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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

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EXECUTIVE SUMMARY

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Acoustic surveys of southern blue whiting *Micromesistius australis* (SBW) biomass on Pukaki Rise were attempted from fishing vessels FV *Aleksandr Buryachenko* and FV *San Waitaki* in September and early October 2012, during the spawning period. SBW acoustic data were also collected opportunistically on Campbell Island Plateau during the course of commercial fishing operations there. The Pukaki Rise surveys were designed to follow up, and be comparable with, acoustic surveys of aggregations there by two commercial vessels in 2009 (O'Driscoll 2011a).

The *Aleksandr Buryachenko* exercise ran between 8 and 17 September. After two days on Pukaki Rise, the vessel spent six days on Campbell Island Plateau before returning for one day's work on Pukaki Rise on 17 September. During this time the vessel made three trawls on the Pukaki Rise and 17 on Campbell Island Plateau. Primarily because of very poor weather for most of the time, no acoustic snapshots were carried out in either area.

The *San Waitaki* survey was mounted at short notice in light of the failure to obtain data for biomass estimation from *Aleksandr Buryachenko.* From 22 to 28 September six trawls and six snapshots were carried out on Pukaki Rise, mostly during a three-day period of good weather. The snapshot grids were all placed over an aggregation on the southern part of the Rise which lay between 300 and 400 m depth. Between 29 September and 2 October the vessel worked on Campbell Island Plateau, carrying out five trawls and a single snapshot of a dense aggregation on the northwestern slope of the Plateau.

Immature and sub-adult fish dominated most of the catches by both vessels on Pukaki Rise, whereas adult fish were dominant in their catches on Campbell Island Plateau. Maturity data indicate that there was active spawning on both grounds during the period of the study. There was a lack of spent fish in the *San Waitaki* samples from Pukaki Rise, suggesting that the spawning there was far from complete at the time of that survey, or that the spent fish had left the area by that time.

The mean of the biomass estimates from all six of *San Waitaki*'s snapshots on Pukaki Rise is 1815 t using the theoretically-derived target strength expression applied in previous acoustic surveys of SBW, and 1056 t using a new (*in situ*) expression (O'Driscoll et al. 2013) which we consider to be more appropriate. If three snapshots in which the cover was probably incomplete are discarded, these means rise to 2715 and 1602 t respectively. In both cases the sampling CV calculated from the CVs of the individual snapshots was 14%. The corresponding estimates of biomass in the aggregation on Campbell Island Plateau are 27 591 and 14 006 t with a sampling CV of 12%.

The biomass estimates on both grounds are well below previous acoustic estimates of SBW biomass on these grounds during the spawning season, clearly due to the comparatively small coverage during the current surveys. On Pukaki Rise, where the coverage was better than on Campbell Island Plateau, it also seems possible that post-spawning fish had left the ground by the time of the *San Waitaki* survey.

We conclude that the estimates of biomass from this survey are of very limited value as estimates of minimum SBW biomass on Pukaki Rise and Campbell Island Plateau in the spawning season, which is the target of aggregation-based surveys such as this. However, observations from the *San Waitaki* survey of Pukaki Rise point to a cost-effective strategy for future aggregation- based surveys of this area from commercial vessels such as this, which is briefly outlined.

1. INTRODUCTION

A programme to estimate the spawning biomass of southern blue whiting (SBW) on the main fishing grounds in New Zealand waters during the spawning season using acoustic techniques was initiated in 1993. The Pukaki Rise was surveyed annually from 1993–1996 and again in 1997 and 2000 through wide-area surveys from RV *Tangaroa* using towed transducers. In September 2009, acoustic surveys of spawning SBW on Pukaki Rise were carried out from two industry vessels (FV *Aleksandr Buryachenko* and FV *Meridian*) using hull-mounted transducers (O'Driscoll, 2011). Six snapshots were carried out; three from each vessel. The current survey continues this work and was designed to produce biomass estimates comparable with those from the 2009 survey.

The current survey was conducted under a contract between Clement and Associates Ltd. (C&A) and the New Zealand Ministry of Primary Industries (MPI), (project code SBW 2010-03A). Fisheries Resource Surveys cc (FRS), Cape Town, South Africa was sub-contracted by C&A to undertake the survey.

It was originally intended that the survey be conducted from *Aleksandr Buryachenko*, through an agreement between MPI and vessel owners (Sealord Group Ltd, Nelson) which provided for three vessel days to be allocated for snapshots on Pukaki Rise. However, no acoustic data of use for biomass estimation were obtained from this vessel before it departed the survey area (see later) and a decision was therefore taken to make a second attempt from a vessel of opportunity. This was facilitated through an *ad hoc* agreement between MPI and Sanford Ltd, Auckland, for a period of dedicated survey time to be made available aboard their vessel FV *San Waitaki* during a scheduled fishing trip to the grounds. Since both vessels' commercial fishing plans included some fishing on the Campbell Island Plateau, MPI agreed that acoustic snapshots of major aggregations on the Plateau would be desirable should the opportunity arise during fishing operations there.

Since acoustic estimates of southern blue whiting biomass were only obtained from the *San Waitaki* survey, this report is concentrated on the survey from that vessel, with a brief account of the work on *Aleksandr Buryachenko* to place the *San Waitaki* survey in context and to highlight some of the difficulties in surveying this species in surveys of short duration from commercial vessels.

2. METHODS

2.1 Equipment

On both vessels the survey was conducted using the vessel's SIMRAD ES60 fishing echo-sounder firing at 2 kW into an ES 38B 38-kHz split-beam transducer mounted in the hull. Further details of the equipment settings are given in Table A-1 in the Appendix. Concerns about the use of this generation of fishing echo-sounder for scientific work were allayed in an orange roughy (*Hoplostethus atlanticus*) survey from *San Waitaki* in 2002, when it was shown that at this power setting (i.e. below the cavitation threshold), there was very little difference between the performance of the SIMRAD ES60 echo-sounder and a SIMRAD EK60 scientific echo- sounder operating into the same transducer and sphere-calibrated to the same accuracy (Hampton & Soule 2003). The effect of the "triangular wave" fluctuation in system sensitivity discovered in the ES60 by Ryan & Kloser (2004) was removed from the survey data through ES60Adjust: a software program developed by CSIRO, Hobart (Keith et al. 2005) specifically to remove this error.

ES60 software was used on *Aleksandr Buryachenko* and ES70 software on *San Waitaki*. Myriax ECHOVIEW software (Version Ver.5.2.60.21114) was used to view and process ES70 raw (power and angle) data files, which were logged and transferred via Myriax ECHOLOG60 (Version 4.70.0.14275) software. Raw data files were also periodically transferred and stored to disc for post processing and analysis.

A Honeywell HMR3000 attitude sensor, interfaced to the logging PC, monitored vessel pitch, roll and heading throughout the survey, enabling echo returns to be corrected for vessel pitch and roll on a ping-by-ping basis through ECHOVIEW's motion-compensation software, which implements correction algorithms developed by Dunford (2005).

The echo-sounder on *San Waitaki* was calibrated by the standard sphere method (Foote et al. 1987) off the Banks Peninsula at the end of an orange roughy survey on the north Chatham Rise on 16 July 2012 (Hampton et al. 2013). The echo-sounder on *Aleksandr Buryachenko*, which was to have been calibrated after the survey, was in the event not calibrated since no acoustic data suitable for biomass estimation were collected from that trip.

On both vessels, wind speed and direction and vessel pitch, roll and heading were monitored continuously throughout the survey. Profiles of water column temperature between the surface and fishing depth were recorded from the temperature sensor on the netsounder headline monitor during a number of the trawls.

Acoustic targets were identified from midwater trawl catches. The nets were fished close to the bottom when the fish were on or near the bottom (usually during the day). Trawling speed was about 4 knots on both vessels. The average vertical mouth opening was 57 m on *Aleksandr Buryachenko* and approximately 40 m on *San Waitaki*.

2.2 Survey strategy and design

Table 1 lists the number of search and survey grids and trawls carried out by the two vessels in both areas. On both vessels, the searches on Pukaki Rise were carried out at the maximum speed consistent with the quality of the echo sounder recordings. They were mostly run on zig-zag grids cutting across the depth contour (Figures 1 and 2), following normal searching practice in commercial fishing on spawning SBW in the region. No such wide area searches were attempted by *Aleksandr Buryachenko* or *San Waitaki* on Campbell Plateau because of the relatively short time available on either vessel for investigating this area.

In the *San Waitaki* survey, during which marks suitable for surveying were detected in both areas, six snapshots consisting of semi- randomly spaced parallel North/South lines cutting across the depth contour were carried out on Pukaki Rise between 23 and 26 September, and one such snapshot on equally spaced lines on Campbell Plateau on 1 October (Table 2). The latter was interrupted by a trawl. The average speed in all snapshots was approximately 10 knots.

Since the processing rate on *San Waitaki* was about 2 t per hour, and catches averaged about 30 t, there was usually considerable time for a snapshot between the trawls (see Table 2). A similar strategy of doing acoustic snapshots while processing fish was used in the acoustic surveys of SBW on Pukaki Rise from commercial vessels in 2009 by O'Driscoll (2011). Every attempt was made, using all the information available from the search grids, to set up the snapshot grids to fully encompass the SBW aggregations in the area, although because of the scattered and extensive nature of the aggregations in some areas, this was not always possible.

The duration of the *San Waitaki* snapshots on Pukaki Rise varied between 4.5 and 8.5 hours, and the mean spacing between the transects was between 0.34 and 0.66 n.mile (Table 2). The two sections of the snapshot on the Campbell Plateau, in which the line spacing was fixed at 0.62 n.mile, took 10.5 hours in total to complete (Table 2).

Wind speed and swell height were often above the limits specified as acceptable by the MPI Deep Water Fisheries Assessment Working Group for acoustic surveys of orange roughy aggregations from vessel-mounted transducers (i.e. 20 knots and 2 m). However, if the targets were suitable, snapshots were done in worse conditions, as it is known that that SBW surveys are less sensitive to vessel pitch and roll than orange roughy surveys are, due to the shorter range to the targets (300–400 m compared to 800–900 m).

