COMPARISONS OF MEASURED AND ESTIMATED DISTANCES AND ANGLES FROM SIGHTINGS SURVEYS.

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ABSTRACT
Photo-grammetric systems using video cameras were used to measure radial distances to sightings during the SCANS-II, CODA and SOWER surveys. These surveys included sightings of a variety of species from harbour porpoise at distances of a few hundred metres to large baleen whales at distances greater than 10km. A total of 885 initial sightings with estimated distances from reticles and measured distances from video, using 7x50 binoculars (610) or 25x 'Big Eyes'(275), were compared. Bearings to sightings were also measured from still images on the SCANS-II and CODA surveys. The CV of the Root Mean Square (RMS) error in distances varied between 0.18 and 0.33. For all data sets there was a significant linear regression between log(estimated)-log(measured) and log(measured) indicating that when using reticles, closer distances were over-estimated and further distances under-estimated. Bearing data showed around 5% of estimates had gross errors greater than 20^o that were attributed to mistakes. For the remaining values, RMS errors were 6-7^o. Analysis of distance estimates to small cetaceans using naked eye from SCANS-II, based on simultaneous surfacings, also suggested a tendency to over-estimate close distances and under-estimate larger ones. In this case, fitted detection functions to estimated and measured distances gave estimated strip widths that differed by 29%. There still remain technological challenges in operating complex electronic systems at sea to measure distances and bearings, but where these have been successfully used there has been a considerable improvement in data quality.

INTRODUCTION
Distances and angles to sightings during line-transect surveys are critical data items but often rely on estimates from observers. Photo-grammetric methods have been used for some time to measure distances and angles and have been incorporated into the data collection system on recent surveys. On the SCANS-II (Small Cetaceans in the European Atlantic and the North Sea) and CODA (Cetacean off-shore Distribution and Abundance) surveys in the Northeast Atlantic in 2005 and 2007, photo-grammetric systems were part of a fully integrated, computer based data collection system. On the SOWER surveys in 2006/07 and 2007/08, the use of video cameras to measure distances was limited to experimental periods. The aim of this analysis was to compare measured and estimated values and examine the implications of errors for survey analysis.

METHODS
The general principle behind the use of video cameras to measure distances at sea is the same as with using reticle binoculars and involves measuring the angle of dip from the horizon to the whale from a platform of known height. One of the main challenges to the system is capturing a suitable quality image of the first surfacing reported by the observer. Photo-grammetric measurement of bearings uses a downward pointing camera taking a still image of reference marks on the deck of the vessel. These methods can only be used for observers searching with binoculars. The basic system and calibration tests are described in Leaper and Gordon (2001). The analyses presented in this paper just considered initial sightings (except for analysis of simultaneous sightings during SCANS-II). Distance estimation errors to re-sightings may be strongly influenced by the initial estimates.

Use of video during SOWER cruises
The video system was used for observers in the top barrel on SOWER cruises in 2006/07 and 2007/08 from an eye height of 20.5m. Observers on SOWER use 7x50 binoculars with a non-linear reticle scale which is marked in nautical miles. On the SOWER 2007/08 cruise the video system was also used during a distance estimation experiment where distances were also measured to a buoy in the water using radar.

The SCANS-II data collection system
The aim of the SCANS-II data collection system was to measure data wherever possible, to record data in different ways to allow errors to be identified, and to allow backwards comparability with previous surveys such

as the first SCANS survey in 1994 (Hammond *et al*., 2001). This backwards comparability required collecting data in the same way as previously but had the added advantage that systems could be compared and the accuracy of previous data collection systems assessed.

The survey used two 'Primary' observers searching with naked eye and two 'Tracker' observers, one searching with 7x50 binoculars and one with 25x 'Big Eyes' (Monk Leviathan) to implement Mark Recapture Distance Sampling methods (Buckland and Turnock, 1992). There were also two other people on the Tracker platform. The 'Data Recorder' sat at a computer and was responsible for entering changes in environmental conditions and survey effort directly into Logger in addition to managing the flow of data from sightings. The 'Duplicate Identifier' stood beside the Trackers in a location where they were aware of all sightings been made from both platforms. The Primary platform was not aware of sightings made from the Tracker platform.

Data on observer effort, environmental conditions and vessel position were all recorded using well established software, Logger[1]. As well as automatically recording GPS data and having forms for entry of effort and sightings, This software was modified to record observer commentary and timing cues, control video cameras for distance measurement and read out web-cams for bearing measurement (see below). All observers were equipped with sighting and re-sighting buttons which were linked to the logger software and would trigger the opening of sighting forms, voice recording and camera readout. All Logger data (apart from recordings, video and web-cam images) were stored in a Microsoft Access database. A further piece of software for off-line data entry and validation was developed specifically for the SCANS-II project. Figure 1 illustrates the flowchart of events following a Tracker observer pressing a button to indicate a sighting. The configuration of binoculars, video camera and webcam is shown in Figure 2.

Measurement of the timing of cues

Accurate timing of cues is in many ways the most straightforward measurement to achieve. However, if timing is to be used as part of a duplicate classification algorithm then the accuracy of timing also needs to be measured. The system designed for SCANS-II relied on the observer pressing a button to indicate a sighting. There are a number of circumstances under which it may not be possible to hit the button at the correct time, particularly if trying to use binoculars to identify a cue (for observers scanning with the naked eye). In addition, an observer may be unwilling to press a button if uncertain that the initial cue was indeed a species of interest. Thus the system was designed with a voice commentary that began prior to the button being pressed (through the use of a rolling buffer of acoustic data). Observers were instructed to say something immediately a potential sighting was made. They then had time to use binoculars if necessary before pressing the button, and it was the timing of the initial vocal event that would be used. The intention was that observers would make a noise for anything that could possibly have been a sighting but would have a few seconds to think before pressing the button.

