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Industry acoustic surveys of spawning southern blue whiting on the Bounty Platform, New Zealand

Richard L. O'Driscoll*, Adam J. Dunford, Alistair Dunn

National Institute of Water and Atmospheric Research, PO Box 14-901, Kilbirnie, Wellington, New Zealand

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ABSTRACT

Annual acoustic surveys of spawning southern blue whiting (*Micromesistius australis*) on the Bounty Platform, southeast of New Zealand, have been carried out using industry vessels since 2004. In most years, surveys were carried out from a single vessel, while in 2009, acoustic data were collected from three vessels. The survey approach in all years was the same—vessels with calibrated Simrad ES60/ES70 echosounders and hull-mounted 38 kHz transducers conducted aggregation-based surveys using an adaptive design. Surveys attempted to cover all areas of high southern blue whiting density. In most years there were multiple snapshots of the same aggregation. The resulting biomass was used as a relative estimate of spawning southern blue whiting abundance. There was a very large (seven-fold) increase in estimated biomass of southern blue whiting at the Bounty Platform from 2006 to 2007, which was due to the recruitment of one very strong year class (2002) into the spawning population. The estimated biomass from 2008 was also high, but biomass declined by a factor of four in 2009. The observed decline in acoustic estimates between 2008 and 2009 was too great to be explained solely by fishing and average levels of natural mortality. The very large changes in estimated abundance between years, and also between snapshots within a year, are related mainly to changes in survey temporal and spatial coverage, and illustrate an important limitation on interpretation of aggregation-based acoustic abundance estimates. In each snapshot an unknown proportion of the spawning aggregation is surveyed, and almost certainly not the entire spawning stock. Survey coverage depended on both the amount of survey time available (which is often limited by commercial constraints) and the behaviour of the fish (e.g., the extent and density of the aggregation, and the timing of spawning). It is therefore difficult to incorporate the resulting series of abundance estimates into a formal stock assessment model as a time series. Despite this, industry acoustic surveys of the Bounty Platform have led directly to management decisions and changes in catch limits.

1. Introduction

Southern blue whiting (*Micromesistius australis*, hereafter SBW) is a gadoid occurring in Sub-Antarctic waters, with known spawning grounds off South America and southeast of New Zealand. SBW is one of New Zealand's largest volume fisheries, with annual landings of between 25 000 t and 40 000 t since 2000 (Ministry for Primary Industries, 2013). Spawning and fishing grounds in New Zealand waters are on the Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise (Fig. 1). Fish from the four areas are treated as separate stocks for stock assessment (Hanchet, 1999). Spawning occurs on the Bounty Platform from mid-August to early September and 3–4 weeks later in the other areas.

SBW form large high density aggregations at depths from 200 to 500 m during spawning and these are estimated using acoustic surveys. A programme to acoustically estimate SBW spawning stock biomass on each New Zealand fishing ground 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 vessel surveys is on the Campbell Island Rise grounds, which have been surveyed in 1998, 2000, 2002, 2004, 2006, 2009, 2011, and 2013 (e.g., O'Driscoll et al., 2012). All these research surveys were carried out from R.V. *Tangaroa* using towed transducers and were wide-area surveys intended to estimate spawning SBW and pre-recruits. The results of these research acoustic surveys are the main input into SBW stock assessments (e.g., Ministry for Primary Industries, 2013).

* Corresponding author. Tel.: +64 4 386 0300; fax: +64 4 386 0574.
E-mail address: richard.odriscoll@niwa.co.nz (R.L. O'Driscoll).

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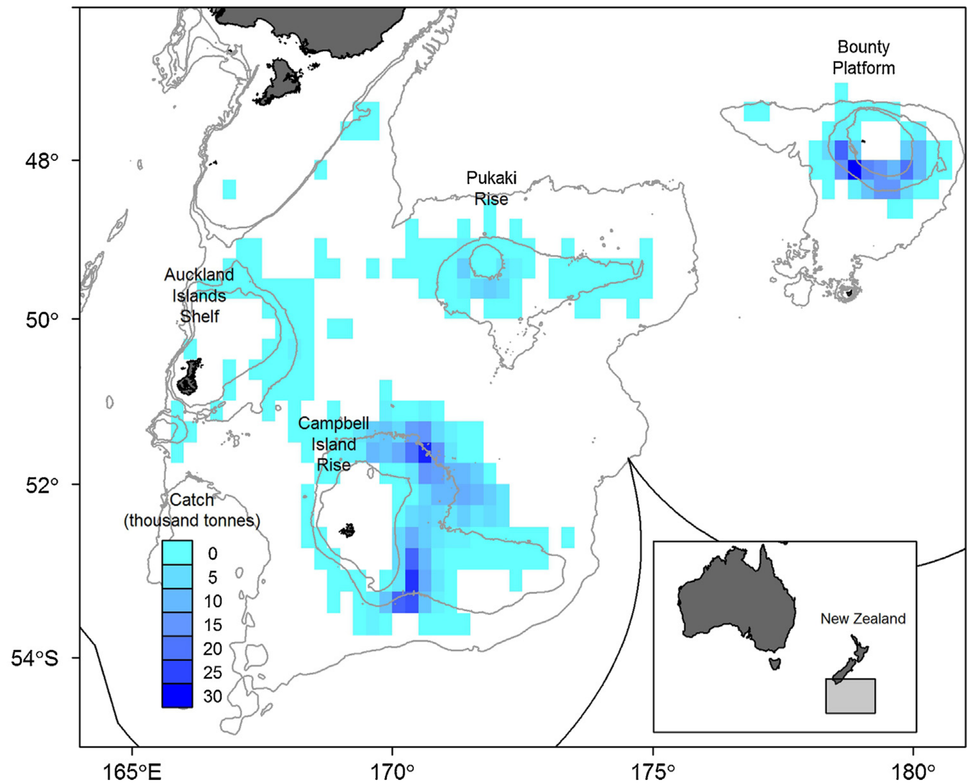

Fig. 1. Location of New Zealand southern blue whiting spawning grounds and fishing areas. Coloured pixels show summed commercial catches in 0.2 degree bins from 1990 to 2013. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The biomass of the Bounty stock declined over the period of the *Tangaroa* acoustic surveys from 1993 to 2001, and the total allowable commercial catch (TACC) was reduced to 3500 t in 2003 (Table 1). Under New Zealand's quota management system, the cost of fisheries research is recovered from industry participants (Mace et al., 2014), and because of the relatively low value of the Bounty SBW stock in 2003, the research vessel survey of this area was no longer deemed affordable.

A pilot acoustic survey of the Campbell Island grounds, carried out from FV *Aoraki* in 2003, showed that industry vessels with hull-mounted acoustic systems could be used to collect acoustic data on SBW in good weather conditions (less than 25 knots of wind) (O'Driscoll and Hanchet, 2004). O'Driscoll and Hanchet (2004) further demonstrated that snapshots of the main spawning aggregations could be carried out using the processing time between commercial trawls without seriously compromising fishing success (O'Driscoll and Macaulay, 2005). Surveys of spawning SBW from industry vessels using this approach have been carried out annually on the Bounty Platform since 2004.

