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Acoustic biomass estimates of southern blue whiting on the Bounty Platform in 2014

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

O'Driscoll, R.L. (2015). Acoustic biomass estimates of southern blue whiting on the Bounty Platform in 2014.

***New Zealand Fisheries Assessment Report 2015/02*. 28 p**

The FV *Tomi Maru 87* collected acoustic data along 43 transects in five snapshots on the Bounty Platform between 24 and 30 August 2014. All snapshots surveyed the main southern blue whiting (SBW) aggregation south of the Bounty Islands, which moved to the east during the survey period. The surveyed areas in the five snapshots ranged from 102 to 176 km^2, smaller than the surveyed areas in 2013, when four completed snapshots covered 132–259 km^2. All five snapshots in 2014 appeared to adequately cover the main SBW aggregation, with no, or only very low, densities of fish detected on the outer transects and at the end of transects. Peak densities of SBW were observed in snapshot 2 on 25 August, but densities were not as high as has been observed in some previous surveys. Spawning appeared to be late in 2014, with running ripe females caught from 24–29 August.

Biomass estimates for 2014, ranged from 7721 t (CV 54%) in snapshot 4 to 18 437 t (CV 71%) in snapshot 2. The "best" estimate of 11 832 t (CV 31%) was based on the average of all five snapshots. The estimate of SBW biomass in 2014 was only 41% of the best estimate of 28 533 t (CV 27%) from 2013, and the lowest in the industry acoustic time-series since 2004. In 2014, acoustic transects crossing the high density aggregation were an average of 4.5 n. miles long, similar to in 2013, but there were fewer transects with high densities in 2014. When SBW abundance was estimated to be highest in 2007 and 2008, transects crossing the aggregation were up to 8 n. miles long.

Data on the size distribution of the fish, collected by Ministry for Primary Industries observers, show that the strong 2002 year-class is still dominant, but that the 2007 year-class is also important.

1. INTRODUCTION

Southern blue whiting (*Micromesistius australis*) 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 2014). Southern blue whiting (SBW) occur in Sub-Antarctic waters, with known spawning grounds on the Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise (Hanchet 1999). Fish from the four spawning grounds are treated as separate stocks for stock assessment. Spawning occurs on the Bounty Platform from mid-August to early September and 3–4 weeks later in the other areas.

A programme to estimate SBW spawning stock biomass on each fishing ground using acoustic techniques from research vessels 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, 2011, and 2013. All these surveys were carried out from *R.V. Tangaroa* using towed transducers and have been wide-area surveys intended to survey spawning SBW and pre-recruits. The results of these research surveys of spawning and pre-recruit SBW are the main input into SBW stock assessments (e.g., Ministry for Primary Industries 2014).

An acoustic survey of the Campbell Island grounds was carried out from FV *Aoraki* in 2003 and showed that industry vessels with hull-mounted acoustic systems could also be used to collect acoustic data on SBW in good weather (less than 25 knots of wind) (O'Driscoll & Hanchet 2004). They 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. Further surveys of spawning SBW using this approach have been carried out on the Bounty Platform in 2004, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013, on the Pukaki Rise in 2009 and 2010, and on the Campbell Island Rise in 2010. Surveys from 2004–09 were summarised by O'Driscoll (2011a), with results from surveys in 2010–14 presented by O'Driscoll (2011b, 2011c, 2012, 2013) and O'Driscoll et al. (2015).

Very strong SBW marks were observed during the industry survey of the Bounty Platform in 2007 and 2008 (O'Driscoll 2011a). The 2007 survey results suggested that the spawning stock size on the Bounty Platform had increased substantially since the 2005 assessment (Hanchet 2005), and, when taken in conjunction with data on the size and age distribution of the fish caught in the fishery, was indicative of very good recruitment from the 2002 year-class. As a result of this survey, the TACC for Bounty Platform SBW was increased to 10 000 t in 2008. The 2008 acoustic survey confirmed the large increase in SBW spawning stock size and the TACC was further increased to 15 000 t from 1 April 2009. However, estimated acoustic biomass on the Bounty Platform declined by a factor of four in 2009 (O'Driscoll 2011a), and this decline was supported by results from the 2010–12 surveys (O'Driscoll 2011b, 2012, 2013). The estimate of SBW biomass in 2013 was higher than the biomass from 2009–12, but less than half of the estimates from 2007 and 2008 (O'Driscoll et al. 2015). 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 SBW6B was decreased to 6860 t from 1 April 2011 (Ministry for Primary Industries 2014). In 2013, the fishing industry agreed to voluntarily 'shelve' 2860 t of quota, so the catch limit for the Bounty Platform in 2013 was 4000 t. The catch limit for 2014 was set at a TACC of 6860 t, but an additional 'research' catch of up to 2000 t was allowed by MPI. The total reported catch from SBW6B in 2014 was 8827 t.

The observed decline between 2008 and 2009 was too great to be explained solely by fishing and average levels of natural mortality of the 2002 year class (Dunn & Hanchet 2011). In the most recent stock assessment of the Bounty Platform in 2014, the assessment model was unable to reconcile the high biomass estimate from the 2013 survey with the series of low biomass estimates between 2009 and 2012 (Ministry for Primary Industries 2014). Although a new moderately strong 2007 year class has entered the fishery, it was not large enough to account for the large increase in biomass seen during the survey. The only way that the model could reconcile these survey estimates was by estimating a much higher catchability for the 2013 survey. Indeed, in that context, the results of the 2013 survey were more consistent with the results of the 2007 and 2008 surveys.

Given the recent changes in TACC and ongoing uncertainty about the status of the Bounty Platform stock, it is very important to continue to monitor acoustic estimates of spawning SBW in that area. The 10-year research programme for deepwater fisheries identifies the need for annual acoustic surveys from industry vessels on the Bounty Platform. A further aggregation-based survey was therefore carried out from *FV Tomi Maru 87* in August 2014 following the same protocols as in 2004–13 (O'Driscoll 2011a).

1.1 Project objectives

This report is the final reporting requirement for Ministry for Primary Industries Research Project SBW2010/02D. The objective of this project is to continue the time-series of acoustic estimates of abundance of spawning SBW on the Bounty Platform using aggregation-based acoustic estimates from industry vessels.

2. METHODS

2.1 Vessel and equipment

FV *Tomi Maru 87* is a 68 m Japanese surimi trawler chartered by Aurora Fisheries Ltd. The vessel is fitted with a Simrad ES70 echosounder. The Simrad ES70 was installed on *Tomi Maru 87* in April 2010 and is an updated version of the previous ES60 echosounder. Most of the developments to the echosounder are software-based, and the unit uses the same general purpose transceiver (GPT) and hull-mounted 38-kHz split-beam transducer as the ES60.

Calibration of the Simrad ES70 echosounder on *Tomi Maru* took place off Timaru immediately before the survey on 5 August 2014 (Appendix 1). Diagnostics indicated a calibration of good quality. The estimated peak gain (G_0) in 2014 based on the mean sphere echo was similar to that estimated in previous calibrations (Appendix 1). The 2014 calibration values from Table A3 in Appendix 1 were used in this analysis. ES70 transceiver settings and other relevant parameters during data collection are given in Table 1.

2.2 Survey design

The aim was to cover the main SBW aggregation(s) using an adaptive design. Detailed written instructions on survey design (described in O'Driscoll 2011a) were translated into Japanese, and vessel officers on FV *Tomi Maru 87* were also personally briefed by the author in Timaru after the acoustic calibration on 5 August 2014.

Vessel officers were instructed to collect acoustic data continuously while trawling and searching to allow examination of the spatial distribution of fish. However, estimating SBW abundance requires a number of straight, parallel lines (transects) across an aggregation. Each of these transects was to be run at a constant speed (usually 6–10 knots), 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 (e.g., 1 n. mile) across each aggregation. The importance of ensuring that transects were long enough and numerous enough to fully encompass the main aggregation(s) was emphasised. Previous acoustic surveys of the Bounty Platform have shown that SBW are very hard to survey acoustically during the day (Hanchet et al. 2000), therefore it was requested that all transects be carried out at night.

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 to avoid interference, and collecting data in suitable weather conditions.

2.3 Acoustic data analysis

Acoustic data were provided to NIWA as .raw ES70 files. 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. Marks were classified subjectively based on their appearance on the echogram (shape, structure, depth, strength, etc.) after Hanchet et al. (2002b).

Backscatter from marks (regions) identified as SBW was then integrated to produce an estimate of acoustic density (in m^{-2}). During integration, acoustic backscatter was corrected for a systematic error in ES60 and ES70 data (Ryan & Kloser 2004) and calculated sound absorption by seawater. In July 2013, an error was found in the software that applied the triangle wave correction for short files (less than 1360 pings), where the correction could not be established from the data. This bug led to a small negative bias in estimates of backscatter (i.e., biomass was underestimated) and affected all previous Bounty surveys from industry vessels. The bug was fixed before analysis of the 2013 data and all previous surveys were re-converted and re-integrated by O'Driscoll et al. (2015).

The estimated sound absorption was 9.47 dB km^{-1}, which was the same value used for previous Bounty surveys (O'Driscoll 2011a), and was based originally on data collected on the Campbell Island Rise in 2006 (O'Driscoll et al. 2007). 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 O'Driscoll et al. (2006) found that correcting 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 2013.

Acoustic density was output in two ways. First, average acoustic density over each transect was calculated. These values were used in biomass estimation. Second, acoustic backscatter was integrated over 10-ping bins (vertical slices) to produce a series of acoustic densities for each transect (typically 20–100 values per transect). These data had a high spatial resolution, with each value (10 pings) corresponding to about 100 m along a transect, and were used to produce plots showing the spatial distribution of acoustic density.

