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MANAGEMENT BRIEF

Estimating Trout Abundance with Cataraft-Mounted Dual-Frequency Identification Sonar: a Comparison with Drift Diving

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Abstract
We investigated the potential of dual-frequency identification sonar (DIDSON) deployed from a drifting cataraft for estimating abundance in rivers of Brown Trout *Salmo trutta* larger than 20 cm. We compared triplicate trout density estimates made by DIDSON with drift-diving density estimates in three reaches of a clear-water river in New Zealand. DIDSON density estimates were much lower (~22% of drift-dive estimates, range = 7–33%) and less precise than drift-dive estimates (DIDSON CV = 0.13–0.47; drift diving CV = 0.15–0.17). Variation in detecting fish in the DIDSON field survey contributed substantially more (95%) to DIDSON count variability than did fish detection in the image files. Highest precision with DIDSON was achieved in the reach with the least shallow habitat and most uniform channel. Fewer person-hours were required to undertake the field component of DIDSON surveys than the drift dives (5 versus 8.3 h), but the substantial time spent on image review (3.3 h) made DIDSON surveys 34% more costly than drift dives in terms of overall effort. Despite observed shortcomings, cataraft-mounted DIDSON has utility as a noninvasive survey method for estimating abundance of large (>20-cm) fish, particularly in situations where turbidity is too high for visual counting methods to be effective.

Counting fish to assess stocks is a fundamental component of fisheries research and management. Monitoring changes in fish abundance over time and space can inform fishery managers on the success or failure of management actions or signal an effect of environmental change. A broad range of methods has been used for estimating fish abundance in rivers, including electrofishing (hand-held and boat-mounted), bank observations, underwater observations (upstream snorkel diving/crawl diving, downstream drift diving), netting, and sonar. Each of these methods can be useful under certain conditions, but all have limitations, potential biases, or both.

Visual methods for estimating trout abundance are appealing in clear-water rivers because they are relatively simple to conduct, inexpensive, and noninvasive. Underwater surveys by snorkel divers are commonly undertaken in North America and elsewhere, when visibility permits (e.g., Young and Hayes 2001; Joyce and Hubert 2003; Hagen and Baxter 2005; Orell and Erkinaro 2007). In New Zealand, drift diving is the preferred method for assessing abundance of adult resident trout populations in clear-water rivers and has been well tested (Hicks and Watson 1985; Teirney and Jowett 1990; Richardson 1992; Young and Hayes 2001). Mainly used to assess abundance for at-a-reach comparisons over time (e.g., Hicks and Watson 1985), drift diving is rarely used to estimate reach population size, which requires sight efficiency to be estimated (e.g., Young and Hayes 2001). Drift diving is cost effective and the method is suitable for the wide range of clear-water river and habitat types that exist in New Zealand (Young and Hayes 2001). Estimates of adult trout abundance from at-a-reach drift-diving densities provide the primary index that Fish and Game New Zealand uses for long-term trend assessments of populations. These population trends are used to assess effects of environmental change and harvest for informing population management decisions, statutory advocacy, and resource consent processes and for managing angler experience and expectations. However, the method is limited to clear water (>3–4 m underwater visibility, depending on current speed; Teirney and Jowett 1990; Dolloff et al. 1996; Hagen and Baxter 2005), and some rivers are too deep and fast for safe diving. Although electrofishing has been used to monitor

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trout abundance in wadable streams in New Zealand, boat-mounted electrofishing has been little used in larger rivers, owing mainly to cost and regulatory hurdles. For safety and precision reasons, boat-mounted electrofishing is limited by river size and morphology, being best suited to small to medium, low-gradient rivers. Thus, a cost-effective method is needed for extending the range of rivers in which salmonid abundance can be monitored in New Zealand and elsewhere.

Dual-frequency identification sonar (DIDSON) is a recent advance in sonar technology that provides video recordings (albeit of limited resolution) of fish, regardless of water visibility conditions (Belcher et al. 2001; Moursund et al. 2003; Tiffan et al. 2004). DIDSON overcomes some of the interpretation issues associated with conventional sonar, and even the standard version (as used in our study) has a reasonably large range (maximum range of 40 m in low-frequency mode [1.1 MHz]; Sound Metrics 2009). With its application to fisheries research, DIDSON provides an alternative technology for detecting and monitoring migrating fish, especially salmon, from fixed positions (e.g., Holmes et al. 2006; Burwen et al. 2007; Maxwell and Gove 2007). The utility of DIDSON for other applications in fishery science has been explored (e.g., predation, Williams et al. 2003; spawning, Tiffan et al. 2004; fish activity under ice cover, Mueller et al. 2006; and fish passage behavior, Moursund et al. 2003; Baumgartner et al. 2006; Pease and Green 2007).