2.3 Biological sampling

Catches were sampled for species composition and for SBW length distribution. The spawning state of female SBW was also recorded, using the 5-stage maturity scale of Hanchet (1999). The required biological sampling was undertaken by MPI observers aboard the two vessels.

2.4 Data analysis

For each snapshot in which there were discernable SBW-like aggregations, estimates of SBW biomass were derived from the acoustic data through the following steps:

- Marks identified directly or indirectly as SBW aggregations were isolated from other biological targets, and their mean area back-scattering strengths estimated through ECHOVIEW.

- $(\overline{S_a})_j$, the mean area back-scattering strength from isolated SBW targets along transect j, was estimated from the relationship

$$(\overline{S_a})_j = 10\,Log\,(\overline{(NASC)}_j / 4\pi\,(1852)^2)$$

  where $(\overline{NASC})_j$ is the mean nautical area scattering cross-section (NASC) of the SBW targets on transect j, as defined by MacLennan et al. (2002), after correction for the “triangular wave” drift in system sensitivity by ES60Adjust and for pitch and roll through Dunford’s (2005) algorithm.

- The mean NASC for each transect was corrected for negative bias arising from the inability to detect SBW in the near-bottom dead-zone, using Barr’s polynomial expression (in Doonan et al. 1999) to estimate the equivalent dead-zone height for a 38 kHz transducer of similar beamwidth to that of the ES 38 B, viz:

$$h_{eq} = 0.001d\,(1.264 - 0.216\alpha + 0.262\alpha^2 - 1.382 \times 10^{-3}\alpha^3 + 2.686 \times 10^{-4}\alpha^4) \quad ,$$

  where d is the distance between the transducer and the target and α the average slope of the bottom along the transect in degrees. The correction was obtained by multiplying the mean NASC for the 10-m channel immediately above the detected bottom by h_{eq} on the assumption that the mean SBW density in this channel was an unbiased estimator of the mean SBW in the dead-zone immediately below it.

- For each snapshot, the SBW biomass was estimated from $\overline{S_a}$, the mean back-scattering strength for the snapshot, which was obtained by averaging the dead-zone corrected $(\overline{S_a})_j$ values with weighting by transect length (see Jolly & Hampton 1990). As recommended by Cordue (2008) for situations where the boundary of the aggregation is well defined, and as implemented in acoustic surveys of orange roughy in the spawning plume on the north

Chatham Rise (e.g. Hampton et al. 2010), outer transects with zero density and sections of transect with zero density on either side of a continuous SBW mark were removed before calculating the $(\overline{S_a})_j$ values, in order to improve the precision.

- The biomass for the snapshot, B, was estimated from the expression:

$$B = A\,\overline{w}\,10^{\,0.1(\overline{S_a} - \overline{TS})} \quad ,$$

where $\overline{TS}$ is the mean SBW target strength for the snapshot, A the snapshot area after removal of the transects and sections of transects with zero density, and $\overline{w}$ the estimated mean weight of individual SBW in the snapshot, obtained from the trawl samples. $\overline{TS}$ was estimated by applying Dunford & Macaulay's (2006) theoretical relationship between TS and fork length (FL):

$$TS = 38\,Log\,FL - 97 \quad , \quad (1)$$

and also from a recent empirical expression developed by O'Driscoll et al. (2013):

$$TS = 22.06\,Log\,FL - 68.54 \quad . \quad (2)$$

This expression was based on *in situ* measurements on SBW which were positively identified using the CSIRO net-mounted acoustic-optical system (AOS) described by Ryan et al. (2009).

- A single correction for inaccuracy in the absorption coefficient used in the ES60's internal range compensation software was applied to all biomass estimates. It was obtained by applying a number of temperature/depth profiles from the temperature monitors mounted on the net to the expression of Doonan et al. (2003) for the absorption coefficient at 38 kHz as a function of temperature, depth and salinity (assumed to be 34.5 ppt throughout).

- The CV of the biomass estimate for a snapshot was estimated from the variation between the $(\overline{S_a})_j$ values, with weighting by transect length as in Jolly & Hampton (1990).

- On Pukaki Rise, where there was more than one acceptable snapshot of the area, estimates of SBW biomass in the area were made by averaging the snapshot estimates with equal weighting, and the CV of the mean estimated from the sum of the sampling variances.

3. RESULTS

3.1 Size distribution

Pukaki Rise

Figure 3 shows the pooled length distributions of SBW taken in the two trawls by *Aleksandr Buryachenko* on Pukaki Rise at the start of the fishing there on 9 September, and from the single trawl at the end of the fishing, on 17 September. It can be seen that on both occasions there was a strong mode around 30 cm, with a much weaker, broad peak between about 40 and 45 cm which was more pronounced on 9 September than on 17 September. From the staging of the length distributions in figure 4 in Hanchet et al. (2002) we surmise that the former mode arose from immature and sub-adult fish and the latter from adults.

The length distributions from the *San Waitaki* catches on Pukaki Rise, which were made about a week after the final trawl there by *Aleksandr Buryachenko*, are shown in Figure 4. The first four trawls (22 – 26 September) have been separated from the last two (27 – 28 September) to show that there was an abrupt change in the size distribution after Trawl 4. The distributions for Trawls 1 to 4 show strong modes at around 30 cm for both sexes (as in Figure 3), and broader ones between about 35 and 45 cm (males) and about 40 and 50 cm (females) which are much more pronounced than the equivalent modes in Figure 3. The second mode is much less evident in the distributions from Trawls 5 and 6, which are heavily dominated by the first mode.

Campbell Plateau

Pooled length distributions for SBW taken in the 17 trawls on the Campbell Plateau by *Aleksandr Buryachenko* are shown in Figure 5. Here the modes between 35 and 40 cm predominate, with a secondary mode around 30 cm, and a suggestion of a third mode above 45 cm in the distribution for females.

Figure 6 shows the length distributions for SBW taken on the Campbell Plateau in all the trawls by *San Waitaki*. There is a strong mode between 35 and 40 cm (males) and between 35 and 45 cm (females), a less pronounced and weaker one around 30 cm, and the suggestion of a third mode between 40 and 45 cm (males) and 45 and 50 cm (females). In these respects, the distributions are very similar to those for SBW caught two to three weeks earlier by *Aleksandr Buryachenko* (Figure 5).

Figures 3 to 6 illustrate that in both areas, and at all times, the females tended to be larger than the males. This is also evident from Table 3, which lists the mean lengths of males, females and for the sexes combined, for all the distributions.

3.2 Reproductive state

The percentages of female SBW in each one of the five maturity stages defined by Hanchet (1999) are listed in Table 4 for all catches by both vessels from which biological samples were taken.

Pukaki Rise

In this area there was a clear progression in maturity stage between the *Aleksandr Buryachenko* visit (8 – 17 September), when most of the females were in Stages 1 (immature) and 2, and the *San Waitaki* survey approximately a week later (22 September), when most female gonads were in Stages 3 and 4, except for the last two trawls, where the fish were smaller, and almost all in Stages 1 and 2.

Campbell Plateau

There were almost no immature SBW in the catches made by *Aleksandr Buryachenko* on Campbell Rise; the fish being predominantly in Stage 2, with significant percentages in Stages 3 and 5 (spent). Table 4 shows that in catches by *San Waitaki* there two weeks later the fish were predominantly in Stage 3. SBW occurred in all stages of gonad development, with the relatively high percentage of both immature and spent fish in the final trawl being particularly notable. The significant percentages of spent fish in almost all of the trawls on Campbell Plateau, compared to the almost total lack of spent fish in Pukaki Rise catches, is also notable.

3.3 Distribution and biomass estimates

Calibration

The echo sounder gain factors from the calibration on 16 July 2012, which are taken from Hampton et al. (2013) are given in Table A-2, where they are compared against the results from previous calibrations of this system. Note that the transducer was replaced between the 2010 and 2011 calibrations, and that the 2011 calibration was carried out by NIWA. All other calibrations were carried out by FRS.

The results show that there was an increase in the sensitivity of the echo sounder when the transducer was replaced before the 2011 calibration. The estimated s_A correction factor of –0.70 dB is in good agreement with the values obtained over the previous five years, while the measured beam angles and offsets remain consistent and in agreement with the manufacturer's specifications. All measurements therefore indicate that the echo-sounder has been operating satisfactorily over a long period, and support the use of the calibration correction factor of 1.39 from the 2012 calibration in the current survey.

Nature of marks

In both areas SBW were generally found in clearly defined schools on or close to the bottom during the day and in more dispersed aggregations 50 to 100 m off the bottom at night. Examples of daytime and night-time marks on Pukaki Rise and Campbell Island Plateau are shown in Figures 7 and 8 respectively. Note that the marks in Figure 8 are more substantial and extensive than those in Figure 7, which is typical of the difference between the aggregations on the two grounds. Figure 8 also clearly shows the vertical migration of the fish off the bottom at dusk which was commonly observed.

Catches

Details of all trawls and SBW catches by both vessels in the two areas are given in Tables A-3 (*Aleksandr Buryachenko*) and A-4 (*San Waitaki*), which show that large SBW catches, ranging from 6.1 to 48.0 t, were made in all of the trawls in both areas. On Pukaki Rise, the average catch was 12.3 t by *Aleksandr Buryachenko* and 31.8 t by *San Waitaki*. On Campbell Island Plateau the average catches by the two vessels were similar (26.6 and 28.4 t respectively).

Identification and sizing of scatterers

Mean lengths, weights and target strengths of SBW taken in the trawls by *San Waitaki* and used in the identification and sizing of SBW for biomass estimation are shown in Table 5. The target strength estimates have been derived using both target strength expressions (i.e. Equations 1 and 2) in the pooled length distributions from the indicated trawls.

The identification trawls were selected from the full set of trawls listed in Table A-4. Catches of other species in these trawls were negligible, making it unnecessary to correct for their contribution to the back-scattered energy.

