Ministry for Primary Industries
Manatū Ahu Matua

Acoustic biomass estimates of southern blue whiting on the Bounty Platform in 2015

New Zealand Fisheries Assessment Report 2017/19

R.L.O'Driscoll
A.J. Dunford

March 2017

New Zealand Government

Growing and Protecting New Zealand

TABLE OF CONTENTS

EXECUTIVE SUMMARY

O'Driscoll, R.L.; Dunford, A.J. (2017). Acoustic biomass estimates of southern blue whiting on the Bounty Platform in 2015.

New Zealand Fisheries Assessment Report 2017/19. 29 p.

The FV *Tomi Maru 87* collected acoustic data along 38 transects in four snapshots on the Bounty Platform between 21 and 26 August 2015. 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 four snapshots ranged from 75 to 165 km^2, similar to the surveyed areas in 2014 when five completed snapshots covered 102–176 km^2. Only the final snapshot in 2015 appeared to adequately cover the main SBW aggregation. The other three snapshots had fish on the outer transects or at the end of transects, suggesting that the aggregation extended beyond the surveyed area. Peak densities of SBW were also observed in snapshot 4 on 25 August, but densities were not as high as observed in most previous surveys. Spawning appeared to be late in 2015, with running ripe females caught from 24–30 August.

Biomass estimates for 2015, ranged from 2771 t (CV 80%) in snapshot 3 to 7961 t (CV 65%) in snapshot 4. The best estimate of SBW biomass in 2015, obtained from the average of snapshots 2 and 4, was 6726 t (CV 42%). This was 43% lower than the best estimate of 11 832 t (CV 31%) from 2014, continuing the decline since 2013, and the lowest in the industry acoustic time-series which started in 2004. In 2015, acoustic transects crossing the high density aggregation were an average of 3.5 n. miles long, shorter than in 2013 and 2014 (when average transects were 4.5 n. miles long), and much shorter than when SBW abundance was estimated to be highest in 2007 and 2008 (transects up to 8 n. miles long).

Data on the size distribution of the fish, collected by Ministry for Primary Industries observers, show that the catch is still dominated by the strong 2002 year-class and, to a lesser extent, the 2007 year-class. In 2015 there was also a mode of younger fish from the 2011 and 2012 year-classes caught at 29–35 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 2015). 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 2015).

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 successfully carried out on the Bounty Platform in 2004, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, and 2014 (O'Driscoll et al. 2016), and attempted on the Pukaki Rise in 2009, 2010, and 2012 and on the Campbell Island Rise in 2010 and 2012 (e.g., Hampton & Nelson 2014).

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. 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 TACC of 6860 t, but an additional 'research' catch of up to 2000 t was allowed by Ministry for Primary Industries. The acoustic biomass estimate for 2014, based on the average of 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 (O'Driscoll 2015). The TACC was reduced to 2940 t from 1 April 2015.

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 2015). 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 (O'Driscoll et al. 2016).

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 identified the need for annual acoustic surveys from industry vessels on the Bounty Platform. No SBW surveys were funded by Ministry for Primary Industries in 2015, but a further aggregation-based survey was carried out from *FV Tomi Maru 87* in August 2015 directly funded by the Deepwater Group Limited. This survey followed the same protocols as those in 2004–14 (O'Driscoll 2011a).

1.1   Project objectives

This report is the final reporting requirement for Deepwater Group Limited contract DWG16301. 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 before the survey on 16 July 2015 (Appendix 1). Diagnostics indicated a calibration of good quality. The estimated peak gain (G_0) in 2015 based on the mean sphere echo increased by 0.25 dB from the 2014 calibration, continuing the recent trend of increasing G_0 for this system (Appendix 1). The 2015 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 Adam Dunford in Timaru after the acoustic calibration on 16 July 2015.

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 (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.

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 2015.

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 2015, 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):

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

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.

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* from departing Timaru on 12 August 2015 to arriving back in port on 3 September 2015 (Figure 1). 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 (Figure 1).

Thirty eight acoustic transects were carried out in four snapshots on the Bounty Platform between 21 and 26 August 2015 (Figure 2, 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 (Figures 1 and 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, O'Driscoll et al. 2016). Transects in all four 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 2015 ranged from 75 to 165 km^2 (Table 2), similar to the surveyed areas in 2014, when five completed snapshots covered 102–176 km^2 (O'Driscoll 2015), and within the range surveyed in previous years when snapshot areas were 10–300 km^2 (O'Driscoll et al. 2016). The spacing between adjacent transects was about 2 km, similar to that in 2013 and 2014, 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 four snapshots (6 days) was much less than in 2011 (when survey duration was 13 days), but only slightly less than that in 2012 (9 days), 2013 (8 days), and 2014 (7 days), and greater than in some previous surveys (Figure 3). Between 2004 and 2010 there was a trend in survey dates occurring earlier over the Bounty Platform time series, but since 2011 surveys have been later in August (Figure 3). Timing of SBW spawning has also varied between years (Figure 3). As in 2014, spawning appeared to be late in 2015, with more than 10% running ripe females recorded by scientific observers 24–30 August. The four snapshots in 2015 were therefore just before, and within, the main spawning period.

3.2   Acoustic data quality

The quality of the acoustic data from Bounty Platform in 2015 was adequate during all four snapshots, but there were some ping drop-outs due to bubble aeration in snapshots, particularly in snapshot 1 (see 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 water depths from 300–400 m in all four snapshots (Figures 4–7). 'Thundercloud' marks, associated with actively spawning SBW (Hanchet et al. 2002b) were observed in snapshots 2–4 on 22–25 August (Figures 5–7).

3.4   Distribution of SBW backscatter

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

Only the final snapshot in 2015 appeared to completely cover the main SBW aggregation. The first snapshot had moderate densities of SBW on the northernmost transects, suggesting that the aggregation extended northwest beyond the surveyed area (Figure 8). Snapshot 2 also had SBW on the northernmost transect, but densities were lower (Figure 8). The first and second snapshot took about 7 hours and 6 hours respectively (see Table 2) and the captain indicated that he needed to resume fishing before the edge of the aggregation was reached. The third snapshot only had high densities on one central transect (Figure 8), but the marks extended right to the start of this transect (see Figure 6) and possibly beyond. Coverage in the fourth snapshot was good, with only very low densities of fish detected on the outer transects and at the end of transects (Figures 7 and 8).

Moderately high densities of SBW were observed in all snapshots, with peak densities in snapshot 4 on 25 August (see Figure 7). The area of SBW marks was more extensive in the first two snapshots, especially in snapshot 1where the aggregation appeared 'long and skinny' (see Figure 8), but became more concentrated in snapshots 3 and 4. Peak densities in 2015 were much lower those seen in some previous surveys (Figure 9). In 2015, In 2015, acoustic transects crossing the high density aggregation were an average of 3.5 n. miles long, shorter than in 2013 and 2014 (when average transects were 4.5 n. miles long), and much shorter than when SBW abundance was estimated to be highest in 2007 and 2008, when transects crossing the aggregation were up to 8 n. miles long (e.g., Figure 9).

3.5   Biological data

FV *Tomi Maru 87* was the only vessel fishing for SBW at the Bounty Platform during the 2015 season. The mean length of SBW was 40.1 cm (Figure 10). Mean weight was 484 g. Mean backscattering cross-section was 0.000491 m^2 (equivalent to –33.1 dB), giving a ratio, r, of 987 kg m^{-2}.

3.6   Biomass estimates

Biomass estimates for all Bounty Platform snapshots in 2004–15 are given in Table 3. The variance of snapshot estimates is generally reduced by removing zero transects, 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 four snapshots in 2015, with zero transects removed, ranged between 2771 t (CV 80%) in snapshot 3 to 7961 t (CV 65%) in snapshot 4. At its meeting on 16 November 2015, the Deepwater Fishery Assessment Working Group (DWFAWG) agreed that the 'best estimate' for 2015 was the average of snapshots 2 and 4. Snapshot 1 was excluded because the density of fish observed on the northernmost transect suggested that this snapshot did not adequately cover the SBW aggregation (see Figure 8) and also because of issues with data quality due to aeration (see Figure 4). Snapshot 3 was excluded because almost all the SBW were concentrated along one transect, which did not appear to be long enough to cover the aggregation (see Figures 6 and 8). Snapshots 2 and 4 also had fish on the outer transects (see Figure 8), but the densities were low, and the DWFAWG judged that these snapshots gave the most suitable estimates of aggregation biomass. The mean estimate from snapshots 2 and 4 was 6726 t (CV 42%). The 2015 estimate was 43% lower than the best estimate of 11 832 t (CV 31%) from 2014, continuing the decline since 2013, and was the lowest in the industry acoustic time-series which started in 2004 (Table 4). However, the DWFAWG 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 11) show that the strong 2002 year-class was still dominant in the 2015 fishery at age 13, but that the 2007 year-class (age 8 in 2015) is also important. Length modes from these cohorts have merged, with a modal length of 39 cm for males and 43 cm for females in 2015 (see Figure 10). In 2015, there was also a mode of younger fish at 30–35 cm from the 2011 year-class at age 4 and 2012 year-class at age 3 (see Figure 10).