2.4 Biomass 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 for the Bounty Platform was calculated from the scaled length frequency distribution of SBW caught by *FV Tomi Maru 87* in this area in 2014, estimated from scientific observer data (Figure 1).

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

$$TS = 22.06 \log_{10} FL - 68.54 \tag{1}$$

where *TS* is in decibels and *FL* is in centimetres. This TS-FL relationship was based on *in situ* measurements made using a net-mounted acoustic-optical system (AOS) on the Campbell Island Rise in 2011 (O'Driscoll et al. 2013), and was adopted by the Middle Depth Fishery Assessment Working Group

(MIDWG) in 2012. Previous estimates in the Bounty SBW time-series were updated to take account of the change in TS-FL relationship by O'Driscoll (2013).

Mean SBW weight, w (in grams), was determined using the combined length-weight relationship for spawning SBW from Hanchet (1991):

$$w = 0.00439 \text{ x } FL^{3.133} \qquad (2)$$

The mean length of SBW caught at the Bounty Platform in 2014 by *FV Tomi Maru 87* was 40.8 cm. Mean weight and mean backscattering cross-sections were obtained by transforming the scaled length frequency distribution in Figure 1 by equations (1) and (2) and then calculating the means of the transformed distributions. Mean weight was 499 g. Mean backscattering cross-section was 0.000504 m^2 (equivalent to –33.0 dB), giving a ratio, r, of 990 kg m^{-2}.

Biomass estimates and variances were obtained from transect density estimates using the formulae of Jolly & Hampton (1990). The surveyed areas (Table 2) 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 leading and trailing transects, which define the extent of the aggregation). Cordue (2008) suggested that inclusion of zero transects may overestimate CVs using the Jolly & 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 collection

Acoustic data were recorded continuously from *FV Tomi Maru 87* from departing Timaru on 12 August 2014 to arriving back in port on 3 September 2014. The vessel was on the Bounty Platform fishing grounds from 14 August to 1 September Although data collected while fishing and searching was affected by acoustic noise due to sonar and other instruments and is not suitable for quantitative analysis, these data do provide a useful record of vessel activities and the presence of fish outside surveyed areas (e.g., O'Driscoll 2011b).

Forty three acoustic transects were carried out in five snapshots on the Bounty Platform between 24 and 30 August 2014 (Table 2). As requested, all transects were carried out at night. All snapshots surveyed the main SBW aggregation south of the Bounty Islands, which moved to the east during the survey period (Figure 2). This movement pattern is consistent with the migration pattern of spawning SBW on the Bounty Platform in previous years (e.g., Hanchet & Grimes 2000, Hanchet et al. 2002a, Figure 2). Transects in all five snapshots were run from east to west (i.e., counter to the expected direction of fish movement) to reduce the risk of bias due to double counting.

Surveyed areas in 2014 ranged from 102 to 176 km^2 (Table 2), smaller than the surveyed areas in 2013, when four completed snapshots covered 132–259 km^2 (O'Driscoll et al. 2015), but within the range surveyed in previous years when snapshot areas were 10–300 km^2 (O'Driscoll 2011a, 2012, 2013). The spacing between adjacent transects was about 2 km, similar to that in 2013, but higher than in 2012 when average transect spacing was 700–1000 m and snapshots covered a much smaller area of 10–41 km^2 (O'Driscoll 2013).

The survey duration covered by the five snapshots (7 days) was less than in 2011 (when survey duration was 13 days), but similar to that in 2012 (9 days) and 2013 (8 days), and greater than in most previous surveys (Figure 3). Between 2004 and 2010 there was a trend in survey dates occurring earlier over the Bounty Platform time series (Figure 3). Timing of SBW spawning has also varied between years (Figure

3). Spawning appeared to be very late in 2014, with more than 10% running ripe females recorded by scientific observers 24–29 August. The 2014 survey was therefore within the main spawning period.

3.2 Acoustic data quality

The quality of the acoustic data from Bounty Platform in 2014 was good during all five snapshots, but there were some ping drop-outs due to bubble aeration in snapshots 1–3 (e.g., Figure 4). ES70 transceiver settings and other relevant parameters during data collection (see Table 1) followed recommended protocols.

3.3 Acoustic mark types

Mark identification of adult SBW is relatively certain at the Bounty Platform (Hanchet et al. 2002b). Relatively dense adult SBW marks were observed in all snapshots. Marks were away from the seabed in 400–500 m water depth in snapshots 1–3 (Figures 4–6), but close to the seabed in 200–300 m water depth in snapshots 4–5 (Figure 7). 'Thundercloud' marks, associated with actively spawning SBW (Hanchet et al. 2002b) were observed in snapshot 2 on 25 August (Figure 6).

3.4 Distribution of SBW backscatter

The spatial distribution of SBW along each transect in the five snapshots is shown in Figure 8. As noted in Section 3.1, transects in all snapshots were carried out sequentially from east to west.

Coverage in all five snapshots appeared adequate, with only very low densities of fish detected on the outer transects and at the end of transects (Figure 8). High densities of SBW were observed in all snapshots, with peak densities in snapshot 2 on 25 August (see Figure 6). Densities were lower and fish more dispersed in snapshots 4–5 compared to snapshots 1–3. Peak densities in 2014 were not as high as those seen in some previous surveys (Figure 9). In 2014, acoustic transects crossing the high density aggregation were an average of 4.5 n. miles long, similar to in 2013, but there were fewer transects with high densities in 2014 compared to 2013. When SBW abundance was estimated to be highest in 2007 and 2008, transects crossing the aggregation were up to 8 n. miles long (e.g., Figure 8).

3.5 Biomass estimates

Biomass estimates for all Bounty Platform snapshots in 2004–14 are given in Table 3. The variance of snapshot estimates is reduced by removing zero transects (see Table 4), but the differences were small. Note that the biomass sometimes changed with exclusion of zero transects as the transect spacing was not always uniform.

Acoustic biomass estimates for the five snapshots in 2014, with zero transects removed, ranged between 7721 t (CV 54%) in snapshot 4 to 18 437 t (CV 71%) in snapshot 2. The "best" estimate of 11 832 t was based on the average of all five snapshots. The sampling precision of the average estimate was calculated in two ways. The first method was to average the variances from each snapshot, which gave a CV of 31%. The second method assumes that the snapshot abundance estimates are independent and identically distributed random variables. The sample variance of the snapshot means divided by the number of snapshots is therefore an unbiased estimator of the variance of the mean of the snapshots. The CV estimated by this second method was 17%.

The estimate of SBW biomass in 2014 was only 41% of the best estimate of 28 533 t (CV 27%) from 2013, and the lowest in the industry acoustic time-series since 2004 (Table 4). However, the MIDWG agreed that industry acoustic surveys do not provide a consistent time-series of SBW abundance on the Bounty Platform.

4. DISCUSSION

Data on the age distribution of the fish from the commercial fishery (Figure 10) show that the strong 2002 year-class was still dominant in the 2014 fishery at age 12, but that the 2007 year-class (age 7 in 2014) is also important. Length modes from these cohorts have merged, with a modal length of 39 cm for males and 40 cm for females in 2014 (see Figure 1).

The very large 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 (2011a) considered three other potential explanations for the large apparent decline in biomass:

1. Changes in acoustic survey methodology and equipment.
2. Changes in timing and extent of survey coverage.
3. 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 (2011a) concluded that the very large changes in estimated SBW abundance were probably related mainly to the timing and extent of survey coverage, and that the 2009 survey probably did not encompass the entire spawning aggregation. This conclusion was re-evaluated in light of the more extensive surveys in 2010–12, which supported the low biomass observed in 2009 (O'Driscoll 2011b, 2012, 2013). It is still only possible to speculate on the causes of this decline, but suggested causes include an unusually high natural mortality (Ministry for Primary Industries 2013).

The estimated biomass increased by 75% in 2013 (O'Driscoll et al. 2015), but then declined in 2014 to a level below the estimates from 2009–12 (see Table 4). It is uncertain whether these recent changes are a function of changes in survey coverage, changes in the spawning population, or both.

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 or Primary Industries 2014). Without 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 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.

5. CONCLUSIONS

Acoustic data from the Bounty Platform in 2014 were collected with appropriate acoustic settings and were of sufficient quality to estimate biomass. The five snapshots were all in the region to the south of the Bounty Islands where the largest aggregations were observed in 2007–13 (see Figure 2) and were in the vicinity of the main commercial fishing effort on the survey dates. Survey design protocols were generally followed, and all five snapshots appeared to adequately cover the aggregation.

The best biomass estimate for 2014, based on the average of all five snapshots was 11 832 t (CV 31%). This was only 41% of the best estimate of 28 533 t (CV 27%) from 2013, and the lowest in the industry acoustic time-series since 2004.

Because of uncertainty about the proportion of fish surveyed every year, it is difficult to interpret results from aggregation-based acoustic surveys. It is uncertain whether the 75% increase in the acoustic index from 2012 to 2013 and the subsequent 41% decrease from 2013 to 2014 are a function of survey coverage, changes in the spawning SBW population, or both.

6. ACKNOWLEDGMENTS

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8. TABLES

Table 1: Echosounder settings and other relevant parameters during acoustic data collection in 2014.

Parameter	Value
Echosounder	ES70
GPT model/serial	GPT Q38(4)-F1.0 009072056ad 38B
GPT software version	070413
Echosounder software version	ES70 1.1.0
Transducer model	ES38B
Transducer serial number	1599
Operating frequency (kHz)	38
Transducer draft setting (m)	0.0
Transmit power (W)	2000
Pulse length (ms)	1.024
Transducer peak gain (dB)	26.5
Sa correction (dB)	0.0
Bandwidth (Hz)	2425
Sample interval (s)	0.192
Two-way beam angle (dB)	–20.60
Absorption coefficient (dB/km)	9.75
Speed of sound (m/s)	1500.0
Angle sensitivity (dB) alongship/athwartship	21.90/21.90
3 dB beamwidth (°) alongship/athwartship	7.10/7.10
Angle offset (°) alongship/athwartship	0.00/0.00

Table 2: Summary of acoustic snapshots carried out at the Bounty Platform in 2014 by *FV Tomi Maru 87.* Times are NZST.