Distribution

Pukaki Rise

Figure 9 shows where *San Waitaki* detected SBW marks while searching and trawling, and during the snapshots on the southern part of Pukaki Rise, and the tracks of the trawls in this area. An overview of the distribution during the snapshots is provided in Figure 10, which shows that the fish were mainly concentrated within a narrow depth range between 340 and 380 m. Figure 11 shows the distribution in each snapshot. The maps for Snapshots 1 and 4 and the marks detected while searching (Figure 9) both suggest that the distribution probably extended further to the east and west than the limits of the survey.

Campbell Island Plateau

The SBW marks detected by *San Waitaki* on Campbell Island Plateau while searching and fishing and in the single composite snapshot (7A + 7B) were on the northwestern slope between about 440 m and more than 500 m depth (Figure 12). Figure 13, which shows the distribution in the snapshot in greater detail, indicates that the highest densities were concentrated around the 450 m contour. Figure 12 shows that SBW marks were also detected during searches and trawls in somewhat shallower water to the southeast of the survey grid, which together with the detection of marks on the outer transects of the snapshot and at the deep-water extremities of many of the transects, indicates that the distribution probably extended beyond the survey limits in all directions.

Biomass estimates

Biomass estimates from both target strength expressions and the CVs are shown in Table 6 for all of *San Waitaki*'s snapshots on Pukaki Rise and for the two composite snapshots on the Campbell Island Plateau.

The mean biomass and CV from the Pukaki Rise snapshots was calculated firstly from all six snapshots, treated equally, and then after discarding those where there were marks on the outer transects (Snapshots 1 and 4 – see Figure 11) as well as the final snapshot (Snapshot 6), in which the SBW were much smaller than in all the previous snapshots, suggesting a change in distribution or behavior towards the end of the survey. The large difference between the biomass estimates for the two target strength expressions, and the marked effect of excluding the three most questionable estimates, is evident. The composite estimate for the Campbell Plateau is roughly an order of magnitude higher than the means from the Pukaki Rise snapshots, despite the stronger evidence of fish being beyond the survey limits in this snapshot. Table 6 shows that in all the snapshots, the dead-zone correction was small; of the order of 1%.

4. DISCUSSION

4.1 Biology

Pukaki Rise

The dominance of small, (around 30 cm) immature or sub-adult SBW in the length distributions from Pukaki Rise suggests that this size group was ubiquitous in the areas sampled by the two vessels, as opposed to the larger, more mature fish, which were only caught in comparable numbers in the first four trawls there by *San Waitaki* (see Figure 4). From the progression of the maturity stages between the *Aleksandr Buryachenko* and *San Waitaki* operations on Pukaki Rise (Table 4) it is clear that spawning was well underway at the time of the acoustic survey by *San Waitaki*. The lack of spent fish indicates either that it was far from complete, or that the spent fish had left the area soon after spawning.

The length distributions in Figure 4 are very similar to those which O'Driscoll (2011) reported for SBW taken on the eastern and southern Pukaki Rise in late August 2009 by *Aleksandr Buryachenko* (his figure 13), which show the same two distinct modes, with the females being generally larger than the males, as in all distributions in our study. The mean length in his study (36.3 cm) is within the range (32.31 to 40.81 cm) of the means in Table 3.

The reproductive state of female SBW in the current survey (Table 4) is consistent with O'Driscoll's (2011) observation that peak spawning on Pukaki Rise in 2009 appeared to be in mid-September, when over 10% of adult female SBW sampled by observers between 15 and 19 September were running ripe (Stage 4) compared to a mean of 22% in the six catches made by *San Waitaki* in mid- to late September 2012.

Campbell Island Plateau

The length distributions in Figures 5 and 6 (from *Aleksandr Buryachenko* and *San Waitaki* catches respectively) are similar, with similar modes at approximately 30 – 32 cm, 36 – 38 cm and 45 – 46 cm, and with a similar relative size between the two major modes. They differ substantially from the length distributions in commercial catches on Campbell Island Rise in September 2011 reported in table 8 of O'Driscoll et al. (2012) in that there is no mode around 30 cm in any of those distributions. We note however that immature SBW of modal length around 25 cm were frequently taken in research trawls by RV *Tangaroa* in a wide-area survey of the Plateau at the time, and that their contribution to *Tangaroa*'s acoustic estimate of SBW biomass on Campbell Island Plateau was over 35% of the total (O'Driscoll et al 2012).

The predominance of females in Stage 2 in the *Aleksandr Buryachenko* catches and in Stage 3 in the *San Waitaki* catches two to three weeks later, and the presence of spent fish throughout the period (Table 4) confirms that spawning was progressing during both visits to the Plateau. This is consistent with the timing of SBW spawning observed on Campbell Island Plateau in previous years (figure 7, O'Driscoll et al., 2012). The variable percentages of females in Stage 5 (spent) and the lack of an increasing trend over time, suggests that while spawning occurred throughout the three-week period, spent fish were leaving the grounds soon after spawning at a variable rate. It could also be at least partly due to an earlier spawning peak, which would be consistent with evidence of multiple SBW spawning peaks on Campbell Island Plateau in O'Driscoll et al. (2012), for example.

4.2 Distribution and aggregating behavior

Pukaki Rise

Because of the sparse searching tracks (Figure 1), little can be concluded from the *Aleksandr Buryachenko* exercise regarding the distribution of SBW on Pukaki Rise at the time, other than that there were significant concentrations on the eastern side of the Rise, where most of the catches were made. In the *San Waitaki* survey, where the coverage of the shelf between 300 and 400 m in all but the north-western sector was somewhat better (Figure 2), the fact that significant aggregations were only found on the southern side of the Rise (Figures 2 and 9) is likely to be more significant. This is in sharp contrast to the SBW distribution in the 2009 survey by *Aleksandr Buryachenko* and *Meridian 1* when commercial concentrations were found over a much larger area on the eastern and southeastern area of the Rise, as well as to the north of it in the last of the six snapshots there (see figure 19, O'Driscoll 2011).

The acoustic marks in the *San Waitaki* survey of Pukaki Rise were more defined and apparently denser than those reported as arising from immature SBW on the Rise in the 2009 survey, but were far less extensive than marks recorded later in that survey from adult, spawning SBW (see figure 11, O'Driscoll 2011). Because of the poor surveying conditions, the marks recorded from *Aleksandr Buryachenko* were generally too indistinct to allow any such comparison.

Campbell Island Plateau

The coverage of Campbell Island Rise by the two vessels was too limited to draw any conclusions about the overall distribution of SBW at the time of their visits to the Plateau. It is however noted that the areas where the vessels made their catches were far removed from one another (i.e. up to 60 n.

miles apart), and that these areas were either well to the east, or towards the northern limit of the distribution of immature and adult SBW recorded during the *Tangaroa* wide-area survey of Campbell Island Plateau in 2011 (see figures 17 to 20, O'Driscoll et al. 2012).

The marks in Figure 8 are most similar to those in figures 9 and 11 in O'Driscoll et al (2012) which show, respectively, tow-body recordings from *Tangaroa* of pre-spawning adults on the bottom on the afternoon of 4 September 2011, and of a dense layer of pre-spawning or spawning SBW ascending from the bottom at dusk on 11 September.

4.3 Biomass estimates

Pukaki Rise

The means in Table 6 for Equation 1 (2754 or 1815 t, depending on whether Snapshots 1 and 4 are included or not) are an order of magnitude lower than most of the estimates of the biomass of 4+ SBW in aggregations on Pukaki Rise from the survey by *Meridian 1* and *Aleksandr Buryachenko* in 2009, using the same target strength/length expression (see table 10, O'Driscoll 2011). They are also an order of magnitude lower than the mean of five estimates of 4+ SBW biomass on the entire Rise from wide-area surveys between 1993 and 2001, based on the same target strength expression (i.e. 18 660 t, Grimes et al. 2007). The fact that the current estimates include all year classes widens the differences further.

It can only be concluded that either SBW were exceptionally scarce on Pukaki Rise in 2012 compared to previous years, and/or that *San Waitaki* did not locate the major spawning aggregations there, either because they were concentrated in the northwest sector, or were outside the depth range covered in the partial circumnavigation of the Rise. It would appear, however, from the extent of the aggregation in Figure 9, and the survey track in Figure 2, that any aggregation of similar or greater extent between the 350 and 400 m depth contours would in all likelihood have been detected. We contend that the combination of the low biomass in the depth range where spawning SBW on Pukaki Rise are commonly found (e.g. Grimes et al. 2007, O'Driscoll 2011) and the absence of spent fish in the biological samples suggests that the main spawning event was not covered during the survey.

Campbell Island Plateau

The estimate in Table 6 of the total SBW biomass in the aggregation on Campbell Island Plateau detected and surveyed by *San Waitaki*, (27 591 t from Equation 1) indicates that the biomass there was much higher than on Pukaki Rise. It is nonetheless well below the estimate of total (immature + adult) SBW biomass on the Plateau (182 727 t) obtained from two wide-area snapshots of the Plateau by *Tangaroa* in September 2011 using the same target strength expression (O'Driscoll et al. 2012), and those from aggregation-based surveys of the Plateau from industry vessels in, for example, 2009 (Gauthier et al. 2011). Since the area surveyed in the *San Waitaki* snapshot (approximately 63 n.mile^2) was less than 1% of the area covered in the two *Tangaroa* snapshots in 2011, and little time was spent searching elsewhere, nothing can be concluded from this snapshot regarding the total SBW biomass on the Plateau at the time of the survey, or of the relative abundance there compared to previous years.