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, but then declined in 2014 to a level below the estimates from 2009–12, and has declined further in 2015 (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 (O'Driscoll et al. 2016). 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 2015 were collected with appropriate acoustic settings and were of adequate quality to estimate biomass. The four snapshots were all in the region to the south of the Bounty Islands where the largest aggregations were observed in 2007–14 (see Figure 2). Survey design protocols were not always achieved, and only the final snapshot in 2015 appeared to adequately cover the main SBW aggregation.

The 'best' biomass estimate for 2015, based on the average of snapshots 2 and 4, was 6726 t (CV 42%). This was 43% lower than the best estimate from 2014, and the lowest in the industry acoustic time-series.

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 decline are a function of survey coverage, changes in the spawning SBW population, or both.

6.   ACKNOWLEDGMENTS

7.   REFERENCES

Cordue, P.L. (2008). Review of estimates of Chatham Rise orange roughy biomass from plume surveys. Report for New Zealand Ministry of Fisheries, 30 August 2008. 39 p. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

Doonan, I.; Coombs, R.; McClatchie, S. (2003). The absorption of sound in seawater in relation to estimation of deep-water fish biomass. *ICES Journal of Marine Science 60* (*5*): 1047–1055.

Dunford, A. (2005). Correcting echo integration data for transducer motion. *Journal of the Acoustical Society of America 118*: 2121–2123.

Dunn, A.; Hanchet, S.M. (2011). Southern blue whiting (*Micromesistius australis*) stock assessment for the Bounty Platform for 2009–10. *New Zealand Fisheries Assessment Report 2011/26*. 30 p.

Fofonoff, P.; Millard, R., Jr (1983). Algorithms for computation of fundamental properties of seawater. *UNESCO Technical Papers in Marine Science 44*. 53 p.

Fu, D.; Hanchet, S.; O'Driscoll, R.L. (2013). Estimates of biomass and c.v.s of southern blue whiting from previous acoustic surveys from 1993 to 2012 using a new target strength – fish length relationship. Final Research Report for Ministry of Fisheries Research Project DEE201002SBWB. 52 p. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

Hampton, I.; Nelson, J.C. (2014). Acoustic estimates of the biomass in aggregations of southern blue whiting (*Micromesistius australis*) on Pukaki Rise (SBW6R) and Campbell Island Plateau (SBW6I) from a commercial vessel in September 2012. *New Zealand Fisheries Assessment Report 2014/23*. 28 p.

Hanchet, S.M. (1991). Southern blue whiting fishery assessment for the 1991–92 fishing year. New Zealand Fisheries Assessment Research Document 91/7. 48 p. (Unpublished report held in NIWA library, Wellington.)

Hanchet, S.M. (1999). Stock structure of southern blue whiting (*Micromesistius australis*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research 33*: 599–610.

Hanchet, S.M. (2005). Southern blue whiting (*Micromesistius australis*) stock assessment for the Bounty Platform for 2004–05. *New Zealand Fisheries Assessment Report 2005/45*. 36 p.

Hanchet, S.M.; Bull, B.; Bryan, C. (2000). Diel variation in fish density estimates during acoustic surveys of southern blue whiting. *New Zealand Fisheries Assessment Report 2000/16*. 22 p.

Hanchet, S.M.; Grimes, P.J. (2000). Acoustic biomass estimates of southern blue whiting (*Micromesistius australis*) from the Bounty Platform, August 1999. *New Zealand Fisheries Assessment Report 2000/30.* 25 p.

Hanchet, S.M.; Grimes, P.J.; Coombs, R.F. (2002a). Acoustic biomass estimates of southern blue whiting (*Micromesistius australis*) from the Bounty Platform, August–September 2001. *New Zealand Fisheries Assessment Report 2002/58.* 35 p.

Hanchet, S.M., Grimes, P.J.; Dunford, A.; Ricnik, A. (2002b). Classification of fish marks from southern blue whiting acoustic surveys. Final Research Report for Ministry of Fisheries Research Project SBW2000/02 Objective 2. 55 p. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

Jolly, G.M.; Hampton, I. (1990). A stratified random transect design for acoustic surveys of fish stocks. *Canadian Journal of Fisheries and Aquatic Sciences 47*: 1282–1291.

MacLennan, D.N.; Simmonds, E.J. (1992). Fisheries Acoustics. Chapman & Hall, London. *Fish and Fisheries Series 5.* 325 p.

McNeill, E. (2001). ESP2 phase 4 user documentation. NIWA Internal Report 105. 31 p. (Unpublished report held by NIWA library, Wellington.)

Ministry for Primary Industries (2013). Report from the Fisheries Assessment Plenary, May 2013: stock assessments and yield estimates. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1357 p.

Ministry for Primary Industries (2015). Report from the Fisheries Assessment Plenary, May 2015: stock assessments and yield estimates. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1475 p.

O'Driscoll, R.L. (2011a). Industry acoustic surveys of spawning southern blue whiting on the Bounty Platform and Pukaki Rise 2004–09. *New Zealand Fisheries Assessment Report 2011/17.* 53 p.

O'Driscoll, R.L. (2011b). Acoustic biomass estimates of southern blue whiting on the Bounty Platform in 2010. NIWA Client Report WLG2011-01 for The Deepwater Group Ltd. 28 p.

O'Driscoll, R.L. (2012). Acoustic biomass estimates of southern blue whiting on the Bounty Platform in 2011. *New Zealand Fisheries Assessment Report 2012/16.* 26 p.

O'Driscoll, R.L. (2013). Acoustic biomass estimates of southern blue whiting on the Bounty Platform in 2012. *New Zealand Fisheries Assessment Report 2013/4.* 26 p.

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

O'Driscoll, R.L.; Dunford, A.J.; Dunn, A. (2016). Industry acoustic surveys of spawning southern blue whiting on the Bounty Platform, New Zealand. *Fisheries Research 178:* 61–70.

O'Driscoll, R.L.; Hanchet, S.M. (2004). Acoustic survey of spawning southern blue whiting on the Campbell Island Rise from FV *Aoraki* in September 2003. *New Zealand Fisheries Assessment Report 2004/27.* 31 p.

O'Driscoll, R.L.; Hanchet, S.M.; Gauthier, S.; Grimes, P.J. (2007). Acoustic estimates of southern blue whiting from the Campbell Island Rise, August–September 2006. *New Zealand Fisheries Assessment Report 2007/20.* 34 p.

O'Driscoll; R.L.; Macaulay, G.J.; Gauthier, S. (2006). Biomass estimation of spawning southern blue whiting from industry vessels in 2006. NIWA Client Report: WLG2006-89 for the Deepwater Stakeholders Group Ltd. 43 p.

O'Driscoll, R.L.; Nelson, R. (2010) *Tomi Maru 87* ES70 and ES60 calibrations, April 2010. NIWA Client Report WLG2010-24 for The Deepwater Group Ltd. 9 p.

O'Driscoll, R.L.; Oeffner, J.; Dunford, A.J. (2013). *In situ* target strength estimates of optically verified southern blue whiting (*Micromesistius australis*). *ICES Journal of Marine Science 70*: 431–439.

O'Driscoll, R.L.; Oeffner, J.; Dunford, A.J. (2015). Acoustic biomass estimates of southern blue whiting on the Bounty Platform in 2013. *New Zealand Fisheries Assessment Report 2015/01.* 28 p.

Ryan, T.E.; Kloser, R.J. (2004). Quantification and correction of a systematic error in Simrad ES60 echosounders. Technical note presented at the Working Group on Fisheries Acoustic Science and Technology (WGFAST), 20–23 April 2004, Gydnia, Poland. ICES CM 2004/B:06.

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 (º) alongship/athwartship	7.10/7.10
Angle offset (º) alongship/athwartship	0.00/0.00

Table 2: Summary of acoustic snapshots carried out at the Bounty Platform in 2015 by *FV Tomi Maru 87*. Times are NZST.

Snapshot	Area (km^2)	Start time	End time	No. of transects
1	165.3	21 Aug 19:17	22 Aug 02:02	13
2	152.5	23 Aug 18:40	24 Aug 00:53	13
3	74.6	24 Aug 18:56	24 Aug 21:40	5
4	110.7	25 Aug 20:08	26 Aug 00:19	7

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 2004–15. 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).

