Acoustic assessment of salmonids in Otago lakes

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Executive summary

An acoustic assessment of salmonids in large Otago lakes was completed in February 2023. The work was conducted onboard the Otago Fish & Game vessel *OFG7* and included acoustic surveys of Lakes Dunstan, Hawea, Wakatipu, and Wanaka. The surveys followed the same protocols developed by NIWA for large South Island lakes in 2007–2009. This was the fourth survey of Lakes Wanaka and Hawea (previous surveys in 2007, 2008, and 2009), repeating the acoustic transects carried out in the 2008 and 2009 surveys, and the third survey of Lake Wakatipu (previous surveys in 2007 and 2008), repeating the 2008 transects. Lake Dunstan was surveyed for the first time in 2023.

The results showed an increase in the number of tracked targets detected (assumed to be salmonids) and fish densities in Lake Wakatipu, with 2023 producing the highest estimates in the time series. The number of tracked targets detected in Lake Hawea were within the range of those in 2007–2009. The abundance estimates for Lake Wanaka were the lowest of the time series, with the number of tracked targets and fish densities being about half of those from the 2007–2009 surveys. These results were consistent with the findings from randomised creel surveys in Lake Wanaka carried out between May and September of the fishing season 2021-22, with most reports indicating poor angling.

The target strength (TS) distributions in Lakes Hawea, Wakatipu, and Wanaka were bimodal with a weak mode centred around -46 dB and strong mode centred around -33 dB. The TS distributions and range of mean TS by lake were consistent with those from previous surveys. The TS distribution in Lake Dunstan was also bimodal but the modes were weaker than in the other lakes (modes centred around -48 and -43 dB). The vertical distribution of tracked targets in 2023 was deeper in comparison with previous surveys for all lakes. Strong tracked targets (TS > -40 dB), corresponding to larger fish, were found deeper in the water column than weaker targets (TS < -40 dB).

Video footage captured from camera drops during the acoustic surveys confirmed the presence of several submerged trees in Lake Dunstan. Based on the different TS distribution of Lake Dunstan and the low presence of strong tracked targets, we believe that submerged trees, vegetation, and bubbles might be responsible for some of the echoes assumed to be fish. Because of the challenges and potential contamination of non-fish targets on the indices of abundance, we do not recommend continuing to monitor Lake Dunstan using acoustic surveys.

There is a 14-year gap in the abundance estimates of salmonids from 2009 to 2023, therefore the interpretation of trends and comparisons with the earlier surveys need to be made with caution. We recommend carrying out further acoustic surveys of the three major lakes (Wanaka, Hawea, and Wakatipu) in 2024 to verify the observed changes, then ongoing monitoring with biennial or triennial surveys. A more regular monitoring program should provide Otago Fish & Game a reliable fishery-independent index of abundance of salmonids to support and inform management strategies.

1 Introduction

The New Zealand Fish and Game Council and 12 regional Fish and Game Councils are collectively branded as New Zealand Fish & Game. Representing the interests of anglers and hunters, the organisation has statutory responsibility for most of New Zealand's freshwater recreational fisheries. This includes the management of large lakes that support populations of rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), Chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*Oncorhynchus nerka*), and/or perch (*Perca fluviatilis*).

In 2007–09, NIWA was contracted by New Zealand Fish & Game to develop and test acoustic techniques to survey some of the large lakes in the South Island supporting recreational salmonid fisheries in an effort to develop a monitoring system for salmonids (Gauthier 2008, 2009, James et al. 2007). The most recent survey from 10–19 February 2009 included five lakes: Lakes Coleridge, Benmore, Hawea, Wanaka, and Te Anau (Gauthier 2009). In association with the acoustic survey, gill netting was carried out in Lake Coleridge and Lake Benmore to confirm and identify species present, and to compare catch rates to acoustic indices along a few transects. In addition, visual surveys at five sites were performed in Lake Te Anau to assess the presence and density of salmonids in shallow waters not accessible to the acoustic survey (areas less than 3 m depth).

Gauthier (2009) concluded that results from the 2009 survey were encouraging and suggested that the approach developed by NIWA and Fish & Game would provide relative indices of abundance to monitor salmonids populations in large lakes using acoustic techniques. Gill net experiments in Lakes Coleridge and Benmore were useful to confirm the presence and composition of salmonid targets, and catch rates appeared to be broadly correlated to acoustic densities. The visual trials in Lake Te Anau were also successful, and suggested that salmonid densities in shallow waters not accessible in the acoustic survey were comparable to the densities obtained in deeper areas (3–30 m).

In 2023 NIWA was contracted by Otago Fish & Game (project FGC22301) to carry out further acoustic surveys to monitor the abundance of salmonids in four Otago lakes: Dunstan, Hawea, Wakatipu, and Wanaka (Figure 1-1). Of these, Lake Hawea and Lake Wanaka had been surveyed in all previous surveys (i.e., 2007, 2008, and 2009), Lake Wakatipu had been surveyed in 2007 and 2008, and Lake Dunstan had not been surveyed previously by NIWA. Gill net experiments were not conducted in the 2023 survey, apart from one set in Lake Dunstan. Similarly, visual surveys to assess the density of salmonids in shallow water not accessible to the acoustic survey, were not conducted in 2023.

This report presents the results from the 2023 survey with comparisons to the previous years.

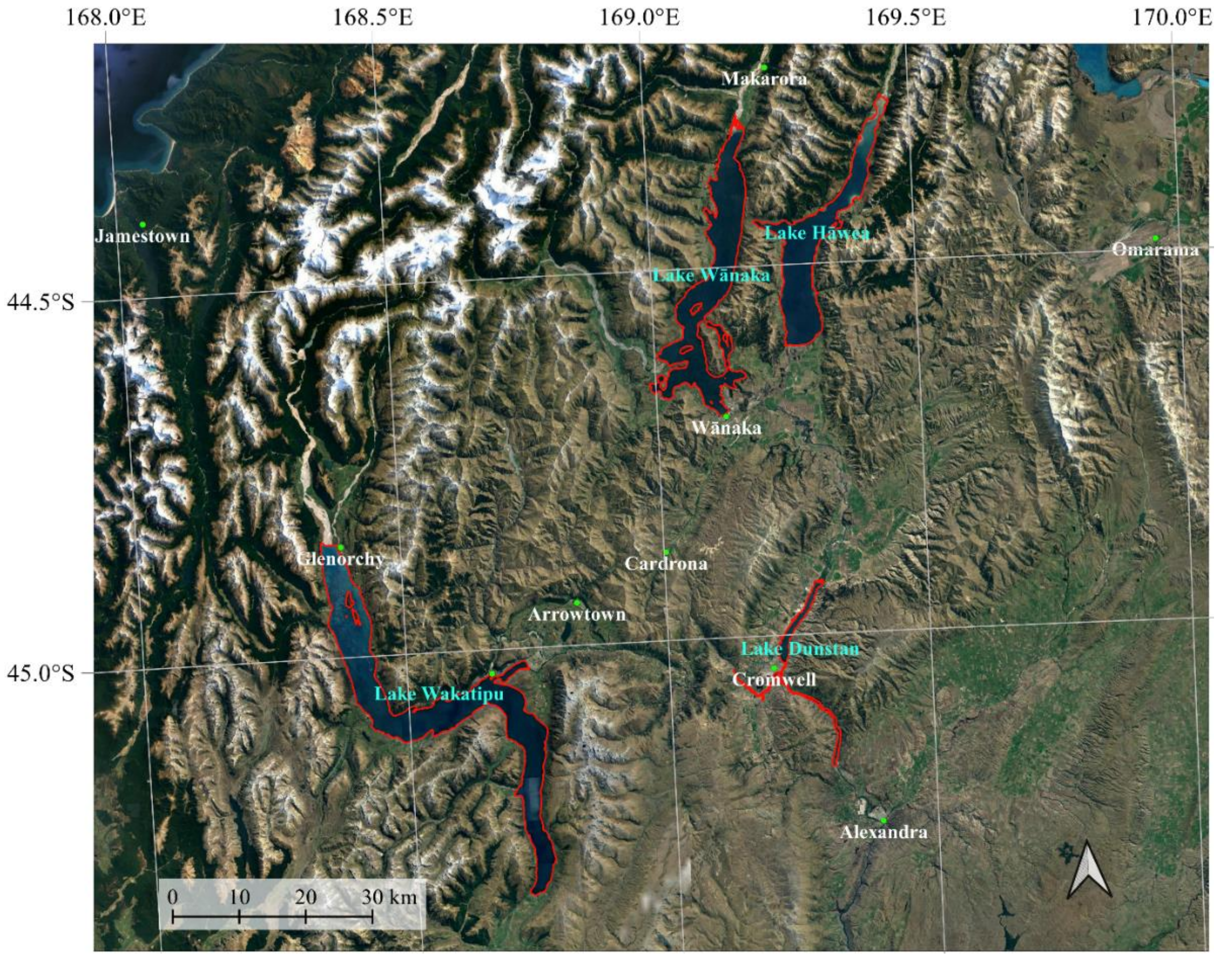

Figure 1-1: Map showing lakes included in this project from north to south: Lakes Hawea, Wanaka, Dunstan, and Wakatipu.

2 Methods

2.1 Acoustic system

To ensure comparability with previous surveys, the acoustic system used for the 2023 surveys was the same as that used in 2009. This consisted of a SIMRAD EK60 echosounder with a 22° (at 3 dB half power points) split-beam 120 kHz transducer, specifically developed for acoustic work on salmonids in South Island lakes (e.g., Gauthier (2009)) by Industrial Research Limited (IRL). The echosounder comprised a transceiver unit (of similar dimensions to a small desktop computer), a transducer mounted on a pole on the side of the vessel, and a laptop running monitoring and data-collection software (SIMRAD EK80). The echosounder and other instruments (i.e., laptops and GPS) were be powered by two separate 12-V batteries.

The surveys were conducted using the research vessel (RV) *Otago Fish & Game 7* (*OFG7*), a 5.5-metre Kwik Kraft aluminium pontoon boat with a 115 hp four-stroke Suzuki outboard. The physically small transducer (12 cm x 12 cm outer-shell) was mounted on the lower end of a pole (50 mm diameter stainless steel tube) in a bracket that fitted onto the gunwale of the vessel on the starboard side at approximately amidships (Figure 2-1). When deployed on the pole the transducer face was submerged approximately 100 cm below the surface and 30 cm below the keel. The pole was slid upwards so the transducer was out of the water for transit and then lowered to resume surveying.

The acoustic system was calibrated before the start of the survey on 8 February in Lake Dunstan using a standard 38.1 mm tungsten carbide sphere, broadly as per the procedures in Demer et al. (2015). A calibration report is available in Appendix C.

Water temperature measurements were taken using an RBR Duet temperature/depth probe, serial number 82705 on each of the lakes. While one RBR cast was done at Lakes Dunstan, Hawea, and Wanaka, three were done at Lake Wakatipu to account for spatial variability of temperature due to lake's large area and distance between transects. The average temperature between 3 m and the maximum depth of the RBR cast was used to calculate sound speed and absorption coefficient for echo-integration using the formulae of Mackenzie (1981) and Francois & Garrison (1982), respectively.

Figure 2-1: Otago Fish & Game 7 (OFG7) vessel showing the transducer mounting arrangement. The pole was mounted amidships off the starboard side with the IRL-120 kHz transducer at the end of the pole (A), and a close-up of the pole mount of 120 kHz transducer on RV OFG7 (B).

2.2 Survey design

The survey design in Lakes Hawea, Wanaka, and Wakatipu consisted of single pass acoustic transects following zigzag patterns alongshore, covering depths from as shallow as possible (usually about 2–3 m) out to 30 m, this being the depth beyond which few fish were found in the earlier gill netting surveys (James & Graynoth (2002) and confirmed in the 2008 acoustic survey by Gauthier (2008)). The 2023 survey covered the same transects surveyed in 2008 and 2009 for Lake Hawea (7 transects) and Lake Wanaka (8 transects). For Lake Wakatipu we covered the same transects surveyed in 2008 (10 transects).

For Lake Dunstan, not surveyed previously, the survey design consisted of an east–west zigzag pattern running across the lake with a total of 18 transects conducted from north to south. Only the Clutha Arm of Lake Dunstan was surveyed; consultation with Otago Fish & Game staff suggested that this arm had the highest angling effort and likely highest densities of salmonids.

The average survey speed remained very consistent between lakes (mean 4.3 knots, standard deviation 0.2 knots). Navigation was provided by a laptop linked to a USB GPS unit running a QGIS project with the location of the acoustic transects of the previous surveys to be repeated in 2023. A separate USB GPS unit was connected to the computer collecting the acoustic data for continuous geo-reference.

2.3 Target identification – drop cameras

A drop-camera system consisting of a GoPro Hero4 camera and associated lights (dive torches; Figure 2-2) was used in conjunction with the acoustic survey as an attempt to visually identify detected acoustic targets. This was lowered on a rope from the vessel while camera depth and fish reaction are monitored on the echosounder. A similar system was used previously to successfully detect schools of perch in Lake Rototoa in 2021 (O'Driscoll et al. 2021). A total of 10 camera drops were carried out.

Figure 2-2: Drop camera system consisting of a GoPro Hero4 camera and associated dive torch.

2.4 Target identification – gill nets

A monofilament gill net comprising two sections, a 20 m section of mesh size 125 mm and a 20 m section of mesh size 60 mm, was set on one occasion in Lake Dunstan. Due to the clarity of water in the other lakes and the time taken to deploy and retrieve the net, the gill net was not used in Lakes Hawea, Wakatipu, or Wanaka.

2.5 Acoustic analyses

Analyses of acoustic data were carried out using 'echo counting' methods (Kieser & Mulligan 1984) as implemented in NIWA's custom post-processing software ESP3 (Ladroit et al. 2020) and described by O'Driscoll et al. (2021). Acoustic data processing consisted of several steps to define bottom echoes, remove noise, create data regions, and identify and quantify potential salmonid targets.

An automatic bottom detection algorithm in ESP3 was applied in all transects. Bottom definitions were inspected visually and edited manually if required. Where beds of aquatic plants were observed in the data, the bottom definition followed the upper edge of the plants (i.e., plant canopy). Bad data regions were created to exclude noise from the analyses (e.g., wind-induced noise near the surface).

Following acoustic data grooming, echograms were scrutinised to detect potential fish targets and manually create data regions around them which were tagged as single targets (tag = ST). All echograms were examined with a 40 Log R time-varied gain, suitable to identify and measure dispersed single targets (Simmonds & MacLennan 2005). The scrutinisation involved using variable target strength (TS) amplitude thresholds in the echograms to determine whether the echo met three main criteria: i) had the distinctive 'thumbnail' shape produced by a single target; ii) TS values of the echoes were greater than -55 dB; and iii) echoes were spatially separated from other echoes. This approach enabled us to isolate fish targets close to the bottom, a technique most useful over steep slopes, where the acoustic dead zone (the superposition of fish and bottom echoes due to beam spreading) is substantial. The technique also enabled the detection of artefacts (such as submerged trees, and bubble plumes) that could otherwise be misconstrued as fish targets, or the detection of single targets within dense clouds of small organisms. For more information on the detection of single targets and examples of the use of multiple thresholds, see James et al. (2007) and Gauthier (2009).

Once all targets were identified and data regions ('boxes') were drawn around potential fish target (or cluster of targets), we applied single target detection and tracking algorithms to these data regions. The first step was to identify single targets using parameters in Table 2-1. The next step was to track single targets between consecutive pings using parameters in Table 2-2. The α-β tracking algorithms (Blackman 1986) implements a fixed coefficient filtering method. A single target was considered as a candidate for appending to a track if it is within a volume or target gate ellipsoid centred about the predicted location of a track. We used tracked targets as an estimate of fish numbers to avoid the issue of multiple counts from same target. The algorithms were applied from 3 m below the transducer down to the detected bottom, consistent with previous data analysis procedures.

Numbers of tracked targets were exported using a 100-ping long (equivalent to ca. 25 m) and 1-m high integration grid.

The single target detection and tracking algorithms were applied automatically to all files using the scripting capabilities of ESP3. We produced three types of result files from the echo-integration: i) tracked target results, which is a Microsoft Excel file with 'TT_'frequency in Hz' appended to its name and contains detailed information of each sample belonging to a tracked target (e.g., range, TS, etc.); ii) sliced transect results, which is a comma separated file with 'sliced' appended to its name and contains tracked targets in a 100-pin long and 1-m high geo- and time-referenced grid; and iii) result output, which is a Microsoft Excel file with 'output' appended to its name and contains a summary of the number of tracked targets per transect and lake. While ESP3 produces a single file per transect for the tracked target and sliced transect results, only a single output file is produced from the echo-integration process of all lakes if this is done using the same ESP3 script file.

The volume of water sampled V_t in m^3 on each transect was obtained as the summation of the volumes of the grid cell from the sliced transects files, which was calculated by:

$$V_t = \sum_{i=0}^{n-1} l_i \sin\frac{\phi}{2}(Rmax_i^2 - Rmin_i^2)$$

Where, ϕ is the across track beam angle in radians, $Rmax$ and $Rmin$ are the minimum and maximum range of the grid cell i in m, and l is the length of grid cell i in m.

Volumetric densities of salmonids were obtained by dividing the number of detected tracks along a transect by its total volume sampled. Results were expressed as fish per cubic metre (m^3) and as fish per cubic hectometre (hm^3). One hectometre is equal to 100 m. Area densities of fish (fish per lake surface area in m^2 or hectare) were also calculated by multiplying the volumetric densities by the mean depth along a transect (Kieser & Mulligan 1984). These units are more commonly used and can be extrapolated to fish population for a given surface area.

Table 2-1: Single target detection parameters used in ESP3 using the 120 kHz wide-beam transducer.

Parameter (unit)	Value
Minimum range (m)	3
Maximum range (m)	Infinite
Target strength minimum threshold (dB)	-55
Target strength maximum threshold (dB)	-20
Pulse length determination level (dB)	6
Minimum normalised pulse length	0.5
Maximum normalised pulse length	2.0
Maximum beam compensation (dB)	12.0
Maximum standard deviation of angles (degrees)	2.0

Table 2-2: Target tracking detection parameters used in ESP3. The TS threshold represents the minimum value for the maximum TS within a track (i.e., if the maximum TS within a track is below -45.0 dB, the track is rejected).

Parameter (unit)	Value
Lower threshold for maximum TS within a track (dB)	-45.0
Alpha	0.7
Beta	0.5
Exclusion distance – major and minor axis (m)	2.0
Exclusion distance – depth (m)	0.4
Major axis weight (%)	20
Minor axis weight (%)	20
Range weight (%)	40
Target strength weight (%)	20
Minimum number of single targets in track	3
Maximum gap between single targets (pings)	3
Exclusion distance – major and minor axis (m)	2.0
Exclusion distance – depth (m)	0.4

The target tracked result files from ESP3 contain individual target strength (TS) values for each of the samples of a tracked target. Because TS is a logarithmic variable, the mean TS (dB) of a track was calculated by averaging its linear equivalent, the acoustic backscattering cross-section (σ_{bs}), of all the samples along the track. If σ_{bs} is the acoustic backscattering cross-section of a target (units of m^2 m^{-2}) then 'target strength' (TS) is

$$TS = 10\ log_{10}\ (\sigma_{bs}) \text{ or equivalently } \sigma_{bs} = 10^{TS/10}$$

taking the mean of these σ_{bs} values and converting the result back into a TS value, gives the mean TS of a track.

