Antarctic minke whale abundance from the SPLINTR model: some 'reference' dataset results and 'preferred' estimates from the second and third circumpolar IDCR/SOWER surveys

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ABSTRACT

Using a customized modelling approach for spatial modelling of the IDCR/SOWER data (the 'SPLINTR' model), the 'survey-once' abundance estimate of Antarctic minke whales (*Balaenoptera bonaerensis*) from the second (CP2) circumpolar series is estimated as 787,000; for the third series (CP3), estimated abundance is substantially lower at 382,000. With the exception of the 2003/04 Ross Sea survey, we fit a single model to each annual survey to obtain abundance. For the 2003/04 survey, during which time the configuration of the pack ice in the survey region changed considerably, we fit two models to attempt to account for the spatio-temporal discontinuities in effort and sightings. To aid and facilitate comparisons of estimates from other methods such as the OK model (Okamura and Kitakado, 2009), we also compare estimates between a non-spatial version of SPLINTR and the fully spatial version, finding evidence supporting the need for a spatial modelling approach for analysing these data, particularly for CP2 when trackline coverage in the southern stratum was not always ideal for stratified estimation. For our preferred estimates, some post-processing of the data was undertaken. The effects of this processing is also discussed in this paper and is found to reduce abundance estimates on average by 2-3%, compared with estimates using data not post-processed in this way.

KEYWORDS: ANTARCTIC MINKE WHALE; MODELLING; SOWER; SOUTHERN OCEAN; ABUNDANCE ESTIMATE; SCHOOL SIZE; SURVEY – VESSEL.

INTRODUCTION

This paper presents an update of results and estimates from applying the SPLINTR model to the second and third circumpolar IWC-IDCR/SOWER surveys (CP2 and CP3). The SPLINTR model assumes Trackline Conditional Independence (or 'point' independence; Laake and Borchers, 2004) to estimate $g(0)$, and estimation of effective strip widths are based on perpendicular distances; the sighting, not the cue, is treated as treated as the unit of observation. Since these parameters depend on school size, and true school sizes are usually unknown for IO mode, school size error models have been developed to handle errors in recorded school sizes. These two components of the model are estimated in tandem – they depend on each other – and then school encounter rate is modelled using a spatial soap-film model designed for regions which may be topographically complex (Wood *et al.*, 2008), but which also accommodates local clustering via a Markov-modulated Poisson process (MMPP; Skaug, 2006). Fuller model details are given in Bravington and Hedley (2009).

At SC61, the two sets of analyses (the SPLINTR analysis referred to above, and those from the OK model of Okamura and Kitakado (2009)) yielded substantially different abundance estimates. Alongside progress made intersessionally in developing a 'Reference dataset' for the two models to use, which as far as possible, was identical, we have also implemented a non-spatial SPLINTR model this year in order to further elucidate the results. Bizarre though this may seem, it was rather difficult to remove the spatial complexities from SPLINTR, but in theory at least, the non-spatial SPLINTR should allow some direct comparisons in modelling sighting parameters between OK and SPLINTR. Since these results are for model comparisons only, they are only presented for the reference dataset.

Our 'preferred' analysis is one in which we slightly adapt the transect lengths to accommodate the true distance searched by the observers. For example, if effort were to begin on a transect, and a sighting is made virtually instantaneously (and then say, the vessel went off effort again), then it is in our view incorrect to allocate only the distance travelled by the vessel in those few seconds as the 'effort associated with that sighting'. Rather, the vessel has travelled that distance along the transect line *and* an area has been searched ahead of the vessel. We have adopted a post-processing stage in the data analysis to better represent such occurrences in which effort was modified by extending such transect legs by half of the mean forward sighting distance. Furthermore, the inclusion of the MMPP component of SPLINTR meant that this processing was a pragmatic solution which avoided the need to reset the MMPP parameter estimates at every single – often very small – break in effort. This post-processing was previously applied in the SPLINTR modelling of the IWC simulated datasets (see, for example, Palka, 2010) apparently without causing significant bias in abundance, but the number of breaks in transect effort in the simulated data is in general fewer than in the IDCR/SOWER data, so its

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effect has not been fully tested. This non-standard treatment is therefore further examined by applying the non-spatial SPLINTR model to the post-processed data.

Finally, the post-processed data are analysed using the spatial version of SPLINTR developed specifically to address the complexities of the IDCR/SOWER data. Together with estimation of g(0) – and in some cases linked to its estimation – these complexities include:

i. the average school size varies in space (even within the designed strata), and has reputedly decreased over the decades during which the surveys have been conducted;

ii. the density of schools varies in space (even within the designed strata), in a way that is correlated with average school size;

iii. the average sighting conditions vary in space (even within the design strata), in a way that is correlated both with average school size and with school density. Near the ice edge, conditions tend to be better, schools tend to be larger, and density is higher. This means that non-covariate-based estimates of, e.g. effective strip width, based on all observations are biased towards conditions close to the ice, where more sightings happen to be made because of better weather;

iv. the coverage within a stratum is often very uneven despite good intentions in the survey design, because weather cannot be controlled for, and the ice edge location is highly variable in some regions;

v. linked to (iv) above, existing line transect spatial model-based approaches (e.g. Hedley and Buckland, 2004) that could be applied when design-based estimates might be considered unreasonable, in practice suffer from the following issues of their own:

   - where survey coverage is poor near the edge of the survey region, particularly towards the corners, typical smoothers tend to extrapolate linearly. This is biologically unreasonable and since smoothers typically describe log-abundance rather than abundance, any increasing linear trend has a disproportionate impact on the abundance estimate, resulting in positively biased , imprecise estimates.
   - where there are complex survey boundaries, e.g. where a narrow peninsula of ice or land sticks out into the middle of a body of water, data from on side of the peninsula will leak across to the other side of the peninsula because the two sections of water are close by a simple distance metric (‘as the crow flies’) – but not by a more reasonable biological distance metric (‘as the whale swims’).

vi. *g*(0) and nominal[1] effective strip widths depend strongly on school size (as well as sighting conditions). In IO mode, *g*(0) could be estimated from the independent platforms, except that school size is frequently underestimated in IO mode;

vii. in Closing mode, school size is reliable, but there is no independent-platform data to estimate *g*(0);

viii. a different combination of platforms operate in IO and Closing modes. Platform C is one-way dependent in IO mode (so there are no data to determine whether Platform C would have seen a school initially sighted by A or B), and in Closing mode, the platforms are not independent at all (closure begins immediately upon a school being sighted – there are no data on whether the other platform – A or C – would have eventually seen the school);

ix. the data records do not include independent estimates of school size or identification of species by platform. Rather they are a ‘joint effort’ between observers on the platforms that sighted the school;

x. there were changes over time in observer habits and experience (Mori *et al.*, 2003), and in platform setup – considerable structural modifications were made to the *Shonan Maru* platforms preceeding the 1998/99 survey, a new IOP platform was installed on the *Shonan Maru No. 2* at the same time, and further modifications were made to her prior to the 1999/2000 survey (Matsuoka *et al.*, 2003);

xi. schools are somewhat clumped spatially, on a small scale.

RESULTS

Effect of ‘pre-extending’ transect legs

Post-processing of the dataset by extending some transect segments (by half of the mean forward sighting distance) was examined using the non-spatial (or stratified) version of SPLINTR. As far as possible, this version mimicked the modelling in the OK model, so that mean school sizes were estimated by stratum but were also allowed to vary with distance-from-ice-edge and flat density surfaces were estimated for each stratum. Thus, differences between the two would be attributed to either differences in modelling sighting probabilities (cue-based radial distance and angle versus whale-based perpendicular distance, assuming TLCI), differences in the school size distribution model, or differences in the school size error model. Results from comparing non-spatial SPLINTR with the

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[1] Nominal effective strip width, i.e. unadjusted for *g*(0)<1.

OK model are presented elsewhere (Hans' IAWP ??). Results from adapting the transect legs in this way (using non-spatial SPLINTR) are as follows:

- for CP2, estimates by stratum were reduced by up to 3.8% in the WN stratum in 1990/91, with mean 2.3%;
- for CP3, the biggest reduction in abundance was by 5.2% in the 2003/04 N1 stratum, with mean 3.3%.

Comparison of non-spatial SPLINTR and SPLINTR

The post-processed data were also used to examine differences in estimates from applying the non-spatial SPLINTR to the fully spatial SPLINTR. Total circumpolar estimates (not corrected for 'survey-once') were some 9.9% lower (730,000 vs. 658,000) in CP2 using SPLINTR; in CP3, the difference was smaller at 6.6% (423,000 vs. 453,000). Interestingly, it is clear from a scatterplot of the estimates that for CP2, estimates in the southern strata were generally higher when for non-spatial SPLINTR (Figure 2a). This is not evident for CP3 (Figure 2b). Therefore, although the difference in total circumpolar abundance estimates is less than 10% between the spatial and non-spatial versions, the spatial SPLINTR model appears to have consistently adjusted for the poorer coverage in (particularly the southern strata of) CP2, e.g. incidences of effort running along the ice edge.

Spatial analysis of CP2 and CP3 data using SPLINTR

There have been no changes to the SPLINTR model structure since SC61 – indeed the results from CP2 are the same as last year. Our principle concern with last year's results was due to a lack-of-fit to the model for the analysis of the 2003/04 Ross Sea survey, s Tpecifically a large excess of predicted schools sighted compared with the observed values... In the event, closer inspection of the ice recession evident during the course of that survey (and the consequential spatial and temporal distribution of search effort and sightings) revealed a large discontinuity in the spatial surface for which a single smooth surface is clearly inappropriate. Attempts to model this as a single surface as in Bravington and Hedley (2009) had forced the MMPP component of the model to work hard to attempt to represent this phenomenon, but despite this lack-of-fit was evident. We have therefore analysed the 2003/04 survey using two separate spatial models, to attempt to accommodate the ice melt and consequential movement of the 'ice-edge'. (Figure 1). We have not fully considered any aspects of this modelling approach in terms of minke whale migration and movement. In doing so, it transpired that variation in school density could be well-modelled for all surveys in CP3 by the soap-film smoothers, without recourse to invoke the local clustering component of SPLINTR. This is in contrast to the analysis of the CP2 surveys, for which local clustering was evident. Whether spatial variation in density is represented simply as a spatial smooth, or as a spatial smooth with clustering makes little difference to the point estimates of abundance on scales larger than the knot spacing for the smooths (90 nmiles).

