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Acoustic biomass estimates of southern blue whiting on the Bounty Plateau in 2017

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EXECUTIVE SUMMARY

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The FV *Tomi Maru 87* collected acoustic data along 15 transects in one snapshot on the Bounty Plateau overnight on 5–6 September 2017. The snapshot covered a spawning southern blue whiting (SBW) aggregation south of the Bounty Islands. The surveyed area in 2017 (153 km^2) was slightly larger than that in 2016 (104–112 km^2), but similar to the area surveyed in 2014–15. As in 2016, spawning was very late in 2017, with running ripe females recorded northeast of the survey location on 1–4 September, and then close to the survey area on 7–9 September. The acoustic biomass estimate from the single snapshot in 2017 was 7719 t (CV 24%). This was 24% higher than the best estimate of 6201 t (CV 35%) from 2016, reversing the decline observed since 2013. However the 2017 estimate was still the third lowest in the industry acoustic time-series (which started in 2004), and only about 10% of the biomass estimated in 2007 and 2008. Data on the size distribution of the fish, collected by Ministry for Primary Industries observers, show that the strong 2002 and 2007 year-classes were still important, but there was also a mode of younger fish from the 2012 year-class caught at 37–41 cm.

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 2017). Southern blue whiting (SBW) occur in Sub-Antarctic waters, with known spawning grounds on the Bounty Plateau, 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 Plateau 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 Plateau, 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 Plateau 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 was surveyed in 1998, 2000, 2002, 2004, 2006, 2009, 2011, 2013, and 2016. All these surveys were carried out from *R.V. Tangaroa* using towed transducers and were 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 2017).

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). O'Driscoll & 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. Surveys of spawning SBW using this approach were successfully carried out on the Bounty Plateau in 2004 and then annually since 2006 (O'Driscoll et al. 2016).

The TACC for the Bounty southern blue whiting was increased from a low level of 3500 t in 2009 to 14 700 t in 2010 after a strong year class (2002 cohort) entered the fishery. A large adult biomass was estimated by acoustic surveys in 2007 and 2008 but estimates from later surveys were much reduced. The SBW6B TACC was reduced to 2940 t from 1 April 2015. The estimated biomass declined by nearly 50% in the 2015 survey estimate, and remained low in the 2016 survey (O'Driscoll & Ladroit 2017). In 2016 however there was evidence of a new cohort (2012 cohort) which should be monitored as it enters the fishery.

Given the recent changes in TACC and ongoing uncertainty about the status of the Bounty Plateau stock, it is very important to continue to monitor acoustic estimates of spawning SBW in that area. An aggregation-based acoustic survey of the Bounty Plateau was carried out in 2017. The acoustic data were analysed to provide a biomass estimate for the stock. This will be used to inform management of the stock based on the harvest control rule that was agreed in early 2017 (Ministry for Primary Industries 2017).

1.1 Project objectives

This report is the final reporting requirement for Ministry for Primary Industries research project SBW2017/01. The objective was to analyse acoustic data collected during the SBW 6B aggregation acoustic survey to estimate current stock biomass.

2. METHODS

2.1 Vessel and equipment

FV *Tomi Maru 87* is a 68 m New Zealand owned surimi trawler operated by Aurora Fisheries Ltd. The vessel is fitted with a Simrad ES80 echosounder. The Simrad ES80 was installed on *Tomi Maru 87* in May 2016 and is an updated version of the previous ES60 and ES70 echosounders. A new ES38-7 38-kHz split-beam transducer was also installed in May 2016 along with a new 70-kHz ES80 echosounder, wide-band transceiver (WBT), and ES70-7C transducer. The 38 kHz general purpose transceiver (GPT) proved incompatible with the ES80 and was replaced by a WBT in February 2017. The echosounder system used in 2017 is therefore different from those used in previous Bounty surveys, and represents the start of a new calibration time series.

Calibration of the Simrad ES80 echosounder on *Tomi Maru 87* took place off Timaru on 9 July 2017 (Appendix 1). Diagnostics indicated a 38 kHz calibration of excellent quality. The estimated peak gain (G_0) was 26.36 dB and the sa correction was -0.03 dB (see Table A3), which were the values used in the analysis of the 2017 survey results.

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 briefed by Richard O'Driscoll in Timaru during the calibration on 9 July 2017.

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 Plateau 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 the 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 ES80 files. Data from acoustic transects were extracted and analysed using NIWA's custom ESP3 software. Echograms were visually examined, and the data groomed by a combination of algorithmic and manual editing. Echoes from the seabed and below were removed, and noise spikes and missing pings were 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. (2002).

Backscatter from regions identified as SBW was then integrated to produce an estimate of acoustic density (m^{-2}). During integration, acoustic backscatter was corrected using an estimated sound absorption of 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 2017. The systematic triangle-wave error found in ES60 and ES70 data (Ryan & Kloser 2004) was not present in ES80 data.

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 Plateau was calculated from the scaled length frequency distribution of SBW caught by FV *Tomi Maru 87* in this area in 2017, 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):

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

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 for New Zealand SBW in 2012.

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

$$w = 0.00439 \text{ x } FL^{3.133} \tag{2}$$

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

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* after departing Timaru on 15 August 2017 to arriving back in port on 12 September 2017, except for a period of three days on 6–9 September, as the master forgot to restart recording following the acoustic snapshot. The vessel was on the Bounty Plateau fishing grounds from 17 August to 9 September. Data collected while fishing and searching was affected by acoustic noise due to sonar and other instruments and is not suitable for quantitative analysis but these data do provide a useful record of vessel activities and the presence of fish outside surveyed areas.

The ES80 system crashed on 25 August 2017 and lost the serial feed to the GPS. This connection was not re-established when the echosounder was re-started (later it was determined that the connection was only restored after the computer was re-booted), and so no position (latitude and longitude) data were contained within the acoustic files for the remainder of the voyage. This included acoustic data collected during the snapshot on 5–6 September. Start and finish positions for acoustic transects were retrospectively extracted from the vessel's radar position log (which electronically recorded latitude and longitude every minute) and positions associated with every acoustic ping were inferred assuming a constant transect speed.

Fifteen acoustic transects were carried out in one snapshot overnight on 5–6 September 2016 (Table 2). This snapshot surveyed a SBW aggregation south of the Bounty Islands (Figure 1). Trawl positions are also shown in Figure 1, which show the daily location of the vessel. The master reported that the SBW aggregation being tracked from 17–28 August was "lost" during a period of bad weather which prevented fishing on 29–31 August. Searching to the east located SBW, and the vessel made some large catches well to the northeast of the snapshot location on 1–4 September. The master reported that these fish then dispersed, but a large aggregation was detected back to the west on 5 August and acoustically surveyed. This surveyed aggregation was then tracked to the east through the remainder of the fishing period on 6–9 September.

The surveyed area in 2017 was 153 km^2 (Table 2). This was slightly larger than that in 2016, when two snapshots covered 104 and 112 km^2 respectively, but similar to the area surveyed in 2014–15 (76–176 km^2). The spacing between adjacent transects in 2017 was about 2 km, similar to that in 2013–16. Transects 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.

The 2017 snapshot had a similar timing to the two snapshots in 2016 (4–6 September), but the two most recent surveys were the latest in the Bounty Plateau time-series, as all previous snapshots occurred in August (Figure 2). Between 2004 and 2010 there was a trend in survey dates occurring earlier, but in 2011–15 surveys were later in August (Figure 2).

Timing of SBW spawning also varied between years (Figure 2). As in 2016, spawning on the Bounty Plateau in 2017 was very late. Running ripe females were first recorded by scientific observers in catches made to the east on 1–4 September, with the proportion of running ripe females exceeding 10% on 3 September (Figure 3). Fish caught in the survey location on 5–6 September were pre-spawning (mainly stage 2), but these fish spawned on 7–9 September (Figure 3). Except in 2004 (one snapshot) and 2016 (two snapshots over 2 days), previous surveys had much longer durations. For example, in 2011 (when 8 snapshots occurred over 13 days), 2012 (10 snapshots in 9 days), 2013 (4 snapshots over 8 days), 2014 (5 snapshots over 7 days), and 2015 (4 snapshots over 6 days).