2.6 Sensitivity analysis

We carried out sensitivity analyses on the target tracking detection parameters used in ESP3 (Table 2-2). We tested how sensitive the target tracking detection algorithm was when changing three parameters separately: i) decreasing the maximum excluding distance on the major/minor axes to 1 m; ii) decreasing the maximum gap between pings in a track to 1 ping; iii) increasing the minimum number of pings per track = 5, and changing all three parameters simultaneously.

3 Results

3.1 Acoustic survey execution

Surveys of the four Otago lakes were conducted between 9–13 February 2023. Weather during all surveys was excellent with light winds and calm waters.

3.1.1 Lake Dunstan

The survey in Lake Dunstan started at 08:30 NZDT on 9 February at the northern end of the Lake. Transects were carried out in sequential order from south to north (Figure 3-1). Seven camera drops were done during the survey: two in transect 6; three in transect 9; and 2 in transect 14. A gillnet was set on targets detected on transect 9 with a soak time of 60 minutes (from 11:00 to 12:00). No fish were caught. An RBR cast was conducted at the end of the acoustic survey near transect 16. The survey in Lake Dunstan finished at 13:45.

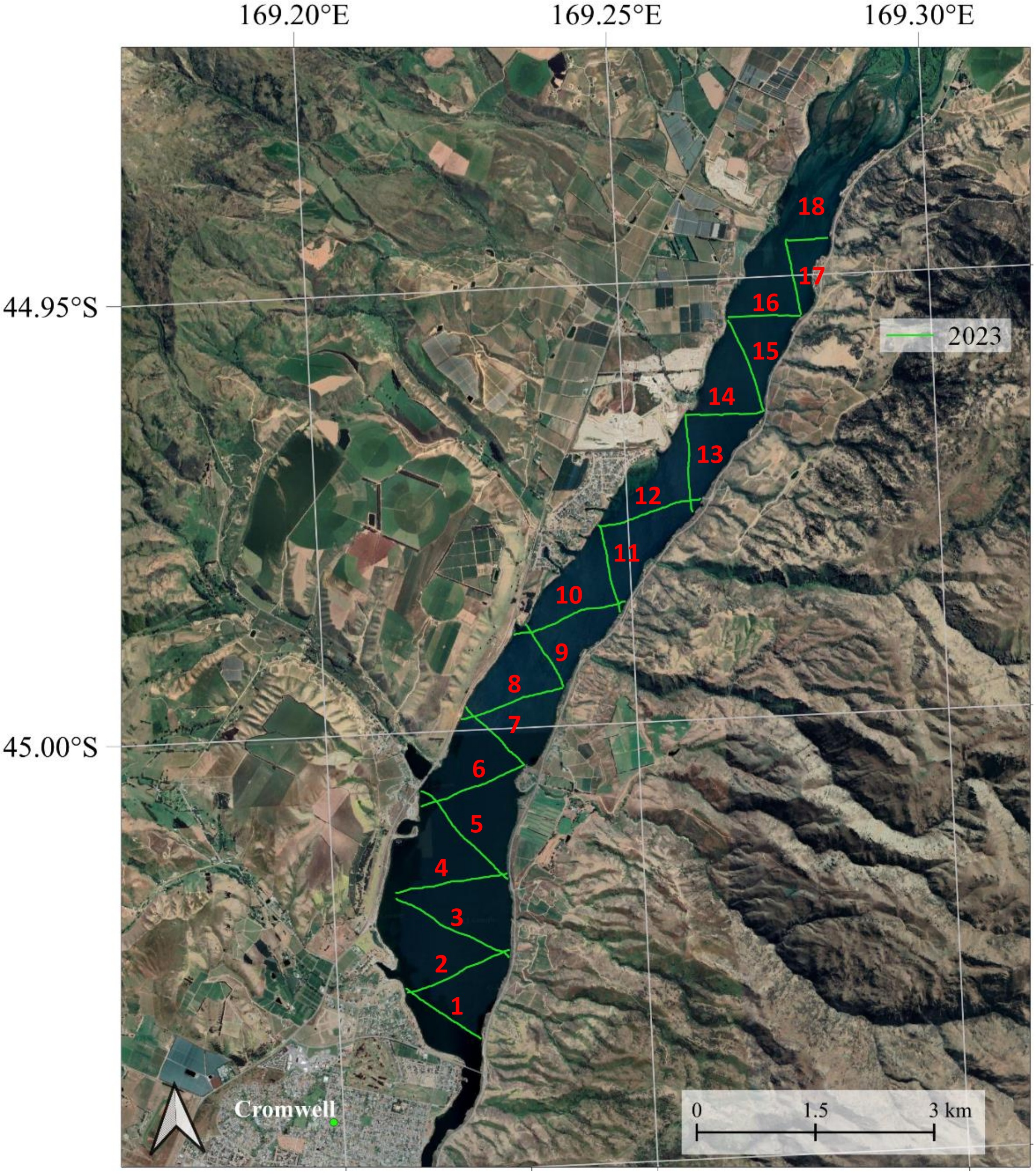

Figure 3-1: Location of the acoustic transects (n = 18) completed in the 2023 acoustic survey in Lake Dunstan.

3.1.2 Lake Hawea

The survey in Lake Hawea started at 08:30 NZDT on 10 February. The first transect surveyed was transect 4 at the southeastern side of the lake, which was followed by transects 7, 1, and 5. An RBR cast was conducted at the end of transect 7 (Figure 3-2). The survey continued on the western side of Lake Hawea with transects 2, 3, and transect 8. The survey was completed at 15:40. No camera drops were done in Lake Hawea.

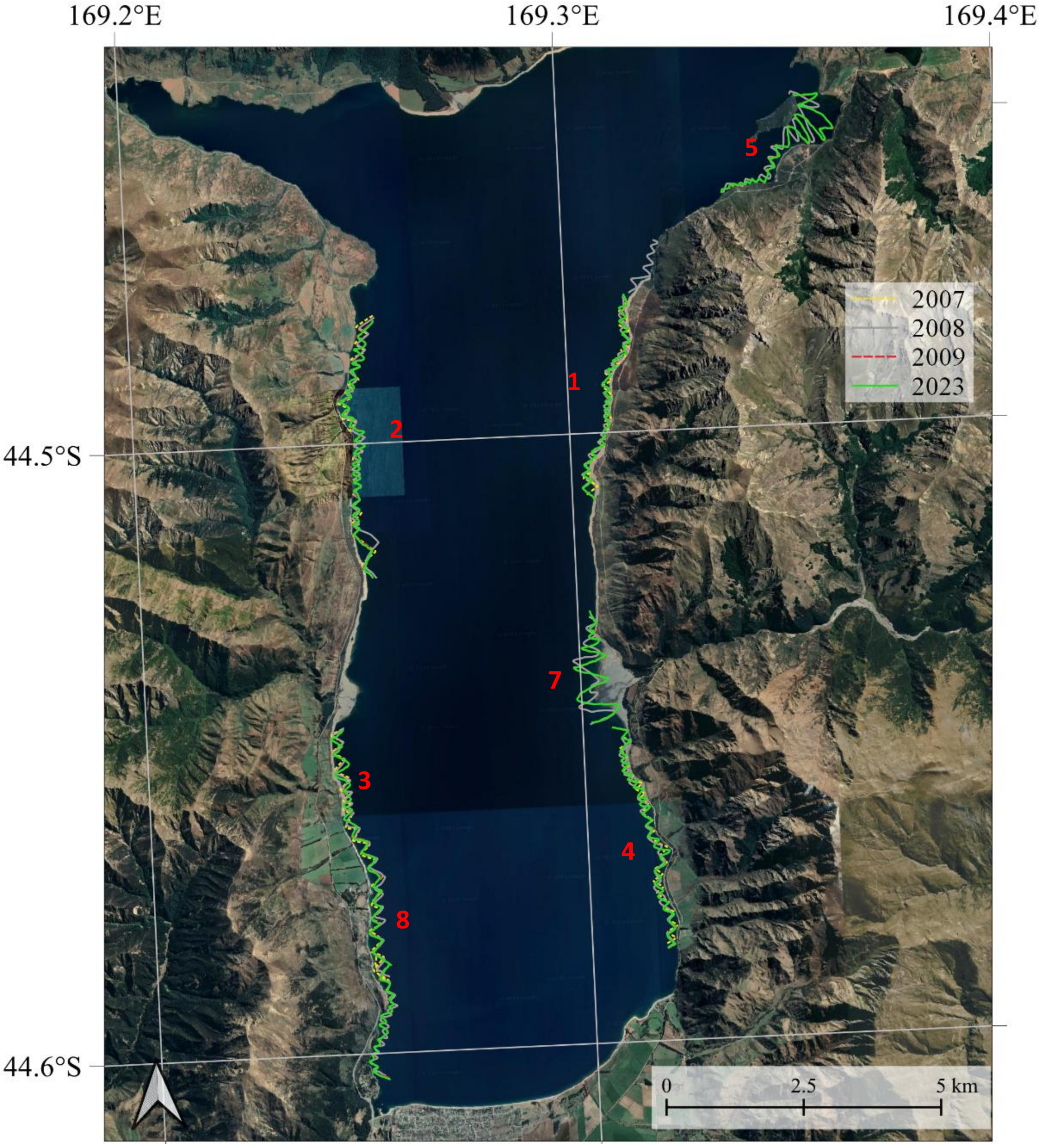

Figure 3-2: Location of the acoustic transects (n = 7) completed in the 2023 acoustic survey in Lake Hawea. Location of transects surveyed in previous years are also shown. The transect numbers were kept consistent with previous surveys.

3.1.3 Lake Wakatipu

The survey in Lake Wakatipu started at 09:00 on 11 February. RV *OFG7* was launched near Kingston at the south of Lake Wakatipu and the first transect surveyed was transect 1 (Figure 3-3). Transects 11 and 10 were surveyed next. Three camera drops and one RBR cast were conducted upon completion of transect 10 before the RV *OFG7* returned to Kingston. RV *OFG7* was relaunched at Frankton and the survey resumed at 14:00. Transects 5 and 4 were completed by 16:00 and then vessel returned to the Frankton ramp.

The survey continued on 12 February from Glenorchy. The RV *OFG7* was launched at 08:45; transects 2, 3, and 8 were completed followed by an RBR cast before returning to Glenorchy at 12:30. RV *OFG7* was relaunched from Frankton Arm to complete the last two transects near Frankton, transects 6 and 7. After completion of transect 7, an RBR cast was conducted, and then the vessel returned to Frankton Arm at 16:30.

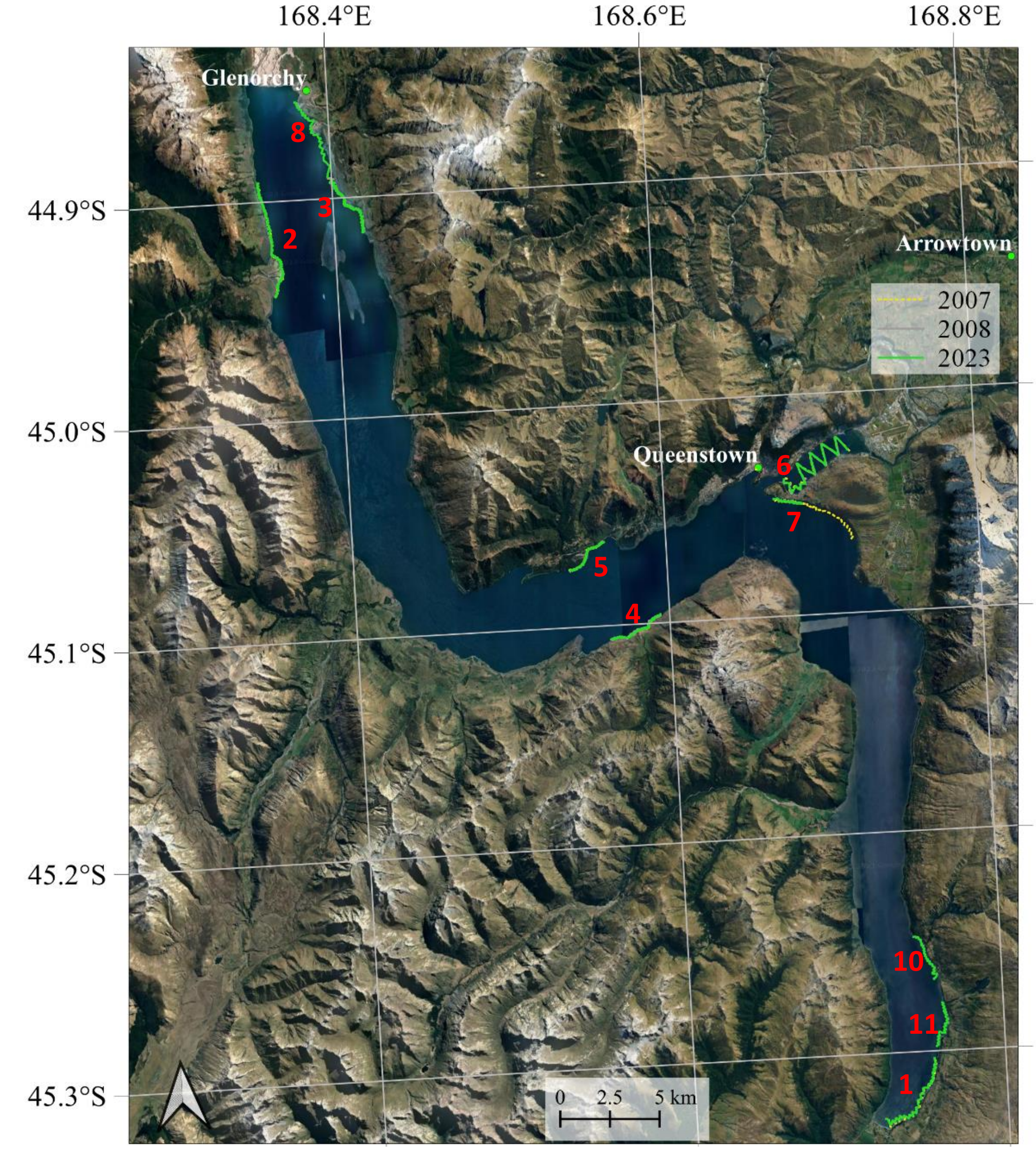

Figure 3-3: Location of the acoustic transects completed (n = 10) in the 2023 acoustic survey in Lake Wakatipu. Location of transects surveyed in previous years are also shown. The transect numbers were kept consistent with previous surveys.

3.1.4 Lake Wanaka

The survey in Lake Wanaka started at 08:45 on 13 February from Glendhu Bay, at the southwestern side of the lake. Transects 12 and 4 near Glendhu Bay were surveyed first, followed by transects 1 and 10 at the northern end of Lake Wanaka (Figure 3-4). Survey continued with transect 2 in central Lake Wanaka where an RBR cast was conducted. Transects 11 and 6 were surveyed next at the eastern side of the lake before the RV *OFG7* returned near Glendhu Bay to complete the survey with transect 3. The survey was completed at 14:40. No camera drops were done in Lake Wanaka.

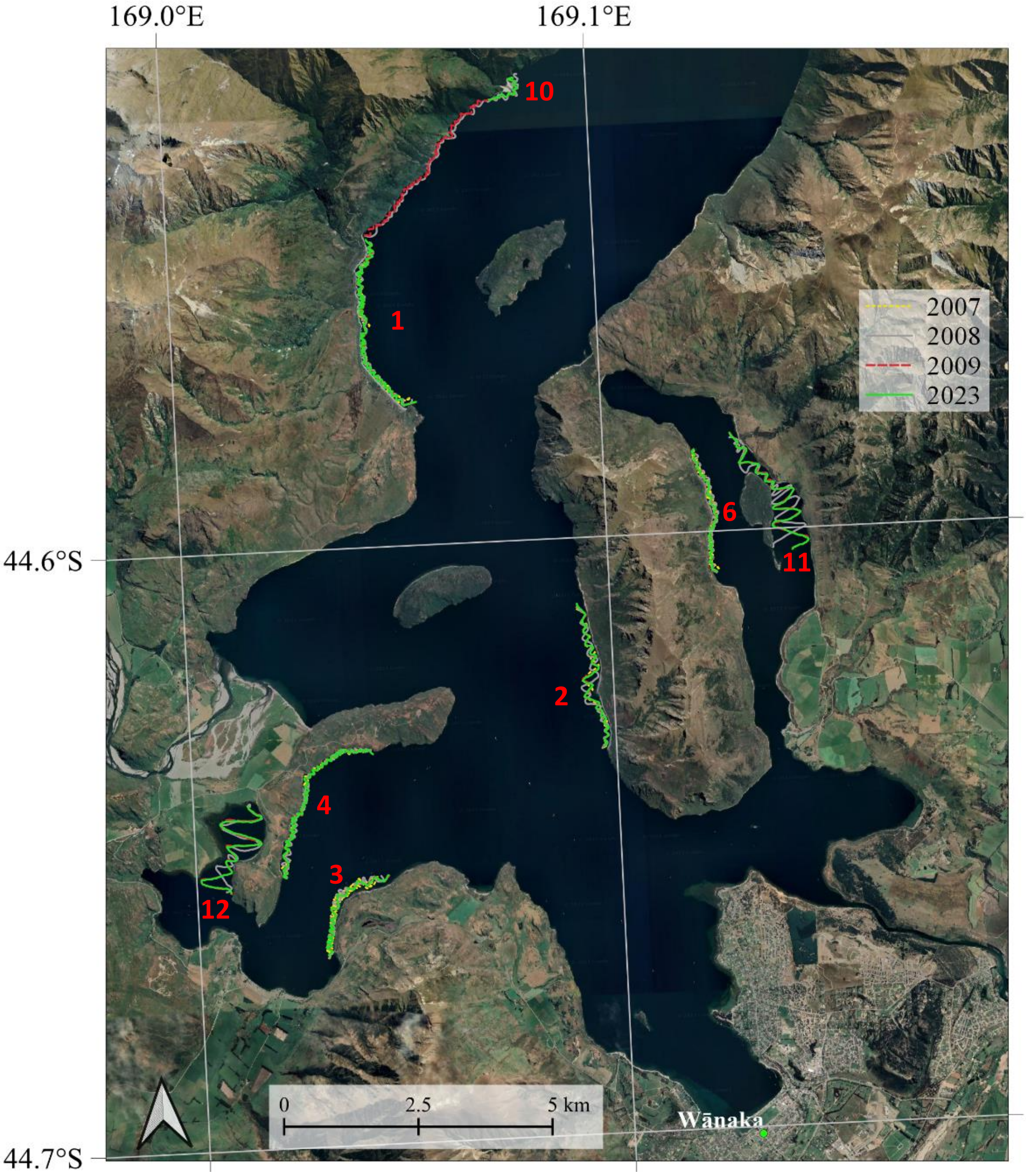

Figure 3-4: Location of the acoustic transects (n = 8) completed in the 2023 acoustic survey in Lake Wanaka. Location of transects surveyed in previous years are also shown. The transect numbers were kept consistent with previous surveys. Note that in 2008 and 2009 zig-zag lines were ran between transects 1 and 10, however these were not considered as transects for the analyses therefore they were not repeated in 2023.

