Analysis of IO and BT search modes on the IWC-SOWER 2007/08 cruise

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ABSTRACT
The 2007/08 IWC-SOWER cruise took place in Area IV between longitudes 105°E to 120°E and from the ice edge upto 180nm from the ice edge. This region was surveyed west to east alternating between IO mode and SS-II mode, and then resurveyed east to west alternating between BT-option 2 mode and SS-II mode. Although one of the main focuses of the cruise was to survey minke whales, there were few sightings of minkes and the most frequently sighted species was humpback whales. This paper summarizes the data collected on these species in IO mode and BT-option 2 mode. Given the small numbers of minkes detected only a crude estimate of abundance for minke whales is presented; a fuller analysis is presented for humpback whales. Using the BT-option 2 mode data, the estimate of minke whales is 1,123 animals (cv=44%). The estimate of humpback whales from the IO mode data is nearly 4,885 animals (cv=20%) which is nearly twice the estimate obtained from the BT-option 2 mode data. This is mainly due to a higher encounter rate obtained in IO mode; sightings from observers on three platforms are included whereas in BT-option 2 mode sightings from only one platform are included.

INTRODUCTION

The 30th annual IWC-SOWER cruise took place between December 2007 and February 2008 in IWC Management Area IV. The main objectives of the cruise were to survey waters (105°E-120°E) outside the pack ice for minke whales and to continue research on other baleen whales. The minke whale research was planned to coincide with an aerial survey of waters mainly inside the pack ice but also overlapping the SOWER research area outside the ice. Unfortunately, the aerial survey was cancelled but the SOWER cruise continued as planned. A systematic survey was conducted west to east throughout the study region alternating IO mode, a standard SOWER search mode, with SS-II mode (closure when abeam). The vessel then covered the region east to west using search modes SS-II and BT-option 2 (Fig. 1). BT-option 2 was a particular configuration of a double-observer survey which combined aspects of mark-recapture and distance sampling (MRDS) to allow the probability of detection to be estimated and hence estimate density without assuming that detection on the trackline is certain. The aim of this analysis was to estimate density and abundance separately for each search mode and compare the results.

Although the focus of the part of the cruise of interest here was on minke whales, there were only a few sightings of this species, but many sightings of humpback whales. Therefore, only simple methods will be used to estimate minke abundance and a fuller comparison of the search modes will be illustrated using humpback sightings.

SURVEY METHODS

Survey design

The study region consisted of two contiguous strata (north and south); the southern stratum extended approximately 60nm north from the ice edge and the northern stratum extended an additional 120nm (i.e. the most northerly boundary was approximately 180nm north of the ice edge). Transects in a zigzag design, as per usual for a SOWER cruise, were planned for the southern stratum but there was insufficient time for a zigzag design to be used in the northern stratum. Therefore, parallel transects aligned north-south were used and these were surveyed in both directions. The vessel travelled west to east covering the region in IO mode and SS-II modes and then resurveyed the area using SS-II mode and BT-option 2 mode.

Search modes

In independent observer (IO) mode (a passing mode so that the vessel doesnot deviate from the trackline) observers were located on the barrel, upper bridge and independent observer platform (IOP). All observers searched with handheld 7x50 binoculars and there was no separation of the regions searched by the observers. In BT-option 2, the observer in the barrel searched with 7x50 binoculars concentrating their search on ±60° either side the trackline and on detecting a minke whale attempted to track it (known as the tracker). The (two) observers on the IOP (known as the primary platform) searched with naked eye. The primary observers searched ±90° either side the trackline and in this variation of BT mode were also instructed to track minke whale sightings until abeam. The upper bridge assisted with tracking animals and classifying duplicates (animals seen by both the barrel and the IOP). The platform configuration is shown in Table 1.

SS-II mode is a passing mode search mode with abeam closure on minke whale sightings to determine group size information and is not considered here.

ANALYSIS METHOD

Several different estimators will be employed to obtain estimates of abundance from the different search mode data.