3.3 Acoustic data quality

The quality of the acoustic data from the single snapshot at Bounty Plateau in 2017 was very good, with less than 2% ping drop-outs due to bubble aeration (see Figure 4). ES80 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 Plateau (Hanchet et al. 2002). SBW marks were observed in water depths from 350–450 m during the snapshot (Figure 4).

3.4 Distribution of SBW backscatter

The spatial distribution of SBW along each transect is shown in Figure 5. As noted in Section 3.1, transects were carried out sequentially from east to west. The snapshot appeared to completely cover the main SBW aggregation. There were no, or very low, densities of SBW on the outer transects and at the end of transects (Figure 5).

Peak mean transect densities were observed along transects 7 and 12 and echograms from these transects are shown in Figure 4. In 2017, acoustic transects that crossed the high density aggregation were an average of 5.3 km long, less than in 2016 (when mean transect length was 6.3 km), and much shorter than when SBW biomass was estimated to be highest in 2007 and 2008 (up to 15 km long).

3.5 Biological data

FV *Tomi Maru 87* was the only vessel fishing for SBW at the Bounty Plateau during the 2017 season. The mean length of SBW caught by *Tomi Maru 87* was 41.8 cm (Figure 6). Mean weight was 544 g. Mean backscattering cross-section was 0.000534 m^2 (equivalent to –32.7 dB), giving a ratio, *r*, of 1017 kg m^{-2}.

The SBW caught to the northeast of the acoustic survey area on 1–4 September were smaller on average (mean length 40.6 cm) than fish caught from the surveyed aggregation on 5–9 September (mean length 43.0 cm) (Figure 7).

3.6 Biomass estimates

Biomass estimates for all Bounty Plateau snapshots in 2004–17 are given in Table 3. The variance of snapshot estimates is generally reduced by removing zero transects, but the differences were small. The biomass sometimes changed when zero transects were excluded as the transect spacing was not always uniform.

The acoustic biomass estimate for the snapshot in 2017, with zero transects removed, was 7719 t (CV 24%). This was 24% higher than the best estimate of 6201 t (CV 35%) from 2016, reversing the decline observed in the industry acoustic time-series since 2013 (Table 4). However the 2017 estimate was still the third lowest in the industry acoustic time-series (which started in 2004), and only about 10% of the biomass estimated in 2007 and 2008.

4. DISCUSSION

Acoustic data from the Bounty Plateau in 2017 were collected with appropriate acoustic settings and were of adequate quality to estimate biomass. A failure in the connection to the GPS on 25 August 2017 meant that position information was not embedded in the acoustic data after this date, but transect positions could be determined from the GPS log of the vessel radar. Only one snapshot was carried out, south of the Bounty Islands within the region where the largest aggregations were observed in 2007–16 (see Figure 1). This snapshot appeared to adequately cover the surveyed aggregation (see Figure 5). Spawning was again very late at the Bounty Plateau in 2017, but the snapshot was within the main spawning period (see Figure 3). Difference in size between SBW caught to the northeast of the survey area on 1–4 September (see Figure 7), and the observation that SBW to the northeast were spawning before the surveyed aggregation (see Figure 3), suggests that there may have been two separate spawning aggregations in 2017. It is not possible to determine the abundance of fish in the northeast area, as no snapshot was carried out, but the vessel caught 595 t from the 5 tows in this area.

The very large decrease observed in acoustic estimates of SBW at the Bounty Plateau between 2008 and 2009 was too great to be explained by fishing and average natural mortality on the dominant 2002 year-class (Dunn & Hanchet 2015). 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 Plateau 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 Plateau 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, but then declined in 2014–16 to below the estimates from 2009–12 (Table 4). There was a 24% increase in estimated biomass in 2017, but it is still 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 (O'Driscoll et al. 2016). The 2014 stock assessment was rejected by the Deepwater Fisheries Assessment Working Group (DWFAWG) because the assumption of a constant catchability (*q*) for the aggregation surveys was not thought to be justified (Ministry for Primary Industries 2017). As an alternative the DWFAWG developed a simple harvest control rule (HCR) that uses the most recent acoustic index of abundance as an absolute measure of abundance. The HCR is given by $TACC_{t+1} = HCR_{-p} (B_t - C_t/2)$, where B_t is acoustic abundance, C_t is catch, and HCR_{-p} is a fixed proportion in year t.

Data on the age distribution of the fish from the commercial fishery (Figure 8) show that the strong 2002 year-class was still present in the 2017 fishery at age 15, and that the 2007 year-class (age 10 in 2017) was also important. The mode of younger fish mainly from the 2012 year-class have continued to grow and were observed centred about 37 cm (males) and 39 cm (females) in 2017 (see Figure 6).

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7. TABLES

Table 1: Echosounder settings and other relevant parameters for acoustic data collection in 2017.

Parameter	38 kHz	70 kHz
Echosounder	ES80	ES80
Software version	1.1.4	1.1.4
Transducer model	ES38-7	ES70-7C
Transducer serial number	130	Not recorded
ES80 WBT serial number	714603	700875
WBT software version	FPGATX firmware Rev 5 FPGARX firmware Rev 7	FPGATX firmware Rev 5 FPGARX firmware Rev 7
Sphere type/size	tungsten carbide/38.1 mm diameter	
Operating frequency (kHz)	38	70
Transducer draft setting (m)	0.0	0.0
Transmit power (W)	2000	1000
Pulse length (ms)	1.024	1.024
Slope (%)	25.699	4.185
Transducer peak gain (dB)	26.5	27.0
Sa correction (dB)	0.0	0.0
Sample interval (m)	0.040	0.048
Two-way beam angle (dB)	-20.7	-20.7
Absorption coefficient (dB/km)	10.0	23.0
Speed of sound (m/s)	1491	1491
Angle sensitivity (dB) alongship/athwartship	28.0/28.0	23.0/23.0
3 dB beamwidth (º) alongship/athwartship	7.0/7.0	7.0/7.0
Angle offset (º) alongship/athwartship	0.0/0.0	0.0/0.0

Table 2: Summary of acoustic snapshot carried out at the Bounty Plateau in 2017 by FV *Tomi Maru 87*. Times are NZST.

Snapshot	Area (km^2)	Start time	End time	No. of transects
1	152.8	5 Sep 19:09	6 Sep 01:18	15

Table 3: Stratum areas, biomass estimates, and coefficients of variation (CV) for all snapshots of spawning SBW on the Bounty Plateau carried out by industry vessels from 2004–17. All snapshots were carried out by *Tomi Maru 87* except for 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 used the TS-FL relationship of O'Driscoll et al. (2013), Estimates from 2004 to 2013 were 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, biomass estimates, and coefficients of variation (CV) for all snapshots of spawning SBW on the Bounty Plateau carried out by industry vessels from 2004–17. Snapshots in bold were averaged to produce the biomass estimates in Table 4.

			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**
	7	**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
	9	**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
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**
	3	**10**	204.5	27 972	37	**2**	**170.9**	**27 491**	**34**
	4	**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**
	2	**7**	102.3	18 363	70	**1**	**96.5**	**18 437**	**71**
	3	**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**
2015	1	13	165.3	5 634	21	0	165.3	5 634	21
	2	**13**	152.5	5 490	40	**0**	**152.5**	**5 490**	**40**
	3	5	74.6	2 809	78	2	54.1	2 771	80
	4	**7**	110.7	7 927	65	**1**	**98.8**	**7 961**	**65**
2016	**1**	**8**	103.5	4 766	42	**1**	**91.7**	**4 813**	**39**
	2	**9**	112.2	7 592	53	**2**	**92.7**	**7 589**	**51**
2017	**1**	**15**	152.8	7 719	25	**1**	**145.5**	**7 719**	**24**

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

Table 4: Estimates of SBW biomass (t) and CV for adult fish from research acoustic surveys of the Bounty Plateau 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 2011–16 were obtained by averaging selected snapshots. All estimates calculated used 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%)
2015	–	6 726 (42%)
2016	–	6 201 (35%)
2017	–	7 719 (24%)

