Active Tracking Sonar Study of Salmon Migration Behaviour at Mission, British Columbia, 1998

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ACTIVE TRACKING SONAR STUDY OF SALMON MIGRATION BEHAVIOUR AT MISSION, BRITISH COLUMBIA, 1998

2000

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ABSTRACT

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An experimental active tracking acoustic system was used at Mission, B.C. to study salmon migration at this site in an attempt to detect fish reaction to an approaching survey vessel used in the Pacific Salmon Commission's regular echosounding programme. The active tracking split-beam system is useful for tracking fish movements over a much larger three-dimensional space than is possible with a fixed-aim split-beam system. We gained information on fish behaviour and acoustic measurements and we documented some interesting fish behaviour at the site. The active tracking split-beam sonar system gives precise information on direction of travel and speed of fish targets. The active system centres its acoustic axis on a moving target and follows the target, thus minimising the position bias caused by lower signal-to-noise levels when the target is located near the edge of the sound-beam. We have documented the position bias effect of a fixed-aim split-beam sounder on both the speed and swimming angle measurements of fish targets by comparing similar measurements acquired with the active tracking split-beam system. It is useful to measure the magnitude of this bias effect in the riverine environment. We did not obtain the definitive answer on the presence or absence of boat avoidance behaviour. In the portion of the river cross section surveyed by the active system, the boat avoidance effect did not appear to be pronounced. We also showed the importance of aiming the acoustic axis perpendicular to the fish passage to maximise fish detection.

RESUME

Cronkite, G.M.W. , Y. Xie, and A.P. Gray. 2000. Active tracking sonar study of salmon migration behaviour at Mission, British Columbia, 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. 2506: 47p.

Un traquer actif expérimental le système acoustique a été utilisé à la Mission, B.C. à la migration de salmon d'étude à ce site dans une tentative à détecte la réaction de poisson à un vaisseau d'étude prochain utilisé dans la Commission de Salmon Pacifique's le programme de echosounding régulier. Le système de division-rayon actif qui traque est utile pour traquer de mouvements de poisson par-dessus un beaucoup plus grand espace trois-à dimensions qu'est possible avec un système de division-rayon de réparé-dessein. Nous avons gagné l'information sur le comportement de poisson et les mesures acoustiques et nous avons documenté quelque comportement de poisson intéressant au site. Le système de sonar de division-rayon actif qui traque donne l'information précise sur la direction de voyage et la vitesse de cibles de poisson. Le système actif centre son axe acoustique sur un cible en mouvement et suit le cible, ainsi minimisant le prejugé de position causé par le signal plus bas-à-le bruit nivelle quand le cible est localisé près du bord du solide-rayon. Nous avons documenté l'effet de prejugé de position d'un division-rayonne de réparé-dessein plus solide sur la vitesse et les mesures d'angle qui nagent de cibles de poisson mesures en comparant similaires acquises avec le système de division-rayon actif qui traque. Il est utile à la mesure la magnitude de cet effet de prejugé dans l'environnement de riverine. Nous n'avons pas obtenu la réponse définitive sur la présence ou l'absence de comportement d'action d'éviter de bateau. Dans la portion de la coupe transversale de rivière examinée par le système actif, l'effet d'action d'éviter de bateau n'a pas apparu à est prononcé. Nous avons montré aussi l'importance de viser la perpendiculaire d'axe acoustique au passage de poisson à maximise la détection de poisson.

1.0 INTRODUCTION

The Pacific Salmon Commission (PSC) uses a downward-looking single-beam echosounder to estimate the passage of migratory sockeye (*Oncorhynchus nerka*) and pink (*Oncorhyncus gorbuscha*) salmon in the Fraser River at Mission B.C. (Woodey 1987). The programme, hereafter referred to as the standard hydroacoustic programme, consists of two components: transect and stationary soundings. These two operational modes are designed to provide data on two aspects of migratory salmon abundance. The first collects information on fish target density across the river; the second acquires statistics on migration speed. The data obtained from the standard programme is processed using a duration-in-beam method (Thorne 1988), which leads to an estimate of salmon escapement past the survey site over a 24 hour period. The statistical handling of the data has been refined and improved recently (Banneheka et al. 1995). However, the accuracy of estimates depends on the validity of a number of assumptions. The following of which are the most important:

1. All fish swim upstream along trajectories parallel to the river bank.
2. The majority of the fish are distributed in the mid-water portion of the water column with few migrating near the river surface where they would not be insonified or near the river bottom where target returns would not be discernible from the bottom echo. Few fish migrate in the shallow water near the shore where sounding cannot be done by the survey vessel;
3. Fish swimming speed is negligible relative to the speed of the survey vessel;
4. Fish behaviour is not altered by the presence of the survey vessel.

The first three assumptions define fish behaviour scenarios that are ideal for downward fish sounding; the last is related to fish and vessel interaction. Violation of any of these assumptions would result in bias in the estimate, as described in Banneheka et al. (1995). Therefore, it is essential that these assumptions be assessed in the river by independent measurements. (Xie et al, 1997).

We hoped to test the assumption that the fish behaviour is not altered by the presence of the survey vessel with the use of the Biosonics Active Tracking Split-Beam Sonar system, from hereon referred to as the active tracking system. Figure 1 shows the sort of behaviour that could affect the acoustic detection of migrating salmon, as a fish reacting to the transecting vessel in this way would never pass through the downward looking sound-beam projected from the vessel. The active tracking system was run in addition to a fixed-aim split-beam echosounder system, manufactured by HTI (Hydroacoustic Technology Inc., Seattle Washington) at the site. We have been operating the HTI split-beam system at the site since 1995 to test the assumptions listed above (Xie et al, 1997) under a joint programme between the Department of Fisheries and Oceans (DFO) and PSC. This report will focus on the active tracking sonar findings with reference to the fixed-aim split-beam system when comparisons are pertinent.

Measurements of vessel avoidance by the fish have proven difficult to obtain. Therefore, we hoped that the ability of the active tracking split-beam sonar to follow a moving target over a long distance would allow us to detect and quantify avoidance behaviour.

2.0 MATERIALS AND METHODS

2.1 STUDY SITE

The 1998 active tracking split-beam experiment was conducted in the Fraser River near Mission, B.C. (Figure 2) located 80 kilometres upstream of the river mouth. The study site is approximately 2 km upstream of the railway bridge that crosses the river at Mission. At this point the Fraser River is approximately 450 metres wide and varies in maximum depth with discharge over the salmon migration season from approximately 18 metres in June during high run-off periods to 12 to 13 metres in September and October at low flow. The river substrate at the site is mud and silt with some large debris present. A tidal affect is present at the study site after the river discharge drops in late summer and fall. The river flow reverses slightly at high tide when the flow is low.

2.2 DATA SAMPLING HARDWARE AND SOFTWARE

The hydroacoustic system consisted of the following hardware units:

- Biosonics Model DT6000 digital echo sounder/computer in tracker configuration
- One 6.4 degree circular split-beam transducer operating at a frequency of 201 kHz
- Tracking Computer
- Transducer-rotating hardware/stepper motors
- Underwater mount to attach transducer and stepper motor to a fixed structure (a log-booming grounds dolphin was used in this study).

The minimum threshold was set at –53 dB with an absorption coefficient of 0.003 dB/m. The salinity was zero and the water temperature was approximately 20° Celsius. The source level was set at 217.5 dB (Relative to 1 μPascal) with a sound velocity of 1522 m/sec. The processing range started at 1 metre and ended at 30 metres. The pulse width used was 0.4 milliseconds and the ping rate varied with the amount of data being collected but nominally was 10 pings per second.

The software used for data acquisition included the following:

- Biosonics echosounder software
- Biosonics real-time target tracking software.

The software developed at DFO and PSC for post-processing and data analyses included the following:

- PSC FishTracker for Biosonics DT-6000 Split-Beam raw echo data (Version 1.2 in C language);
- PSC-DFO FishTrack Editor for Biosonics DT-6000 Split-Beam data (Version 1998. Built on MathSoft S-Plus 3.1©);
- MathSoft S-Plus 3.1© and 4.5© for visualising various results and porting final plots to other graphic software such as Microsoft® PowerPoint® for storage and presentation of these plots.

We will explain the need for developing these post-processing software programs in Section 3.

2.3 INSTRUMENT SETUP AND CONFIGURATION

The active tracking system was operated from July 27 to August 31 at which time the predominant fish species migrating upstream was sockeye. All electronic components of the system including the active tracking split-beam sounder and the tracking computer and stepper motor controller were installed inside the cabin of a landing craft tied to a log-booming ground piling or 'dolphin' at the study site. This dolphin was located on the left bank (south shore) of the river. A tide gauge attached to the dolphin permitted monitoring of water level. Using a differential global positioning system (DGPS), the location of the dolphin was determined to be 49" 08.175'N and 122"16.466'W. This location is a reference point for all our hydroacoustic studies at Mission (Figure 3). A tungsten carbide sphere of -42dB target strength was positioned in the beam at the start of the experiment. The system appeared to be operating normally at that time.

The active tracking sonar was set-up in resting mode with a horizontal aim pointing approximately 45° downstream. If a target greater than -53dB in target strength was detected, the tracking algorithm would come into play and the system would track the target by predicting its position several pings ahead. The system would attempt to keep the target in the centre of the acoustic beam. Tracking would terminate when the fish reached the end of the pre-set range of rotator movement, or if the track was lost. At this time, it would return to its starting position and wait for another fish. This procedure could be controlled manually and the operator could start the tracking process when a fish was seen on the echo sounder screen, but it was found to be more effective to allow the system to automatically initiate the tracking process for fish targets. This meant that the system had a tendency to track more upstream travelling fish, although some downstream fish were tracked during the experiment. Downstream fish could be tracked if they were picked up while the system was still searching for a lost track and then the system would follow the fish downstream. (Very few downstream targets are present at this site as seen by the fixed-aim split-beam acoustic system.)

The water depth at the time of the study was approximately 6 metres at the dolphin. The transducer was mounted approximately 2 metres below the water surface and lowered as necessary as the water level dropped. With the 6.4° circular beam we were able to obtain a maximum range of approximately 30 metres from the dolphin without receiving interference from the surface or the bottom. Figure 4 shows the bottom profile at the site with the width and depth in perspective to show the shallowness of the river relative to the width. Shallow water causes many challenges with all types of acoustic measurements due to the close proximity of the boundaries, i.e., the surface and bottom.

The geometry of the insonified river volume for the active tracking sonar is shown from both the aerial view (Figure 5) and the view from out in the river towards the transducer mount (Figure 6). The co-ordinates of the targets are expressed in a Cartesian system with upstream-downstream (X), vertical (Y) and horizontal distance from transducer (Z). Figure 5 represents an aerial view of the dolphin where the transducer was mounted. The compass bearing of 308° is perpendicular to the river bank at this site. The light blue triangles represent consecutive transducer sound-beam positions as the system follows the fish upstream. The fish is represented by the red line, moving from –X to +X. The angle at which the transducer is oriented relative to the 308 degree reference angle is referred to as +Alpha (downstream) and –Alpha (upstream) in degrees. Figure 6 shows the geometry from the perspective of out in the river looking toward the transducer. The additional axes shown are Y (up and down in the water column) and Z (inshore and offshore). The light blue colour outlines the geometry of the -3dB sound-beam with a fish shown in the beam for reference. The dolphin was located about 20 metres from the shore during this experiment.

3.0 RESULTS AND DISCUSSION

3.1 FISH TRACK PROJECTIONS AND STATISTICS

All the data collected with the active tracking system had to be re-tracked and examined using our software developed in-house (listed in Section 2.2). This was necessary as the Biosonics real-time tracker severely truncated coherent fish traces and the system did not have a software utility to allow users to critique output data from the system. The results presented in this report were based on data analyses facilitated with our own data processing software. Figure 7 shows a standard echogram of Range vs. Time for some active-tracking sonar data. The track highlighted in red is shown in more detail in the following figures. When the active tracking sonar tracks a fish travelling parallel to shore a strong 'U' shape is seen on the echogram due to the change in range of the fish relative to the transducer as the fish passes the site. The sonar first detects the fish at long range at approximately 45° downstream. The range gets progressively shorter as the fish travels upstream until the fish is perpendicular to the acoustic axis, at which time the range is at a minimum. The fish continues its upstream movement and as it does the range again increases.

Figure 8 presents some of the details that are contained in the data that give us more insight into the fish behaviour. In addition, some acoustic properties are also presented. The upper left plot shows the fish position in the YX plane or as if you were sighting along the transducer sound-beam. The small circle represents the size of the sound-beam relative to the fish trace. The size of the circle increases as it shows the size of the beam where the fish entered the beam and where it exited. If the fish travelled through in a perfectly straight line perpendicular to the transducer's acoustic axis, then the two circles would be the same size. This fish displays a commonly seen trajectory at this site. The 'S' and 'F' represent the start and finish of the track. A least squares fitted line (shown in red) is drawn through the fish trajectory to show the straight-line approximation of the fish path.

In the top centre plot, the ZX projection, or aerial view, is shown with the transducer beam represented by the blue lines. The least squares fitted line is drawn through the trajectory in red. The top right plot shows the YZ projection which is as if the observer is standing in the river, looking downstream at the fish coming towards him. The transducer beam is again represented by the blue lines.

The lower left plot displays the Target Strength in Decibels vs. the Aspect Angle in Degrees. The aspect angle is the angle that the fish is oriented with respect to the acoustic axis. The values of this angle were given on an echo-to-echo basis but derived from a smoothed trajectory based on the entire raw track of the fish target. It can be seen that the target strengths increase to a maximum when the acoustic axis is perpendicular to the direction of the travelling fish. This quantitatively demonstrates the variation in target strength measurements due to the effect of aspect angle.

The bottom centre plot presents the Target Strength in Decibels vs. the X co-ordinate, or upstream/downstream position in metres. A peak in these target strength values can be seen at about 2.5 metres downstream. This is due to an almost perpendicular orientation of the fish relative to the acoustic axis, resulting in a maximum target strength reading. The list of statistics, bottom right, shows various measurements for this particular fish as it travelled past the site. For example we can see that this fish was tracked for a total of 22.79 metres at an average speed of 0.82 m/s. Some fish were tracked for as much as 35 metres.

Figure 9 presents the standard echogram for another fish. Figure 10 shows the details of this particular fish track. This fish took an abrupt turn as it passed the site as can be seen in the ZX projection, top centre. A very low target strength value is measured when the fish is moving straight away from the transducer. It is likely that this fish is not facing completely tail-on to the transducer as we would likely not detect a fish in that orientation. It is more likely that this fish is side-slipping out into the river away from the transducer. It is worth noting that the Pacific Salmon Commission transecting vessel was very far away from this fish at the time.

Figure 9 and subsequent echograms display a green line trace. This line represents the distance from Pacific Salmon Commission's vessel to the active-tracking system's transducer. This indicates the range between the two at a particular time but not the direction of the vessel from the transducer. Due to the Differential Global Positioning

System (DGPS) on-board the transecting vessel, we have the three-dimensional information as to where each fish is located relative to the vessel at any point in time.

Figure 11 presents a fish travelling away from the transducer for all of the time it was tracked. One can see the effect on the target strength values in the Target Strength vs. Aspect Angle plot in Figure 12. The target strength values are low, due to the partial tail-on aspect, and consistent, due to the consistent travel in the Z direction.

Figure 13, 14 and 15 show fish behaviour we had not seen before. In Figure 13, the echogram could be interpreted as one, two or even three fish traces. The transecting vessel appears in this echogram but is not particularly close to this fish. Figure 14 shows the various plots of this fish's behaviour. As can been seen in the ZX projection, this fish appears to have done a complete loop during the time it was observed. Figure 15 shows this behaviour in more detail. The fact that this trajectory is so perfect in time and space means that it is likely one fish and not a coincidental interaction of two or more fish.

The fish tracks were divided up into those that came, at some point in their trajectory, to within 50m of the transecting vessel and those whose closest distance from the vessel was greater than 50m. This was done to observe any difference in the behaviour between the two groups. Figure 16 shows a fish that approached the transecting vessel very closely. The top left plot displays the fish's movement in the X direction vs. Time. A fairly straight line, as displayed here, means that the fish travelled through the beam without much deviation in its path. The top right plot shows the fish movement in the Y direction or up and down in the water column. This fish moved up in the water column and then back down again. It should be noted that the zero on the Y-axis represents the location of the transducer, which was generally 2 metres below the surface. Therefore a Y reading of -2 metres would correspond to a depth of 4 metres below the surface. One needs to watch the scale of the y-axis as what appears to be a large change in depth may only be a metre or less, as is the case here.

The bottom left plot of Figure 16 shows the movement in the Z direction or inshore/offshore. Again a fairly straight line represents little deviation in the trajectory. The bottom right plot shows the relationship between the transecting vessel and the fish from an aerial perspective. The blue line represents the fish trajectory and the red line represents the transecting vessel trajectory. This fish approached the transecting vessel very closely and likely passed underneath it with very little apparent effect on its trajectory except for some change in depth. The target strength for this fish is presented in the upper right corner. The presented value is the mean for the echoes within an upstream/downstream angle of ± 5°.

This was done to allow direct comparisons with the target strength values from the fixed-aim split-beam system, which used an elliptical sound-beam, 4° high and 10° wide at the -3dB point. The target strength values obtained with the active tracking system are small for sockeye and this will be discussed in more detail later. At the time of this study, sockeye were the predominant species migrating past the site.

Figure 17 to 21 show examples where the transecting vessel is close to the fish and the fish's trajectory appears to be affected. A possible conclusion is that boat avoidance is occurring. Figure 18 shows a fish rising up in the water column and apparently moving away from the vessel. Figure 19 shows a fish taking a fairly abrupt turn while moving down in the water column, as the vessel approached. Figure 20 shows a fish diving in the water 3m in approximately 3.5 seconds. (The boat was about 15m away at the time.) Figure 21 shows a fish heading downstream. The target strength is not available as this fish never came within the ± 5° range used in calculating target strength. Figure 22 presents a fairly typical example of the migration behaviour past the site and shows no apparent behaviour change.

Figure 23 shows a fish passing when the transecting vessel is doing a stationary sounding (at which time the vessel is anchored and the engine is turned off). Again, the typical offshore movement is present. This sort of behaviour could be interpreted as avoidance even though the vessel was not moving nor making much noise. This led to the realisation that we needed to compare the behaviour of the fish when the boat was far away from the fish.

Figure 24 shows a fish track during a time when the transecting vessel was very far away. The trajectory is quite sinuous even in the absence of the vessel. If the vessel had been present, one might believe that the vessel had some affect on the fish's behaviour. In Figure 25 the vessel was again far away from the fish and the track shows the migration pattern we have come to recognise as typical for this site.

We examined many fish traces in this way. We did not see much difference in the behaviour of the fish when they were approached by the transecting vessel. However, boat avoidance may be occurring in other areas, such as the very shallow water areas near shore. These are areas where the downward looking system has limited or non-existent detection of fish targets and are better covered by a sideways-looking split-beam system.

3.2 TARGET STRENGTH MEASUREMENTS

We wanted to look at target strength measurements from the active tracking split-beam and fixed-aim split-beam systems to verify some of the target strength work we have done to date at this site. For this reason we compared target strength distributions for the two systems for data taken as close as possible to the same time periods. We were not able to run the two systems simultaneously as the operating frequencies were virtually identical (201 kHz vs. 200 kHz), which would have caused cross-talk interference with data collection had the two systems run at the same time. Figure 26 shows the target strength distributions for all of the targets tracked by the active tracking system. The histograms present the mean target strength for each tracked fish. The target strengths for the downstream travelling fish shown in the bottom plot appear considerably smaller in size than the upstream travelling fish. This may be an indication of resident species and possibly some debris. If we look at the mean target strengths within the ± 5° angle range as mentioned before, it causes a shift in the distribution into the higher target strength values (Figure 27). This is expected as the targets are more side aspect to the transducer's acoustic axis and therefore give a higher target strength value. We looked at the fish within this angular range, as it provides a more direct comparison with the fixed-aim split-beam data using the 4x10° transducer.

For the fixed-aim split-beam data set, we used twenty files collected just prior to the time we started running the active tracking system. This was to compare fish sampled in similar time periods, as we could not run the two systems at the same time due to cross-talk problems. We examined the target strengths from the two systems as we wanted to compare the sockeye tracked by the two systems. The sample size for the fixed-aim split-beam data set was 1000 tracks for the horizontal aim. The fixed-aim split-beam data from only the horizontal aim was used to make the sample most similar to the active-tracking system.

Figure 28 shows the mean track target strength distributions for the active and stationary systems. The fish observed from both systems have been selected to have their mean target strength per tracked fish lie within the range of –23 to –33 dB. The blue histogram presents the active tracking split-beam data and the green presents the fixed-aim split-beam data. We currently use –23 to –33 dB for our fixed-aim split-beam work at Mission to obtain the sockeye size targets. This range was derived at a time when sockeye were by far the predominant species in the river. This selection process caused a drop in the sample size for the active tracking data set to only 66 tracks out of about 1300 well-tracked fish.