Year	Snapshot	No. of transects	Calculated areas			Zero transects removed			
			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 2004–15. Snapshots in bold were averaged to produce the biomass estimates in Table 4.

Year	Snapshot	No. of transects	Calculated areas Area (km^2)	Biomass (t)	CV (%)	Zero transects removed 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**

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

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 2011–15 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%)
2015	–	6 726 (42%)
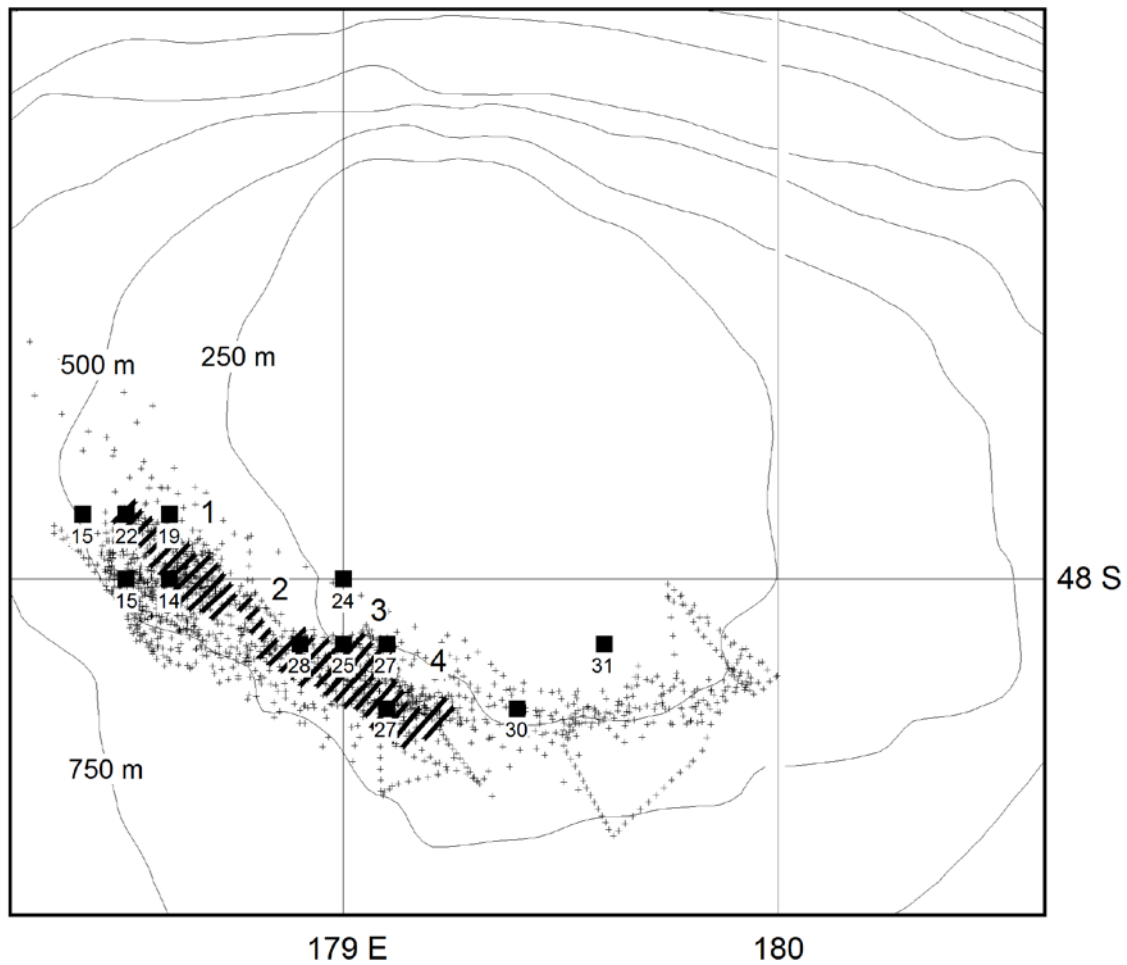
Figure 1: Map showing position of the *FV Tomi Maru 87* at the Bounty Platform in 2015 every 10 minutes from 14 August to 1 September (grey crosses). Solid squares are locations of commercial trawls (plotted to the nearest 0.1 