3.2 Environmental parameters and acoustic coefficients

Temperature data collected with the RBR data logger were used to calculate the sound speed and sound absorption coefficient for each lake (Table 3-1). While a single sound speed value and a single sound absorption coefficient were applied for echo-integration for Lakes Dunstan, Hawea, and Wanaka, three different values were applied in Lake Wakatipu based on the proximity of the transects to the closest RBR cast. The transects in Lake Wakatipu were grouped into three areas: Wakatipu – Frankton (transects 4, 5, 6, and 7); Wakatipu – Glenorchy, (transects 2, 3 and 8); and Wakatipu Kingston (transects 1, 10, and 11). Water temperatures were warmest in Lake Dunstan and were coldest in Lake Wakatipu near Glenorchy.

Table 3-1: Mean water temperature from RBR casts in each of the lakes. Estimates of sound speed and sound absorption coefficient were calculated using the formulae of Francois & Garrison (1982) and Fofonoff & Millard (1983), respectively.

Lake	Temperature (°C)	Max. depth (m)	Sound speed (m s^{-1})	Absorption (dB km^2)
Dunstan	18.0	7.3	1476.2	3.38
Hawea	17.0	23.8	1473.1	3.50
Wakatipu - Frankton	17.1	28.7	1473.4	3.49
Wakatipu - Glenorchy	16.3	27.5	1470.9	3.58
Wakatipu - Kingston	17.5	17.7	1474.6	3.45
Wanaka	19.9	29.1	1482.6	3.18

3.3 Drop camera verification

Ten camera drops were carried out from RV *OFG7* to identify acoustic targets observed while running the transects: 7 in lake Dunstan; and 3 in Lake Wakatipu (Table 3-2). The recorded videos in Lake Dunstan showed submerged trees, bubbles, and aquatic plants, however no observations of fish were made. Nothing was observed on videos from Lake Wakatipu. This could be due to an avoidance effect of fish to the lights or the boat. An example of validated targets using the footage from the drop camera system is shown in Figure 3-5.

Table 3-2: Camera drop deployments in the 2023 acoustic survey.

Lake	Transect number	Number of deployments	Target/Observations
Dunstan	6	2	Vertical stacks/No observations
	9	3	Fish looking marks/Trees
	14	2	Bubbles/Bubbles and weeds
Hawea	–	0	–
Wakatipu	10	3	Fish looking marks /No observations
Wanaka	–	0	–

A

B

C

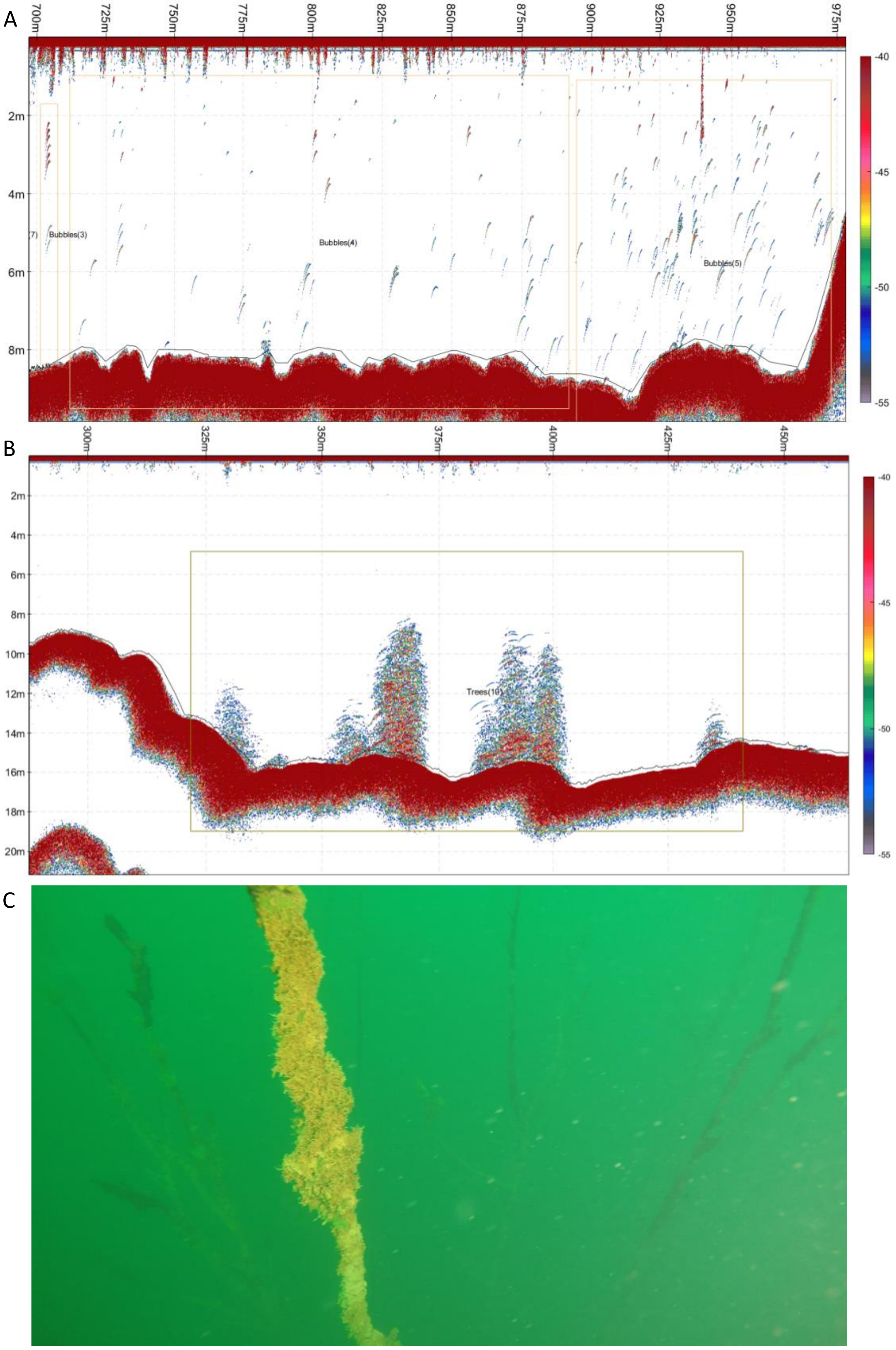

Figure 3-5: Echograms showing volume backscatter strength (dB) collected in transect 14 (panel A) and 9 (panel B) in Lake Dunstan, and screenshot of submerged tree identified using the drop camera system in transect 9 (panel C). Acoustic targets identified as bubbles and trees using the drop camera system have been marked as bad data regions (i.e., excluded from analysis).

3.4 Echo-counting and density estimates

Lake Wakatipu had the highest tracked target count and density of all lakes, while Lake Dunstan had the lowest target count and Lake Wanaka had the lowest density. Tracked targets here were assumed to be salmonids, although it is known that other species occur (e.g., perch *Perca fluviatilis* in Lake Dunstan). A summary of the results from the 2023 acoustic assessment by lake are shown in Table 3-3 and in Figure 3-6. Results by lake and transect are given in Appendix A.

Table 3-3: Number of salmonid targets counted by lake during the acoustic survey in February 2023, with corresponding densities. Densities are expressed by volume (cubic metre (m^{-3}) and cubic hectometre (hm^{-3})) and by area (metre square (m^{-2}) and hectare (ha^{-1})). Detailed values for each transect are given in Appendix A.

Lake	Target count	Volume sampled (m^{-3})	Fish (m^{-3})	Fish (hm^{-3})	Fish (m^{-2})	Fish (ha^{-1})
Dunstan	69	816 689	8.45E-05	84.5	9.84E-04	9.8
Hawea	150	3 086 941	4.86E-05	48.6	7.38E-04	7.4
Wakatipu	352	6 459 937	5.45E-05	54.5	1.11E-03	10.8
Wanaka	74	3 169 247	2.33E-05	23.4	4.11E-04	4.1

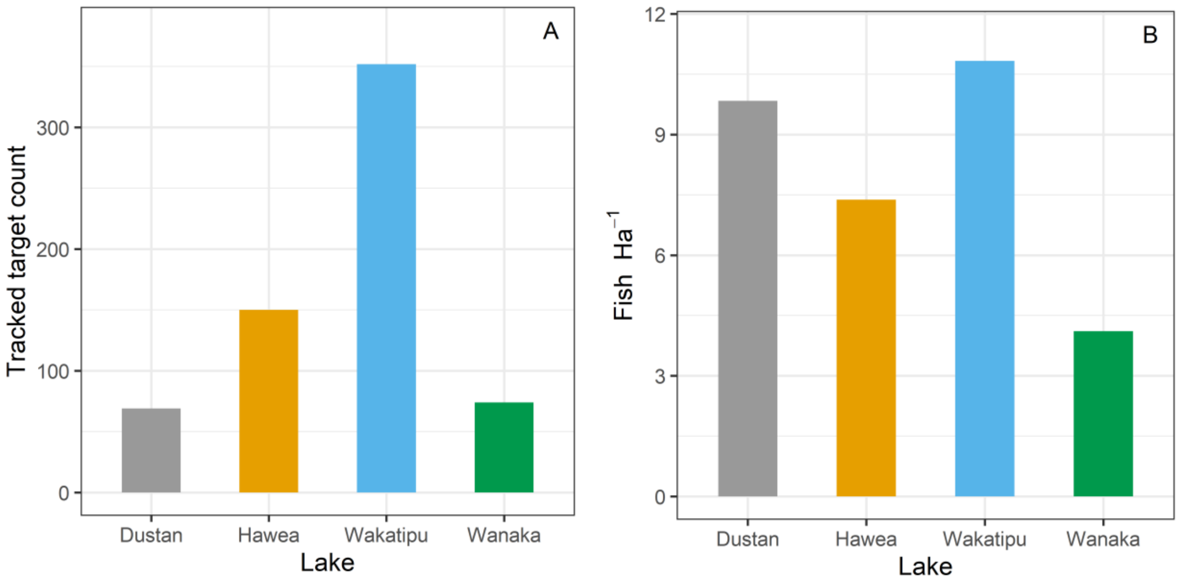

Figure 3-6: Number of tracked targets and fish densities (fish hectare-1) in each lake surveyed in 2023.

Compared to previous surveys, the number of tracked targets in Lake Wakatipu in 2023 was higher than in the last survey conducted in 2008 (results are not comparable with the 2007 survey because of a different set of transect was surveyed then). The number of tracked targets in Lake Hawea in 2023 was similar to that in 2009. The number of tracked targets in Lake Wanaka in 2023 was lower than in the last survey caried out in 2009 (Figure 3-7). The 2023 survey was the first survey in Lake Dunstan.

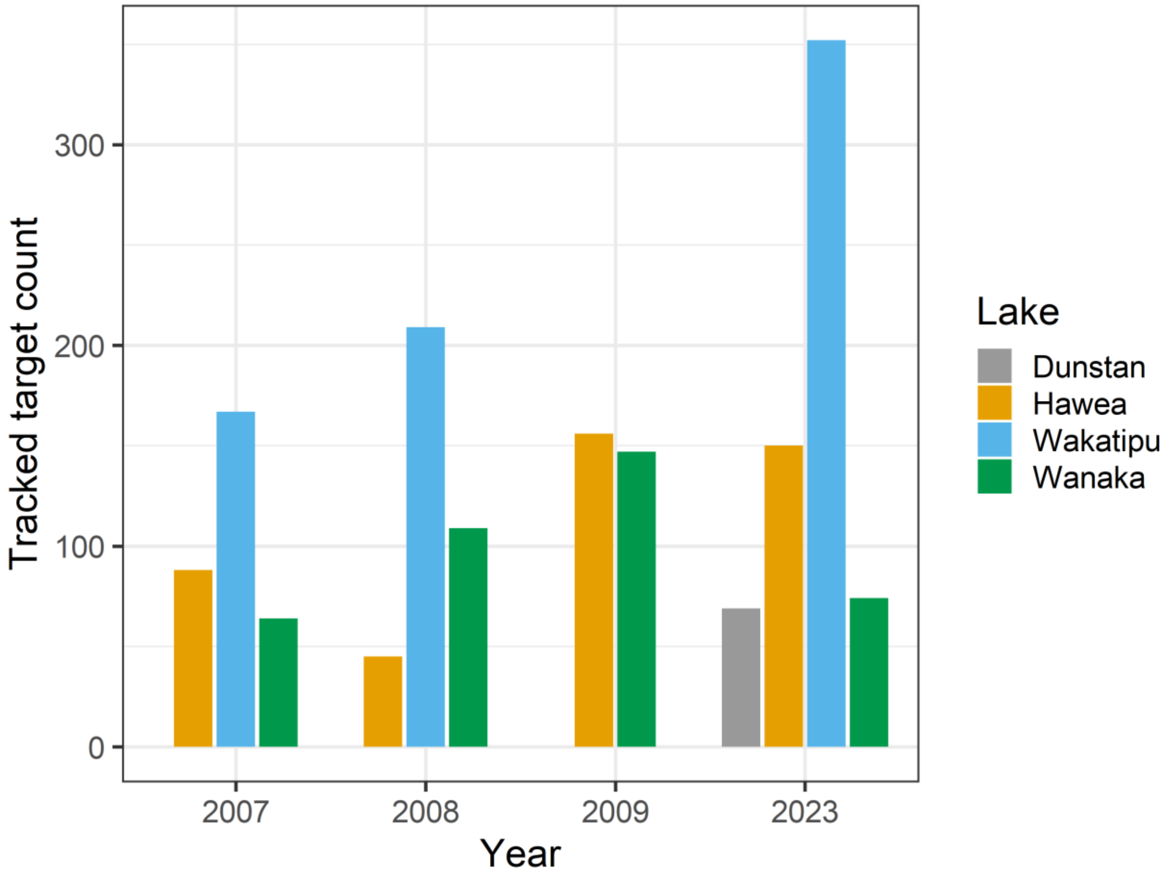

Figure 3-7: Number of tracked targets by lake and survey year. In 2007 only 4, 7, and 5 transects were surveyed in Lakes Hawea, Wakatipu, and Wanaka, respectively. Since 2008 7, 10, and 8 transects have been surveyed in Lakes Hawea, Wakatipu, and Wanaka.

Fish densities in Lake Hawea in 2023 were lower than in 2009 and 2007 and higher than those recorded in 2008 when only four transects were surveyed. Fish densities in Lake Wanaka in 2023 were about half of the fish densities recorded between 2007–2009 (Table A-4).

Out of the three lakes previously surveyed, fish densities in 2023 were higher than previous estimates only in Lake Wakatipu. It is worth noting that this comparison is valid for year 2008 only, as a lower number of transects (n = 7) were completed in 2007 (no survey was carried out in 2009). Time series of fish densities for each lake are shown in Figure 3-8.

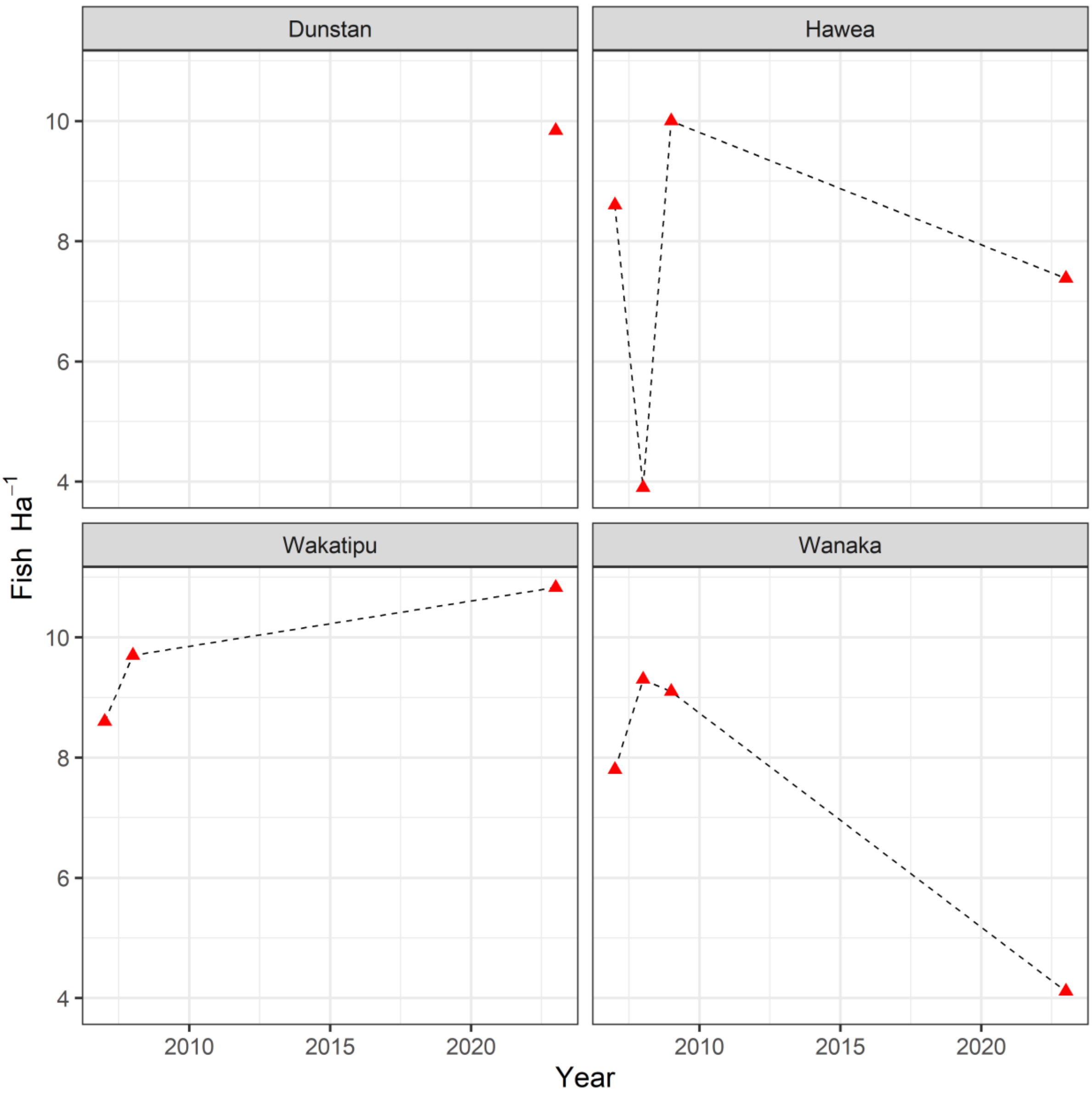

Figure 3-8: Areal fish density (fish hectare-1) in each lake for the four years surveyed. Density estimates are based on different number of transects: in 2007 only 4, 7, and 5 transects were surveyed in Lakes Hawea, Wakatipu, and Wanaka, respectively. Since 2008 7, 10, and 8 transects have been surveyed in Lakes Hawea, Wakatipu, and Wanaka. Density estimates for surveys between 2007–2009 as in reports by James (2007) and Gauthier (2008, 2009).