Conventional distance sampling (CDS)

Conventional distance sampling methodology (Buckland *et al*. 2001) will be used to estimate school abundance from the IO mode data. This method assumes that detection on the trackline is certain (denoted by $g(0)=1$) and sightings from observers on all platforms are used to try and ensure this assumption is fulfilled. The detection function can take either a hazard rate or half-normal form. An estimate of expected school size is used to convert estimated school abundance to an estimate of the number of individual animals (see later).

Mark-recapture distance sampling (MRDS)

MRDS combines a mark-recapture (MR) component to estimate the probability of detection on the trackline and a distance sampling (DS) component to estimate the probability of detection away from the trackline (Borchers *et al*. 1998; 2006). In BT-option 2, the probability of detection for the primary observer is of interest and the role of the tracker is to generate sightings which serve as a set of binary trials in which success corresponds to a detection by the primary (IO) observer. Thus, the probability that an animal is detected by the primary observer is modelled as a logistic function. Sightings of the primary observer are used to estimate the DS component. Borchers *et al*. (2006) called this version of MRDS model, a point independence model – only detections on the trackline (i.e. at point x=0) are assumed to be independent. If there is responsive movement between detection by the tracker and detection by the primary, the DS model of the primary may be unreliable, therefore, detection away from the trackline is also estimated from the MR component – called a full independence model (detections are assumed to be independent at all distances). Explanatory variables, in addition to perpendicular distance, can be included into both components. A Horvitz-Thomson-like (HT) estimator is used to estimate abundance and an estimate of animals is obtained by including observed school size in the HT estimator. The expected school size is obtained from the number of animals divided by the number of schools.

Simple mark-recapture estimator

As with the any estimator, MRDS requires enough sightings and duplicates to be able to fit the components reliably. If the sample size is small, then alternative methods may be used to obtain an estimate of abundance (albeit not the best estimate). A CDS analysis could be undertaken of all unique sightings, possibly making an adjustment for uncertain detections on the trackline. Alternatively, the MR nature of the data could be exploited in a crude estimator of abundance as in Chapman (1951) who defined the number of schools (N_s) as

$$N_s = \frac{A}{2wL}\left(\frac{(n_1+1)(n_2+1)}{(m+1)} - 1\right)$$

The parameter A is the size of the study region, w is the truncation distance, L is the total search effort, n_1 is the number of schools detected by the primary, n_2 is the number of schools detected by the tracker and m is the number of duplicates. This is similar to the Petersen estimator but is less positively biased when the sample size is small (Borchers *et al*. 2002). A simple estimator of primary probability of detection, p_1, is given by

$$p_1 = \frac{m}{n_2}.$$

RESULTS

Sightings and search effort

Due to the ice retreating southwards during the second part of the cruise, the strata surveyed in IO mode were slightly different to those covered in BT-option 2 mode (Figure 1). In IO mode, 601nm of trackline were covered and in BT-option 2, 564nm were covered. Eight minke schools were detected in IO mode and 13 unique schools were detected in BT-option 2 mode (in BT-option 2 mode, any sightings made by the upper bridge were ignored). The most numerous species detected was humpback whales (Table 2). The number of sightings includes species classified as ‘like minke’ and ‘like humpback’ and also ‘undetermined minke’ (see Table 3 for a breakdown of species codes). Both confirmed and unconfirmed school size estimates were used to calculate mean school sizes; there were too few confirmed records to be able to use confirmed school sizes only.

An experiment to investigate any bias in the estimated sighting angles and radial distances was conducted. The perpendicular distances were corrected using the bias factors given in Table 5.

CDS of IO mode data

There were only eight sightings of minke schools; this was too few to be able to fit a model reliably. Therefore, the analysis of this data is not pursued further.