Next we looked at the maximum target strength values within a tracked fish for the tracks measured by the two systems. The active tracking system again returned a much lower maximum target strength value (Figure 29). Due to the fact that more samples were needed to make any meaningful comparisons between the systems, we chose to use the maximum target strength values for the active-tracking system to obtain the –23 to –33 dB tracks. This increased the sample size to 500 out of the 1300 track sample. The validity of this approach is somewhat uncertain, but it is hard to believe that the active tracking system could track 1300 fish during some very dense sockeye passage periods and that most of them could have been small resident fish. The sockeye far outnumber the resident species at these times. In addition, all of these fish in the larger target strength range are travelling upstream which indicates they are likely sockeye, as resident species would tend to be travelling in both directions. The conclusion is that these two acoustic systems were measuring target strengths differently, even though both had been calibrated in the field with a stationary standard target. We suspect that the active tracking system was underestimating the target strength for moving targets.

3.3 ANGLE OF FISH TRAVEL

We looked at the angle of fish travel relative to the shore. Figure 30 shows the aerial view of the geometry of the site. The brown circles represent the tops of the dolphin pilings where the active tracking split-beam system was attached. The black square represents the transducer. The blue line pointing at 308° is perpendicular to the shoreline and is the centre point for the active-tracking transducer. The green line labelled 300° is the standard reference aim for the fixed-aim split-beam system at the horizontal aim. This reference aim was chosen two years ago as it was perpendicular to the average angle of fish passage at this site. This maximises fish detection and tracking. The angle theta shown by the red arrow is the angle of the fish track relative to the shore when a straight line is fitted to the trajectory. The river flow direction is also shown and is from right to left.

Figure 31 shows the histograms of the angle measurements of well-tracked fish. The blue distribution is from the active tracking system and shows a mean of 8.83°. The green distribution is from the fixed-aim split-beam system and shows a mean of 4° which must have 8° added to compensate for the difference in the reference aim as mentioned above. This gives a mean of 12°. A t-test was performed to see if these data could be described as coming from the same distribution. For these sample sizes, the result of the t-test rejects the hypothesis, with a 95% confidence level, that the distributions are identical. This contradicts our expectation that the mean swimming angles observed by the two systems should be very similar, as they were looking at the same type of targets (sockeye salmon) in the same section of the river. The standard deviations for the two data sets are, however, virtually identical.

A possible explanation for the difference in the observed migration direction between these two systems is presented in Figure 32. Figure 32 shows an aerial view of the fixed-aim split-beam system showing the -3 dB beam geometry in black and a hypothetical fish trajectory in red. The apparent shift in the trajectory to a more offshore angle as shown by the blue line is due to the split-beam position bias effect on targets near the beam edge, as documented by Mulligan et al, 1999. This inherent property of the split-beam acoustic system has the consequence of making an off-axis target appear to be closer to the centre of the beam than is true. This effect becomes apparent at lower signal-to-noise levels and is therefore more pronounced in the riverine environment where background noise levels are high. An on-axis target will show very little bias in position. The active tracking split-beam sonar system minimises this bias effect by keeping a moving target very close to the acoustic axis. Therefore, when we compare the mean travel-angles of fish targets measured by the two systems we see a significant difference. The deviation (from the true angle) of the angle data acquired with the fixed-aim system is in the direction we would expect if the split-beam bias effect is responsible for the observed result.

3.4 FISH SPEEDS

Figure 33 shows the histograms of the speed measurements of well-tracked fish. These speed measurements are the resultant speeds in X, Y and Z or vector speeds of the fish as they passed by the site. The blue distribution is based on the active-tracking data and shows a mean of 0.87 metres/second. The green distribution is derived from the fixed-aim data and shows a mean of 0.81 metres/second. For these sample sizes, we see that this difference is highly significant within the 95% confidence interval. Again, this result contradicts our expectation that the speeds should be the same as measured by the two systems. The standard deviations for the two data sets are similar.

Figure 34 shows the same active tracking split-beam data, but with the very slow speeds removed. We believe these very slow speeds to be anomalous. This has the effect of increasing the mean speed to 0.93 metres/second, making the difference even more significant when compared with the fixed-aim split-beam system's measurement of 0.81 metres/second.

A possible explanation for these results is presented in Figure 35. Figure 35 shows an XY view of the stationary split-beam system with an ellipse representing the -3 dB beam geometry and a hypothetical fish trajectory in red. The split-beam bias effect will move the true fish positions towards the centre of the beam. This apparent shift in the trajectory towards the centre of the beam as shown by the blue line has the effect of reducing the measured speed as the fish appears to have moved a shorter distance in the same amount of time. The active tracking split-beam sonar minimises this effect while tracking a target as the system keeps the target very close to the centre of the sound-beam. Therefore, when we compare the mean travel speed of fish targets measured by the two systems we see a significant difference in the two and the difference is in the direction we would expect if the split-beam bias effect is responsible for the observed result.

4.0. CONCLUSIONS AND RECOMMENDATIONS

We did not obtain the definitive answer on the presence or absence of boat avoidance behaviour of salmon. Boat avoidance did not appear to be pronounced in the area where we were able to look. Boat avoidance may occur in the shallow near-shore areas or when the fish are very surface oriented as they were at times in 1998.

The active tracking split-beam system is useful for tracking fish movements over a much longer distance than is possible with a fixed-aim system. We gained information on fish behaviour and acoustic measurements with this system and we documented some interesting fish behaviour at the site. The active tracking system should give more accurate information on fish movement and speed as it avoids the position bias problems. We may be seeing the effects of the split-beam position bias on both the speed and swimming angle measurements. It is useful to measure the magnitude of the effect in the riverine environment if it is the cause of the differences we noticed.

We have also shown the importance of aiming the axis of the acoustic beam perpendicular to the fish passage to maximise fish detection. The best aim may not always be perpendicular to the shore. The mean angle of passage relative to the shore should be measured and then the transducer aimed accordingly.

5.0 ACKNOWLEDGEMENTS

The authors would like to thank the following people: Tim Mulligan for his acoustic expertise, his suggestions for data analyses and for his review of this report; Jim Woodey for the Pacific Salmon Commission's funding of this study; John Hedgepeth for his technical expertise, for taking the time to help in the equipment set-up and testing, and for training us in the operation of the equipment; and Peter Withler for his help in developing many software routines in SPlus to analyse and display the data.

6.0 REFERENCES

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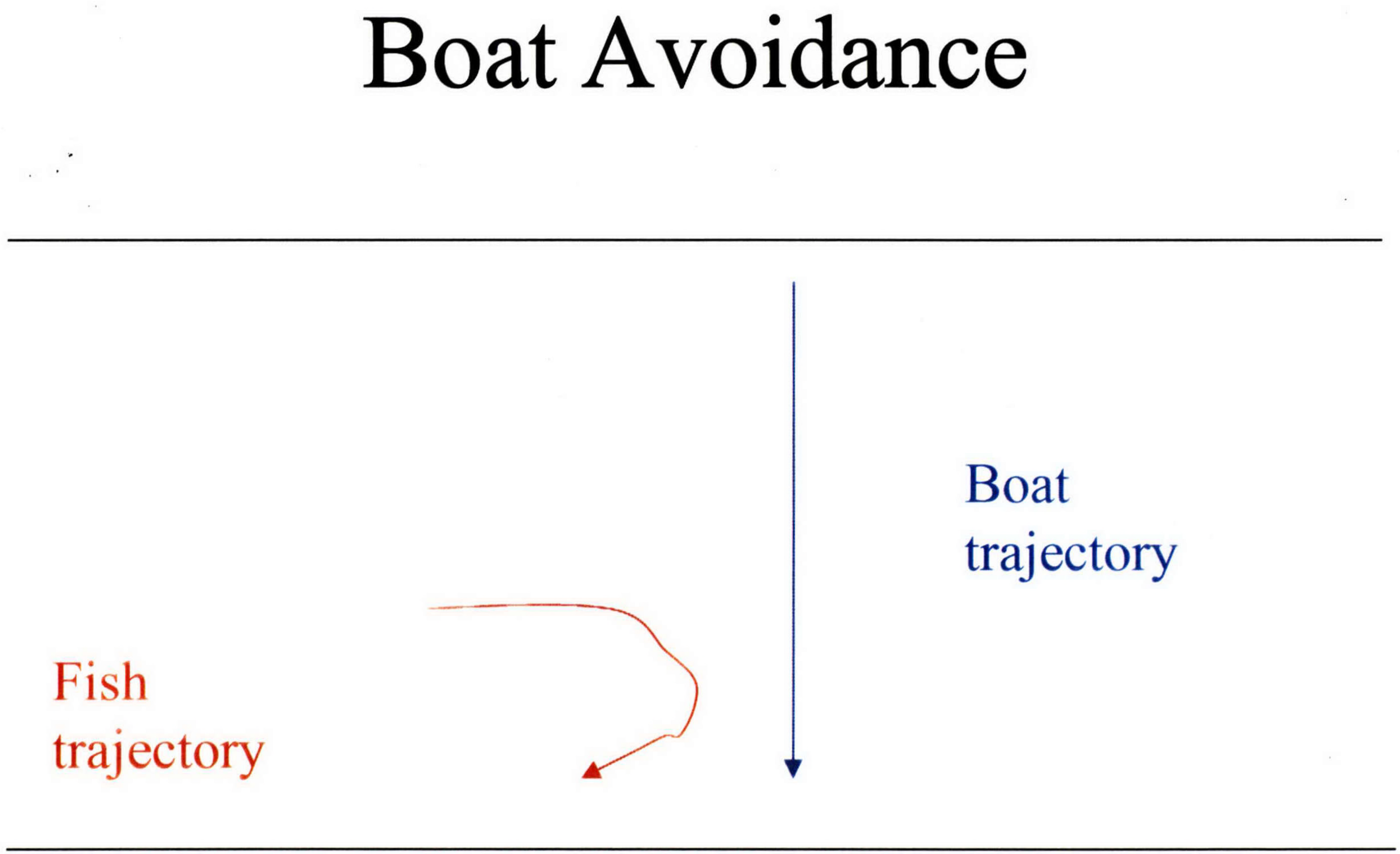


Fig. 1. Fish behaviour that could affect the acoustic detection of migrating salmon. A fish acting in this way would never pass through the downward-looking sound-beam projected from transecting vessel.

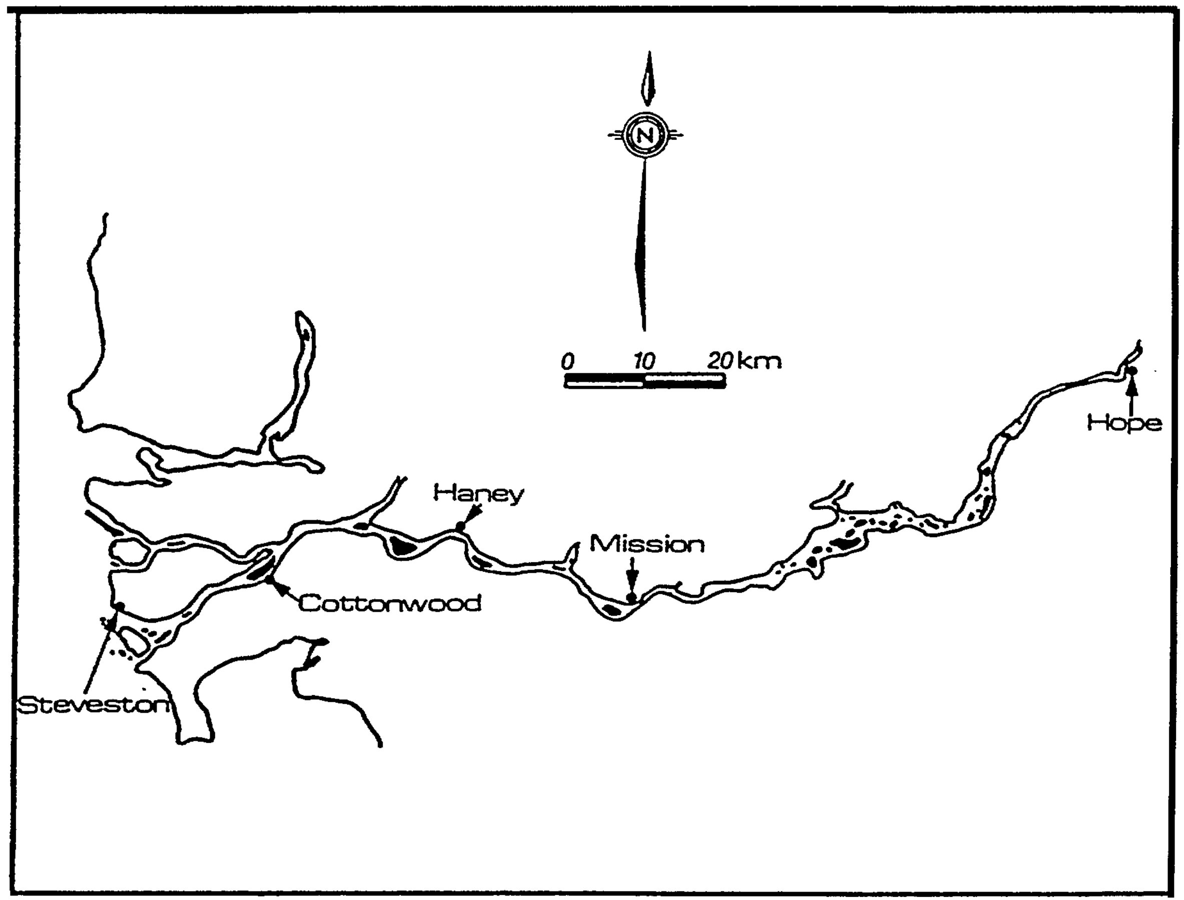


Fig. 2. The 1998 active tracking split-beam experiment was conducted in the Fraser River near Mission B.C. located 80 kilometres upstream of the river mouth.

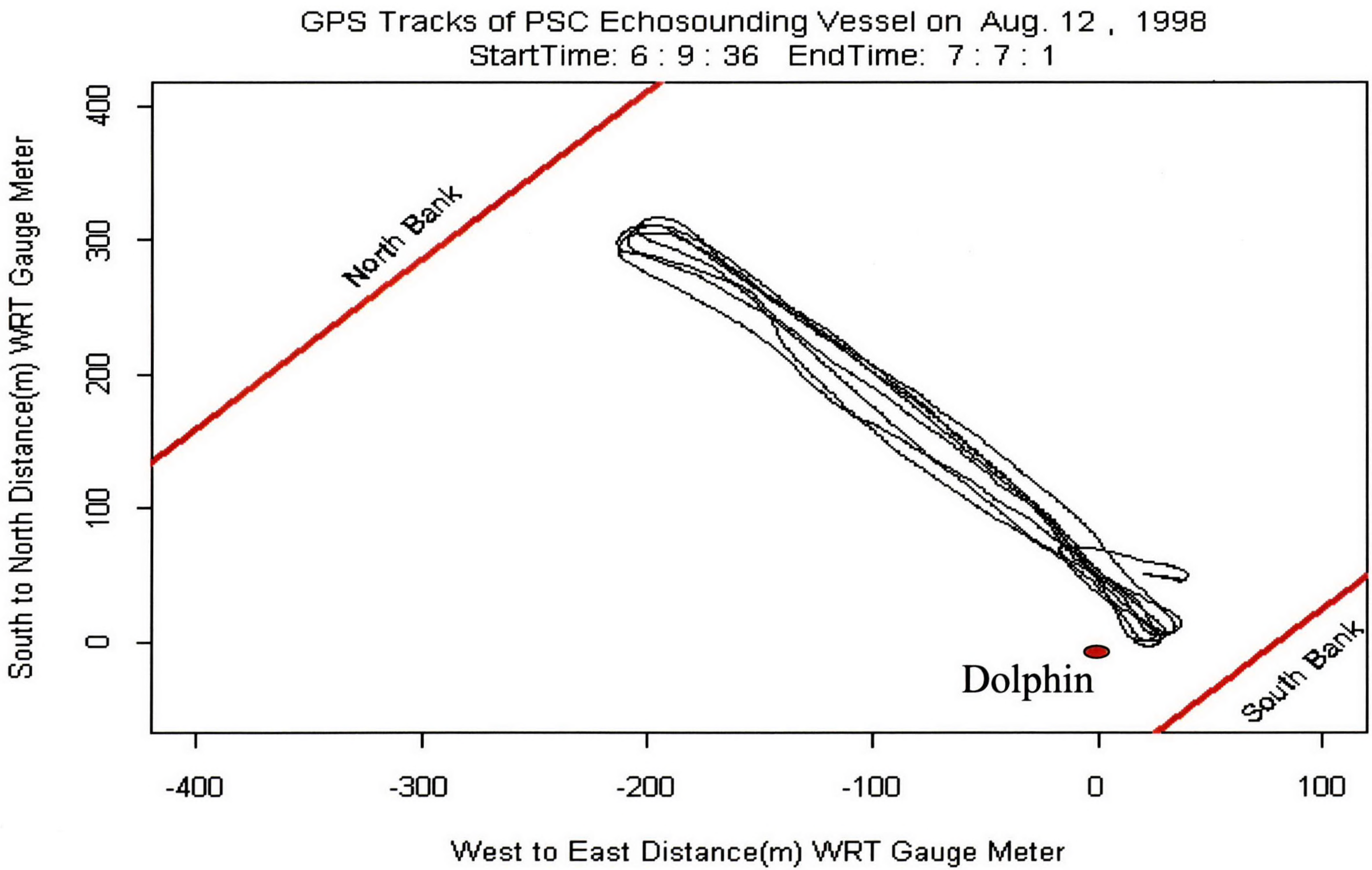


Fig. 3. Global Positioning System tracks of the echosounding vessel as it transects back and forth across the river. The red mark shows the location of the reference dolphin from which all the acoustic measurements are related to.

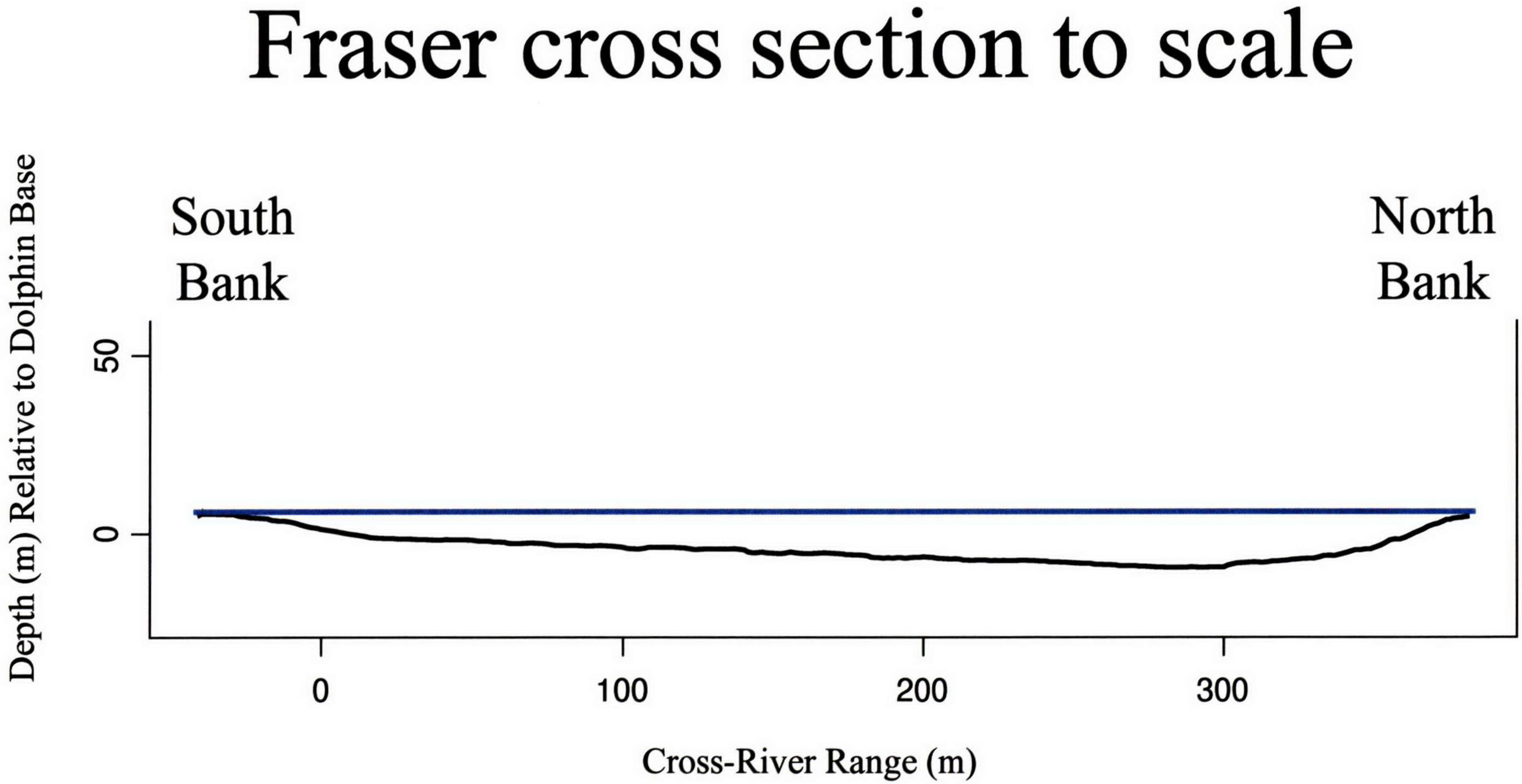


Fig. 4. Bottom profile at the site with the width and depth in perspective to show the shallowness of the river relative to the width. Shallow water causes many challenges with all types of acoustic measurements due to the close proximity of the boundaries, i.e., the surface and bottom.