Although DIDSON has been used primarily from fixed platforms in most fisheries applications to date (but see Tiffan et al. 2004), it was originally designed to be deployed from mobile platforms, such as submersibles (e.g., manned or remotely operated underwater vehicles) or small boats, for harbor surveillance operations (Belcher et al. 2001). This knowledge encouraged us to undertake the present study, investigating the utility of DIDSON to estimate the abundance of Brown Trout *Salmo trutta* L. larger than 20 cm from a cataraft for monitoring population trends. While our ultimate interest in DIDSON was as a population monitoring tool for turbid rivers, we undertook our study on a clear-water river so that we could compare the DIDSON abundance and precision estimates with those based on drift diving.

STUDY SITE

The study was undertaken in three 950- to 1280-m reaches (Dove, Woodstock, Peninsular Bridge) of the Motueka River, in the Nelson region, South Island, New Zealand (Table 1). The Motueka is a clear, single-channel river with 7-day mean annual low, median, and mean flows of 9.84, 33.2, and 56.7 m^3/s, respectively, as recorded at the Woodstock flow recorder near the study reaches (Tasman District Council flow data). The mean wetted width of the study reaches was 40–53 m; the maximum depth varied between ~2.0 and 3.5 m, and the gradient was 0.002–0.003 m/m (Table 1). The reaches comprised mainly medium–deep run, the remainder being riffle and fast, shallow run. The Woodstock reach was the most homogeneous, having the highest proportion of medium–deep run, and the Dove reach was the least homogeneous (Table 1). The substrate comprised mainly cobbles and gravels (26% and 36%, respectively), with occasional boulders and bedrock outcrops (15%). The summer through early autumn water temperatures during sampling were 14–20°C, and trout were observed to be active and feeding.

The Motueka River supports a nationally important Brown Trout fishery. Abundance is comparatively high by New Zealand standards. In a nationwide drift-diving study, Teirney and Jowett (1990) reported the number of trout larger than 20 cm in the river was 53 fish/ha. The fish community also includes several, mainly small (<10 cm), species of native fish. Other than Brown Trout, fish exceeding 20 cm in length in the surveyed reaches includes two species of eel, *Anguilla dieffenbachii* and *A. australis*, but these are mainly nocturnally active.

METHODS

Cataraft platform, DIDSON setup, and counting procedure.—We used a 3.7-m two-seater cataraft as a working platform, attaching a standard DIDSON beneath a custom-built frame located ahead of the forward seat (Figure 1). The frame was equipped with a manually operated pivoting mount, which allowed the DIDSON to be raised, lowered, panned, and tilted. The person sitting in the front seat controlled the DIDSON, while the person in the rear seat maneuvered the raft with the oars. The DIDSON operator also had a waterproof ruggedized laptop (Getac M220) mounted on the pontoon next to the

TABLE 1. Lengths, mean widths, and mesohabitat composition of the three study reaches in the Motueka River.

			Mesohabitat composition (%)	
Reach	Length (m)	Mean width (m)	Riffle–fast run	Medium–deep run
Dove	1,220	40	40	60
Woodstock	950	53	20	80
Peninsula Bridge	1,280	43	22	78

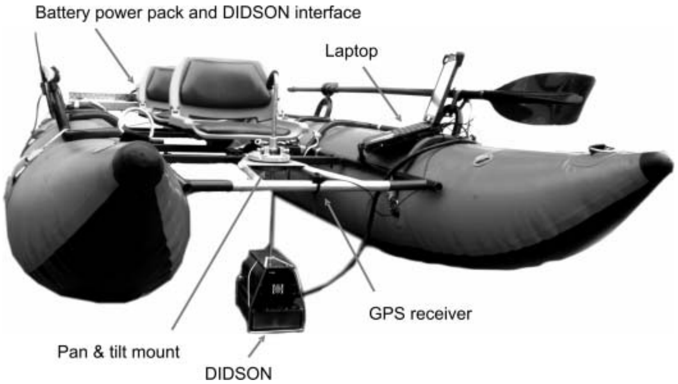

FIGURE 1. Cataraft with the DIDSON mounted for directional fish counting; key features are labeled.

occupants, so that they could view the footage in real-time and operate the DIDSON software controls. However, in situ recognition of fish was very limited, owing to background clutter and movement as well as reflection from the screen, despite the presence of a shade bellows. A GPS was also connected to the laptop, the antennae being located on the frame directly above the DIDSON mount, so that geographic coordinates were recorded to the DIDSON files. The DIDSON was powered by two 12-V, 7-Ampere-hour (Ah) gel-cell lead acid batteries, carried on the rear gear tray of the cataraft and wired in series to give 24-V output. The cataraft, laden with the DIDSON and associated gear, could easily be drifted from a tether in shallow sections, or portaged over very shallow sections by the two operators. About 5–15% of the reaches were too shallow to use the DIDSON. These locations were confined to shallow portions of riffles. Drift diving also is inefficient in riffles (Teirney and Jowett 1990). Notwithstanding restricted view, observations by divers suggest that trout >20 cm are uncommon in riffles.