In this paper we describe the survey design and outcomes of the Bounty SBW surveys from 2004 to 2013. We use this time-series to illustrate the advantages and limitations associated with using aggregation-based acoustic abundance estimates for stock assessment and management.

Table 1
Estimated catches and catch limits for southern blue whiting for Bounty Platform from 1990 to 2013. From 1990 to 1998, the fishing year was defined from 1 October to 30 September (i.e., 1990 fishing year was 1 October 1989 to 30 September 1990), but this was changed to 1 April to 31 March in 1999 to reflect the timing of the main fishing season (i.e., 1999 fishing year was from 1 April 1999 to 31 March 2000). Catch limits were introduced for the first time in the 1993 fishing year (n/a, indicates no catch limit in place). SBW were introduced to the Quota Management System on 1 November 1999.

Fishing year	Catch (*t*)	Catch limit (*t*)
1990	4430	n/a
1991	10 897	n/a
1992	58 928	n/a
1993	11 908	15 000
1994	3877	15 000
1995	6386	15 000
1996	6508	8000
1997	1761	20 200
1998	5647	15 400
1999	8741	15 400
2000	3997	8000
2001	2262	8000
2002	7564	8000
2003	3812	3500
2004	1477	3500
2005	3962	3500
2006	4395	3500
2007	3799	3500
2008	9863	9800
2009	15 468	14 700
2010	13 913	14 700
2011	6660	6860
2012	6827	6860
2013	4278	4028*

* While the TACC remained at 6860 t in 2013, the catch limit was reduced to 4028 t under a voluntary agreement.

2. Materials and methods

2.1. Vessels and equipment

Acoustic data were collected from three fishing vessels, each fitted with a Simrad ES60 or ES70 echosounder and hull-mounted split-beam 38 kHz transducer. Echosounders were calibrated

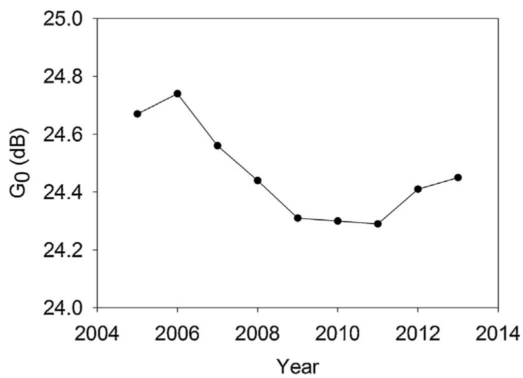

Fig. 2. Changes in 'on axis' transducer peak gain (G_0) for the ES60 and ES70 echosounders on *Tomi Maru 87*.

regularly by NIWA using standard scientific methods (Foote et al., 1987). Standard acoustic settings were required including power output of 2000 W, pulse length 1.024 ms, and fixed ping interval 2 s.

In all years from 2004 to 2013, acoustic data were collected from FV *Tomi Maru 87*, a 68 m Japanese surimi trawler chartered by Aurora Fisheries Ltd. The vessel was fitted with a Simrad ES60 echosounder, which was replaced with a Simrad ES70 in 2010. The changes to the echosounder are software-based, and both ES60 and ES70 echosounders on this vessel used the same general purpose transceiver (GPT) and hull-mounted 38-kHz split-beam transducer. The echosounder on *Tomi Maru 87* was calibrated annually since 2005. The long-term calibration trend for this echosounder is shown in Fig. 2 and is consistent with that observed for similar systems elsewhere (Knudsen, 2009).

In 2009, acoustic data were also collected from two other vessels. FV *Meridian 1* and FV *A. Buryachenko* are 105-m Ukranian factory-freezer trawlers chartered by Sealord Ltd. Both vessels had 38-kHz ES60 echosounders which were calibrated in 2009.

2.2. Survey design

Spawning SBW form dense, mobile aggregations during spawning. The aim was to cover the main SBW aggregation(s) using an adaptive design. Surveys were supervised by vessel officers in all years except 2006, when an industry representative supervised acoustic data collection on FV *Tomi Maru 87*. Government scientific observers were onboard to collect biological data on catch composition and fish size and condition in all surveys, but were not involved in acoustic data collection. Detailed written and illustrated instructions on survey design (O'Driscoll 2011) were translated and provided, and vessel officers were also personally briefed before each survey. A summary of these instructions is described below and illustrated in Fig. 3.

Vessel officers were instructed to collect acoustic data continuously while trawling and searching to allow examination of the spatial distribution of fish. However, surveys to estimate SBW abundance required a number of straight, parallel lines (transects) across an aggregation. Each of these transects was to be run at a constant speed, with a separate, documented, acoustic file. Transect spacing and orientation was dependent on the size and shape of the aggregation and the prevailing weather conditions, but the aim was to obtain 5–10 transects at regular intervals across each aggregation. The importance of ensuring that transects were long enough and numerous enough to fully encompass the main aggregation(s) was emphasised. Three steps to designing a useful survey were outlined:

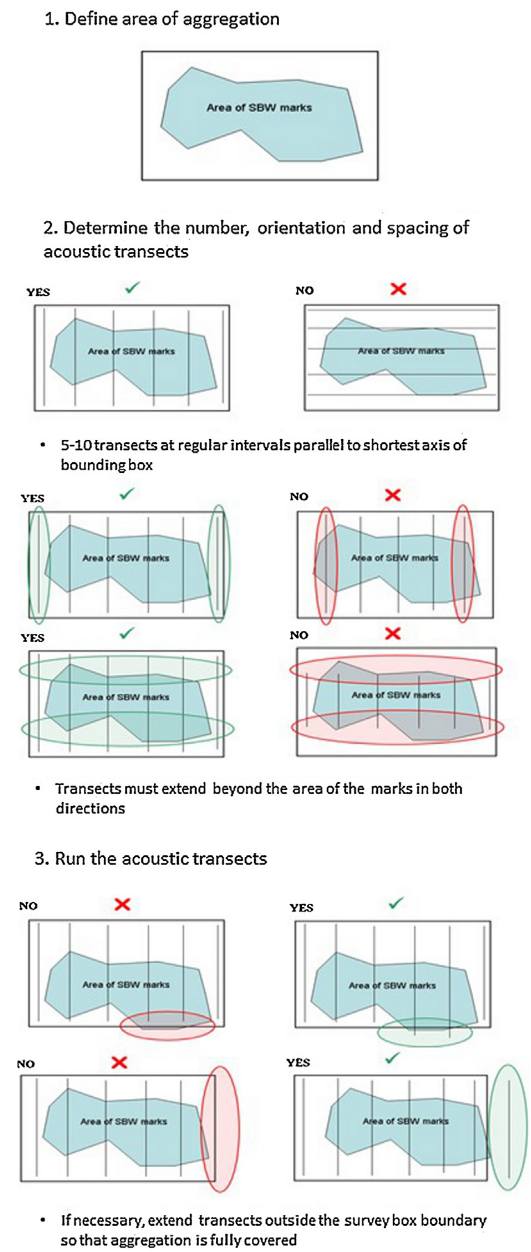

Fig. 3. Illustration of survey design instructions provided to vessel officers for acoustic survey of southern blue whiting aggregations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2.1. Define the approximate boundaries of the aggregation

A rectangular box (with latitude and longitude boundaries) containing most of the fish was defined based on fisher experience and the use of scanning sonar (Fig. 3). This box was chosen to be larger than the area in which the aggregation was detected and provided the basic survey area. If during the survey the fish were found to extend out of the box then this was modified (Fig. 3).

