Female	Male	Female
1990	20	498	144	0	0	0	0	0	0	0
1991	27	899	70	0	0	0	0	0	0	0
1992	39	1 441	658	0	0	0	0	0	0	0
1993	21	655	711	0	0	0	0	0	0	0
1994	19	1 128	305	0	0	0	0	0	0	0
1995	14	642	693	1	1	20	139	19	4	2
1996	7	405	45	0	0	0	0	0	0	0
1997	13	823	163	0	0	0	0	0	0	0
1998	23	1 082	93	0	0	0	0	0	0	0
1999	26	1 732	14	0	0	0	0	0	0	0
2000	26	1 803	0	0	0	0	0	0	0	0
2001	29	1 660	52	0	0	0	0	0	0	0
2002	29	1 948	4	0	0	0	0	0	0	0
2003	23	1 187	8	1	1	0	54	1	0	0
2004	23	1 394	0	0	0	0	0	0	0	0
2005	22	1 388	0	0	0	0	0	0	0	0
2006	22	1 230	1	0	0	0	0	0	0	0
2007	19	1 402	0	0	0	0	0	0	0	0
2008	22	1 609	6	0	0	0	0	0	0	0
2009	22	1 243	226	0	0	0	0	0	0	0
2010	23	1 569	0	0	0	0	0	0	0	0
2011	20	909	0	0	0	0	0	0	0	0

6. DISCUSSION

This document compiles the large amount of research carried out on southern blue whiting over the past 20 years into one document. We have included here biological parameters, time series of relative abundance from acoustic surveys for each of the four main stocks from the wide area R.V. *Tangaroa* surveys as well as from local area aggregation industry vessel surveys, CPUE indices for Bounty Platform and Campbell Island Rise, and trawl survey indices for the Auckland Islands Shelf, Campbell Island Rise, and Pukaki Rise, as well as updated time series of length-at-age and catch-at-age.

R.V. *Tangaroa* acoustic surveys were carried out on the three main stocks from 1993 until around 2000, when because of the low catch limits on the Bounty and Pukaki stocks, the returns from the fishery were too low to be able to afford funding additional R.V. *Tangaroa* acoustic surveys and the time series of acoustic surveys was discontinued. Local area aggregation surveys from industry vessels on the Bounty Platform since 2004, and more recently on the Pukaki Rise, have provided the only biomass information on these stocks. However, there has been very large inter-snapshot and inter-annual variability in these biomass estimates making it difficult to use them for assessment and management purposes. On the Bounty Platform there was a seven-fold increase in biomass between 2006 and 2007 followed by a similar sized decline in biomass between 2008 and 2009. On the Pukaki Rise, acoustic snapshots ranged from 400 to 24 000 t in 2009 but declined to 2 211 t in 2010. Without a wide-area survey to provide a ground truthing of the local area survey results there will be on-going uncertainty about the status of these stocks (O'Driscoll 2011c, O'Driscoll et al. 2012).

Industry acoustic surveys on the Campbell Island Rise have also been unsuccessful, in part because of the much larger area which needs to be surveyed and the rougher weather conditions. Wide area acoustic surveys using the R.V. *Tangaroa* are likely to be the preferred option for monitoring the Campbell

Island stock because of the ability to use a towed acoustic array and the reliable estimates of immature (age 2 and 3 year old) fish provided by this survey.

Estimates of abundance from the sub Antarctic trawl surveys on the Auckland Islands Shelf, Campbell Island Rise, and Pukaki Rise were available for the period 1991 to 2011. While the surveys were not designed to monitor southern blue whiting, the biomass estimates for the latter two areas had moderate c.v.s, showed some consistency between years, and the trends showed some correspondence with biomass trajectories from stock assessments (Hanchet & Stevenson 2006). However, Dunn & Hanchet (2011b) concluded that the time series is not particularly useful for monitoring abundance in their present form.

CPUE indices for the Bounty Platform and Campbell Island Rise are available for the period 1990–2002 and 1986–2005 respectively. Although most fishing is carried out on highly aggregated spawning concentrations of southern blue whiting, there was moderate agreement between some of the CPUE indices and the biomass trajectories from modelling the stocks (Hanchet et al. 2003, Hanchet 2005). However, the Middle Depths Working group was unable to agree on a time series to use and rejected these indices for stock assessment modelling (Ministry of Fisheries 2009).

The time series of catch-at-age and length-at-age were updated for this report. The numbers differed slightly from that in a previous report, due to additional observer data being loaded after the original analysis was completed. Catch on the Bounty Platform was dominated by the 2002 year class, with almost no recruitment until 2011, where there is some evidence of recruitment from the 2007 year class in the commercial catch-at-age proportions.

There is strong evidence of several year classes of moderate strength at the Campbell Island Rise, with both acoustic indices and commercial catch-at-age proportions suggesting strong recruitment in 2006 and 2007; and the acoustic indices suggesting another strong year class in 2009. Very few otoliths were collected from the Pukaki Rise and Auckland Islands in 2011 and so the catch data have not been aged and the length data in recent years are not sufficient to infer when or if strong recruitment has entered those fisheries.

7. ACKNOWLEDGMENTS

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