Whale density maps by survey are given in Figures 3 and 4; results are tabulated in Tables 1-4. Note, however, that we have not yet run the Additional Variance code, which will inflate CVs substantially.

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Table 1. Estimates of g(0) and ESW by conditions, platform, and CP series.

(a) CP2, Beaufort (Good=0-2, Bad=3+)

		1	2	3-4	5-9	10+
	g0A	0.27	0.56	0.69	0.72	0.81
Good	g0B	0.13	0.34	0.48	0.50	0.64
	g0C	0.32	0.60	0.72	0.74	0.83
	ESW	0.33	0.69	0.89	1.03	1.30

		1	2	3-4	5-9	10+
	g0A	0.26	0.39	0.62	0.65	0.74
Bad	g0B	0.12	0.20	0.39	0.43	0.53
	g0C	0.31	0.44	0.65	0.68	0.76
	ESW	0.29	0.46	0.65	0.69	1.04

(b) CP3, Sightability (2=Poor,3=Fair,4+=Good or better)

		1	2	3-4	5-9	10+
	g0A	0.13	0.38	0.53	0.59	0.65
Sig2	g0B	0.06	0.19	0.31	0.36	0.42
	g0C	0.16	0.44	0.59	0.65	0.71
	ESW	0.17	0.63	0.77	0.82	0.99

		1	2	3-4	5-9	10+
	g0A	0.33	0.40	0.67	0.72	0.80
Sig3	g0B	0.16	0.20	0.44	0.49	0.61
	g0C	0.38	0.46	0.71	0.75	0.84
	ESW	0.43	0.66	0.84	0.89	1.43

		1	2	3-4	5-9	10+
	g0A	0.41	0.55	0.68	0.73	0.81
Sig4+	g0B	0.21	0.32	0.45	0.50	0.63
	g0C	0.46	0.60	0.72	0.77	0.85
	ESW	0.51	0.78	0.98	1.02	1.46

Table 2. Estimates by AVB block, without Common Northern Boundary. No process error

	1986	1987	1988	1989	1990	1991	Y1993	Y1994	Y1995	Y1996	Y1997	Y1998	Y1999	Y2000	Y2001	Y2002	Y2003	Y2004
1W					24,200										21,400			
					0.41										0.22			
1M					63,600			22,800										
					0.23			0.17										
1E					29,100			35,100						6,960				
					0.26			0.27						0.29				
2W		26,400										24,800						
		0.23										0.17						
2E		115,000									34,800							
		0.26									0.25							
3W			80,600				33,100											
			0.54				0.13											
3E			6,560				9		25,900									
			0.50				1.13		0.17									
4W				23,400					12,900									
				0.18					0.18									
4E				37,200									22,800					
				0.24									0.18					
5W	41,000															13,700		
	0.38															0.18		
5M	80,200																30,900	
	0.15																0.24	
5E	161,000																	89,700
	0.21																	0.14
6W						25,500				34,800								
						0.24				0.18								
6E						33,900												
						0.36												

Table 3. Estimates by original SOWER stratum. *MA*=Management Area; *cpsurv*=CP2 or CP3; *strat*=stratum; *totarea* =stratum area in n.mile^2; *n.io*=number of sightings after truncation at 1.5nmiles; *L.io*=IO effort in nmiles; *mss*=mean true school size; esw_s = 1.5*P[seeing a randomly-chosen school within 1.5nmile of transect]; *abund*=estimated whale abundance.

MA	*cpsurv*	*strat.yr*	*strat*	*totarea*	*n.io*	*L.io*	*mss*	*esw_s*	*abund*
A1	CP2	1986	ES	107,000	156	609	2.37	0.50	51,400
		1990	EN	155,000	59	761	1.67	0.43	22,300
			ESBA	62,800	70	819	1.89	0.39	14,200
			WN	167,000	35	569	1.73	0.35	29,700
			WS	43,400	212	829	2.03	0.46	17,100
	CP3	1994	EN	297,000	16	760	1.28	0.56	21,600
			ES	71,400	82	556	1.76	0.49	18,000
			WN	249,000	9	467	1.13	0.36	7,820
			WS	52,200	80	571	1.61	0.60	8,490
		2000	EN	58,800	9	242	1.55	0.56	3,320
			ES	24,600	9	174	1.61	0.46	1,740
			WN	110,000	2	302	1.48	0.42	1,240
			WS	20,500	5	253	1.40	0.57	484
		2001	EN	127,000	2	381	1.76	0.59	1,820
			ES	29,400	17	309	2.95	0.56	3,910
A2	CP2	1987	EBAY	13,600	40	125	2.30	0.52	8,350
			EM	69,000	74	438	3.25	0.51	24,100
			EN	125,000	36	328	3.25	0.50	38,500
			ES1	22,800	20	283	2.11	0.42	5,650
			ES2	43,300	110	711	2.47	0.46	16,400
			WBAY	9,550	11	33	2.32	0.39	2,700
			WN	94,000	2	203	1.62	0.31	9,920
			WS1	8,450	13	86	2.35	0.43	2,560
			WS2	21,700	5	221	1.77	0.40	1,880
			WS3	76,000	82	815	1.73	0.43	13,800
	CP3	1997	EN	243,000	24	678	1.35	0.38	15,300
			ES	51,700	37	687	1.63	0.69	4,120
			WN	113,000	8	198	1.45	0.41	10,800
			WS	23,800	39	240	1.66	0.53	4,150
		1998	EN1	86,100	9	358	1.26	0.44	4,250
			EN2	80,200	7	267	1.34	0.47	3,820
			ES1	46,900	47	391	1.68	0.50	10,900
			ES2	10,200	24	145	1.74	0.67	2,610
			WN	53,400	5	257	1.40	0.44	1,180
			WS	33,500	1	276	1.51	0.58	594
		2000	ENA	7,080	0	35	1.47	0.37	98
			ESA	6,200	0	56	1.57	0.41	126
		2004	AN1	125,000	4	145	1.26	0.38	5,910
			BROSS	55,400	127	533	1.50	0.53	16,800
A3	CP2	1986	EM	163,000	183	1061	1.78	0.38	70,200
		1988	ENS	257,000	8	504	1.34	0.39	8,160
			WNS	221,000	120	497	2.31	0.50	55,600
	CP3	1993	EN	149,000	9	577	1.72	0.47	3,790
			ES	22,800	18	441	2.23	0.72	1,650
			WN	208,000	34	710	1.83	0.61	10,300