8. FIGURES

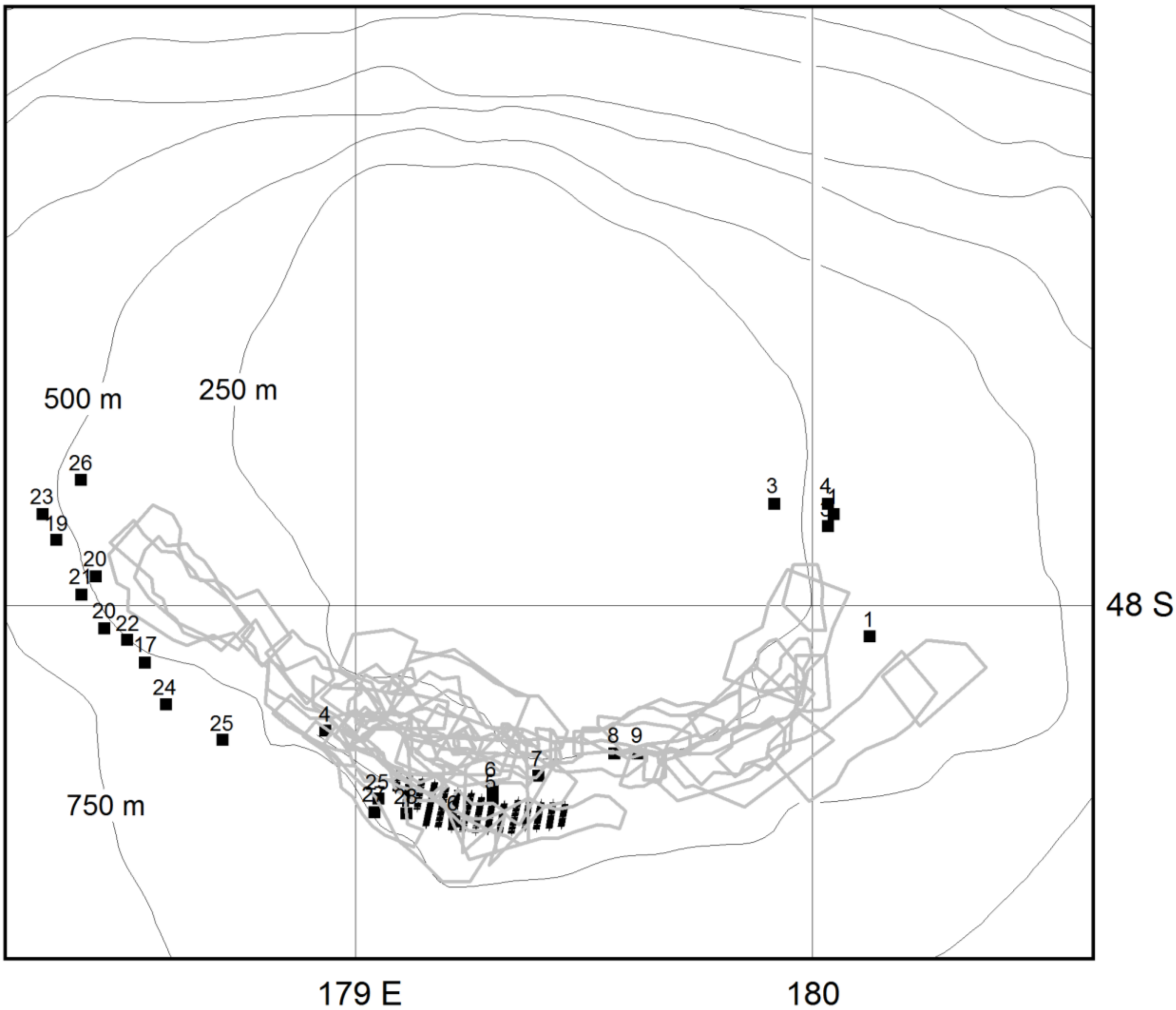

Figure 1: Map showing location of transects carried out in the snapshot by FV *Tomi Maru 87* at the Bounty Plateau in 2017 (black lines). Transect locations are compared with the areas surveyed in 2004–16 (grey polygons). Solid squares are locations of commercial trawls in 2017, numbered above by date in August or September.

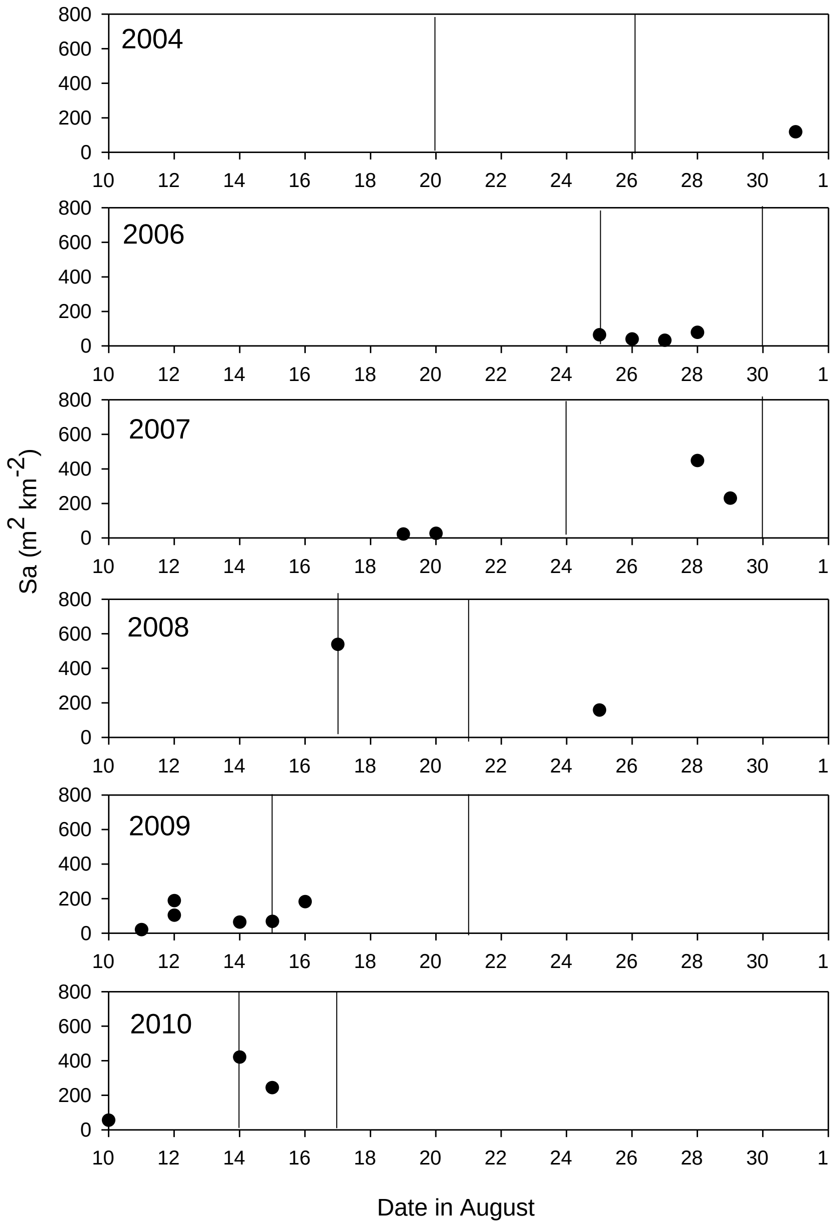

Figure 2: Weighted (by transect length) mean densities for each snapshot (solid circles) plotted as a function of date for all snapshots carried out by industry vessels on the Bounty Plateau 2004–10. Vertical lines indicate estimated period of peak spawning based on gonad staging by observers.