Distance measurement

We are currently not aware of any distance measuring instrumentation that has been used by observers scanning with the naked eye. Previous experience with video systems in conjunction with naked eye observers had been that even with a helmet mounted camera, the field of view of the camera required to capture cues resulted in insufficient image quality. Thus the distance measuring system was limited to the Trackers searching with binoculars. Video cameras were attached to the binoculars in such a way that the field of view of the camera matched that of the binoculars and distances were calculated from the angle of dip between the horizon and the animal. The major enhancement for SCANS-II was the use of portable hard disk video recorders (Firestore FS4) which included a rolling buffer. Thus when the sighting button was pressed, video beginning from 6 seconds previously was recorded. The Firestore units were started and stopped directly by Logger in response to tracker button presses. This ensured that the first cue seen by the observer was included in the recorded video sequence. The 25x Big Eye binoculars were mounted on a sturdy stand attached to the deck by rubber mounts (these mounts were off-the-shelf vibration mounts selected for the weight of stand and binoculars). The video camera was mounted on top of the binoculars. The 7x50 binoculars were not mounted on a rigid stand, but on a monopod with a ball joint at the top. This allowed the observer maximum freedom of movement to compensate for the motion of the vessel.

Measurement of bearings to sightings

Although a number of instruments are available to either measure the rotation angle of a shaft, these were judged to be too expensive and could not be applied to the monopods on the 7x50 binoculars without severely restricting

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[1] The Logger software was developed by the International Fund for Animal Welfare to assist with benign research on cetaceans and is available to download from www.ifaw.org/sotw

freedom of movement. At the time, gyro-based heading systems were also too expensive. Thus the system selected for measurement of bearings was the photo-grammetric system described by Leaper and Gordon (2001). This system consists of a small, downward pointing, camera mounted to the binoculars. Images of reference markers on the deck are then used to measure bearings. The advantage of this system is that it is cheap, accurate and allows full freedom of movement (to anywhere where appropriate markings have been placed on the deck). The disadvantage is that each image needs to be analysed by hand to measure the bearing.

Capture of a bearing image was triggered by pressing either the sighting or resighting buttons. In each case a sequence of 10 images was captured from 5 seconds before the button to 5 seconds after. This allowed comparison of bearings between images to check for circumstances where the observer may have been changing the orientation of their field of view rapidly resulting in less accurate bearings. In addition to capture of bearing images in response to sightings, images were collected at random intervals in order to allow analysis of observer scanning patterns. These were used for example to provide feedback following the experimental survey on the scanning patterns that were actually achieved in relation to what was intended.

Data Validation

A major requirement of the system was that at the end of the survey there should be a database with complete data on each sighting including measurements of distances and angles with the majority of processing, such as watching video or listening to commentaries, to extract the basic data being conducted at sea. Hence an off-line data entry system was required which allowed observers to listen to commentaries, analyse video and measure bearings from the webcams at the end of the survey period each day. This clearly required access to a computer for each observer and so the system was designed to allow several machines to be networked to a machine with the central database. The system was designed such that the Data Recorder would enter as much data for each sighting as possible but if there were several events happening at the same time then data items may have only been recorded in the commentary and not into the Logger forms. In these circumstances the Data Recorder's main task was to monitor the commentaries and check that they were clear (i.e. all microphones were working and well positioned) and to remind observers if they had missed key data items. At the end of each observation session there were thus a set of observation records with gaps for some data fields. For each record the validation software would list possible problems as 'errors' or 'warnings'. 'Errors' were problems with the data that would preclude standard distance analysis (e.g. distance, angle, species) and 'warnings' were problems with ancillary data e.g. swim direction, cue type.

As well as identifying blank fields, errors and warnings would be triggered by the situations including values outside of predetermined ranges for all parameters, inconsistencies between the observer reporting the sighting and the effort status. For records that had errors or warnings, the observer would listen to the commentary to fill in blanks and try and resolve any discrepancies. The record was then saved with a code indicating whether there were no warnings or errors, further processing was planned, or the data could not be resolved. The validation software also allowed cruise leaders to extract summary statistics of the type of errors that were occurring and plots of distances angles (similar diagnostics as recommended by SC for cruise reports). These could be selected by species or observer and were particularly intended to identify rounding in estimated values and any problems that could be corrected during the survey.

The SCANS-II systems was also used on the CODA survey but with standard resolution digital video cameras (720x576 pixels) being replaced by high definition (1440x1080 pixels). The model used on CODA was the Canon HV20 which gave a slightly narrower field of view than the 7x50 binoculars at full zoom. The HV20 with an additional Canon TL-43 1.7x conversion lens was used with the Big Eyes.