2.2.2. Determine the number, orientation and spacing of acoustic transects

Transects were assigned to run across the aggregation. If the survey box was longer in one dimension than the other, then the transects were parallel to the short axis (Fig. 3). Between 5 and 10 transects were evenly spaced across the rectangular survey box. The number of transects depended on their length and the time available for surveying. For example, if there was

4 h available for the acoustic survey, and each transect took 30 min, then it was possible to do only 6 transects (allowing time for the steams between adjacent transects). The transect spacing depended on the size of the box and the number of transects. For example, if the survey box was 10 km long, and there was time for 6 transects, then the transects were 10/6 = 1.6 km apart.

2.2.3. Run the acoustic transects

Transects were run at a constant speed of 6–10 knots. The actual speed depended on the vessel and the weather conditions. The maximum speed (less than 10 knots) was chosen that gave a good echosounder picture. Faster speeds were possible only in good weather. We required all transects to be carried out sequentially with no interruptions. To adequately describe the extent of the aggregation, the transects needed to extend beyond the area of the marks in both directions. If necessary, transects were extended outside the survey box boundary so that the marks are fully covered, and additional transects were added at the same regular interval outside the original survey box boundary until no SBW were detected on the outer (bounding) transects (Fig. 3)

Previous research surveys of the Bounty Platform showed that SBW are very hard to survey acoustically during the day because fish are very close to the seabed (Hanchet et al., 2000), therefore we requested that all transects be carried out at night. Because aggregation acoustic abundance estimates are highly variable, the aim was to carry out at multiple surveys (snapshots) covering the main spawning aggregation on the Bounty Platform grounds on several nights during the main spawning season.

Clear instructions were also provided on protocols for acoustic data collection, including use of standard scientific settings on the echosounder, turning other acoustic equipment off during transects to avoid interference, and collecting data in suitable weather conditions. Based on previous experience (O'Driscoll and Hanchet, 2004), suitable conditions were defined as less than 25 knots of wind and 2 m swell. There was no targeted trawling for mark identification or biological data collection. Biological data from commercial trawls were collected by government scientific observers during all surveys.

2.3. Acoustic data analysis

Acoustic data (Simrad .raw files) were recorded onto a removable USB drive. Data from acoustic transects were extracted and analysed using NIWA's custom ESP2 software (McNeill, 2001). Echograms were visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Noise spikes and missing pings were manually defined as 'bad transmits' so these were not included in subsequent analysis. Regions corresponding to spawning SBW were then identified. Classification of spawning SBW aggregations is relatively straightforward (McClatchie et al., 2000).

Backscatter from regions identified as SBW was then integrated to produce estimates of acoustic areal density (s_a in m^2 m^{-2}). During integration, acoustic backscatter was corrected for a systematic error in ES60 and ES70 data (Ryan and Kloser, 2004) and calculated sound absorption by seawater. No correction was applied for vessel motion. A Microstrain 3DM-GX1 gyro-enhanced orientation sensor was used to record vessel motion on FV *Tomi Maru 87* in 2006, but corrections for the effects of vessel motion (Dunford, 2005) had very little effect (less than 1%) on biomass estimates in good weather and sea conditions because of the relatively shallow depth. Motion sensors were not fitted to FV *Tomi Maru 87* in other years or to FV *Meridian 1* or FV A. *Buryachenko* in 2009.

2.4. Abundance estimation

Acoustic density estimates were converted to SBW biomass using a ratio, *r*, of mean weight to mean backscattering cross section (linear equivalent of target strength) for SBW. This ratio was calculated from the annual scaled length frequency distribution of SBW estimated from scientific observer data.

Acoustic target strength was derived using the target-strength-to-fork-length (TS-FL) relationship for SBW of O'Driscoll et al. (2013):

$$\mathrm{TS} = 22.06 \log_{10}\mathrm{FL} - 68.54 \quad (1)$$

where TS is in decibels and FL is in centimetres. Mean SBW weight, *w* (in grams), was determined using the combined length–weight relationship for spawning SBW from Hanchet (1991):

$$w = 0.00439 \times \mathrm{FL}^{3.133} \quad (2)$$

Mean weight and mean backscattering cross-sections were obtained by transforming the scaled length frequency distributions by Eqs. (1) and (2) and then calculating the means of the transformed distributions.

Biomass estimates and variances for each snapshot were obtained from transect density estimates using the formulae of Jolly and Hampton (1990). The surveyed areas were calculated from transect start and finish positions using the formula: $a = nLW$ where n is the number of transects, L is the mean length of transects, and W is the mean transect spacing. Biomass estimates and CVs were then estimated with and without removing "zero-transects" (i.e., the bounding transects, which define the extent of the aggregation). Inclusion of zero transects may overestimate CVs using the Jolly and Hampton (1990) methodology. Only whole transects with zero density were removed. No attempt was made to remove parts of transects with zero density, as most non-zero transects had SBW over most of their length.

3. Results

3.1. Acoustic data quality

The quality of the acoustic data from *Tomi Maru 87* was generally good except in 2005 when data could not be used for abundance estimation because of acoustic interference from a scanning sonar which was left on throughout the survey. Data from *Meridian 1* and *A. Buryachenko* in 2009 were of lower quality, with some ping dropouts due to the vessel pitching in bad weather, but these could be identified and removed. Echosounder settings and other relevant parameters during data collection followed recommended protocols, except that *A. Buryachenko* collected acoustic data during its first snapshot in 2009 with a transducer power output of 2400 W rather than the recommended 2000 W. As the echosounder was not calibrated at this power setting, this snapshot was not used for abundance estimation.

Relatively dense adult SBW aggregations were observed along most transects on the Bounty Platform (e.g., Fig. 4). All transects except for those in 2004 were carried out at night, when the backscatter attributable to southern blue whiting is highest (Hanchet et al., 2000). Aggregations were usually within 50–100 m of the bottom in 250–400 m water depth, but marks (echotraces) were variable. In general, weaker marks were observed close to the bottom in deeper water pre-spawning, with denser marks observed in shallower water during spawning and post-spawning.