Humpback sightings were truncated at a perpendicular distance of 2.6nm, which excluded approximately 10% of sightings, leaving 77 sightings. The encounter rate was higher in the northern stratum than in the southern stratum (Table 6). AIC (the model selection criterion) suggested that sightings from both strata should be combined to fit a single half-normal detection function (Figure 2). Generally, expected school size, estimated from a regression of log(school size) vs. detection probability, is used to convert group density to animal density. This regression takes into account the fact that at larger distances selectively larger schools are being seen. In this application however, the expected school size was greater than the mean school size. Therefore, the mean school sizes estimated only from sightings detected within 1nm of the trackline were used; it was expected that the whole range of school sizes would be detected within this distance range. This truncation left 23 and 13 sightings in the northern and southern stratum, respectively. The mean school size was greater in the northern stratum than in the southern stratum (Table7a).

The number of humpback schools was estimated to be 3,153 (cv=19.5%) and the number of individuals was 4,885 (cv=19.7%).

Simple mark-recapture estimates of BT-option 2 mode data

There were only 13 unique sightings of minke whales and two duplicates and so the simple MR estimator defined by Chapman (1951) was used to estimate school abundance. An estimate for humpback whales is also given to provide a comparison with the humpback MRDS estimate. Due to the small numbers of minke whale sightings overall and small number of humpback duplicate sightings in the northern stratum, sightings from both strata were combined to produce overall abundance estimates for each species. Truncation distance was taken to be the maximum recorded perpendicular distance (2.76nm for humpback whales and 2.85 for minke whales). Expected school sizes for both species were estimated using the mean school size of all unique sightings within nm (the sample sizes were 9 and 21 for minke and humpback, respectively).

The number of minke groups was estimated to be 532 (cv=31.6%) and the number of individuals was 1,123 (cv=44.1%). The number of humpback groups was estimated to be 1,105 (cv=8.0%) and the number of individuals was 1,895 (cv=12.1%). Density estimates are given for both in Table 7b. The probability of detection for the primary observer at all distances was 0.2 for minke whales and 0.4 (cv=22%) for humpback whales.

MRDS estimates of BT-option 2 mode data

Figure 3 suggested that humpbacks tended to move towards the vessel although caution is required in interpreting the figure since animals moving towards the vessel are more likely to be seen. If there was responsive movement, then the full independence assumption is more viable than the point independence assumption. However, results from both options are provided here. Different explanatory variables were chosen (by AIC) under the different model assumptions: in the full independence option, the final MR model included perpendicular distance and Beaufort sea state (as a factor variable with 3 levels); in the point independence model, the MR component included distance and sightability (a factor variable with two levels describing the general impression for spotting whales) and the DS component included distance and Beaufort sea state (2 levels). The detection functions can be seen in Figure 4.

The probability of detection of humpback schools by the primary observer under the point independence was 0.89 (cv=10.5%) and 0.85 (cv=33.3%) under full independence. The abundance estimates under the point independence were slightly higher with 2,407 animals (cv=51.1%) compared to the 2,294 animals (cv=55.4%) estimated under the full independence assumption (Table 7c).

DISCUSSION

There were not enough sightings of minke whales to be able to analyse the minke whale data comprehensively. Using the BT-option 2 mode data, a crude estimate of primary probability of detection at all perpendicular distances was 0.2. BT-option 2 mode trials had also been conducted during the 2006/07 SOWER cruise (Ensor *et al*., 2007) and using an MRDS methodology the estimates of primary detection probability for minke whales on the trackline on that cruise were 0.31 (cv=49%) and 0.25 (cv=59%) from a full independence model and a point independence model, respectively (Burt *et al*., in prep), with detection decreasing away from the trackline. Given that the crude estimator used here assumed that detection remained constant away from the trackline, the minke whale estimate for the 2007/08 cruise of 1,123 animals (cv=44%) is likely to be a conservative estimate.

Humpbacks were the most frequently sighted species. The lower encounter rates seen in Table 6 for BT-option 2 mode data reflected the fact that only sightings for the primary observers, searching with naked eye, were included, whereas in IO mode sightings from three platforms were included. In IO mode, both the encounter rate and mean school size were higher in the northern stratum than in the southern stratum. In CDS, the probability of detection is assumed to be one, whereas in MRDS it can be estimated. The probability of detection on the trackline for the primary observers, obtained from the BT-option 2 mode data, was close to one, therefore, it does not seem unreasonable to assume that $g(0)$ would be one, or very close to it, in IO mode. Given the higher encounter rate in IO mode, it is not surprising that the overall abundance estimate was twice that of the estimates

obtained from the BT-option 2 mode data. The abundance estimates for the BT-option 2 mode data obtained using both simple MR and MRDS methods were very similar although the variance associated with the simple MR estimator was lower than those associated with the MRDS estimators.