The Mark Recapture Distance Sampling methods used on SCANS-II have the potential to correct for certain errors in distance estimation by the Primary observers searching with the naked eye because of the use of duplicate sightings from the Trackers. However, many surveys still rely on distances from naked eye observers (e.g. Schweder *et al*., 1997). To investigate errors in distances and angles by naked eye observers a subset of data classed as simultaneous surfacings were analysed. Simultaneous sightings were sightings made by observer 1 (Primary) and observer 2 (Tracker) that occurred close together in time and location but were not necessarily classed as duplicate sightings. They were defined as sightings which occurred within 10 seconds (the observer 2 sighting does not necessarily have to have occurred first as with usual duplicate sightings) and on a similar bearing ($\pm 5^{o}$). Sightings of tracked animals were also included. To assess the potential effect on the abundance estimate due to the distance and angle errors of observer 1, detection functions were fitted to the perpendicular distances for each observer separately.

RESULTS

Radial distances from SOWER cruises
On the 2006/07 cruise, 7 minke whale surfacings were measured on video out of a total of 21 sequences that were recorded (Leaper, 2007). The main reason for sightings not being detectable on video appeared to be related to image quality and the characteristics of minke whale blows. The maximum distance that a minke body was detected on video was 3.6km (2nm) and the maximum distance that a blow was detected was 1.9km (1nm). Even at this distance this sighting was only detected for certain due to being a combined blow/body cue. These results were presented in SC/59/IA25. On the 2007/08 cruise, experiments were mainly conducted in the presence of large baleen whales using a high definition video camera. In this case 34 video measurements were obtained out of a possible 64 sequences (53%). Large baleen whale blows were detected out to measured ranges of 10km.

Figure 3 shows a significant linear regression (d.f.=40, r=0.44, p<0.01) of log(estimated)-log(measured) against log(measured). This indicates underestimation of larger distances. If only data out to 6km (3.2nm) are considered then the linear regression in Figure 4 suggests minimal bias. These distances are more typical of expected sighting distances for minke whales and are also representative of the range of distances used in buoy experiments. For distances greater than 6km the results suggest potentially substantial bias (Figure 4). Figure 5 shows the result of the buoy experiments for both the video system and a single observer. In this case, radar distances are treated as the 'true' values and plotted on the x-axis. However, it is not certain whether radar readings are necessarily more accurate. The slight (3%) bias in the video measurements is within the range of values that could be explained by refraction effects. Overall the CV of the Root Mean Square Error (CV_{RMSE}) was 0.26. For distances out to 6km CV_{RMSE} was 0.23 compared to CV_{RMSE} for the buoy experiment of 0. 07.

Analysis of radial distances from SCANS-II and CODA surveys
Figures 6 and 8 show a significant linear regressions (df = 243, r=0.31, p<0.01 and df=134, r=0.38, p<0.01) of log(estimated)-log(measured) against log(measured) for 7x50 and Big Eye binoculars respectively in SCANS-II. Overall CV_{RMSE} was 0.31 for 7x50 (Figure 7) and 0.33 for Big Eyes (Figure 9). Eye heights on SCANS vessels varied between 10 and 14m.

Equivalent results for the CODA survey are shown in Figures 10 and 12 indicating linear regressions (df = 321, r=0.24, p<0.01and df =137, r=0.51, p<0.01) of log(estimated)-log(measured) against log(measured) for 7x50 and Big Eye binoculars respectively. Overall CV_{RMSE} was 0.32 for 7x50 (Figure 11) and 0.19 for Big Eyes (Figure 13). Rounding to certain reticle values, indicated by points in a horizontal line, is apparent for the 7x50 data in both surveys, particularly at larger distances (Figures 7 and 11). The 7x50 estimates on CODA were the only ones that showed substantial overall bias (given by the linear regression estimated = 0.83measured), but the cause of this has not been determined.

All the surveys (SOWER, SCANS-II and CODA) showed the same trend of error in distance with distance. For 7x50 binoculars the angle of dip from the horizon to the whale at which distances changed from over to underestimation was approximately 0.26° for SOWER or 0.37° for SCANS. For the 25x Big Eyes these angles were in the range 0.08° to 0.13°. When these angles are multiplied by the magnification of the binoculars they result in angles of around 2-3° at the eye, roughly the field of view of foveal vision.

Analysis of simultaneous sightings from SCANS-II
In total, 52 sightings were classified as simultaneous. In 44 cases, the observers had recorded the same species code. The differences in species codes related to one observer recording either an unidentified dolphin code or a 'combined species' code and the other recording a dolphin species or combined species code. To examine the combined effect of errors in distances and angles, perpendicular distances were used rather than radial distances for this analysis. Figure 14 shows that perpendicular distances of less than around 150m were over-estimated by observer 1, but greater distances were under-estimated. There were three influential points (black dots in Figure 14) and a further regression model was fitted excluding these points.

The data were truncated at 400m to avoid long tails in the fitted detection functions. For observer 1, a half-normal detection function gave the best fit giving an estimated strip width (esw) of 147 (14.6)m. For observer 2 a hazard-rate function gave the best fit giving an esw of 114 (33.8)m.

Analysis of bearings from SCANS-II

Measured bearings were obtained for 91% of sightings for all vessels combined. Where large discrepancies between estimated and measured were observed these were resolved wherever possible by listening to the commentaries and re-analysing the bearing images. Bearing images were taken in sequences, 1 second apart and so it was possible to measure whether the observer was looking steadily at a target, or still scanning when the sighting button was pressed. For the 7x50 binoculars this resulted in 651 initial sightings where both estimated and measured bearings were available. Of these 5% (34 sightings) showed gross errors of more than 20^o which could not be resolved and were assumed to be either observer error or related to angle pointers becoming mis-aligned. For the remaining sightings the root mean square (RMS) error was 7.1^o. The average of sin(estimated)-sin(measured) was 0.016 suggesting that errors would likely make minimal overall contribution to bias in perpendicular distances. For the Big Eyes there were 355 sightings with both estimated and measured bearings with 6% of sightings showing errors of more than 20^o. Excluding these gave a RMS error of 6.0^o. The average of sin(estimated)-sin(measured) was 0.02.