Snapshot	Area (km^2)	Start time	End time	No. of transects
1	127.8	24 Aug 19:13	24 Aug 23:55	8
2	102.3	25 Aug 19:11	25 Aug 22:58	7
3	105.8	26 Aug 19:51	27 Aug 00:28	8
4	142.3	28 Aug 20:24	29 Aug 01:23	8
5	175.8	29 Aug 19:37	30 Aug 02:13	12

Table 3: Stratum areas, abundance estimates, and coefficients of variation (CV) for all snapshots of spawning SBW on the Bounty Platform carried out by industry vessels from 2004–14. All snapshots carried out by *Tomi Maru 87* except M1 and M2 by *Meridian* and AB1 and AB2 by *A. Buryachenko* in 2009. Snapshots in bold were averaged to produce the biomass estimates in Table 4. All estimates calculated using the TS-FL relationship of O'Driscoll et al (2013) and re-calculated in 2013 to correct for a bug in the conversion script and inconsistencies in the estimation of calibration parameters (O'Driscoll et al. 2015).

			Calculated areas			Zero transects removed			
Year	Snapshot	No. of transects	Area (km^2)	Biomass (t)	CV (%)	No. of zero transects	Area (km^2)	Biomass (t)	CV (%)
2004	**1**	**5**	69.7	8 572	69	**0**	**69.7**	**8 572**	**69**
2006	**1**	**7**	199.4	12 600	16	**0**	**199.4**	**12 600**	**16**
	2	**5**	286.2	11 298	19	**0**	**286.2**	**11 298**	**19**
	3	4	41.3	1 327	34	0	41.3	1 327	34
	4	4	57.9	4 504	45	0	57.9	4 504	45
2007	1	7	234.5	4 100	38	1	199.0	4 081	35
	2	5	122.6	2 968	35	0	122.6	2 968	35
	3	**5**	250.2	85 700	35	**1**	**218.5**	**89 629**	**29**
	4&5	**10**	435.0	77 339	20	**1**	**417.1**	**68 942**	**20**
2008	**1**	**6**	260.4	119 017	45	**1**	**230.8**	**117 675**	**43**
	2	**5**	229.5	34 123	22	**0**	**229.5**	**34 123**	**22**
2009	M1	11	335.7	6 233	15	0	335.7	6 233	15
	M2	**8**	125.6	20 519	29	**1**	**107.4**	**19 622**	**27**
	1	**3**	232.3	14 067	42	**0**	**232.3**	**14 067**	**42**
	2	**5**	276.2	15 344	45	**1**	**249.9**	**16 230**	**44**
	AB1	7	38.8	3 858	26	0	38.8	3 858	26
	AB2	5	25.1	3 839	29	1	21.9	3 839	23
2010	1	6	52.5	2 770	51	0	52.5	2 770	51
	2	4	38.5	11 504	69	1	29.4	11 951	64
	3	**9**	85.7	17 426	37	**2**	**77.0**	**18 074**	**35**
2011	1	9	118.5	24 948	23	0	118.5	24 948	23
	2	11	136.7	6 762	17	0	136.7	6 762	17
	3	9	83.6	12 724	28	0	83.6	12 724	28
	4	7	53.9	6 614	34	2	43.9	6 614	30
	5	8	80.4	6 208	28	0	80.4	6 208	28
	6	**8**	76.8	14 090	44	**2**	**60.7**	**14 090**	**42**
	7	**8**	104.9	27 889	36	**2**	**91.4**	**27 889**	**35**
	8	9	132.2	6 304	21	0	132.2	6 304	21

Table 3 cntd: Stratum areas, abundance estimates, and coefficients of variation (CV) for all snapshots of spawning SBW on the Bounty Platform carried out by industry vessels from 2004–13. Snapshots in bold were averaged to produce the biomass estimates in Table 4. All estimates calculated using the TS-FL relationship of O'Driscoll et al (2013) and re-calculated in 2013 to correct for a bug in the conversion script and inconsistencies in the estimation of calibration parameters (O'Driscoll et al. 2015).

			Calculated areas			Zero transects removed			
Year	Snapshot	No. of transects	Area (km^2)	Biomass (t)	CV (%)	No. of zero transects	Area (km^2)	Biomass (t)	CV (%)
2012	1	6	23.9	3 524	49	1	20.3	3 591	45
	2	6	10.2	322	84	1	8.7	336	82
	3	6	17.8	1 771	45	0	17.8	1 771	45
	4	6	16.8	6 213	39	0	16.8	6 213	39
	5*	3	4.6	46	27	0	4.6	46	27
	6	**10**	32.9	16 386	16	**1**	**30.4**	**16 288**	**14**
		8	20.2	15 093	17	**0**	**20.2**	**15 093**	**17**
	8*	3	16.7	2 029	57	0	16.7	2 029	57
		8	28.2	17 618	18	**0**	**28.2**	**17 618**	**18**
	10	5	41.2	3 383	14	0	41.2	3 383	14
7 2013	1	12	259.2	21 051	31	1	251.1	21 051	31
	2	**14**	175.6	44 517	46	**0**	**175.6**	**44 517**	**46**
9	**3**	**10**	204.5	27 972	37	**2**	**170.9**	**27 491**	**34**
		9	131.7	14 364	36	**3**	**94.0**	**13 592**	**30**
2014	**1**	**8**	127.8	14 542	72	**2**	**107.2**	**14 336**	**72**
		7	102.3	18 363	70	**1**	**96.5**	**18 437**	**71**
		8	105.8	8 301	46	**2**	**84.5**	**8 209**	**43**
4		**8**	142.3	7 732	56	**2**	**117.1**	**7 721**	**54**
	5	**12**	175.8	10 474	48	**2**	**158.6**	**10 458**	**47**

2

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

4

Table 4: Estimates of SBW biomass (t) for adult fish from research acoustic surveys of the Bounty Platform in 1993–2001 (from Fu et al. 2013), and 'best estimates' of spawning stock biomass (SSB) from acoustic estimates from industry vessels (with zero transects removed). Estimates in 2006–09 and 2011–14 were obtained by averaging selected snapshots. All estimates calculated using the TS-FL relationship of O'Driscoll et al. (2013).

Year	*Tangaroa* Adult fish	Industry Vessel 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	–	8 572 (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%)
2014	–	11 832 (31%)

9. FIGURES

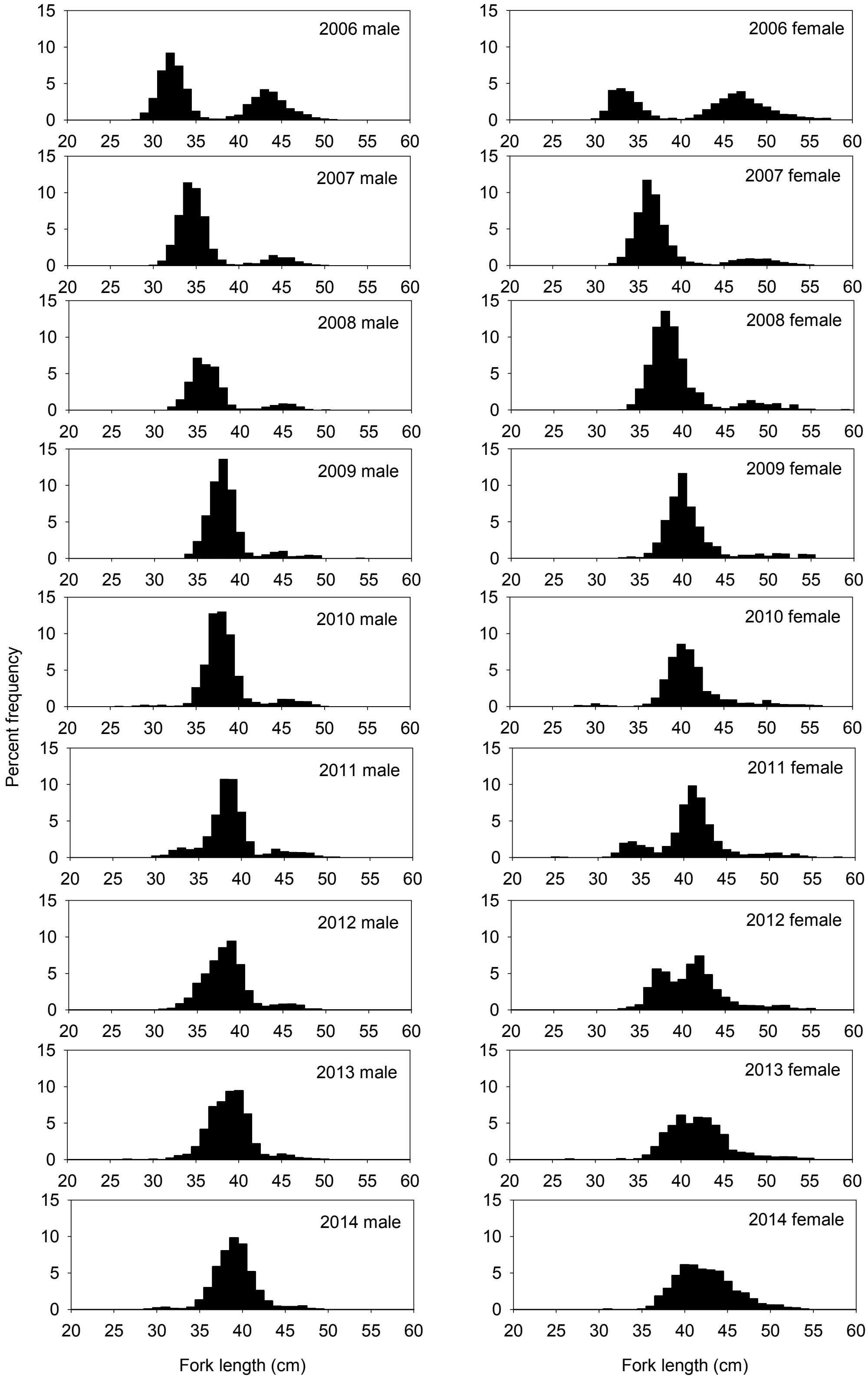


Figure 1: Scaled length frequency of SBW caught on the Bounty Platform by *FV Tomi Maru 87* in 2006–14 based on scientific observer data. Data from 2014 are from observer trip 4196.