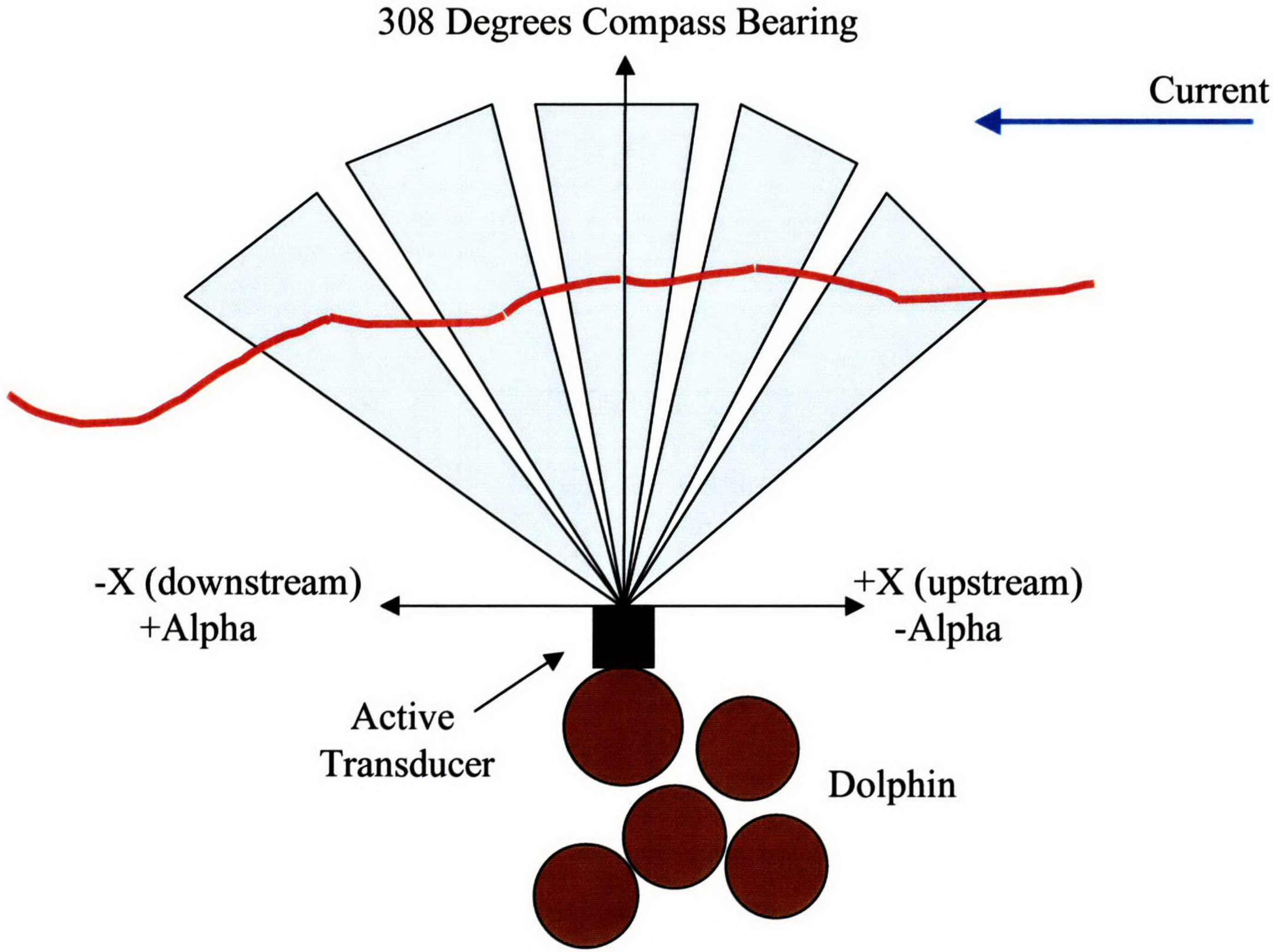


Fig. 5. The aerial view geometry of the insonified river volume for the active tracking sonar. The co-ordinates of the targets are expressed in a Cartesian system with upstream-downstream (X), vertical (Y) and horizontal distance from transducer (Z). The compass bearing of 308° is perpendicular to the river bank at this site. The light blue triangles represent consecutive transducer sound-beam positions as the system follows the fish upstream. The fish is represented by the red line, moving from –X to +X. The angle at which the transducer is oriented relative to the 308 degree reference angle is referred to as +Alpha (downstream) and –Alpha (upstream) in degrees.

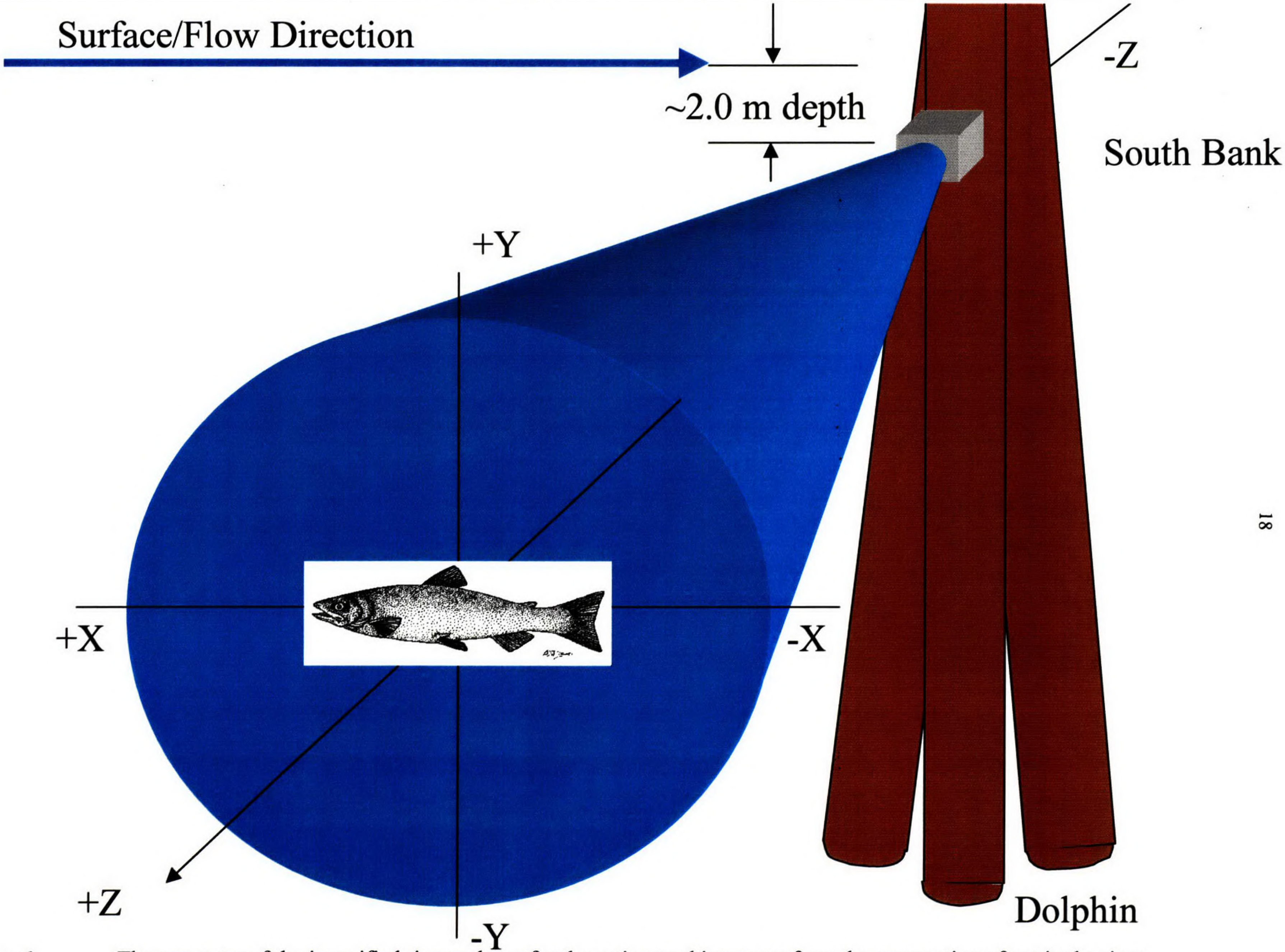


Fig. 6. The geometry of the insonified river volume for the active tracking sonar from the perspective of out in the river looking toward the transducer. The additional axes shown are Y (up and down in the water column) and Z (inshore and offshore). The light blue outlines the geometry of the -3dB sound-beam with a fish shown in the beam for reference.

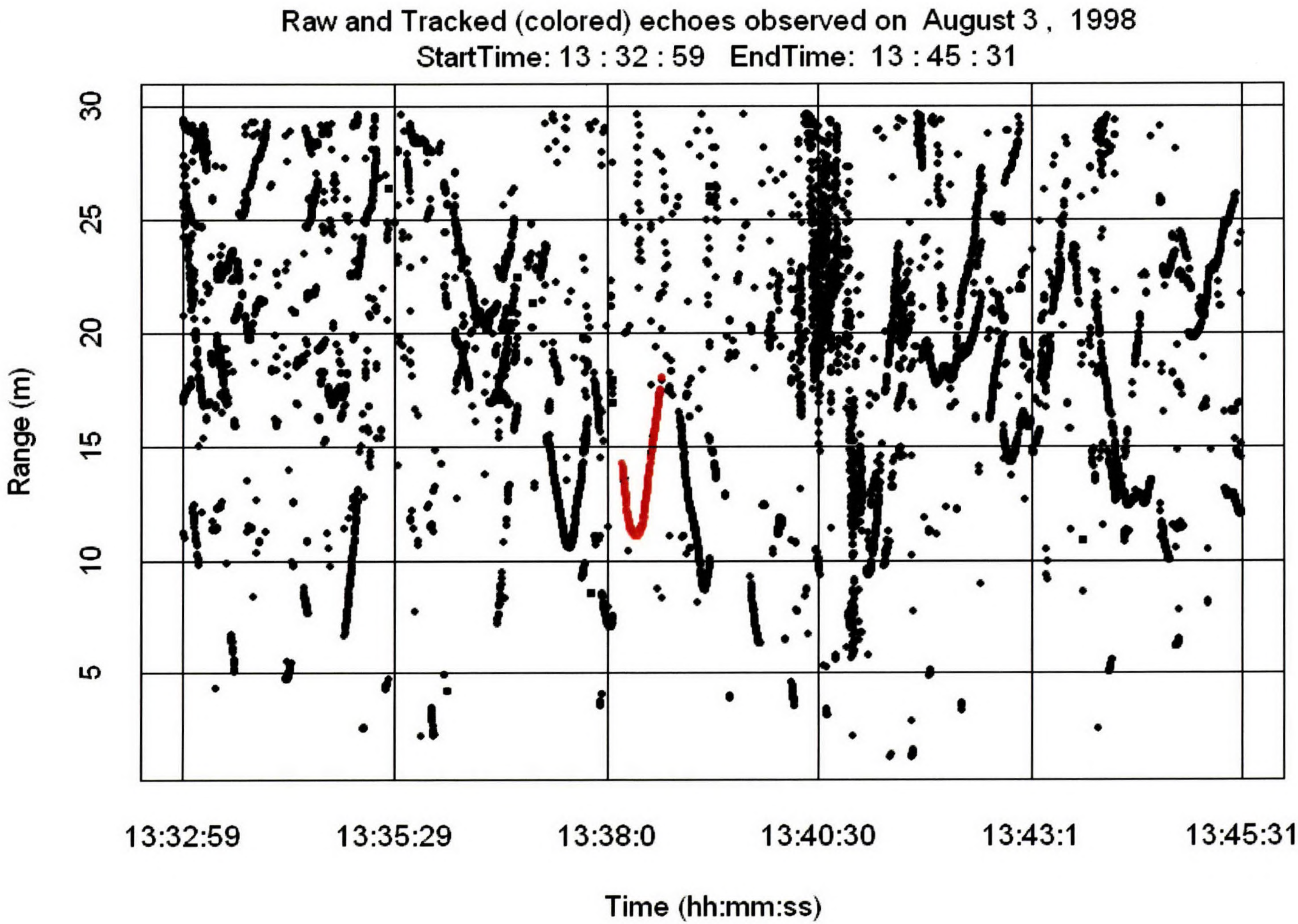


Fig. 7. Standard echogram of range vs. time for some active-tracking sonar data. The track highlighted in red is shown in more detail in the following figures.

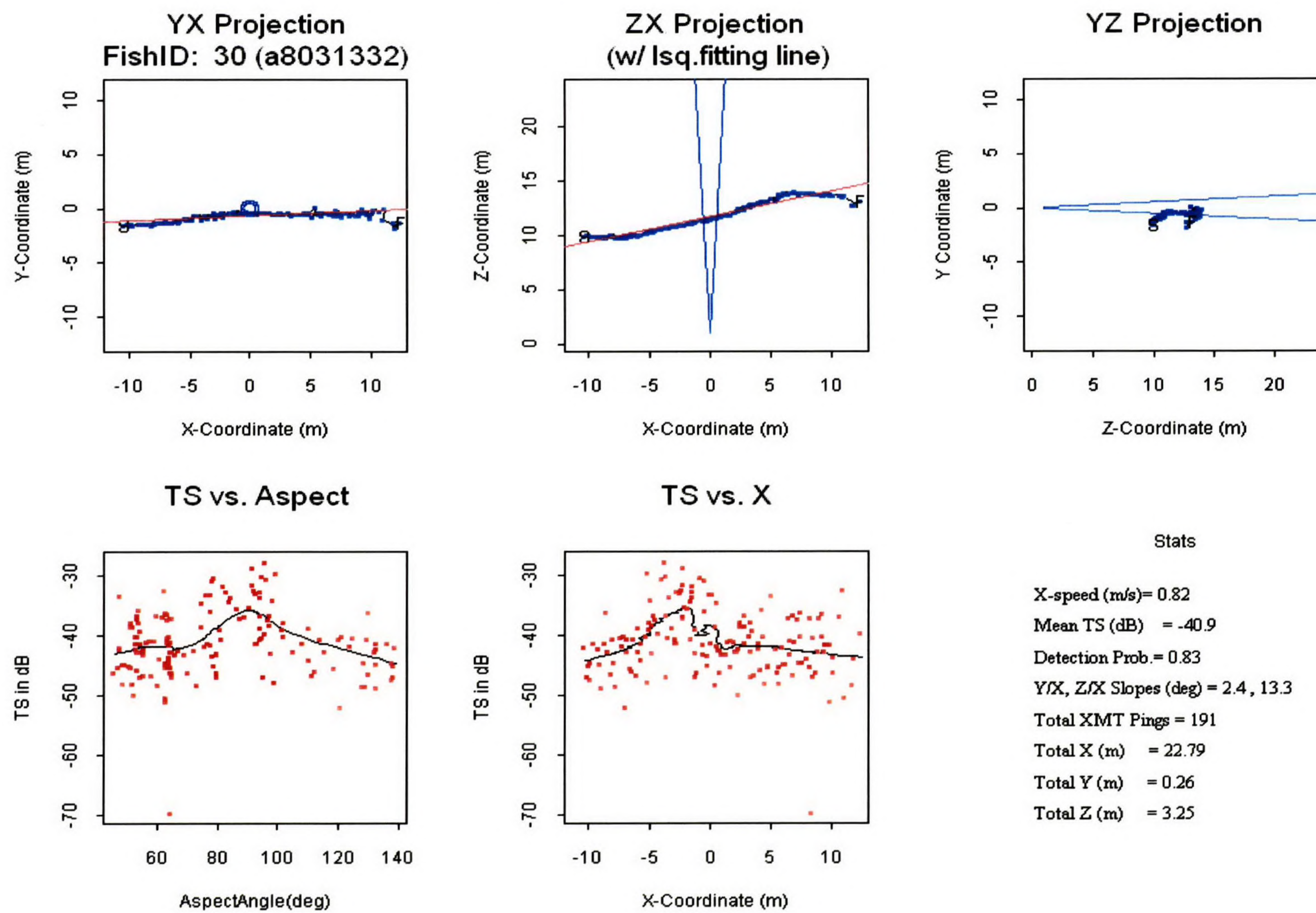


Fig. 8. The upper plots show the fish position in the YX, ZX, and YZ planes. The small circles represent the size of the sound-beam relative to the fish trace where the fish entered the beam and where it exited. The 'S' and 'F' indicate the start and finish of the track. A least-squares fitted straight line (shown in red) is drawn through the fish trajectory to show the straight-line approximation of the fish path. The lower left plot displays the Target Strength in Decibels vs. the Aspect Angle in degrees. The bottom centre plot displays the Target Strength in Decibels vs. the X co-ordinate, or upstream/downstream position in metres. The bottom right shows various statistics for this particular fish.

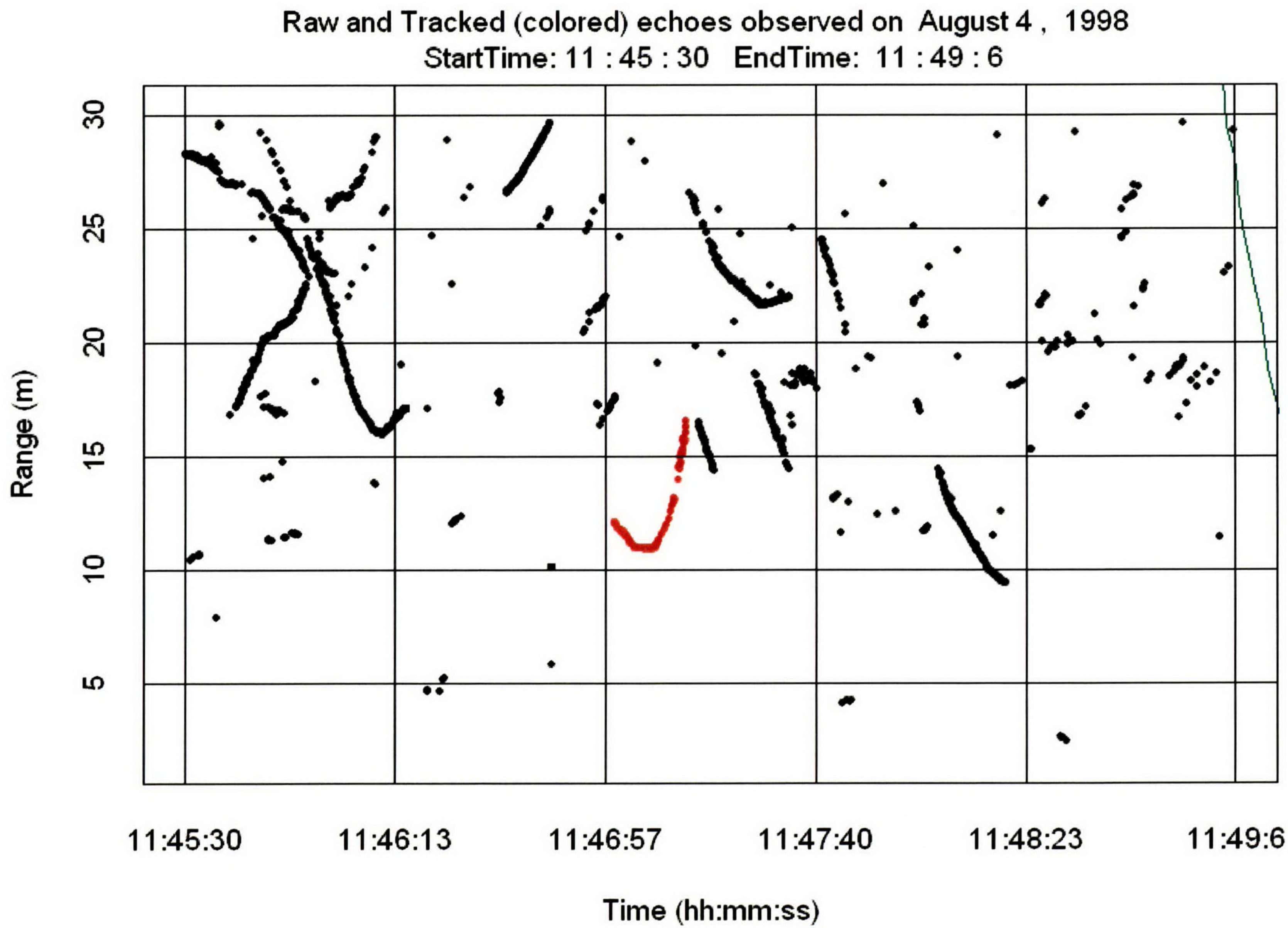


Fig. 9. Standard echogram of another fish track shown in red. This echogram and subsequent echograms display a green line trace. This line represents the distance from Pacific Salmon Commission's transecting vessel to the active-tracking system's transducer.