4.4 Methodological Issues

Incomplete cover

The greatest methodological problem in the *San Waitaki* surveys was the incomplete cover of the aggregations detected in some cases, and more importantly, of the entire population. In both surveys this has led to biomass estimates which are of little value even as estimates of minimum population size. In order to provide useful estimates of minimum biomass, aggregation-based surveys need to locate and survey all major aggregations (e.g. O'Driscoll 2011), which the vessel clearly did not do. This was mainly because of the shortage of time on the grounds and, in the case of the Pukaki Rise, probably because there was a more scattered distribution due to the survey being late in the spawning cycle. To increase the chance of success in future aggregation-based surveys of SBW on their spawning grounds from commercial vessels, and to capitalise on the strategic advantages of such surveys as outlined by O'Driscoll (2011), it would seem imperative to develop a strategy which ensures that a) all major aggregations are detected and their movement monitored during the survey, and b) that a sufficient number of snapshots is carried out on each to achieve an acceptable precision in the estimate of total abundance. In Section 6 we suggest a possible cost-efficient strategy for such surveys of the Pukaki Rise from commercial vessels which process catches sufficiently slowly to allow long periods of down-time for surveying between catches.

Target strength

Of the two target strength expressions used here, preference must be given to Equation 2, firstly since it is based on *in situ* measurements on SBW which were positively identified photographically, rather than on a theoretical model, and secondly because it is in close agreement with a new expression for the closely related species, northern blue whiting (*Micromesistius potassou*) obtained from *in situ* measurements in the north Atlantic between 2003 and 2007 (Pedersen et al. 2013). For the range of fish lengths in the *San Waitaki* survey, their expression:

$$TS = 20 \, Log \, TL - 65.2 \qquad ,$$

where *TL* is total length, gives target strengths which are between 0.3 and 1.0 dB higher, which would lead to biomas estimates between 7 and 26% lower)than those from Equation 2 after conversion from *FL* to *TL* through the expression $TL = 1.06 \, FL - 0.28$ (in Pedersen et al. 2013).

Aeration loss

A source of bias not accounted for in our study, or in any of the previous acoustic surveys of SBW in New Zealand waters using hull-mounted transducers, is that arising from loss of signal due to aeration of the near-surface water in bad weather. An upper limit for this loss can be estimated from the analysis of weather-induced reduction in the strength of the bottom signal in annual surveys from *San Waitaki* of the orange roughy Spawning Plume on the north Chatham Rise between 2002 and 2010 (e.g. Hampton et al. 2010) by Cordue (2010), who derived a general correction of 1.33 for the combined effects of transducer pitch and roll and aeration loss in those surveys. Since the losses due to transducer motion in the current survey would have been less because of the shorter range to the targets, and in any event were corrected for through ECHOVIEW, it seems reasonable to assume that corrections for aeration loss in the *San Waitaki* snapshots would amount to considerably less than this.

5. CONCLUSION

The survey from *San Waitaki* achieved the primary objective of the study, in that six snapshots covering a commercial concentration of SBW on Pukaki Rise were completed during the spawning period, yielding biomass estimates with an acceptably low sampling CV (14 %). However, it seems from the very low estimates compared to previous acoustic estimates there that the major part of the adult population may have been missed. Since the coverage of the shelf, although sparse, should have been adequate to have detected large concentrations elsewhere on the shelf, the most likely explanation seems to be that the bulk of the spawning population had left the shelf by the time of the survey. This interpretation is supported by the fact that the survey was approximately a month later than the surveys by *Meridian* and *Alexandr Buryachenko* in 2009, from which estimates an order of magnitude higher were derived. We note too that the *San Waitaki* skipper's decision to leave Pukaki Rise on 28 September and move to Campbell Island Plateau was prompted primarily by declining catch rates and the perception that the spawning peak had passed and that the bulk of the fish had left the ground.

The single snapshot from *San Waitaki* of the aggregation encountered on the Campbell Island Plateau yielded a precise (CV 12%) estimate of SBW biomass within the area surveyed, but since the aggregation itself was clearly not completely covered, and because spawning aggregations are known to occur elsewhere on the Plateau, the estimate is of value only as very conservative estimate of minimum biomass.

Although no acoustic data of quantitative value could be collected from *Aleksandr Buryachenko,* because very poor weather precluded any snapshots, and the generally poor quality of the recordings , it is worth noting that usable snapshots may have been achievable had the fishing plan allowed for a longer period on Pukaki Rise. This needs to be a major planning consideration for future aggregation-based acoustic surveys of SBW using commercial vessels, either on Pukaki Rise or elsewhere.

6. RECOMMENDATIONS

Given that spawning SBW in New Zealand waters consistently form aggregations which are suitable for acoustic surveying from commercial vessels, the recent progress in estimating SBW target strength *in situ* (O' Driscoll et al. 2013) is encouraging for further attempts to estimate absolute biomass acoustically from commercial vessels, on at least some of the commercial fishing grounds. However, meaningful results from aggregation-based surveys will only be achieved through improved areal coverage of the spawning grounds, as discussed in Section 4. Below we suggest possible improvements to the design for future Pukaki Rise SBW surveys, based on the 2012 endeavour.

Firstly, we emphasise that the survey should be conducted earlier in the spawning season than the 2012 survey to coincide more with peak spawning. Secondly the vessel should spend a continuous period of at least 10 days on the ground if at all possible. The survey should start with a circumnavigation of the shelf on a zig-zag grid between about 300 and 500 m to locate any significant aggregations on the shelf. . At a survey speed of 10 knots it should be possible to complete this grid in 24 hours, with allowance for a few trawls on dense marks for target identification and to provide fish for the factory. The next two days could then be spent on snapshots of all major aggregations detected, with further fishing for target verification and to keep the factory working. This process could be repeated at least twice over the period of 10 days, enabling the location and movement of the major aggregations to be monitored throughout the survey, and many replicate snapshots to be undertaken of all major aggregations to reduce the CV in the estimate of total biomass. A heading-and-gutting vessel such as *San Waitaki*, which takes approximately 15 hours to process a catch of 30 t (roughly the average catch on Pukaki Rise during the 2012 survey), would be ideal as it would require only two catches per day to keep the factory fully occupied throughout the survey. Therefore there would be no need to purchase dedicated vessel time for research purposes, making this an extremely cost-effective operation. A further advantage is that the knowledge gained on the movement of the aggregations from the periodic surveys of the entire shelf would make it easier to decide whether to add or average snapshot estimates made at different times, which has sometimes caused difficulty in interpreting snapshot estimates from aggregation-based acoustic surveys of SBW (see for example O'Driscoll 2011).

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8. TABLES

Table 1: Number of search grids, trawls and snapshots carried out by *Alexandr Buryachenko* and *San Waitaki* on Pukaki Rise and Campbell Island Plateau. Number of trawls used for acoustic target identification shown in parenthesis.

Vessel	Area	No. of search grids	No. of trawls	No. of snapshots
A. Buryachenko	Pukaki Rise	10	3	0
	Campbell Plateau	12	17	0
	Total	22	20	0
San Waitaki	Pukaki Rise	14	6(4)	6
	Campbell Plateau	8	5(1)	1
	Total	22	11(5)	7

Table 2: Details of snapshots carried out by *San Waitaki* on Pukaki Rise and Campbell Island Plateau.

Area	Snapshot no.	Date (2012)	No. of lines	Mean spacing (n.mile)	Duration (hrs:min)
Pukaki Rise	1	23-Sep	9	0.34	05:14
	2	23-Sep	10	0.58	04:27
	3	24-Sep	12	0.57	05:38
	4	24-Sep	10	0.65	04:43
	5	25-Sep	10	0.65	05:48
	6	26-Sep	11	0.66	08:26
Campbell Plateau	7A	01-Oct	6	0.62	03:19
	7B	01-Oct	7	0.62	07:11

Table 3: Mean lengths and weights of SBW taken in trawls by *Alexandr Buryachenko* and *San Waitaki* on Pukaki Rise and Campbell Island Plateau.

Area	Vessel	Date	Mean FL (females) (cm)	Mean FL (males) (cm)	Mean FL (all) (cm)	Mean weight (all) (g)
Pukaki Rise	*Alexandr. Buryachenko*	09-Sep	31.89	38.15	34.29	347
		19-Sep	30.52	33.58	32.31	236
	San Waitaki	22 to 26- Sep	38.00	43.90	40.81	505
		27 to 28- Sep	33.19	34.42	33.71	267
Campbell Plateau	*Alexandr Buryachenko*	11 to 17- Sep	35.88	38.64	37.30	366
	San Waitaki	29- Sep to 2-Oct	36.43	40.02	38.08	363

Table 4: Percentage of female SBW in each of the five maturity stages of Hanchet (1999) in all trawls by *Alexandr Buryachenko* and *San Waitaki* on Pukaki Rise and Campbell Island Plateau.

Area		Trawl No.	Date	% of females Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Mean wt (g)
Pukaki Rise	*Alexandr. Buryachenko*	1	08-Sep	0	97	3	0	0	519
		2	09-Sep	65	29	6	0	0	176
		20	17-Sep	66	15	8	2	9	236
		Mean		**43**	**47**	**5**	**1**	**3**	**310**
	San Waitaki	1	22-Sep	15	3	47	35	0	357
		2	24-Sep	6	10	72	12	0	587
		3	25-Sep	0	2	15	83	0	591
		4	26-Sep	3	31	61	4	0	486
		5	27-Sep	69	23	8	0	0	282
		6	28-Sep	73	20	6	0	0	252
		Mean		**28**	**15**	**35**	**22**	**0**	**426**
Campbell Plateau	*Alexandr. Buryachenko*	3	11-Sep	0	53	24	9	14	374
		4	11-Sep	0	70	17	3	10	379
		5	11-Sep	0	59	23	0	18	388
		6	12-Sep	0	56	28	0	16	364
		7	12-Sep			No biological sample			
		8	13-Sep			No biological sample			
		9	13-Sep	0	66	19	0	16	364
		10	13-Sep	0	77	14	0	9	360
		11	13-Sep			No biological sample			
		12	13-Sep			No biological sample			
		13	14-Sep	0	54	29	4	13	358
		14	14-Sep	0	60	25	3	13	389
		15	15-Sep	0	62	19	2	17	351
		16	15-Sep	1	59	21	0	20	333
		17	15-Sep			No biological sample			
		18	16-Sep			No biological sample			
		19	16-Sep	4	49	18	1	28	271
		Mean		**0**	**60**	**22**	**2**	**16**	**366**
	San Waitaki	7	29-Sep	0	2	75	23	0	364
		8	29-Sep	7	3	83	0	7	366
		9	30-Sep	6	3	75	14	3	392
		10	01-Oct	13	5	75	0	8	380
		11	02-Oct	22	0	38	4	36	312
		Mean		**10**	**3**	**69**	**8**	**11**	**363**

Table 5: Mean length, weight and target strength of SBW in trawls by *San Waitaki* used for target identification.