3.2. Survey coverage

Although it was requested that data be recorded continuously while on the fishing grounds, raw data were recorded along

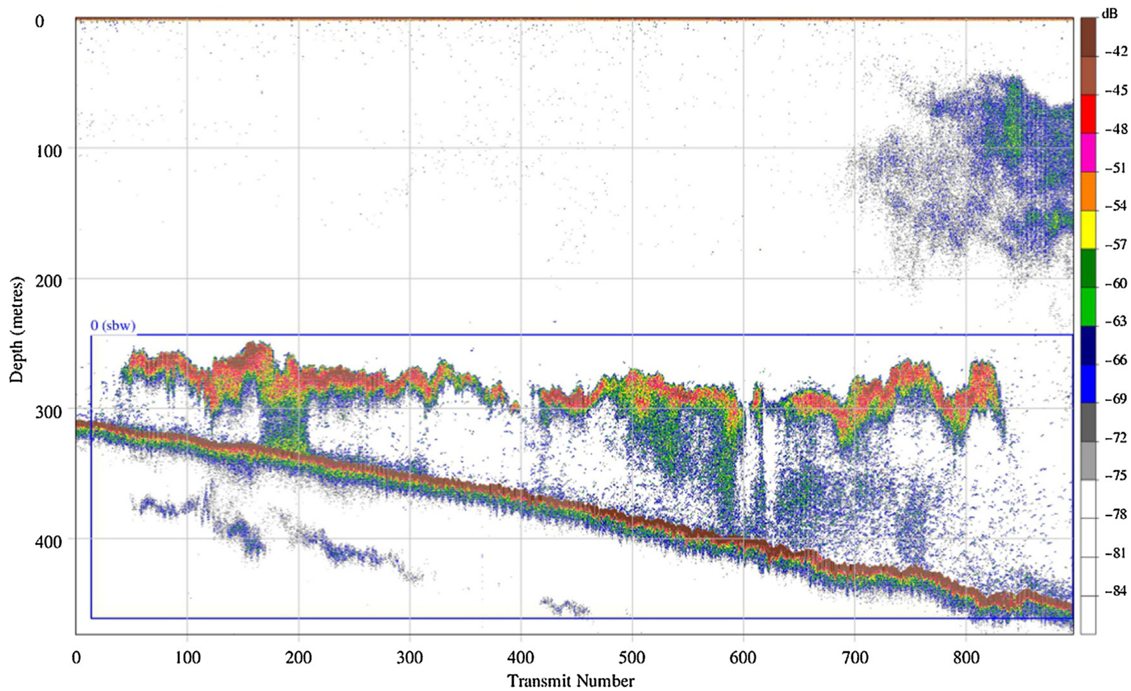

Fig. 4. Example of acoustic echogram collected at the Bounty Platform in snapshot 2 on 20 August 2013 showing SBW aggregation between 250 m and 350 m depth. Transmit number shows relative distance along the transect: 100 transmits is equivalent to about 1 km.

transects only in 2004, 2007, 2009, and 2011. This indicates either a failure in communication or reluctance by vessel officers to continually record data while fishing. The area surveyed in each snapshot was related to the amount of survey time available and was usually constrained by the fishing operations. This meant that the survey area varied considerably between years, and between snapshots within a year (Table 2, Fig. 5). Between one and eight snapshots were completed on the Bounty Platform in 2004–2013. Surveyed areas in 2010 to 2012 were small compared to other years (Table 2).

The distribution of spawning SBW on the Bounty Platform changes during the spawning season. As spawning approaches, SBW typically move into relatively shallow water (200 m) and then migrate anti-clockwise along the depth contour (i.e. west to east). Changes in location of the surveyed areas during the fishing season reflected the changing distribution of spawning SBW (e.g., Fig. 5).

Between 2004 and 2009 there was a trend in survey dates occurring earlier over the Bounty Platform time series (Fig. 6). Timing of SBW spawning has also varied between years, with the main spawning season (defined as the period in which more than 10% of female SBW are running ripe) getting earlier from 2004 to 2010, but becoming later in 2011–2013 (Fig. 6). In most years snapshots were of pre-spawning and spawning aggregations. The single snapshot in 2004, the second snapshot in 2008, and the final snapshot in 2012 were likely post-spawning (Fig. 6).

Spatial coverage of each snapshot was evaluated by examining plots of acoustic density integrated over 10-ping bins (approximately 100 m slices) for each transect (typically 20–100 values per transect) (e.g., Fig. 7). Few of the completed snapshots appeared to completely cover the main aggregation(s), with fish detected on the outer transects and at the end of transects. The exceptions were snapshots 1, 3, and 4–5 in 2007, snapshot 1 in 2008, snapshots 2 and 3 in 2010, and snapshots 2–4 in 2013 (Fig. 7). Vessel officers indicated that survey coverage was often limited by the requirement to trawl (to provide more fish for processing) before the survey was completed.

3.3. Abundance estimates

Abundance estimates for all Bounty Platform snapshots in 2004–2013 are plotted in Fig. 6. Abundance estimates were variable both within and between years, ranging from 336 t in snapshot 2 in 2012 to 117 675 t in snapshot 1 in 2008. Decisions about which snapshots to include when estimating annual SBW abundance were made by the New Zealand Middle Depths Fishery Assessment Working Group (MDFAWG), a group consisting of scientists, fisheries managers, commercial fishers, and representatives of non-governmental organisations, chaired by the New Zealand Ministry for Primary Industries. The MDFAWG considered the spatial coverage of each snapshot (whether SBW were detected on the outer transects and at the end of transects suggesting that the survey did not adequately cover the aggregation), the location of the snapshot relative to commercial fishing effort (e.g., Fig. 5), the timing of the snapshot relative to the observed SBW spawning period (e.g., Fig. 6), and the estimated biomass. Ideally snapshots would be in the main spawning period (when SBW are thought to be most aggregated) and have good coverage. In practice, there were few snapshots that met these criteria, and a pragmatic approach was used to select 'best' snapshots for each year which were then averaged to obtain annual abundance indices. For example, the 'best' estimate from 2004 was from the single acoustic snapshot available, even though this was post-spawning, the survey was carried out during the day, and SBW occurred on all transects, including the outer lines. Similarly, none of the six snapshots in 2009 adequately surveyed the SBW aggregation. However, SBW were more aggregated in the second snapshot from *Meridian 1* and the two snapshots from *Tomi Maru 87* and so these three snapshots were averaged to obtain the 'best' estimate from 2009.

The 'best' estimates of SBW spawning biomass from the industry surveys at the Bounty Platform are given in Table 3 and compared to estimates of SBW adult biomass from *Tangaroa* research surveys in 1993–2001. Research surveys of the Bounty Platform covered a wide area (over 11 000 km^2) from 200 to 550 m depth around the entire Bounty Platform.

Table 2
Summary of acoustic snapshots carried out at the Bounty Platform 2004–2013.

