Abundance estimation for the western North Pacific common minke whales based on sighting information from JARPN and JARPN II

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ABSTRACT

This paper summarizes the information on sighting surveys and abundance estimation for western North Pacific common minke whales (*Balaenoptera acutorostrata*) based on JARPN (1994-95) and JARPN II (2002-07). This summary took into consideration the suggestions offered by the Consultation Group on Sighting Data (CGSD). Beaufort state and other factors that may affect the whale sightability were taken into account for the estimation of the effective strip half width (ESHW). AIC showed that the hazard-rate function with Beaufort state as a covariate was the best-fitted model. The Horvitz-Thompson like estimator, which considered the covariate effects, was employed for the abundance estimation in each sub-area. Abundance estimates in the sub-areas 7CS, 7CN, 7W, 7E, 8 and 9 are 1,224, 184, 387, 301, 344 and 1,438, respectively in average among the surveys. The abundance estimates derived from this study can be used for the conditioning of the current RMP *Implementation* of western North Pacific common minke whale.

INTRODUCTION

Sighting surveys under the Japanese whale research program under special permit in the western North Pacific (JAPRN) and its second phase, JARPN II, have been conducted annually since 1994 and sighting data for the western North Pacific common minke whales (*Balaenoptera acutorostrata*) were collected. Hakamada *et al*. (2010) showed some summarized information on the planned and actual track lines and results for abundance estimation using a standard line transect method. However, the work was not fully completed unfortunately in terms of lack of estimation exercises with consideration of covariates for the detection probability (hence the effective strip half width, ESHW).

This paper attempts to provide refined information on the dedicated sighting surveys and update abundance estimates in the sub-areas defined for *Implementation* for the western North Pacific common minke whales considering covariates for the ESHW such as Beaufort state.

MATERIALS AND METHOD

Survey information

Planned and realized track lines and order of the survey area

Figures 1-11 show planned track lines for JARPN (1994-1995) and JARPN II (2002-2007). Figures 12-22 show order of the survey area for each survey. Figures 23-33 show track line surveyed actually and primary sighting positions of the minke whales. Red lines in each figure indicate the survey area to which estimate was applied.

Sighting mode conducted in JARPN and JARPN II surveys

JARPN: Sighting survey was conducted by Sampling and Sighting Vessels (SSVs) in closing mode (coded as "NSC"). Two SSVs (*Toshi-maru* No 18 (T18) and *Toshimaru* No 25 (T25)) surveyed in parallel track line in 1994 and three SSVs (*Kyo-maru* No. 1, T25 and T18) did in 1995.

JARPN II: Sighting survey was conducted by dedicated sighting vessel (*Kyoshin-maru* No. 2). The sighting survey by the SV was conducted under the limited closing mode (ASP mode; same manner as "NSC" without sampling of whales) and the passing mode (NSP mode; even if sighting was made on the predetermined track line, the vessel did not approach the whale directly and searching from the top barrel was uninterrupted). Survey mode of NSP was conducted during transit survey and sighting data in this mode were not used for abundance estimation.

Differences among these survey modes are summarized in Table 1. For JARPN, sighting survey was conducted in closing mode with whale sampling. For JARPN II closing mode and passing mode were conducted by dedicated sighting vessel. Sighting data in passing mode were not used because passing mode was conducted only in transit survey. In summary, abundance estimate are based on data collected sighting surveys in closing mode for JARPN and JARPN II.

Searching distance during each Beaufort

Searching distance during each Beaufort state in each sub-area and year was calculated for 2002-2007 JARPN II surveys. Beaufort state was recorded every hour during the surveys. It was assumed that the just former recorded weather conditions are constant until the next record.

Estimation method

Detection function considering covariates

In order to consider the effect of covariates such as Beaufort state, sub-area and year on estimated detection functions for JARPN II data, MCDS (Multiple Covariates Distance Sampling) engine in DISTANCE ver 6.0 was used. MCDS methods are based on a Horvitz-Thompson like estimator of abundance (Thomas *et al.*, 2010). Hazard-rate model was considered. Full model of the detection function was provided by

$$g(x) = 1 - \exp\left\{ -\left({x}/{a \exp(Beaufort + SA + year)} \right)^{-b} \right\}$$

AIC was used to select the best model to estimate ESW.

Estimation of abundance

Searching distance and the number of the primary sightings are stratified by new sub-areas. CV of the encounter rate was calculated under the new stratification. The Horvitz-Thompson like estimator was applied for the abundance estimation, with consideration of the covariate effects. Detection function was modelled globally, and estimated separately in each stratum, given the covariate values of the observations in the strata to estimate ESHW for each stratum.

RESULTS

Searching distance during each Beaufort

Table 2 shows the searching distance during each Beaufort state in each sub-area and year was calculated for 2002-2007 JARPN II surveys. Most of the survey was conducted during Beaufort state 2-4 for each stratum. Table 2 may suggests that distribution of searching distance by Beaufort state could be different among sub-areas and years. Some of the total effort was allocated to the Beaufort 5. It was conducted as some exception for Guideline of 'acceptable' sighting condition (Kiwada *et al*, 2009).

Detection function considering covariates

Table 3 shows the AIC for each model. Model using Beaufort as a covariate was selected by AIC. This estimate would not be substantially different from those derived by other models. Table 4 shows estimated coefficients of the estimated model. Plot of the detection functions are provided in Figure 34. The estimated coefficients and shape of the detection functions reflect the fact that the schools are easier to detect as Beaufort state is less. Estimated ESHW using the selected model are applied to estimate abundance estimates.

Revised abundance estimates

Considering the results of the tasks above, abundance estimates were obtained and shown in Table 5. ESHW and mean school size estimate were revised by using detection function with covariate. Table 5 includes relevant survey information such as the number of primary sightings of the minke whales, searching distance, areal coverage of survey area and the proportions of the intended track line covered on primary search effort for each sub-area. Such information could be used judging which abundance estimate in each stratum can be used.

The abundance estimates derived by this work can be used in the conditioning process for the *Implementation*.

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Thomas, L., S.T. Buckland, E.A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R.B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47: 5-14.

Table 1. Difference in survey mode conducted in JARPN and JARPN II.