Snapshot	Trawls	Mean FL (cm)	Mean weight (g)	TS (Eqn. 1) (dB)	TS (Eqn. 2) (dB)
Pukaki Rise					
1	MWT 1 - MWT 4	40.81	505	-35.20	-32.85
2	MWT 1 - MWT 4	40.81	505	-35.20	-32.85
3	MWT 1 - MWT 4	40.81	505	-35.20	-32.85
4	MWT 1 - MWT 4	40.81	505	-35.20	-32.85
5	MWT 1 - MWT 4	40.81	505	-35.20	-32.85
6	MWT 5, MWT 6	33.71	267	-38.24	-34.68
Campbell Plateau					
7A+7B	MWT 11	38.08	363	-36.37	-33.43

Table 6: Estimates of SBW biomass, CVs and dead-zone corrections from all snapshots by *San Waitaki* on Pukaki Rise and Campbell Island Plateau.

Area	Snapshot no.	Dead zone correction (%)	Biomass (Eqn. 1) (t)	Biomass (Eqn. 2) (t)	CV (%)
Pukaki Rise	1	2.53	1 103	642	45
	2	0.82	3 290	1 914	15
	3	0.70	3 336	1 940	38
	4	2.03	1 635	951	28
	5	1.40	1 285	748	22
	6	0.00	322	142	23
	Mean (all)		1 815	1 056	14
	Mean (2 , 3 and 5)		2 754	1 602	14
Campbell Plateau	7A	3.43	9 113	4 626	30
	7B	0.74	18 478	9 380	9
	7A + 7B	2.54	27 591	14 006	12

9. FIGURES

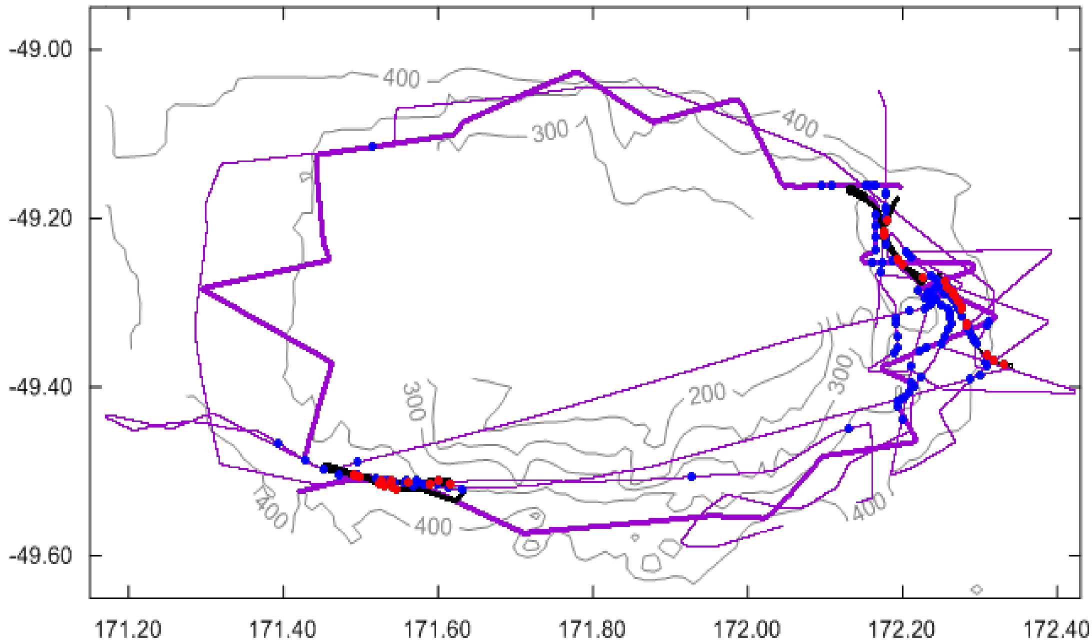

Figure 1: Search tracks during first and second visits of *Alexandr Buryachenko* to Pukaki Rise (dark and light purple lines respectively) and location of SBW marks detected while searching (blue) and trawling (red). The trawl tracks are shown in black.

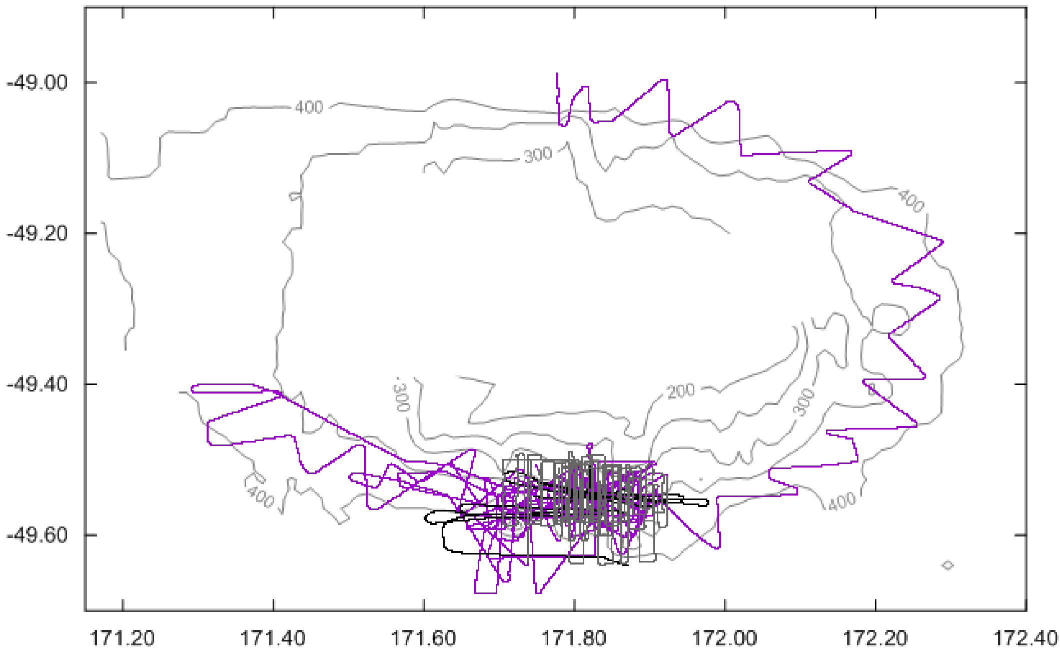

Figure 2: Search tracks (purple) and snapshot grids (grey) in survey of Pukaki Rise by *San Waitaki*.

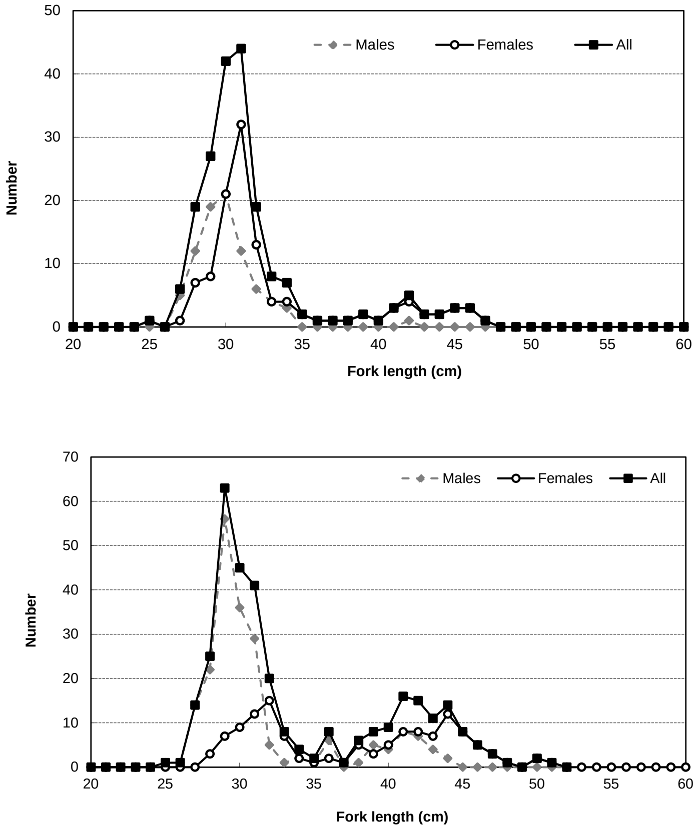

Figure 3: Length distributions of SBW taken by *Alexandr Buryachenko* on Pukaki Rise during the first visit on 9 September (top) and the second visit on 17 September (bottom).

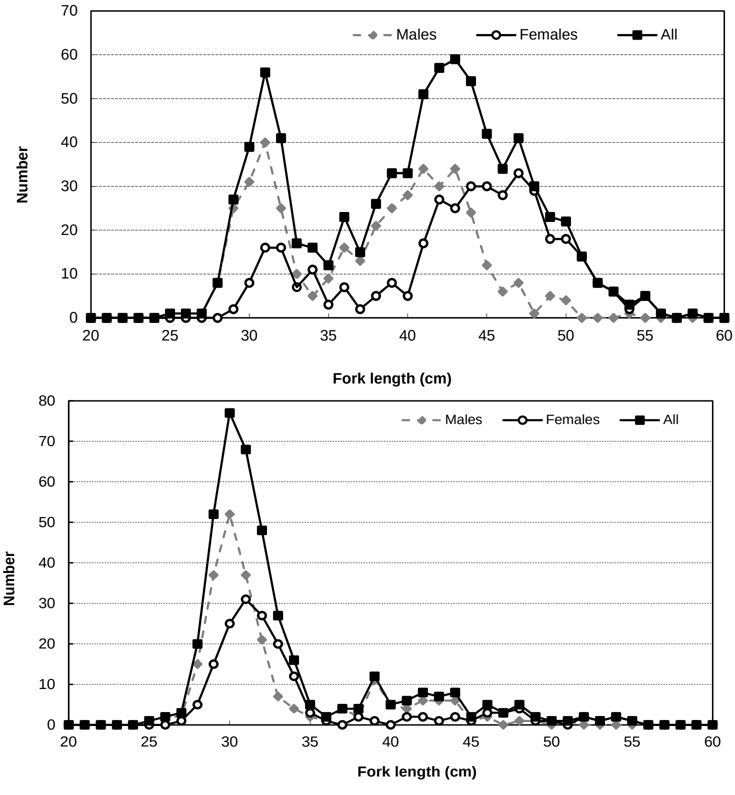

Figure 4: Length distributions of SBW taken by *San Waitaki* on Pukaki Rise in Trawls 1 to 4 from 22 to 26 September (top) and Trawls 5 and 6 on 27 and 28 September (bottom).