Year	Vessel	Snapshot	Surveyed area (km^2)	Start time(NZST)	End time(NZST)	No. of transects
2004	*Tomi Maru 87*	1	70.5	31 Aug 13:57	31 Aug 15:55	5
2006	*Tomi Maru 87*	1	195.5	25 Aug 19:16	25 Aug 22:40	7
	Tomi Maru 87	2	289.7	26 Aug 19:54	26 Aug 22:28	5
	Tomi Maru 87	3	36.6	27 Aug 22:04	27 Aug 23:22	4
	Tomi Maru 87	4	54.1	28 Aug 19:55	28 Aug 21:25	4
2007	*Tomi Maru 87*	1	236.7	19 Aug 17:20	19 Aug 21:16	7
	Tomi Maru 87	2	128.6	20 Aug 19:33	20 Aug 22:25	5
	Tomi Maru 87	3	261.3	28 Aug 03:47	28 Aug 07:48	5
	Tomi Maru 87	4	319.6	28 Aug 18:30	29 Aug 00:39	7
	Tomi Maru 87	5	93.5	29 Aug 03:47	29 Aug 05:40	3
2008	*Tomi Maru 87*	1	263.0	17 Aug 18:21	17 Aug 22:53	6
	Tomi Maru 87	2	237.5	25 Aug 19:32	25 Aug 23:21	5
2009	*Meridian 1*	1	300.3	10 Aug 21:06	11 Aug 06:22	11
	Meridian 1	2	126.2	11 Aug 23:17	12 Aug 03:50	8
	Tomi Maru 87	1	196.4	14 Aug 18:30	14 Aug 23:00	5
	Tomi Maru 87	2	278.1	15 Aug 19:40	15 Aug 23:59	5
	A. Buryachenko	1	39.9	11 Aug 23:10	12 Aug 01:40	7
	A. Buryachenko	2	28.6	16 Aug 22:55	17 Aug 01:37	5
2010	*Tomi Maru 87*	1	52.5	10 Aug 04:21	10 Aug 06:40	6
	Tomi Maru 87	2	38.5	14 Aug 00:55	14 Aug 01:46	4
	Tomi Maru 87	3	85.7	15 Aug 19:31	15 Aug 23:03	9
2011	*Tomi Maru 87*	1	118.5	13 Aug 00:40	13 Aug 04:46	9
	Tomi Maru 87	2	136.7	13 Aug 22:32	14 Aug 03:12	11
	Tomi Maru 87	3	83.6	18 Aug 20:50	19 Aug 00:30	9
	Tomi Maru 87	4	53.9	19 Aug 21:23	19 Aug 23:43	7
	Tomi Maru 87	5	80.4	20 Aug 19:41	20 Aug 23:03	8
	Tomi Maru 87	6	76.8	21 Aug 19:42	21 Aug 23:03	8
	Tomi Maru 87	7	104.9	25 Aug 01:15	25 Aug 05:00	8
	Tomi Maru 87	8	132.2	25 Aug 19:44	25 Aug 23:57	9
2012*	*Tomi Maru 87*	1	23.9	18 Aug 02:04	18 Aug 04:07	6
	Tomi Maru 87	2	10.2	19 Aug 00:27	19 Aug 01:56	6
	Tomi Maru 87	3	17.8	19 Aug 02:55	19 Aug 04:55	6
	Tomi Maru 87	4	16.8	20 Aug 00:21	20 Aug 02:25	6
	Tomi Maru 87	6	32.9	21 Aug 00:42	21 Aug 04:14	10
	Tomi Maru 87	7	20.2	21 Aug 23:23	22 Aug 02:03	8
	Tomi Maru 87	9	28.2	24 Aug 20:27	24 Aug 23:31	8
	Tomi Maru 87	10	41.2	26 Aug 19:59	26 Aug 22:50	5
2013	*Tomi Maru 87*	1	259.2	18 Aug 19:04	19 Aug 03:42	12
	Tomi Maru 87	2	175.6	20 Aug 19:29	21 Aug 02:11	14
	Tomi Maru 87	3	204.5	21 Aug 20:00	22 Aug 03:28	10
	Tomi Maru 87	4	131.7	25 Aug 19:06	25 Aug 23:35	9

* Snapshots 5 and 8 in 2012 were aborted due to fish movement or interference from other vessels.

There was a very large (nearly 7-fold) increase in estimated SBW abundance at the Bounty Platform between industry surveys 2006 and 2007 (Table 3). The 2007 estimate was nearly double the highest estimate in the research survey time-series for the Bounty Platform (Table 3). The 2008 acoustic survey confirmed the large increase in SBW spawning stock size. However, estimated acoustic biomass on the Bounty Platform declined by a factor of four in 2009, and this decline was supported by results from the 2010 to 2012 surveys. The estimate of SBW biomass in 2013 was higher than the re-calculated biomass from 2009 to 2012, but less than half of the estimates from 2007 to 2008 (Table 3).

4. Discussion

Aggregation-based acoustic surveys from industry vessels provided annual estimates of spawning stock biomass for SBW on the Bounty Platform from 2004 to 2013 (except 2005). There was a very large increase in estimated SBW biomass at the Bounty Platform between industry surveys 2006 and 2007, and the 2007 survey results suggested that the spawning stock size at the

Table 3
Estimates of SBW biomass (t) for adult fish from research acoustic surveys of the Bounty Platform in 1993–2001 and 'best estimates' of spawning stock biomass (SSB) from acoustic estimates from industry vessels (with zero transects removed). Estimates in 2006–2009 and 2011–2013 were obtained by averaging selected snapshots (see Fig. 6). Estimated coefficient of variation (CV) in parentheses.

	Tangaroa	Industry vessel
Year	Adult fish	SSB
1993	43 338 (58%)	–
1994	17 991 (25%)	–
1995	17 945 (23%)	–
1997	27 594 (37%)	–
1999	21 956 (75%)	–
2001	11 784 (35%)	–
2004	–	8572 (69%)
2006	–	11 949 (12%)
2007	–	79 285 (19%)
2008	–	75 899 (34%)
2009	–	16 640 (21%)
2010	–	18 074 (35%)
2011	–	20 990 (27%)
2012	–	16 333 (7%)
2013	–	28 533 (27%)