	JARPN	JARPN II	
Survey mode	NSC	ASP	NSP
Closing or Passing	Closing	Closing	Passing
Sampling whales or not	Yes	No	No
Remark			not used for estimation

Table 2. Searching distance during each Beaufort state in each sub-area and year for JARPN II (2002 – 2007).

sub-area	year	Beafort State					
		0	1	2	3	4	5
7CS	2003	1.1	0.0	0.0	345.7	10.3	0.0
	2004	0.0	57.3	20.7	59.3	65.3	0.0
	2006	8.0	31.4	102.5	74.4	44.1	0.0
	2007	0.0	0.0	8.6	1.2	0.0	0.0
7CN	2003	6.0	6.8	68.1	134.2	31.9	0.0
7W	2002	0.0	0.0	3.3	136.2	104.7	0.0
	2003	21.3	17.4	191.0	629.4	127.1	3.1
	2004	0.0	83.6	190.5	351.3	155.4	8.5
	2006	0.0	0.0	106.5	202.0	102.9	0.0
	2007	0.0	36.3	167.1	161.2	102.6	0.0
7E	2003	0.0	0.0	121.6	227.9	193.7	0.0
	2004	0.0	0.0	204.8	154.8	29.9	0.0
	2006	0.0	10.6	205.0	231.5	14.6	0.0
	2007	0.0	12.4	191.7	120.4	0.0	0.0
8	2002	0.0	61.3	105.5	551.9	466.3	0.0
	2003	0.0	0.0	35.1	132.1	104.5	0.3
	2004	0.0	47.3	207.3	401.8	261.7	0.0
	2005	0.0	7.8	202.4	953.8	258.6	13.8
	2006	0.0	0.0	251.9	356.6	434.6	0.0
	2007	0.0	31.7	76.2	247.0	438.5	122.8
9	2002	0.0	0.0	79.1	906.3	877.8	3.4
	2003	0.0	160.6	1,075.3	984.9	315.4	0.0
	2004	0.0	185.2	403.7	600.9	339.2	14.9
	2005	0.0	177.8	1,006.1	1,540.0	745.4	33.7
	2006	0.0	24.9	433.3	1,362.6	1,414.2	8.5
	2007	0.0	0.0	118.5	821.5	789.4	332.7

Table 3. AIC for each model. The selected model was indicted by an asterisk.

covariate	AIC
Beaufort+Year+Sub-Area	732.4
Beaufort+Sub-Area	723.2
Beaufort+Year	724.0
Year+Sub-Area	724.1
Beaufort*	718.6
Year	721.4
Sub-Area	723.8
no covariate	719.3

Table 4. Estimates of coefficients for the selected model. The parameters *a* and *b* are those for Beaufort state 4.

	coef.	*se*
a	0.199	0.051
b	2.192	2.869
*Beaufort1**	1.141	0.474
Beaufort2	0.810	0.450
Beaufort3	0.356	0.446

*Including one sighting that Beaufort was 0.

Table 5. Abundance estimates with the best model by sub-area and year using JARPN and JARPN II data.

sub-area	year	Areal covarage	Timing	Area size (n.miles2)	effort (n.miles)	*n*	Encounter rate (/100 n.miles)	ESW (n.miles)	Mean school size	*P*	CV(P)	planned trackline	% of realised trackline
7CS	2003	62.6%	May	16,789	367	6	1.636 (1.092)	0.431 (0.179)	1.00 (-)	319	0.786	524	70.0%
	2004	100.0%	May	26,826	199	7	3.511 (1.451)	0.606 (0.171)	1.14 (0.14)	886	0.502	301	66.2%
	2006	100.0%	Jun - Jul	26,826	264	23	8.718 (9.001)	0.431 (0.263)	1.36 (0.11)	3,690	1.199	453	58.2%
	2007	100.0%	Jun - Jul	26,826	10	0	0 (-)	-	-	0	-	98	9.8%
7CN	2003	75.4%	May	18,281	247	3	1.214 (0.837)	0.604 (0.251)	1.00 (-)	184	0.805	562	43.9%
7W	2002	30.5%	Aug	25,059	244	0	0 (-)	-	-	0	-	618	39.5%
	2003	54.2%	May - Jun	44,589	986	10	1.014 (0.348)	0.431 (0.263)	1.00 (-)	524	0.700	1,725	57.2%
	2004	88.8%	May - Jun	72,991	789	7	0.887 (0.323)	0.484 (0.240)	1.29 (0.18)	863	0.648	1,558	50.7%
	2006	88.8%	Jun - Jul	72,991	411	0	0 (-)	-	-	0	-	519	79.2%
	2007	88.8%	Jun - Jul	72,991	465	3	0.645 (0.525)	0.431 (0.214)	1.00 (-)	546	0.953	764	60.8%
7E	2003	26.3%	May - Jun	22,166	535	6	1.121 (0.929)	0.642 (0.107)	1.33 (0.21)	257	0.866	610	87.7%
	2004	57.1%	May - Jun	48,208	390	3	0.77 (0.423)	0.422 (0.233)	1.00 (-)	440	0.779	683	57.1%
	2006	57.1%	May - Jun	48,208	461	2	0.433 (0.372)	0.423 (0.101)	1.00 (-)	247	0.892	517	89.2%
	2007	57.1%	Jun - Jul	48,208	360	0	0 (-)	-	-	0	-	480	74.9%
8	2002	65.0%	Jun - Jul	162,689	1,184	0	0 (-)	-	-	0	-	1,736	68.2%
	2003	13.1%	Jul	32,857	272	1	0.368 (0.304)	0.431 (0.214)	1.00 (-)	140	0.964	306	88.7%
	2004	40.5%	Jun	101,373	917	8	0.872 (0.404)	0.461 (0.139)	1.14 (0.14)	1,093	0.576	1,636	56.1%
	2005	65.0%	May - Jul	162,789	1,434	1	0.07 (0.069)	0.431 (0.152)	1.00 (-)	132	1.047	1,915	74.9%
	2006	65.0%	May - Jul	162,789	1,039	3	0.289 (0.152)	0.761 (0.324)	1.00 (-)	309	0.677	1,680	61.8%
	2007	65.0%	Jun - Jul	162,789	914	2	0.219 (0.208)	0.456 (0.161)	1.00 (-)	391	1.013	1,623	56.3%
9	1994 1st	42.5%	Jul. - Aug.	244,172	1,608	12	0.746 (0.228)	0.321 (0.091)	1.08 (0.08)	3,065	0.423	6,884	23.4%
	1994 2nd	32.9%	Aug. - Sep.	189,012	2,118	7	0.331 (0.185)	0.321 (0.091)	1.00 (-)	973	0.628	5,807	36.5%
	1995 1st	54.7%	Jun.	314,082	2,907	12	0.413 (0.076)	0.481 (0.095)	1.00 (-)	1,348	0.272	5,035	57.7%
	1995 2nd	13.2%	Jul. - Aug.	75,635	791	10	1.264 (0.436)	0.481 (0.095)	1.00 (-)	994	0.396	3,119	25.4%
	1995 3rd	28.5%	Aug.	163,610	1,706	4	0.234 (0.142)	0.481 (0.095)	1.00 (-)	399	0.636	2,470	69.1%
	2002	62.4%	Jun. - Jul.	358,530	1,866	3	0.161 (0.124)	0.310 (0.109)	2.00 (-)	1,859	0.847	3,504	53.3%
	2003	33.2%	Jul.-Sep.	190,676	2,533	40	1.579 (0.38)	0.609 (0.081)	1.03 (0.03)	2,546	0.276	3,619	70.0%
	2004	42.6%	Jun.-Jul.	244,759	1,542	4	0.259 (0.157)	0.538 (0.192)	1.00 (-)	590	0.703	3,180	48.5%
	2005	63.0%	May -Aug.	362,113	3,502	13	0.371 (0.195)	0.686 (0.208)	1.11 (0.11)	1,088	0.676	4,593	76.2%
	2006	86.9%	May - Aug.	499,235	3,238	17	0.525 (0.146)	0.484 (0.240)	1.00 (-)	2,708	0.569	5,107	63.4%
	2007	86.9%	May - Jul.	499,235	2,067	1	0.048 (0.049)	0.497 (0.172)	1.00 (-)	243	1.078	4,903	42.2%