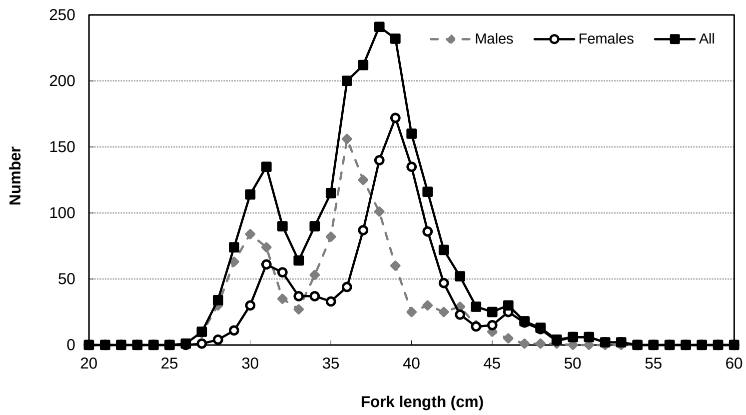

Figure 5: Length distributions of SBW taken by *Alexandr Buryachenko* on Campbell Island Plateau from 11 to 16 September.

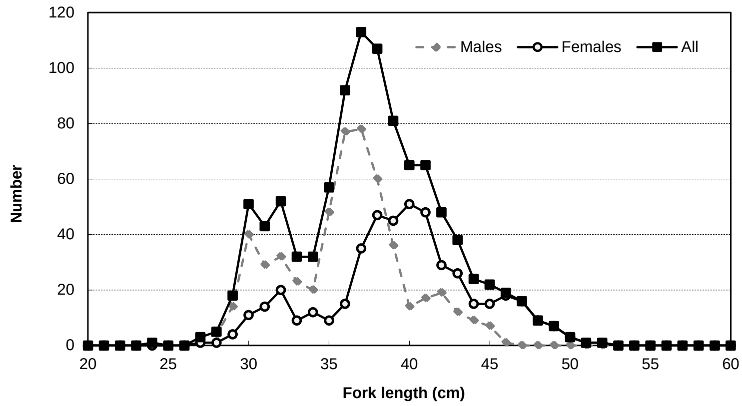

Figure 6: Length distributions of SBW taken by *San Waitaki* on Campbell Island Plateau from 29 September to 2 October.

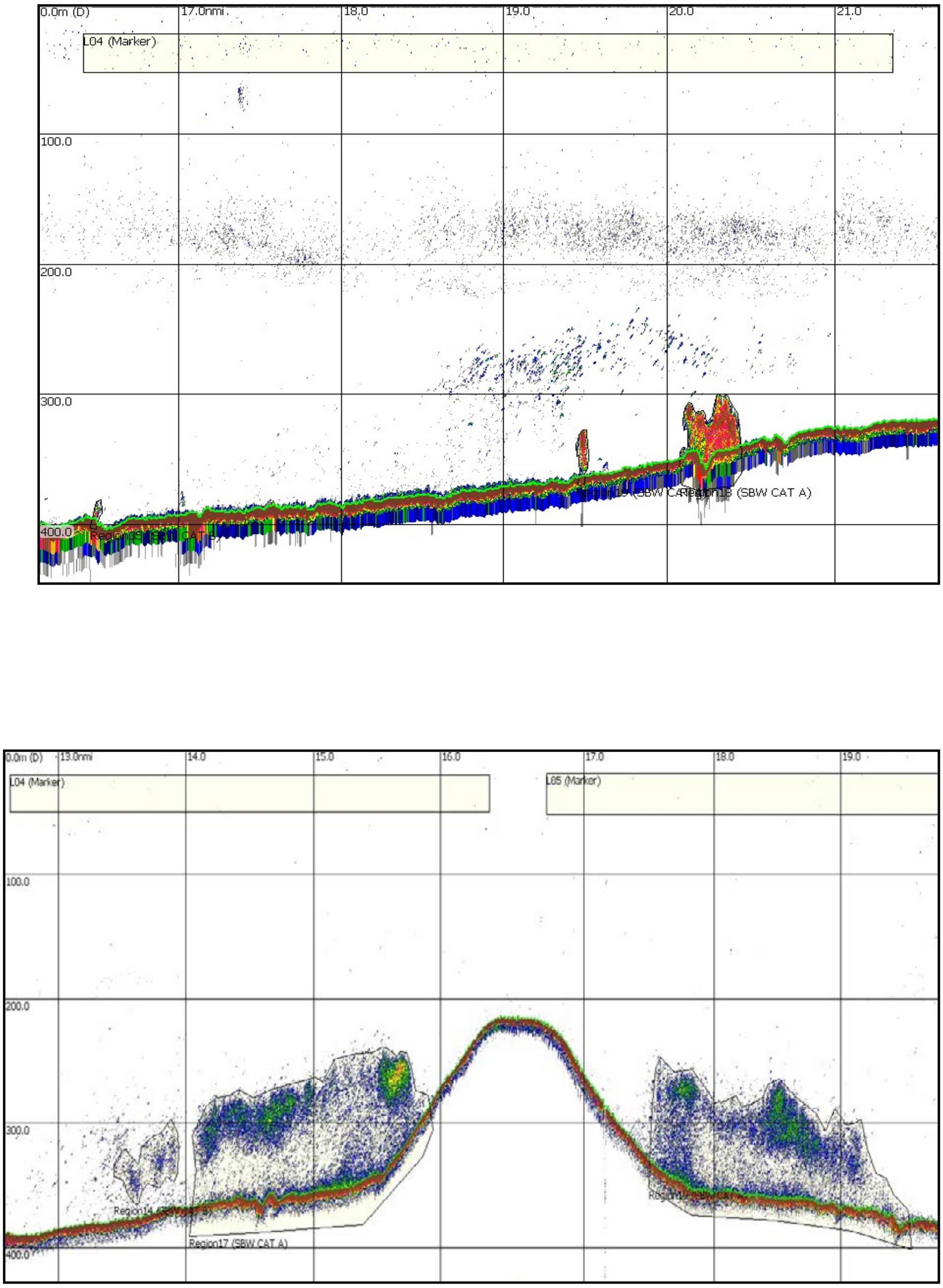

Figure 7: SBW marks detected on Pukaki Rise by *San Waitaki* in daytime (top) and at night (bottom).

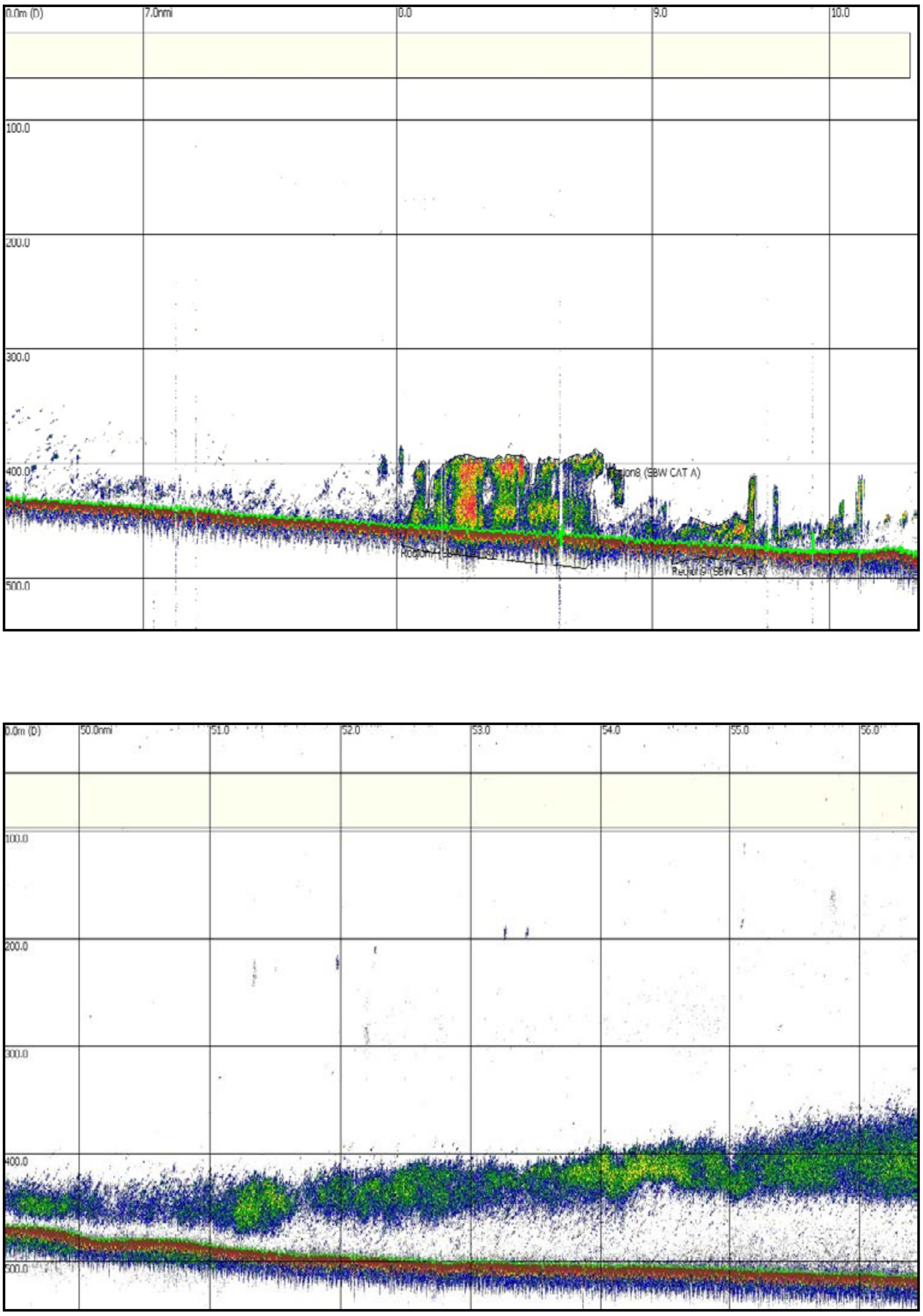

Figure 8: SBW marks detected on Campbell Island Plateau by *San Waitaki* in daytime (top) and at night (bottom).