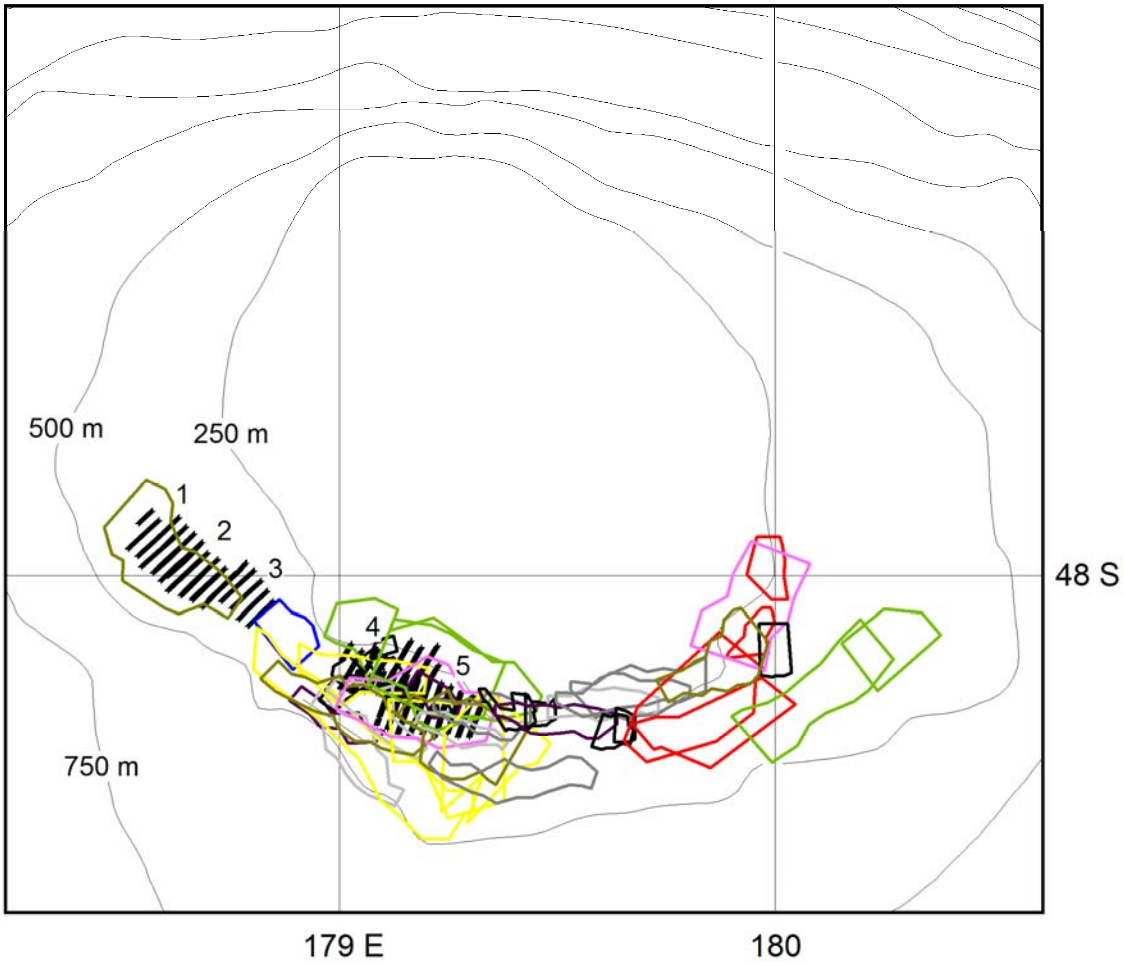


Figure 2: Map showing location of transects carried out in snapshots by *FV Tomi Maru 87* at the Bounty Platform in 2004–14. Transects for the five snapshots in 2014 (black lines) are compared with the areas surveyed in 2004 (blue), 2006 (red), 2007 (green), 2008 (pink), 2009 (yellow), 2010 (magenta), 2011 (grey), 2012 (black), and 2013 (olive).

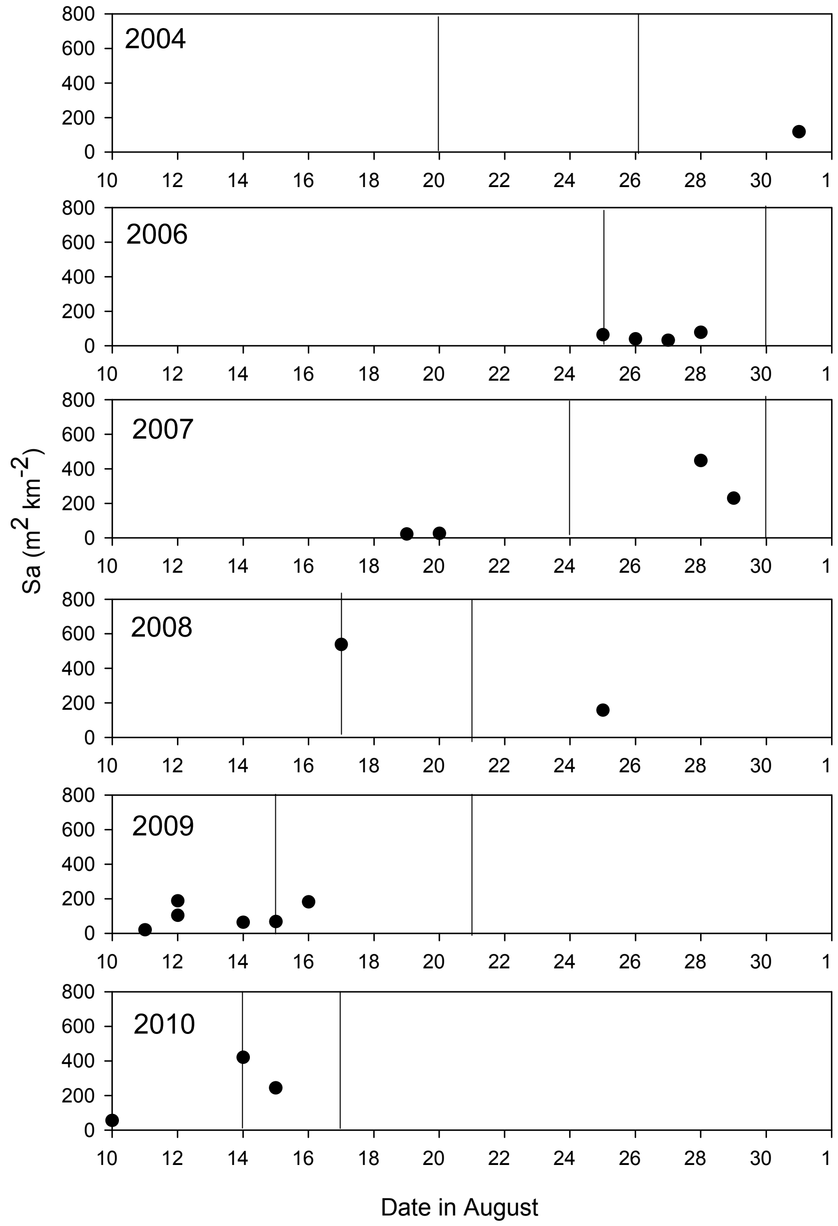


Figure 3: Weighted (by transect length) mean densities for each snapshot (solid circles) plotted as a function of date for all snapshots carried out by industry vessels on the Bounty Platform 2004–10. Vertical lines indicate estimated period of peak spawning based on gonad staging by observers.