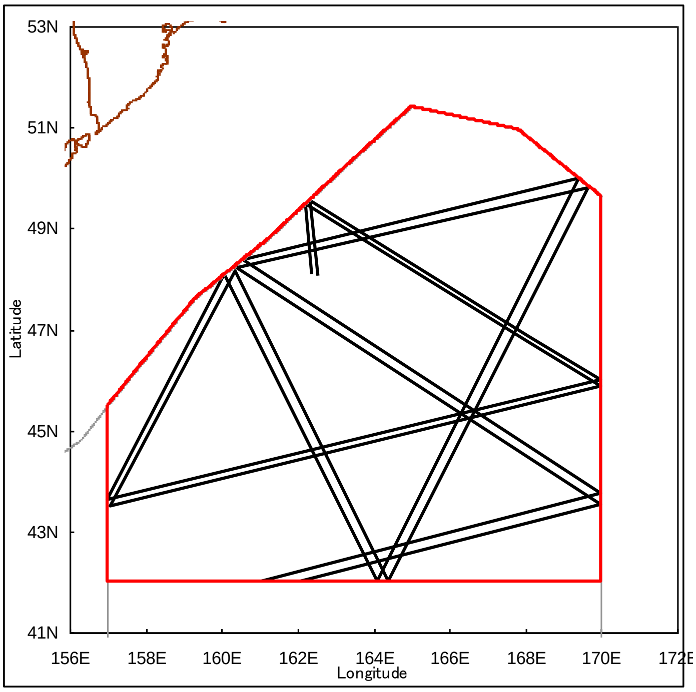


Figure 1. Pre-determined track lines for T18 and T25 in the first half of 1994 JARPN. (5 Jul. – 8 Aug.)

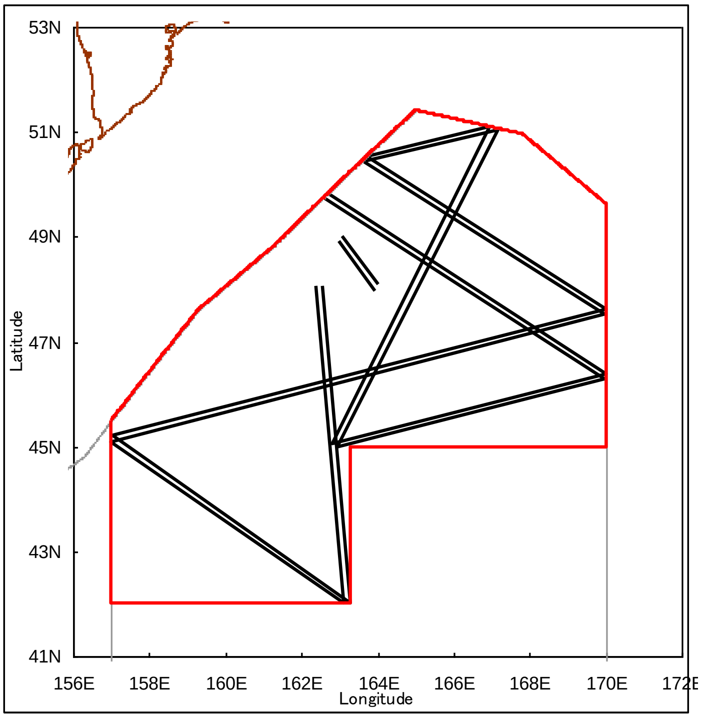


Figure 2. Pre-determined track lines for T18 and T25 in the second half of 1994 JARPN. (7Aug. – 7Sep.)

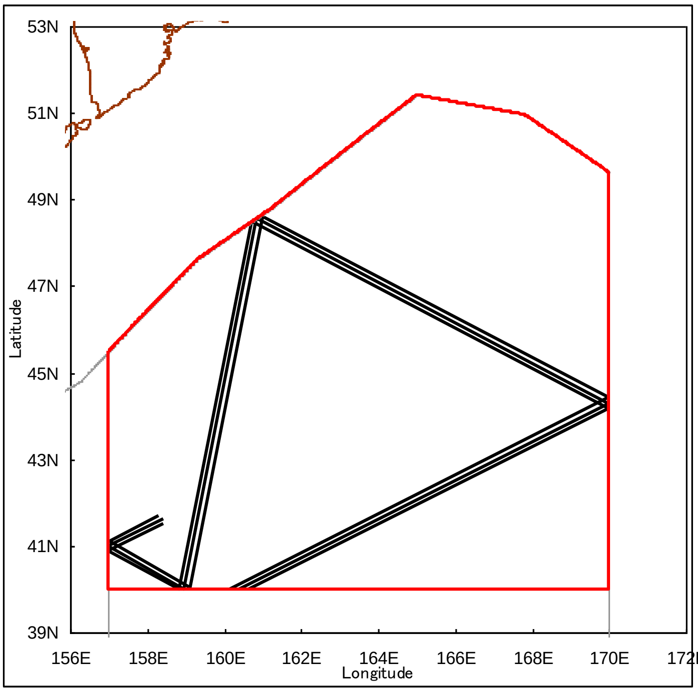


Figure 3. Pre-determined track lines for K01, T18 and T25 in the first period of 1995 JARPN. (13 Jun.-30 Jun.)

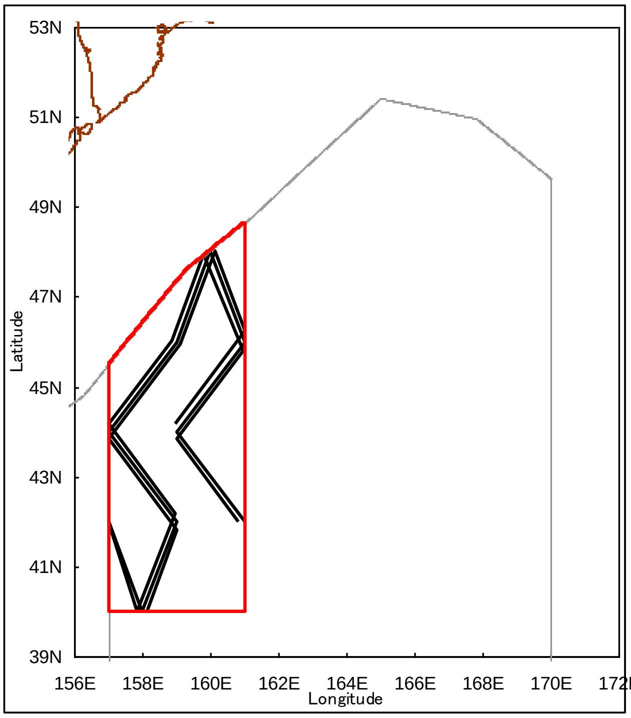


Figure 4. Pre-determined track lines for K01, T18 and T25 in the second period of 1995 JARPN. (1 Jul.-6 Aug.)