3.5 Distributions of target strength

The distribution of the tracked target TS (which correlates to fish size) for each lake are presented in Figure 3-9. The TS distribution of tracked targets in Lakes Hawea, Wakatipu, and Wanaka were bimodal and similar, showing a higher mode around -33 dB and lower mode around -46 dB. The TS distribution from these lakes was similar to those observed in 2008 and 2009. The TS distribution in Lake Dunstan was bimodal with two weak modes around -48 and -43 dB. Mean TS ranged from -40.85 in Lake Dunstan to -33.66 dB in Lake Hawea. Excluding Lake Dunstan, the range of mean TS for the other three lakes overlapped with the mean TS range observed in 2009 (-35.5 to -31.6 dB). The lowest mean TS observed in Lake Dunstan suggests that most of the tracked targets in this lake were smaller than the tracked targets in the other lakes. Alternatively, this might indicate that some of the tracked targets detected might not correspond to fish which would be consistent with the common presence of submerged trees, vegetation, and bubbles in the lake (see Figure 3-5).

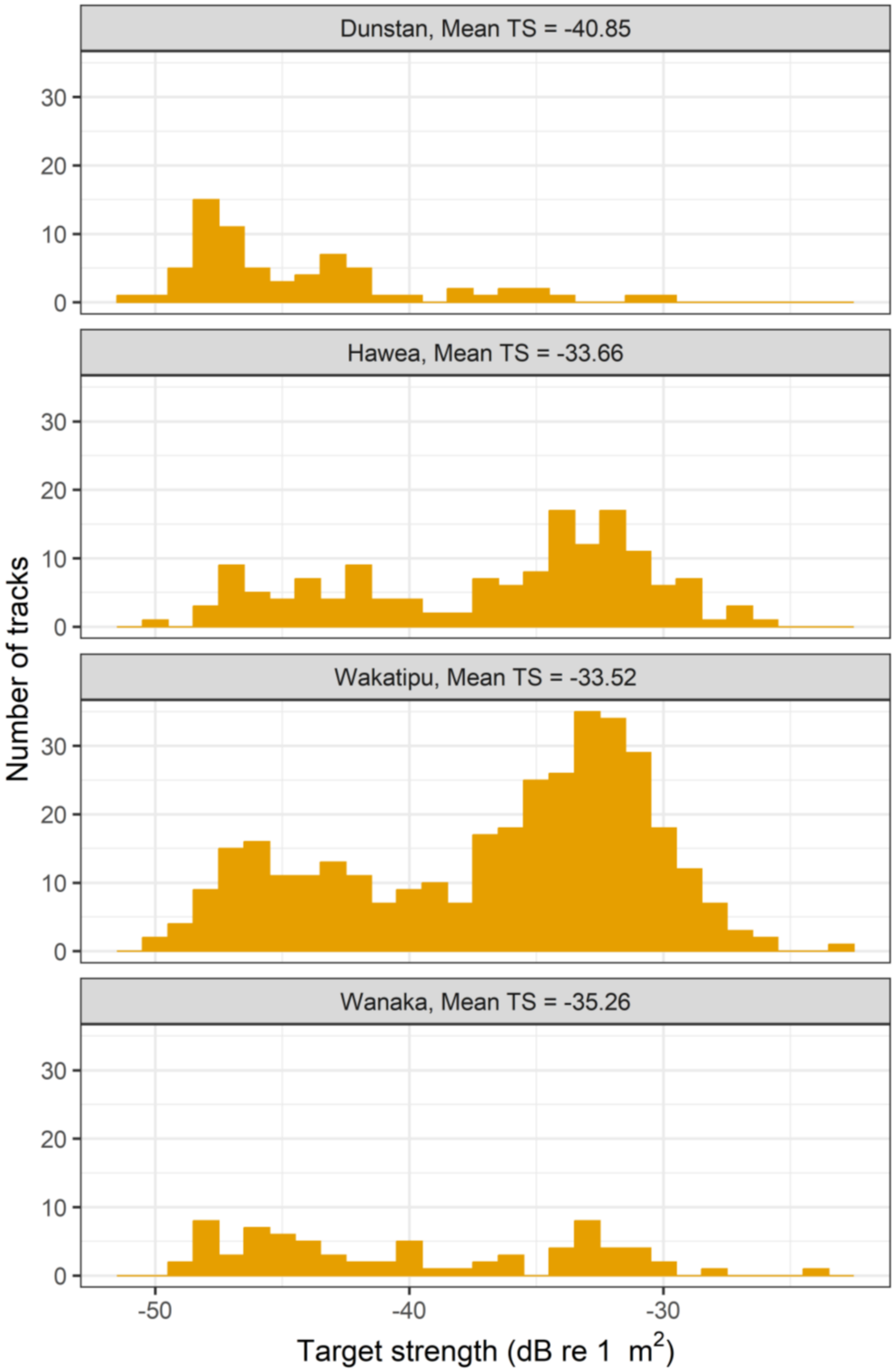

Figure 3-9: Distributions of acoustic target strength (TS) for each of the four lakes surveyed during February 2023. Mean target strength for all tracks are given on top of each histogram.

Based on the two TS modes observed in the data, we grouped the tracked targets into strong and weak tracked targets using a -40 dB threshold, and evaluated their vertical distribution independently (see section 3.6).

3.6 Spatial distribution of tracked targets and fish densities

The spatial distribution of tracked targets for each lake is available in Appendix B.

In Lake Dunstan, tracked targets were concentrated between transects 5 and 9, corresponding to the central/south-central area of the lake (Figure B-1). Transect number 9 had the highest number of tracked targets (n = 12); there were no tracked targets in transect 4 (Table A-1). Despite the lower number of tracked targets at the northern end of Lake Dunstan, the highest areal fish densities were observed there. In Lake Hawea, transect 5 had the highest number of tracked targets and density (Table A-2). Tracked targets were concentrated in the northern section of transect 5, between the shore and Silver Island (Figure B-2). Figure 3-10 shows an example echogram containing tracked targets detected in transects 5. The lowest number of tracked targets and fish densities were found in transect 8, at the southwestern end of the lake (Figure B-4).

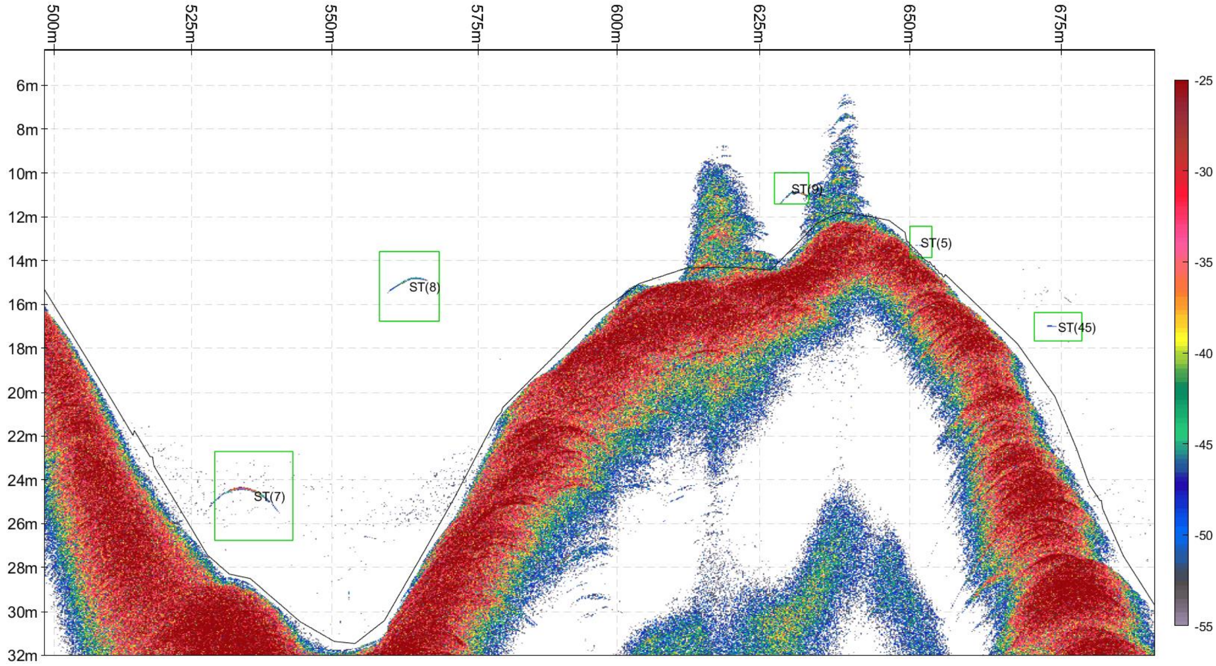

Figure 3-10: Echogram from transect 5 in Lake Hawea showing five tracked targets at different depths identified by the green rectangles. Echogram shows volume backscattering strength with a 40 log time varied gain (TVG). Aquatic plants and be seen at the shallowest part of the echogram.

The spatial distribution fish in Lake Wakatipu showed three areas with high number of tracked targets and fish densities: the northern area of Lake Wakatipu near Glenorchy (transects 2, 3, and 8, Figure B-5), the central area of Lake Wakatipu near Frankton (transects 6 and 7, Figure B-7; and near Kingston in the southern area of the lake (transects 1, 10, and 11, Figure B-8). The lowest number of tracked targets and fish densities were observed in the northern area of Lake Wakatipu (Figure B-5). Transect 6 in Lake Wakatipu had the highest number of tracked targets of all lakes (n = 88) (Table A-3). An example echogram of tracked targets of transect 6 in Lake Wakatipu is shown in Figure 3-11.

In Lake Wanaka, the number of tracked targets and fish densities were low in most transects (Table A-4). The highest number of tracked targets and fish densities were observed in enclosed areas on the eastern side of the lake in transect 11 (Figure B-10) and on the southwestern side of the lake near Glendhu Bay in transect 12 (Figure B-11). An echogram showing tracked targets in transect 11 from Lake Wanaka is shown in Figure 3-12.

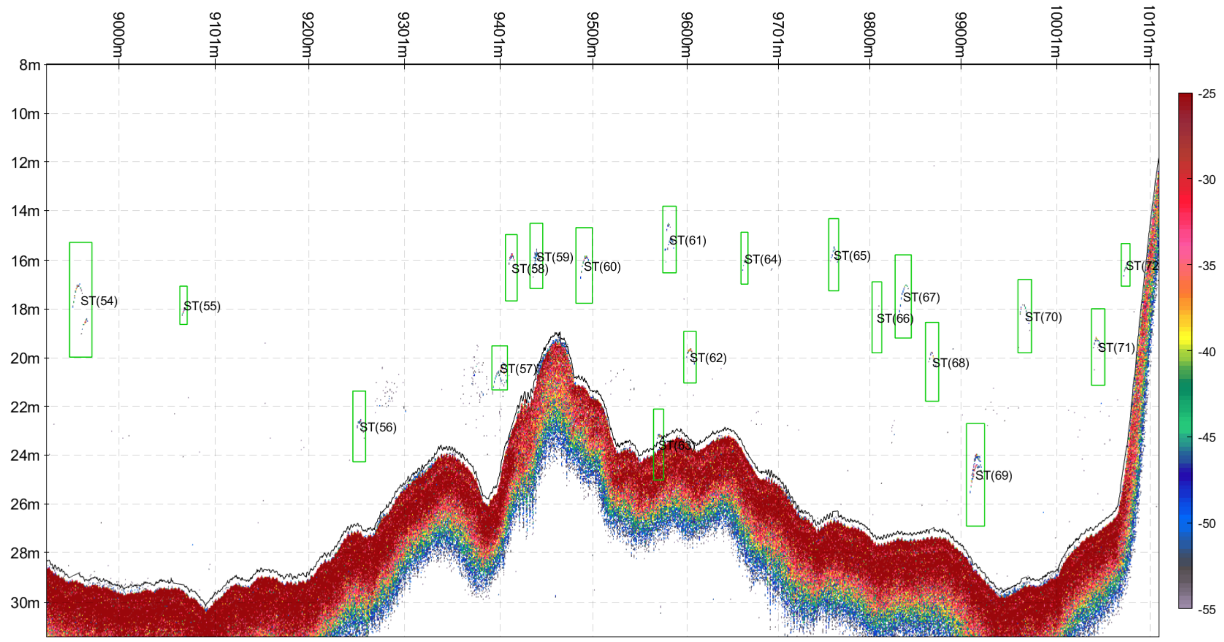

Figure 3-11: Echogram from transect 6 in Lake Wakatipu showing tracked targets at different depths identified by the green rectangles. Echogram shows volume backscattering strength with a 40 log time varied gain (TVG).

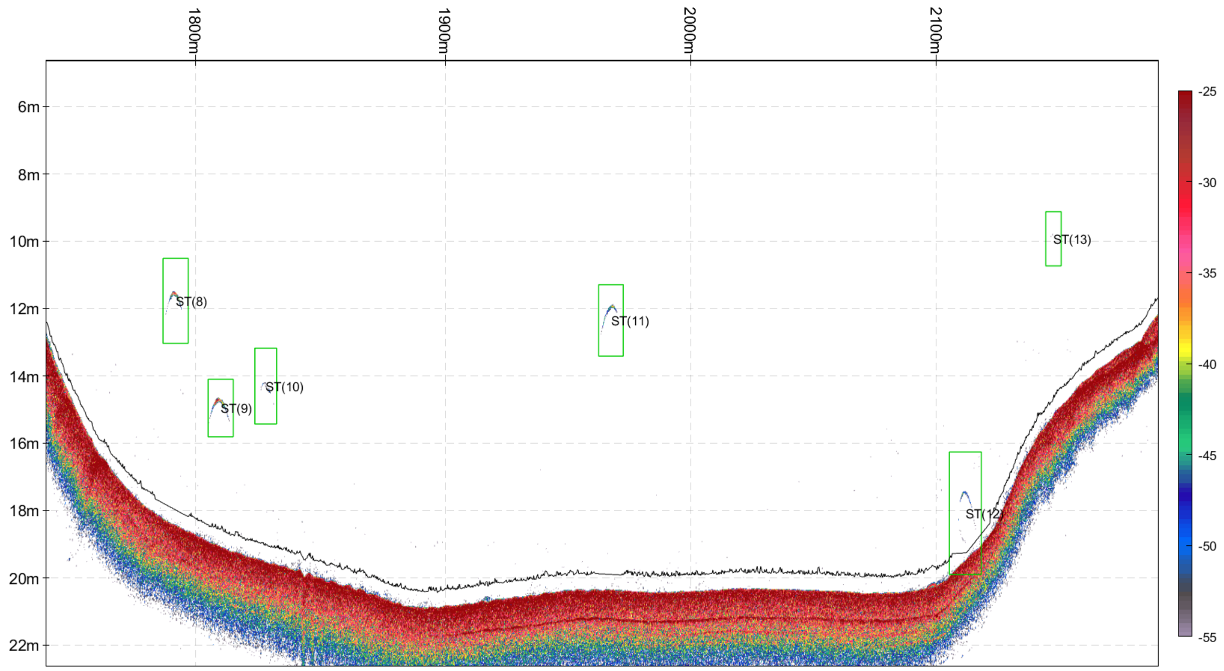

Figure 3-12: Echogram from transect 11 in Lake Wanaka showing tracked targets at different depths identified by the green rectangles. Echogram shows volume backscattering strength with a 40 log time varied gain (TVG).

The vertical distribution of tracked targets for each lake is shown in Figure 3-13. The vertical distribution of tracked targets in Lakes Hawea, Wakatipu, and Wanaka were unimodal and similar, with most targets found from 15–25 m depth, although their mean depths varied slightly. While the mean depth of the tracked targets in Lakes Hawea and Wakatipu were similar (mean depth 19.1, s.d. 7.3 m, and 20.5 m, s.d. 5.4 m, respectively), the mean depth in Lake Wanaka was shallower (16.9 m, s.d. 6.3 m). The vertical distribution of tracked targets in Lake Dunstan was bimodal, with a mode shallower and a mode deeper than 10 m. The mean depth of tracked targets in Lake Dunstan was the shallowest of the four lakes (10.7 m, s.d. 4.8).

Compared to the results from the 2009 and 2008 surveys, the mean depth of the tracked targets in Lakes Hawea and Wakatipu in 2023 was greater by 4 and 5 m, respectively. The mean depth of the tracked targets was also deeper in Lake Wanaka (< 2 m).

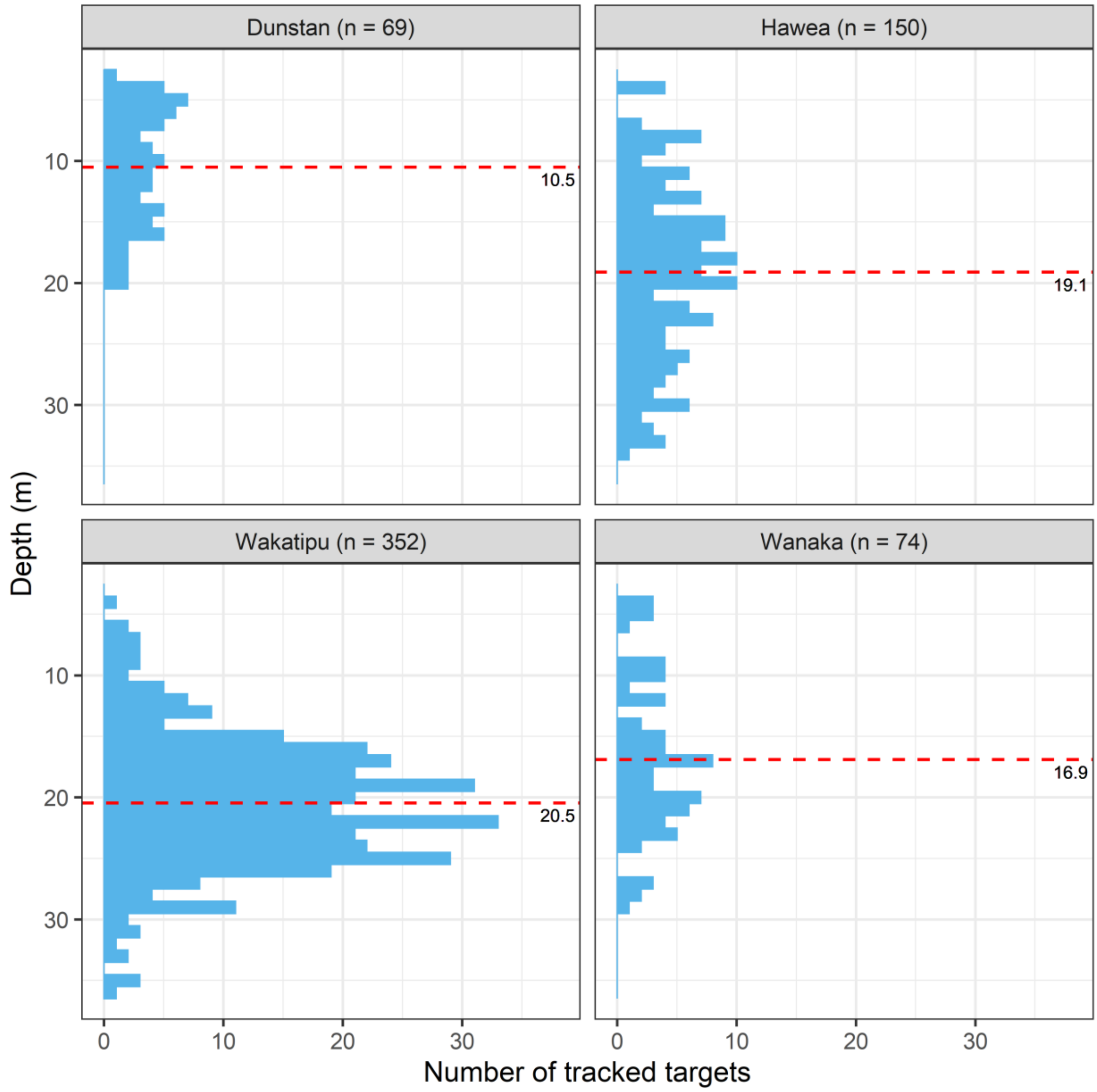

Figure 3-13: Vertical distribution of tracked targets by lake in the 2023 acoustic survey. Dashed lines indicate the mean depth of the tracked targets.