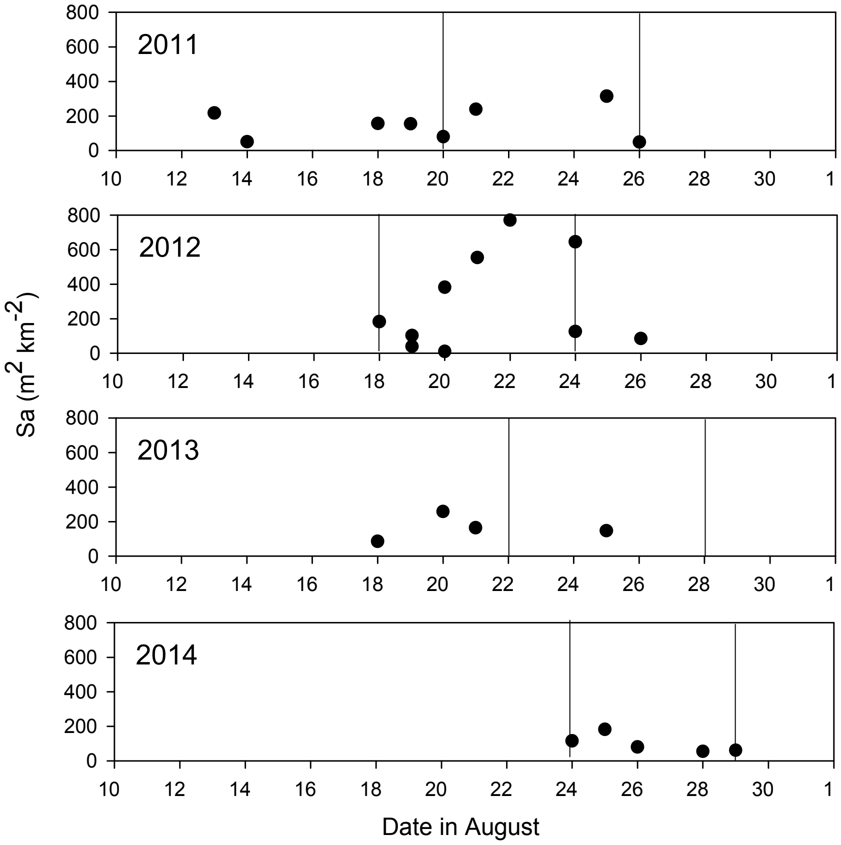


Figure 3 cntd: Weighted (by transect length) mean densities for each snapshot (solid circles) plotted as a function of date for all snapshots carried out by industry vessels on the Bounty Platform 2011–14. Vertical lines indicate estimated period of peak spawning based on gonad staging by observers.

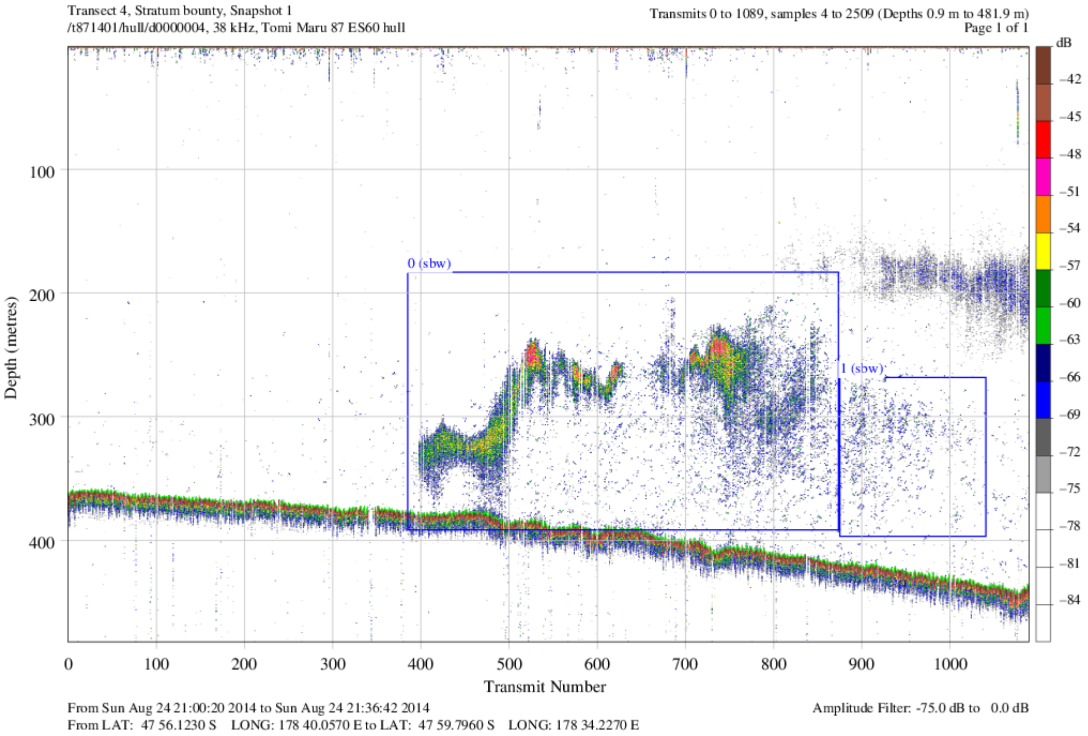


Figure 4: Example of acoustic echogram collected at the Bounty Platform in snapshot 1 on 24 August 2014 showing ping drop-outs due to bubble aeration in poor weather.

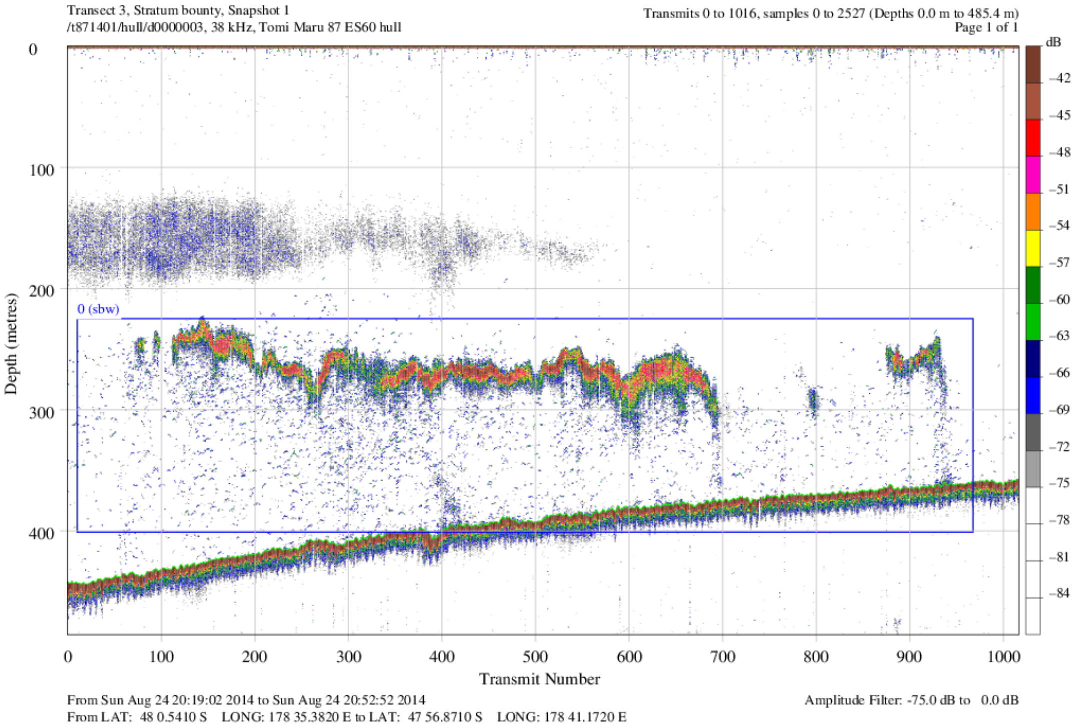


Figure 5: Example of acoustic echogram collected at the Bounty Platform in snapshot 1 on 24 August 2014 showing strong SBW mark away from the seabed.

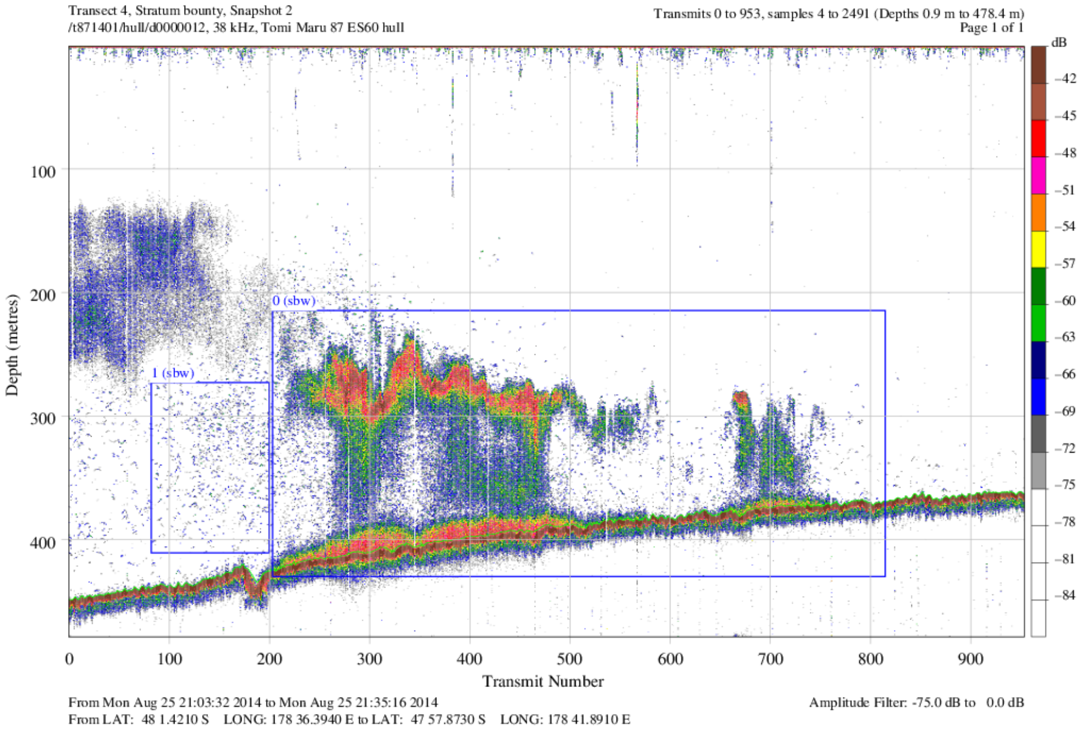


Figure 6: Example of acoustic echogram collected at the Bounty Platform in snapshot 2 on 25 August 2014 showing very strong 'thundercloud' SBW mark.