When surveying by DIDSON, we steered the cataraft down the reach near the thalweg with the DIDSON trained toward one of the banks. Whole-reach counts required a second drift of the reach with the DIDSON trained toward the other bank, after which the counts from each side were summed. The cataraft was rowed against the current, as required to maintain a relatively constant, slow speed throughout the reach—similar to the current speed encountered in the middle of pools and in slow runs in which the craft was allowed to passively drift. We continually altered the angle of the DIDSON relative to the direction of travel according to the width of the channel, to maximize the width of the river ensonified. Where the channel was narrow, the DIDSON was angled forward of the cataraft, whereas in wider sections it was moved closer to perpendicular to the direction of travel. We also panned and tilted the DIDSON as necessary in an attempt to achieve a thorough coverage of the bed; this included panning back upstream to attempt to see behind big boulders, bedrock outcrops, and woody debris.

The DIDSON was operated with firmware version 5.70, and footage was collected and processed using versions 5.20.09 and 5.23.09 of the DIDSON operating-system software (Sound Metrics 2009). The standard DIDSON was operated in low-frequency mode (1.1 MHz), whereby 48 horizontally arranged beams (four sets of 12 beams) produce images from a field of view that is nominally 12° vertically by 29° horizontally, and had a nominal maximum range of 40 m. We operated with a 3.33-m window start length and usually a 20-m window length, recording at 7 frames per second (fps), and a maximum receiver gain of 30 dB. Occasionally, in wide sections of the reaches, we increased the window length to 40 m. The probability of detecting fish within the beams declines with distance from the DIDSON (Burwen et al. 2010).

Potentially the probability of detecting fish is lower in the first few meters from the DIDSON than further away because the narrow vertical beam array (12°) does not cover the entire water column close to the transducer. The 12° vertical field of view covers a depth of ∼1 m at 5 m from the DIDSON and ∼2 m at 10 m. Depths greater than 2 m were rare in the study reaches and, as previously mentioned, we made an effort to vary the vertical scanning angle with the pan and tilt mechanism to cover deep water.

Reviewing DIDSON images.—All DIDSON image files from 2009 and 2010 surveys were reviewed by an observer with a high degree of experience viewing both static and mobile platform files. DIDSON image files from a survey of one side of the 1,220-m Dove reach (the 2009 surveys) were also reviewed by two other observers with a moderate level of experience—to examine variation in DIDSON trout counts among observers. These survey data were randomly selected from nine single-sided surveys from the three reaches (three surveys × three reaches) undertaken in 2009; the remaining 2009 data were discarded for the present study. In total, approximately 23 h and 52 h of DIDSON image files were reviewed from the 2009 and 2010 surveys, respectively.

DIDSON image files were viewed in a darkened room at approximately 30–100 fps, i.e., about 4–14 times the recorded frame rate, depending on the rate of movement of the DIDSON relative to the riverbed in the footage. Watching the files at these high playback speeds helped to highlight movement of trout relative to the bed. The transmission loss function was turned on, to correct the image for acoustic propagation losses due to spreading and absorption (Sound Metrics 2009). To inform this function, the sound absorption coefficient was calculated within the software, using the water temperature range and salinity setting in the initiation file, whereas the spreading factor was left at the default value of 20 after a sensitivity analysis indicated that this setting was best for the files being reviewed.

The sound speed was not manually corrected; the default 1,457 m/s was used. No additional threshold was applied to remove noise, and the image intensity was set to minimum (90 dB). The “Smooth” function was also turned on, to reduce the blocky appearance of the image by interpolating between beams (Sound Metrics 2009). The observer paused and replayed sections of footage as required to thoroughly search for fish against the background noise and moving riverbed. Sometimes fish were detected from their acoustic shadows sweeping across the screen. Pause and playback then allowed the observer to find the source of the shadows.

When fish were located in a file, they were measured (approximate total length, using the DIDSON software measurement tool), and the frame number was noted, along with the geographic coordinates. Mobile and stationary fish were recorded at average ranges of 9.9 and 12.5 m, respectively. At these ranges, when operating in low-frequency mode, the DIDSON beam pixel widths would be 11.3 and 13.4 cm, respectively (Sound Metrics 2009). Error in the fish length measurements ought to be similar to the pixel width, and detecting a fish requires it to track across at least two pixels. With a 20-m window length and a 3.33-m window start length, the pixel length at the maximum range (23.3 m) would be about 25 cm. For these reasons we were unable to detect and measure objects identified as fish smaller than ~20 cm.

To minimize double counting, we included fish in the tally only if they were observed to move upstream relative to the cataraft after being counted, or if they moved off sideways and looked like they were headed upstream. Drifting objects that moved downstream at a velocity similar to that of the current were ignored, as were stationary objects that appeared to have a "tail beat" but no movement of the "nose." These were assumed to be stationary willow tree branches, roots, etc., and their locations were compared with aerial photographs in Google Earth (Mountain View, California) to confirm willow tree locations.