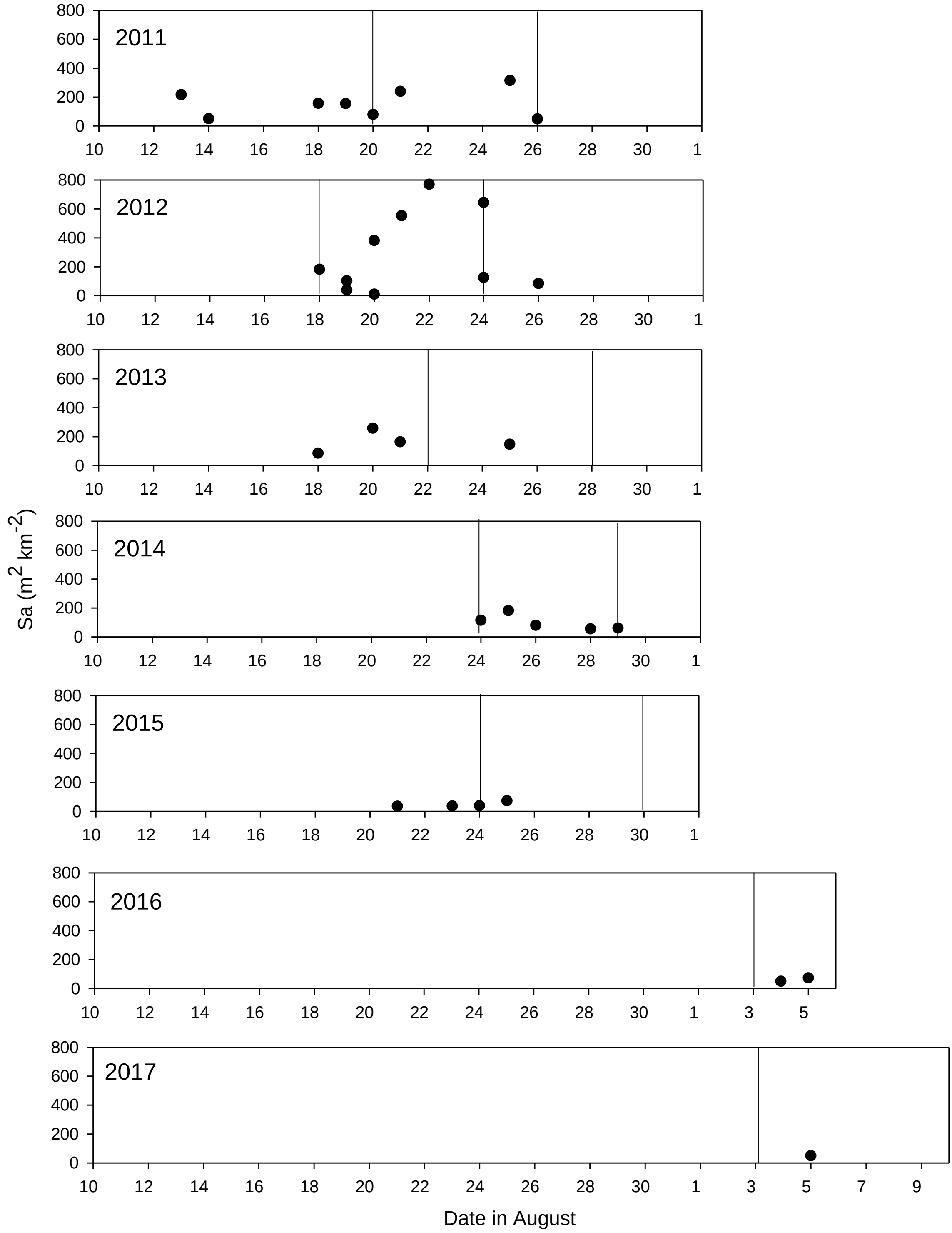

Figure 2 cntd: Weighted (by transect length) mean densities for each snapshot (solid circles) plotted as a function of date for all snapshots carried out by industry vessels on the Bounty Plateau 2011–17. Vertical lines indicate estimated period of peak spawning based on gonad staging by observers.

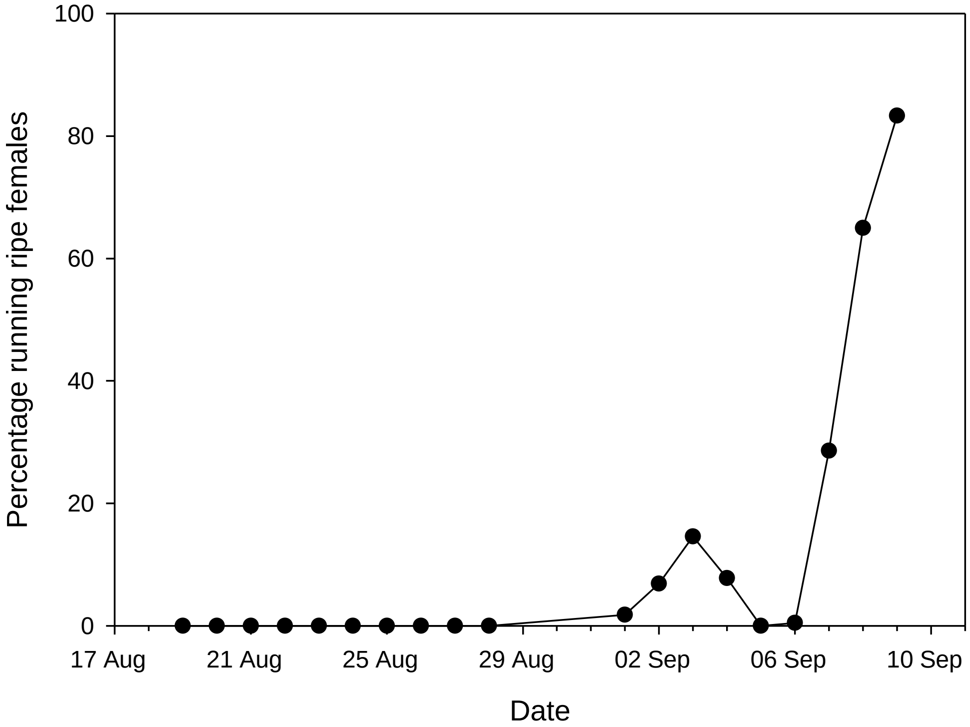

Figure 3: Percentage of running ripe (observer stage 4) female southern blue whiting by date based on gonad staging by observers on *Tomi Maru 87* in 2017.