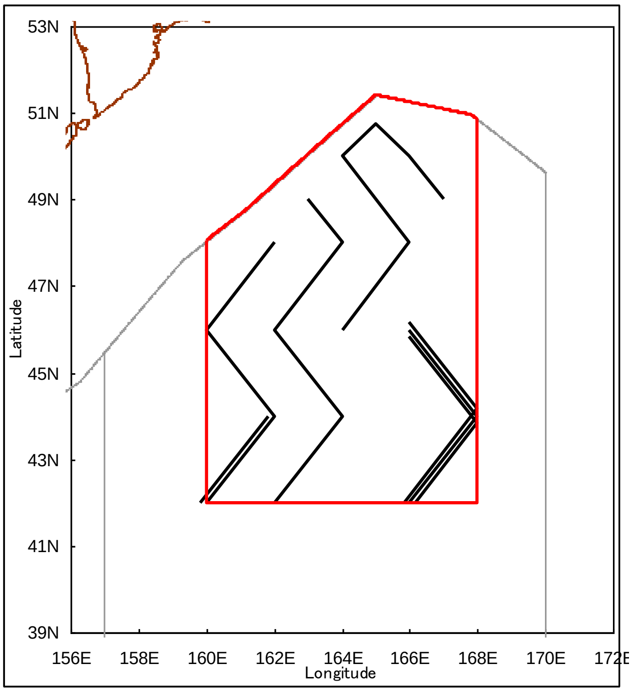


Figure 5. Pre-determined track lines for K01, T18 and T25 in the third period of 1995 JARPN. (7Aug.-22 Aug.)

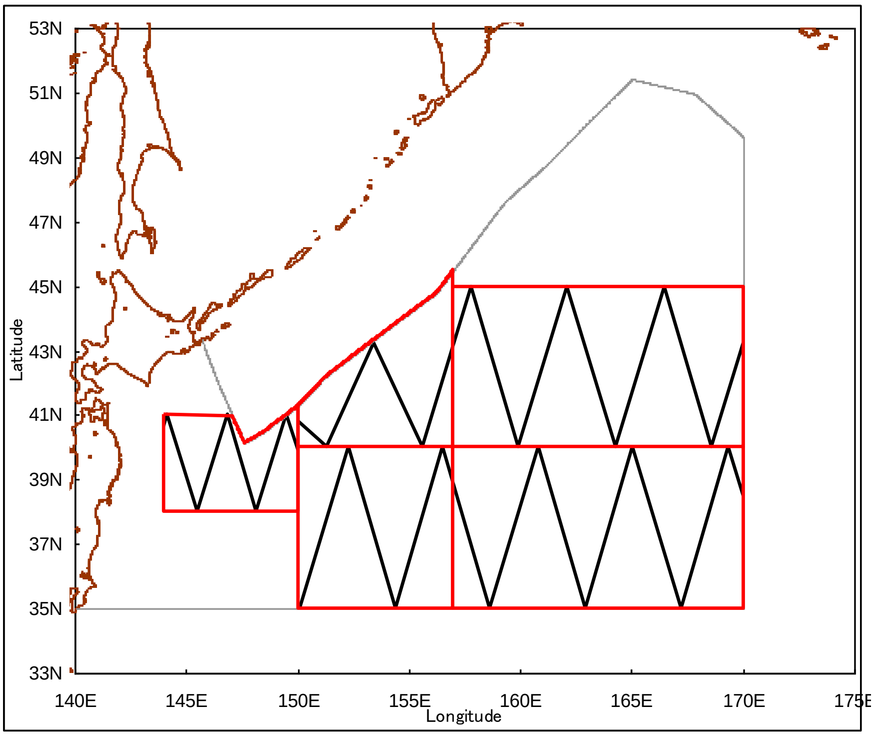


Figure 6. Pre-determined track lines for KS2 in 2002 JARPN II.

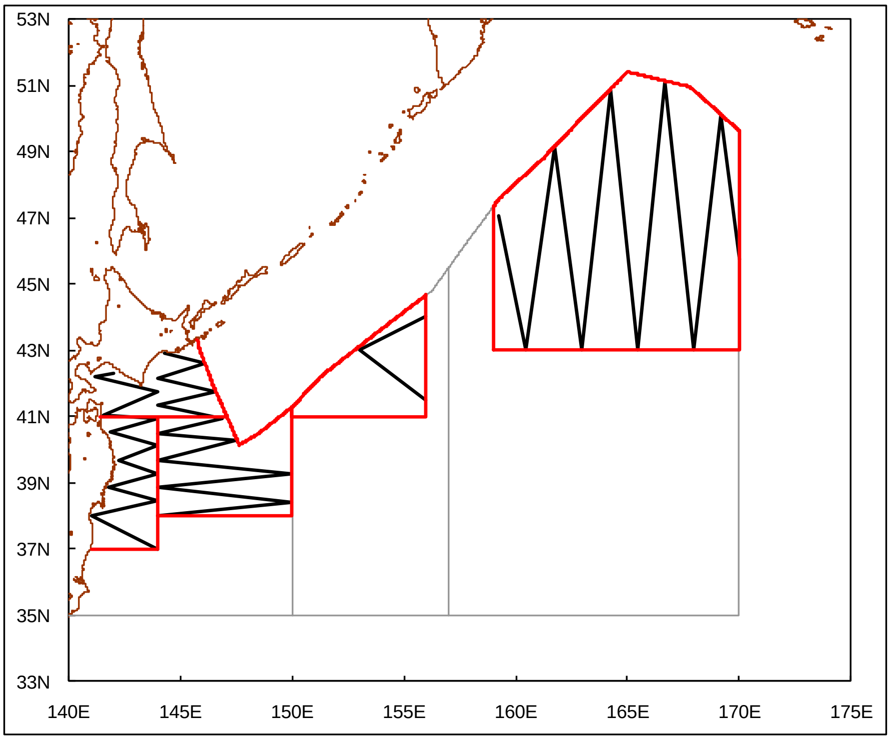


Figure 7. Pre-determined track lines for KS2 in 2003 JARPN II.