DISCUSSION

For all surveys, for all types of binoculars there was a significant regression between error in distance estimate and distance. In all cases the trend was to underestimate larger distances and to over-estimate small ones. This could be a result of rounding effects at small reticle readings if observers tend to round up the reticle reading, and difficulties in counting reticles at larger reticle readings. Rounding was most apparent in the 7x50 binoculars used on SCANS-II and CODA which had widely spaced reticles (Figures 7 and 11). The implications of the compression of the range of true distances for abundance estimation are not easy to predict. In the analysis of the simultaneous SCANS-II sightings the fitted Primary (Observer 1) strip width was actually wider than that of the Tracker (Observer 2) despite the majority of distances being underestimated by Observer 1. This appears to be due to overestimation of distances to a small number of closer animals causing a substantial change in the shape of the detection function for small perpendicular distances. Thus the overall distribution of distances to sightings and chosen truncation distance will affect the overall bias. For the SOWER cruises this may not have a large influence on minke whale estimates (which were for example truncated at 1.5nm by Branch and Butterworth (2001)), but it could potentially have a large effect on estimates for larger species if truncation distances of greater than 3nm were used. Cue counting methods may be especially sensitive to non-linearity in errors in distance estimation (e.g. Borchers *et al*., 2003) because these are based on area (i.e. square of distance).

One result apparent from the SOWER 2007/08 data was the comparison between the distance estimation errors during buoy experiments (CV_{RMSE} =0.07) and to whales during survey conditions (CV_{RMSE} = 0.24). It would be expected that estimated distances to a stationary object that remains at the surface are more accurate than those to whales, but the extent of the difference is surprisingly large. These results would tend to suggest that distance experiments using fixed buoys are unlikely to yield much information about the errors that occur under real conditions. Williams *et al*. (2007) reached a similar conclusion based on data showing that errors in distances to transient cues were larger than those to cues that were visible for a longer period of time.

The results presented here all involved data that has been through a careful validation process, both at sea and also prior to analysis. Recording distances and bearings by two separate methods allowed an initial screening for gross errors which could then be checked against the complete verbal commentary for each sighting. This validation process involved double checking around 10% of sightings which showed the greatest discrepancies. Although the majority of these cases involved errors with the estimated values there were also errors in measured values. Errors in measured values could be corrected because all the raw images were stored. Overall, the rate of large discrepancies was higher than might have been expected, but was only apparent because of having two independent sets of data on the same value and there was no reason to assume that this was not typical of most surveys.

The use of high definition video has resulted in a marked improvement in image quality on the most recent surveys (CODA and SOWER 2007/08). Detecting minke whale blows on the standard resolution video images was identified as a problem in the 2006/07 SOWER data (Leaper, 2007). However, there were insufficient sightings of minke whales during the video experiments on SOWER 2007/08 to establish whether the high definition video was capable of detecting minke whale blows across the range of distances that they are sighted by visual observers. One vessel on the CODA survey had major technical problems resulting in a very low success rate in obtaining measured distances. On the other vessels, the success rate was considerably higher than SCANS-II at 67% and 63% for the Investigador and Mars Chaser respectively, compared to 41% on SCANS-II.

In conclusion, measurement error from use of reticle binoculars has a CV that may be considerably greater than the CV of the final abundance estimate. Although none of the surveys showed substantial overall bias, bias can nevertheless occur due to the non-linear relationships between errors and distance. In the case of the simultaneous sightings from SCANS-II, the bias would have been 29% if the survey had been reliant on observer 1 estimates. Distance errors are difficult to predict or correct from typical distance experiments using fixed targets and ultimately there appears no substitute for measuring these at sea. Video systems are still not at the stage where close to 100% success in obtaining images to sightings can be expected but high definition cameras have allowed considerable improvements. Operating and maintaining complex electronics in harsh marine environments also remains a challenge.

ACKNOWLEDGEMENTS

The data presented here were collected by a large number of observers on different vessels. We would especially like to thank the data collection methods group for SCANS-II, the cruise leaders for SCANS-II, CODA and SOWER for their patience and persistence in keeping the data collection systems working at sea.