degree), numbered below by date in August. Transect locations are shown as black lines, with larger numbers indicating the four snapshots (see Figure 2).
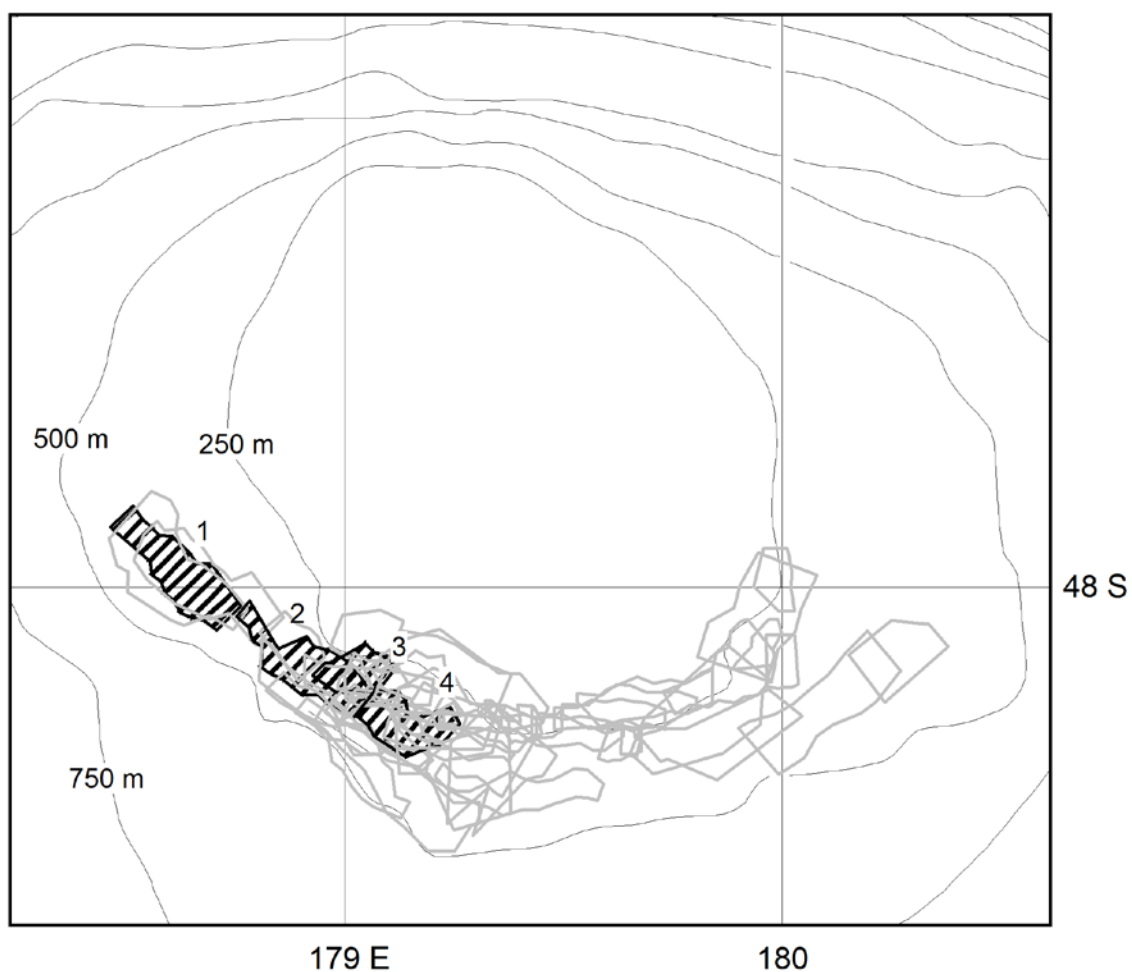
Figure 2: Map showing location of transects carried out in the four snapshots by _FV Tomi Maru 87_ at the Bounty Platform in 2015 (black lines and numbered polygons). Transect locations are compared with the areas surveyed in 2004–14 (grey polygons).
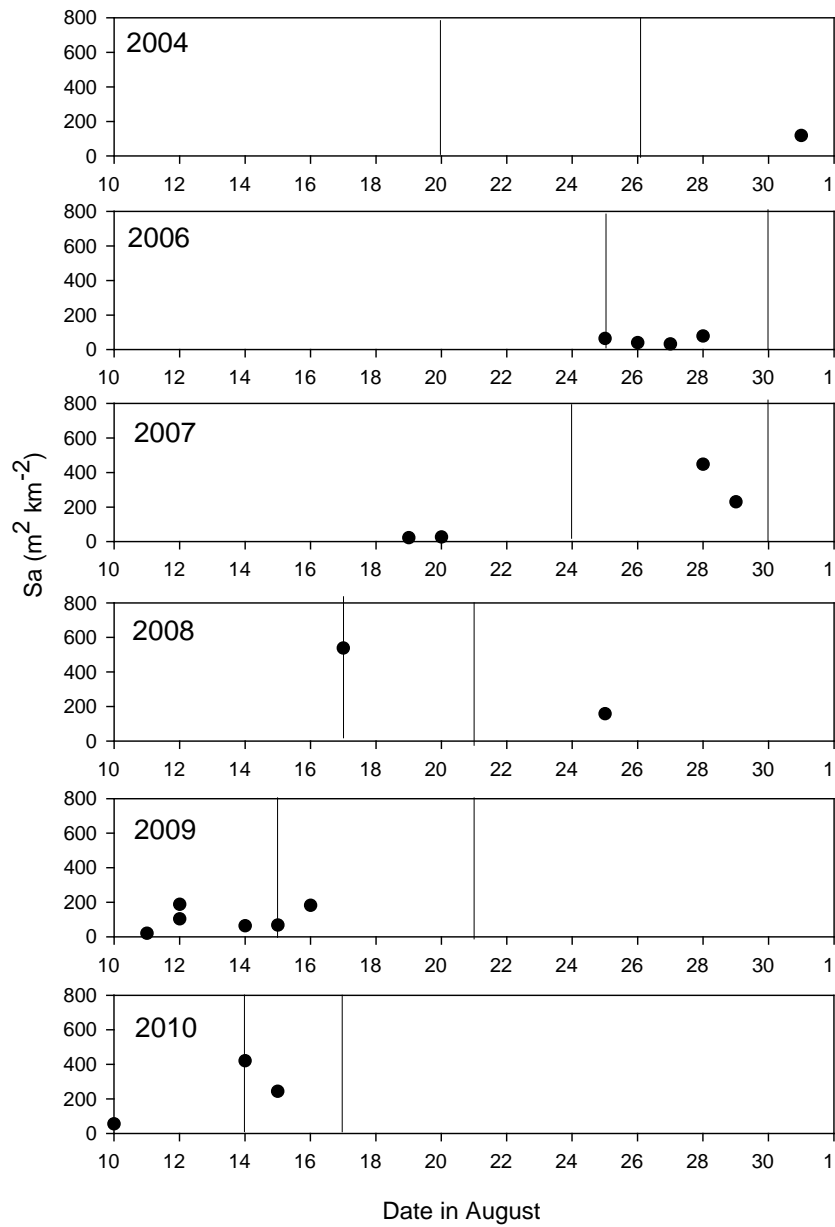
Figure 3: Weighted (by transect length) mean densities for each snapshot (solid circles) plotted as a function of date for all snapshots carried out by industry vessels on the Bounty Platform 2004–10. Vertical lines indicate estimated period of peak spawning based on gonad staging by observers.
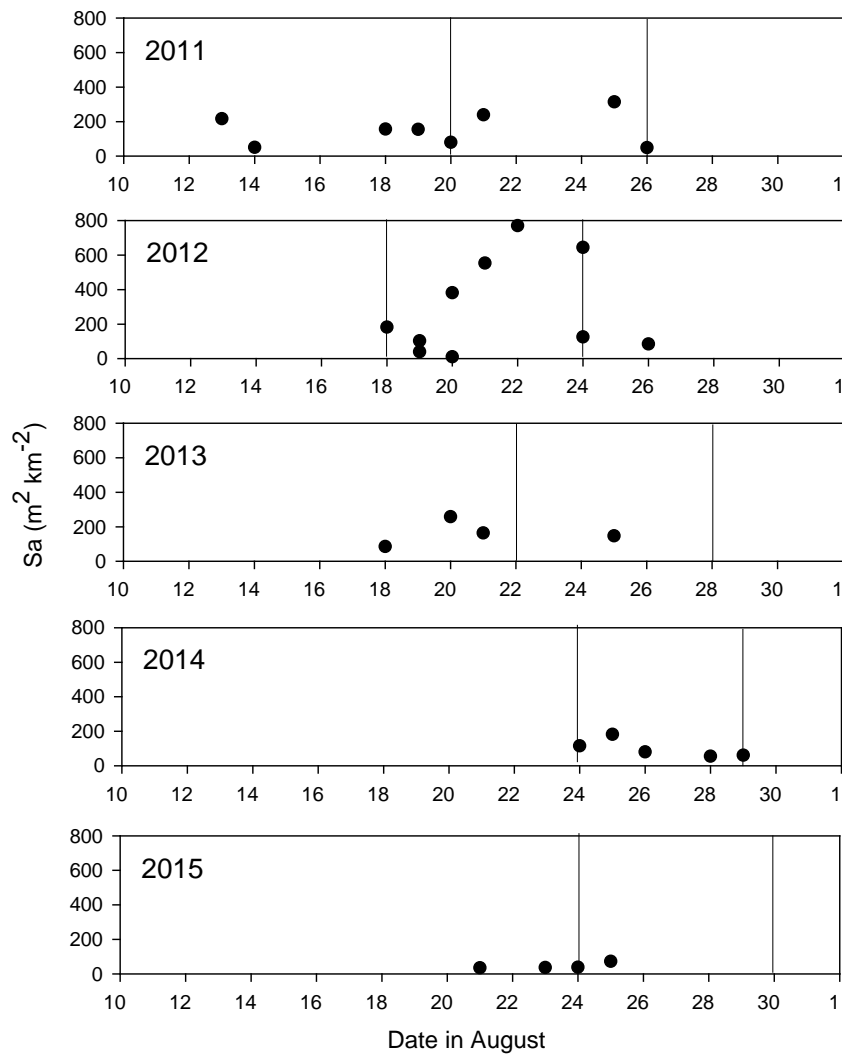