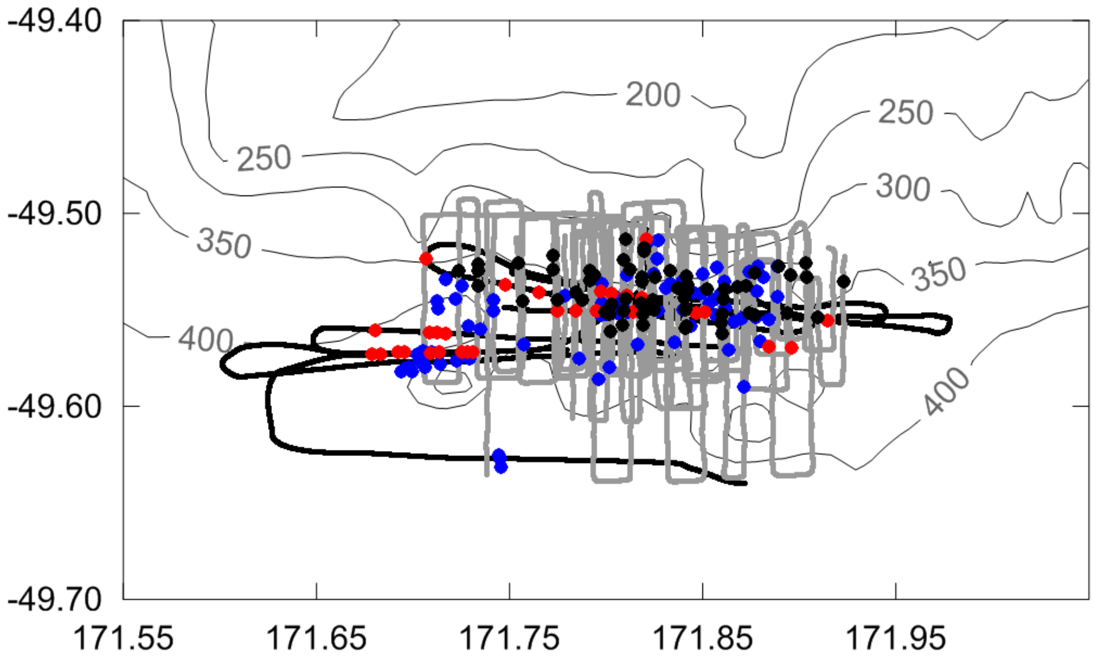

Figure 9: SBW marks detected by *San Waitaki* on Pukaki Rise while searching (blue), surveying (black) and trawling (red). The black and grey lines show the trawling and surveying tracks respectively.

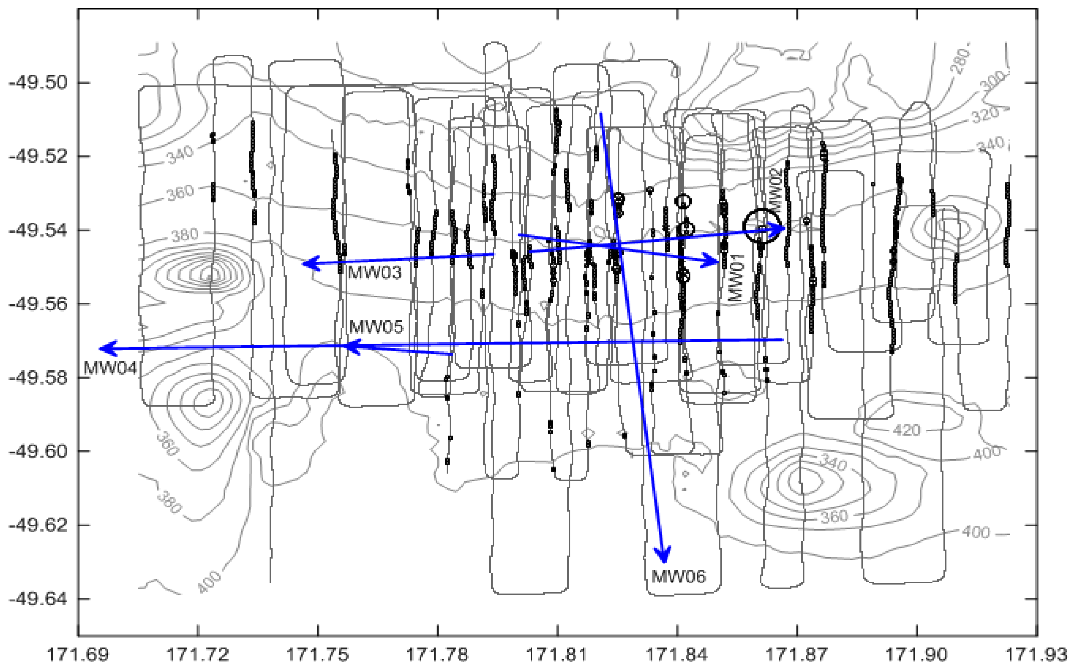

Figure 10: SBW distribution in all snapshots of Pukaki Rise by *San Waitaki.* Circle diameter is proportional to density. Arrows mark ship's position at start and end of each trawl.

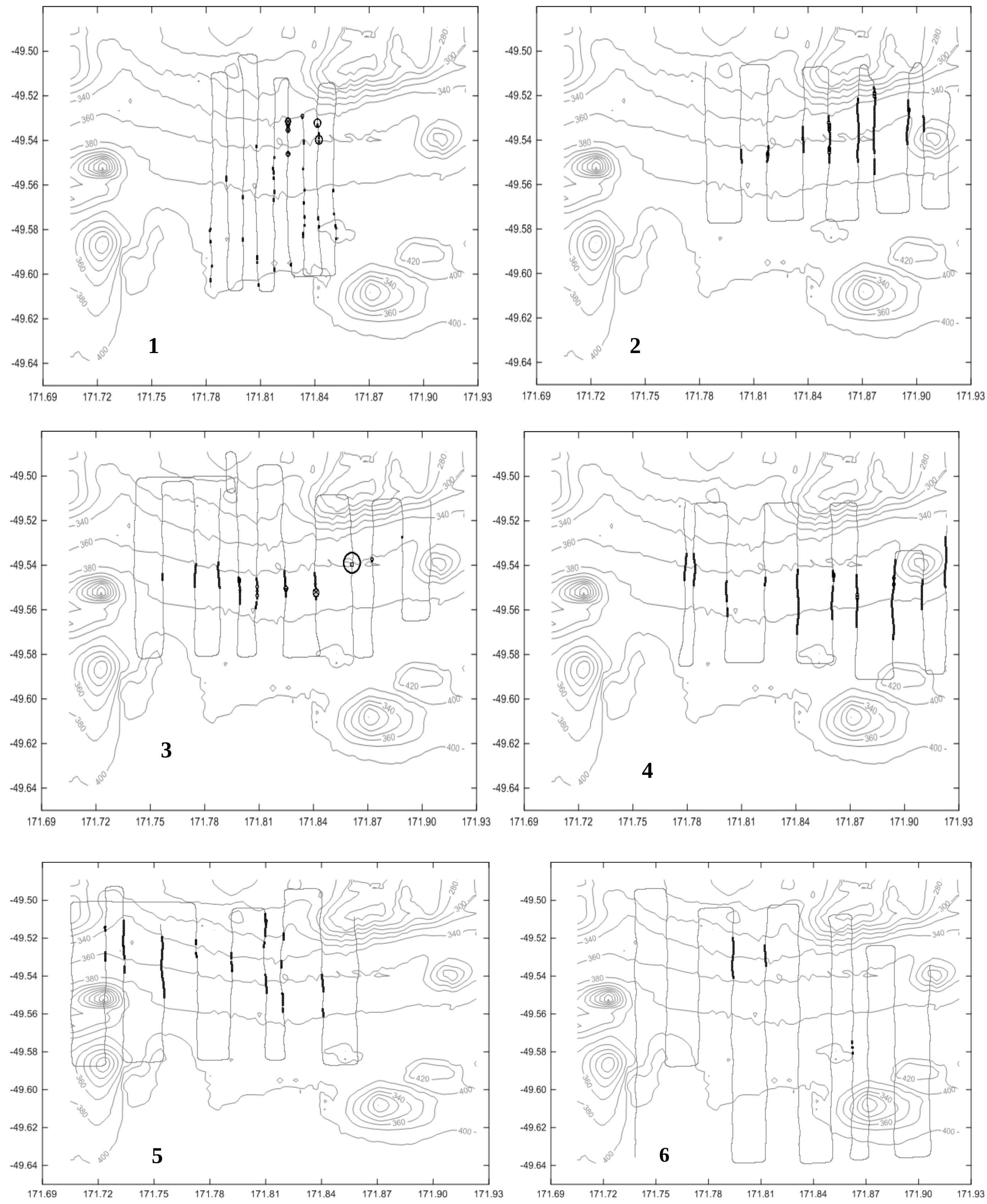

Figure 11: Distribution of SBW in each snapshot of Pukaki Rise aggregations by *San Waitaki.* Circle diameter is proportional to density.