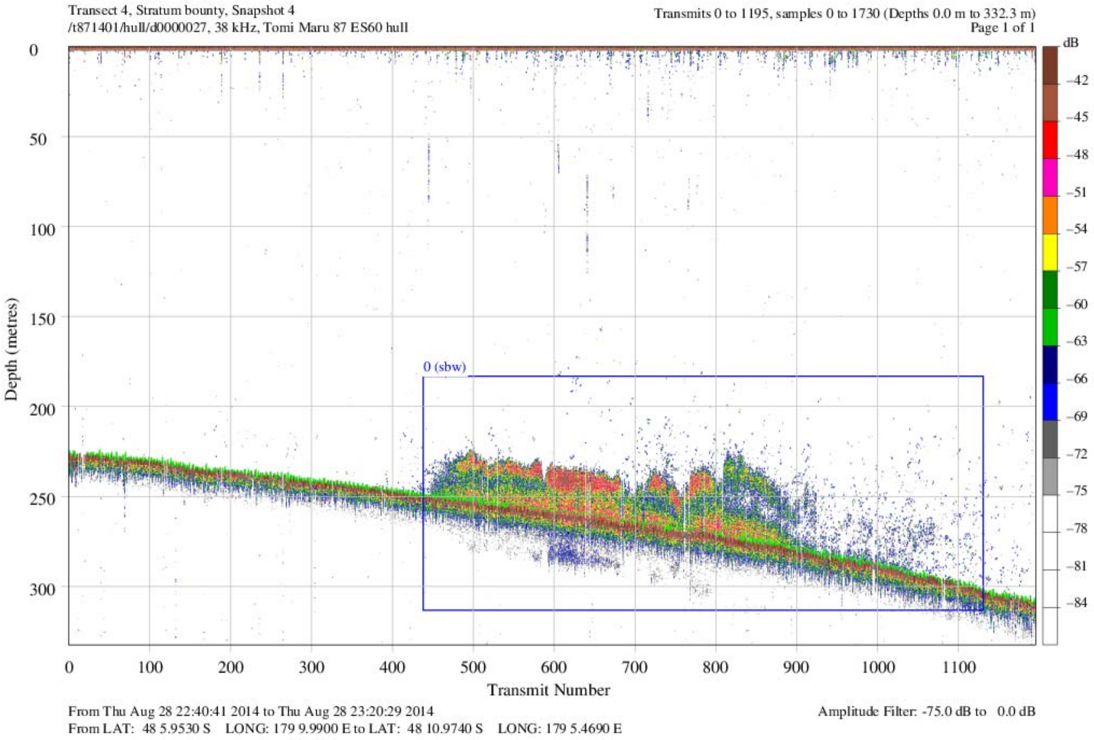


Figure 7: Example of acoustic echogram collected at the Bounty Platform in snapshot 4 on 28 August 2014 showing strong SBW mark close to the seabed.

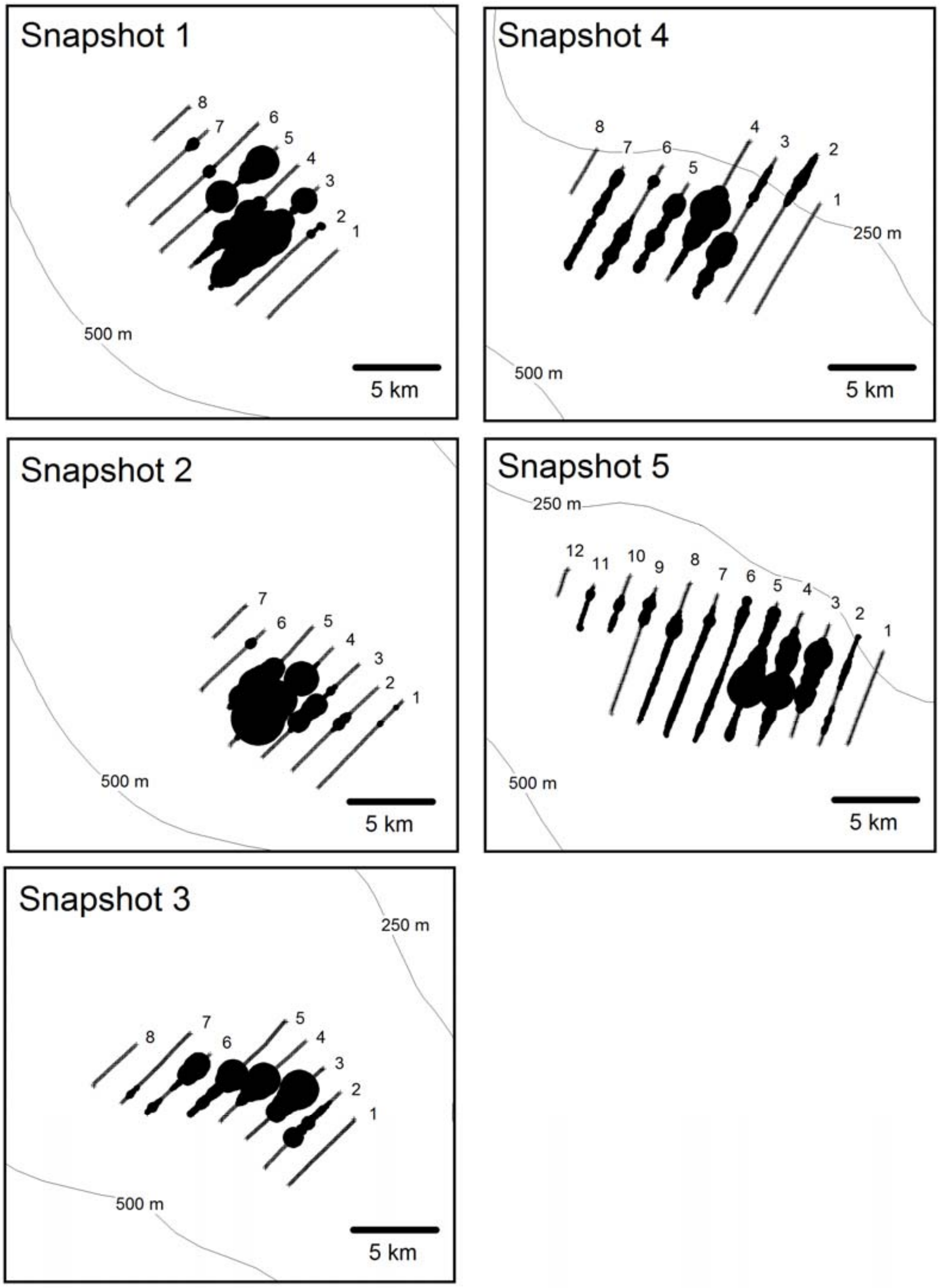
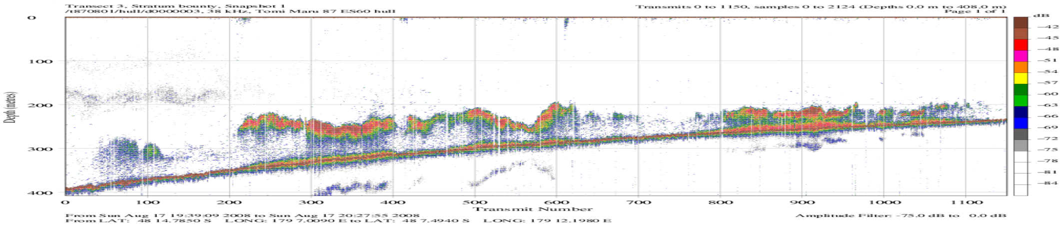
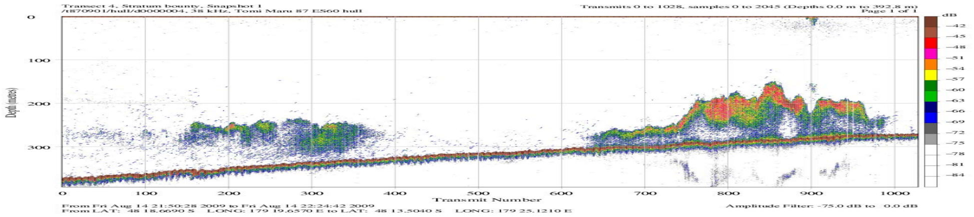


Figure 8: Spatial distribution of SBW backscatter plotted in 10-ping bins for the five snapshots at the Bounty Platform in 2014. Transects are numbered in the order in which they were carried out. Circle area is proportional to the log of the acoustic backscatter. Crosses indicate zero backscatter.

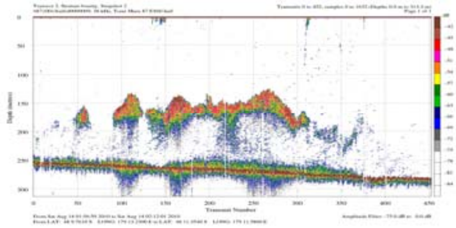
2008 ($1027\ m^2\ km^{-2}$)



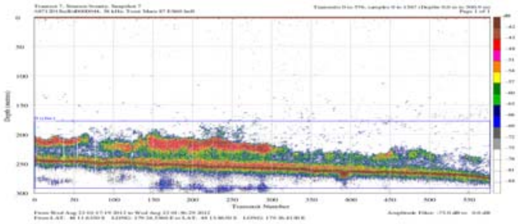
2009 ($422\ m^2\ km^{-2}$)



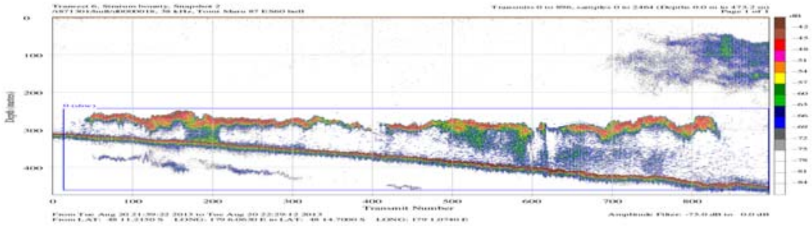
2010 ($1029\ m^2\ km^{-2}$)



2012 ($1180\ m^2\ km^{-2}$)



2013 ($1295\ m^2\ km^{-2}$)



2014 ($752\ m^2\ km^{-2}$)

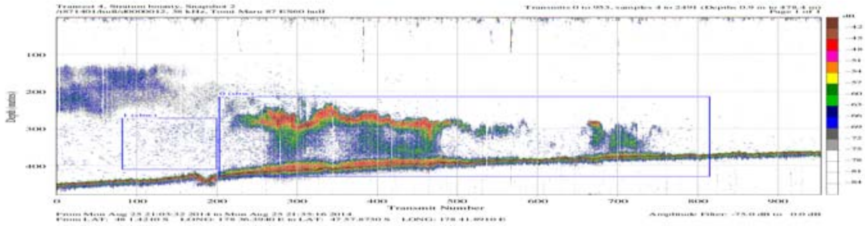


Figure 9: Echograms illustrating the densest SBW marks observed in surveys of the Bounty Platform by FV *Tomi Maru 87* in 2008–10 and 2012–14. Values in parentheses are transect mean density (Sa) values. Echogram size has been scaled so that distance scales (x-axes) are equivalent.