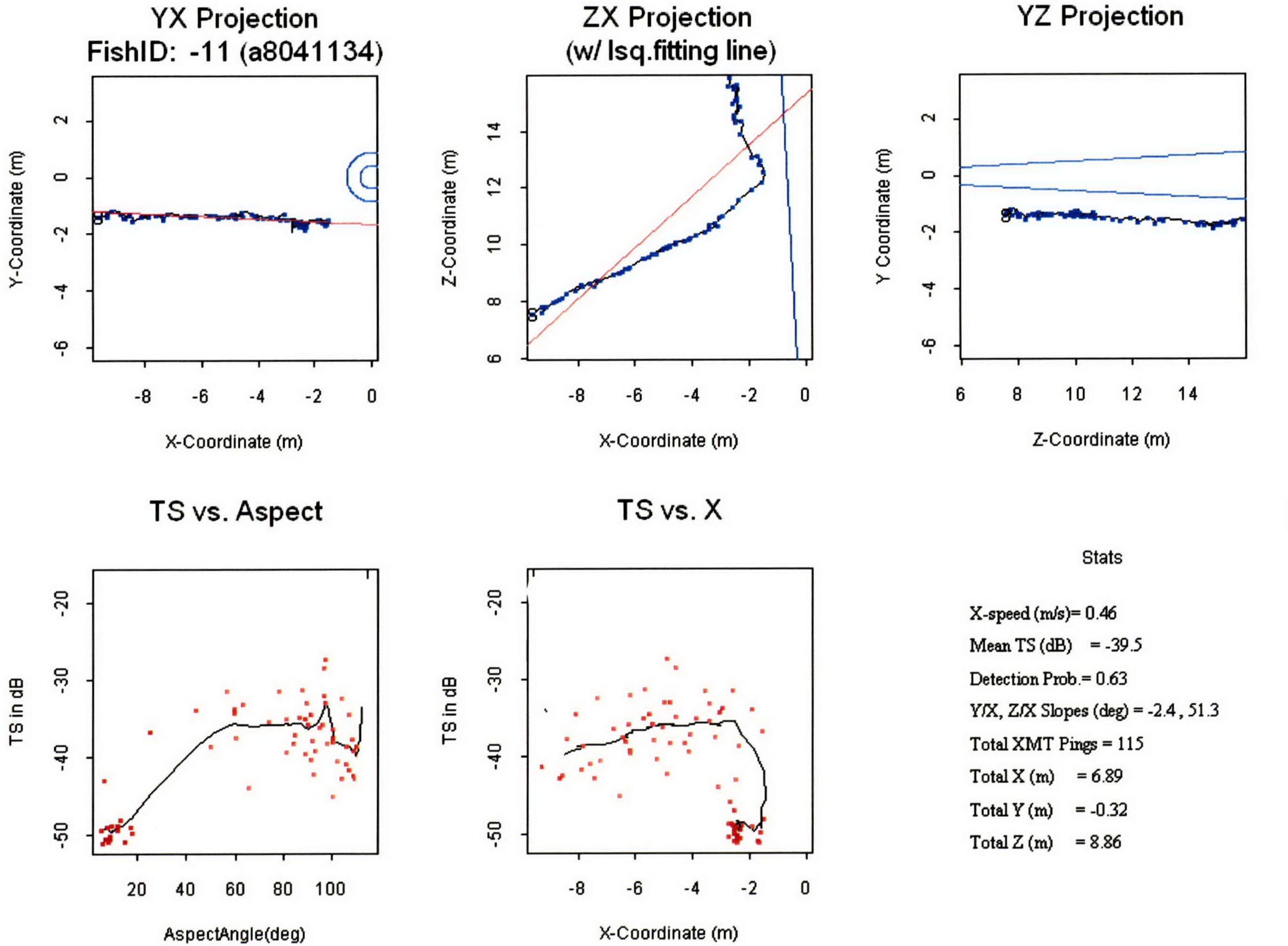


Fig. 10. This fish took an abrupt turn as it passed the site as can be seen in the ZX projection, top centre.
A very low target strength value is measured when the fish is moving straight away from the transducer.

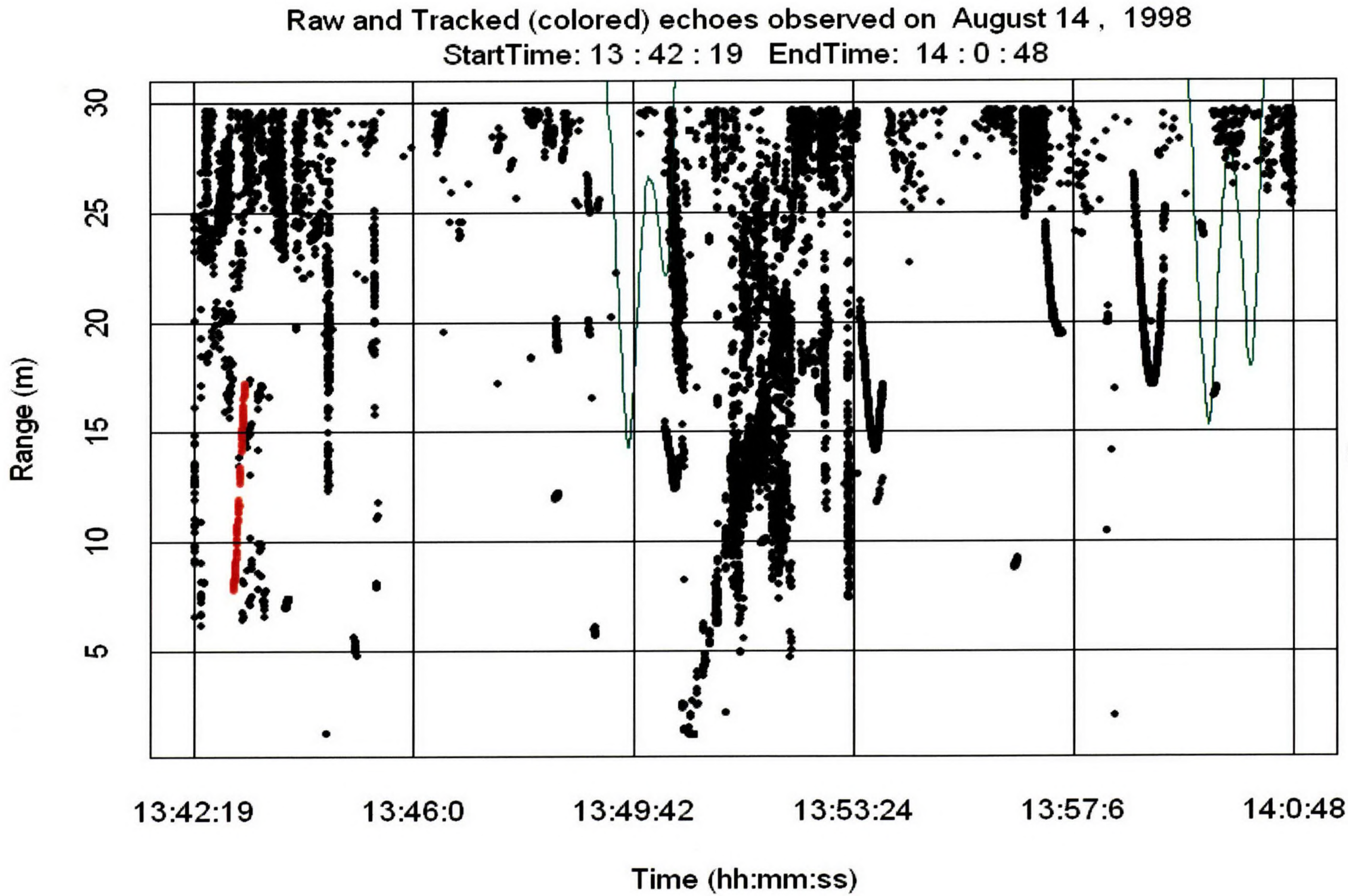


Fig. 11. This fish (shown in red) is travelling away from the transducer during the time it was tracked.

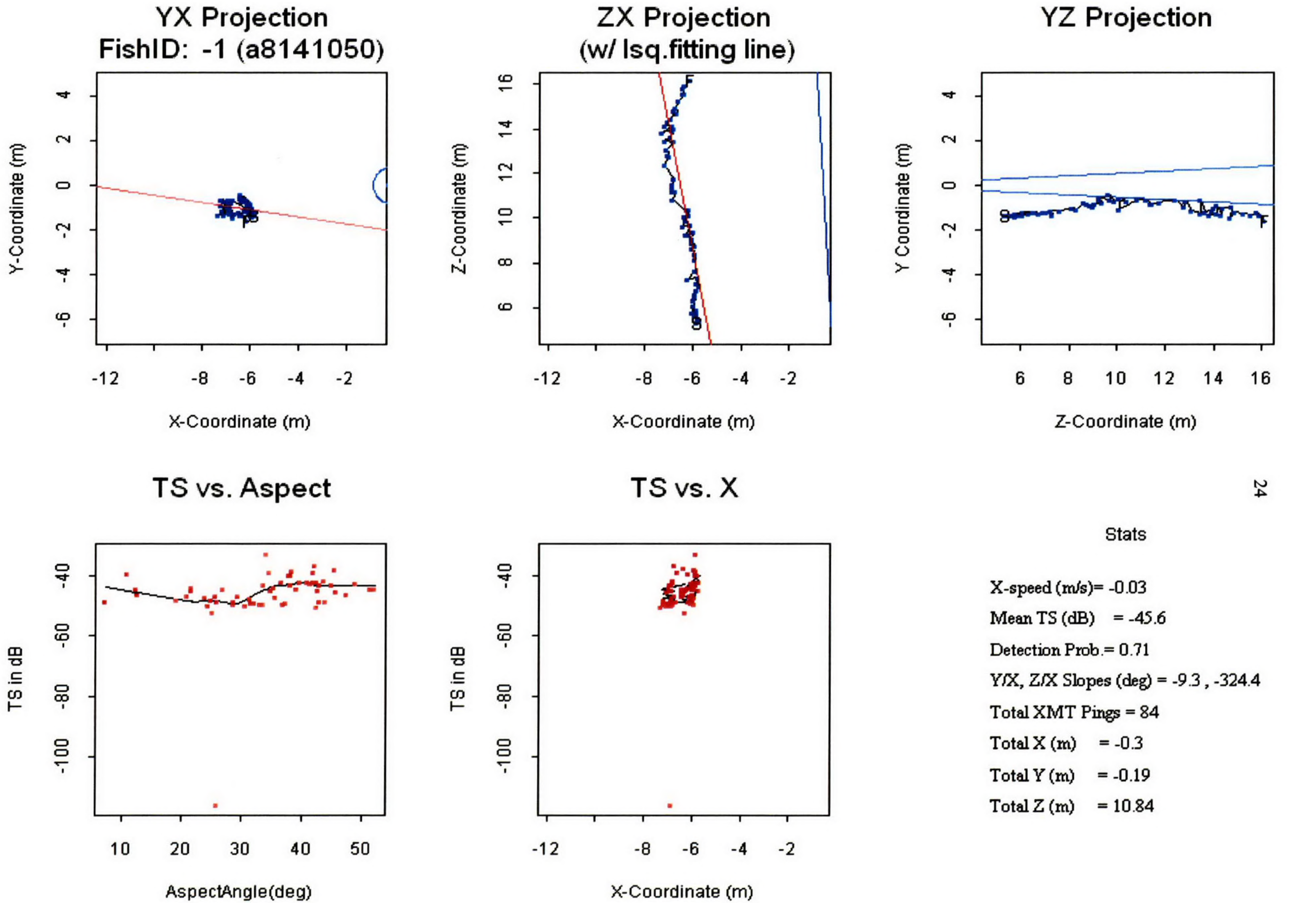


Fig. 12. This plot shows the effect that travelling away from the transducer has on the target strength values. The target strength values are low, due to the partial tail-on aspect, and consistent, due to the consistent travel in the Z direction.

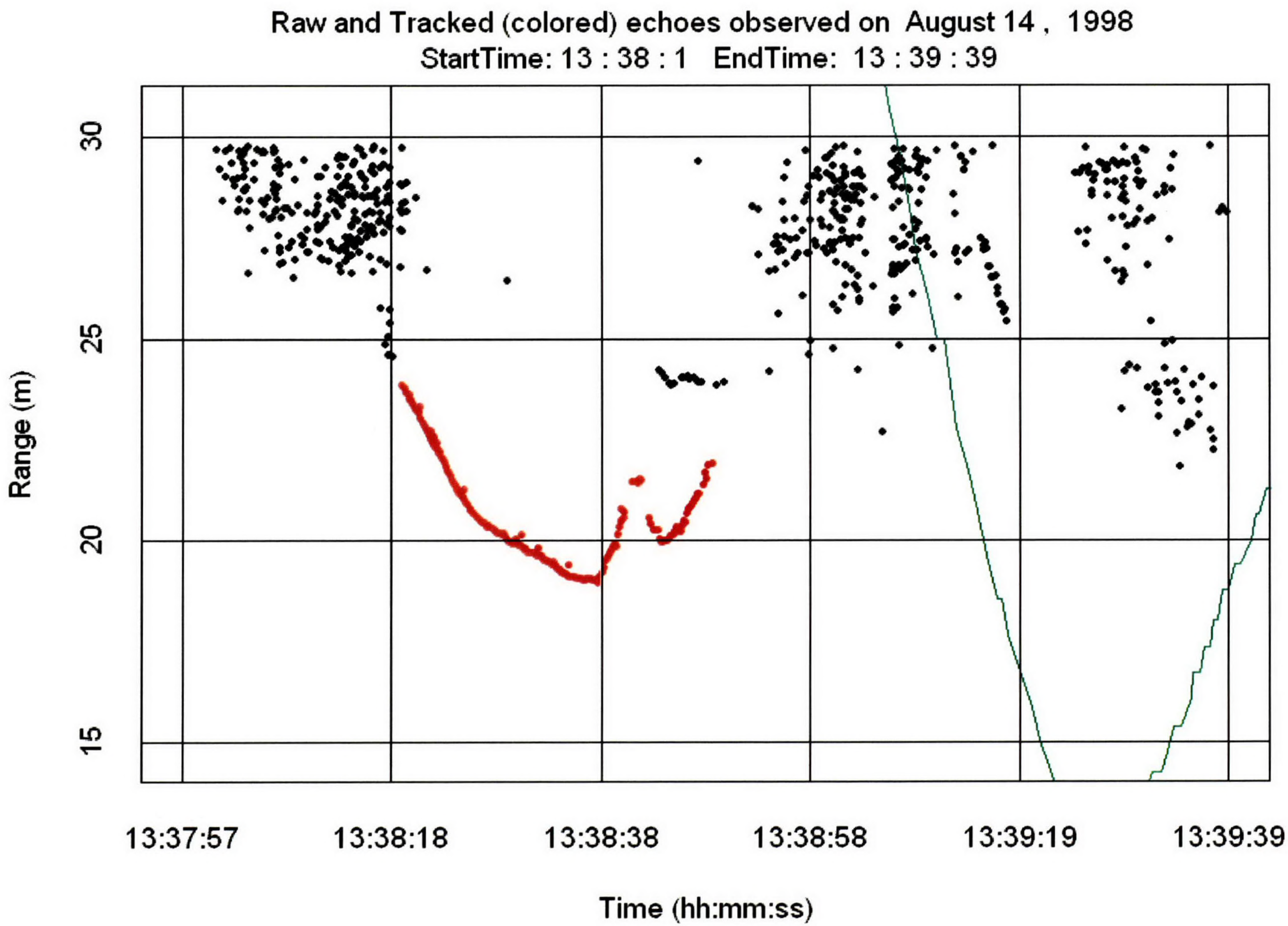


Fig. 13. This echogram could be interpreted as one, two, or even three fish traces. The transecting vessel appears in this echogram but is not particularly close to this fish.

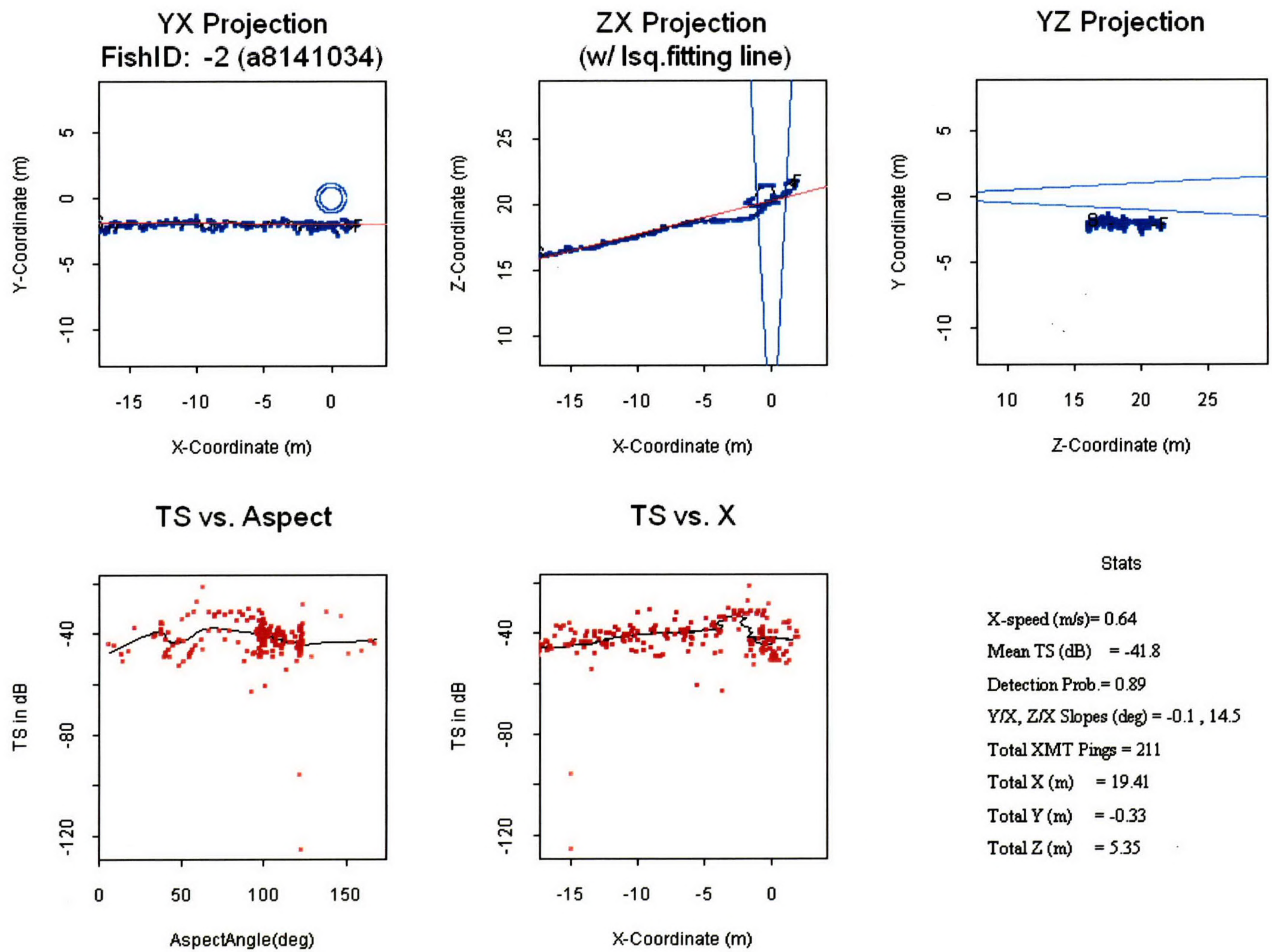


Fig. 14. Plots showing this fish's behaviour in more detail. As can been seen in the ZX projection, this fish appears to have done a complete loop during the time it was observed.