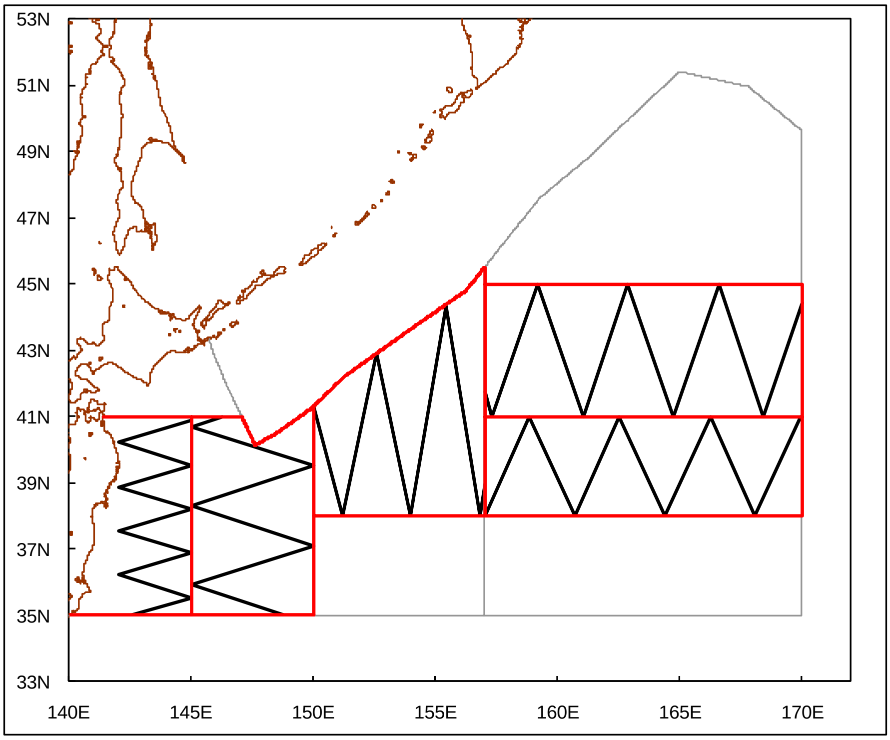


Figure 8. Pre-determined track lines for KS2 in 2004 JARPN II.

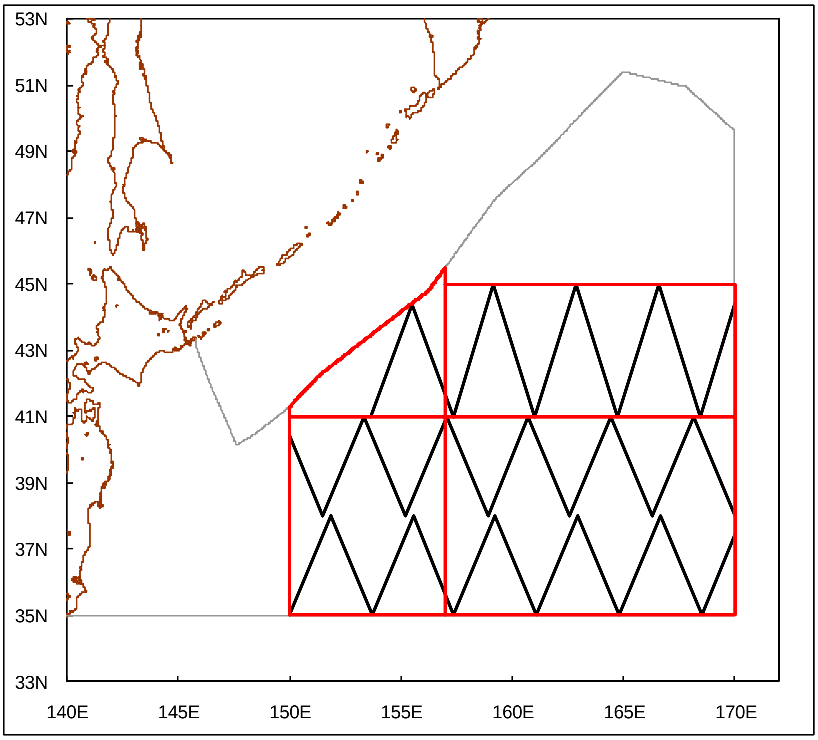


Figure 9. Pre-determined track lines for KS2 in 2005 JARPN II.

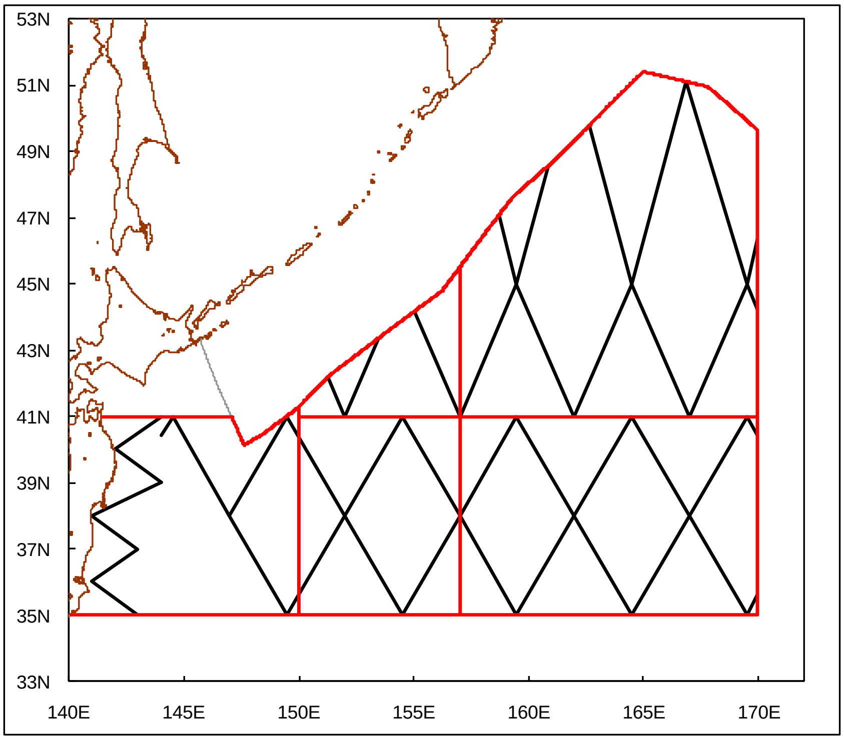


Figure 10. Pre-determined track lines for KS2 in 2006 JARPN II.