Branch (in prep) used CDS methods to estimate humpback abundance for each IWC Management Area and for each circumpolar (CP) set of surveys. The estimate for CPIII Area IV (70°E – 130°E) was 17,938 animals (cv=18%). Given that only 15° of longitude of Area IV was surveyed in 2007/08, then an estimate of nearly 4,900 whales obtained using similar methods is in line with Branch's estimate.

REFERENCES

Branch, T.A. (in prep) Humpback whale abundance south of 60°S from three complete circumpolar sets of survey. Journal of Cetacean Research Management

Borchers, D.L., Buckland, S.T., Goedhart, P.W., Clarke, E.D. and Hedley, S.L. (1998) Horvitz-Thompson estimators for double-platform line transect surveys. *Biometrics* 54: 1221-1237

Borchers, D.L., Buckland, S.T. and Zucchini, W. (2002) *Estimating Animal Abundance: closed populations*. Springer-Verlag, London

Borchers, D.L., Laake, J.L., Southwell, C. and Paxton, C.G.M. (2006) Accommodating unmodelled heterogeneity in double-observer distance sampling surveys. *Biometrics* 62: 372-378

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. (2001) *Introduction to Distance Sampling*. Oxford University Press, Oxford

Burt, M.L., Ensor, P. and Borchers, D.L. (in prep) Detection probability of Antarctic minke whales: analyses of the BT mode experiments conducted on the IWC-SOWER cruises 2005/06 – 2007/08.

Chapman, D.G. (1951) Some properties of the hypergeometric distribution with applications to zoological censuses. *University of California Publications in Statistics*, 1, 131-160

Ensor, P., Komiya, H., Beasley, I., Kukutome, K., Olsen, P. and Tsuda, Y. (2007) 2006-2007 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) cruise. Unpublished. Presented to the IWC SC meeting, Anchorage, document SC/59/IA1.

Ensor, P., Minami, K., Morse, L., Olson, P. and Sekiguchi, K. (2008) 2007-2008 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) cruise. Unpublished. Presented to the IWC SC meeting, Santiago, document SC/60/IA1.

Laake, J.L. and Borchers, D.L. (2004) Methods for incomplete detection at distance zero. In Buckland, S.T., Anderson D.R., Burnham, K.P, Laake, J.L., Borchers, D.L. and Thomas, L. (eds) *Advanced Distance Sampling*. Oxford University Press, Oxford.

Table 1 Platform configuration for IO mode and BT-option 2.

Search mode	Platform	Binoculars	No. of observers
IO mode	Barrel	7x50	2
	Upper bridge	7x50	5
	IOP	7x50	1
BT- option 2	Barrel (tracker)	7x50	2
	Upper bridge (assistant tracker)	7x50	5
	IOP (primary)	Naked eye	2

Table 2 Size of strata, amount of search effort (*L*) and the total number of unique sightings (i.e. duplicate sightings are excluded). In IO mode, sightings from platforms 1, 2 and 3 are included; in BT-option 2 only sightings from platforms 1 and 2 are included. See table 3 for a breakdown of species codes included.

Search mode	Strata	Size (nm^2)	*L* (nm)	Minke	Humpback
IO mode	North	52 887	321.7		53
	South	28 995	279.2		35
	Total	**81 882**	**600.9**	**8**	**88**
BT- option 2	North	54 797	272.9		9
	South	26 652	291.3		29
	Total	**81 449**	**564.2**	**13**	**38**

Table 3 Number of unique sightings recorded for each species code.