Table 3. …continued.

MA	*cpsurv*	*strat.yr*	*strat*	*totarea*	*n.io*	*L.io*	*mss*	*esw_s*	*abund*
			WS	61,200	146	916	1.81	0.51	16,100
		1995	ENW	70,600	17	328	1.19	0.57	2,960
			ESW	32,800	31	240	1.63	0.47	7,970
			WN	149,000	19	448	1.28	0.39	8,360
			WS	52,700	43	514	1.66	0.65	5,920
		2003	ES	127,000	38	550	1.33	0.64	10,400
		2004	BMID	129,000	222	907	2.24	0.67	49,700
			AN2	94,100	24	271	1.38	0.56	10,600
A4	CP2	1986	EN	277,000	68	844	1.59	0.40	54,900
		1989	BN	17,200	28	413	2.57	0.48	9,410
			BS	7,120	49	147	2.68	0.45	5,930
			EN	180,000	16	597	1.52	0.33	13,200
			ES	53,400	49	255	2.01	0.49	10,700
			WN	156,000	5	726	2.05	0.44	7,290
			WS	60,300	20	240	2.00	0.34	11,100
	CP3	1995	ENE	78,600	5	307	1.23	0.55	2,020
			ESE	26,000	11	217	1.50	0.43	4,180
			PRYD	20,700	47	201	1.29	0.41	6,320
		1999	EN	171,000	21	577	1.12	0.47	4,970
			ES	69,700	34	705	1.27	0.38	5,750
			WN	107,000	26	369	1.32	0.47	6,120
			WS	42,000	29	452	1.81	0.58	5,280
		2003	EN	137,000	16	550	1.21	0.40	5,170
		2004	AN3	15,100	40	113	1.98	0.66	7,260
A5	CP2	1986	WM	168,000	50	479	1.84	0.36	46,400
			WN	140,000	58	360	1.49	0.41	22,900
			WS	98,500	93	615	1.86	0.47	30,700
	CP3	2002	EN	82,600	4	303	1.34	0.40	2,050
			ES	36,200	38	234	1.45	0.59	5,630
			WN	47,500	4	188	1.46	0.45	1,220
			WS	35,300	25	291	1.64	0.58	5,140
		2003	W1N	75,800	23	240	1.41	0.41	9,630
			W1S	22,200	25	235	2.17	0.68	3,590
			W2N	100,000	13	289	1.38	0.57	12,100
			W2S	21,600	18	243	1.94	0.50	3,800
A6	CP2	1991	EN	192,000	22	448	1.75	0.35	22,600
			ES	108,000	25	457	1.47	0.41	9,160
			WN	214,000	17	525	1.73	0.42	15,200
			WS	44,400	40	637	2.07	0.41	5,400
	CP3	1996	EN	242,000	31	551	1.63	0.62	17,000
			ES	72,400	40	543	1.30	0.41	8,580
			WN	97,800	13	286	1.47	0.35	7,920
			WS	34,500	5	327	1.60	0.61	1,050
		2001	WN	252,000	18	468	1.49	0.53	14,000
			WS	43,700	48	411	1.74	0.63	7,010

Table 4. ``Survey-once'' estimates, without CNB

		MA1	MA2	MA3	MA4	MA5	MA6	Total
CP2	abund	117,000	141,000	87,200	60,700	282,000	59,400	747,000
	CV	0.22	0.23	0.51	0.18	0.15	0.25	0.13
CP3	abund	34,800	55,900	59,300	36,000	140,000	56,600	382,000
	CV	0.14	0.17	0.11	0.14	0.11	0.14	0.09