The mean distance between the average depth of the tracked targets and the bottom depth (mean distance to or above bottom) in 2023 was greatest in Lake Wakatipu (5.2 m, s.d. 5 m) and shortest in Lake Hawea (mean 3 m, s.d. 3.5 m). The mean distance to bottom in Lakes Hawea and Wakatipu was greater in 2023 than it was in 2009 and 2008, respectively. This information and the deeper vertical distribution observed in 2023 indicated that the tracked targets in these lakes were in deeper waters than in previous surveys. The mean distance to bottom in Lake Wanaka (4.2 m, s.d. 4.5 m) was shorter in 2023 than it was in 2009. The mean distance to bottom for each lake is displayed in Figure 3-14.

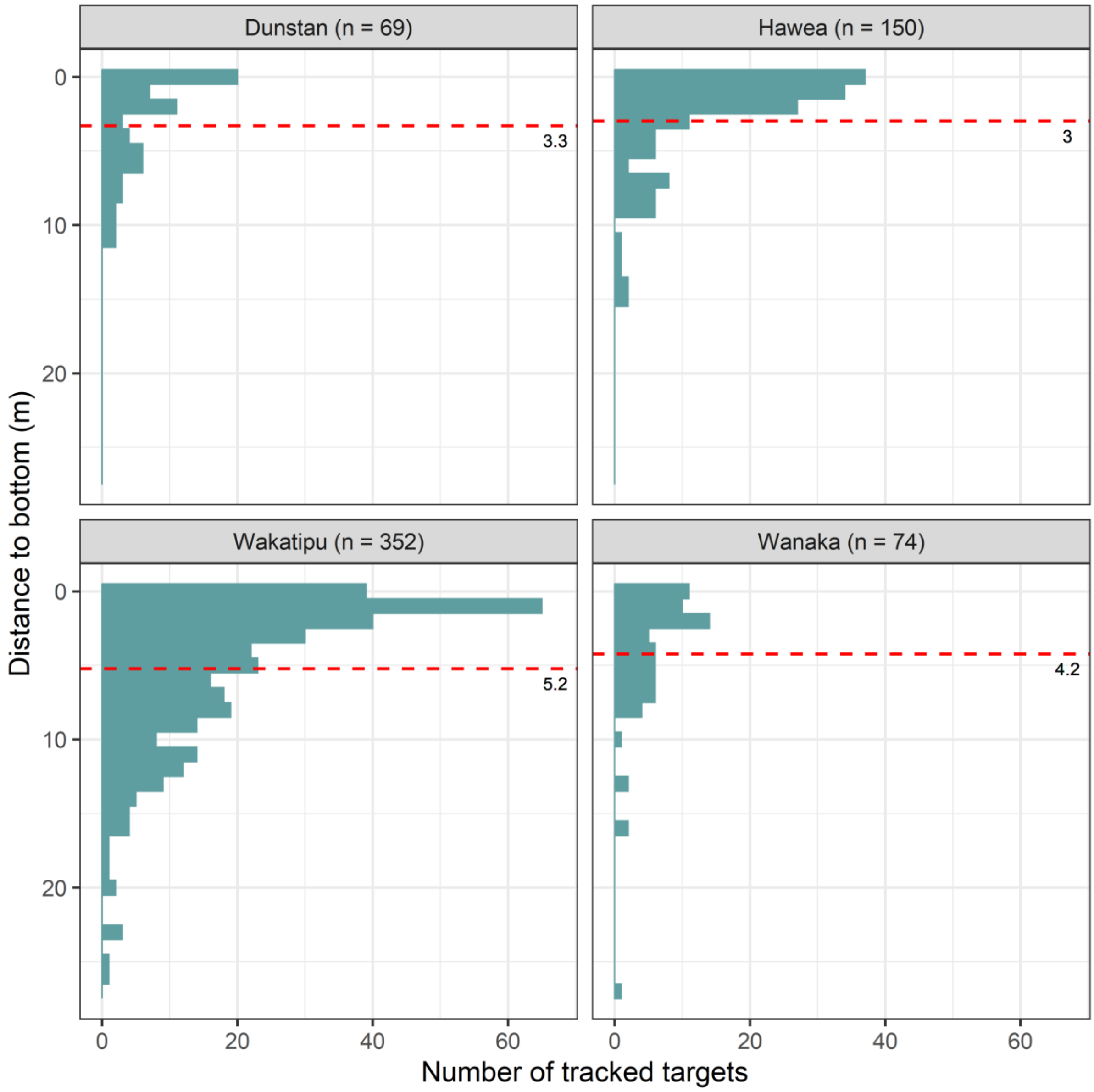

Figure 3-14: The mean distance between the average depth of the tracked targets and the bottom depth (distance to or above bottom) of tracked targets by lake in the 2023 acoustic survey. Dashed lines indicate the mean distance to the bottom of the tracked targets.

Tracked targets were separated into two groups based on their TS, namely strong and weak, and the vertical distribution by group is shown in Figure 3-15. With the exception of Lake Wakatipu, the mean depth of the strong tracked targets was greater than that of weak targets across all lakes. The vertical distribution of strong and weak tracked targets in Lake Wakatipu was almost identical. This pattern could indicate a vertical segregation between the tracked targets responsible for the different TS groups (and hence putative smaller and larger fish).

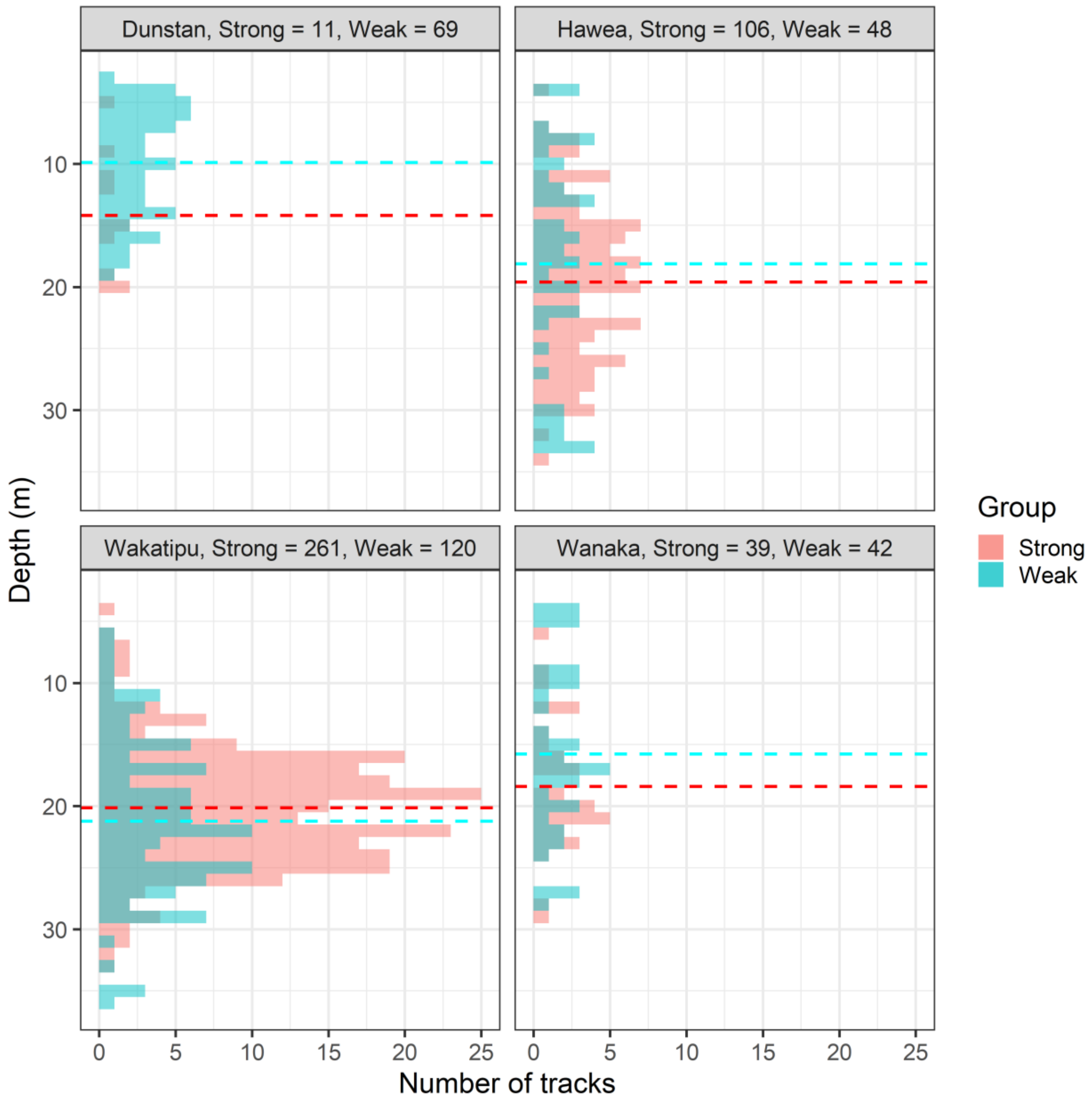

Figure 3-15: Vertical distribution of tracked targets by target strength group and lake in the 2023 acoustic survey. Dashed lines indicate the mean depth of the two target strength groups. Mean depths are: Lake Dunstan, weak TS = 10.2 m and strong TS = 13.8 m; Lake Hawea, weak TS = 18.3 m and strong TS = 19.9 m; Lake Wakatipu, weak TS = 20.8 m and strong TS = 20.5 m; Lake Wanaka, weak TS = 14.7 m and strong TS = 18.9 m.

3.7 Sensitivity analysis

Sensitivity analysis revealed that the target tracking detection parameters used as standard for the Otago lakes acoustic surveys were generally robust (Table 3-4). Although the number of tracked targets by lake varied across the sensitivity analyses, these remained reasonably consistent, with the standard parameters yielding a number of tracked targets comparable to the average number resulting from all four sensitivity scenarios.

Sensitivity 1 (reducing maximum exclusion distance on the major/minor axes to 1 m) resulted in the largest changes in the number of tracked targets observed in Lakes Hawea and Dunstan, where this increased the number of tracked targets by 18.2% and 16.0%, respectively.

Sensitivity 2 (reducing of the maximum gap between pings in the track target detection algorithm) increased the number of tracked targets in all lakes, ranging from 11.0% in Lake Dunstan to 24.1% in Lake Hawea. This likely was due to the splitting of some long tracked targets into two or multiple targets because of the more restrictive value used for the gap between pings.

As expected, increasing the minimum number of pings per track (sensitivity 3) reduced the number tracked targets in all lakes, with the most substantial impact observed in Lake Wanaka. This indicates that a considerable proportion of the tracked targets detected in this lake using the standard parameters consisted of less than five pings.

Under sensitivity 4 (changing parameters simultaneously), the number of tracked targets was within 8% of the number of tracked targets detected using the standard detection parameters for Lakes Wakatipu, and Wanaka. There was no difference on the number of tracked targets for Lake Dunstan under sensitivity 4 relative to the standard target tracking detection parameters The difference in Lake Hawea under sensitivity 4 relative to the standard target tracking detection parameters was larger than for the other lakes, reflecting the greater influence of sensitivities 1 and 2.

Table 3-4: Number of tracked targets detected using different target tracking parameters as part of the sensitivity analysis. Established target tracking parameters are shown in Table 2-2. Target tracking parameters in the four sensitivity analysis scenarios were: Sensitivity 1, maximum excluding distance on the major/minor axes reduced to 1 m; Sensitivity 2, maximum gap between pings in a track reduced to 1 ping; Sensitivity 3, minimum number of pings per track increased to 5; Sensitivity 4; changing parameters from sensitivity analysis 1, 2, and 3, simultaneously.

Lake	Established parameters	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4
Dunstan	69	81	77	63	69
Hawea	150	180	191	138	169
Wakatipu	352	400	441	316	380
Wanaka	74	81	89	59	75

4 Discussion

Acoustic surveys of four large lakes in the Otago region were conducted by NIWA and Otago Fish and Game in February 2023 onboard the RV *OFG7*: Lakes Hawea and Wanaka, previously surveyed in 2007, 2008, and 2009; Lake Wakatipu, previously surveyed in 2007 and 2008; and Lake Dunstan, not surveyed previously (Gauthier 2008, 2009, James et al. 2007). The acoustic surveys were conducted using the same acoustic system as in previous surveys, and the acoustic data collection and analyses followed protocols established for the earlier surveys to ensure the comparability of the results and continuation of the time series of salmonids abundance.

The results from the 2023 survey showed almost a two-fold increase in the number of tracked targets (assumed to be salmonids) in Lake Wakatipu in relation to the last survey of the lake in 2008. Fish densities in Lake Wakatipu in 2023 were the highest in the time series. The number of tracked targets in Lake Hawea remained similar to that in 2009, however the fish densities were slightly lower. The number of tracked targets and fish density in Lake Wanaka halved between 2009 and 2023 and were the lowest of the time series (excluding 2007 when a lower number of transects were surveyed). The low abundance estimates for Lake Wanaka are consistent with the results from randomised creel surveys carried out between May and September of the fishing season 2021-22, with most reports indicating poor angling (Otago Fish and Game Council 2022).

The TS distributions and mean TS values of Lakes Hawea, Wakatipu, and Wanaka in 2023 resembled those from previous surveys. The relationship between fish TS and fish length can be expressed as $TS = m\ log10\ L + b$, where b is the intercept and m is the slope which is assumed to be a value of 20 for a dorsal-aspect TS, but it can vary widely amongst species or morphotypes (McClatchie et al. 2003). There is limited information on TS-L relationships for salmonids at 120 kHz. Available relationships in the literature have been established for frequencies above 120 kHz, have focused on lateral and ventral-aspects for riverine applications, or have only covered a limited range of fish sizes (Frouzova et al. 2005, Knudsen et al. 2004, Kubecka 1998). Fish sizes recorded in gill-net experiments in Lake Benmore in 2009 and from creel surveys in Lake Wanaka in 2022 (Gauthier 2009, Otago Fish and Game Council 2022), show that salmonids in the South Island lakes exceed the fish size for which TS-L relationships have been established, therefore it is not possible to convert TS values to fish sizes accurately. Establishing dorsal-aspect TS-L relationships for the salmonid species in the South Island Lakes will improve the understanding and interpretation of the results of acoustic assessments. This could be achieved by *ex-situ* experiments to measure the TS of alive or tethered fish (e.g., James et al. 2007) and/or the development of scattering models for salmonids (e.g., Jech et al. 2015).

The 2023 survey was the first attempt to assess salmonids in Lake Dunstan using acoustics. Although the fish densities in Lake Dunstan were the second highest in 2023, the absence of a strong mode (greater than -40 dB) in the TS distribution of the tracked targets raises concerns around the origin of the acoustic echoes assumed to be salmonids. The observation of submerged trees, vegetation, and bubbles made the classification of echoes in the data difficult and we cannot discard a potential contamination from non-fish targets. Camera drops validated some of the suspected non-fish echoes as being submerged trees (see Figure 3-5). Lake Dunstan is a shallow man-made lake formed by damning of the Clutha River in 1992, therefore the presence of submerged trees and vegetation is expected. Therefore, we do not recommend continuing to monitor the abundance of salmonids in Lake Dunstan using acoustic techniques.

The acoustic surveys of Lakes Hawea, Wakatipu, and Wanaka provide relative indices of abundance which are useful to track and detect changes in abundance of the populations of salmonids of these lakes. A relative index of abundance is a quantitative measure of the abundance of a particular species or population in a given area or time period. As a fisheries-independent monitoring tool, acoustic techniques are robust, and offer continuous, calibrated, high-resolution data in time and space. The standardisation of the survey methodology and consistency of the survey execution (i.e., time of the year and survey area) are key factors to obtain a reliable index of abundance and infer trends over time. Acoustic indices of abundance should be complemented with observations from other sampling methods such as underwater cameras and/or gillnets. This information will further validate the acoustic results, reduce uncertainties regarding species identification, and inform changes in community composition and structure in the lakes (e.g., strong year class of a particular salmonid species). A well-structured acoustic monitoring programme will be a cost-efficient and effective approach to assess the stocks of salmonid species in the Otago lakes.

Between 2023 and the last survey in 2009 there was a 14-year gap in the time series of abundance, therefore the interpretation of trends and comparisons with the earlier surveys need to be made with caution. We recommend carrying out further acoustic surveys of the three major lakes in 2024 to verify the observed changes, then ongoing monitoring with biennial or triennial surveys. Future surveys should incorporate time to explore methods to determine species composition and size of observed targets. Underwater camera deployments and gillnet experiments were unsuccessful at detecting and catching salmonids in 2023, and alternative methods (e.g., low-light cameras, hookand-line sampling, comparison with creel surveys) could be considered. Underwater camera deployments were useful to discriminate non-fish targets (bubbles and vegetation) and should be included on future surveys. A more regular monitoring program should provide Otago Fish & Game a reliable fishery-independent index of abundance of salmonids to support and inform management strategies.

5 Acknowledgements

We thank the Otago Fish and Game Council and Clutha Fisheries Trust for providing funding and support for this research. In particular, we thank Helen Trotter and David Priest for project development and oversight. We also thank Ben Sowry (skipper) and Jayde Couper for their hard work and dedication during the survey. Their efforts were essential to the success of the project. Gavin James (formerly of NIWA) also participated in fieldwork on Lake Hawea and provided valuable context on the history of this research. This report was reviewed by Darren Stevens.

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Appendix A Summary tables by lake and transect.

Table A-1: Number of salmonid targets counted in Lake Dunstan during the acoustic survey in February 2023, with corresponding densities. Densities are expressed by volume (cubic metre (m^{-3}) and cubic hectometre (hm^{-3})) and by area (metre square (m^{-2}) and hectare (ha^{-1})).