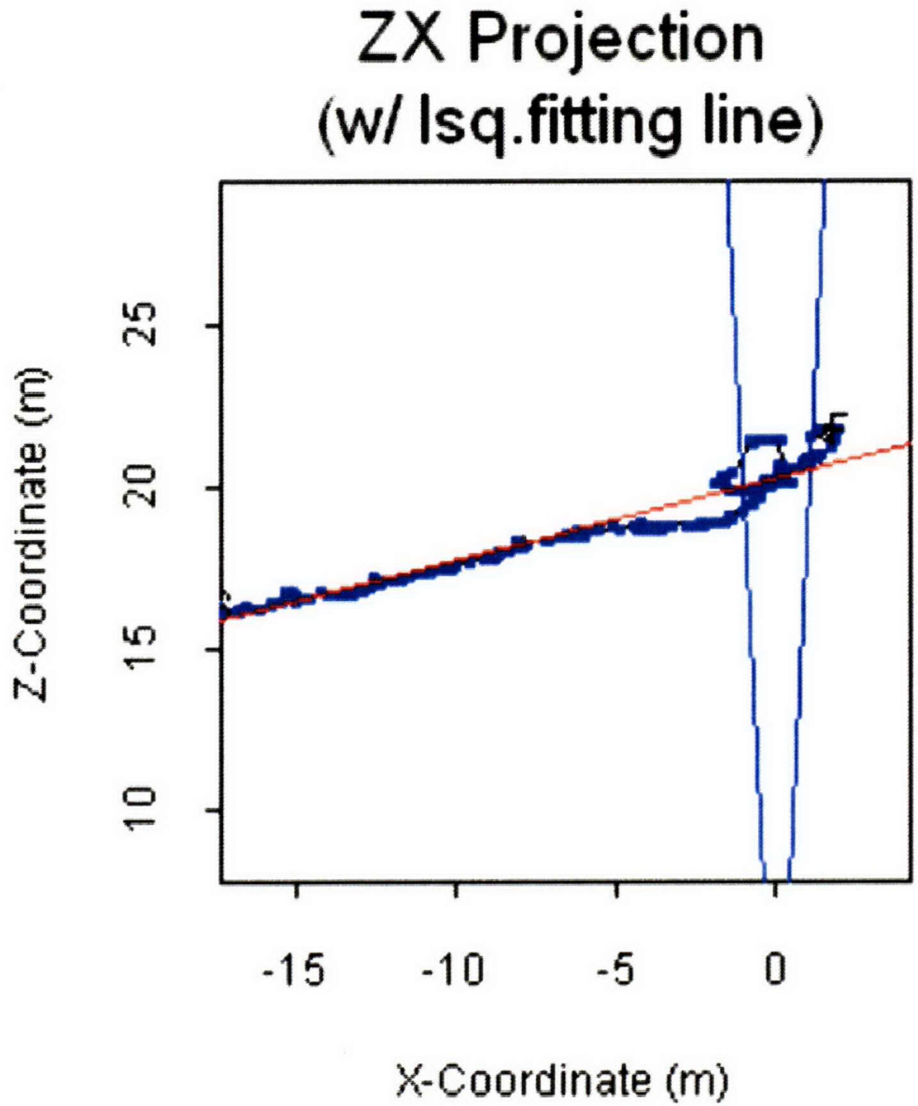


Fig. 15. This is the previous figure's ZX projection to show the fish behaviour in more detail. This is likely one fish and not a coincidental interaction of two or more fish.

Boat Close

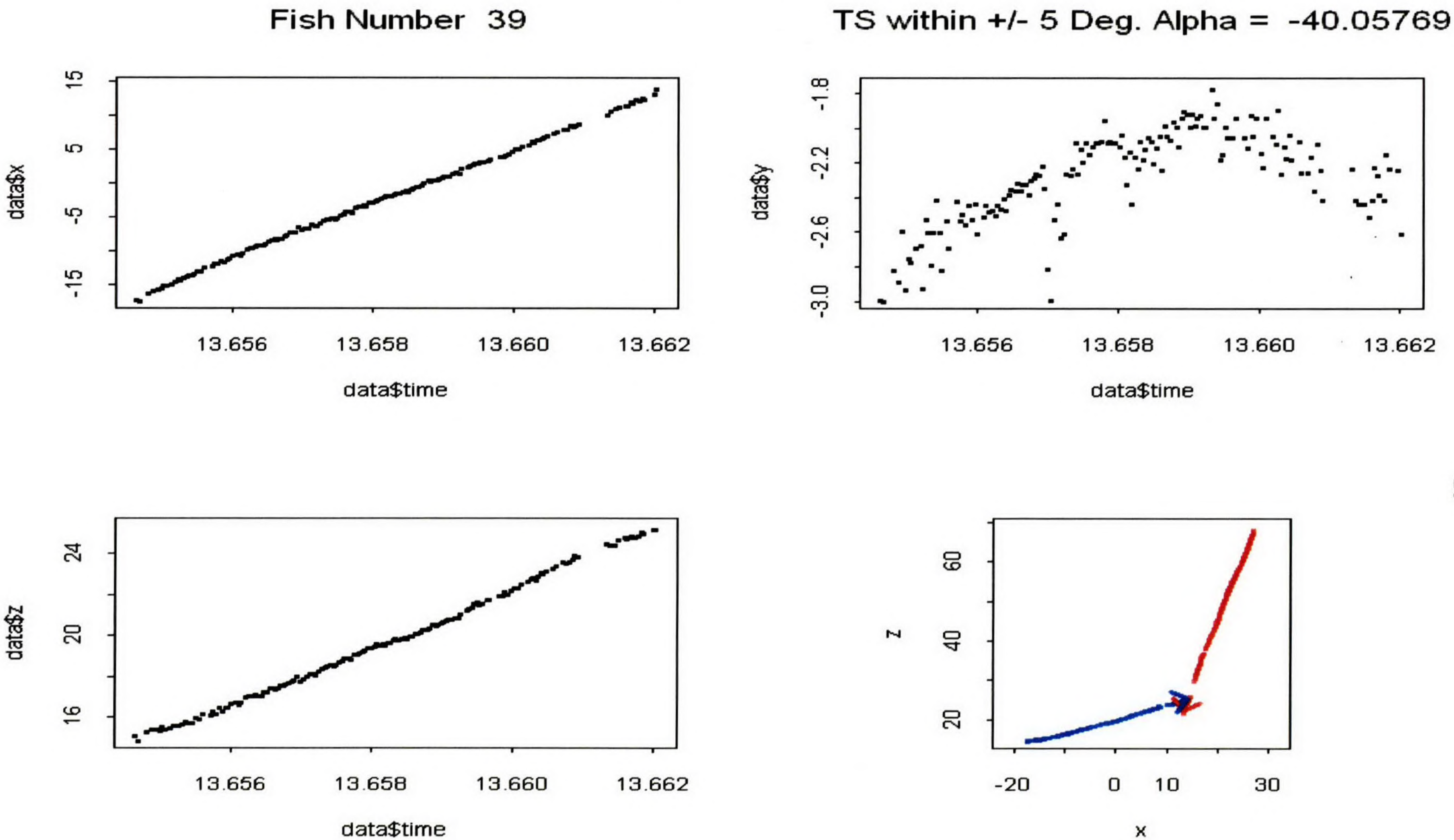


Fig. 16. This fish approached the transecting vessel very closely. The top left plot displays the fish's movement in the X direction vs. time. A fairly straight line means that the fish travelled through the beam without much deviation in its path. The top right plot shows the fish movement in the Y direction or up and down in the water column. This fish moved up in the water column and then back down again. The bottom left plot shows the movement in the Z direction or inshore/offshore. Again a fairly straight line represents little deviation in the trajectory. The bottom right plot shows the relationship between the transecting vessel and the fish from an aerial perspective. The blue line represents the fish trajectory and the red line represents the transecting vessel trajectory. This fish may have passed underneath the transecting vessel with very little apparent effect on its trajectory except for some change in depth.

Boat Close

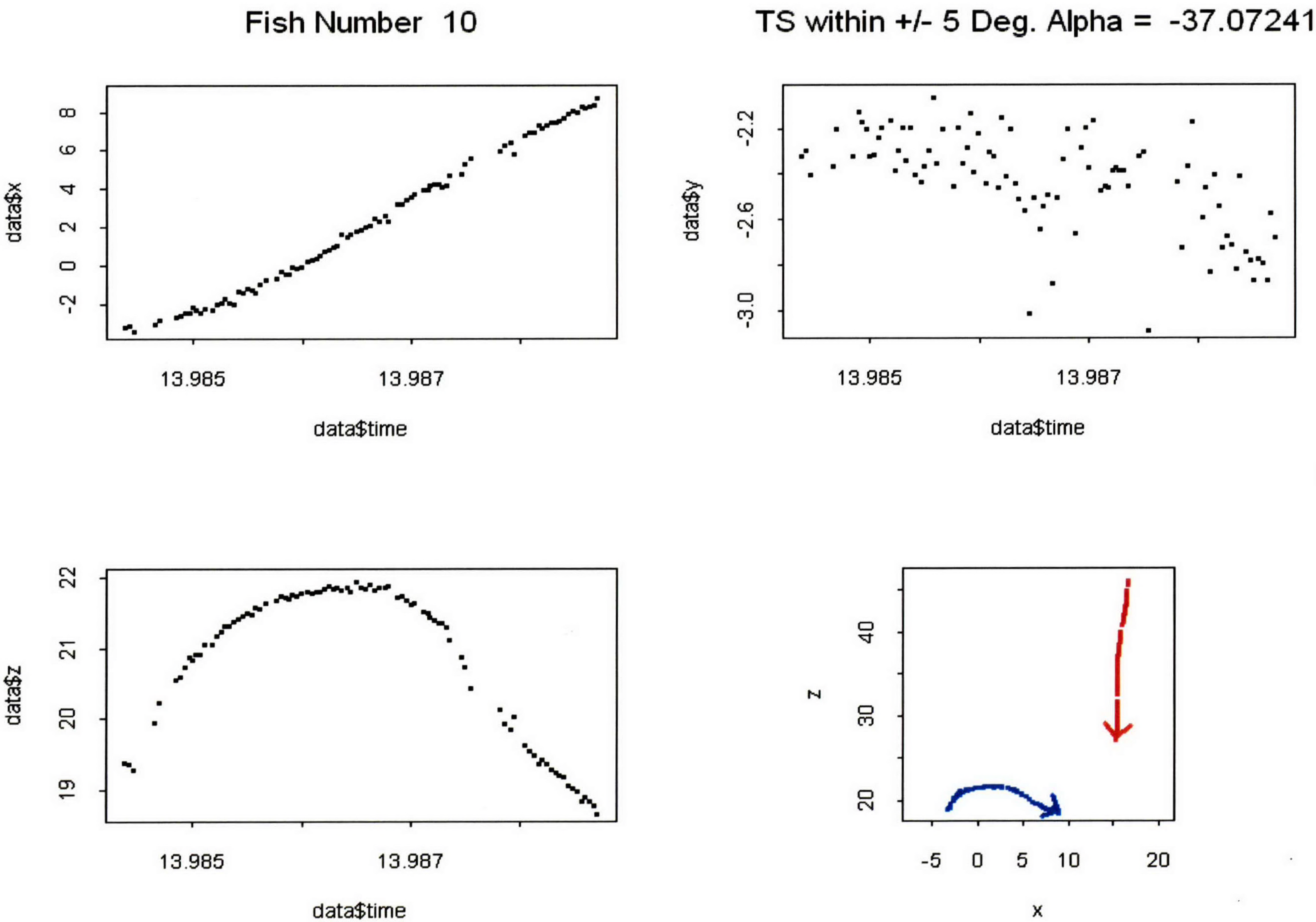


Fig. 17. These plots show a fish close to the transecting vessel and the fish's trajectory appears to be affected. A possible conclusion is that boat avoidance is occurring.

Boat Close

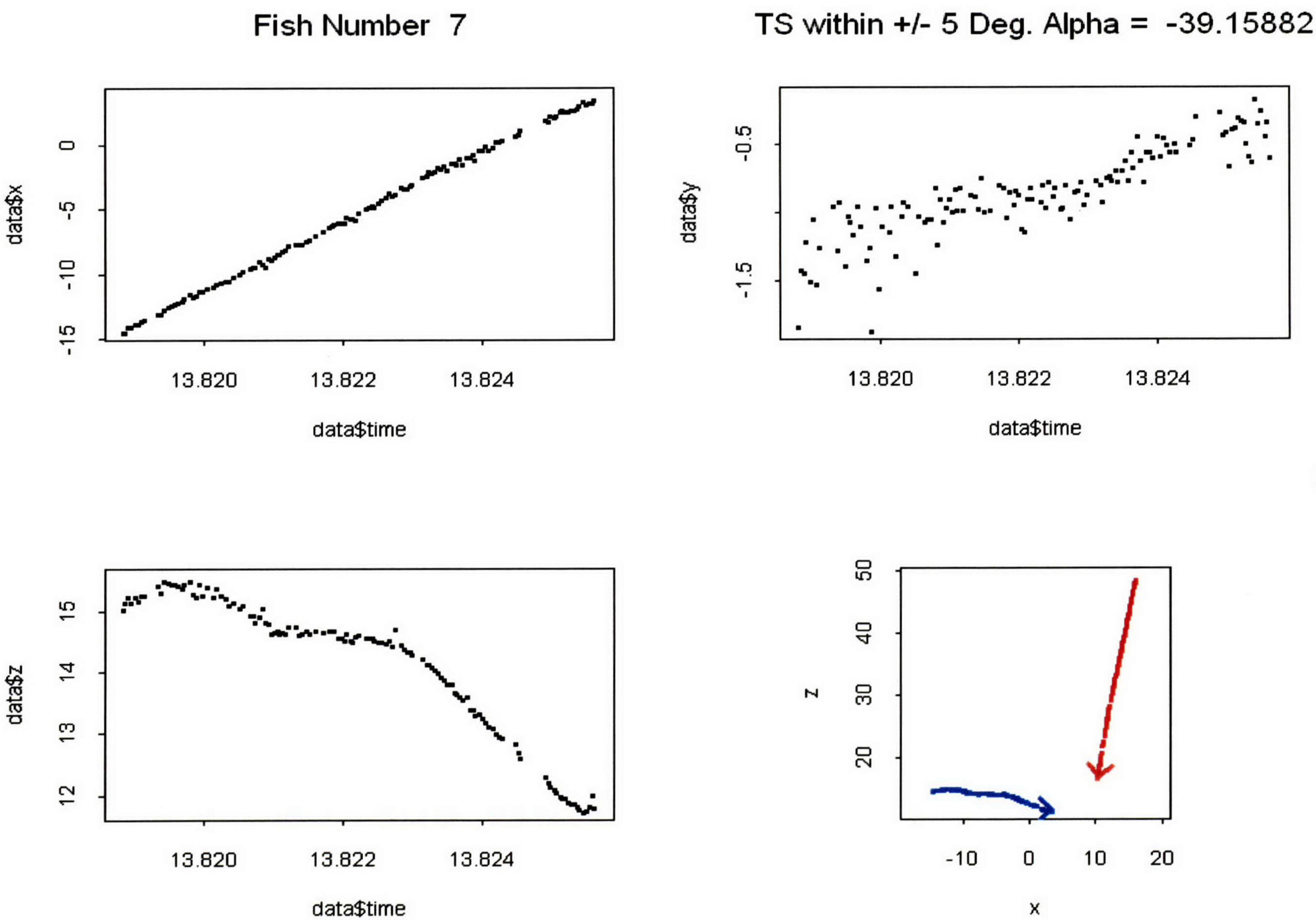


Fig. 18. This plot shows a fish rising up in the water column and apparently moving away from the transecting vessel.

Boat Close

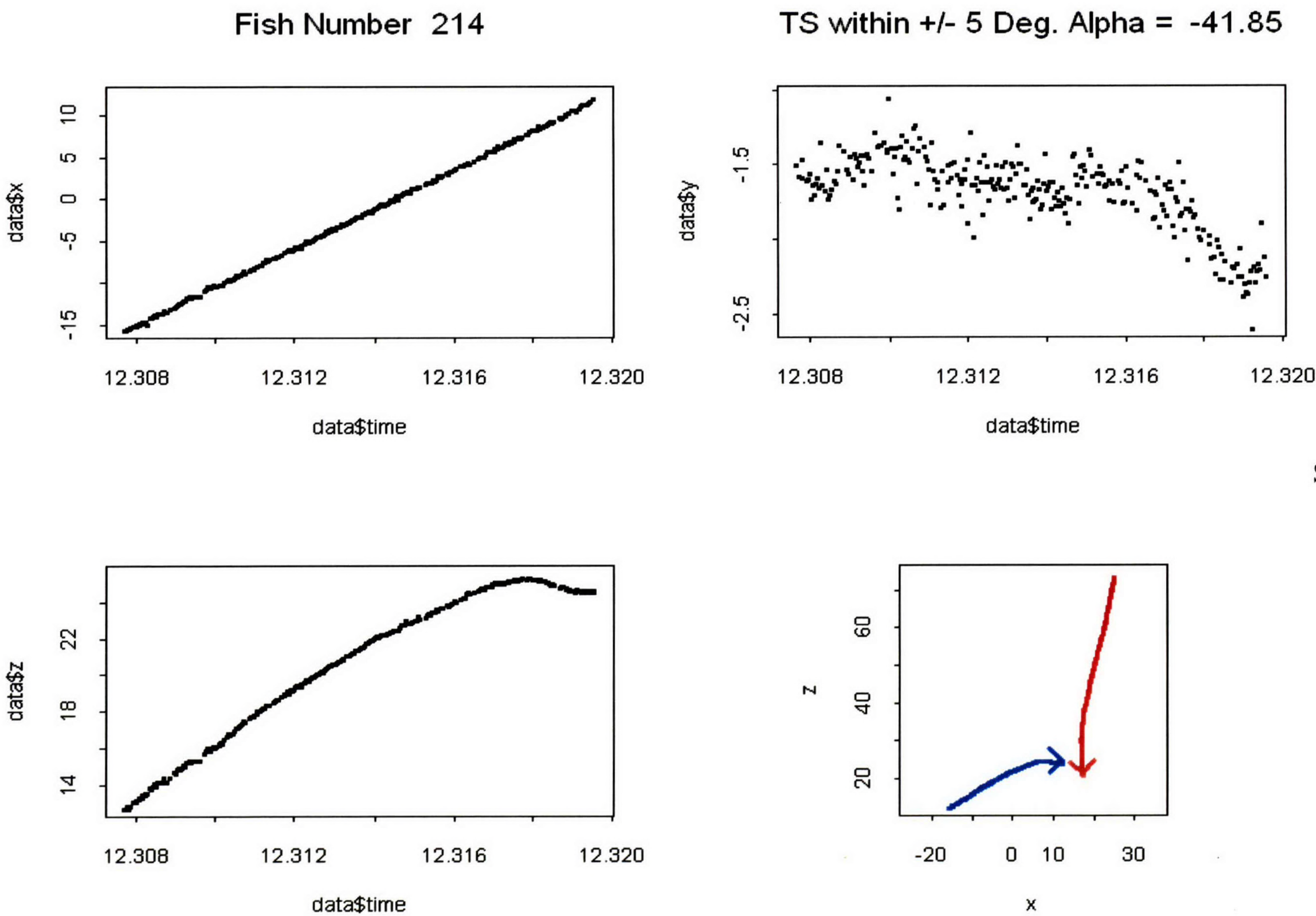


Fig. 19. As the vessel approached, this fish took a fairly abrupt turn while moving down in the water column.

Boat Close

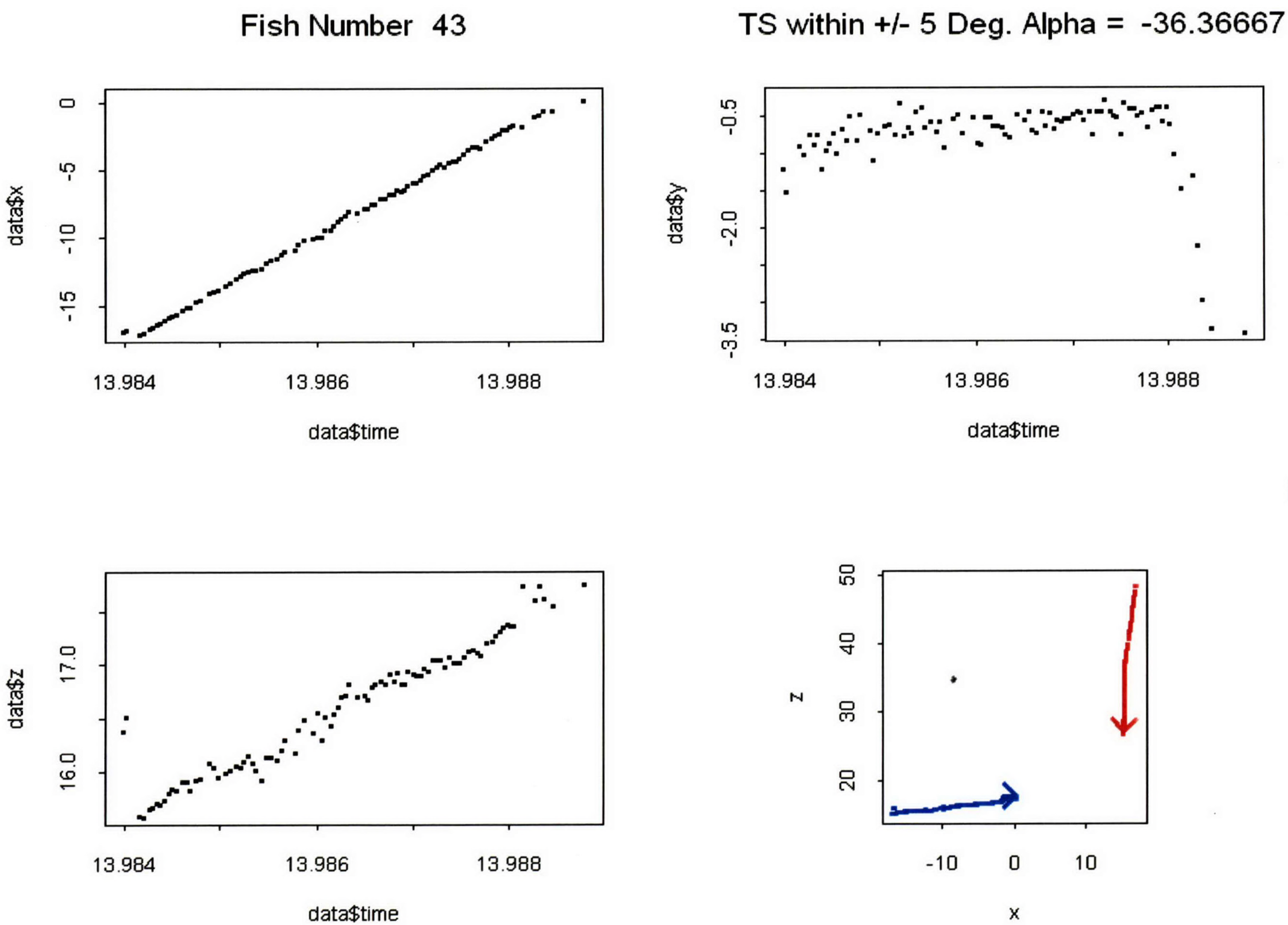


Fig. 20. This plot shows a fish diving in the water 3m in approximately 3.5 seconds when the boat was about 15m away.