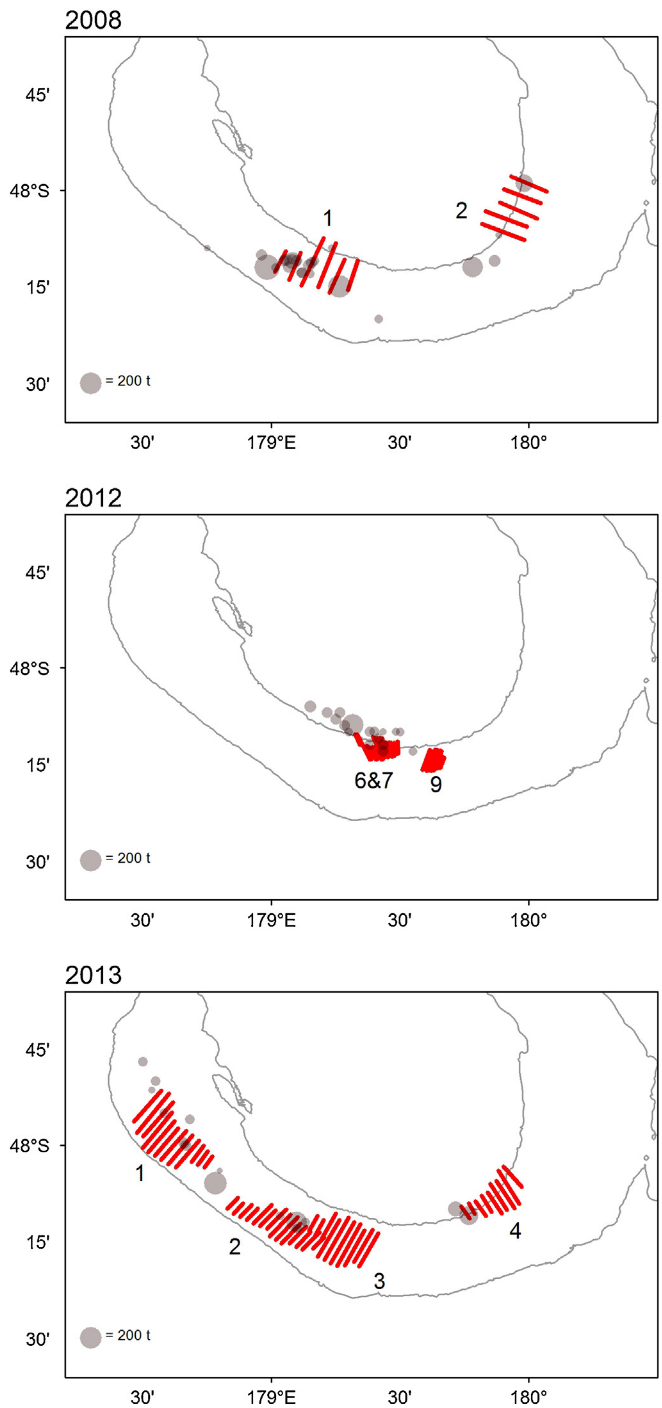

Fig. 5. Examples of acoustic survey execution in 2008, 2012, and 2013. Red lines show transects in numbered snapshots. Grey circles show commercial catch rates of SBW on tows carried out on dates corresponding to the snapshots. Not all 2012 snapshots are plotted (see Table 2). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

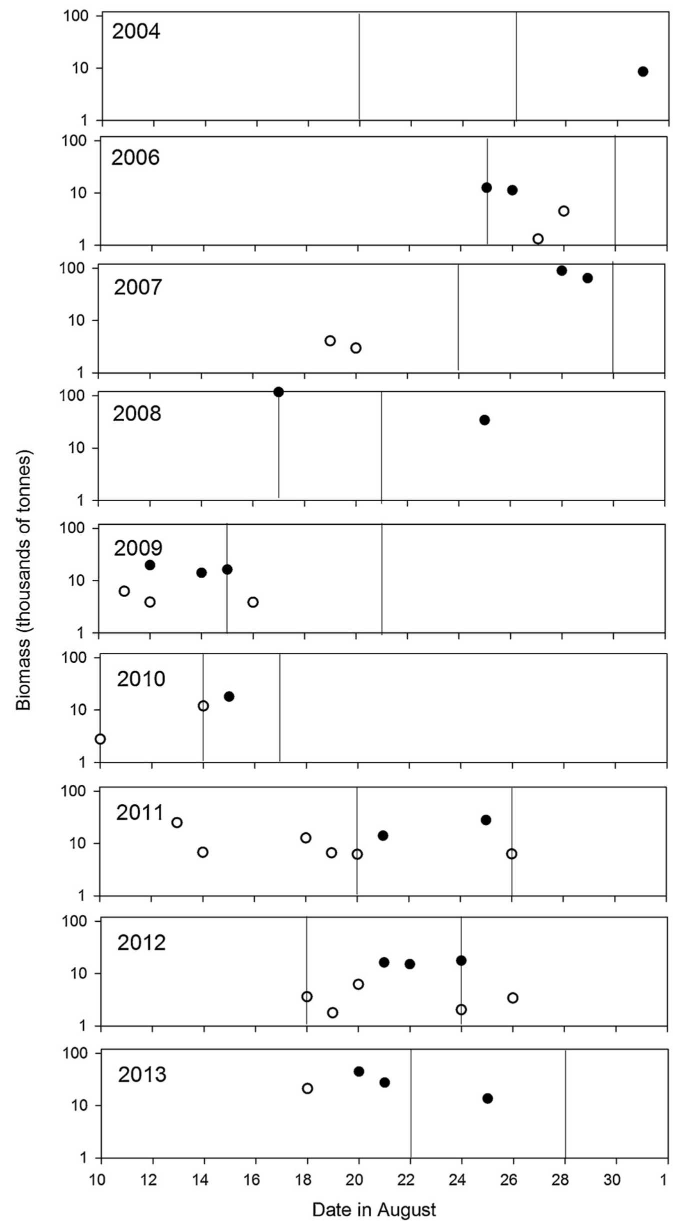

Fig. 6. Abundance estimates for each snapshot plotted as a function of date for all snapshots carried out by industry vessels on the Bounty Platform 2004–2013. Solid circles show snapshots that were averaged to produce the abundance estimates in Table 3. Open circles show snapshots which were rejected for various reasons (see text for details). Note logarithmic scale on *y*-axes. Vertical lines indicate estimated period of peak spawning based on gonad staging by observers.

Bounty Platform was much greater than that projected for 2007 by the assessment at that time (Hanchet, 2005). When taken in conjunction with data on the size and age distribution of the fish caught in the fishery (Fig. 8), this increase in abundance was indicative of very good recent recruitment from the 2002 year-class.

Without a formal stock assessment, the MDFAWG decided that it was not possible to quantify the size of the Bounty SBW stock and to determine a constant annual yield (CAY) for the fishery in 2008. However, conservative estimates of CAY were made by applying the reference fishing mortality ($U_{CAY} = 0.2$) to estimates of current vulnerable biomass based directly on the industry acoustic survey. As a result, the total allowable commercial catch (TACC) for Bounty Platform SBW was increased to 10 000 t from 1 April 2008 (see Table 1). The 2008 acoustic survey supported the very large recent increase in SBW spawning stock size (see Table 3) and, by applying the same methodology, the TACC was further increased to 14 700 t from 1 April 2009 (see Table 1). Industry acoustic surveys of the Bounty Platform therefore led directly to management decisions.