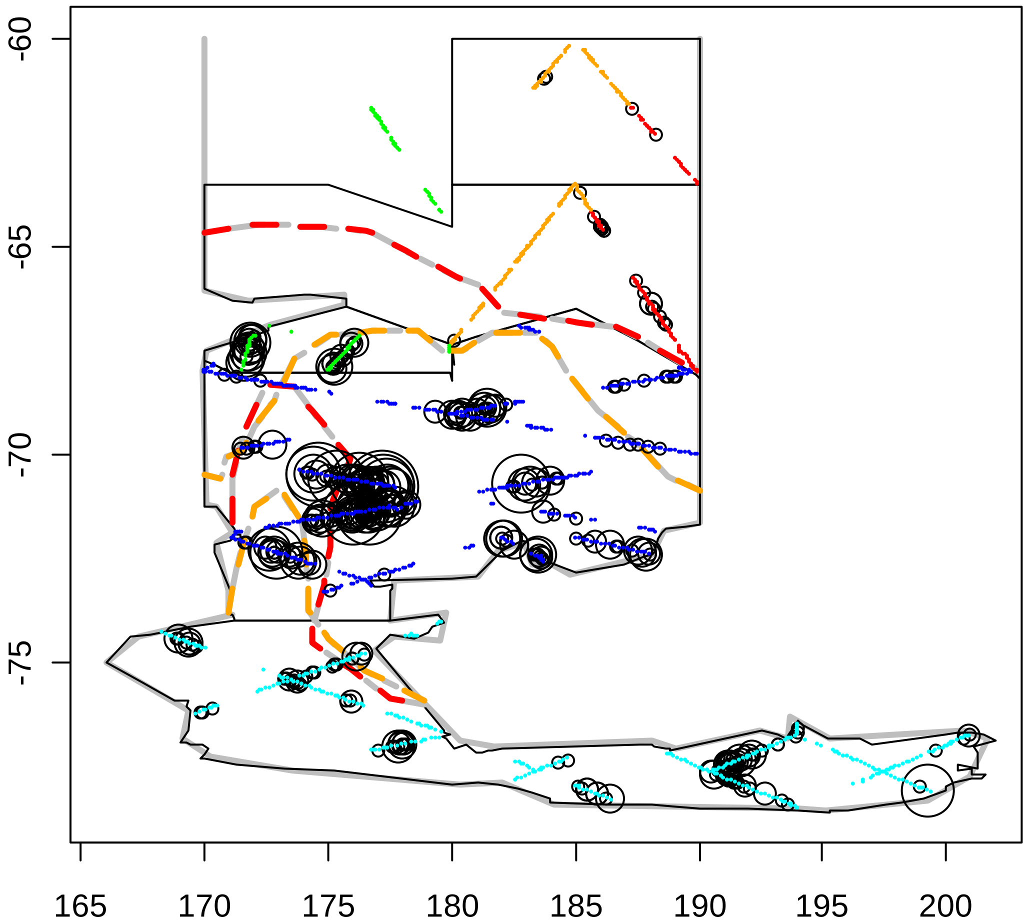

Figure 1: Sightings, IO effort and approximate ice edge from 2003/04 survey. Sightings are plotted as open circles and are scaled according to recorded school sizes. Red-grey dashed line denotes approximate ice edge location when the Ross Sea was 'closed' (but note polynya in the south) from 28/12/03 satellite image in Ensor *et al* (2004). Orange-grey dashed line is corresponding location on 10/01/04. Effort is shown corresponding to dates surveyed. Red=27-31 Dec; Orange=4-8 Jan; Green=9-19 Jan; Cyan=28 Jan-5 Feb; Blue=5-28 Feb.