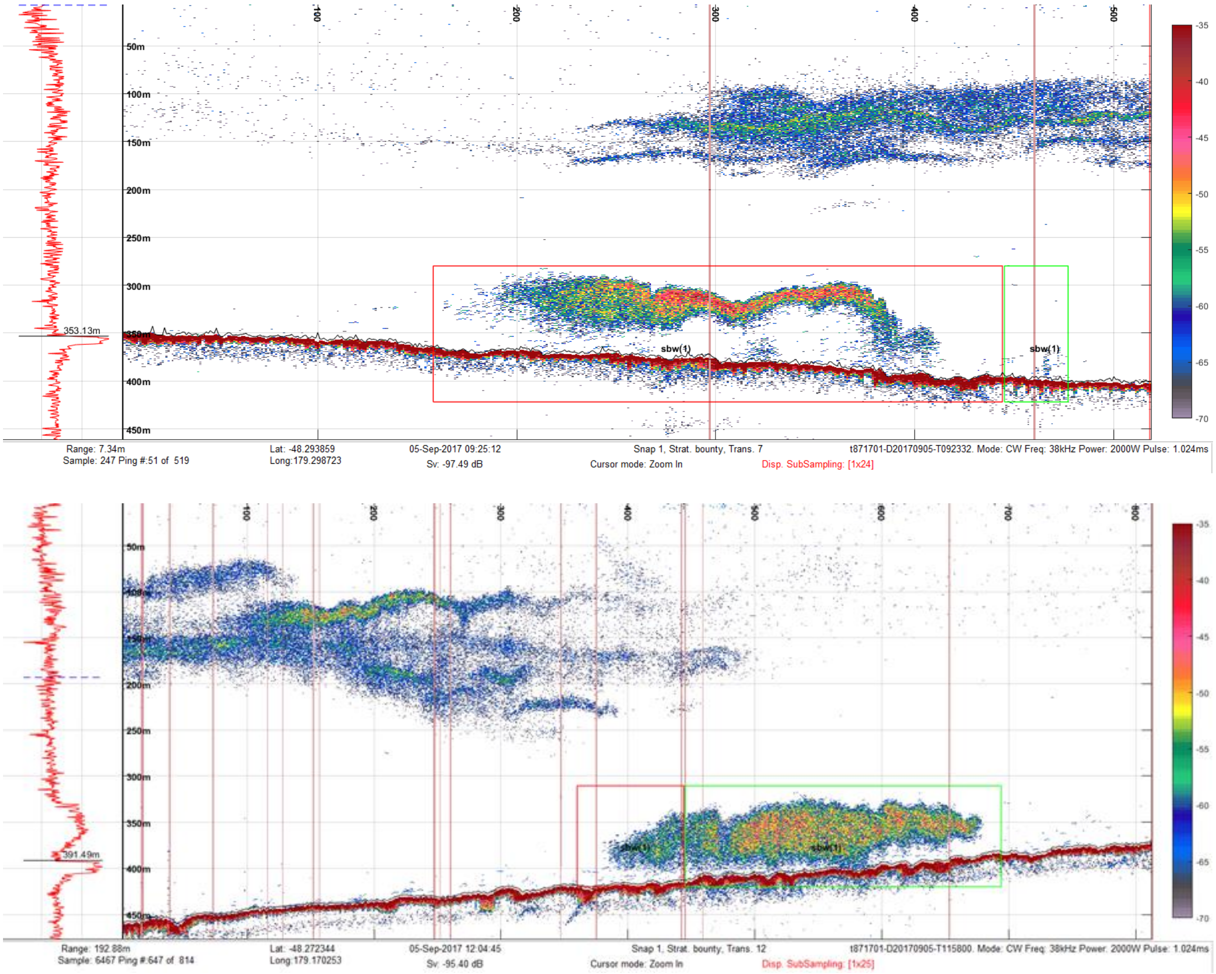

Figure 4: Example of acoustic echogram collected at the Bounty Plateau during snapshot 1 on 5 September 2017 on transect 7 (upper panel) and transect 12 (lower panel). Red vertical lines are where ping drop-outs due to bubble aeration in poor weather were removed. Southern blue whiting aggregations were defined inside a rectangular box.

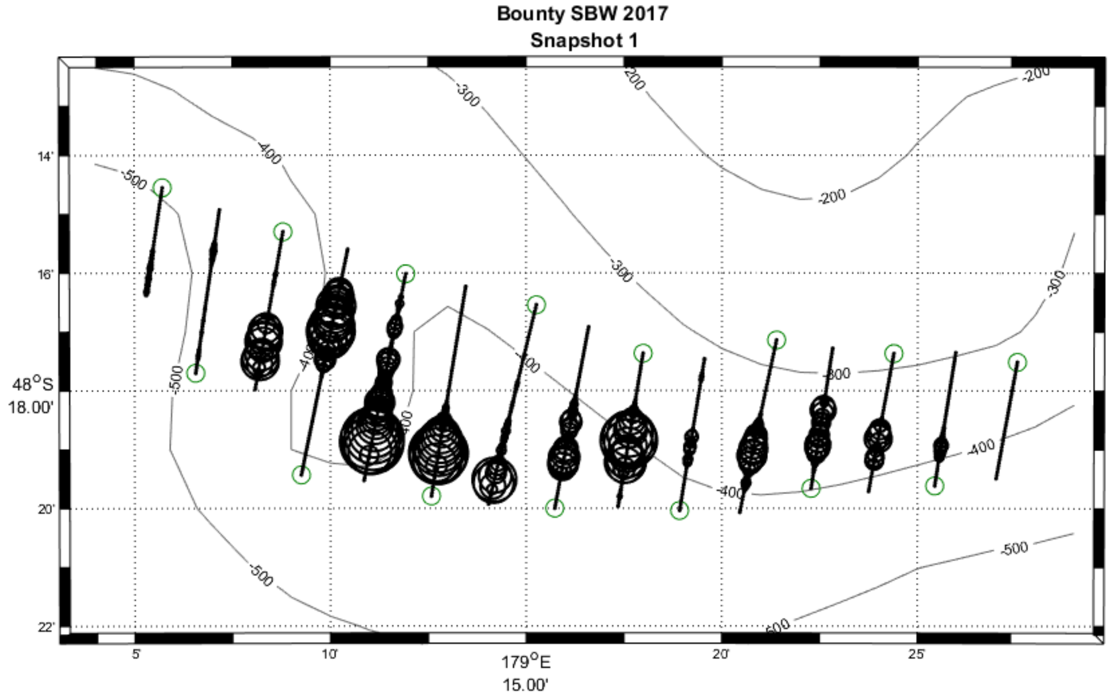

Figure 5: Spatial distribution of SBW backscatter plotted in 10-ping bins for the snapshot at the Bounty Plateau in 2017. Transects were carried out from east to west. Circle area is proportional to the log of the acoustic backscatter. Green circles denote start position of each transect.

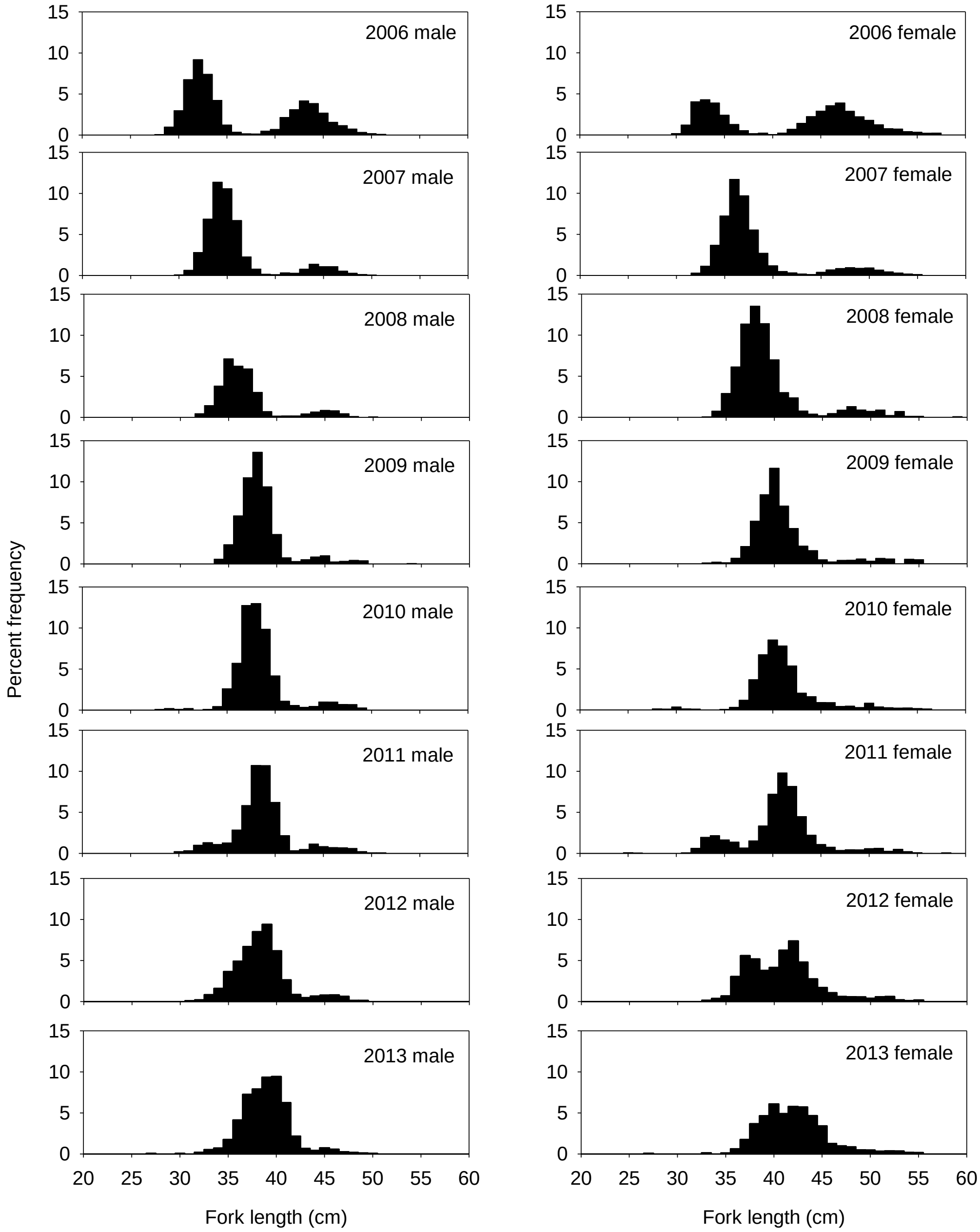

Figure 6: Scaled length frequency distributions of SBW caught on the Bounty Plateau by FV *Tomi Maru 87* in 2006–13 based on scientific observer data.