Species	Minke schools			Humpback schools	
Search mode	Minke (04)	Undetermined minke (91)	Like minke (39)	Humpback (07)	Like humpback (71)
IO	4	1	3	87	1
BT-option 2	9	1	3	36	2

Table 4 Sightings by platform and school size recoded in BT-option 2. The maximum school size of minke schools was 15 animals.

School size	Minke schools			Humpback schools		
	Primary (2)	Tracker (1)	Duplicates (1:2)	Primary (2)	Tracker (1)	Duplicates (1:2)
1	3	2		5	16	5
2		2		10	17	8
3	2	1		2	2	1
4		2	2			
>=5		3				
Total	**5**	**10**	**2**	**17**	**35**	**14**

Table 5 Bias correction factors for each platform. A dash indicates no correction was necessary.

Platform	Number of trials	Angle bias factor	Distance bias factor
1: Barrel	36	0.934	1.056
2: IOP	36	-	1.045
2: IOP naked eye	30	1.066	1.084
3+4: Upper bridge	36	-	1.102

Table 6 Sightings rates (*n*/*L*) of humpback whale schools (schools/nm). In IO mode, sightings are truncated at 2.6nm and at 2.76nm in BT-option 2. The parameter *k* is the number of transects, *L* is effort and *n* is the number of sightings. In BT-option 2 mode, the sightings are for the primary observer only. Coefficients of variation are given in parentheses and expressed as a percentage.

Search mode	Stratum	*k*	*L* (nm)	*n*	*n*/*L*
IO mode	North	3	321.7	46	0.1430 (10.5)
	South	8	279.2	31	0.1110 (47.6)
	Total	11	600.9	77	0.1281 (24.2)
BT-option 2	North	3	272.9	3	0.0110 (46.2)
	South	8	291.3	14	0.0481 (38.0)
	Total	11	564.2	17	0.0301 (41.6)

Table 7 Abundance estimates for humpbacks (unless specified otherwise) using a) CDS of IO mode data, b) a simple MR estimator and c) MRDS of BT-option 2 mode data. The columns (common to all tables) are school density, D_s, school abundance, N_s, animal density, D, and animal abundance, N. Other columns are described below. Coefficients of variation are given in parentheses and expressed as a percentage.

a) CDS analysis of IO mode data. The *esw* is the effective strip half-width and $\bar{s}$ is the mean school size of all sightings within 1nm.

Stratum	*esw*	$\bar{s}$	D_s	N_s	D	N
North	1.71 (11.0)	1.65 (9.8)	0.0418 (15.2)	2 212 (15.2)	0.0691 (18.1)	3 654 (18.1)
South		1.31 (10.2)	0.0325 (48.9)	942 (48.9)	0.0425 (50.0)	1 231 (50.0)
All		1.52 (7.6)	0.0385 (19.5)	**3 153** (19.5)	0.0597 (19.7)	**4 885** (19.7)

b) Simple MR estimate of BT-option 2 mode data. The truncation distance is denoted by w, p_1 is the probability of detection by the primary observer and $\bar{s}$ is the mean school size of all sightings within 1nm.

Species	w (nm)	p_1	$\bar{s}$	N_s	N
Humpback	2.76	0.4 (21.7)	1.71 (9.1)	**1 105** (7.98)	**1 895** (12.3)
Minke	2.85	0.2	2.11 (30.8)	**532** (31.6)	**1 123** (44.1)

c) MRDS estimate of BT-option 2 mode. The parameter $p_1(0)$ is the probability of detection on the trackline for the primary observer and $E[s]$ is the expected school size.