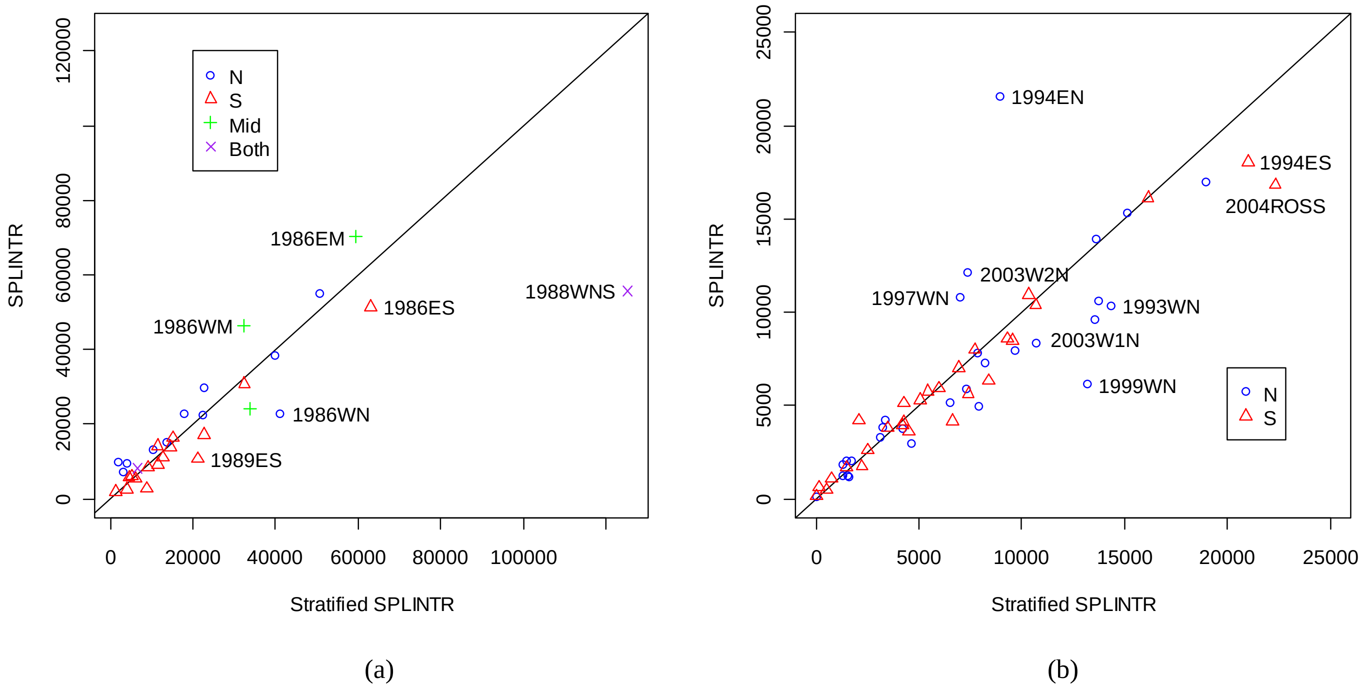

Figure 2: Abundance estimates by stratum for post-processed IDCR/SOWER data, calculated using non-spatial and fully spatial SPLINTR models. (a) CP2 estimates; (b) CP3 estimates, excluding value for stratum 2004MID (P=58,300 for non-spatial and P=49,700 for SPLINTR).

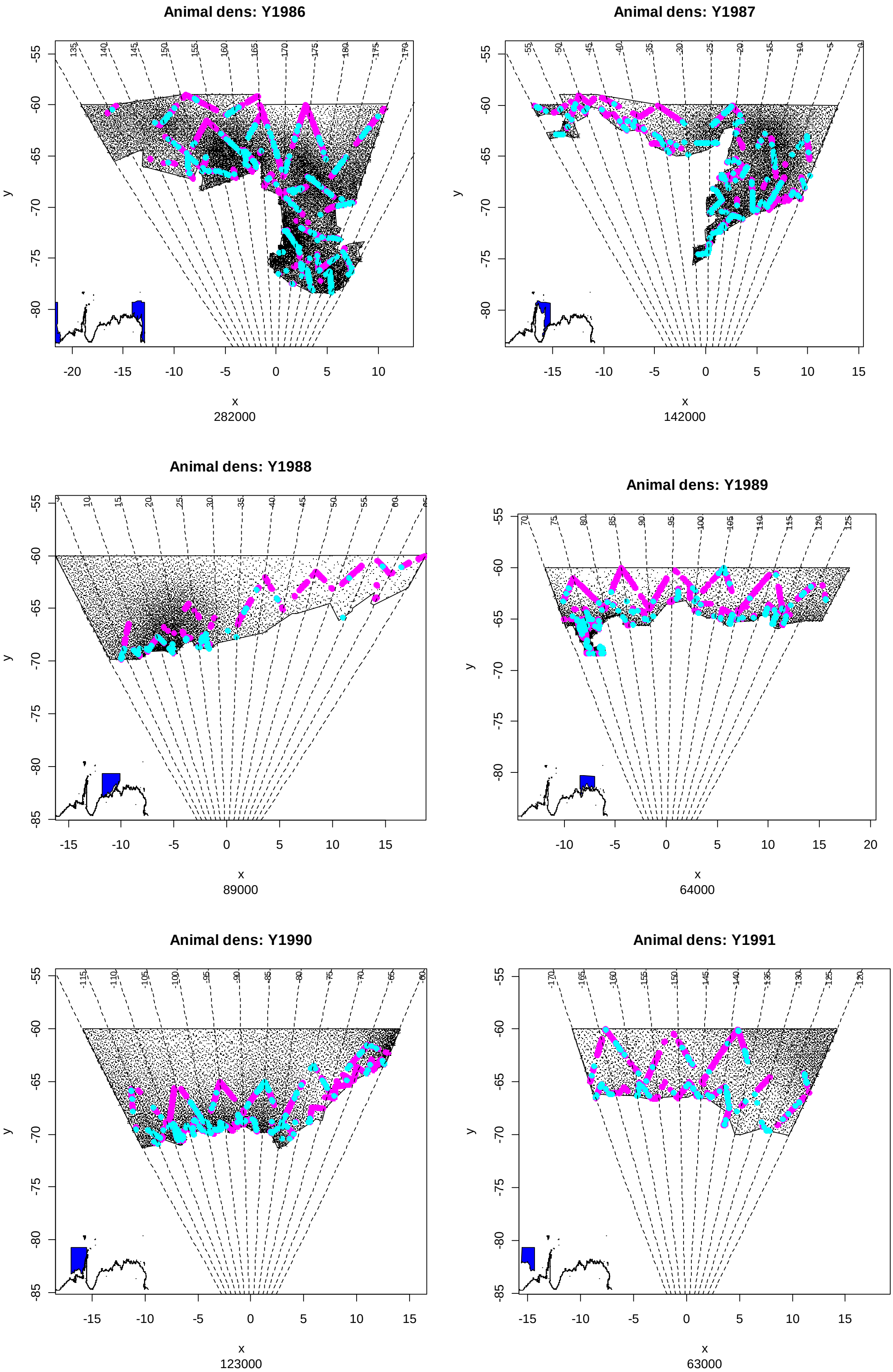

Figure 3: Estimated whale density by survey for CP2. 1 dot=100 whales.