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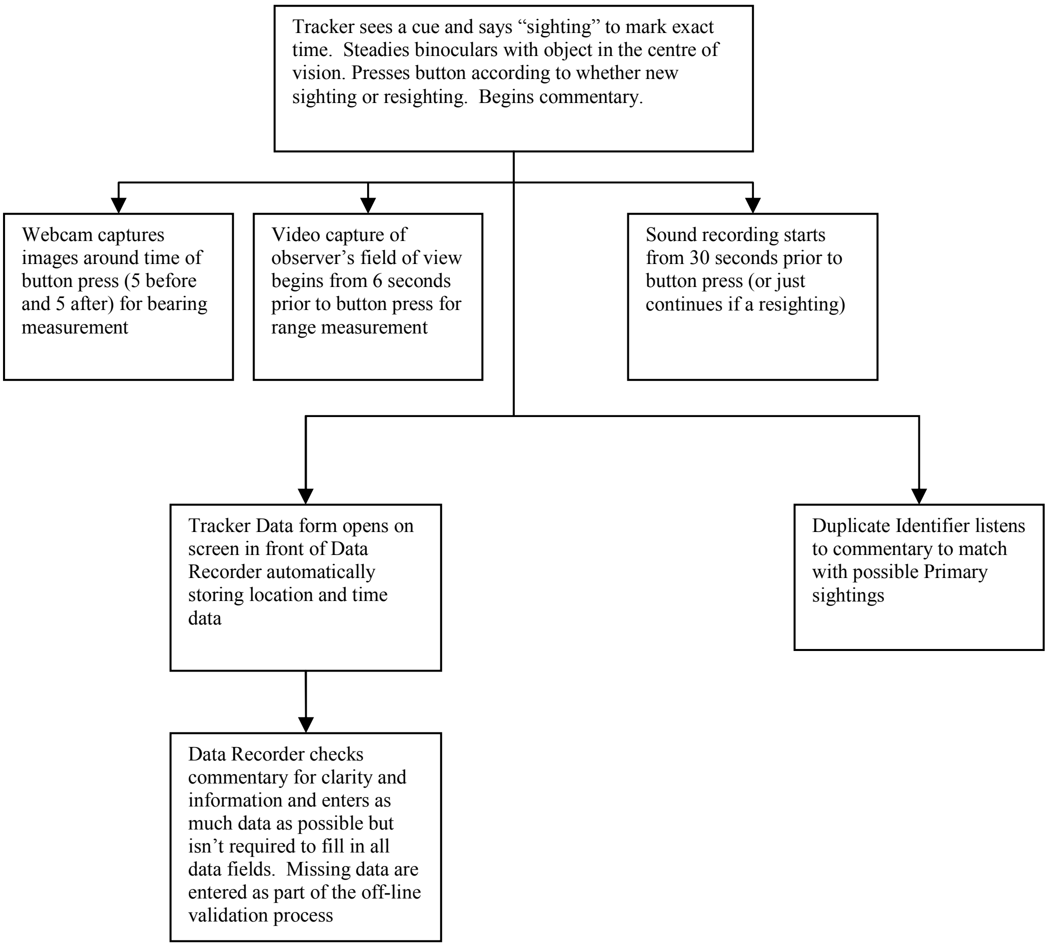

Figure 1. Flowchart of events following pressing of sighting button on SCANS-II and CODA surveys.

Photo Ana Canadas

Figure 2. Arrangement of binoculars, video camera and downward pointing webcam on SCANS-II and CODA surveys.

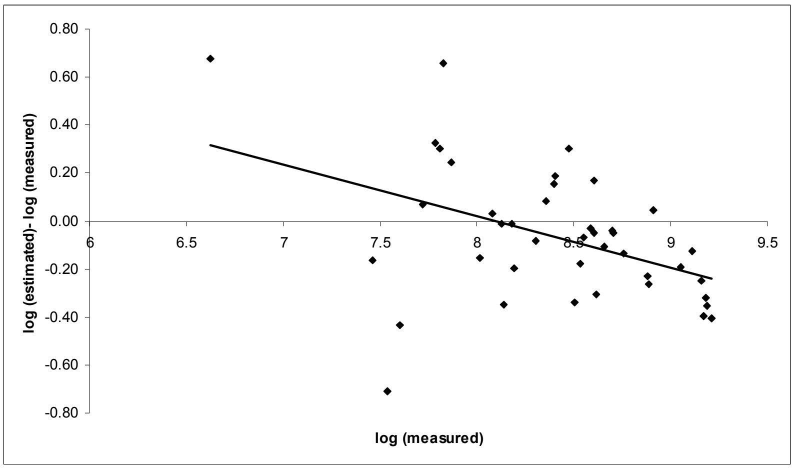

Figure 3. Log(estimated)-log(measured) against Log (measured) distances from SOWER cruises in 2006/07 and 2007/08. Measured values are distances from video in metres, estimates are from reticle binoculars.

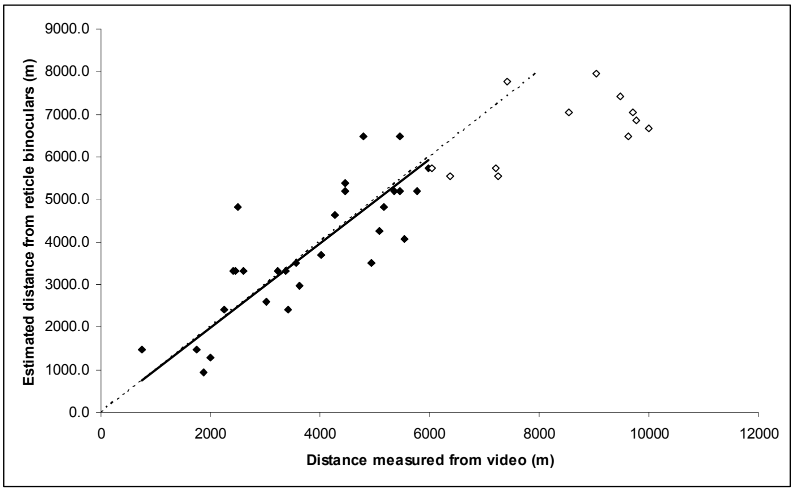

Figure 4. Estimated against measured distances from SOWER cruises in 2006/07 and 2007/08. Dotted line indicates no error, solid line indicates fitted linear regression up to a truncation distance of 6km.