DIDSON and drift-dive surveys for estimating abundance and precision.—Triplicate DIDSON survey data from one side of the Dove reach (half the channel width) on February 19, 2009 (discharge, ~10 m^3/s), were used for comparing within-observer count variation and among-observer variation. The latter was based on three observers reviewing the DIDSON image files from the same single-sided survey randomly selected from the triplicate surveys. In March 2010, triplicate, whole-reach DIDSON and drift-dive surveys were made in the Dove, Woodstock, and Peninsula Bridge reaches to provide comparative data on both abundance and precision of density estimates. The whole-reach DIDSON surveys included both sides of the reaches, comparable with drift-dive surveys that covered the entire river width. The DIDSON surveys were undertaken a minimum of 1 h after the drift-dive surveys and the reach was rested for a minimum of 1 h between the repeat surveys. The Dove reach was drift dived on March 1, 2010, and surveyed with drifting DIDSON on March 3, 2010. The other two reaches were drift dived on March 2, 2010, and surveyed by DIDSON between March 3 and 5, 2010. The mean daily discharge varied between 10.2 and 11.9 m^3/s over the sampling period. Each reach was spelled for a minimum of 2 h between repeat surveys. When repeat DIDSON surveys were undertaken, fish often were observed to be feeding on the water surface, indicating they had recovered from previous disturbance.

Drift-dive snorkel surveys were undertaken with a team of nine divers. The survey methodology followed drift-dive protocols described by Hicks and Watson (1985) and Teirney and Jowett (1990) and is summarized below. Adequate water clarity for reliable counts is a prerequisite for drift diving. Water clarity was measured by black disk (Davies-Colley 1988) at the time of each drift dive; this reading was 6.1 m during the drift dives in the Dove reach and 5.5 m in the Woodstock and Peninsular Bridge reaches. These clarities substantially exceeded the minimum clarity recommend for drift diving, i.e., 3 m in slowly flowing rivers and 4 m in swifter rivers (Teirney and Jowett 1990). All divers entered the water at the same time and were evenly spaced across the width of the channel. As the river width changed, the spacing between divers also changed, the divers endeavoring to achieve full visual coverage of the area between themselves and the adjacent diver, or between themselves and the banks in the case of the outside divers. Divers either drifted with the current or actively swam through slower water. They actively searched for fish hiding in and around boulders, bedrock channels, overhangs and crevices, and woody debris. To prevent overlap of counts, divers communicated when they observed large groups of trout. Brown Trout counts were recorded for three size-classes: small (<20 cm), medium (20–40 cm), and large (>40 cm). Size-classes were roughly estimated by divers who calibrated their eye according to the lengths of their hand (roughly 20 cm) and forearm plus hand (roughly 40 cm). The medium and large size-classes were pooled for comparing with abundance of trout >20 cm estimated by DIDSON surveys.

The lengths and mean widths of the study reaches were estimated from measurements made on mesohabitats (riffles, runs, pools) with a laser range finder (Leupold RX III) to estimate the area surveyed (for calculating density from count data). At least five width estimates were made per mesohabitat.

The number of person-hours taken to complete a survey of a reach by each method was recorded (including reviewing of DIDSON images) to provide a cost comparison. However, travel time to and from and between reaches was not included, because this was assumed to be common among methods.

Data analysis.—For estimates of trout abundance to be of use, they need to be repeatable within reasonable margins of error (i.e., be reasonably precise). There were two sources of variation in the fish counts made with DIDSON in the present study: (1) variation in detecting fish in the field, and (2) variation in detecting fish in the DIDSON images. The 2009 data from one reach (Dove) informed both sources of variation. The triplicate counts made by one observer from single-sided surveys of the Dove reach gave an estimate of the error attributable to both sources of error. The counts made by three observers from one of the same triplicate single-sided surveys provided an estimate of the error attributable to variation in detecting fish during review of the DIDSON images. We calculated an estimate of the error due to counting fish in the field, using the error propagation law for addition and subtraction (Ku 1966) as follows:

$$\delta A = \sqrt{(\delta AB)^2 - (\delta B)^2}$$

where δA and δB represent the two sources of error (SD) defined above and $\delta(AB)$ represents the combined error.

The 2010 DIDSON and drift-dive triplicate whole-reach counts provided the main data for comparing both the abundance and precision of density estimates between methods. Comparisons of 2010 densities between reaches and methods were made with two-way analysis of variance (ANOVA) and Tukey's post hoc contrasts in R (R Development Core Team 2008). The numbers of mobile versus stationary fish detected by DIDSON were compared with Student's t test (in Excel; Microsoft, Redmond, Washington). Comparative precision of density estimates between methods was assessed with the coefficient of variation (CV [SD/mean]); the variance of DIDSON estimates was the combined error of detecting fish in the field survey and detecting fish in the DIDSON image files.

Small fish (<20 cm) were excluded from the analysis because they are known to be undercounted by drift divers (Teirney and Jowett 1990) and are unlikely to be detected by DIDSON. Small fish comprised a small proportion of the trout recorded in the drift dives in all reaches (mean = 6.7%, range = 2.8–18.6%).

RESULTS

General Observations

Trout appeared to be disturbed by the cataraft. Most fish observed in the DIDSON footage appeared to be moving evasively, shoaling or moving laterally (or both) to avoid passing under the raft, or bolting upstream as the raft passed over them. Of 513 individual fish observations, the fish were stationary in only 65 cases. On average, stationary fish were observed significantly farther from the raft than were mobile fish: 12.5 and 9.9 m, respectively ($t = -5.32$, df = 71, $P <$ 0.001, assuming unequal variances). Ninety percent of trout in both categories were recorded at more than 7 m from the DIDSON. Fish that were not actively moving relative to the bed were much more difficult to detect in the DIDSON images.