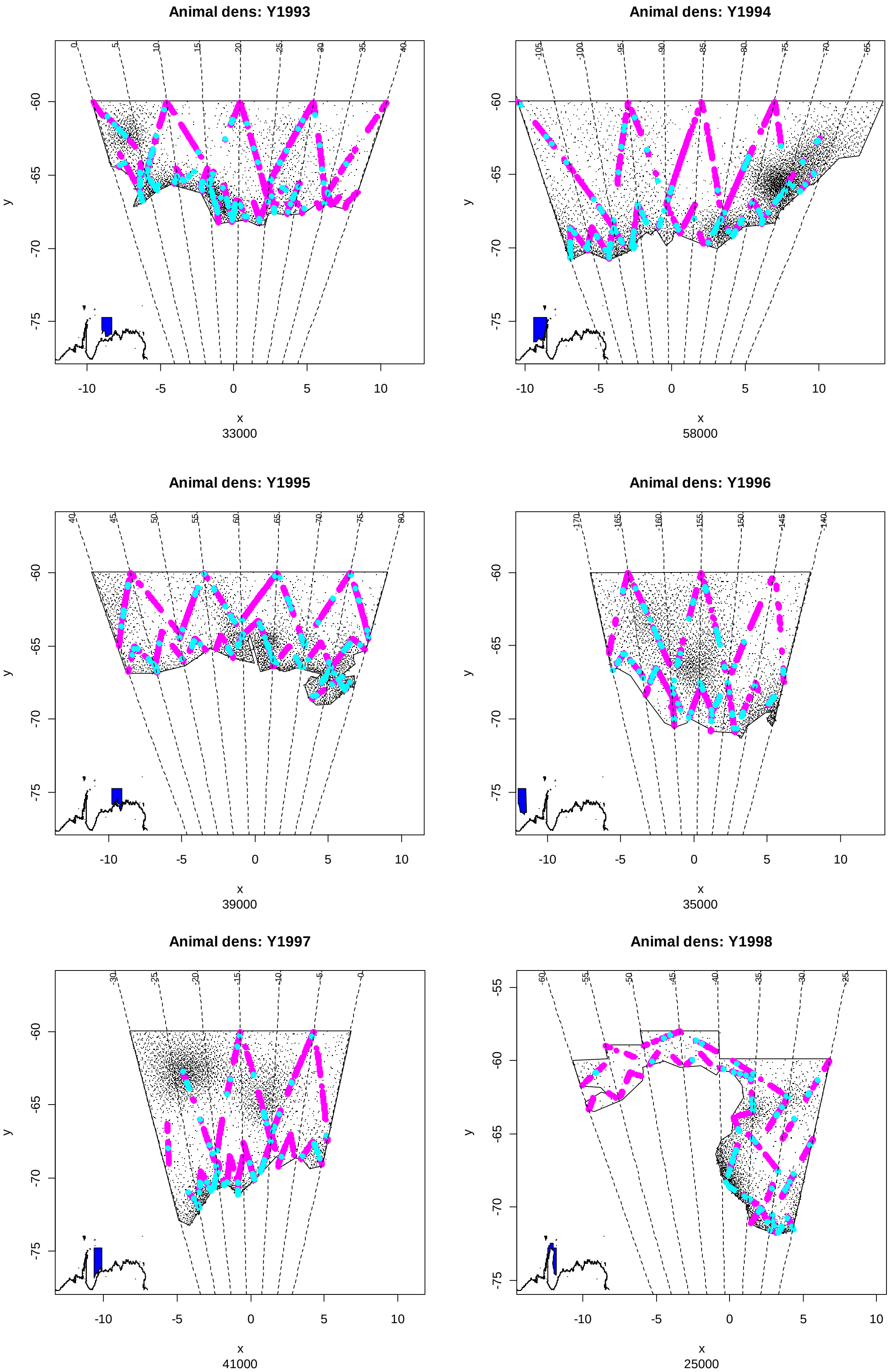

Figure 4 Estimated whale density by survey for CP3 (continued on next two pages). 1 dot=100 whales.