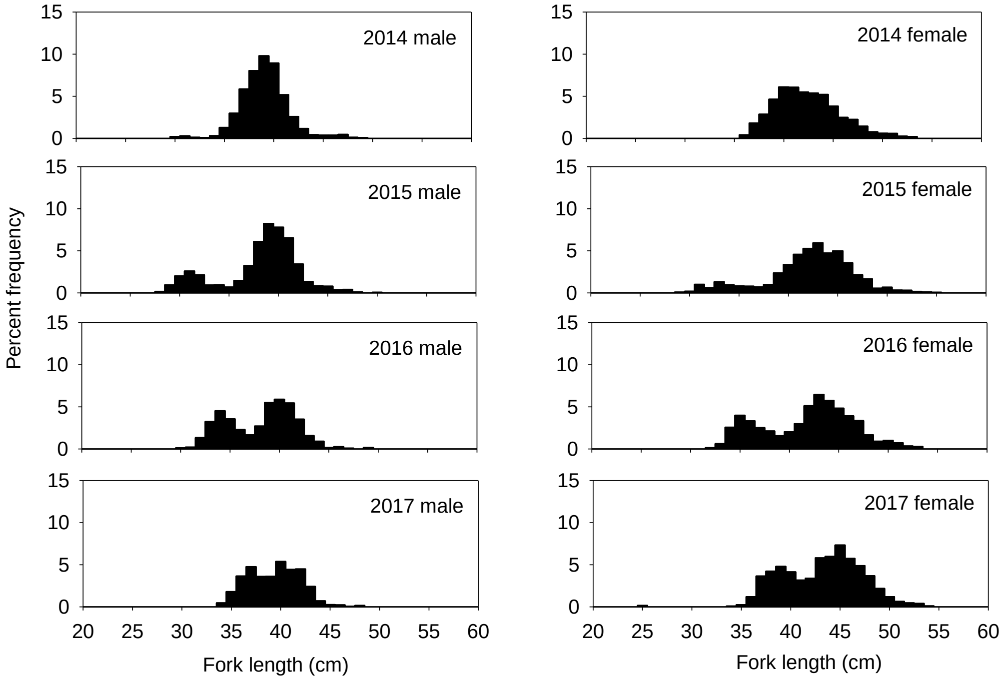

Figure 6 cntd: Scaled length frequency of SBW caught on the Bounty Plateau by FV *Tomi Maru 87* in 2014–17 based on scientific observer data. Data from 2017 are from observer trip 5104.

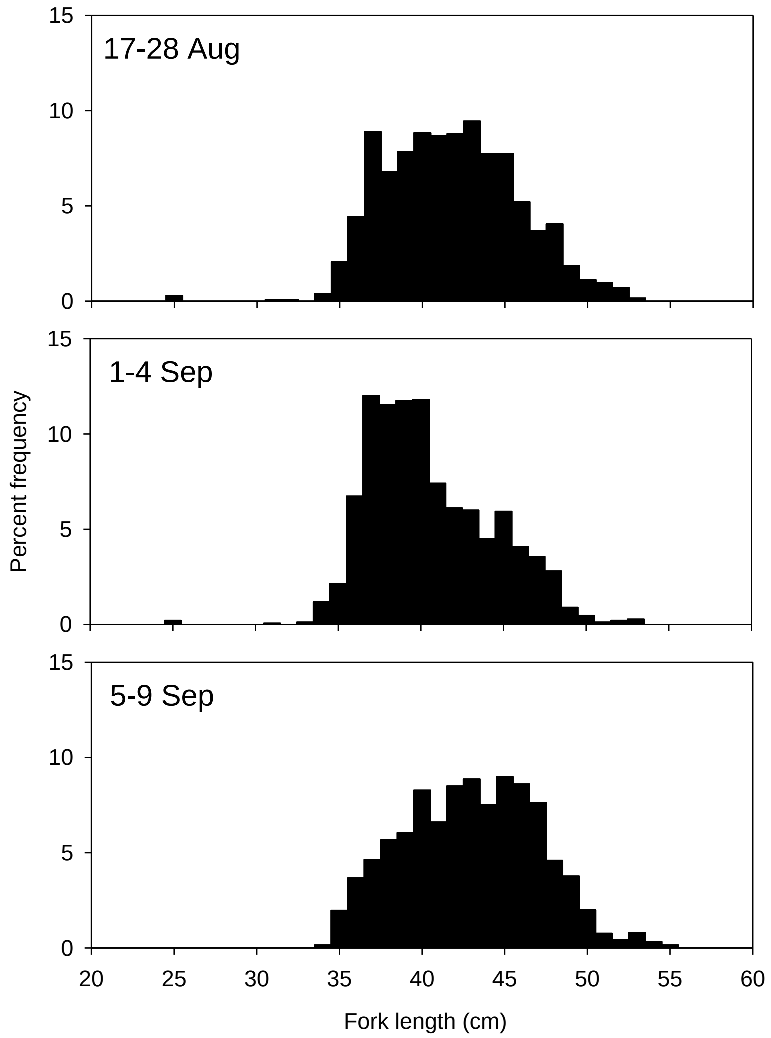

Figure 7: Scaled unsexed length frequency of SBW caught on the Bounty Plateau by FV *Tomi Maru 87* in 2017 by time. Fishing on 1–4 September occurred to the northeast of the spawning aggregation surveyed on 5–6 September (see Figure 1).

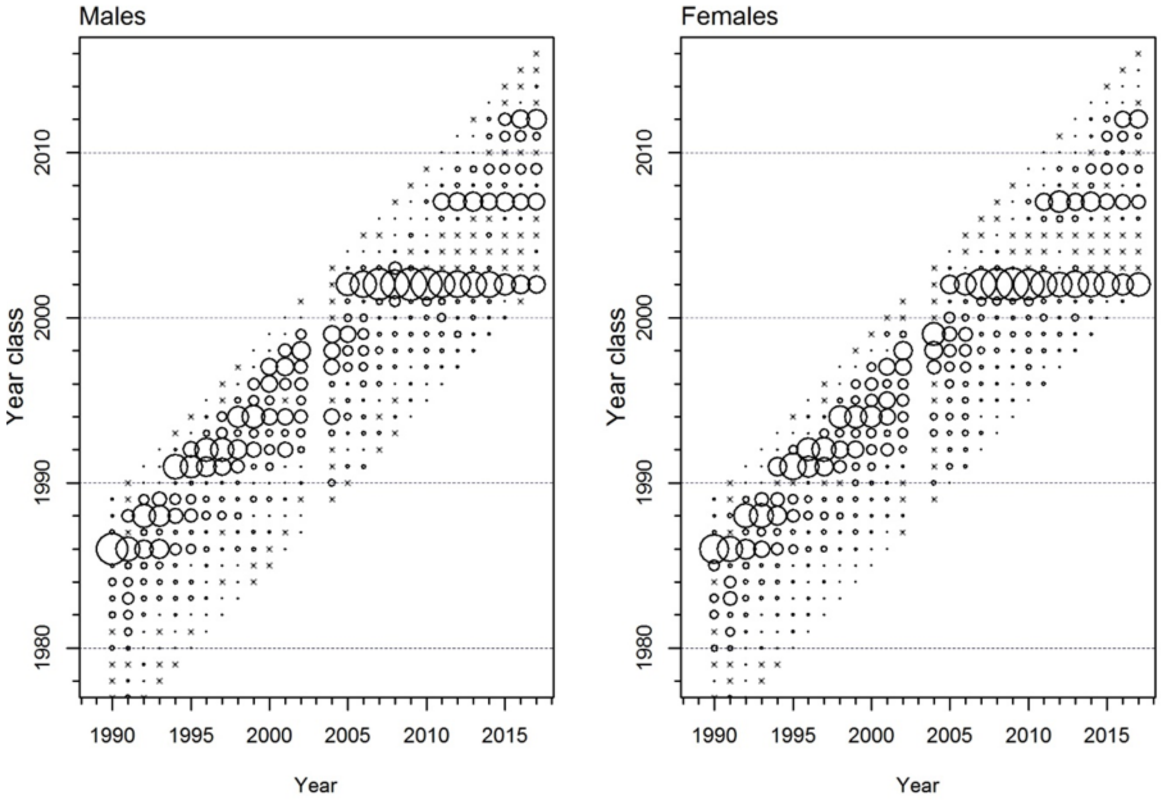

Figure 8: Estimated proportions at age of SBW in the commercial catch from the Bounty fishery 1990–2017. Circle area shows estimated proportion. Crosses indicate a proportion of zero.