In turbulent, aerated water, the effective field of view of the DIDSON could be substantially reduced; down to a few meters. Often in these situations the DIDSON had to be raised from the water to prevent damage from rocks as the raft drifted through boulder rapids (approximately 5% of each reach). The ability to see fish by drift diving is also limited in such conditions, but few fish probably occupy such turbulent habitats.

Partitioning DIDSON Count Variance

We estimated the variation in detecting fish in the DIDSON images from the following counts made by three observers who viewed the DIDSON image files from the same randomly selected 2009 single-sided survey of the Dove reach: 39, 44, and 49 trout (mean = 44.0, SD = 5.00, CV = 0.11). All three observers located some fish that were not noticed by the other two. After making their individual counts, the three observers together assessed all fish observations and formed a consensus view on whether to include each in a combined tally (i.e., deciding whether targets were fish or debris, and the likelihood of double counting). This resulted in a final tally of 53 fish.

We estimated the total DIDSON count variability (error in detecting fish in the DIDSON field surveys plus error in detecting fish in the DIDSON images) from the following triplicate counts made by one observer from one side of the Dove reach in 2009 on the same day: 52, 58, and 28 trout (mean = 46, SD = 15.87; CV = 0.35). The variation in detecting fish in the DIDSON field surveys (SD = 15.07; calculated with the equation given earlier) contributed substantially more (95%) to total count variability than did variation among observers in detecting fish in DIDSON image files (i.e., SD = 5.00).

DIDSON versus Drift-Dive Density Estimates—Abundance and Precision

Mean densities of trout >20 cm estimated from 2010 DIDSON surveys were consistently lower than those from the drift-dive surveys (two-way ANOVA: $F_{1,14} = 148.50$, $P <$ 0.001; Table 2). Overall densities estimated by DIDSON were 21.8% (range = 7–34%) of those estimated by drift diving (Table 2). Trout density estimates differed significantly among reaches (two-way ANOVA: $F_{2,14} = 21.56$, $P < 0.001$). Tukey's post hoc tests showed that drift-dive densities in the Woodstock reach were significantly higher than those in the Dove ($P = 0.003$) and Peninsula Bridge ($P = 0.002$) reaches; DIDSON densities in the Woodstock reach also were significantly higher than those in the Peninsula Bridge reach ($P =$ 0.023). Other reach mean contrasts were not significant.

The CV of trout densities estimated by drift diving in 2010 was very similar between reaches (range = 0.15–0.17) (Table 2). By contrast the CVs for DIDSON densities were much more variable (range = 0.13–0.47); they were more than double those for drift diving for the Dove and Peninsula Bridge reaches but similar to those for the Woodstock reach (Table 2).

Cost Comparison

Ignoring capital or rental costs, the DIDSON surveys were about 34% more costly in terms of overall personnel effort than drift diving. The DIDSON two-sided surveys took 8.3 person-hours per kilometer of river on average, approximately 60% as field work and 40% as review of DIDSON images. The drift-dive surveys took 6.2 person-hours/km on average, the vast majority (~98%) of the time being spent on the field work (i.e., nine divers taking approximately 30–40 min/km).

DISCUSSION

Our results demonstrate that both abundance and mean precision estimates are substantially lower for DIDSON than for drift-dive surveys. The precision of DIDSON abundance estimates was much more variable among reaches than drift-dive estimates. The low precision (and probably also the variation in precision between reaches) was due mainly to variation in detecting fish in the field; much less was due to variation in detecting fish in the DIDSON images. Trout abundance estimates determined by cataraft-DIDSON survey appear to be more sensitive to differences in the physical characteristics of a reach than drift-dive estimates are. The reach with lowest precision (Dove) had the highest proportion of shallow habitat (riffles and fast, shallow runs). The precision of drift-dive abundance estimates was remarkably similar between reaches (CV = 0.15–0.17). Of note, precision of the drifting DIDSON method was similar to that of drift diving in one of the reaches: Woodstock. This reach was also where the highest mean density estimate was achieved by DIDSON relative to the mean density estimated by drift diving. The Woodstock reach had the most uniform channel and the fewest obstructions obscuring the DIDSON beams.

The greater abundance estimates by drift diving are not surprising, given that divers actively search for trout (Teirney and Jowett 1990). Nevertheless, dive-count efficiencies are known to vary with the amount of cover, water depth, temperature, and water clarity (Dolloff et al. 1996; Young and Hayes 2001; Hagen and Baxter 2005; Orell and Erkinaro 2007). Fish are obscured by cover elements, but at higher temperatures they are more active, hiding less under cover, and so are more likely to be seen (Heggenes et al. 1993; Hayes and Baird 1994). The efficiency of DIDSON counts will be even more reduced by cover and similarly improved by increasing temperature–within their feeding range. Trout feeding activity increases with consumption demand to a maximum at about 18°C for Brown Trout and 20°C for Rainbow Trout *Oncorhynchus mykiss* (Dickson and Kramer 1971; Elliott 1994). Hence the efficiency of counting trout by DIDSON (and by drift diving) ought to be highest in summer when temperatures are near these upper limits.