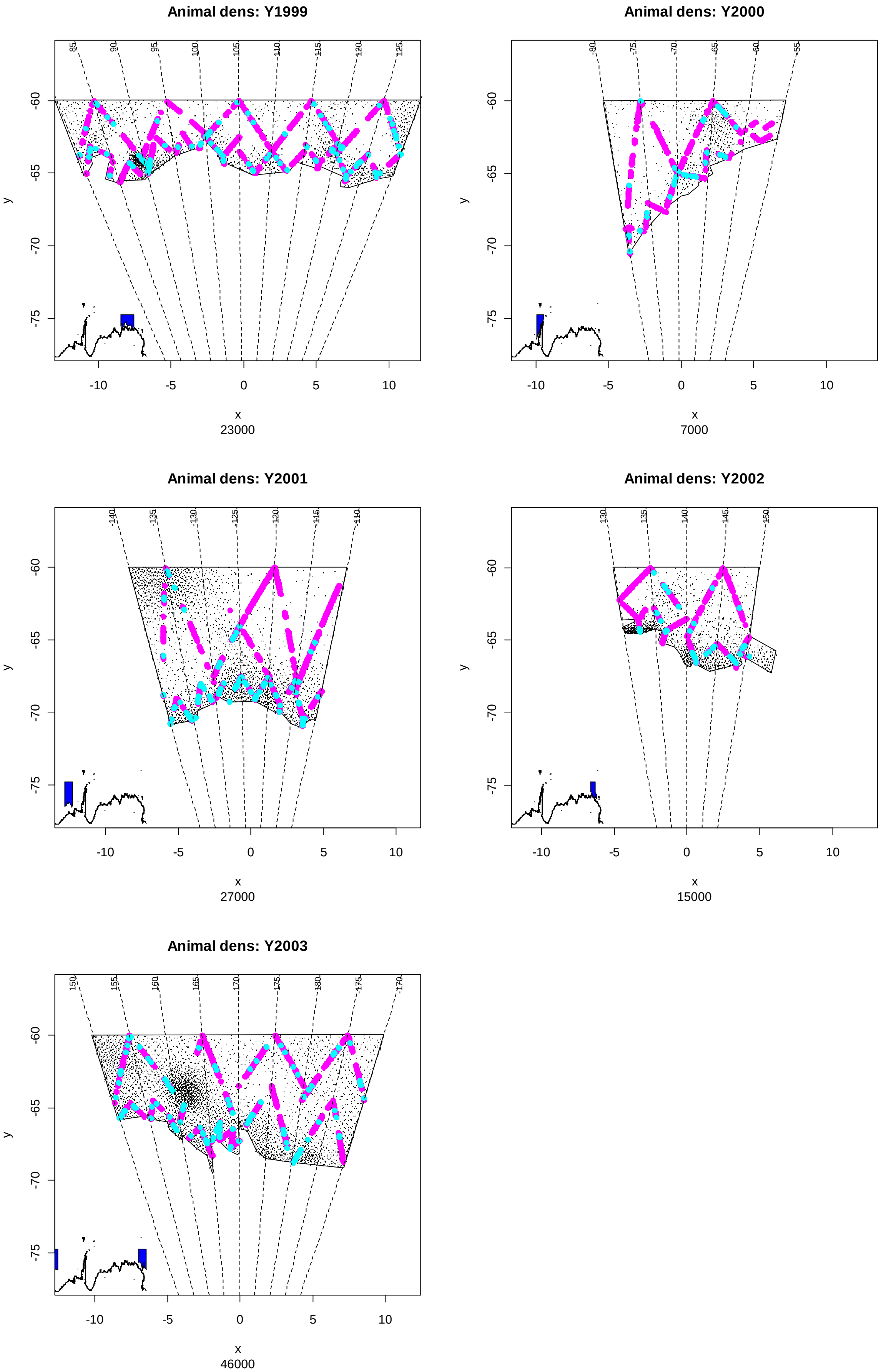

Figure 4 continued: Estimated whale density by survey for CP3 (continued on next page). 1 dot=100 whales.

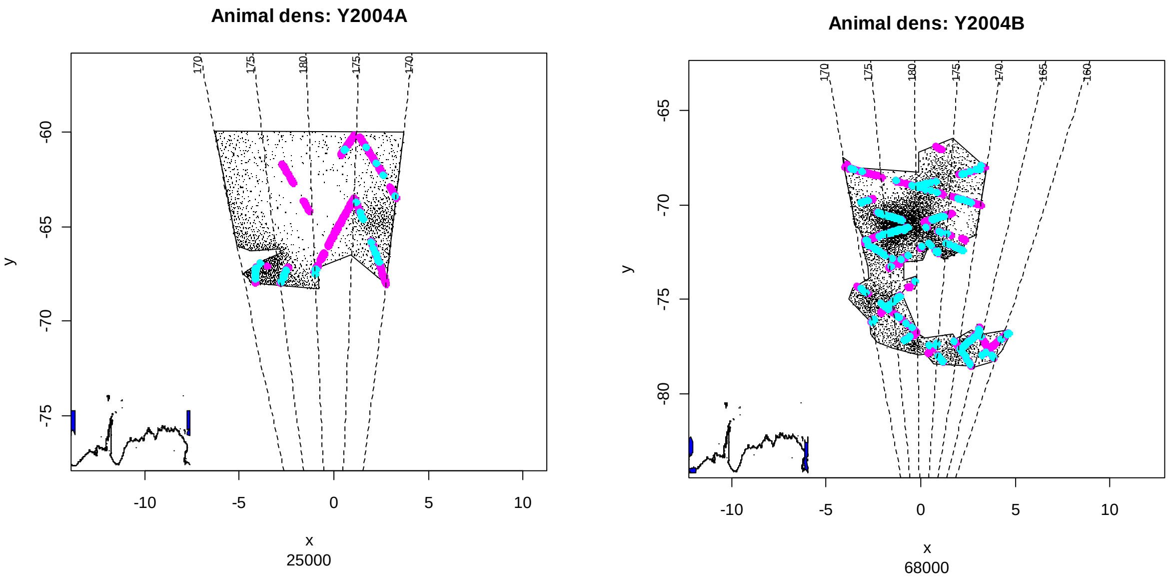

Figure 4 continued: Estimated whale density by survey for CP3. 1 dot=100 whales.