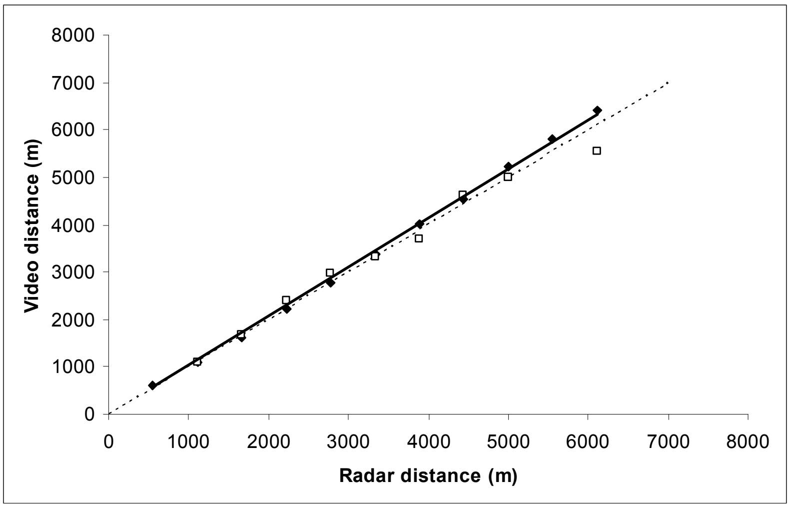

Figure 5. Buoy experiment on SOWER 2007/08 cruise. Black diamonds indicate video measurements. Open squares indicate observer estimates using reticle binoculars.

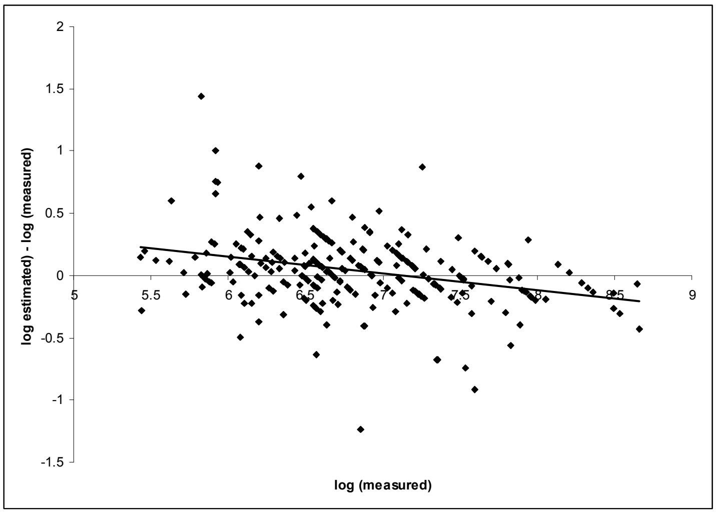

Figure 6. Log(estimated)-log(measured) against Log (measured) distances from SCANS-II. Measured values are distances from video in metres, estimates are from 7x50 reticle binoculars

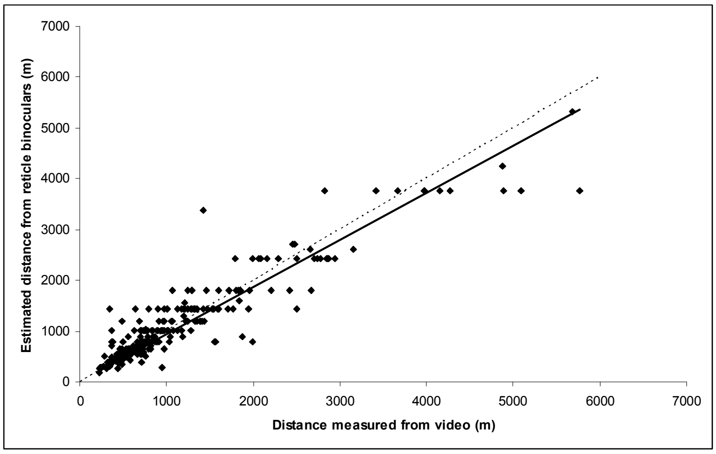

Figure 7. Estimated against measured distances from SCANS-II for 7x50 binoculars. Dotted line indicates no error, solid line indicates fitted linear regression.

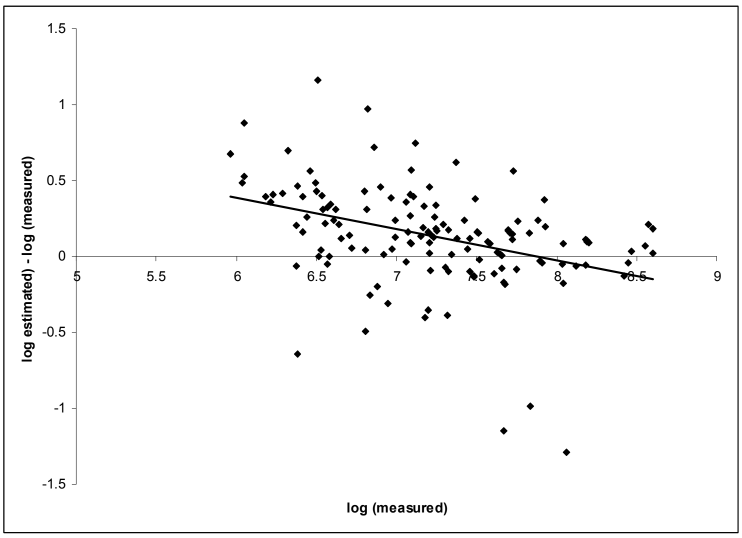

Figure 8. Log(estimated)-log(measured) against Log (measured) distances from SCANS-II. Measured values are distances from video in metres, estimates are from Big Eye reticle binoculars