TABLE 2. Brown Trout (>20 cm) triplicate density estimates (no./ha) and their means and coefficients of variation (CVs) made by drift diving and cataraft-DIDSON in three study reaches in the Motueka River in March 2010 ($N = 3$). Density estimates for DIDSON are the sum of density estimates from consecutive surveys of each side of a reach.

	Drift dive		DIDSON	
Reach	Density	CV	Density	CV
Dove	32.2		5.0	
	25.2		11.6	
	35.7		6.0	
Mean	31.0	0.17	7.5	0.47
Woodstock	44.8		17.0	
	45.8		18.6	
	59.2		14.2	
Mean	49.9	0.16	16.6	0.13
Peninsula Bridge	32.9		1.3	
	24.6		2.8	
	30.9		2.1	
Mean	29.5	0.15	2.1	0.36

Our focus for assessing the utility of cataraft-mounted DIDSON for estimating abundance of trout was on precision rather than accuracy, because most applications will be at-a-reach monitoring of trends. For this purpose, knowledge of precision (variability in replicate abundance estimates) is required and knowledge of accuracy (i.e., how close estimated abundance is to actual abundance) is not essential. An understanding of accuracy requires estimates of count efficiencies (i.e., proportion of population counted). For observational methods (including sonar) this requires mark/tag resighting (or recapture) or radiotelemetry studies, which are costly and run a high risk of failure in flood-prone rivers. The challenge and cost of estimating count efficiency (and related accuracy) is of course why drift diving is nearly always used to estimate at-a-reach abundance for providing an index of trout population change over time in New Zealand. The drifting DIDSON method is best applied in the same context.

The vast majority of fish detected by observers reviewing DIDSON image files were moving, apparently disturbed and attempting to evade the cataraft. The difficulty of comprehensively and consistently ensonifying all of the reach, especially around structures, and then identifying stationary fish against the moving background in the DIDSON footage is probably in large part why we detected mainly moving fish. This bias also no doubt contributed to the lower abundance estimates and precision achieved by DIDSON relative to drift diving. The mobility bias suggests that the DIDSON technique is better for counting fish that are less substrate oriented and more likely to be active in the water column than Brown Trout are (e.g., Rainbow Trout: Hicks and Watson 1985; Cutthroat Trout *O. clarkii*: Joyce and Hubert 2003). As already mentioned, count efficiency will also depend on water temperature due to its influence on fish activity and cover-seeking behavior.

The fact that stationary fish were detected on average further from the raft than moving fish (12.5 versus 9.9 m) suggests that proximity to the raft has an influence on the behavioral response of trout. Ninety percent of stationary, and moving, fish were recorded >7 m from the raft. Xie et al. (2008) found that the maximum reaction distance of migrating salmon to a motorized vessel in highly turbid waters in the Fraser River was ~7 m. They observed that fish maneuvered laterally to position themselves at least 2 m away from the vessel's path, and they also discussed the influence of water depth on the reaction of salmon to the vessel, contributing to what they termed the "3D interference range of the vessel." Brown Trout are known for their tendency to hunker down on the streambed or seek cover when threatened, as they often do in the presence of drift divers (e.g., Young and Hayes 2001; J.W.H. and I.M., personal observations). In deep water, Brown Trout may be more prone to act in this way, rendering them difficult to find in the DIDSON footage, or they may even be missed if they are within the blind spot defined by the window start length and DIDSON tilt angle, whereas in shallower pools and runs they may be more inclined to evade the raft, and so be easier to detect.

We have not yet tested the drifting DIDSON method in turbid rivers, where it has most potential (i.e., where visual counts are not possible). We focused first on a clear-water river to bench-mark the precision of the method against drift diving. In lowland rivers, which tend to be more turbid, the lower gradient and less complex bed morphology ought to mean that fish are easier to detect by DIDSON. Moreover, trout may be less inclined to seek cover in turbid rivers.

The key limitations with the drifting DIDSON method are related to the ability to ensonify the entire surveyed reach, obstructions obscuring the DIDSON beams, detection of stationary versus moving fish, and difficulties identifying fish against a moving background. The limitation of not being able to survey the entire wetted width of rivers >20 m wide is problematical. We estimated whole-reach trout abundance by alternately surveying each side of a reach from the midline of the channel. However, this approach introduced an increased possibility of abundance bias or variability due to double counting of fish moving across the channel between passes. Deployment of two DIDSONs from the same raft, or more likely, from two rafts, simultaneously is an expensive solution. Even with the alternate-pass approach, we were not always able to ensonify the full width of the channel. We tried to alleviate this problem by using a longer window length in wide sections (40 m). However, the exaggeration of even subtle movements of the DIDSON at long ranges, especially when viewing files at high playback speeds to enhance detection of fish movements, made these images very difficult to interpret. They could be used if the movement of the DIDSON relative to the bed during data collection was very slow and steady. However, this is difficult to achieve when the cataraft is being buffeted by currents; perhaps it may be possible in tranquil lowland rivers.