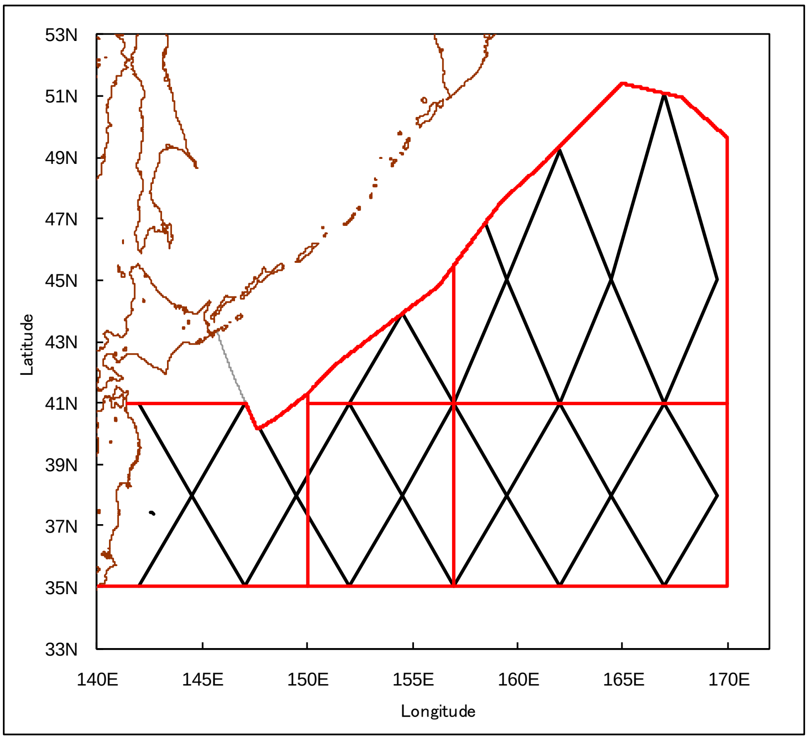


Figure 11. Pre-determined track lines for KS2 in 2007 JARPN II.

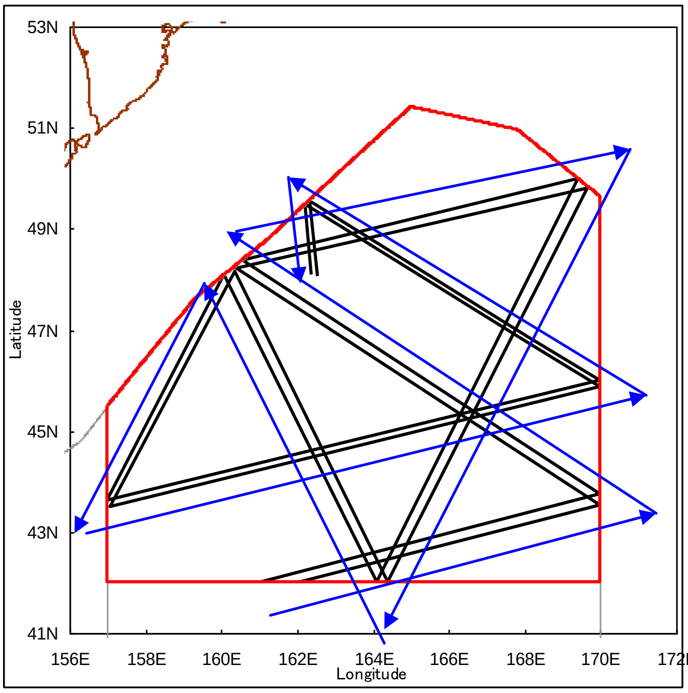


Figure 12. Survey order in the first half of 1994 JARPN.

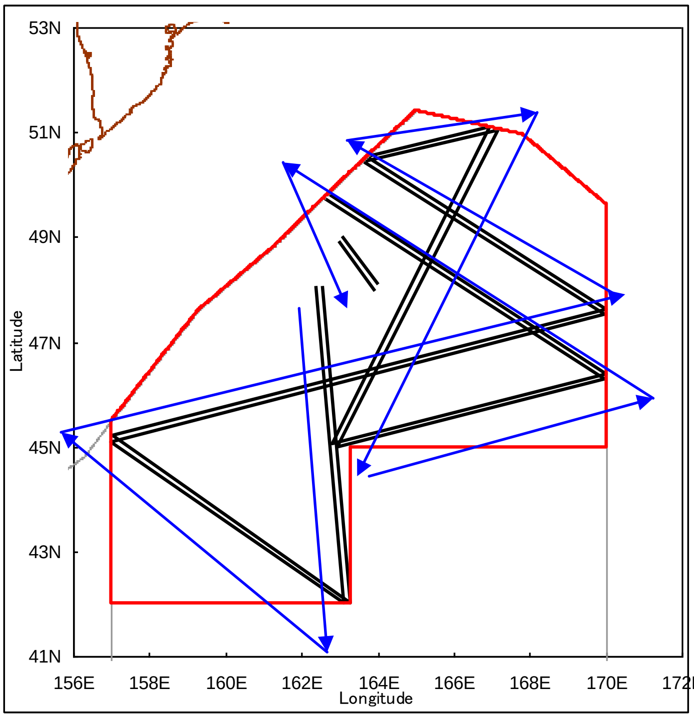


Figure 13. Survey order in the second half of 1994 JARPN.

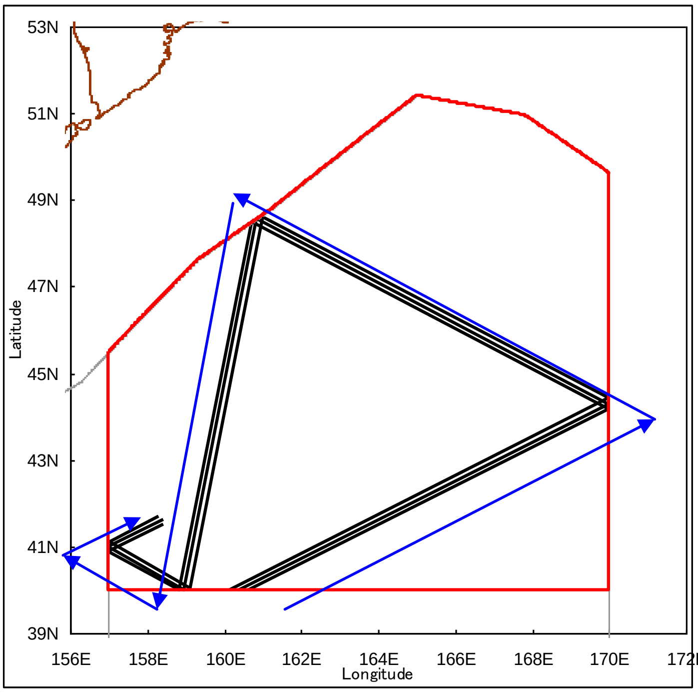


Figure 14. Survey order in the first period of 1995 JARPN.