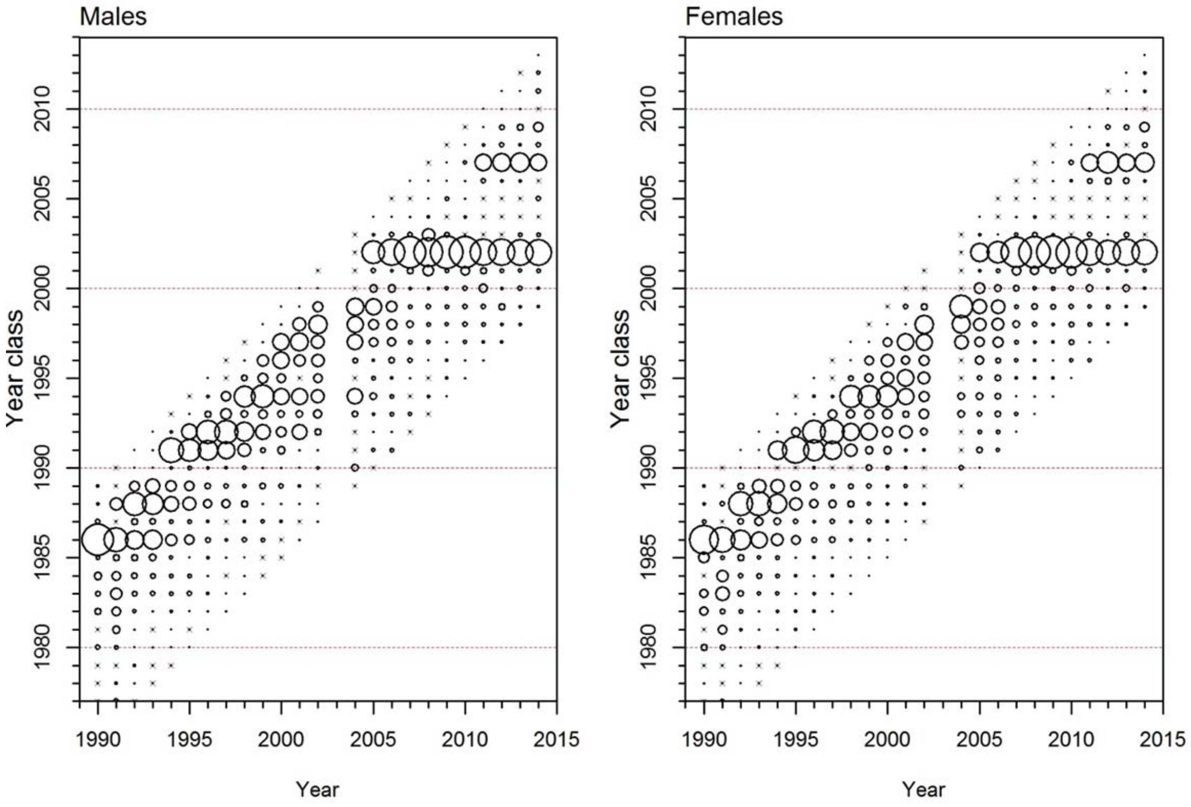


Figure 10: Estimated proportions at age of SBW in the commercial catch from the Bounty fishery 1990–2014.

APPENDIX 1: Calibration Report: *Tomi Maru 87* 5 August 2014

Calibration of the Simrad ES70 echosounder on *Tomi Maru* took place off Timaru (44° 27.2’ S 171° 31.9’ E) on 5 August 2014. Water depth was about 40 m (below the transducer). This was the tenth time that the echosounder on this vessel has been calibrated, with annual calibrations since 2005. The ES70 computer and software were installed on *Tomi Maru 87* in April 2010 and connected to the same 38-kHz GPT and transducer as the previous ES60 system. Both the ES60 and ES70 were calibrated together on 30 April 2010 (O’Driscoll & Nelson 2010). Because the ES60 and ES70 use the same hardware, the calibrations with the two software systems were identical within the measurement uncertainty (O’Driscoll and Nelson 2010). The calibration was carried out by Richard O’Driscoll (NIWA) following the procedures in MacLennan & Simmonds (1992).

The ES70 was configured to recommended settings (2000 W power and 1.024 ms pulse). A weighted line was passed under the keel to facilitate setting up the three lines and calibration sphere. Long (3.8 m) fibreglass calibration poles were used to help keep the calibration lines clear of the hull. The sphere and associated lines were immersed in a soap solution prior to entering the water. A lead weight was also deployed about 4 m below the sphere to steady the arrangement of lines. The sphere was centered in the beam to obtain data for the on-axis calibration, and was then moved around the beam to obtain data for the beam shape calibration.

The weather was calm with a 5 knot breeze and 0.5 m swell. The vessel was allowed to drift, and the drift speed was about 0.2 knots. The sphere was located in the beam immediately the lines were set at 08:33 NZST and the calibration was completed at 09:28 NZST. Calibration data were recorded in one ES60 raw format file (t871401-D20140804-T203334.raw). Raw data are stored in the NIWA Fisheries Acoustics Database. The ES70 transceiver settings in effect during the calibration are given in Table A1.

Water temperature measurements were taken using an RBR-2050 temperature depth probe, serial number 11817. The water column was unstratified, with a temperature of 10.1° at all depths. The salinity was not measured and was assumed to be 35 PSU. An estimate of acoustic absorption was calculated using the formulae in Doonan et al. (2003) and an estimate of sound speed was calculated using the formulae of Fofonoff & Millard (1983).

The data in the ES70 file were extracted using custom-written software. The amplitude of the sphere echoes was obtained by filtering on range, and choosing the sample with the highest amplitude. Instances where the sphere echo was disturbed by fish echoes were discarded. The alongship and athwartship beam widths and offsets were calculated by fitting the sphere echo amplitudes to the Simrad theoretical beam pattern:

$$compensation = 6.0206\left(\left(\frac{2\theta_{fa}}{BW_{fa}}\right)^2 + \left(\frac{2\theta_{ps}}{BW_{ps}}\right)^2 - 0.18\left(\frac{2\theta_{fa}}{BW_{fa}}\right)^2\left(\frac{2\theta_{ps}}{BW_{ps}}\right)^2\right),$$

where θ_{ps} is the port/starboard echo angle, θ_{fa} the fore/aft echo angle, BW_{ps} the port/starboard beamwidth, BW_{fa} the fore/aft beamwidth, and *compensation* the value, in dB, to add to an uncompensated echo to yield the compensated echo value. The fitting was done using an unconstrained nonlinear optimisation (as implemented by the Matlab `fminsearch` function). The Sa correction was calculated from:

$$S_{a,corr} = 5\log_{10}\left(\frac{\sum P_i}{4P_{\max}}\right),$$

where P_i is the sphere echo power measurement and P_{max} the maximum sphere echo power measurement. A value for $S_{a,corr}$ is calculated for all valid sphere echoes and the mean over all sphere echoes is used to determine the final $S_{a,corr}$.

A correction for the triangle wave error in ES70 data (Ryan & Kloser 2004) was also applied as part of the analysis.

Results

The mean range of the sphere and the sound speed and acoustic absorption between the transducer (about 6 m deep) and the sphere are given in Table A2.

The calibration results are given in Table A3. The estimated beam pattern and sphere coverage are given in Figure A1. The symmetrical nature of the pattern and the zero centre of the beam pattern indicate that the transducer and ES70 transceiver were operating correctly. The fits between the theoretical beam pattern and the sphere echoes is shown in Figure A2 and confirms that the transducer beam pattern is correct. The RMS of the difference between the Simrad beam model and the sphere echoes out to 3.5° off axis was 0.22 dB (Table A3), indicating that the calibration was of good quality (<0.4 dB is poor, <0.3 dB good, and <0.2 dB excellent).

The number of echoes in this calibration (2037) was lower than in calibrations from 2009–13 (Table A3), because the record range was mistakenly left set at 700 m, meaning that the maximum ping rate was slower than when the record range is shorter. This meant that the number of echoes close to the beam centre (39) was lower than desirable, but still acceptable, and the standard deviation of the sphere TS was consequently slightly higher (Table A3).

The estimated peak gain (G_0) increased by 0.09 dB from the 2013 ES70 calibration, continuing the recent trend of increasing G_0 for this system (Figure A3).

The 2014 calibration was used for analysis of results from the 2014 Bounty southern blue whiting survey.

Table A1: ES70 transceiver settings and other relevant parameters during the calibration.