Transect number	Volume sampled (m^{-3})	Tracked target count	Fish (m^{-3})	Fish (hm^{-3})	Mean depth	Fish (m^{-2})	Fish (ha^{-1})
1	90 714	2	2.20E-05	22.0	19.3	4.25E-04	4.3
2	118 854	3	2.52E-05	25.2	20.2	5.10E-04	5.1
3	101 235	8	7.90E-05	79.0	16.8	1.33E-03	13.3
4	75 909	0	0	0.0	15.3	0	0.0
5	71 462	7	9.80E-05	98.0	14.3	1.40E-03	14.0
6	57 939	9	1.55E-04	155.3	13.3	2.07E-03	20.7
7	43 647	5	1.15E-04	114.6	12.7	1.46E-03	14.6
8	61 860	2	3.23E-05	32.3	13.7	4.43E-04	4.4
9	30 520	10	3.28E-04	327.7	13.2	4.33E-03	43.3
10	48 373	1	2.07E-05	20.7	12.0	2.49E-04	2.5
11	34 068	1	2.94E-05	29.4	11.7	3.44E-04	3.4
12	33 785	2	5.92E-05	59.2	11.1	6.56E-04	6.6
13	21 518	2	9.29E-05	92.9	9.1	8.42E-04	8.4
14	4 662	1	2.15E-04	214.5	6.6	1.41E-03	14.1
15	10 214	8	7.83E-04	783.2	7.3	5.75E-03	57.5
16	7 027	1	1.42E-04	142.3	5.9	8.34E-04	8.3
17	4 502	6	1.33E-03	1332.7	4.5	6.02E-03	60.2
18	399	1	2.51E-03	2508.9	2.5	6.24E-03	62.4

Table A-2: Number of salmonid targets counted in Lake Hawea during the acoustic survey in February 2023. , with corresponding densities. Densities are expressed by volume (cubic metre (m^{-3}) and cubic hectometre (hm^{-3})) and by area (metre square (m^{-2}) and hectare (ha^{-1})).

Transect number	Volume sampled (m^{-3})	Tracked target count	Fish (m^{-3})	Fish (hm^{-3})	Mean depth	Fish (m^{-2})	Fish (ha^{-1})
1	364 002	14	3.85E-05	38.5	14.4	5.53E-04	5.5
2	677 469	26	3.84E-05	38.4	17.5	6.71E-04	6.7
3	422 141	18	4.26E-05	42.6	14.6	6.24E-04	6.2
4	491 165	32	6.52E-05	65.2	14.7	9.56E-04	9.6
5	730 311	39	5.34E-05	53.4	19.5	1.04E-03	10.4
7	171 190	16	9.35E-05	93.5	10.5	9.85E-04	9.9
8	230 664	5	2.17E-05	21.7	15.0	3.25E-04	3.3

Table A-3: Number of salmonid targets counted in Lake Wakatipu during the acoustic survey in February 2023, with corresponding densities. Densities are expressed by volume (cubic metre (m^{-3}) and cubic hectometre (hm^{-3})) and by area (metre square (m^{-2}) and hectare (ha^{-1})).

Transect number	Volume sampled (m^{-3})	Tracked target count	Fish (m^{-3})	Fish (hm^{-3})	Mean depth	Fish (m^{-2})	Fish (ha^{-1})
1	684 035	41	5.99E-05	59.9	18.7	1.12E-03	11.2
2	993 610	52	5.23E-05	52.3	18.5	9.67E-04	9.7
3	877 028	37	4.22E-05	42.2	21.1	8.90E-04	8.9
4	573 322	16	2.79E-05	27.9	19.7	5.50E-04	5.5
5	524 009	23	4.39E-05	43.9	21.8	9.58E-04	9.6
6	1 152 607	88	7.63E-05	76.3	22.6	1.73E-03	17.3
7	260 728	20	7.67E-05	76.7	19.0	1.46E-03	14.6
8	559 167	15	2.68E-05	26.8	18.9	5.07E-04	5.1
10	404 644	33	8.16E-05	81.6	18.9	1.54E-03	15.4
11	430 787	27	6.27E-05	62.7	19.5	1.22E-03	12.2

Table A-4: Number of salmonid targets counted in Lake Wanaka during the acoustic survey in February 2023, with corresponding densities. Densities are expressed by volume (cubic metre (m^{-3}) and cubic hectometre (hm^{-3})) and by area (metre square (m^{-2}) and hectare (ha^{-1})).

Transect number	Volume sampled (m^{-3})	Tracked target count	Fish (m^{-3})	Fish (hm^{-3})	Mean depth	Fish (m^{-2})	Fish (ha^{-1})
1	673 908	6	8.90E-06	8.9	17.4	1.55E-04	1.5
2	369 509	5	1.35E-05	13.5	17.9	2.43E-04	2.4
3	346 261	7	2.02E-05	20.2	18.2	3.68E-04	3.7
4	686 771	4	5.82E-06	5.8	19.1	1.11E-04	1.1
6	290 680	2	6.88E-06	6.9	18.4	1.26E-04	1.3
10	106 476	2	1.88E-05	18.8	16.1	3.03E-04	3.0
11	325 985	31	9.51E-05	95.1	15.4	1.46E-03	14.6
12	369 656	17	4.60E-05	46.0	18.2	8.36E-04	8.4

Appendix B Spatial distribution plots of tracked targets by lake

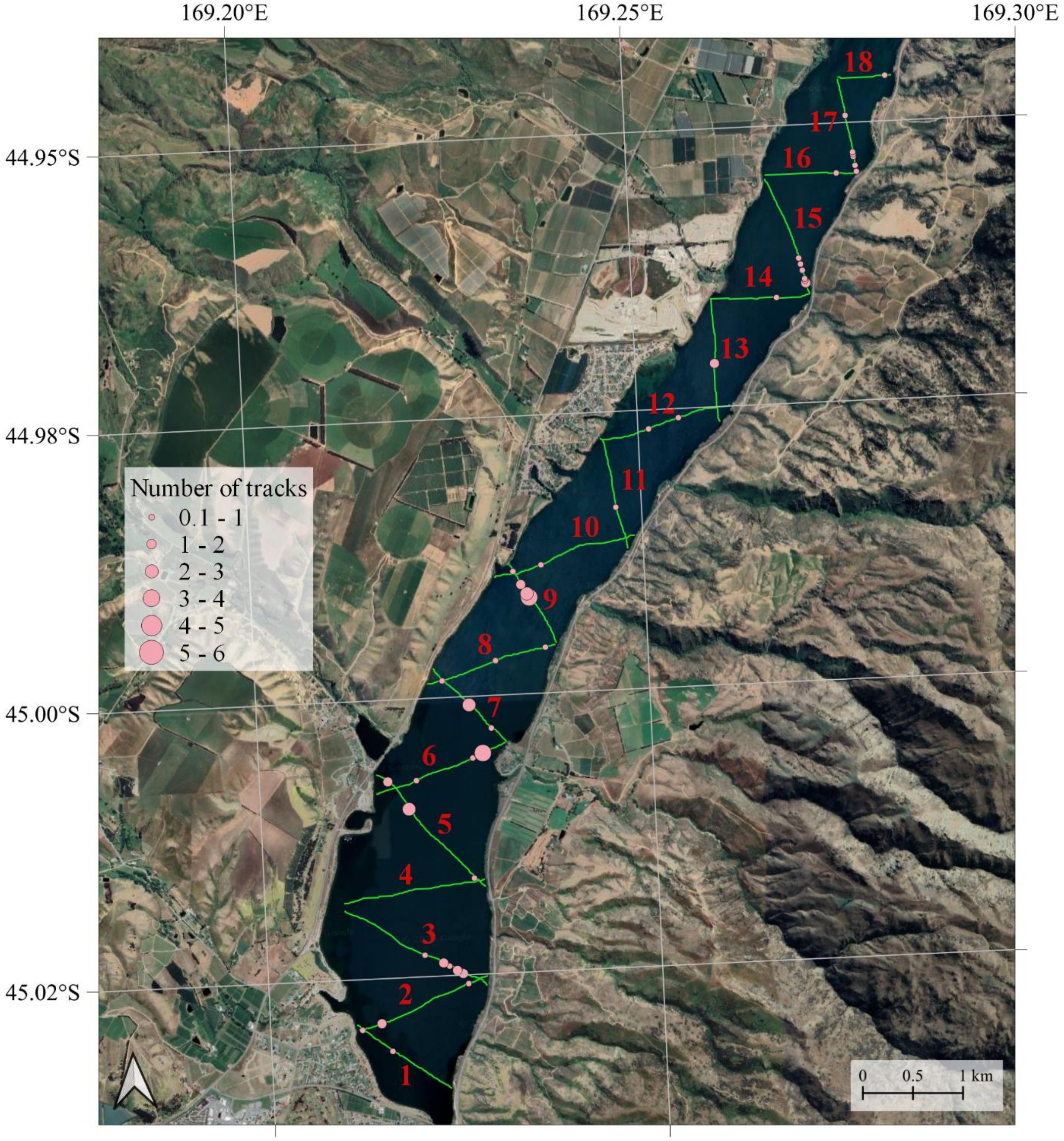

Figure B-1: Distribution of tracked targets in transects in Lake Dunstan.

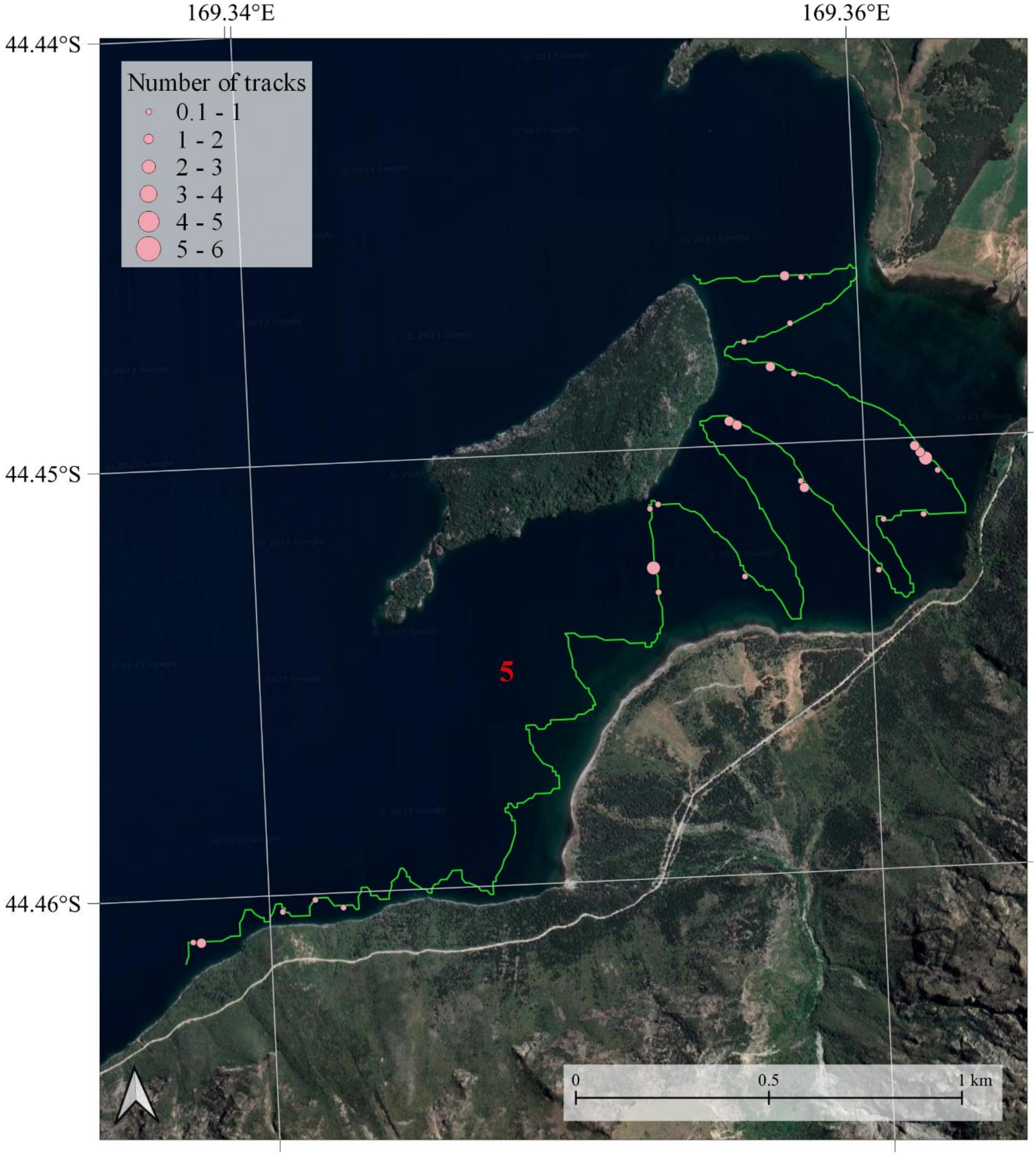

Figure B-2: Distribution of tracked targets in transect 5 at the northern end of Lake Hawea. Refer to Figure 3-2 to visualise the location of transects in Lake Hawea.

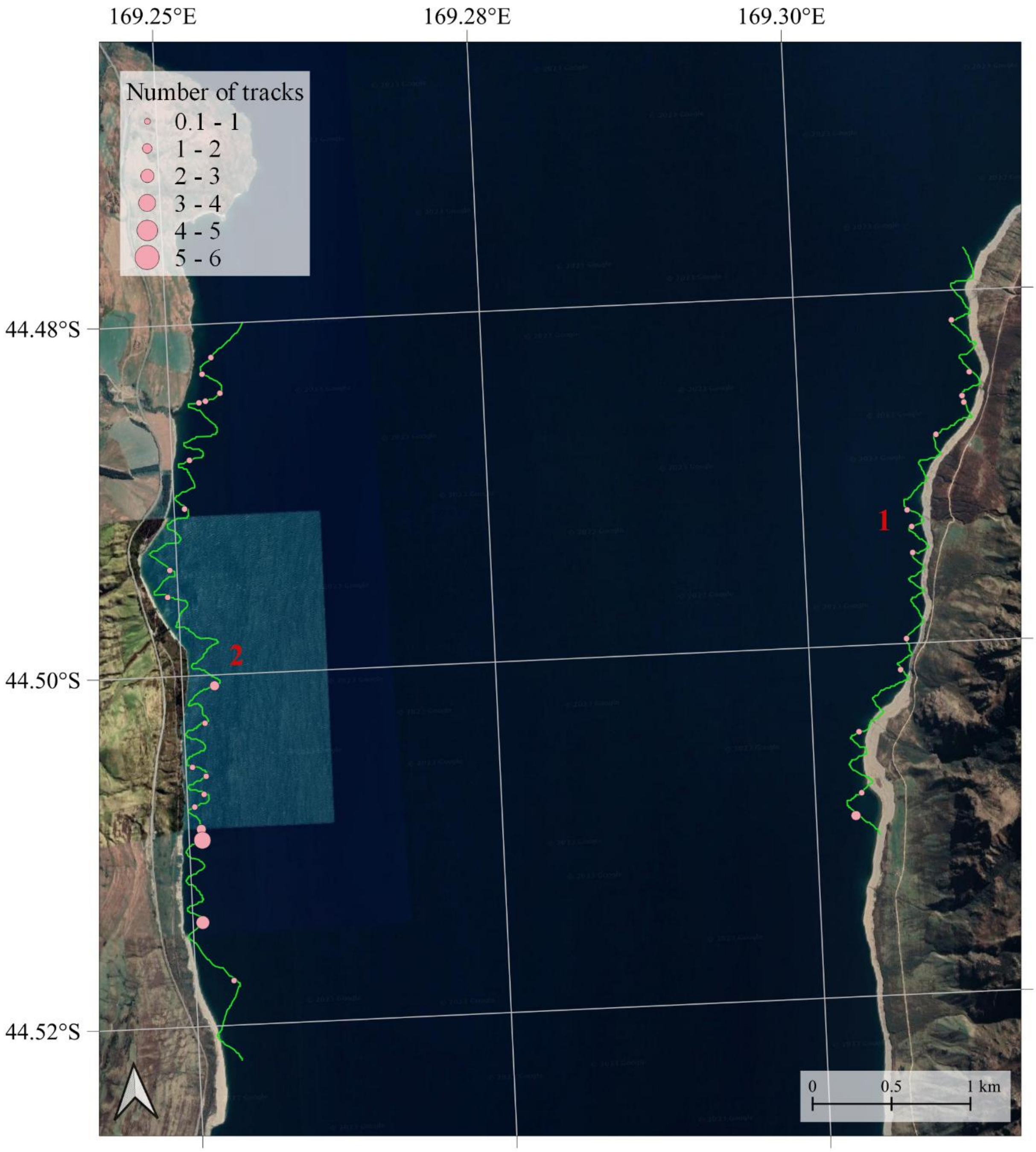

Figure B-3: Distribution of tracked targets in transects 1 and 2 in Central Lake Hawea. Refer to Figure 3-2 to visualise the location of transects in Lake Hawea.

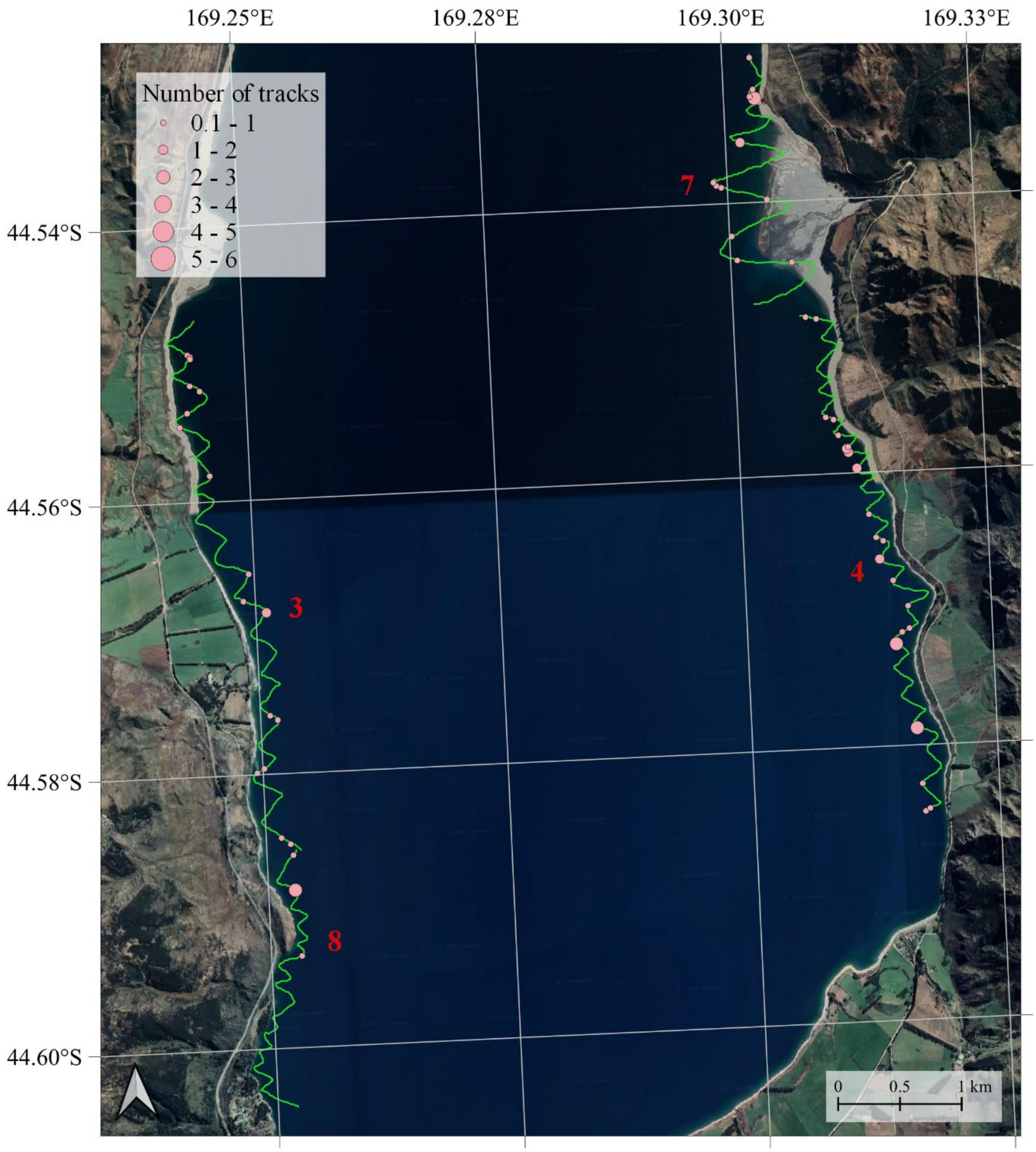

Figure B-4: Distribution of tracked targets in transects 3, 4, 7, and 8 at the southern end of Lake Hawea. Refer to Figure 3-2 to visualise the location of transects in Lake Hawea.