The four-fold decrease observed in acoustic estimates of SBW at the Bounty Platform between 2008 and 2009 was too great to be explained by fishing and average natural mortality on the dominant 2002 year-class. O'Driscoll (2011) considered three other potential explanations for the large apparent decline in biomass:

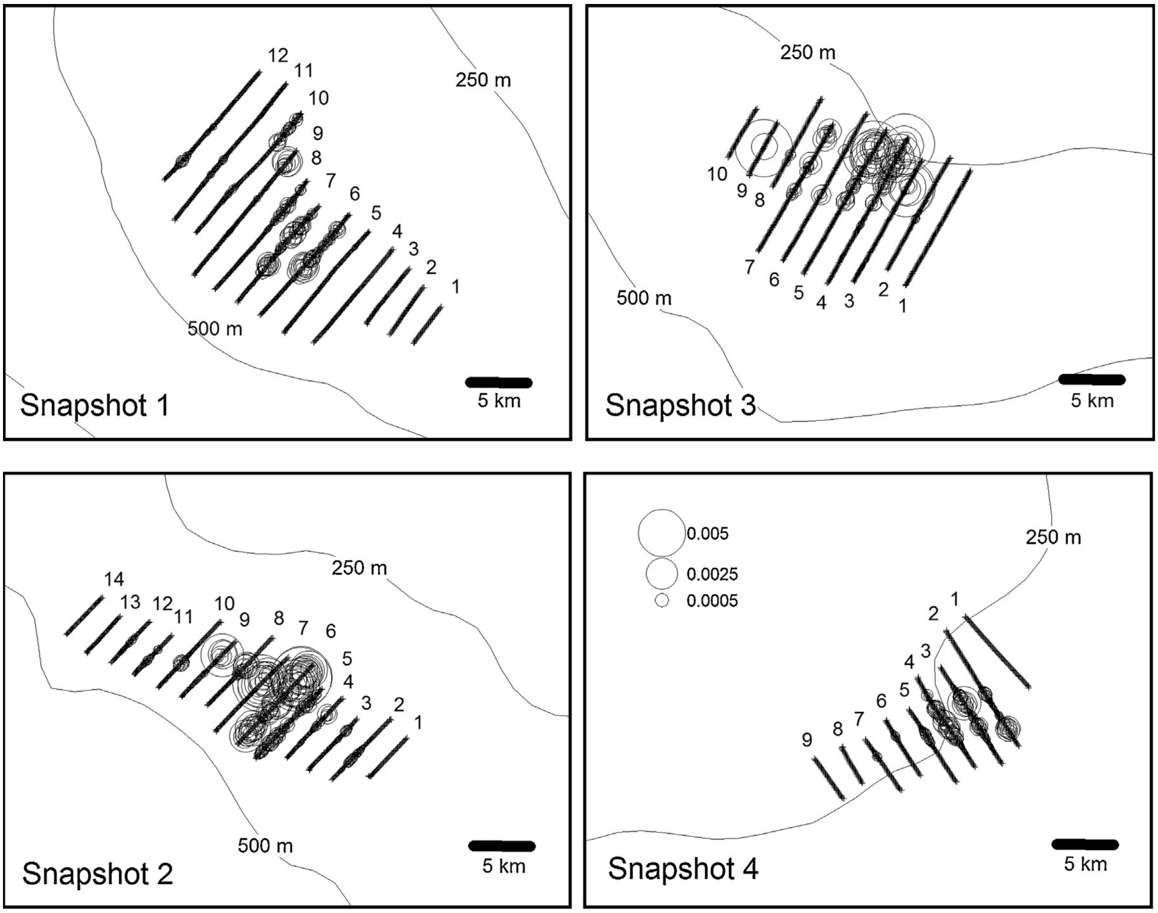

Fig. 7. Spatial distribution of SBW density plotted in 10-ping bins for the four snapshots at the Bounty Platform in 2013. Transects are numbered in the order in which they were carried out. Circle area is proportional to the acoustic areal density (s_a in m^2 m^{-2}). Timing of snapshots is shown in Fig. 6 and relative locations of snapshots are shown in Fig. 5.

- Changes in acoustic survey methodology and equipment.
- Changes in timing and extent of survey coverage.
- Movement of fish from the Bounty Platform to other areas.

Acoustic methodology, analysis, and equipment were consistent between years and based on comparisons of the length frequency distribution of the fish, there was no evidence of movement of fish from the Bounty Platform to other areas. Therefore O'Driscoll (2011) concluded that the 2009 survey probably did not encompass the entire spawning aggregation. Surveys in 2010–2012 supported the low biomass observed in 2009. Due to the low biomass estimates in 2009 and 2010, and the uncertainty in how to interpret the changes in acoustic indices, the TACC for Bounty SBW was decreased to 6860 t from 1 April 2011 (Table 1).

The SBW biomass estimated by the industry acoustic survey increased by 75% in 2013 (Table 3). It is uncertain whether this recent increase was a function of improved survey coverage (see Figs. 5 and 7), an increase in the spawning population, or both. Although a new moderately strong 2007 year class has entered the fishery (see Fig. 8), it was not large enough to account for the large increase in biomass seen during the survey.

The very large changes in estimated SBW abundance seen in industry surveys (Fig. 6) are probably related mainly to the timing and extent of survey coverage. The fish processing time available between commercial trawls to carry out acoustic transects was often insufficient to fully cover the distribution of the fish. This meant that the area surveyed has varied considerably between years, and between snapshots within a year (see Table 2). In each snapshot an unknown proportion of the spawning SBW are surveyed, and almost certainly not the entire spawning stock. When abundance estimates from some of the snapshots are high or increasing (as in 2007 and 2008) then survey coverage is less of a concern, as we know there is 'at least' that biomass of SBW on the fishing grounds within the specified confidence limits (i.e., a minimum biomass approach). However, when biomass is low (as in 2009–2012), it is impossible to determine whether there are real sustainability issues or whether the apparent decline is due to survey bias.

Because the proportion of the stock surveyed varies between years, it is very difficult to incorporate the time series of industry acoustic abundance estimates into a formal stock assessment model. The only way to achieve reasonable fits is by assuming that the 'catchability coefficient' q (defined as the ratio of the survey estimate to actual spawning stock biomass) for the industry surveys varies between years (Dunn and Hanchet, 2011). A two-sex, single stock and area Bayesian statistical catch-at-age model for the Bounty Platform SBW stock was implemented in CASAL (Bull et al., 2012). The model was fitted to the two time-series of acoustic biomass estimates (Table 3) and the proportion-at-age data from the fishery (Fig. 8). Acoustic survey estimates were input as relative estimates of mid-season mature stock biomass with a CV equal to the sampling CV estimated from the survey (Table 3). It was assumed that the wide-area (*Tangaroa*) surveys covered all of the mature population with a constant q of 0.87. The estimate of 0.87 was obtained from the mean of the Bayesian prior of q for wide-area surveys from a previous assessment of an adjacent