Figure 3 cntd: Weighted (by transect length) mean densities for each snapshot (solid circles) plotted as a function of date for all snapshots carried out by industry vessels on the Bounty Platform 2011–15. Vertical lines indicate estimated period of peak spawning based on gonad staging by observers.
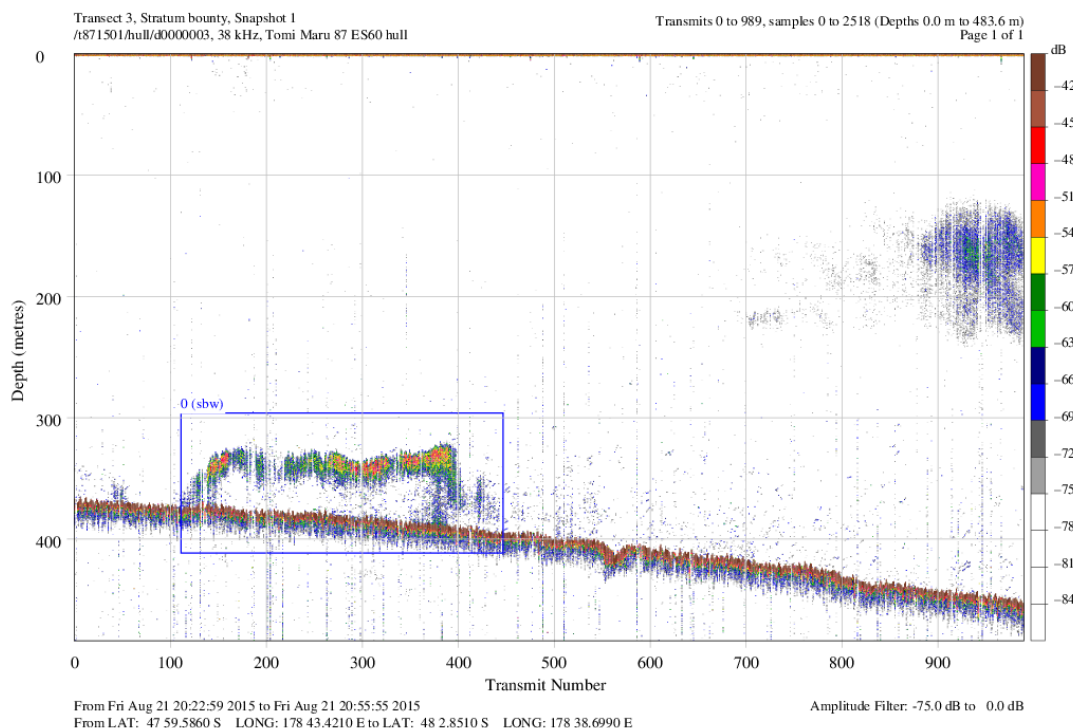
Figure 4: Example of acoustic echogram collected at the Bounty Platform in snapshot 1 on 21 August 2015 showing ping drop-outs due to bubble aeration in poor weather.
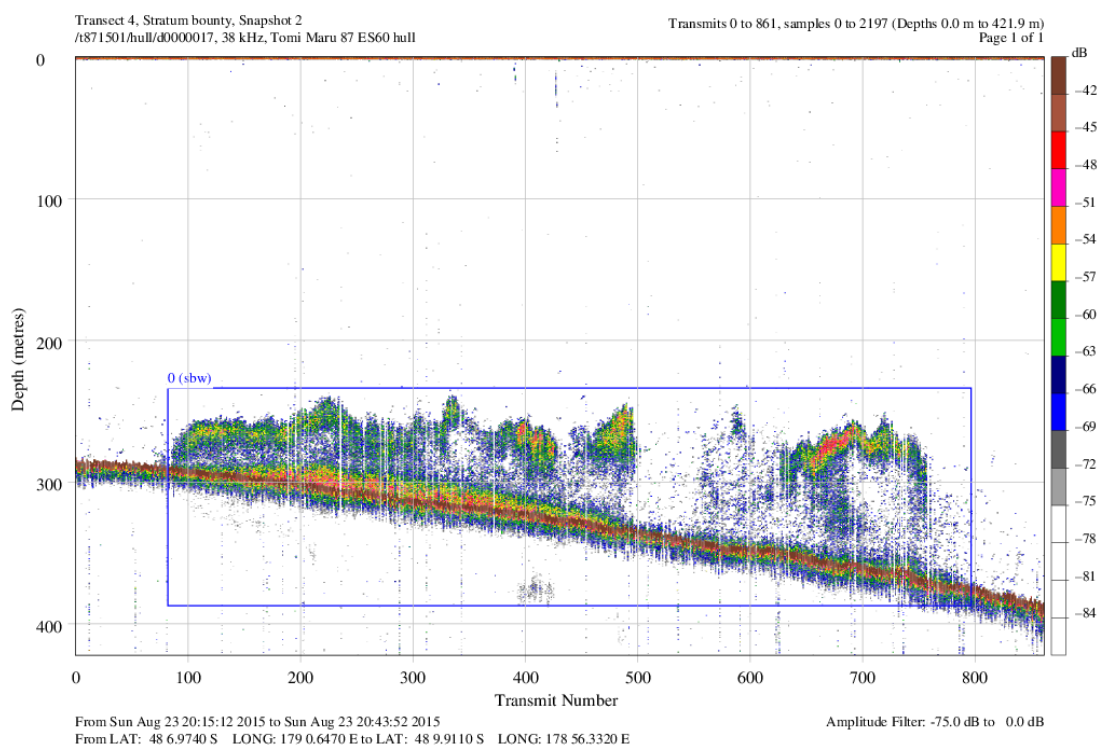
Figure 5: Example of acoustic echogram collected at the Bounty Platform in snapshot 2 on 23 August 2015 showing characteristic 'thundercloud' SBW mark.
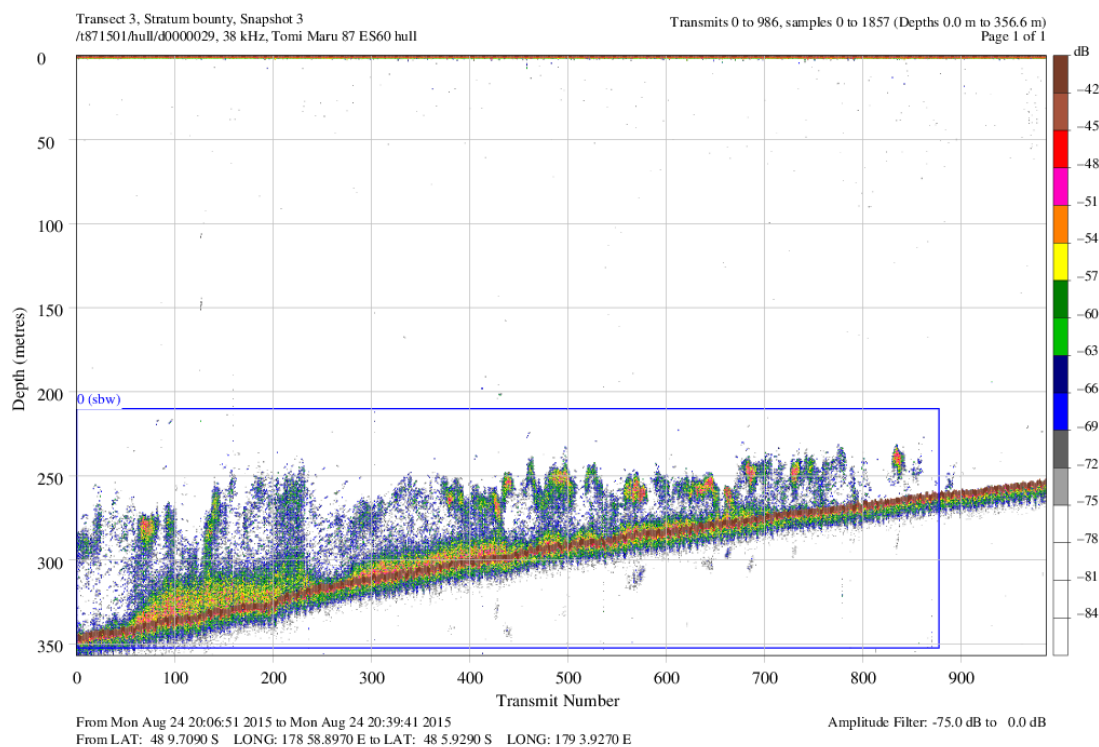
Figure 6: Example of acoustic echogram collected at the Bounty Platform in snapshot 3 on 24 August 2015 where SBW mark extended beyond the start of the transect.