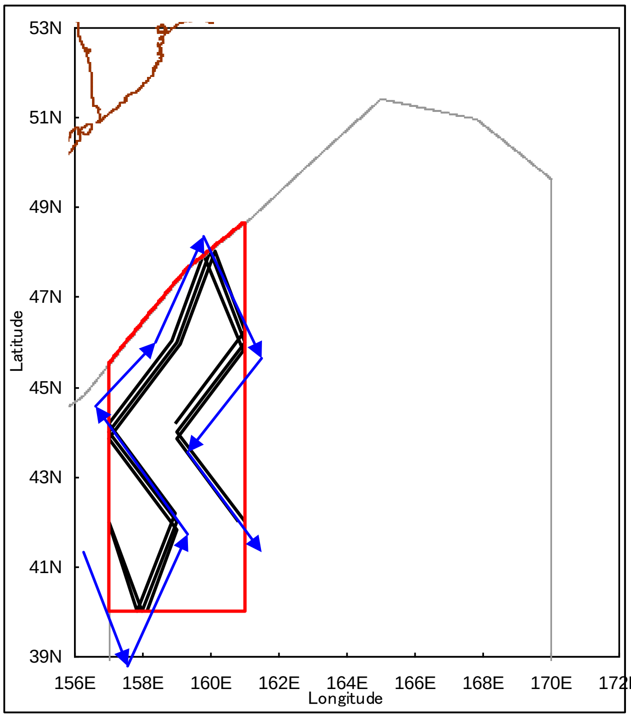


Figure 15. Survey order in the second period of 1995 JARPN.

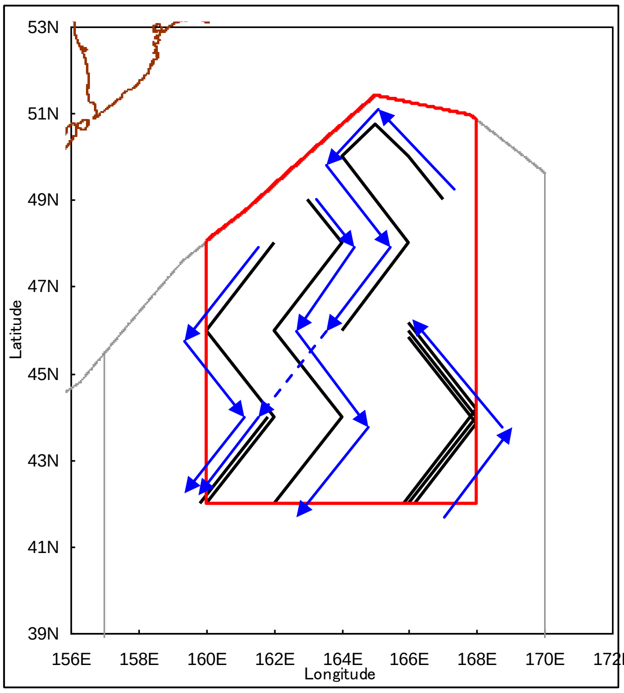


Figure 16. Survey order in the third period of 1995 JARPN.

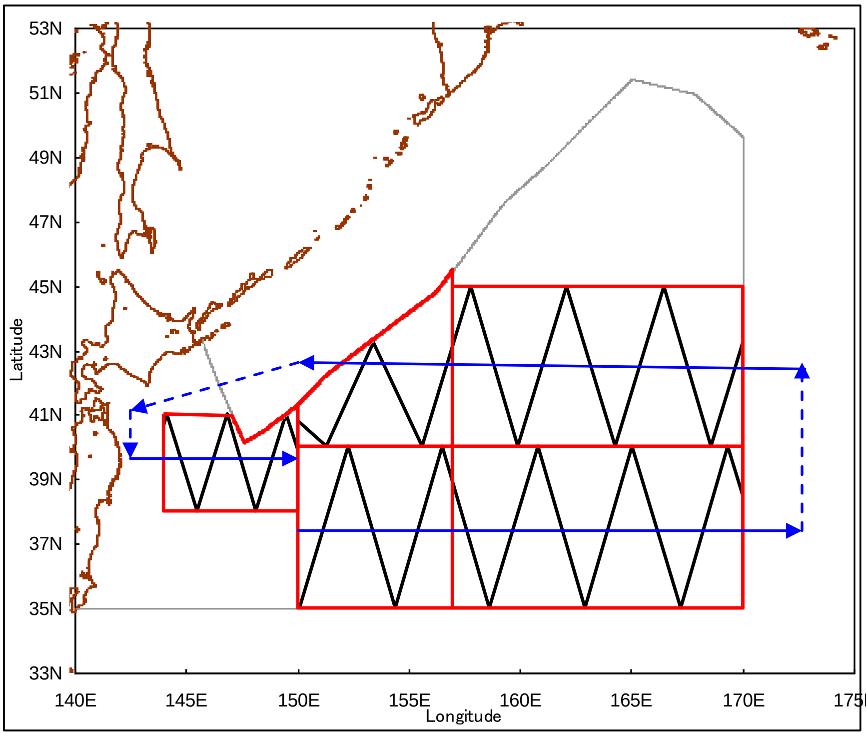


Figure 17. Survey order in 2002 JARPN II.

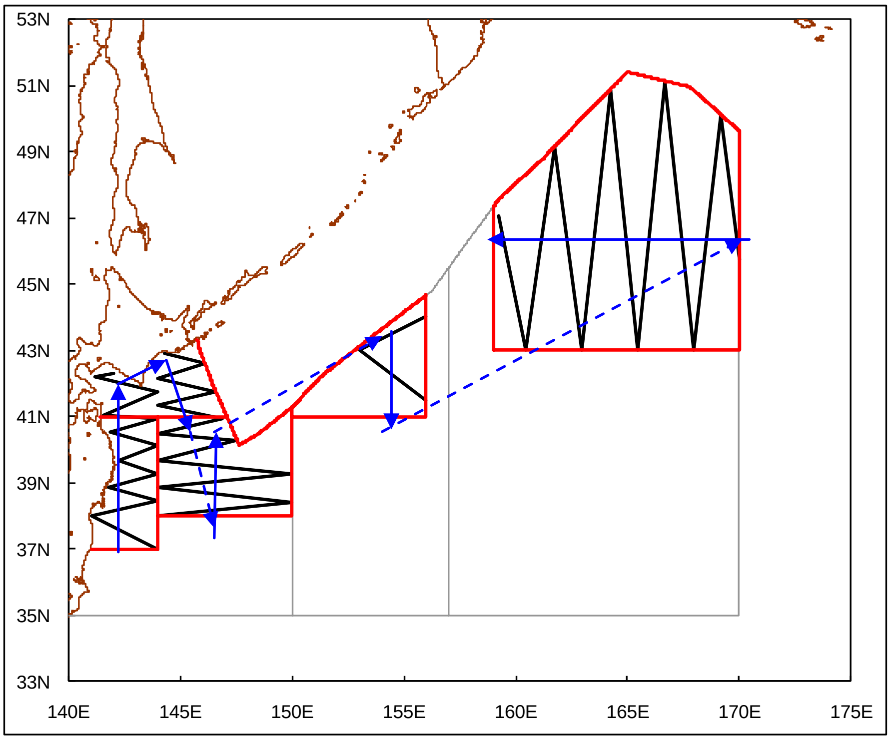


Figure 18. Survey order in 2003 JARPN II.