The limitation of not being able to ensonfiy the entire wetted width has recently been overcome with the new range of Adaptive Resolution Imaging Sonars (Aris; Sound Metrics 2009), which have a greater range (35–80 m) over the low-frequency range (1.1–0.7 MHz). They also offer higher resolution over the short to medium depth range (<15 m), operating with a greater number of beams and higher frequencies (1.8 MHz). However, a blind spot will be still present due to the window start length and tilt angle. The size of the blind spot will increase with water depth and will include the habitat along the bank away from where the sonar is aimed across the channel. Thus, a prime strip of habitat will be omitted from the survey. The solution is to survey only one side of a reach from midchannel. There is no compelling reason to survey both sides of the channel to estimate abundance for trend monitoring.

Other issues related to fish detection are possibly more difficult to address. Some are due to the resolution of the data (e.g., the potential for size bias in fish detection) and the escalating error in measurements of fish as range increases. The latter makes it difficult to confidently classify fish into size-classes, although recent investigations suggest accurate length measurement can be obtained at considerable distance (Burwen et al. 2010). This issue is exacerbated by the fact that fish are often distinguishable from the background when only the moving image file is playing, so determining the length of the fish in the paused file also can be difficult. This also means that freezing the image to count clusters of fish is not possible, at least with software presently available. Another problem is that filamentous algae and roots waving in the current can easily be mistaken for fish because the movement mimics the tail beat of a fish. This problem cannot easily be addressed without discounting possible stationary fish observations.

Finally, with moving-platform DIDSON survey, discrimination between fish species with similar body form is unlikely. There has been some success in discriminating between species by using tail-beat frequencies (Meuller et al. 2010) and Fourier analysis of acoustic shadows (Langkau et al. 2012) from fixed platforms. However, the challenges in doing this will be greater for moving platform images, where the fish images can be fleeting and exhibit various aspects.

Image processing algorithms for subtracting the moving background, leaving only objects traveling with different speeds or directions, would make locating and counting fish much easier. However, this would also be technically difficult for a moving platform, and may overlook stationary fish (i.e., those holding station relative to the bed). Another improvement offered by image processing is to create a montage of the ensonified area with sequential DIDSON frames, whereby moving fish would be evident as streaks in the montage image. Again, stationary fish may be difficult to locate. This type of frame montage would also allow direct calculation of the area surveyed to more accurately calculate fish density, rather than using reach measurements.

The DIDSON survey method was more costly in terms of person-hours than drift diving was, by about 34%, owing to extensive time required for review of the image files; however, fewer personnel were required. In our study reaches the DIDSON surveys required a minimum of two people with a third person sometimes included for drop off and pick up at either end of the reach. By contrast, the drift dives required nine experienced divers to cover these reaches. The lower staff numbers may be an advantage in some situations despite the higher overall time costs, because it is often difficult to obtain enough experienced divers to survey large rivers (Orell and Erkinaro 2007). The above comparison of costs dealt only with labor effort. The capital costs for the cataraft-mounted DIDSON gear are about 10 times higher than for drift diving, including outfitting and training divers. Capital costs of the DIDSON with field laptop and external hard disk storage were ~US$90,200–94,000, the DIDSON pan and tilt mounting mechanism cost ~$400, and the cataraft cost ~$3,200.

In conclusion, the drifting DIDSON method has utility for assessing abundance of trout >20 cm for monitoring trends. While it is more costly and less versatile, accurate, or precise than drift diving in clear rivers, it offers a viable means of estimating abundance in turbid rivers, where visual estimates of abundance by divers is impossible.

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REFERENCES

Baumgartner, L. J., N. Reynoldson, L. Cameron, and J. Stanger. 2006. Assessment of a dual-frequency identification sonar (DIDSON) for application in fish migration studies. New South Wales Department of Primary Industries, Fisheries Final Report Series 84, Narrandera, New South Wales, Australia.

Belcher, E. O., B. Matsuyama, and G. M. Trimble. 2001. Object identification with acoustic lenses. Pages 6–11 *in* Proceedings of Oceans 2001 Conference. Marine Technical Society, Washington, D.C., and Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Burwen, D. L., S. J. Fleischman, and J. D. Miller. 2007. Evaluation of a dual-frequency imaging sonar for estimating fish size in the Kenai River. Alaska Department of Fish and Game, Fishery Data Series 07–44, Anchorage.

Burwen, D. L., S. J. Fleischman, and J. D. Miller. 2010. Accuracy and precision of salmon length estimates taken from DIDSON sonar images. Transactions of the American Fisheries Society 139:1306–1314.

Davies-Colley, R. J. 1988. Measuring water clarity with a black disk. Limnology and Oceanography 33:616–623.

Dickson, I. W., and R. H. Kramer. 1971. Factors influencing scope for activity and active and standard metabolism of Rainbow Trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 28:587–596.