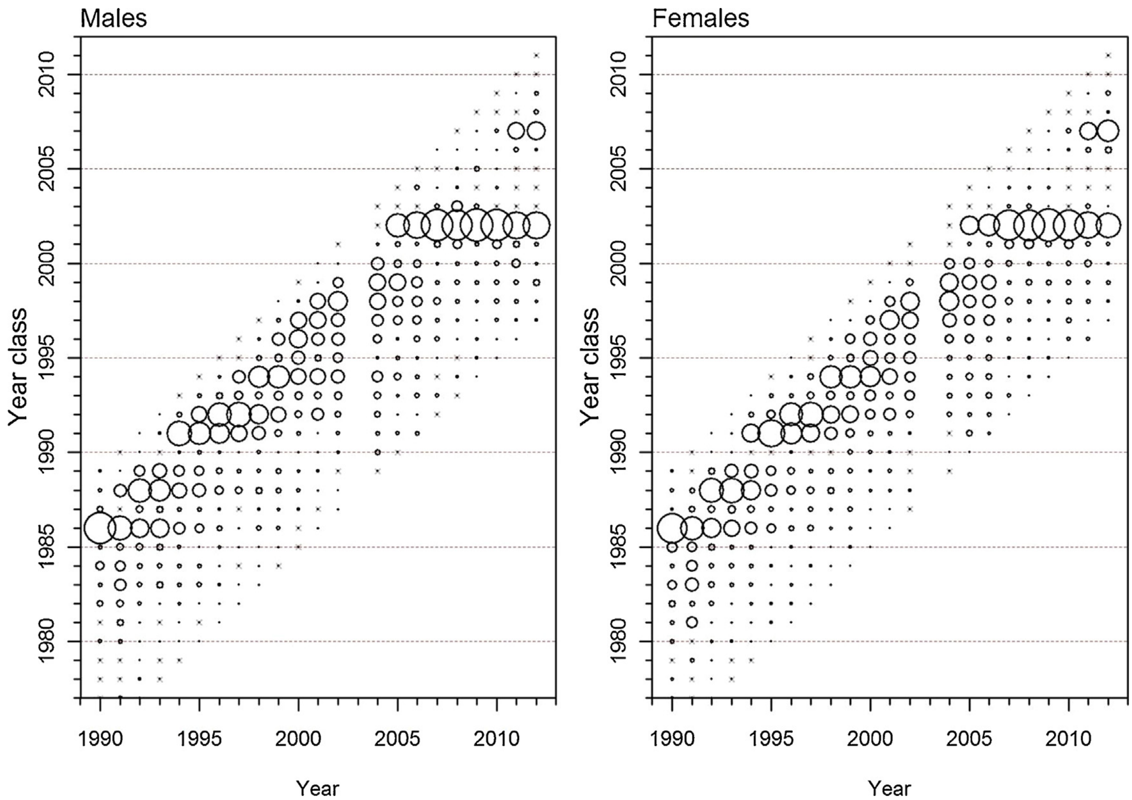

Fig. 8. Proportion at age in commercial catches of spawning SBW on the Bounty Platform from 1990 to 2012. Strong year-classes are indicated by horizontal rows of large circles. The 2002 year-class stands out as being particularly strong.

(Campbell Plateau) SBW stock which has regular research surveys. Note that q for wide-area surveys may be less than 1 because of potential bias in acoustic TS (the TS-FL relationship in Eq. (1) was based on TS measurements of SBW being herded in a trawl with no correction for *in situ* orientation O'Driscoll et al., 2013), as well as presence of low densities of SBW outside aggregations which were not counted. The q for each industry acoustic survey was allowed to be an independent parameter in the model, related to the wide-area acoustic survey estimates via a q ratio prior.

Two model runs were considered the first assumed a q ratio prior that constrained the catchability coefficients of the 2007 and 2008 industry surveys to be similar to the catchability coefficient of the wide-area Bounty surveys, but relaxed the constraint on surveys since 2009 (i.e., effectively down-weighting the surveys from 2009 to 2013); the second constrained the catchability coefficients of the 2009–2013 surveys to be similar to the catchability coefficient of the wide-area surveys, but relaxed the constraint for the 2007 and 2008 surveys (i.e., effectively down-weighting the surveys from 2007 to 2008). Based on the observations and preliminary model fits, the MDFAWG considered that the first model (down-weighting surveys from 2009 to 2013) was more plausible. Estimated catchability coefficients from this run are shown in Fig. 9, and suggested that industry surveys in 2004, 2006, and 2009–2012 covered less than 50% of the spawning stock biomass. The only way that the stock assessment model could reconcile the 2013 survey estimate was by estimating a much higher q. In this context, the results of the 2013 survey were more consistent with the results of the 2007 and 2008 surveys (Fig. 9).

Although the stock assessment did not provide a satisfactory fit to the industry acoustic time-series, the MDFAWG considered that it provided useful information to assist managers (Ministry for Primary Industries, 2013). The model estimated that SBW biomass in 2013 was between 40 and 50% B_0 and unlikely to be below the soft limit of 20% B_0 set by the Harvest Strategy Standard for the stock (Ministry for Primary Industries, 2013). However, biomass was projected to decline over the next 5 years at the current catch level as the 2002 and 2007 year classes are fished down. As a consequence of the 2013 assessment, the fishing industry agreed to voluntarily 'shelve' 2860 t of Bounty SBW quota in 2013, so the catch limit was 4028 t (see Table 1).

The inconsistency in the ability of the aggregation type survey to reliably monitor the same proportion of the population each year has led to a non-robust stock assessment of the Bounty stock with high uncertainty (Ministry for Primary Industries, 2013). Without

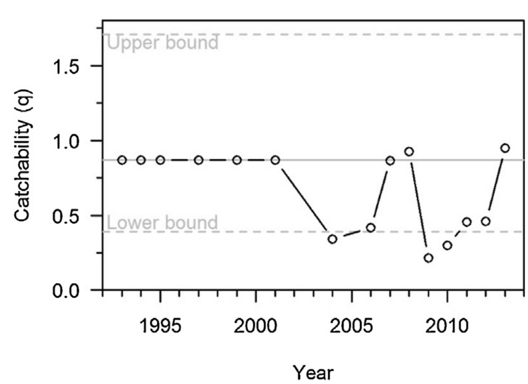

Fig. 9. Estimated catchability coefficients (q) for acoustic surveys of spawning SBW at the Bounty Platform from Bayesian stock assessment model. Upper and lower bounds show prior estimates of plausible range of catchability for wide-area acoustic surveys from 1995 to 2001. The assessment model assumed a q-ratio prior that constrained the catchability coefficients of the 2007 and 2008 industry surveys to be similar to the catchability coefficient of the wide-area surveys, but relaxed the constraint on surveys since 2009 (i.e., effectively down-weighting the surveys from 2009 to 2013).

a wide-area survey periodically to provide a 'ground truthing' for such aggregation survey results, this will be an on-going problem. While the data collected from aggregation surveys are useful for determining if evidence exists for a change in stock status, they cannot be used to determine the extent of that change. Put simply, it is impossible to determine whether changes in observed biomass are due to variability in the survey coverage or to real changes in stock size. This problem is compounded by the incomplete execution of survey design instructions in some years. Despite these limitations, industry acoustic surveys of the Bounty Platform have led directly to management decisions and changes in catch limits, and are still regarded as the most cost-effective method of monitoring stock status in this fishery.

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