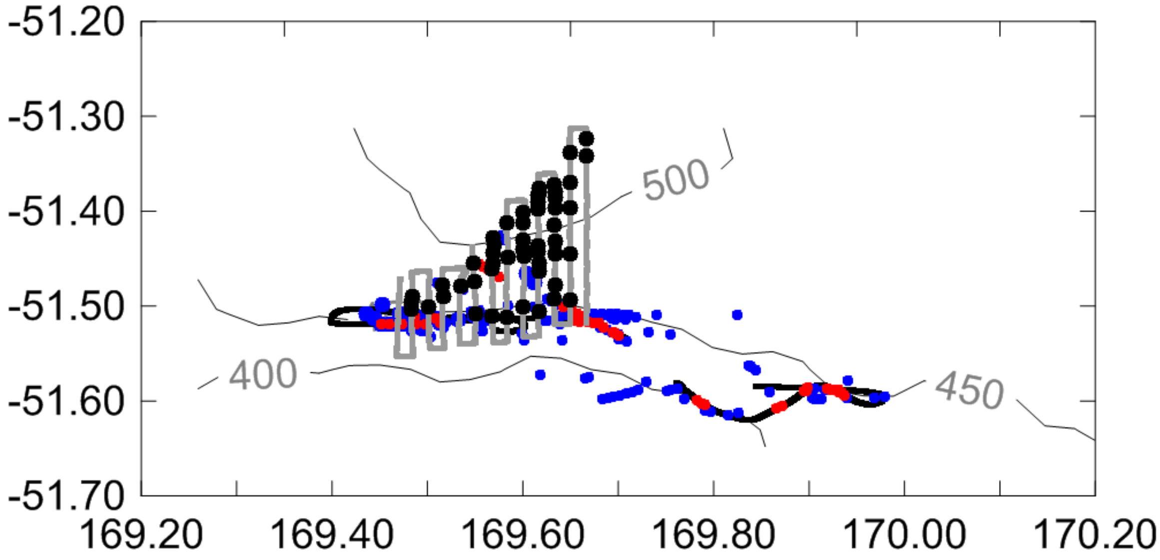

Figure 12: SBW marks detected by *San Waitaki* on Campbell Island Plateau while searching (blue), surveying (black) and trawling (red).

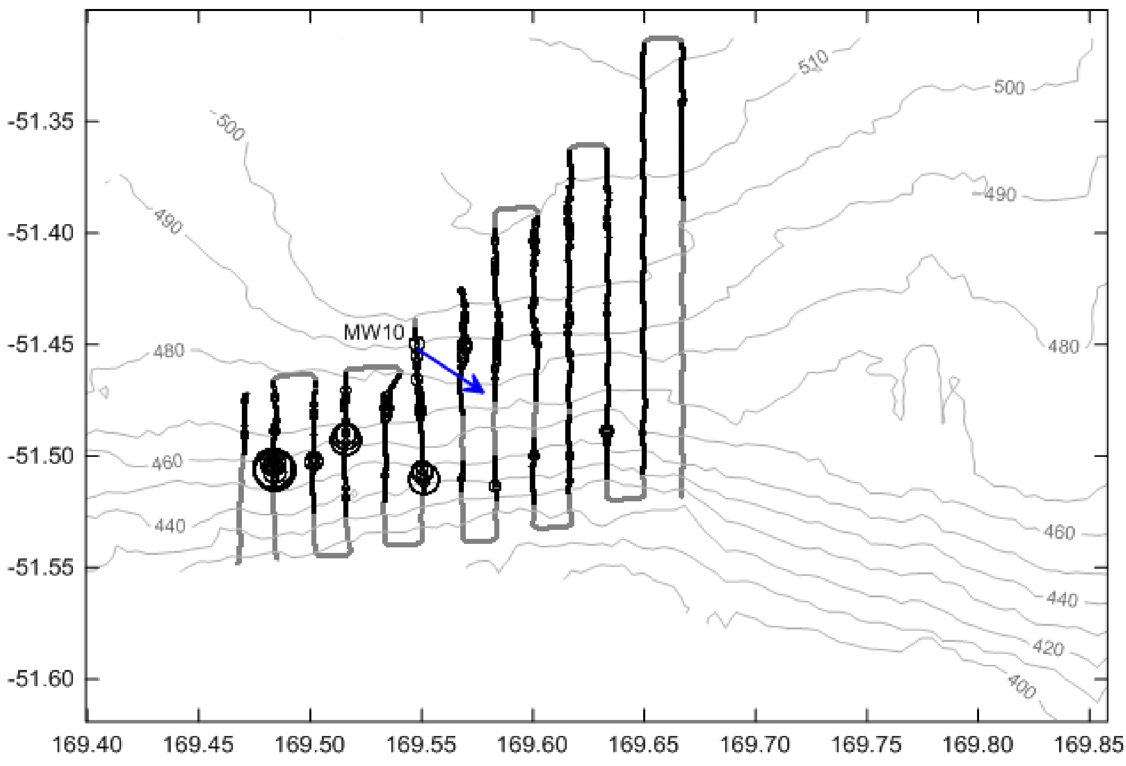

Figure 13: Distribution of SBW in snapshot 7A + 7B on Campbell Island Plateau by *San Waitaki.* Circle diameter is proportional to density. The arrow marks the ship's position at the start and end of the trawl used for target identification.

10. APPENDIX

Table A-1: Details and settings of acoustic equipment.

Echosounder	Simrad ES-70
Transducer	ES38B
Operating frequency	38 000 Hz
Bandwidth	2 425 Hz
Transmit power	2 000 W
Pulse length	1.024 ms
2-way beam angle	-20.6 dB re 1 steradian
Gain	26.5 dB
Sa correction	0.0
Absorption (α)	9.43 dB km^{-1}
Sound velocity	1 500 m s^{-1}
3 dB beam width	
Alongship	7.1°
Athwartship	7.1°
Angle sensitiviy	
Alongship	21.9
Athwartship	21.9
Angle offset	
Alongship	0.0
Athwartship	0.0

Table A-2: ES 60/70 calibration results: 2010 – 2012. Note that the transducer was replaced between the 2010 and 2011 calibrations. Calibration in 2011 carried out by NIWA. (Values from, or calculated from table 1.3 in Doonan et al. 2012)

Parameter	2010	2011	2012
Gain (dB)	25.87	26.22	26.48
S_A correction factor (dB)	-0.64	-0.69	-0.70
S_A Gain (dB)	25.23	25.53	25.79
Biomass correction factor	1.80	1.53	1.39
Alongships beamwidth (^{0})	7.13	6.5	6.81
Alongships offset (^{0})	0.02		-0.03
Athwartships beamwidth (^{0})	7.04	6.9	6.76
Athwartships offset (^{0})	0.06		0.08

Table A-3: Details of trawls by *Alexandr Buryachenko* on Pukaki Rise and Campbell Island Plateau, and the SBW catches.

Trawl	Date (2012)	Location	Duration	Start Depth (m)	Start Latitude (S)		Start Longitude (E)		SBW catch (kg)
MW01	08-Sep	Pukaki Rise	02:31	353	49	30.00	171	34.56	19 429
MW02	09-Sep		00:40	393	49	18.18	171	16.51	13 523
MW03	11-Sep	Campbell Plateau	01:04	556	52	20.80	171	44.95	13 471
MW04	11-Sep		04:19	544	52	22.89	171	40.02	59 765
MW05	11-Sep		02:24	579	52	18.38	171	58.58	49 606
MW06	12-Sep		05:25	560	52	17.14	171	57.17	53 369
MW07	12-Sep		05:41	562	52	17.13	171	1.92	33 137
MW08	13-Sep		01:05	562	52	18.76	172	0.65	13 205
MW09	13-Sep		05:14	564	52	17.22	172	2.09	27 107
MW10	13-Sep					Aborted			
MW10A	13-Sep		01:06	560	52	20.60	171	58.52	32 299
MW11	13-Sep		02:48	564	52	17.86	172	1.88	1 897
MW12	13-Sep		01:15	565	52	18.49	172	4.58	107
MW13	14-Sep		03:25	516	52	28.06	171	4.97	16 127
MW14	14-Sep		03:21	475	52	19.21	170	48.89	9 303
MW15	15-Sep		02:20	468	52	29.93	170	38.87	8 015
MW16	15-Sep		02:04	428	52	7.32	170	37.12	19 502
MW17	15-Sep		02:14	454	51	46.60	170	33.86	24 498
MW18	16-Sep		02:10	459	51	45.63	170	36.60	19 200
MW19	16-Sep		01:00	459	51	45.54	170	36.62	71 960
MW20	17-Sep	Pukaki Rise	02:30	361	49	12.76	172	10.43	4 000

Table A-4: Details of trawls by *San Waitaki* on Pukaki Rise and Campbell Island Plateau, and the SBW catches.

Trawl	Date (2012)	Location	Trawl duration (hr:min)	Start Depth (m)	Start Latitude (°S)		Start Longitude (°W)		SBW catch (kg)
MW01	22-Sep	Pukaki Rise	00:27	303	49	32.48	171	48.13	48000
MW02	24-Sep		07:38	344	49	32.60	171	47.80	34507
MW03	25-Sep		02:43	317	49	32.70	171	47.20	42179
MW04	26-Sep		02:41	338	49	34.17	171	51.98	35000
MW05	27-Sep		03:18	373	49	34.00	171	46.90	25000
MW06	28-Sep		05:00	261	49	30.20	171	49.20	6100
MW07	29-Sep	Campbell Plateau	03:50	360	51	55.00	169	53.90	16000
MW08	29-Sep		00:53	454	51	29.80	169	38.20	45899
MW09	30-Sep		00:51	382	51	30.70	169	35.60	37573
MW10	01-Oct		00:23	421	51	27.17	169	39.22	22164
MW11	02-Oct		03:38	335	51	30.80	169	32.30	20215