Assumption	Stratum	$p_1(0)$	D_s	N_s	D	N	$E[s]$
Point	North	0.89 (10.5)	0.0086 (106.9)	473 (106.9)	0.0086 (106.9)	473 (106.9)	1.00 (0.0)
	South		0.0370 (48.3)	989 (48.3)	0.0726 (54.1)	1 934 (54.1)	1.96 (11.9)
	Total		0.0179 (50.9)	**1 459** (50.9)	0.0296 (51.1)	**2 407** (51.1)	1.65 (17.7)
Full	North	0.85 (33.3)	0.0098 (108.3)	539 (108.3)	0.0098 (108.3)	539 (108.3)	1.00 (0.0)
	South		0.0329 (51.5)	878 (51.5)	0.0658 (58.9)	1 754 (58.9)	2.00 (12.9)
	Total		0.0174 (55.9)	**1 417** (55.9)	0.0282 (55.4)	**2 293** (55.4)	1.62 (19.8)

Figure 1 Stratum boundaries (N=North and S=South) and survey effort. The strata were surveyed going west to east using IO mode and then east to west in BT-option 2 mode. The thick lines indicate the tracklines covered in the two search modes. The line along the bottom of the southern stratum is the ice edge.

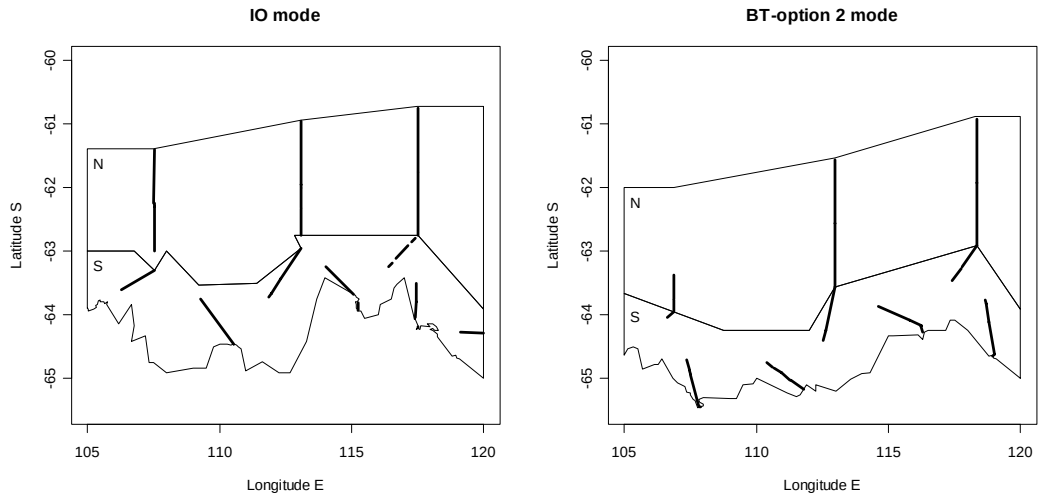


Figure 2 Distribution of perpendicular distances of all sightings from the IO mode data for humpback whales and fitted half-normal detection function.

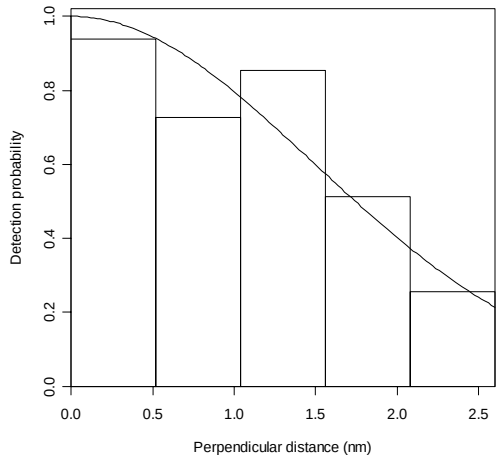


Figure 3 Perpendicular distances of duplicate humpback whale sightings seen by the tracker (*y*-axis) and then by the primary (*x*-axis).