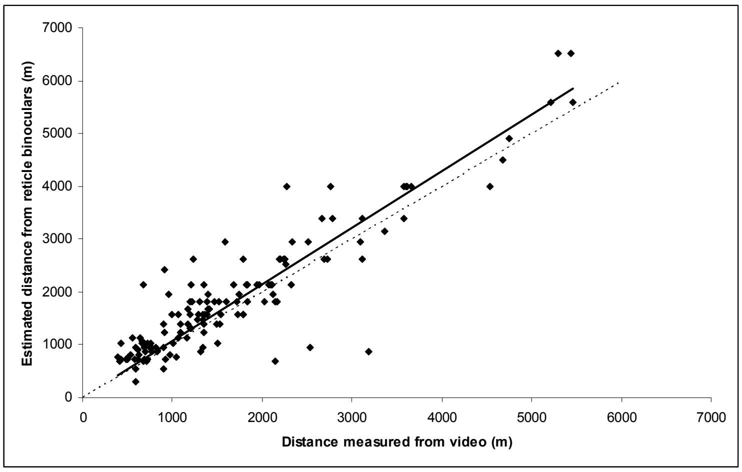

Figure 9. Estimated against measured distances from SCANS-II for Big Eye binoculars. Dotted line indicates no error, solid line indicates fitted linear regression.

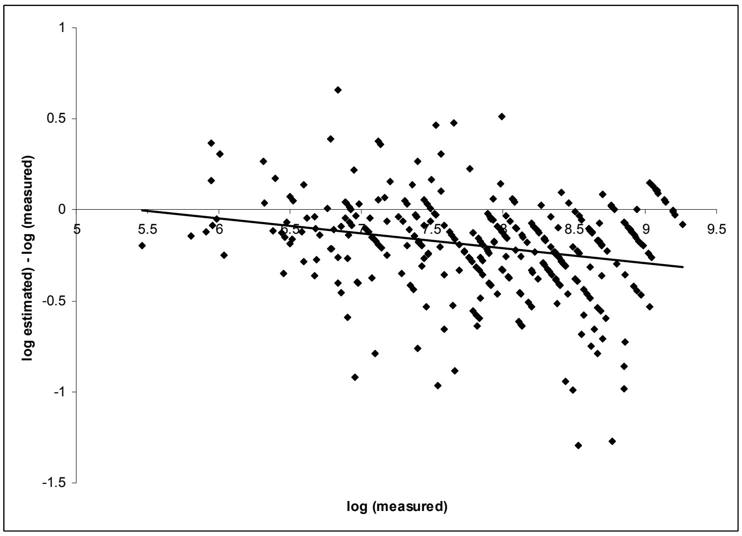

Figure 10. Log(estimated)-log(measured) against Log (measured) distances from CODA. Measured values are distances from video in metres, estimates are from 7x50 reticle binoculars.

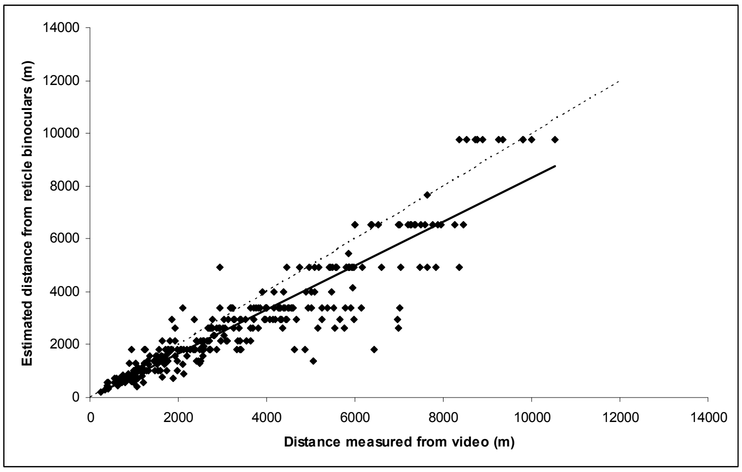

Figure 11. Estimated against measured distances from CODA for 7x50 binoculars. Dotted line indicates no error, solid line indicates fitted linear regression.