Boat Close

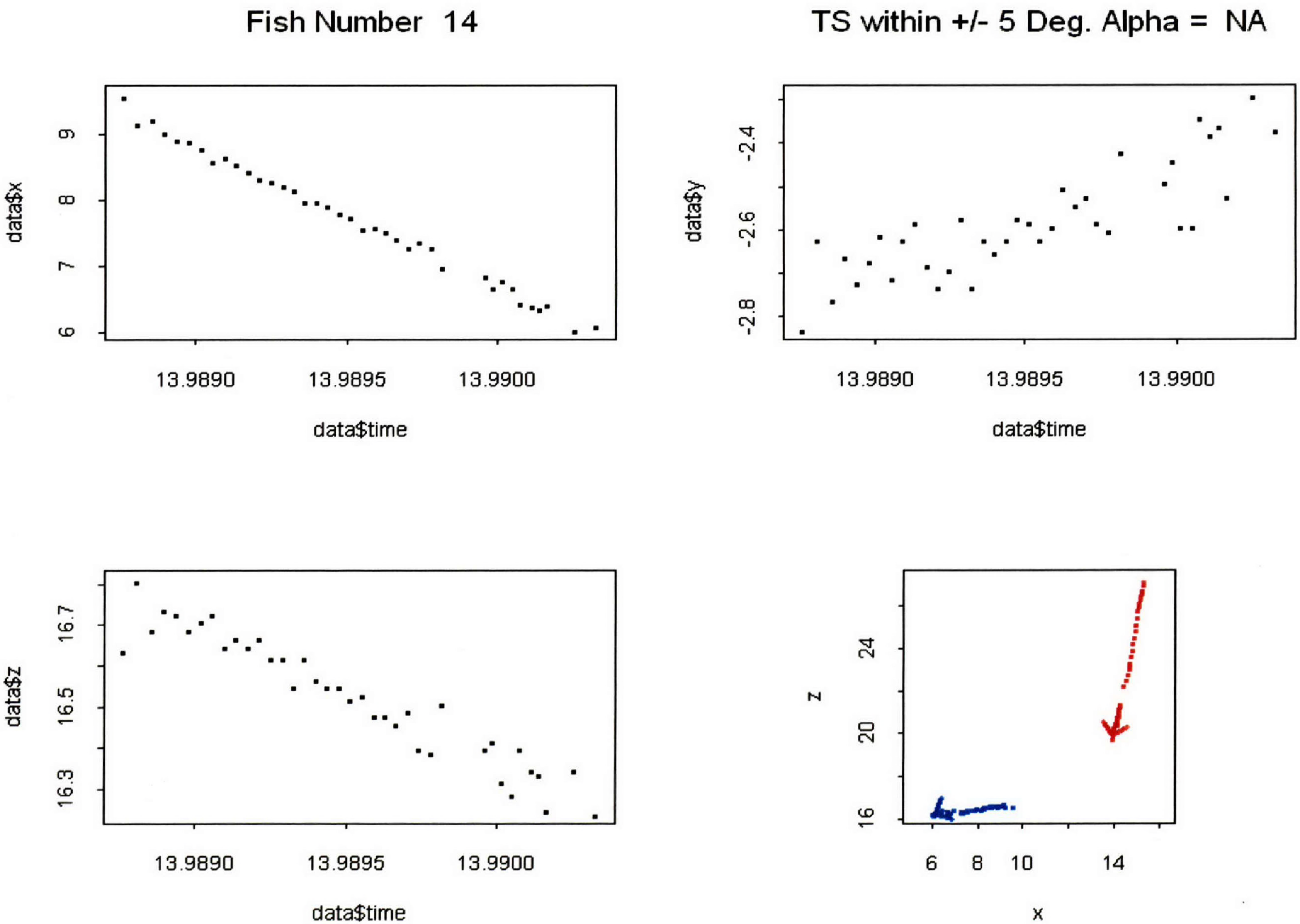


Fig. 21. This plot shows a fish heading downstream in the presence of the transecting vessel.

Boat Close

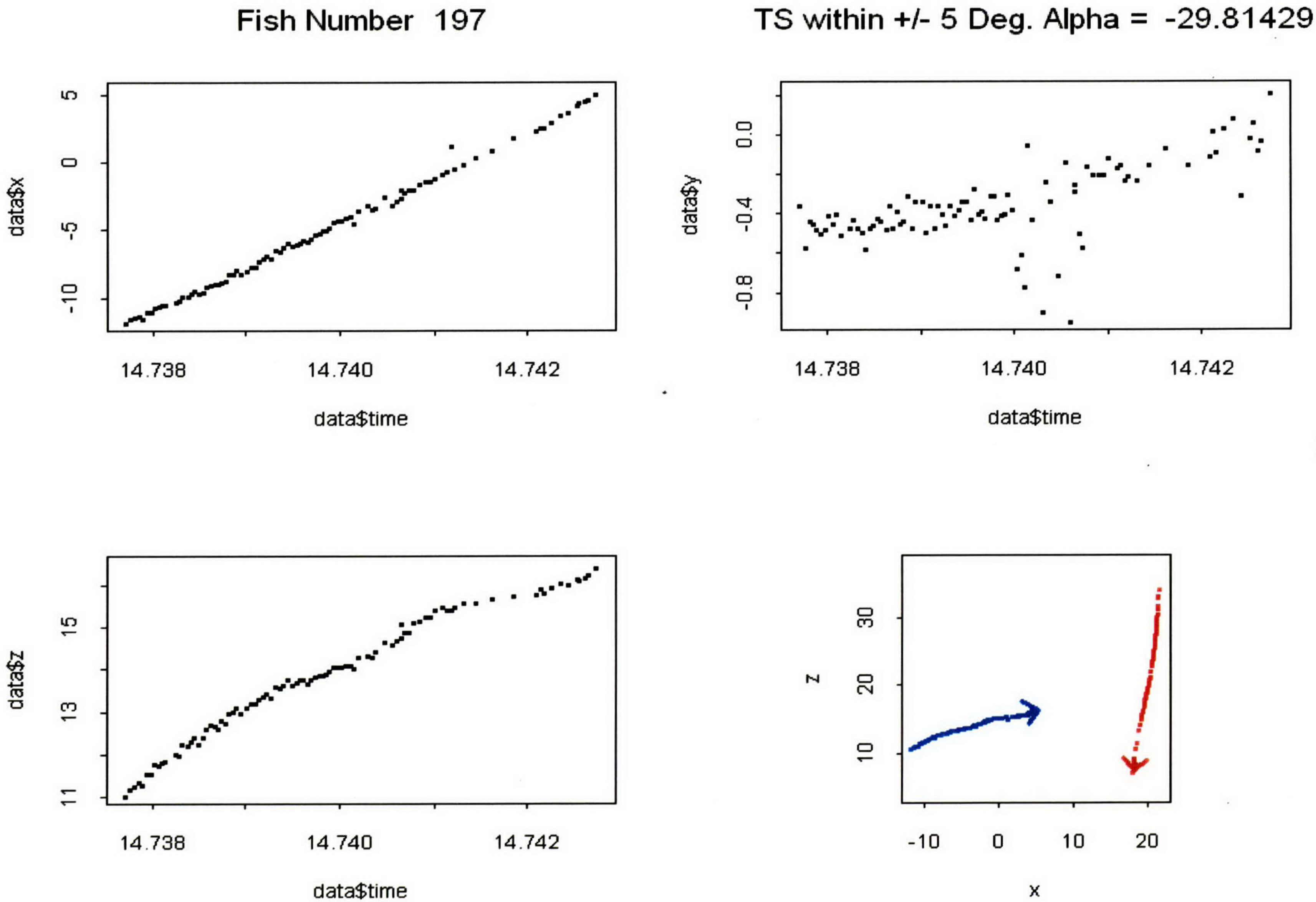


Fig. 22. This plot displays a typical example of the migration behaviour past the site, showing no apparent behaviour change in the presence of the transecting vessel.

Boat Close and Stationary

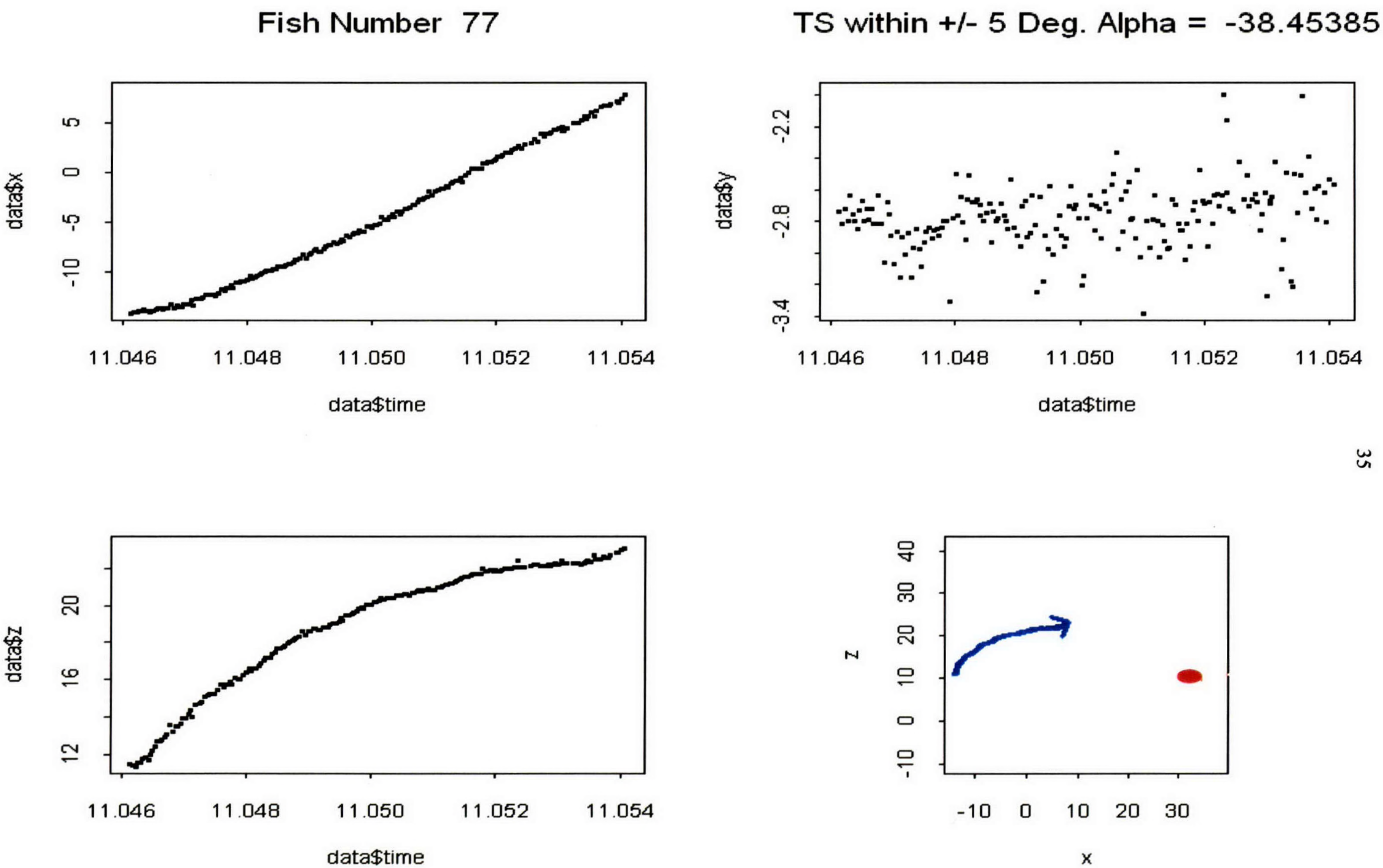


Fig. 23. This plot shows a fish passing when the transecting vessel is doing a stationary sounding at which time the vessel is anchored and the engine is turned off. The typical offshore migration pattern is present. This sort of behaviour could be interpreted as avoidance even though the vessel was not moving or making much noise.

Boat Far

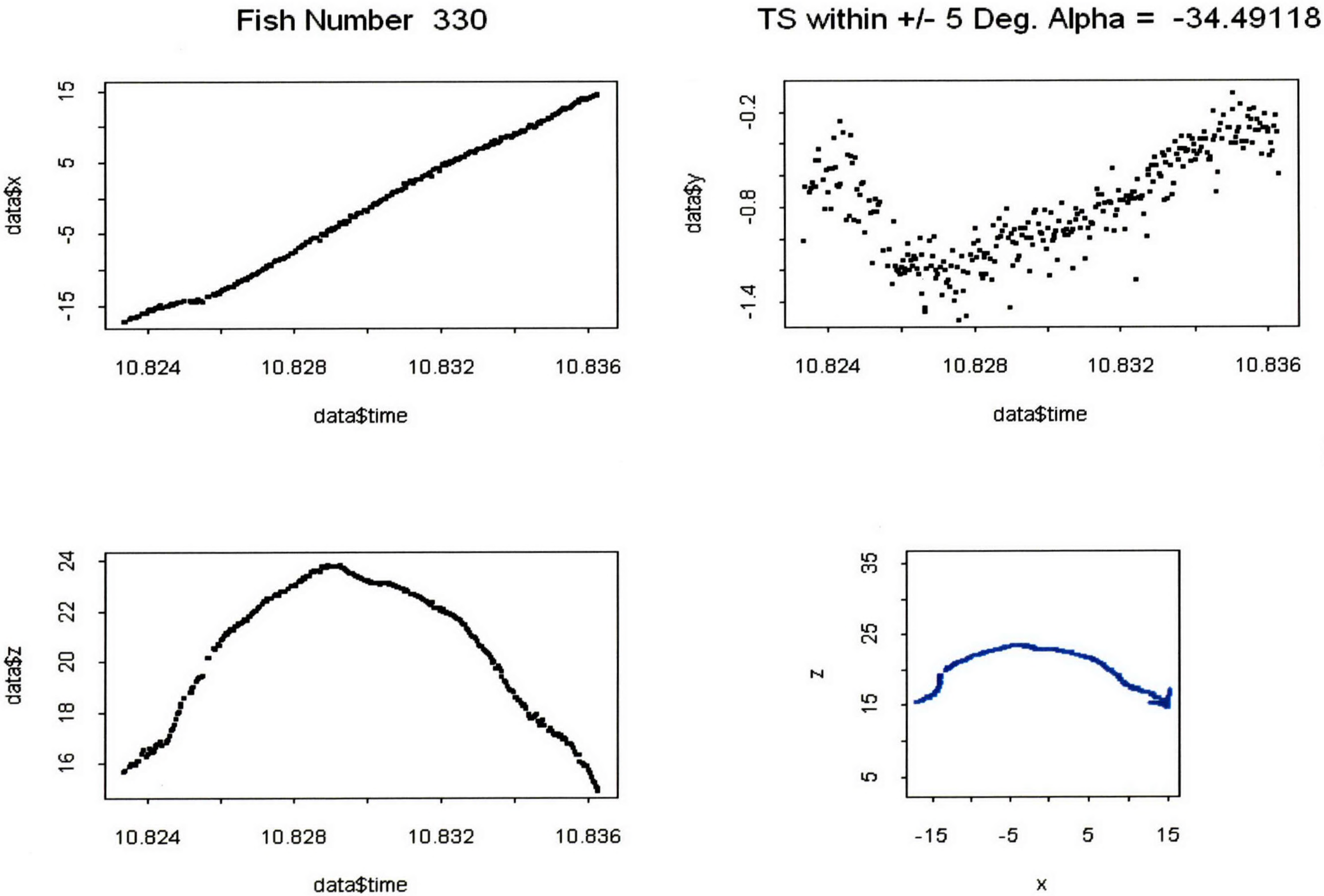


Fig. 24. This plot shows a fish track during a time when the transecting vessel was far away. The trajectory is quite sinuous even in the absence of the vessel. If the vessel had been present, one might believe that the vessel had some effect on the fish's behaviour.

Boat Far

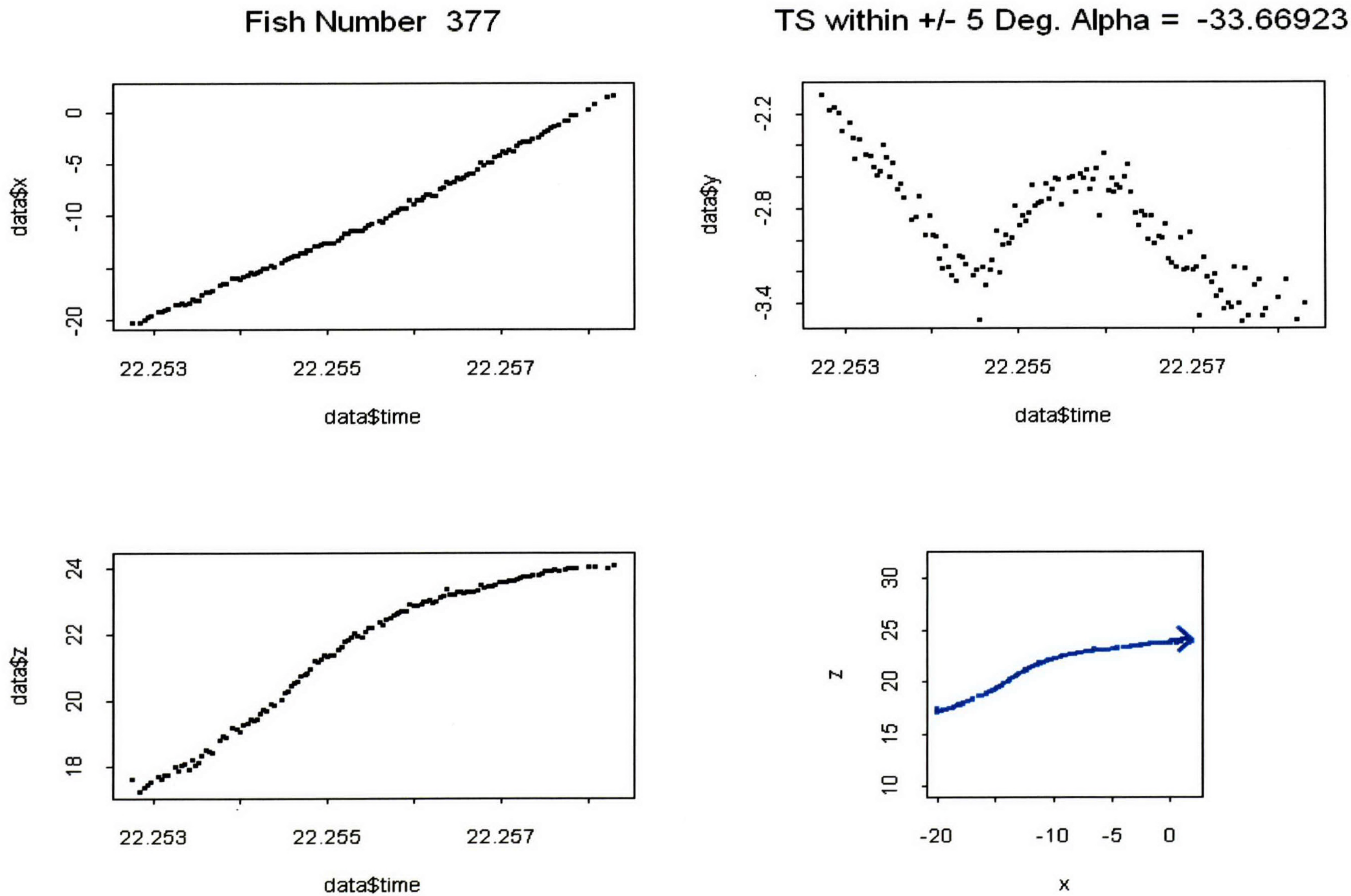


Fig. 25. This fish passed the site when the vessel was far away and the track shows the migration pattern we have come to recognise as typical for this site.