APPENDIX 1: Calibration Report: *Tomi Maru 87* 9 July 2017

Calibration of the Simrad ES80 echosounder on *Tomi Maru 87* took place off Timaru (44° 21.6' S 171° 33.4' E) on 9 July 2017. Water depth was about 32 m (below the transducer). The calibration was carried out by Richard O'Driscoll and Pablo Escobar-Flores (NIWA) following the procedures in Demer et al. (2015).

There were 11 calibrations of the previous ES60 and ES70 echosounders on this vessel, with annual calibrations since 2005. In May 2016 the ES38B transducer was replaced with a new Simrad ES38-7 unit which had a different element configuration and required a new processing card to be installed in the GPT. The echosounder system used in 2016 was therefore different from those used in previous Bounty surveys. A calibration took place after the installation of the new transducer in the Hauraki Gulf on 25 May 2016. This calibration was carried out with the new transducer and GPT, but with the old (ES70) software. However, data collection during the 2016 SBW season was carried out with newer (ES80 version 1.0.0) software which had different transducer configuration settings, and a bug which meant that the echosounder operated in single-beam mode. This meant that results from the ES70 calibration could not be applied to the survey data and the Simrad ES80 was re-calibrated (as a single-beam echosounder) off Timaru on 11 January 2017 (O'Driscoll & Ladroit 2017).

Because the incompatibility between the ES80 and the GPT was not resolved by later versions of the ES80 software, a new 38 kHz WBT was installed in February 2017. This is the first calibration using the new WBT and therefore represents the start of a new calibration series. Both the 38 kHz and 70 kHz ES80 echosounders were operated synchronously and were calibrated together.

Richard O'Driscoll and Pablo Escobar-Flores boarded *Tomi Maru 87* at 10:00 NZST at Primeport Timaru. The vessel departed at 10:30 and steamed offshore for trials on the main engine. The ES80 was configured to survey 38 kHz and 70 kHz settings (see Table A1) and the PC time was set to the GPS before the calibration began. A new 4 TB hard drive was installed to record data. No keyboard was available, and the ES80 computer only had one available USB port, so a portable keyboard was used to configure settings before installing the hard drive.

The calibration commenced at 13:00 NZST. 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 3 m below the sphere to steady the arrangement of lines. The sphere was centred in the 38 kHz beam, and was then moved around the beam to obtain data for the beam shape calibration.

The weather was good with light winds and 1 m easterly swell. The vessel was allowed to drift, and the drift speed was about 0.6 knots. The sphere was located in the beam at 13:25 and calibration data were collected until 15:00 in three ES80 .raw format files (t871701-D20170709-T010538, t871701-D20170709-T015117, t871701-D20170709-T024135). Raw data are stored in the NIWA *acoustics* database.

Before leaving the calibration site, water temperature measurements were taken using an RBR Duet temperature depth probe, serial number 82705. The water column was unstratified, with a surface temperature of 9.8º and a temperature at the sphere depth (23 m) of 10.1º. 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).

After the calibration, the *Tomi Maru 87* returned to Timaru berthing at about 17:30.

The data in the ES80 files were extracted using custom-written ESP3 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 $S_{a,corr}$ was calculated for all valid sphere echoes and the mean over all sphere echoes was used to determine the final $S_{a,corr}$.

No correction was necessary for the triangle wave error in ES60 and ES70 data (Ryan & Kloser 2004) as this was not applied in ES80 data.

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 for the 38 kHz transducer are given in Figure A1. The symmetrical nature of the pattern and the zero centre of the beam pattern indicate that the transducer and ES80 transceiver were operating correctly. The fit 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 0.13 dB (Table A3), indicating that the 38 kHz calibration was of excellent quality (>0.3 dB is poor, 0.2–0.3 dB good, and <0.2 dB excellent). The estimated peak gain (G_0) was 26.36 dB and the sa correction was -0.03 dB. Note that the sa correction differs from that for ES60 and ES70 echosounders as the pulse shape is no longer assumed to be rectangular in the ES80. Results from the 38 kHz calibration were used for analysis of results from the 2017 Bounty southern blue whiting survey.

Results from the simultaneous calibration of the 70 kHz echosounder are also given in Table A3 with the estimated beam pattern and sphere coverage in Figure A3 and the beam fit in Figure A4. This was also an excellent quality calibration (RMS 0.15 dB) which showed the 70 kHz echosounder was operating correctly. The estimated peak gain (G_0) at 70 kHz was 27.93 dB and the sa correction was -0.06 dB.

Table A1: Transceiver settings and other relevant parameters for 38 kHz and 70 kHz echosounders during the ES80 calibration in July 2017.

Parameter	38 kHz	70 kHz
Echosounder	ES80	ES80
Software version	1.1.4	1.1.4
Transducer model	ES38-7	ES70-7C
Transducer serial number	130	Not recorded
ES80 WBT serial number	714603	700875
WBT software version	FPGATX firmware Rev 5 FPGARX firmware Rev 7	FPGATX firmware Rev 5 FPGARX firmware Rev 7
Sphere type/size	tungsten carbide/38.1 mm diameter	
Operating frequency (kHz)	38	70
Transducer draft setting (m)	0.0	0.0
Transmit power (W)	2000	1000
Pulse length (ms)	1.024	1.024
Slope (%)	25.699	4.185
Transducer peak gain (dB)	26.5	27.0
Sa correction (dB)	0.0	0.0
Sample interval (m)	0.040	0.048
Two-way beam angle (dB)	-20.7	-20.7
Absorption coefficient (dB/km)	10.0	23.0
Speed of sound (m/s)	1491	1491
Angle sensitivity (dB) alongship/athwartship	28.0/28.0	23.0/23.0
3 dB beamwidth (°) alongship/athwartship	7.0/7.0	7.0/7.0
Angle offset (°) alongship/athwartship	0.0/0.0	0.0/0.0

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

Parameter	38 kHz	70 kHz
Mean sphere range (m)	16.1	16.1
S.D. of sphere range (m)	0.65	0.64
Mean sound speed (m/s)	1 490	1 490
Mean temperature (°C)	9.9	9,9
Mean absorption (dB/km)	9.60	22.77
Sphere TS (dB re 1m^2)	-42.39	-41.28

Table A3: Calculated echosounder calibration parameters for *Tomi Maru 87* based on ES80 calibration on 9 July 2017. Values were calculated using ESP3 software version 0.4.0.