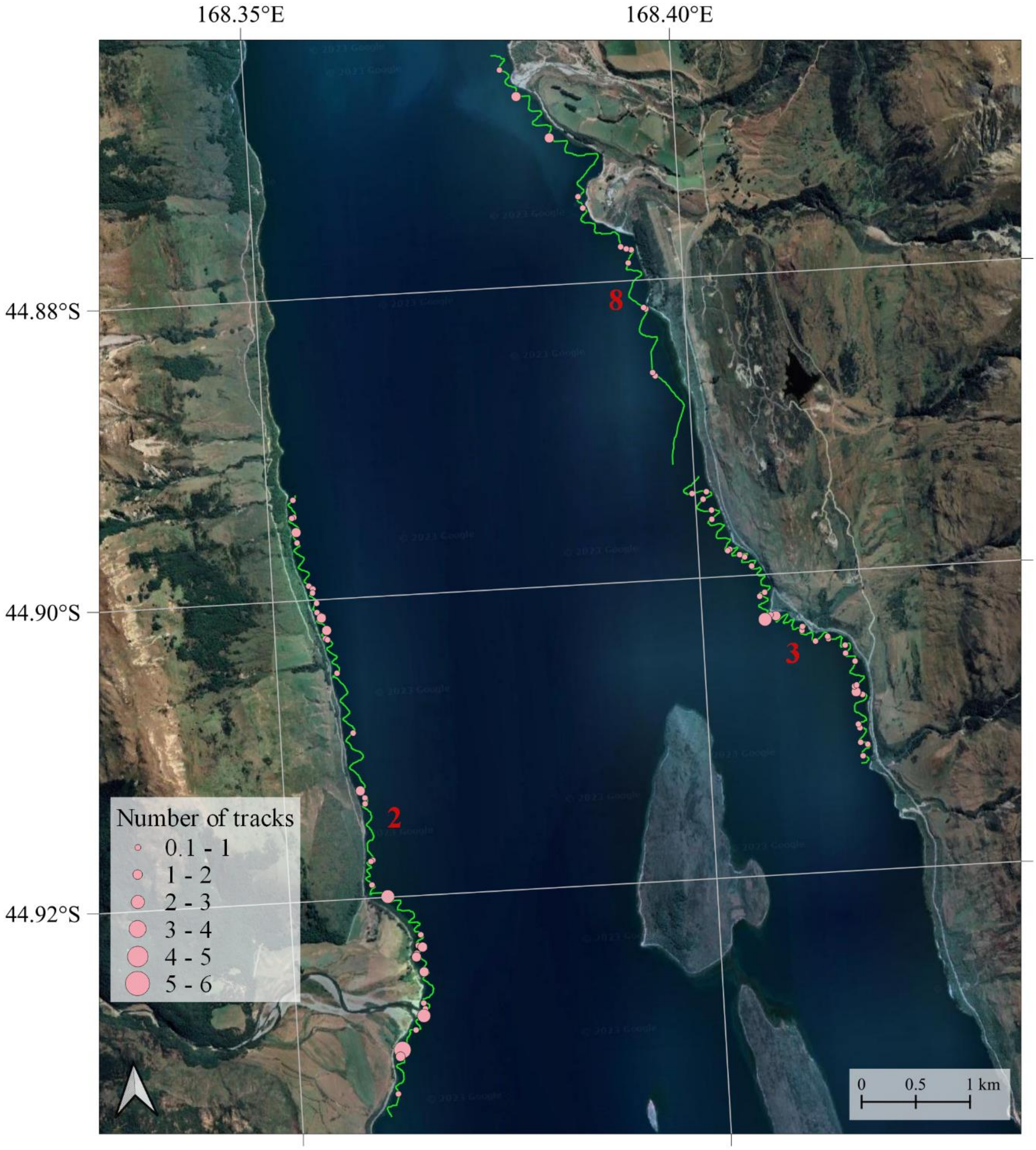

Figure B-5: Distribution of tracked targets in transects 2, 3, and 8 at the northern end of Lake Wakatipu. Refer to Figure 3-3 to visualise the location of transects in Lake Wakatipu.

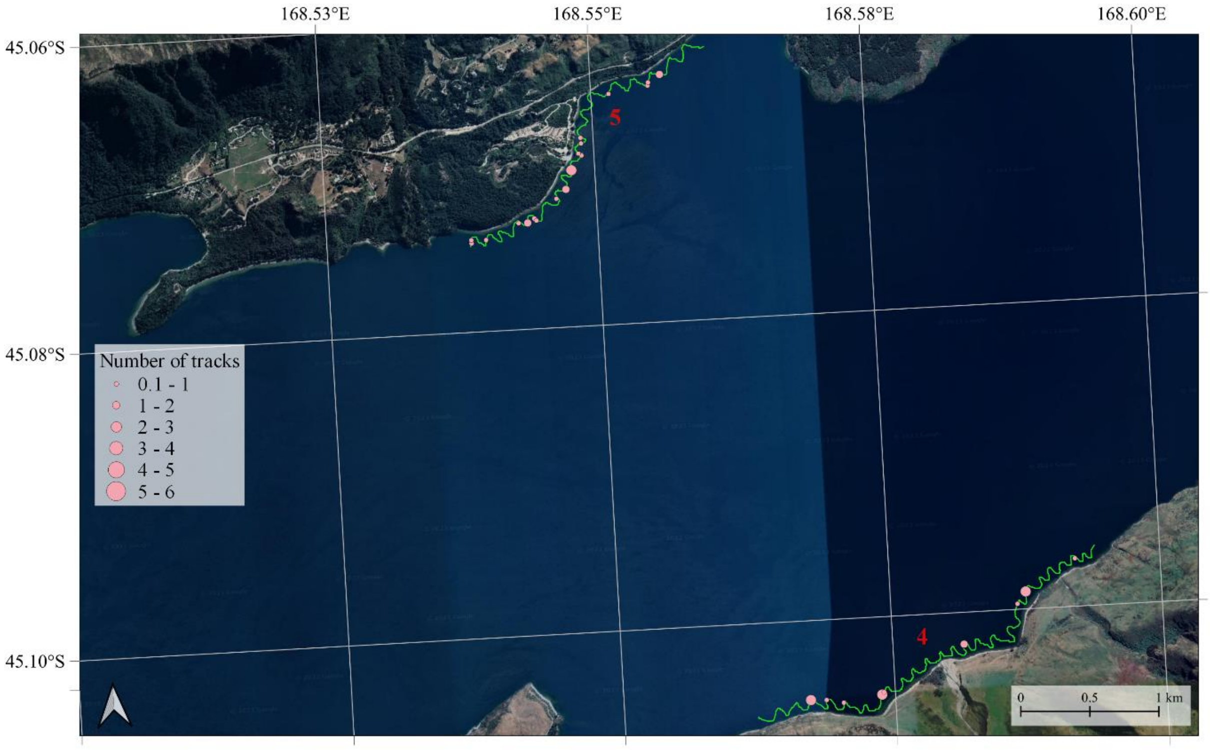

Figure B-6: Distribution of tracked targets in transects 4 and 5 in Central Lake Wakatipu. Refer to Figure 3-3 to visualise the location of transects in Lake Wakatipu.

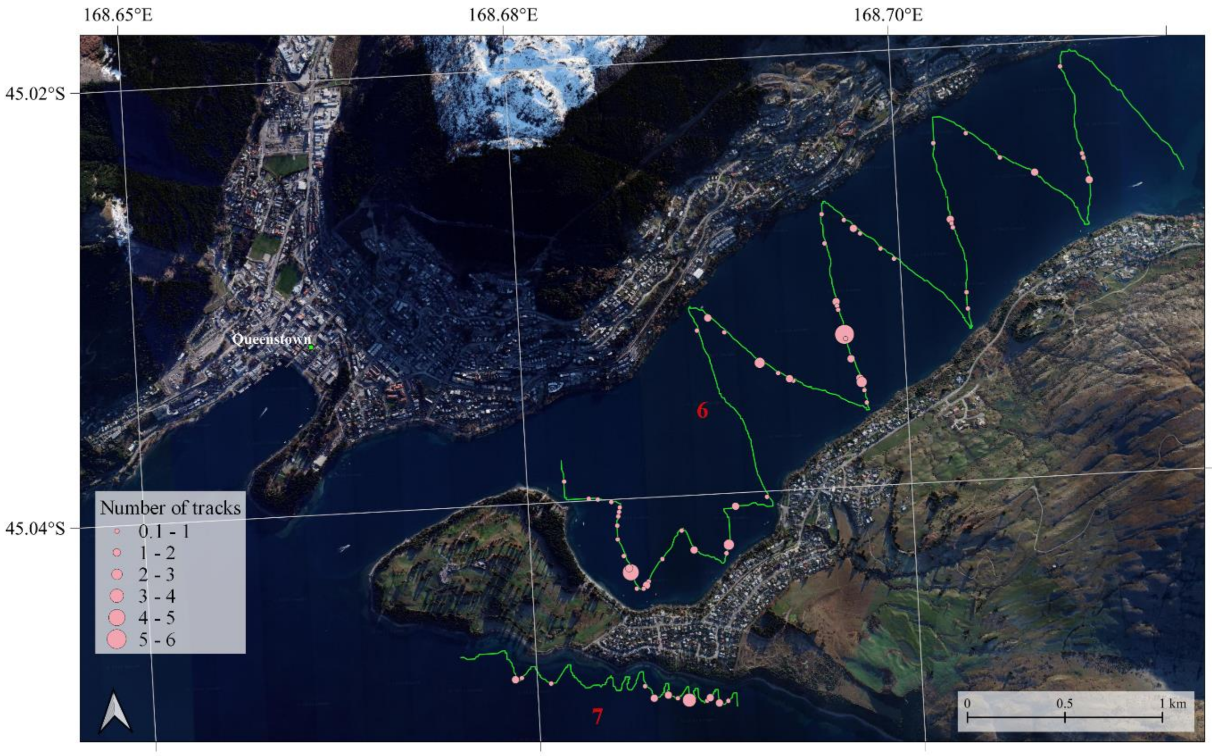

Figure B-7: Distribution of tracked targets in transects 6 and 7 in Central Lake Wakatipu. Refer to Figure 3-3 to visualise the location of transects in Lake Wakatipu.

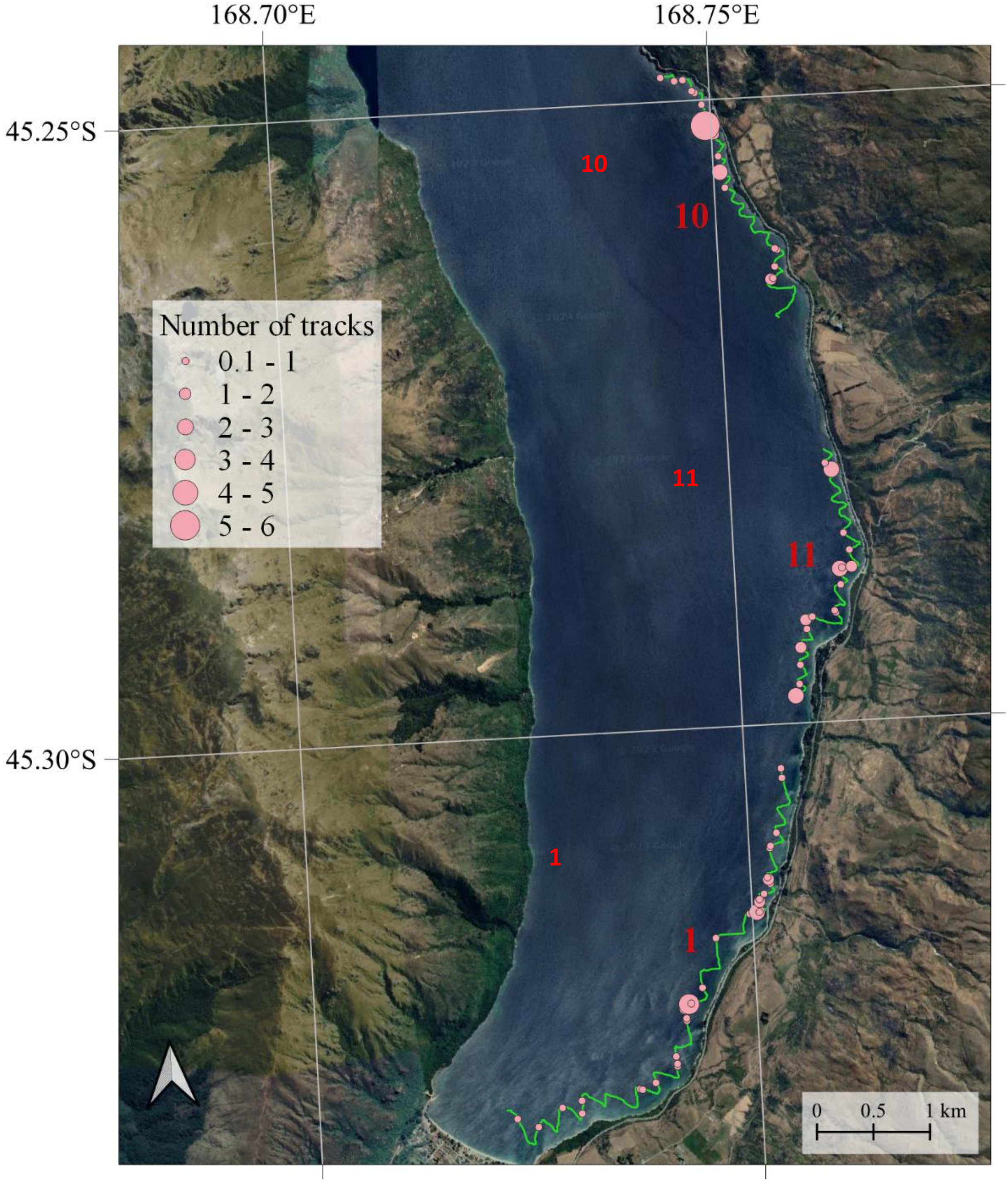

Figure B-8: Distribution of tracked targets in transects 1, 10, and 11 at the southern end of Lake Wakatipu. Refer to Figure 3-3 to visualise the location of transects in Lake Wakatipu.

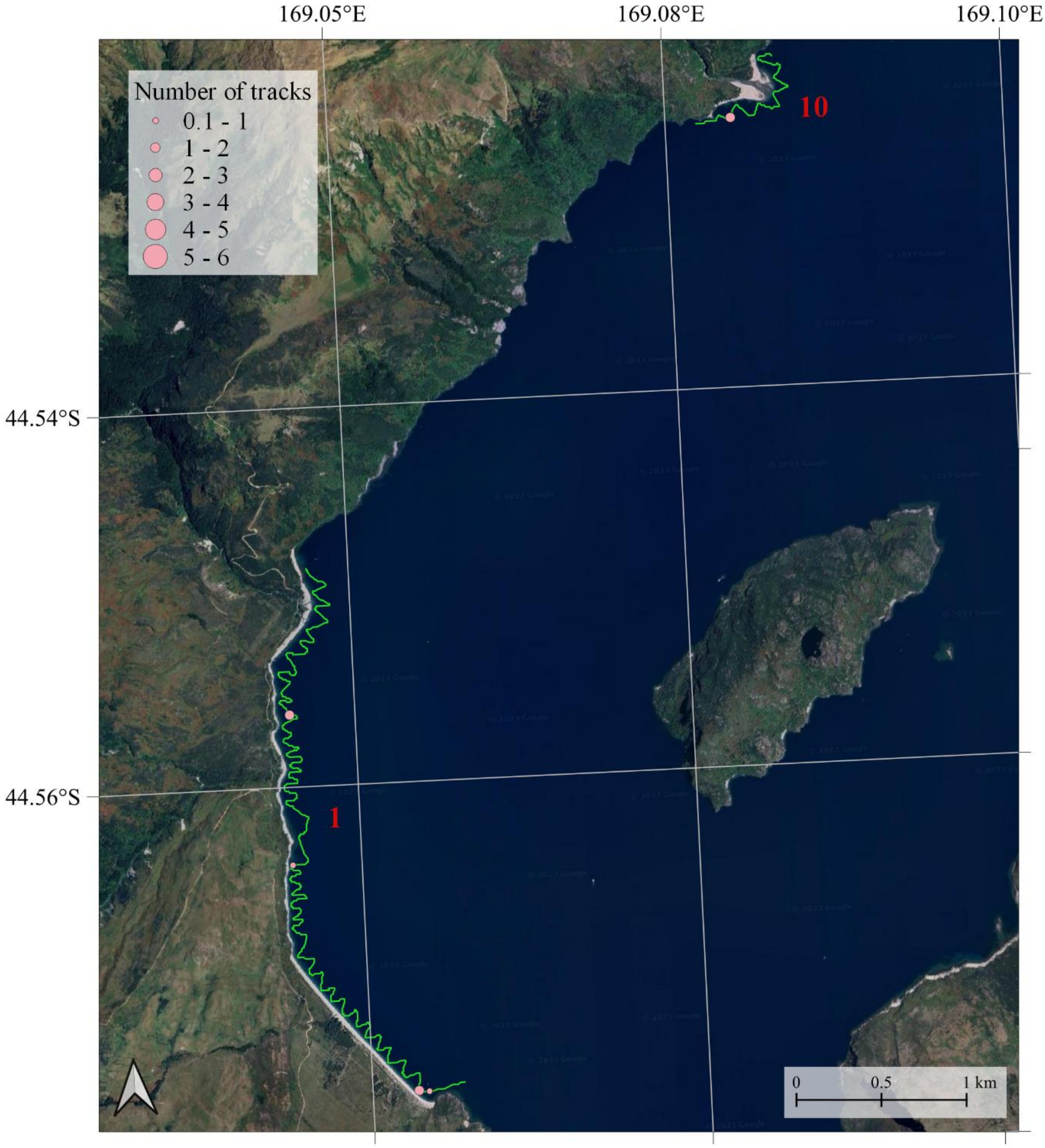

Figure B-9: Distribution of tracked targets in transects 1 and 10 at the northern end of Lake Wanaka. Refer to Figure 3-4 to visualise the location of transects in Lake Wanaka.