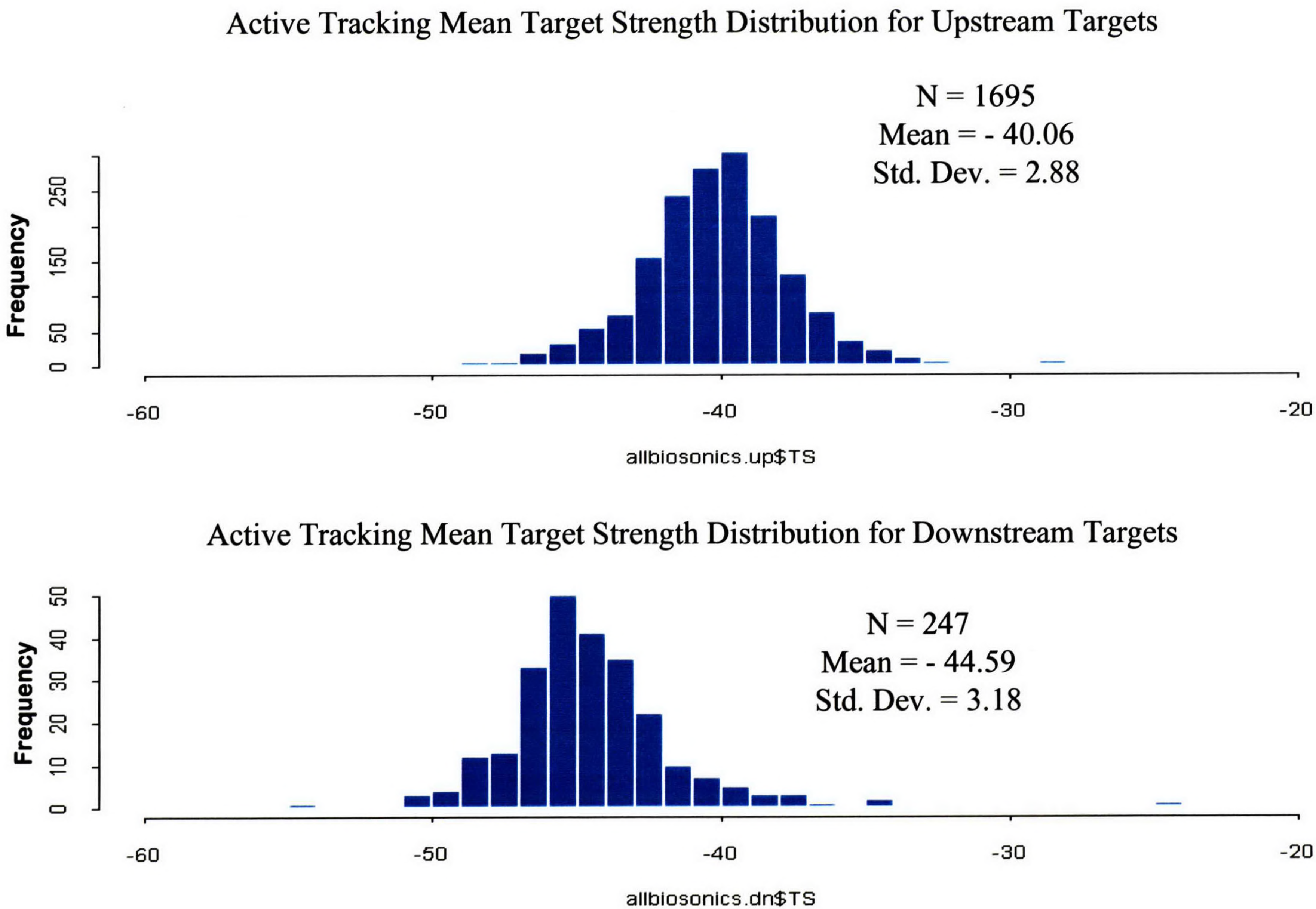


Fig. 26. These histograms present the target strength distributions for all of the targets tracked by the active tracking system. They present the mean target strength for each tracked fish. The target strengths for the downstream travelling fish shown in the bottom plot appear considerably smaller than the upstream travelling fish. This may be an indication of resident species and possibly some debris.

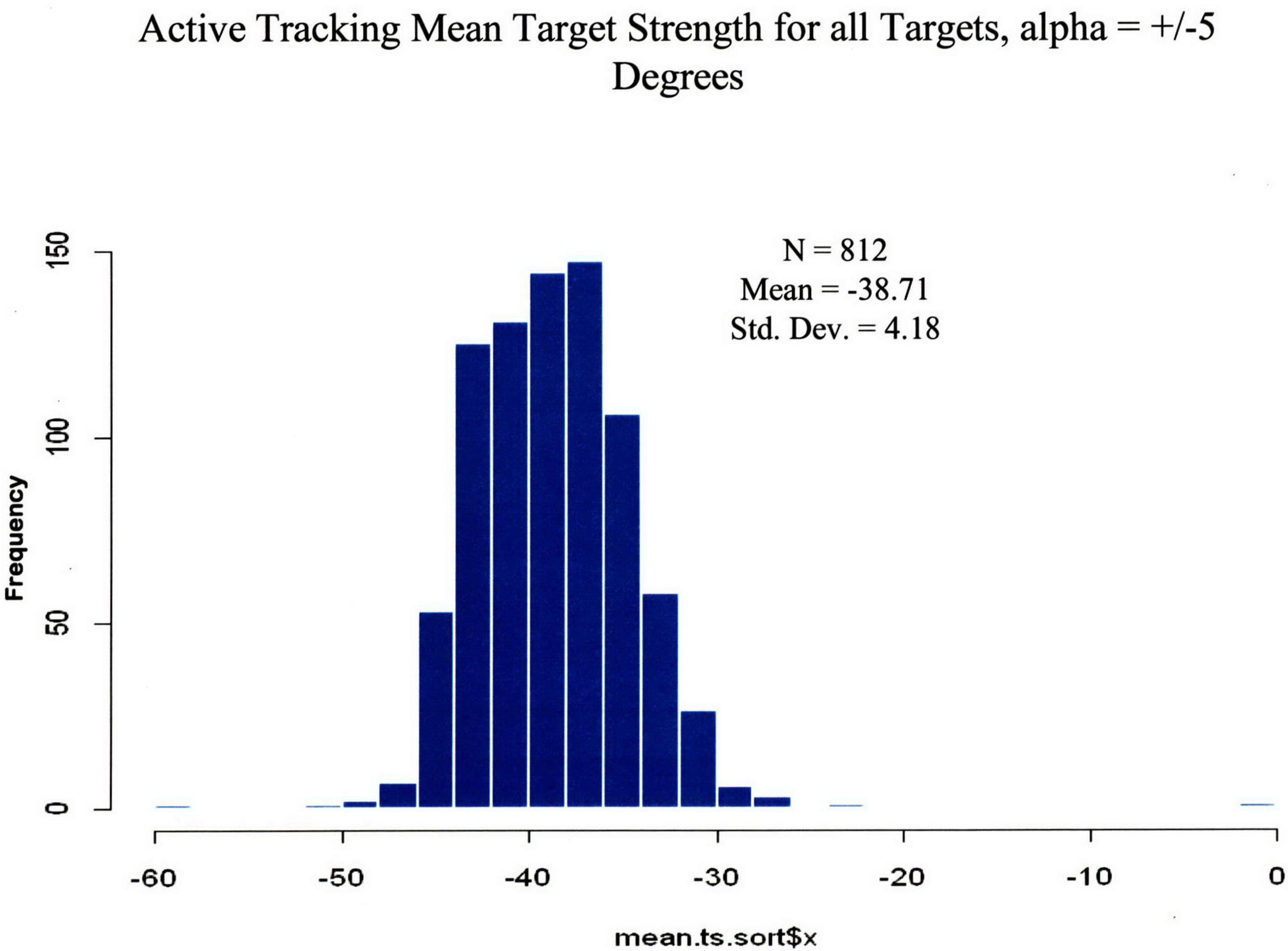


Fig. 27. If we look at the mean target strengths within the ± 5° angle range to be most comparable to the split-beam measurements, it causes a shift in the distribution toward the higher target strengths.

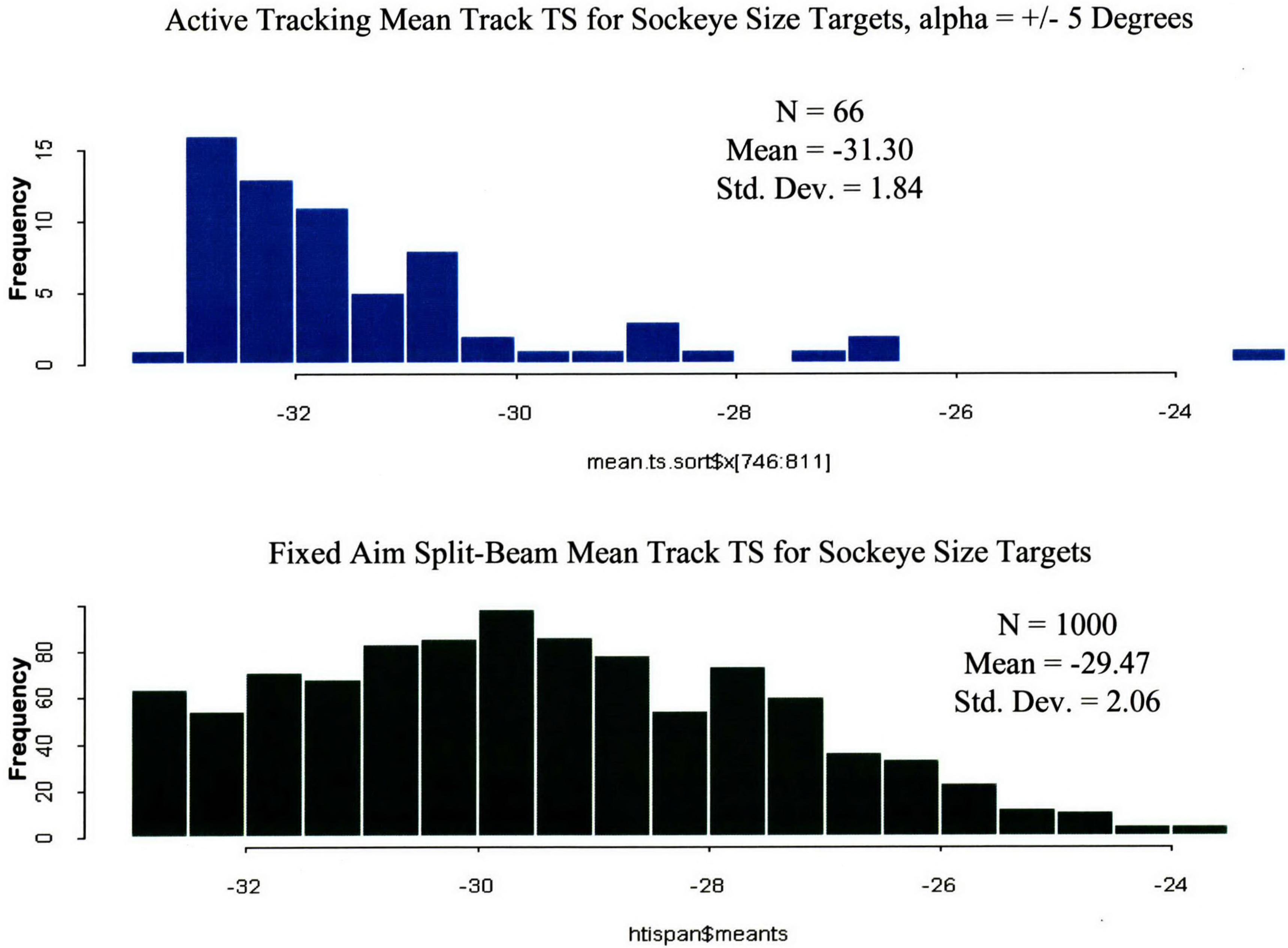
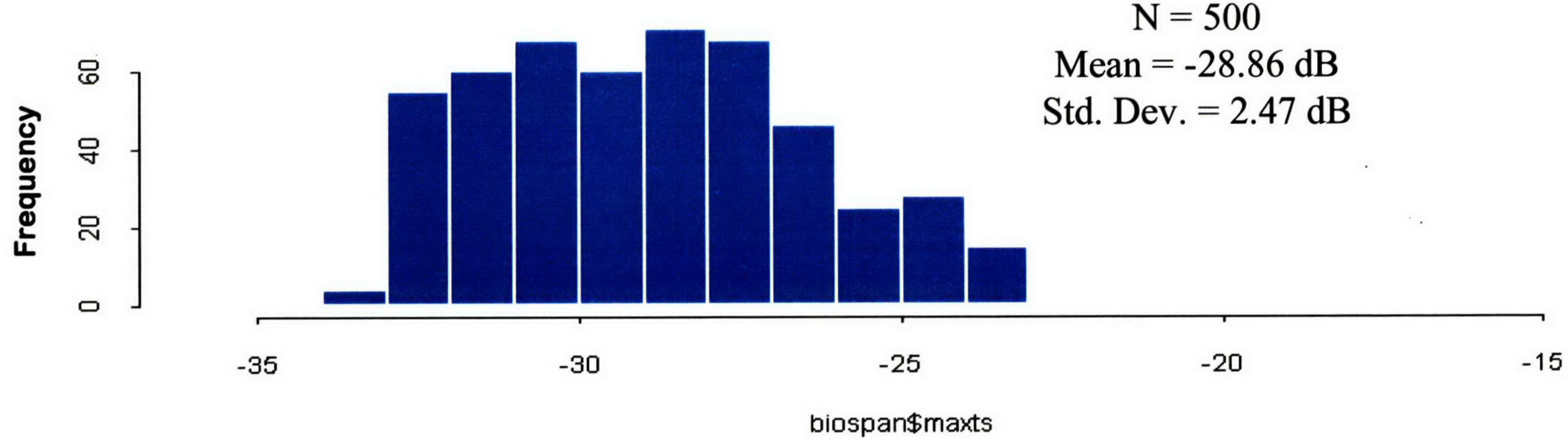


Fig. 28. These histograms show the mean track target strength distributions for the active and fixed aim systems. The fish observed from both systems have been selected to have their mean target strength per tracked fish lie within the range of –23 to –33 dB. The blue histogram presents the active tracking split-beam data and the green presents the fixed aim split-beam data.

Active Tracking Maximum Track TS for Sockeye Size Targets, alpha = +/- 5 Degrees



Fixed Aim Split-Beam Maximum Track TS for Sockeye Size Targets

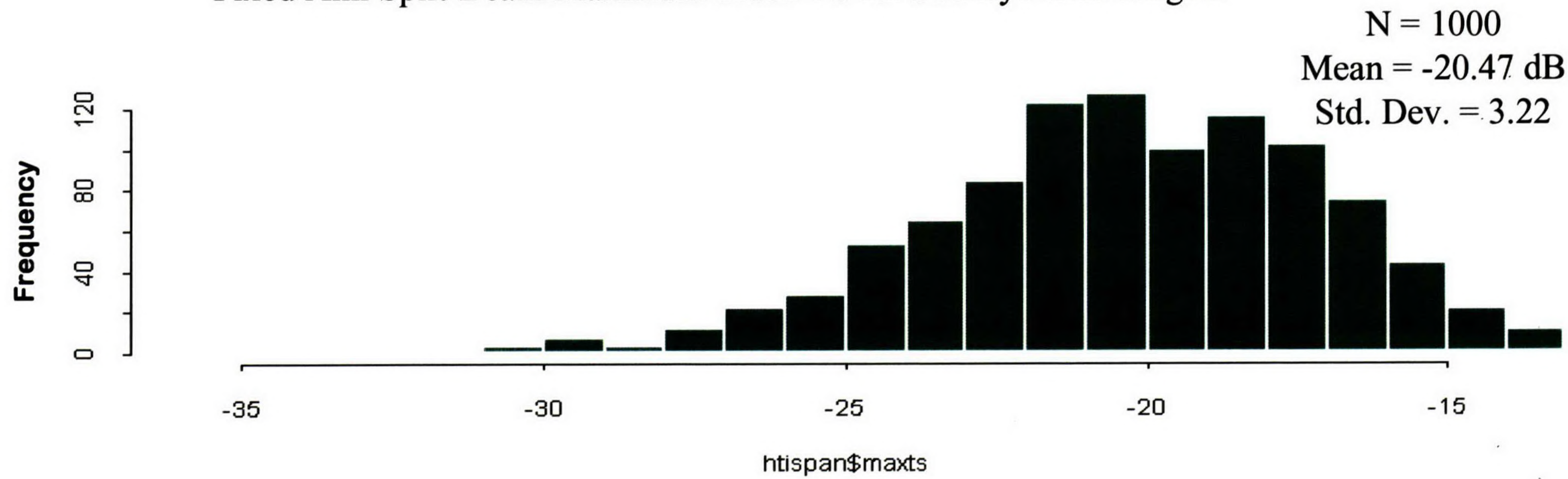


Fig. 29. These histograms show the maximum target strength values within a tracked fish for the tracks measured by the two systems. The active tracking system again returned a much lower maximum target strength value. Due to the fact that more samples were needed to make any meaningful comparisons between the systems, we chose to use the maximum target strength values for the active-tracking system to obtain the –23 to –33 dB tracks. This increased the active tracking sample size to reasonable levels.

Aerial View of Active and Fixed Aim Sonar Geometry

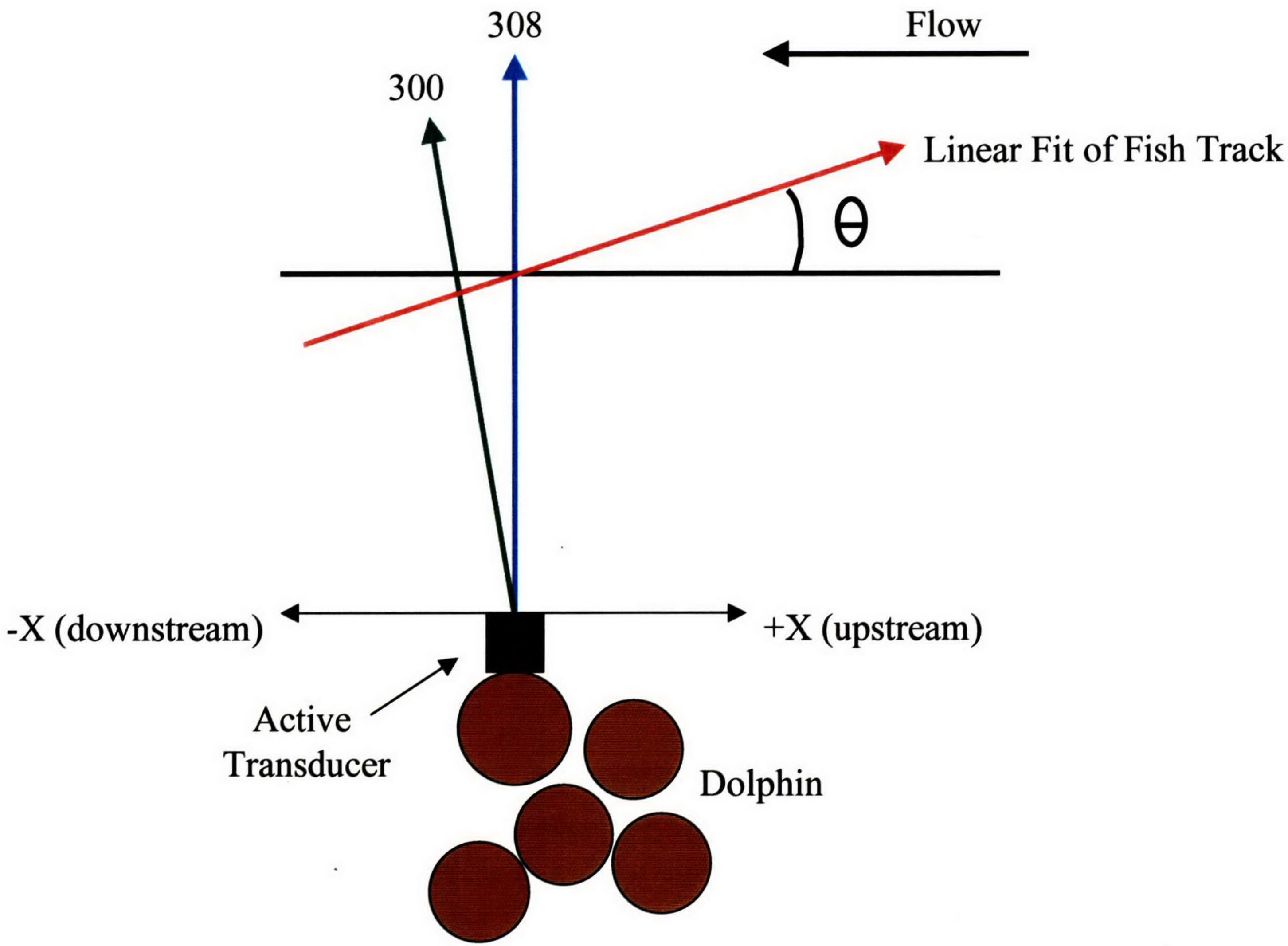


Fig. 30. This figure shows the aerial view of the geometry of the site. The brown circles represent the tops of the dolphin logs where the active tracking split-beam system was attached. The black square represents the transducer. The blue line pointing at 308° is perpendicular to the shoreline and is the centre point for the active-tracking transducer. The green line labelled 300° is the standard reference aim for the fixed aim split-beam system at the horizontal aim. The angle theta shown by the red arrow is the angle of the fish track relative to the shore when a straight line is fitted to the trajectory. The river flow direction is also shown and is from right to left.