Parameter	38 kHz	70 kHz
Mean TS within 0.21° of centre	-42.68	-39.44
Std dev of TS within 0.21° of centre	0.27	0.16
Max TS within 0.21° of centre	-41.71	-39.10
No. of echoes within 0.21° of centre	147	51
On axis TS from beam-fitting	-42.63	-39.25
Transducer peak gain (dB) mean TS	26.36	27.93
Sa correction (dB)	-0.03	-0.06
Beamwidth (°) along/athwartship	6.4/6.4	6.5/6.5
Beam offset (°) along/athwartship	0.05/-0.02	-0.03/0.04
RMS deviation	0.13	0.15
Number of echoes	10 079	7 253

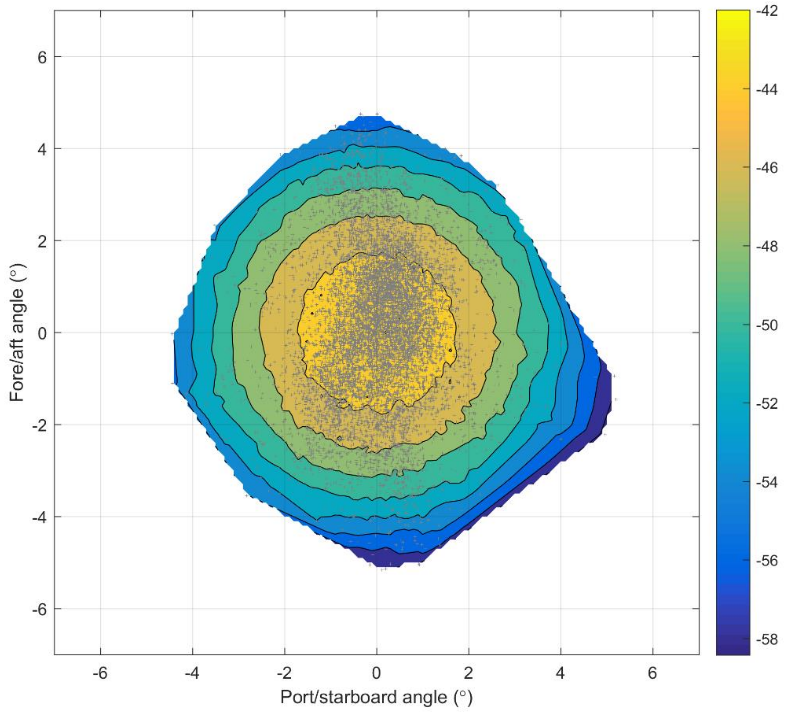

Figure A1: The estimated beam pattern from the sphere echo strength and position for the 38 kHz calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

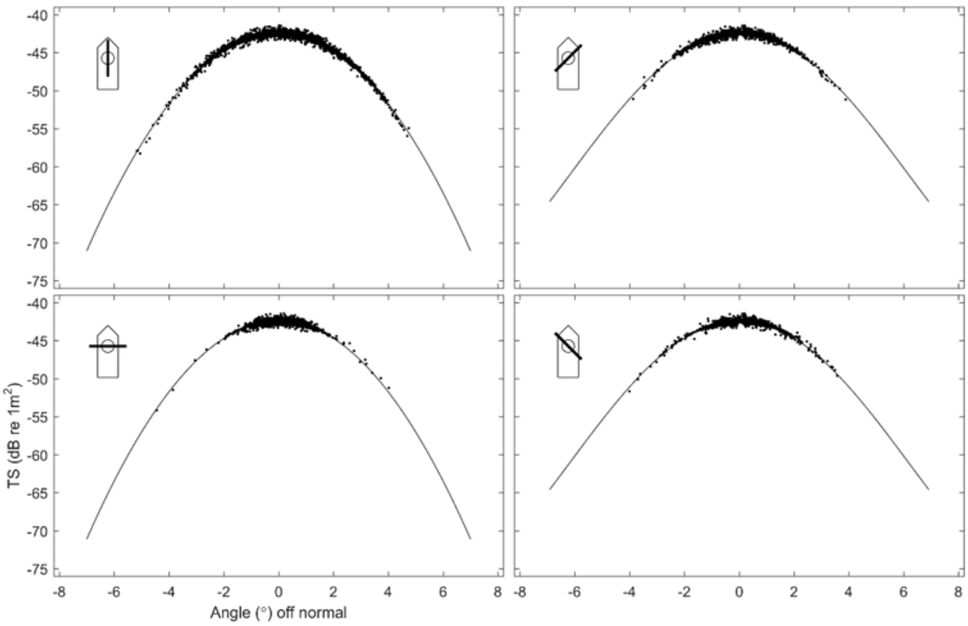

Figure A2: Beam pattern results from the 38 kHz calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

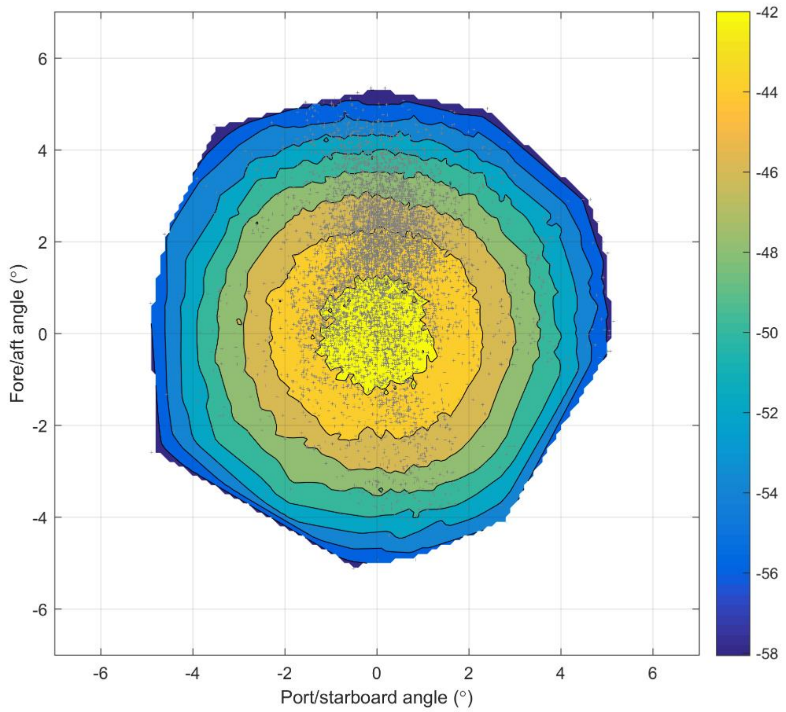

Figure A3: The estimated beam pattern from the sphere echo strength and position for the 70 kHz calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

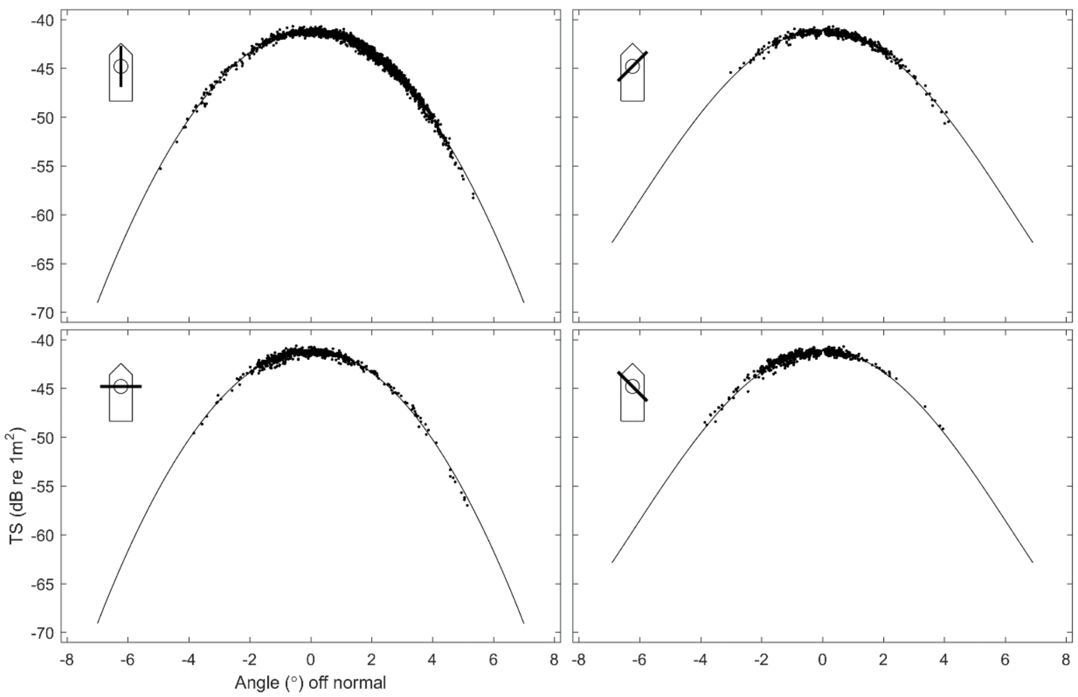

Figure A4: Beam pattern results from the 70 kHz calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.