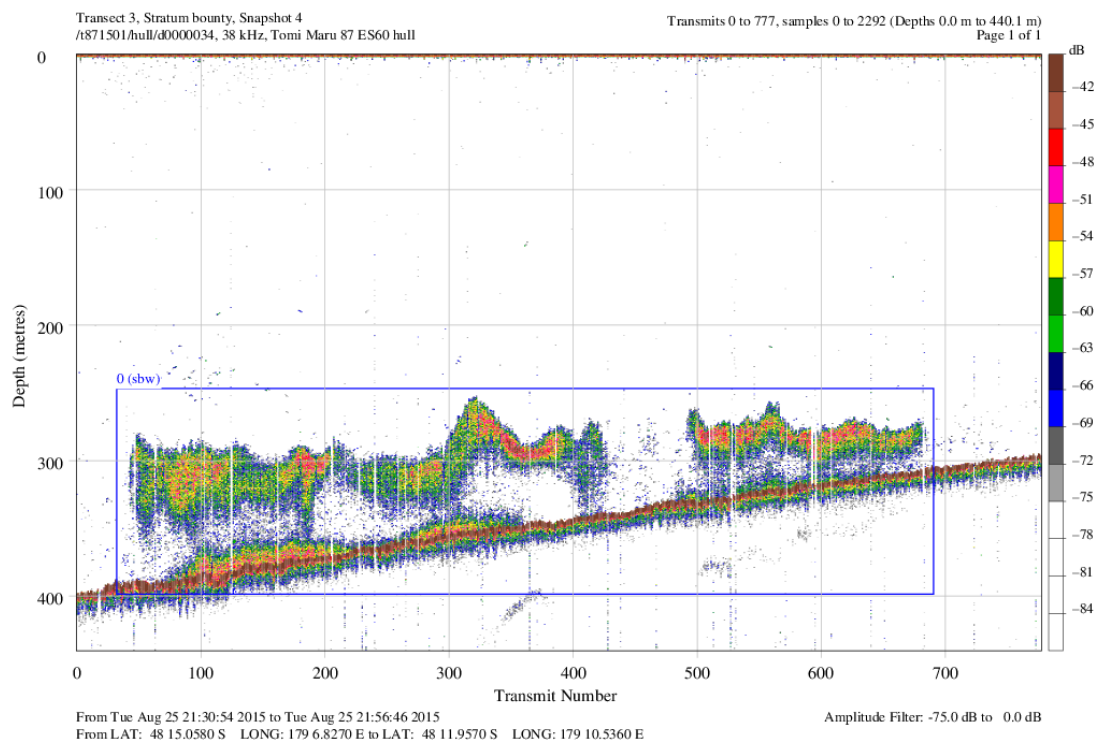
Figure 7: Example of acoustic echogram collected at the Bounty Platform in snapshot 4 on 25 August 2015 showing strongest SBW mark observed during 2015 survey.
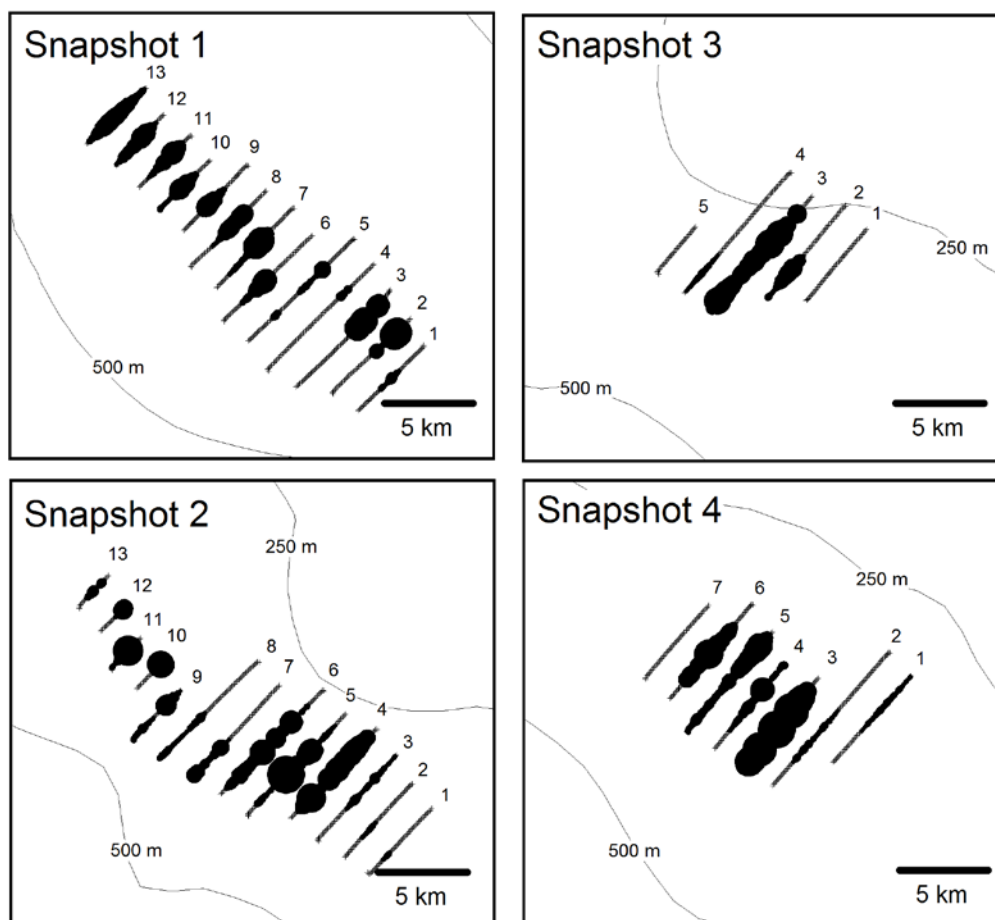
Figure 8: Spatial distribution of SBW backscatter plotted in 10-ping bins for the four snapshots at the Bounty Platform in 2015. Transects are numbered in the order in which they were carried out. Circle area is proportional to the log of the acoustic backscatter. Crosses indicate zero backscatter.
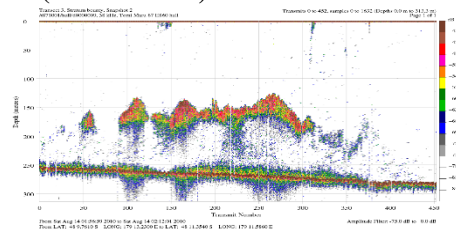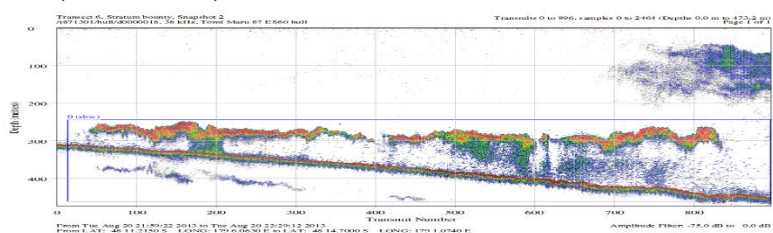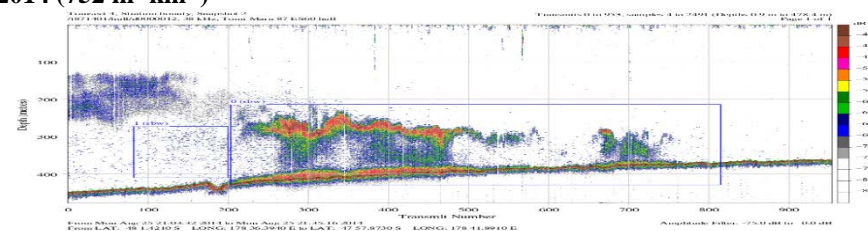
2008 (1027 m² km⁻²)
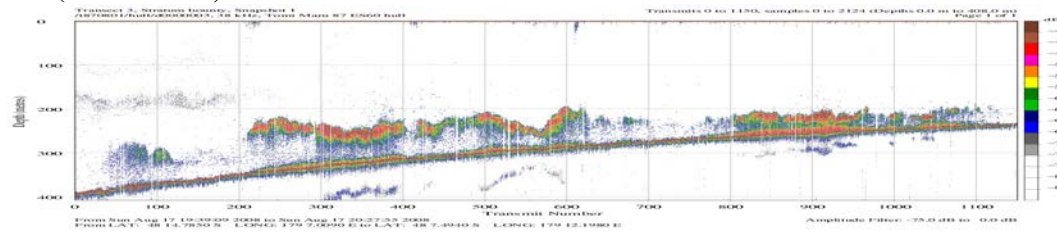
2009 (422 m² km⁻²)
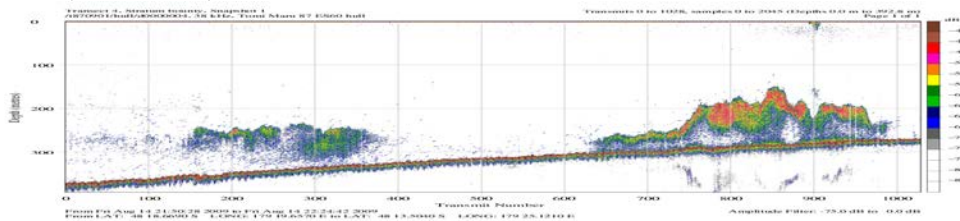
2010 (1029 m² km⁻²)