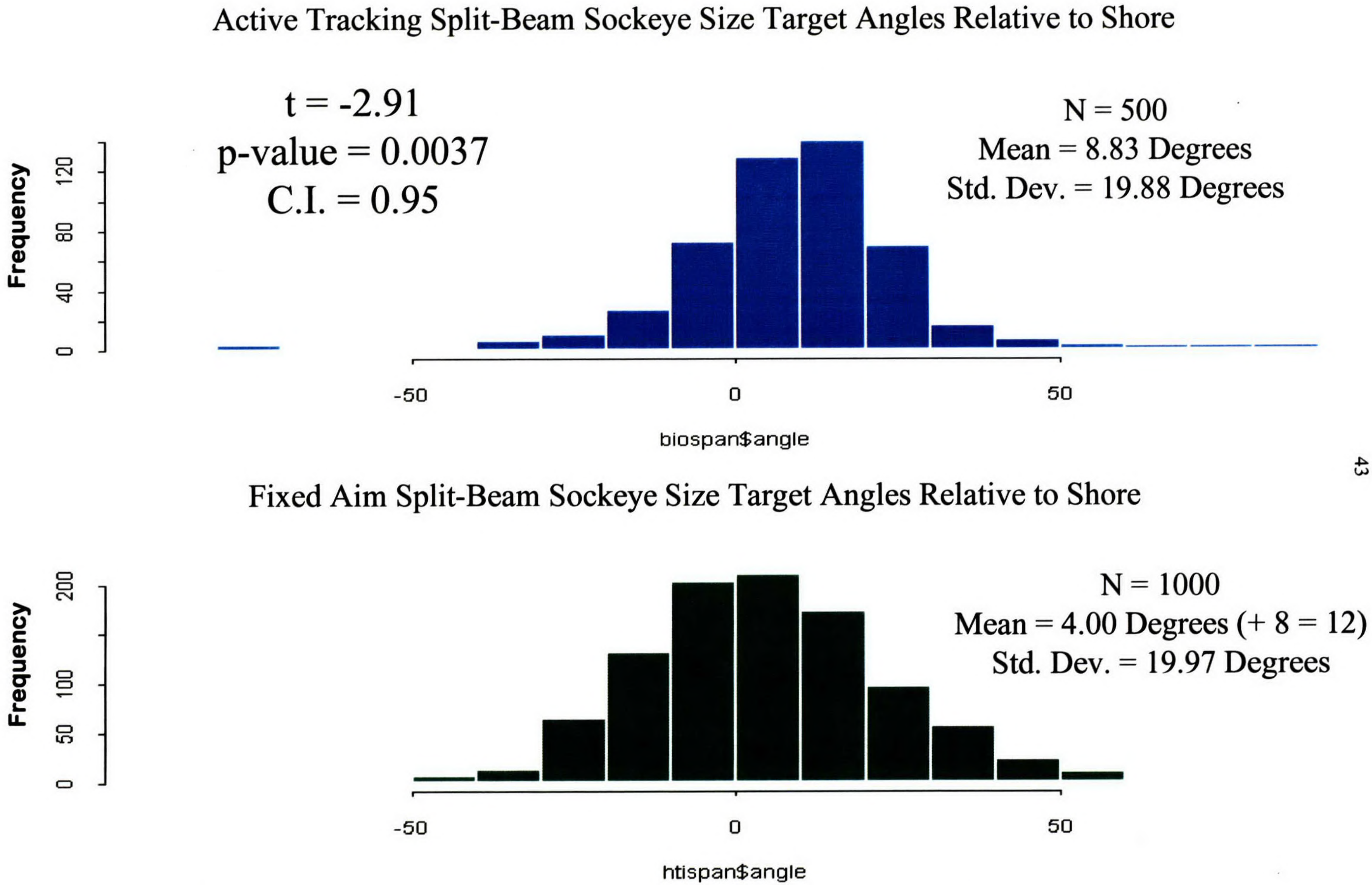


Fig. 31. Histograms of the angle measurements of well-tracked fish. The blue distribution is from the active tracking system and shows a mean of 8.83°. The green distribution is from the fixed aim split-beam system and shows a mean of 4° which must have 8° added to compensate for the difference in the reference aim giving a mean of 12°. A t-test was performed to see if these data could be described as coming from the same distribution. For these sample sizes, the result of the t-test rejects the hypothesis that the distributions are identical, and is highly significant within the 95% confidence interval. We would expect the angles to be the same.

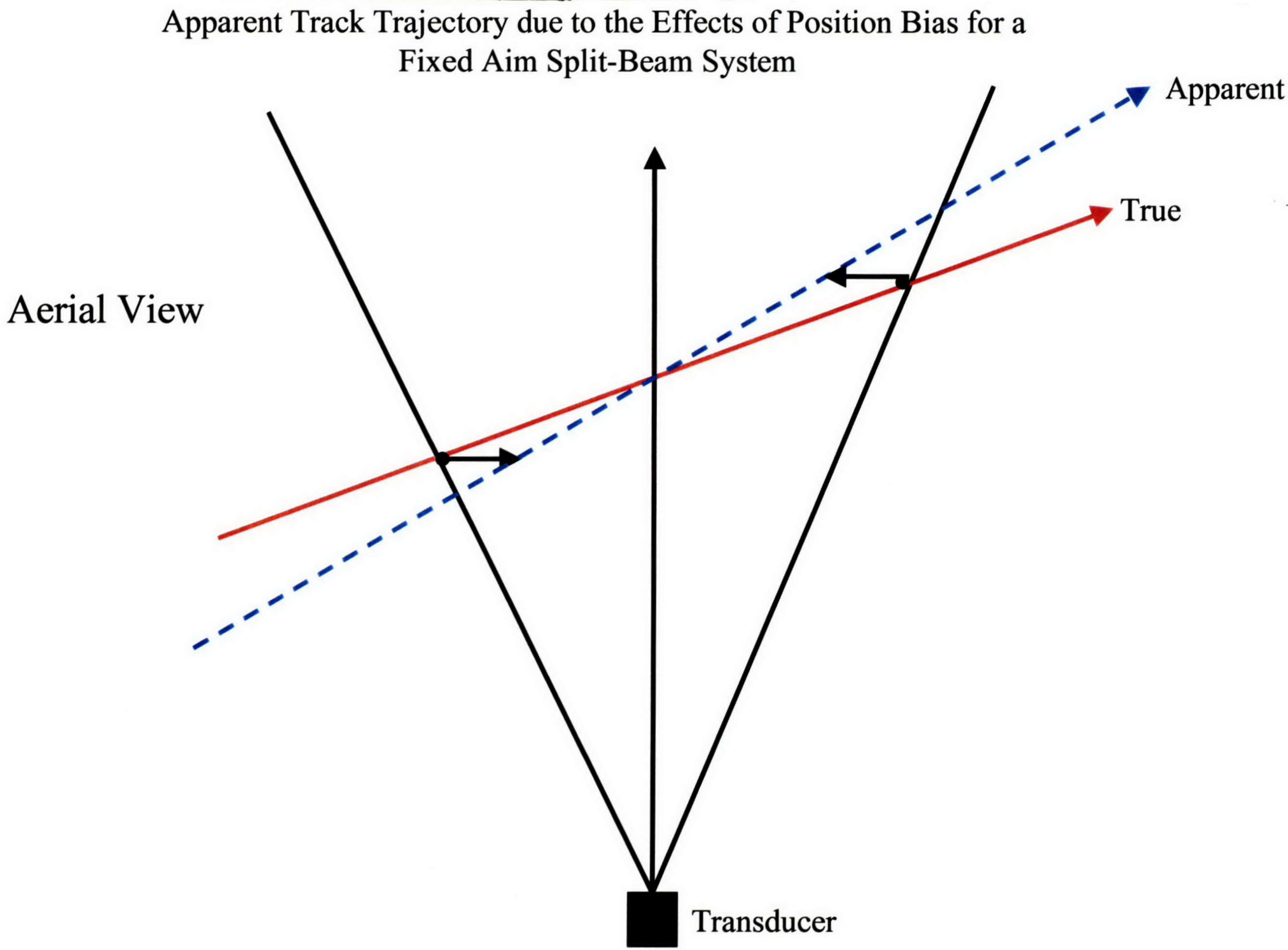


Fig. 32. This figure shows an aerial view of the fixed aim split-beam system showing the -3 dB beam pattern lines and a hypothetical fish trajectory in red. The apparent shift in the trajectory to a more offshore angle as shown by the blue line is due to the split-beam position bias effect. This inherent property of the split-beam acoustic system has the consequence of making an off-axis target appear to be closer to the centre of the beam than is true.

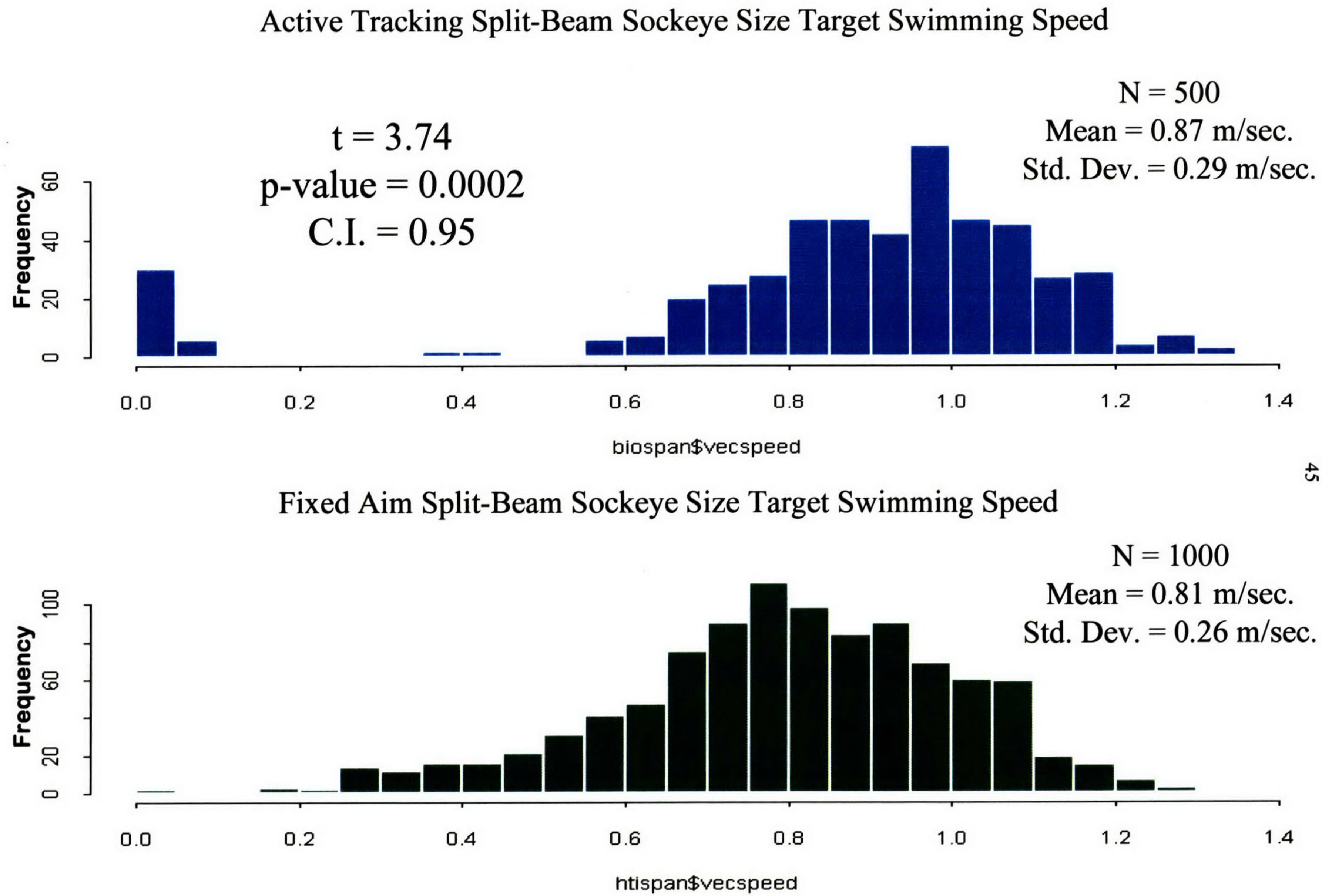


Fig. 33. Histograms of the vector speed measurements of well-tracked fish. The blue distribution is the active-tracking system and shows a mean of 0.87 metres/second. The green distribution is the fixed aim split-beam system and shows a mean of 0.81 metres/second. For these sample sizes, we see that this difference is highly significant within the 95% confidence interval. We would expect the speeds to be the same as measured by the two systems. The standard deviations for the two data sets are similar.

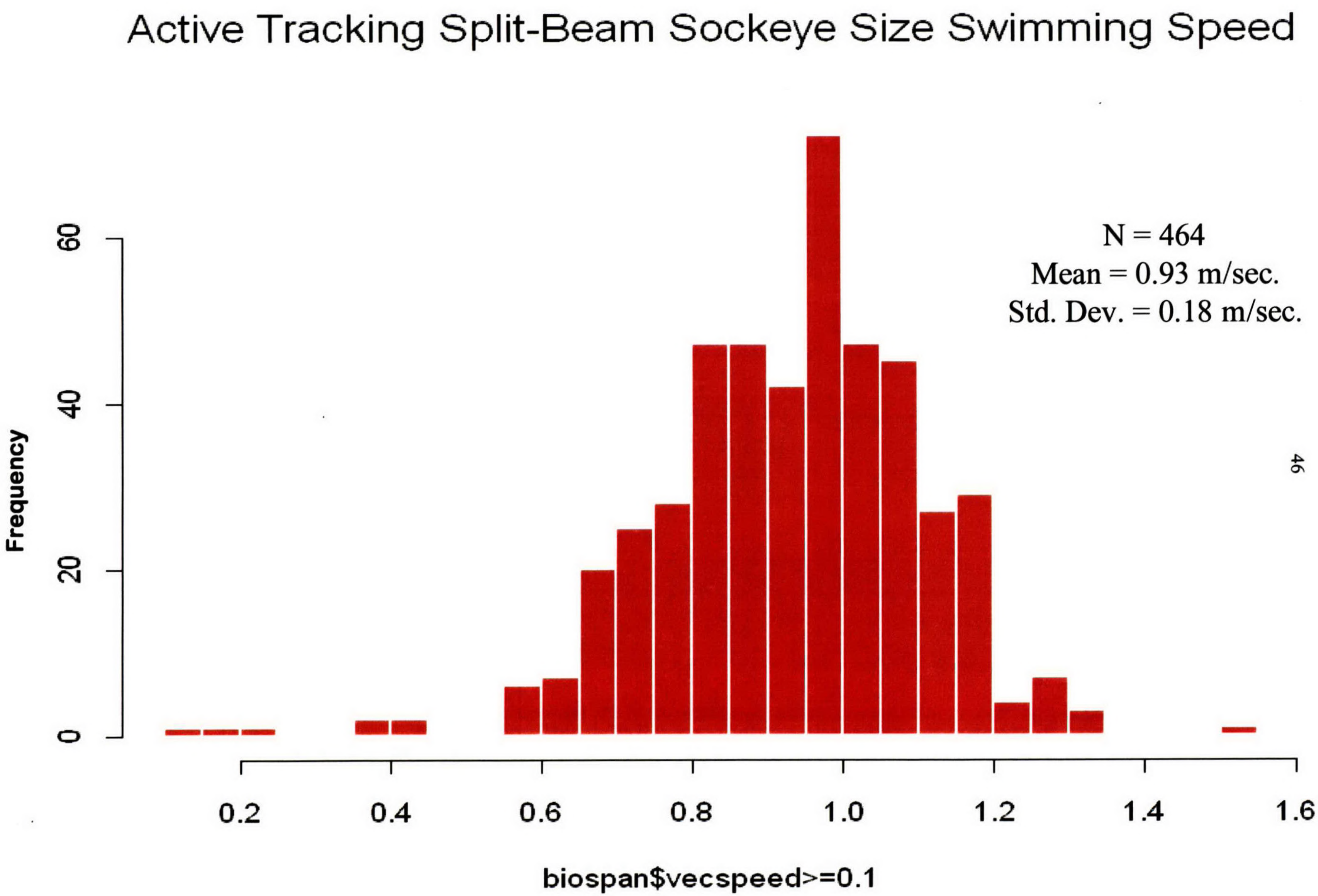


Fig. 34. This histogram shows the same active tracking split-beam data, but with the anomalous very slow values removed. This has the effect of increasing the mean speed to 0.93 metres/second, making the difference even more significant when compared with the fixed aim split-beam system's measurement of 0.81 metres/second.

Apparent Track Trajectory due to the Effects of Position Bias for a Fixed Aim Split-Beam System

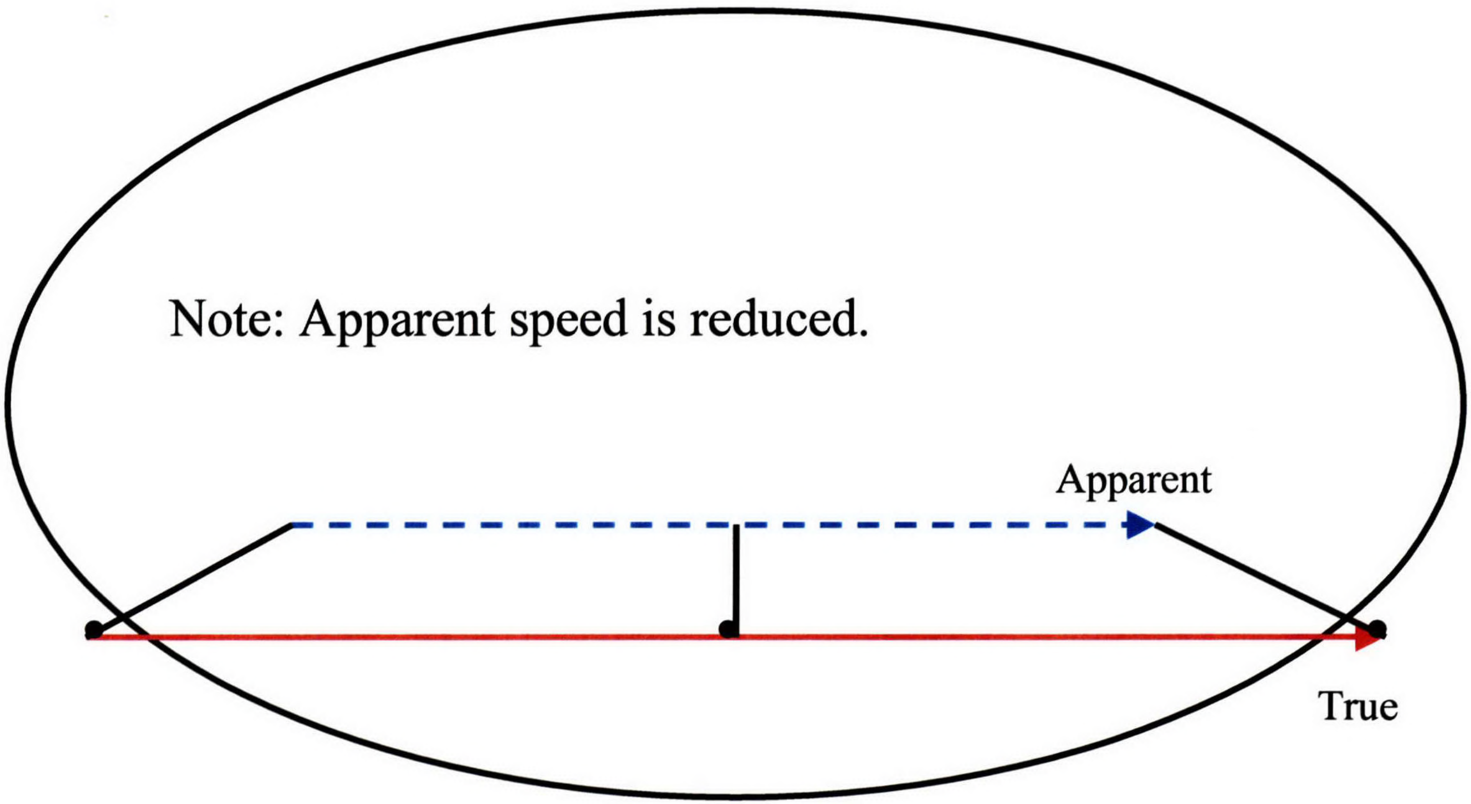


Fig. 35. This plot shows an XY view of the stationary split-beam system with an ellipse representing the -3 dB beam geometry and a hypothetical fish trajectory in red. The split-beam bias effect will move the true fish positions towards the centre of the beam. This apparent shift in the trajectory towards the centre of the beam as shown by the blue line has the effect of reducing the measured speed as the fish appears to have moved a shorter distance in the same amount of time.