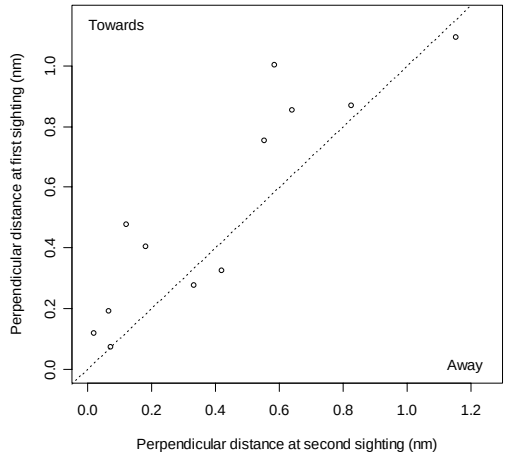
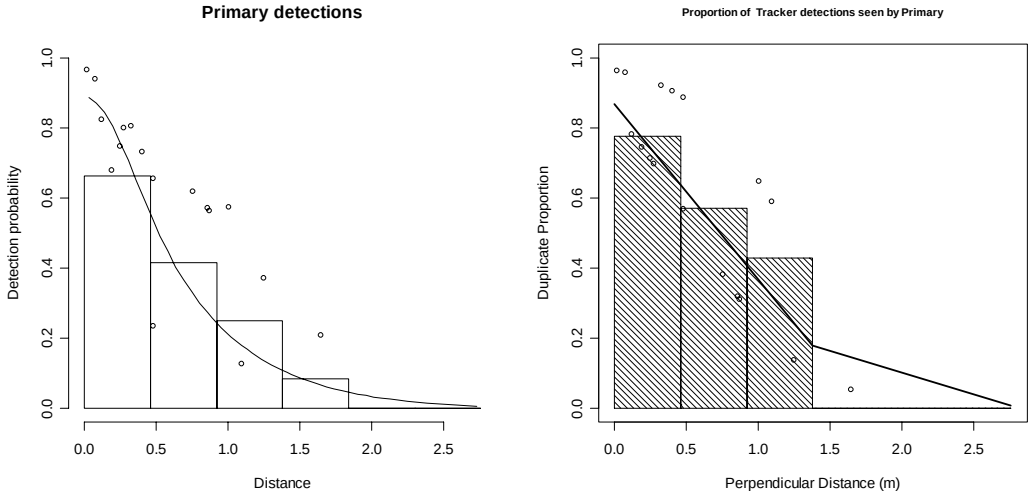
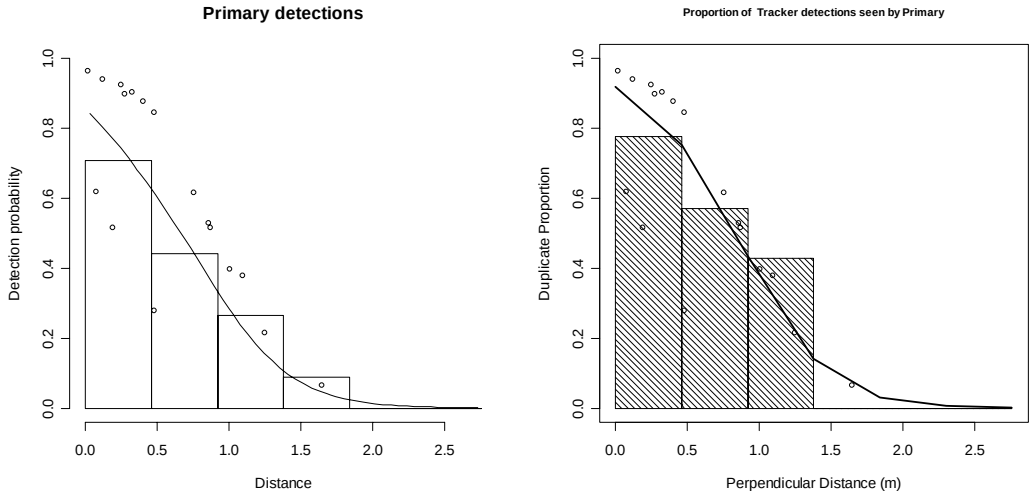


Figure 4 MRDS detection functions from the BT-option 2 mode data for humpback whales. The 'Primary detections' plots show the distribution of perpendicular distances for primary observers superimposed with the fitted detection function. The 'Proportion of tracker detections seen by primary' show the proportion of duplicate sightings for each distance bin superimposed with the MR model.

a) Point independence model



b) Full independence model