2013 (1295 m² km⁻²)

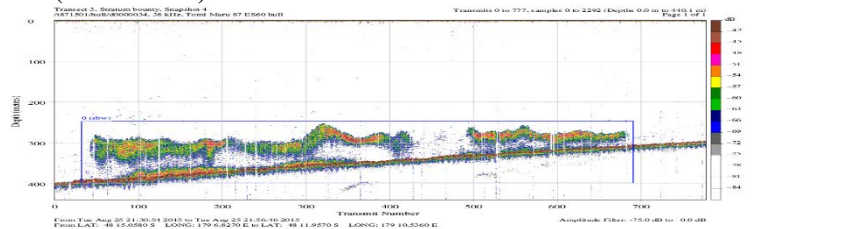**2014 (752 m² km⁻²)**

2015 (358 m² 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 2013–15. Values in parentheses are transect mean density (Sa) values. Echogram size has been scaled so distance scales (x-axes) are equivalent.
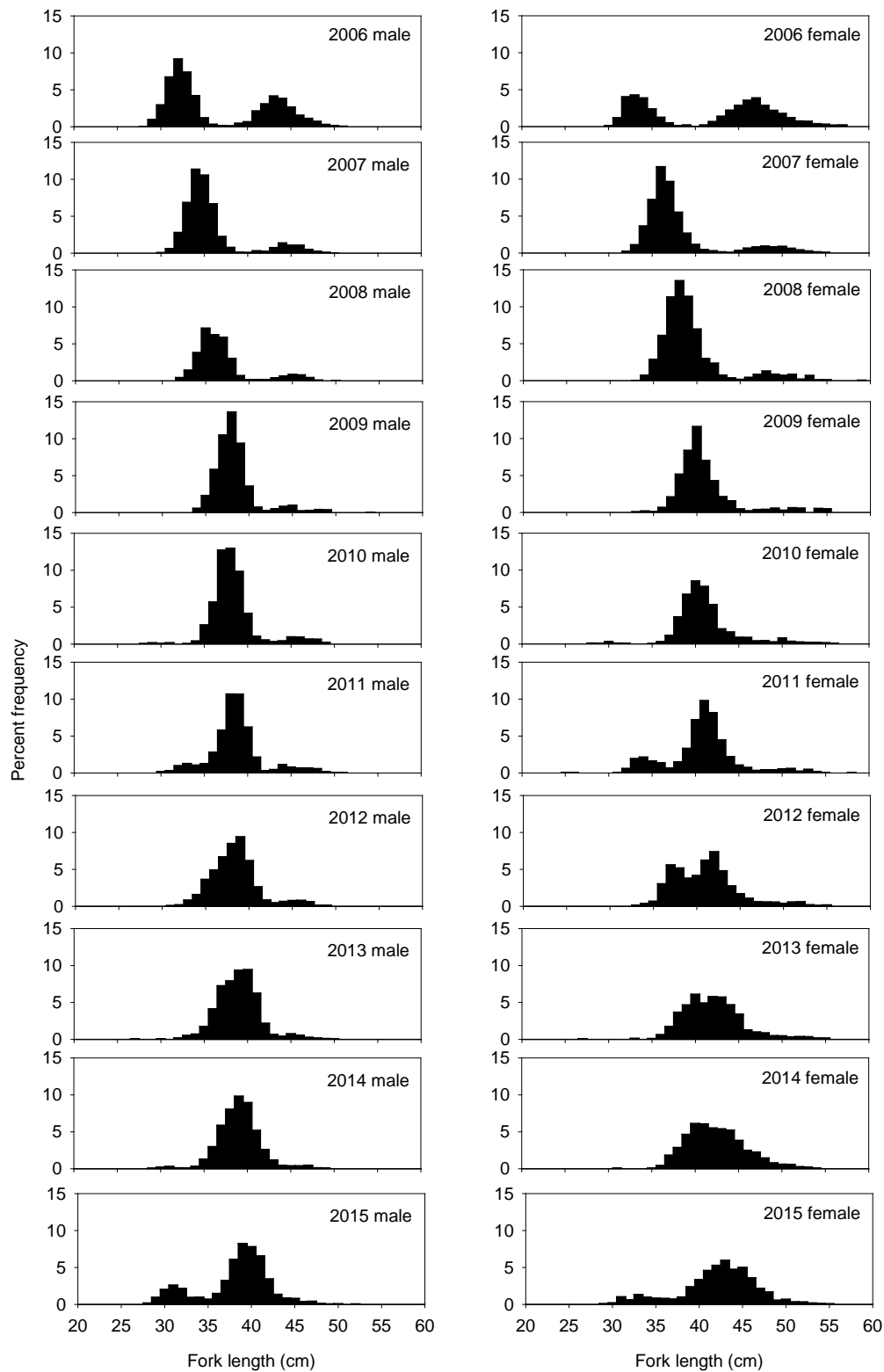
Figure 10: Scaled length frequency of SBW caught on the Bounty Platform by *FV Tomi Maru 87* in 2006–15 based on scientific observer data. Data from 2015 are from observer trip 4483.
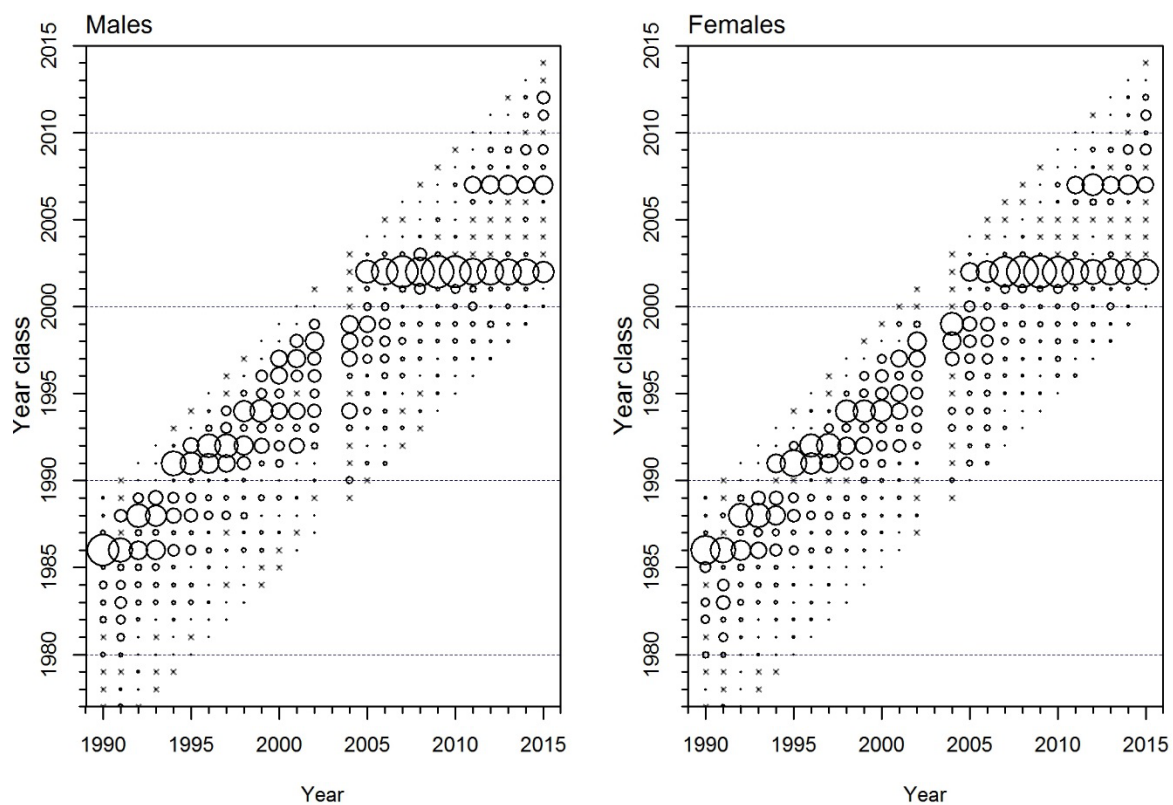
Figure 11: Estimated proportions at age of SBW in the commercial catch from the Bounty fishery 1990–2015.

APPENDIX 1: Calibration Report: *Tomi Maru 87* 16 July 2015

Calibration of the Simrad ES70 echosounder on *Tomi Maru 87* took place off Timaru (44° 25.9' S 171° 30.8' E) on 16 July 2015. Water depth was about 37 m (below the transducer). This was the eleventh 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 & Nelson 2010). The calibration was carried out by Adam Dunford (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 reasonable with a 10–15 knot breeze and 1–2 m swell. The vessel departed Timaru at 08:00 NZST for engine trials and calibration commenced at 11:34. The vessel was allowed to drift, and the drift speed was about 1–2 knots. The sphere was located in the beam at 12:33 NZST and the calibration completed at 13:25 NZST. Calibration data were recorded in one ES70 .raw format file (t871501-D20150715-T233409.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 duet temperature depth probe, serial number 82704. The water column was unstratified, with a temperature of 8.66° 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 0.21 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 estimated peak gain (G_0) increased by 0.25 dB from the 2014 ES70 calibration, continuing the recent trend of increasing G_0 for this system (Figure A3).