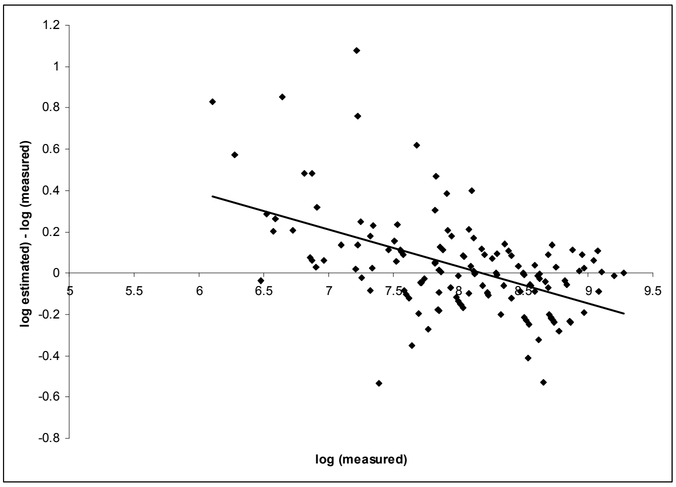

Figure 12. Log(estimated)-log(measured) against Log (measured) distances from CODA. Measured values are distances from video in metres, estimates are from Big Eye reticle binoculars

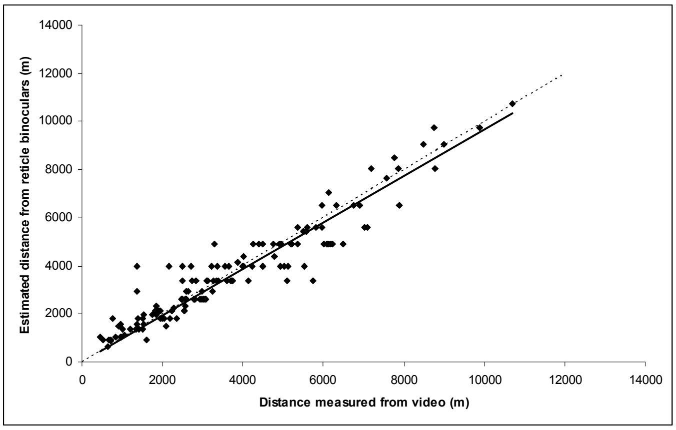

Figure 13. Estimated against measured distances from CODA for Big Eye binoculars. Dotted line indicates no error, solid line indicates fitted linear regression

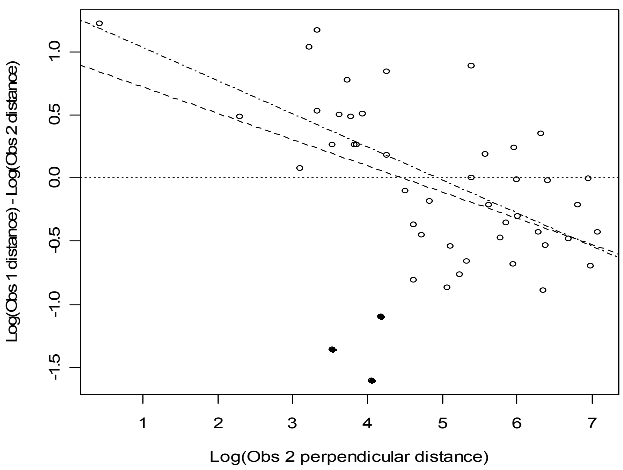

Figure 14. Log(observer1 distance)-log(observer2 distance) against Log (observer2 distance) from simultaneous sightings during SCANS-II. The dashed line is the regression line fitted to all the data and the black dots are the influential points. The dash-dot line is the regression fitted with the influential points excluded.

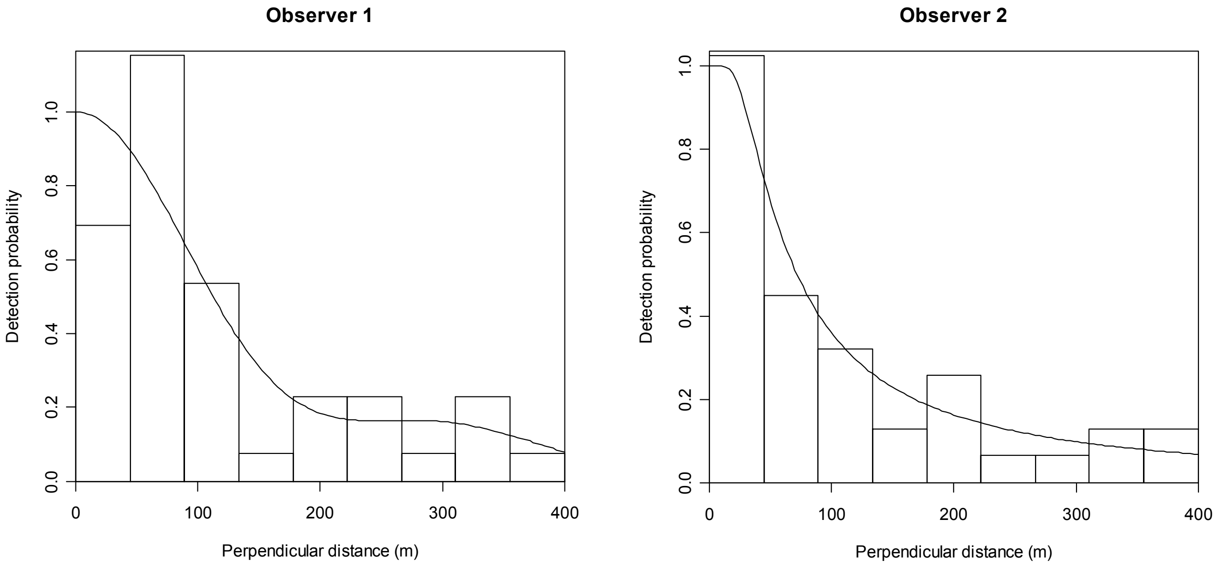

Figure 15. Detection functions fitted to SCANS-II simultaneous sightings.