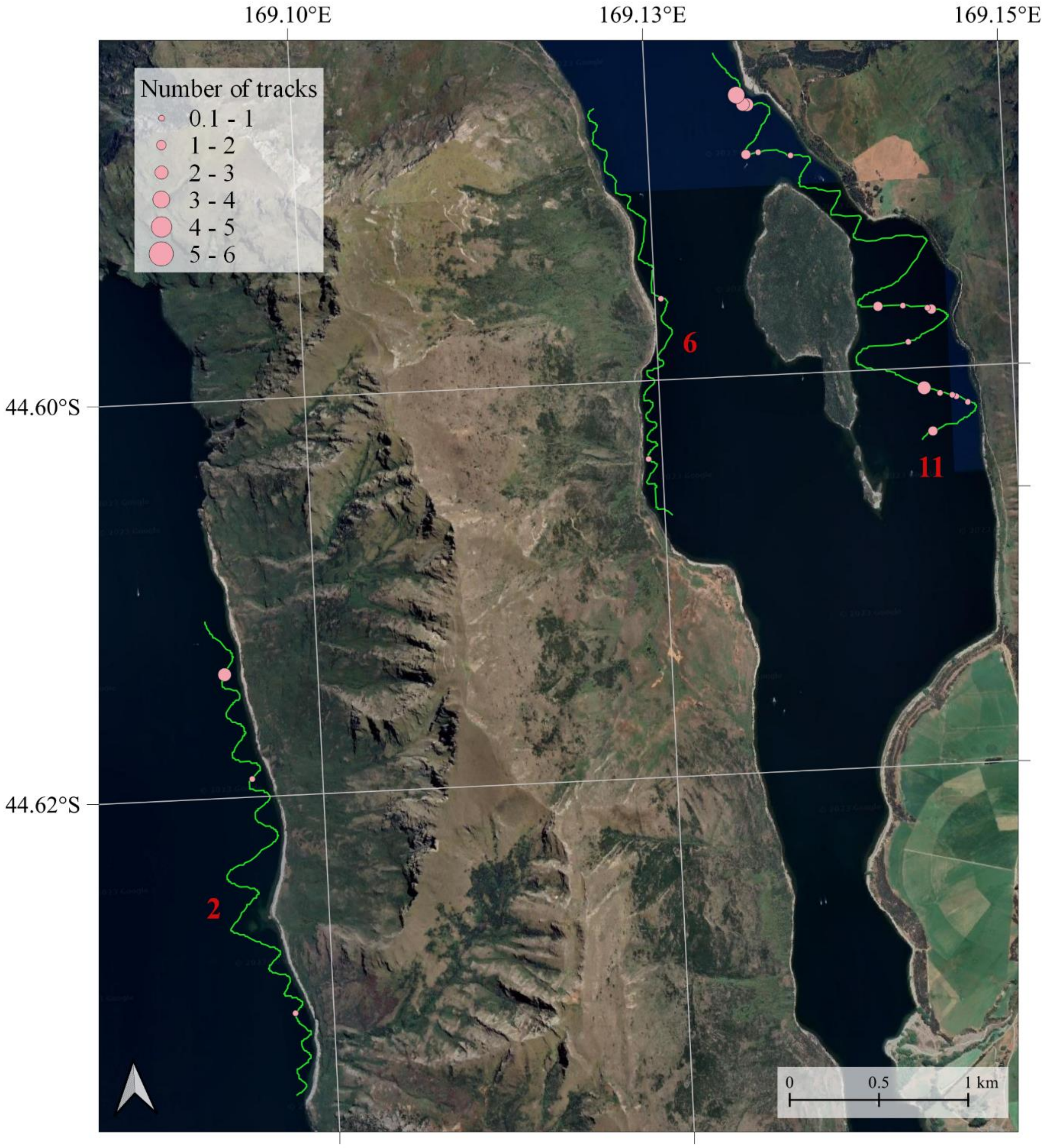

Figure B-10: Distribution of tracked targets in transects 2, 6, and 11 in East-Central Lake Wanaka. Refer to Figure 3-4 to visualise the location of transects in Lake Wanaka.

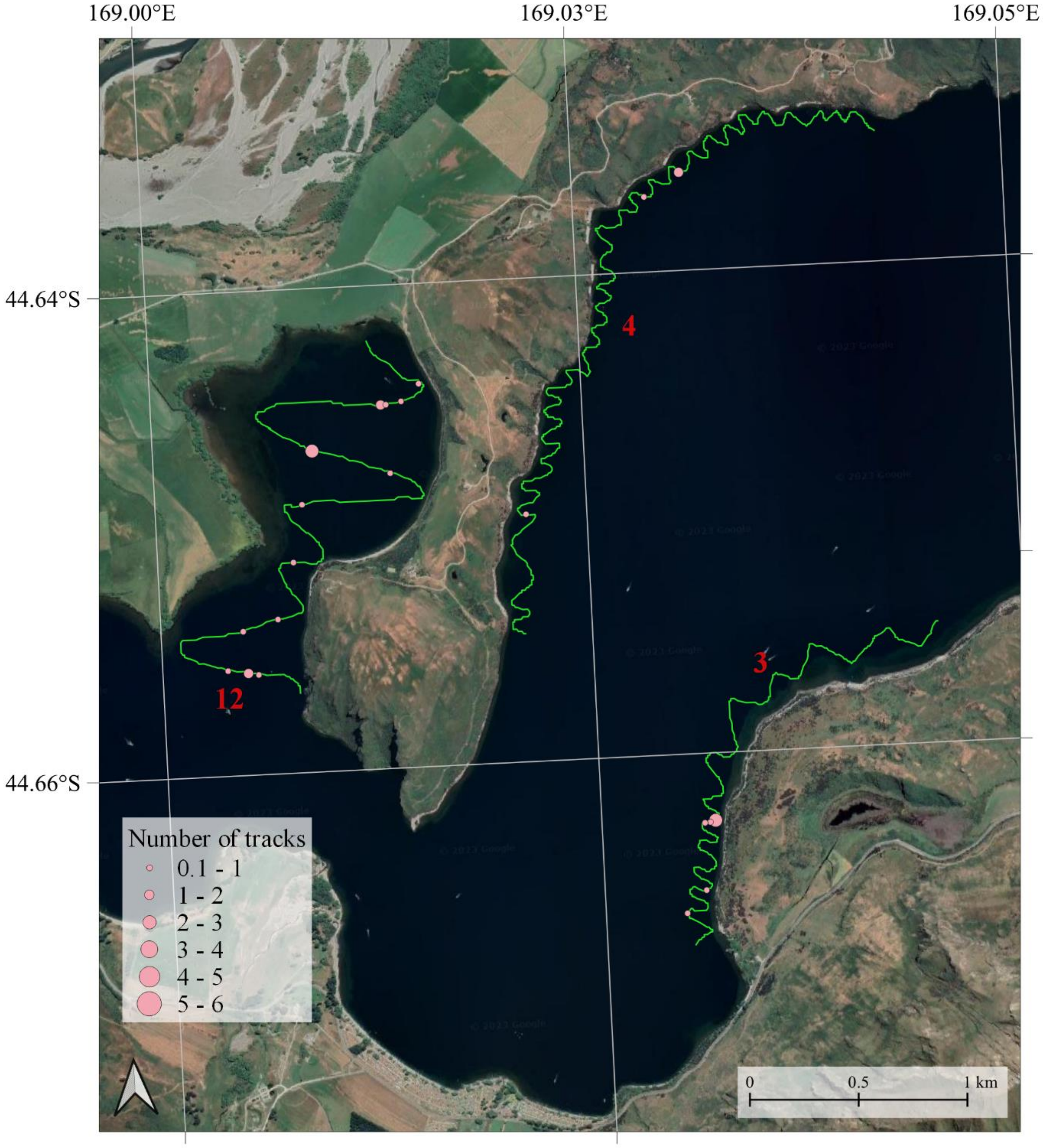

Figure B-11: Distribution of tracked targets in transects 3, 4, and 12 in West-Central Lake Wanaka. Refer to Figure 3-4 to visualise the location of transects in Lake Wanaka.

Appendix C Calibration report

The 120 kHz IRL wide-beam transducer was calibrated in Lake Dunstan near Cromwell (45° 02.49’ S 169° 13.26’ E) on 8 February 2023. This calibration was done before the salmonid survey of the Otago lakes (FGC22301). The vessel was *OFG7,* a 5.5 m Kwik Kraft aluminium pontoon boat operated by Otago Fish & Game. The transducer was mounted on a pole amidships off the starboard side The transducer face was approximately 1 m below the surface and 0.3 m below the keel.

The calibration was conducted broadly as per the procedures in Demer et al. (2015). The vessel was anchored in 23 m of water. A 38.1 mm diameter tungsten-carbide sphere was suspended directly under the transducer with a monofilament line at a range of 9.0 m. The weather was good with 5 knot west-northwest winds and 0.1 m surface chop. There was some background scatter from small particles in the water, likely sediment from the nearby Kawarau River.

The calibration data were recorded in four EK80 raw format files (ofg2301-D20230207-T225839, ofg2301-D20230207-T224631, ofg2301-D20230207-T223423, ofg2301-D20230207-T222215). These files are stored in the NIWA Fisheries *acoustics* database.

The EK80 transceiver settings in effect during the calibration are given in Table C-1.

Water temperature measurements were taken using an RBR Duet temperature depth probe, serial number 208312 immediately after the calibration. The water column was unstratified, with average temperature of 20.3º C. Estimate of acoustic absorption and sound speed were calculated using the formulae of Francois & Garrison (1982) and Fofonoff & Millard (1983), respectively.

Analysis

The data in the EK80 files were extracted using custom-written software ESP3 version 1.47.0 (Ladroit et al. 2020). 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 $S_{a,corr}$.

Results and Discussion

The results from the RBR cast are given in Table C-2, along with estimates of the sphere target strength, sound speed, and acoustic absorption. The calibration results are given in Table C-3. The estimated beam pattern and coverage for the calibration are given in Table C-1. The symmetrical nature of the pattern and the centering on zero indicates that the transducer and transceiver are operating correctly. The fit between the theoretical beam pattern and the sphere echoes is shown in Table C-2, and indicates that the transducer beam pattern is shaped correctly. The RMS of the difference between the Simrad beam model and the sphere echoes out to 25º was 0.11 dB, indicating a calibration of excellent quality (< 0.4 dB is acceptable, 0.3-0.4 dB good, and < 0.2 dB excellent).

References

Demer, D.A., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., Domokos, R., Dunford, A., Fässler, S., Gauthier, S., Hufnagle, L.T., Jech, J.M., Bouffant, N., Lebourges-Dhaussy, A., Lurton, X., Macaulay, G.J., Perrot, Y., Ryan, T., Parker-Stetter, S., Stienessen, S., Weber, T., Williamson, N. (2015) Calibration of acoustic instruments. *ICES Cooperative Research Report,* 326: 133.

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

Francois, R.E., Garrison, G.R. (1982) Sound absorption based on ocean measurements: Part I: Pure water and magnesium sulfate contributions. *The Journal of the Acoustical Society of America,* 72: 896-907.

Ladroit, Y., Escobar-Flores, P.C., Schimel, A.C.G., O'Driscoll, R.L. (2020) ESP3: An open-source software for the quantitative processing of hydro-acoustic data. *SoftwareX,* 12: 100581-100581.

Mackenzie, K.V. (1981) Nine-term equation for sound speed in the oceans. *The Journal of the Acoustical Society of America,* 70: 807-812.

Table C-1: ES60 transceiver settings and other relevant parameters during the calibrations.

Parameter	Value
Echosounder	EK80
GPT model/serial	120 kHz 374286
GPT software version	50112.00
EK80 software version	2.0.0
Transducer model	IRL 120-22
Transducer serial number	12022
Sphere type/size	tungsten carbide/38.1 mm diameter
Operating frequency (kHz)	120
Transducer draft setting (m)	0.0
Transmit power (W)	100
Pulse length (ms)	0.064
Transducer peak gain (dB)	13.3
Sa correction (dB)	0.0
Receiver sample frequency (kHz)	500
Sample interval (m)	0.016
Two-way beam angle (dB)	–10.00
Angle sensitivity (dB) alongship/athwartship	6.10/6.10
3 dB beamwidth (º) alongship/athwartship	22.0/22.0
Angle offset (º) alongship/athwartship	0.0/0.0

Table C-2: RBR data logger cast details and derived water properties. The values for sound speed and absorption are at a depth of 8 m.

Parameter	Value
Date/time (NZDT, start)	8 February 2023 12:01
Mean sphere range (m)	8.94
S.D. of sphere range (m)	0.006
Mean temperature (ºC)	20.33
Mean salinity (psu)	0 (freshwater)
Mean sound speed (m/s)	1 484
Mean absorption (dB/km)	3.14
Sphere TS (dB re 1m^2)	–39.49

Table C-3: Calculated echosounder calibration parameters. Transducer peak gain was estimated from mean sphere TS.

Parameter	
Mean TS within 0.66° of centre	-39.41
Std dev of TS within 0.66° of centre	0.22
Max TS within 0.66° of centre	-38.63
No. of echoes within 0.66° of centre	1 695
On axis TS from beam-fitting	-39.45
Transducer peak gain (dB) mean TS	13.34
Sa correction (dB)	-0.29
Beamwidth (º) along/athwartship	25.8/26.1
Beam offset (º) along/athwartship	0.25/-0.46
RMS deviation	0.11
Number of echoes	21 887

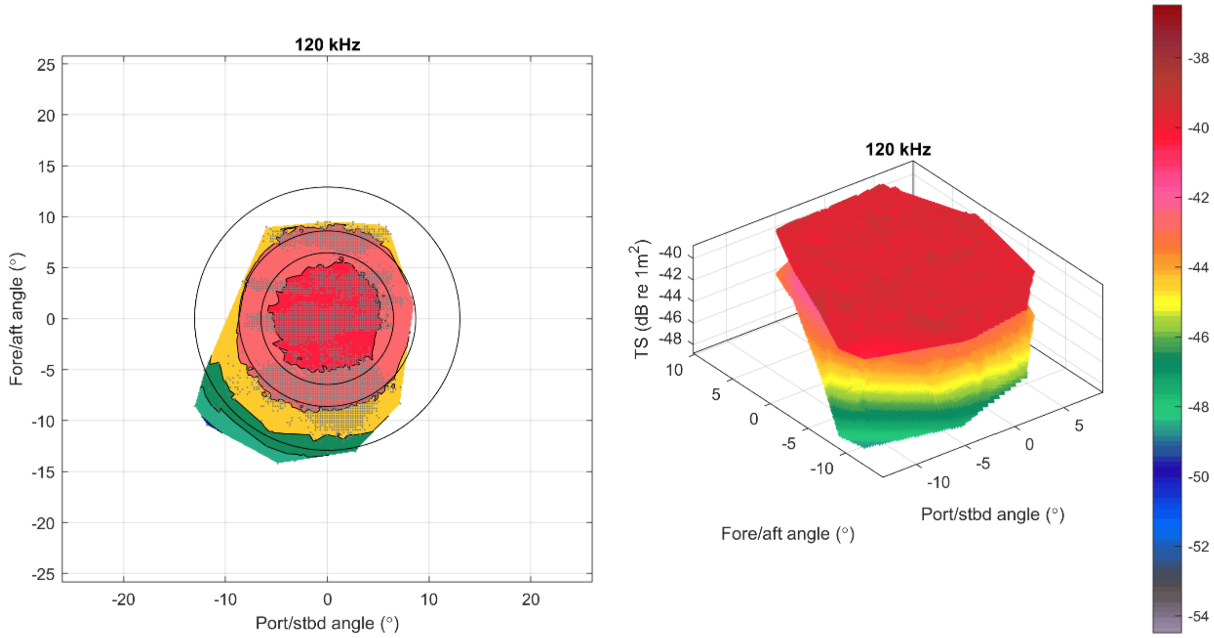

Figure C-1: The estimated beam pattern from the sphere echo strength and position for the calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m2.

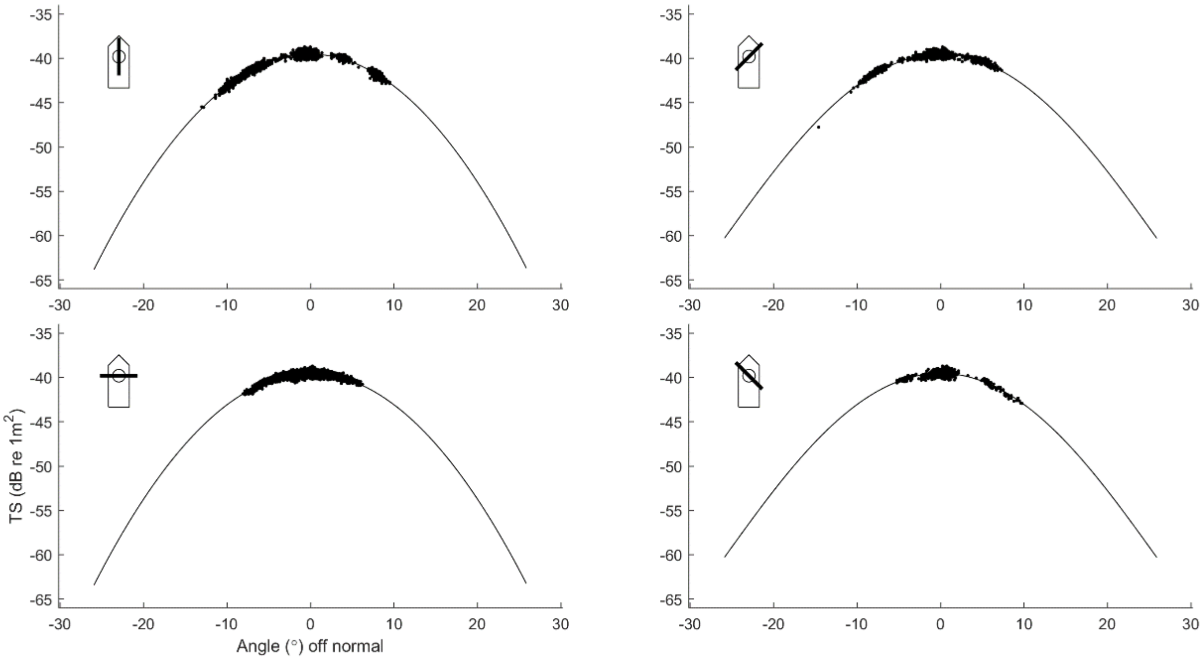

Figure C-2: Beam pattern results from the calibration. The solid line is the theoretical beam pattern fit to the sphere echoes (points) for four slices through the beam.