The 2015 calibration was used for analysis of results from the 2015 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 (º) alongship/athwartship	7.10/7.10
Angle offset (º) alongship/athwartship	0.0/0.0

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

Parameter	Value
Mean sphere range (m)	20.9
S.D. of sphere range (m)	0.8
Mean sound speed (m/s)	1 485
Mean absorption (dB/km)	9.78
Sphere TS (dB re 1m^2)	–42.37

Table A3: Calculated echosounder calibration parameters for *Tomi Maru 87*. Values were calculated using version 7027 (2005-13) and 7152 (2014–15) of NIWA's Matlab calibration function.

| Parameter	2015	2014	2013	2012	2011	2010		2009	2007	2006	2005
	ES70	ES70	ES70	ES70	ES60	ES70	ES60	ES60	ES60	ES60	ES60
Mean TS within 0.21° of centre	-45.7974	-46.3186	-46.4927	-46.5925	-46.8347	-46.8238	-46.7535	-46.7798	-46.3050	-45.9008	-46.0495
Std dev of TS within 0.21° of centre	0.351	0.5191	0.3940	0.4155	0.1645	0.1968	0.4178	0.4025	0.2343	0.3639	0.4606
Max TS within 0.21° of centre	-45.0735	-45.3948	-45.6984	-45.9441	-46.4650	-45.9478	-45.9913	-46.0580	-45.8414	-45.4503	-45.2827
No. of echoes within 0.21° of centre	70	39	694	340	422	1 274	6 438	279	98	17	1 841
On axis TS from beam-fitting	-45.6557	-46.1098	-46.3721	-46.6729	-46.6851	-46.6375	-46.7343	-46.8018	-46.2647	-45.9472	-46.0144
Transducer peak gain (dB) max TS	25.15	25.00	24.85	24.74	24.48	24.74	24.71	24.67	24.79	24.96	25.05
Transducer peak gain (dB) mean TS	24.79	24.54	24.45	24.41	24.29	24.30	24.33	24.31	24.56	24.74	24.67
Sa correction (dB)	-0.68	-0.66	-0.66	-0.66	-0.69	-0.67	-0.71	-0.60	-0.65	-0.63	-0.69
Beamwidth (°) along/athwartship	6.9/6.7	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	7.2/7.3	6.8/7.3	7.0/7.1
Beam offset (°) along/athwartship	0.00/0.00	-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	-0.04/-0.12	0.00/0.00	-0.09/0.06
RMS deviation	0.21	0.22	0.19	0.21	0.11	0.13	0.21	0.20	0.15	0.20	0.22
Number of echoes	13 237	2 048	16 544	23 423	29 780	30 727	23 277	7 362	1 416	4 632	19 534
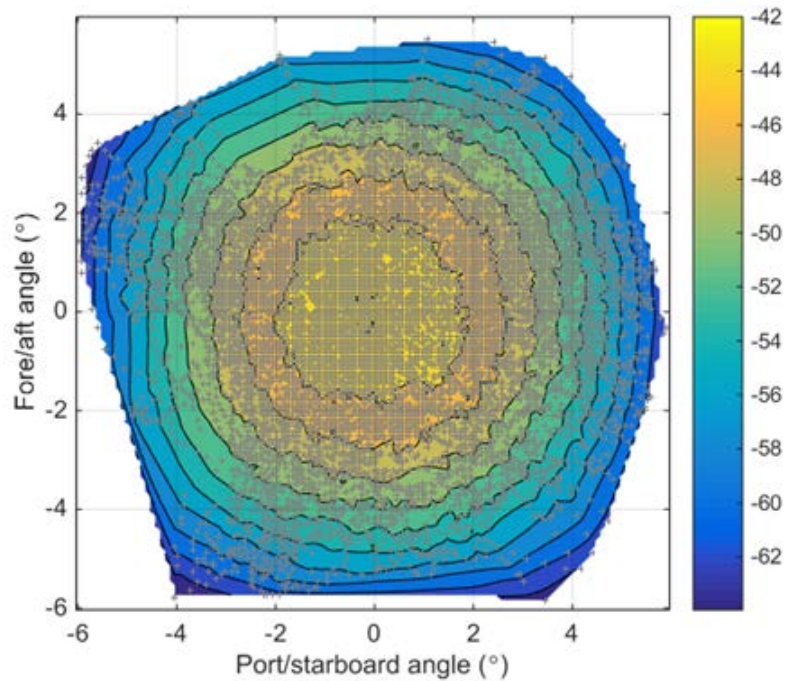
Figure A1: The estimated beam pattern from the sphere echo strength and position for the calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m².
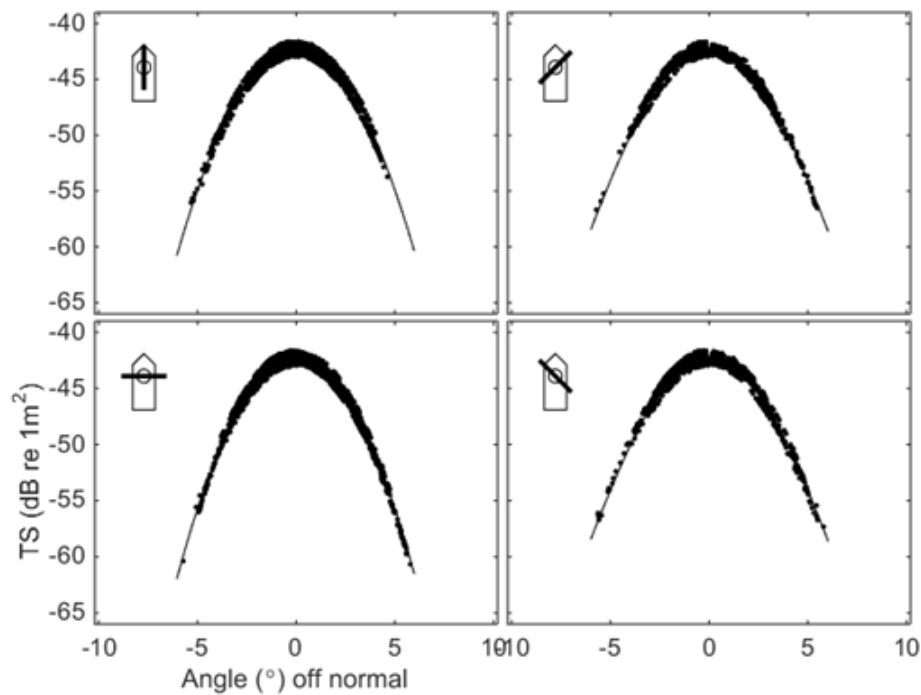

Figure A2: Beam pattern results from the calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.
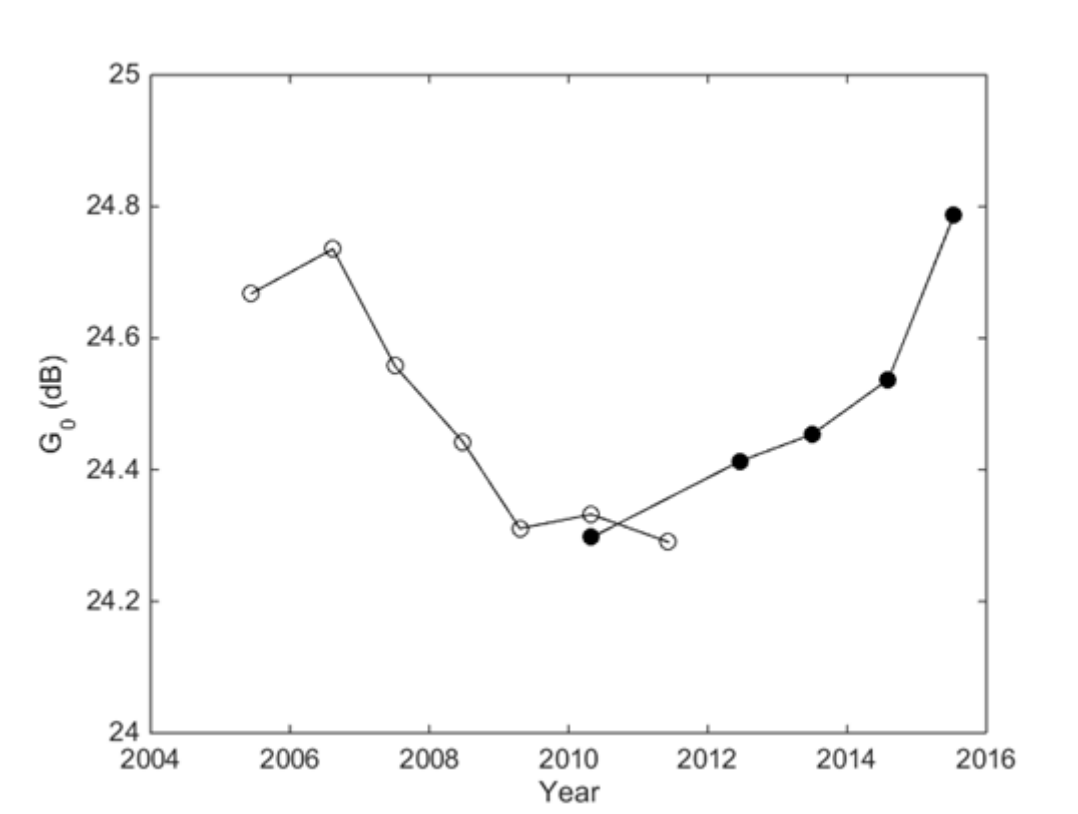
Figure A3: Changes in 'on axis' gain, G_0, based on the mean sphere echo for the ES60 (open circles) and ES70 (closed circles) echosounders on *Tomi Maru 87* from 2005 to 2015.