Parameter	Value
Echosounder	ES70
ES70 software version	1.1.0
Transducer model	ES38B
Transducer serial number	1599
ES70 GPT serial number	GPT Q38(4)-F1.0 009072056ad 38B
GPT software version	070413
Sphere type/size	tungsten carbide/38.1 mm diameter
Operating frequency (kHz)	38
Transducer draft setting (m)	0.0
Transmit power (W)	2000
Pulse length (ms)	1.024
Transducer peak gain (dB)	26.5
Sa correction (dB)	0.0
Bandwidth (Hz)	2425
Sample interval (m)	0.3192
Two-way beam angle (dB)	–20.60
Absorption coefficient (dB/km)	9.75
Speed of sound (m/s)	1500
Angle sensitivity (dB) alongship/athwartship	21.90/21.90
3 dB beamwidth (°) alongship/athwartship	7.10/7.10
Angle offset (°) alongship/athwartship	0.0/0.0

Table A2: Auxiliary calibration parameters derived from depth and temperature measurements.

Parameter	Value
Mean sphere range (m)	22.8
S.D. of sphere range (m)	0.3
Mean sound speed (m/s)	1 490
Mean absorption (dB/km)	9.57
Sphere TS (dB re $1m^2$)	–42.39

Table A3: Calculated echosounder calibration parameters for Tomi Maru 87. Values were calculated using version 7027 (2005-13) and 7152 (2014) of NIWA's Matlab calibration function. Note that 2008 calibration was rejected and was not used in biomass estimation.

Parameter	2014	2013	2012	2011	2010		2009	2008	2007	2006	2005
	ES70	ES70	ES70	ES60	ES70	ES60	ES60	ES60	ES60	ES60	ES60
Mean TS within 0.21° of centre	-46.3186	-46.4927	-46.5925	-46.8347	-46.8238	-46.7535	-46.7798	-46.5339	-46.3050	-45.9008	-46.0495
Std dev of TS within 0.21° of centre	0.5191	0.3940	0.4155	0.1645	0.1968	0.4178	0.4025	0.0166	0.2343	0.3639	0.4606
Max TS within 0.21° of centre	-45.3948	-45.6984	-45.9441	-46.4650	-45.9478	-45.9913	-46.0580	-46.5222	-45.8414	-45.4503	-45.2827
No. of echoes within 0.21° of centre	39	694	340	422	1 274	6 438	279	2	98	17	1 841
On axis TS from beam-fitting	-46.1098	-46.3721	-46.6729	-46.6851	-46.6375	-46.7343	-46.8018	46.3047	-46.2647	-45.9472	-46.0144
Transducer peak gain (dB) max TS	25.00	24.85	24.74	24.48	24.74	24.71	24.67	24.45	24.79	24.96	25.05
Transducer peak gain (dB) mean TS	24.54	24.45	24.41	24.29	24.30	24.33	24.31	24.44	24.56	24.74	24.67
Sa correction (dB)	-0.66	-0.66	-0.66	-0.69	-0.67	-0.71	-0.60	-0.49	-0.65	-0.63	-0.69
Beamwidth (º) along/athwartship	7.3/7.1	7.0/6.9	7.1/6.8	7.1/6.9	7.0/7.0	6.9/7.0	7.4/7.3	7.1/6.8	7.2/7.3	6.8/7.3	7.0/7.1
Beam offset (º) along/athwartship	-0.00/+0.00	-0.00/0.00	-0.00/-0.00	-0.06/-0.05	0.00/0.00	-0.00/0.00	-0.00/-0.00	0.00/0.00	-0.04/-0.12	0.00/0.00	-0.09/0.06
RMS deviation	0.22	0.19	0.21	0.11	0.13	0.21	0.20	0.20	0.15	0.20	0.22
Number of echoes	2 048	16 544	23 423	29 780	30 727	23 277	7 362	996	1 416	4 632	19 534

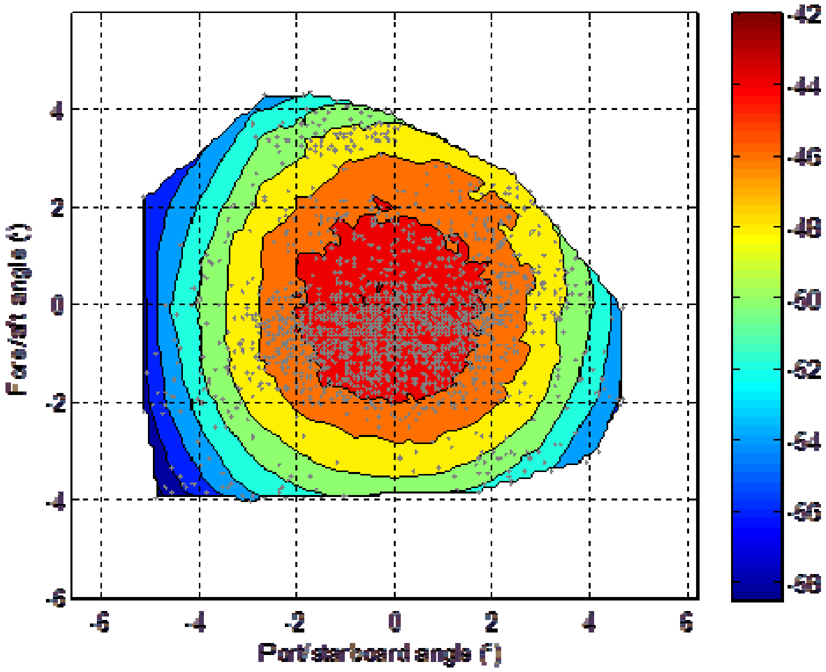


Figure A1. The estimated beam pattern from the sphere echo strength and position for the calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

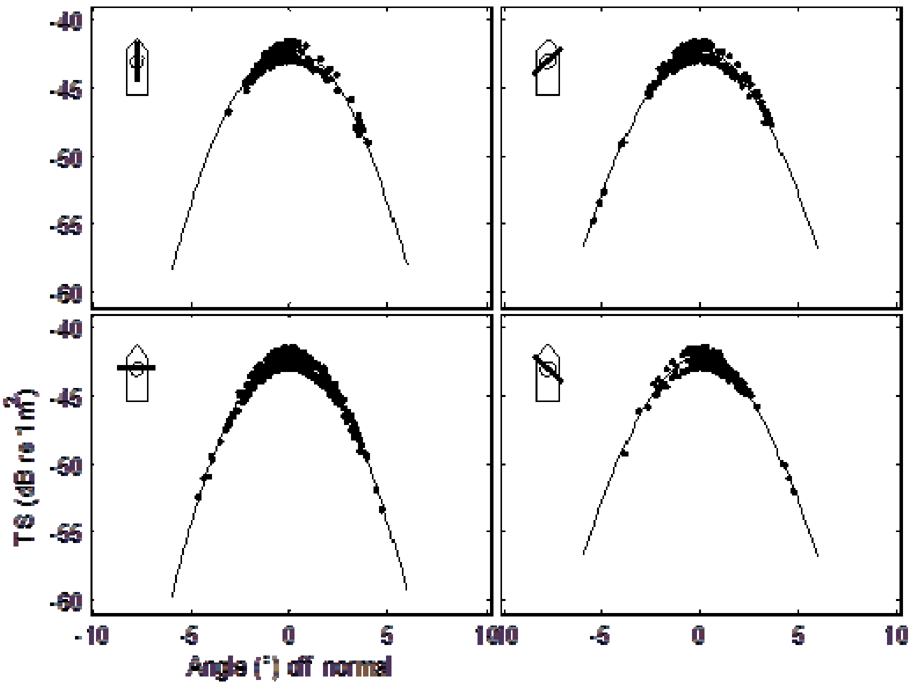


Figure A2. Beam pattern results from the calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

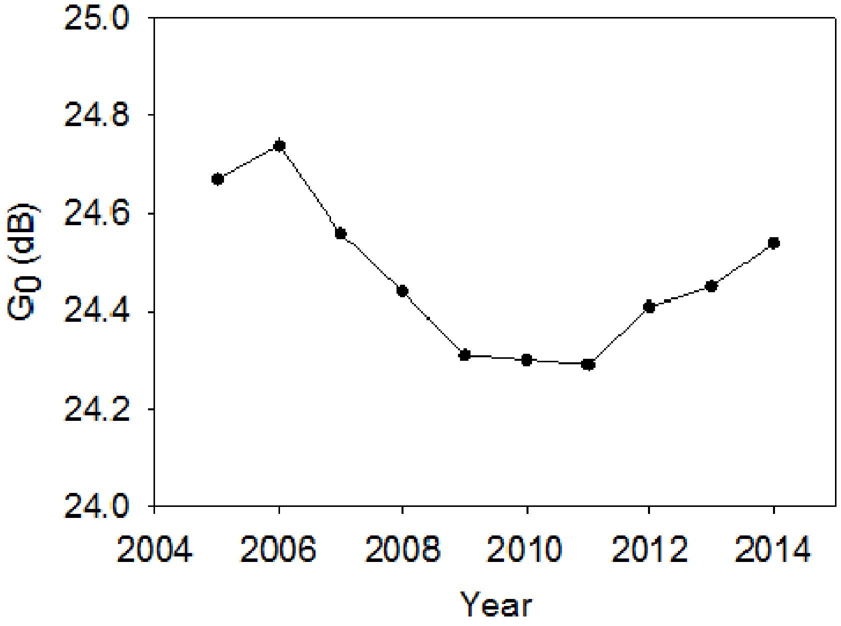


Figure A3. Changes in 'on axis' gain, G_0, based on the mean sphere echo for the ES60 and ES70 sounders on *Tomi Maru 87* from 2005 to 2014.