Dolloff, A., J. Kershner, and R. Thurow. 1996. Underwater observation. Pages 533–554 *in* B. R. Murphy, and D. W. Willis, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Elliott, J. M. 1994. Quantitative ecology and the Brown Trout. Oxford University Press, Oxford Series in Ecology and Evolution, Oxford, UK.

Hagen, J., and J. S. Baxter. 2005. Accuracy of diver counts of fluvial Rainbow Trout relative to horizontal underwater visibility. North American Journal of Fisheries Management 25:1367–1377.

Hayes, J. W., and D. Baird. 1994. Estimating relative abundance of juvenile Brown Trout in rivers by underwater census and electrofishing. New Zealand Journal of Marine and Freshwater Research 28:243–253.

Heggenes, J., O. M. W. Krog, O. R. Lindas, J. G. Dokk, and T. Bremnes. 1993. Homeostatic behavioral responses in a changing environment: Brown Trout (*Salmo trutta*) become nocturnal during winter. Journal of Animal Ecology 62:295–308.

Hicks, B. J., and N. R. N. Watson. 1985. Seasonal changes in abundance of Brown Trout (*Salmo trutta*) and Rainbow Trout (*S. gairdneri*) assessed by drift diving in the Rangitikei River, New Zealand. New Zealand Journal of Marine and Freshwater Research 19:1–10.

Holmes, J. A., G. M. W. Cronkite, H. J. Enzenhofer, and T. J. Mulligan. 2006. Accuracy and precision of fish-count data from a 'dual-frequency identification sonar' (DIDSON) imaging system. ICES Journal of Marine Science 63:543–555.

Joyce, M. P., and W. A. Hubert. 2003. Snorkeling as an alternative to depletion electrofishing for assessing Cutthroat Trout and Brown Trout in stream pools. Journal of Freshwater Ecology 18:215–222.

Ku, H. H. 1966. Notes on the use of propagation of error formulas. Journal of Research of the National Bureau of Standards 70C:263–273.

Langkau, M. C., H. Balk, M. B. Schmidt, and J. Borcherding. 2012. Can acoustic shadows identify fish species? A novel application of imaging sonar data. Fisheries Management and Ecology 19:313–322.

Maxwell, S. L., and N. E. Gove. 2007. Assessing a dual-frequency identification sonar's fish-counting accuracy, precision, and turbid river range capability. Journal of the Acoustical Society of America 122:3364–3377.

Meuller, A.-M., D. L. Burwen, K. M. Boswell, and T. Mulligan. 2010. Tail-beat patterns in dual-frequency identification sonar echograms and their potential use for species identification and bioenergetics studies. Transactions of the American Fisheries Society 139:900–910.

Mueller, R. P., R. S. Brown, H. Haakon, and L. Moulton. 2006. Video and acoustic camera techniques for studying fish under ice: a review and comparison. Reviews in Fish Biology and Fisheries 16:213–226.

Moursund, R. A., T. J. Carlson, and R. D. Peters. 2003. A fisheries application of a dual-frequency identification sonar acoustic camera. ICES Journal of Marine Science 60:678–683.

Orell, P., and J. Erkinaro. 2007. Snorkelling as a method for assessing spawning stock of Atlantic Salmon, *Salmo salar*. Fisheries Management and Ecology 14:199–208.

Pease, B., and B. Green. 2007. Observing fish behaviour at tidal floodgates. Society of Wetland Scientists Bulletin 24:29–30.

R Development Core Team. 2008. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Richardson, J. 1992. Drift diving validation. Ministry of Agriculture and Fisheries, New Zealand Freshwater Fisheries Miscellaneous Report 122, Rotorua, New Zealand.

Sound Metrics. 2009. Dual-frequency identification sonar DIDSON. Operation manual V5.21. Sound Metrics, Seattle.

Teirney, L. D., and I. G. Jowett. 1990. Trout abundance in New Zealand rivers: an assessment by drift diving. New Zealand Ministry of Agriculture and Fisheries, Freshwater Fisheries Report 118, Christchurch.

Tiffan, K. F., D. W. Rondorf, and J. J. Skalicky. 2004. Imaging fall Chinook Salmon redds in the Columbia River with a dual-frequency identification sonar. North American Journal of Fisheries Management 24:1421–1426.

Williams, G. D., R. M. Thom, D. K. Shreffler, J. A. Southard, L. K. O'Rourke, S. L. Sargeant, V. I. Cullinan, R. Moursund, and M. Stamey. 2003. Assessing overwater structure-related predation risk on juvenile salmon: field observations and recommended protocols. Pacific Northwest National Laboratory, Sequim, Washington.

Xie, Y. B., C. G. J. Michielsens, A. P. Gray, F. J. Martens, and J. L. Boffey. 2008. Observations of avoidance reactions of migrating salmon to a mobile survey vessel in a riverine environment. Canadian Journal of Fisheries and Aquatic Sciences 65:2178–2190.

Young, R. G., and J. W. Hayes. 2001. Assessing the accuracy of drift-dive estimates of Brown Trout (*Salmo trutta*) abundance in two New Zealand rivers: a mark-resighting study. New Zealand Journal of Marine and Freshwater Research 35:269–275.