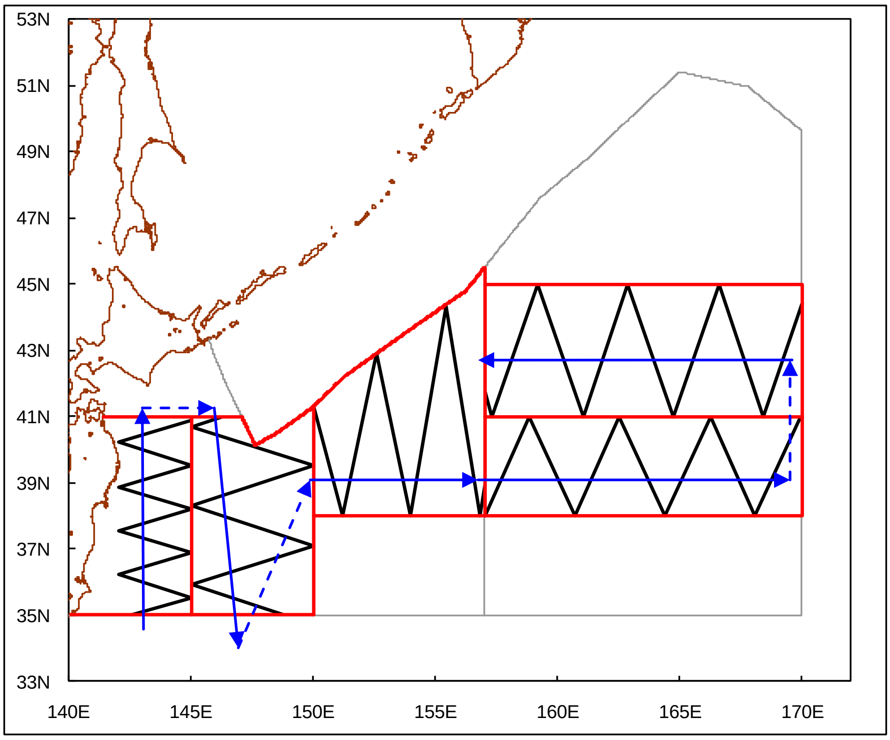


Figure 19. Survey order in 2004 JARPN II.

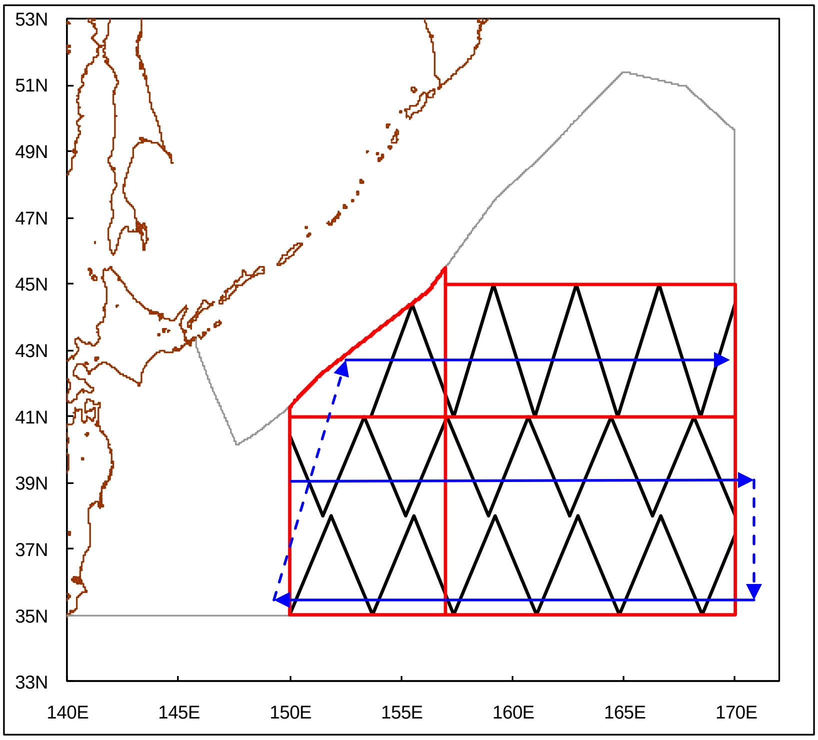


Figure 20. Survey order in 2005 JARPN II.

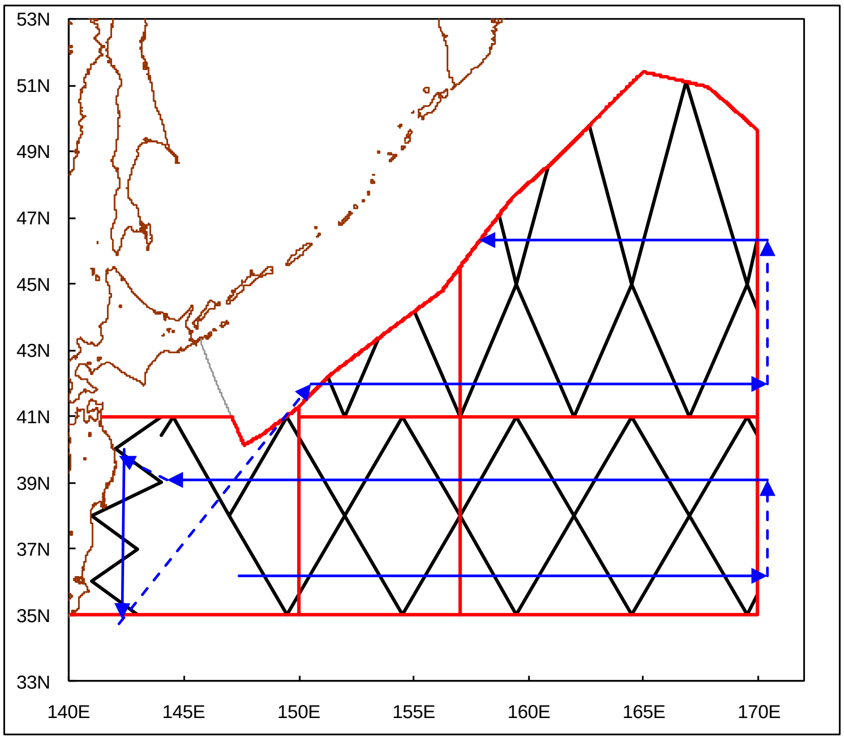


Figure 21. Survey order in 2006 JARPN II.

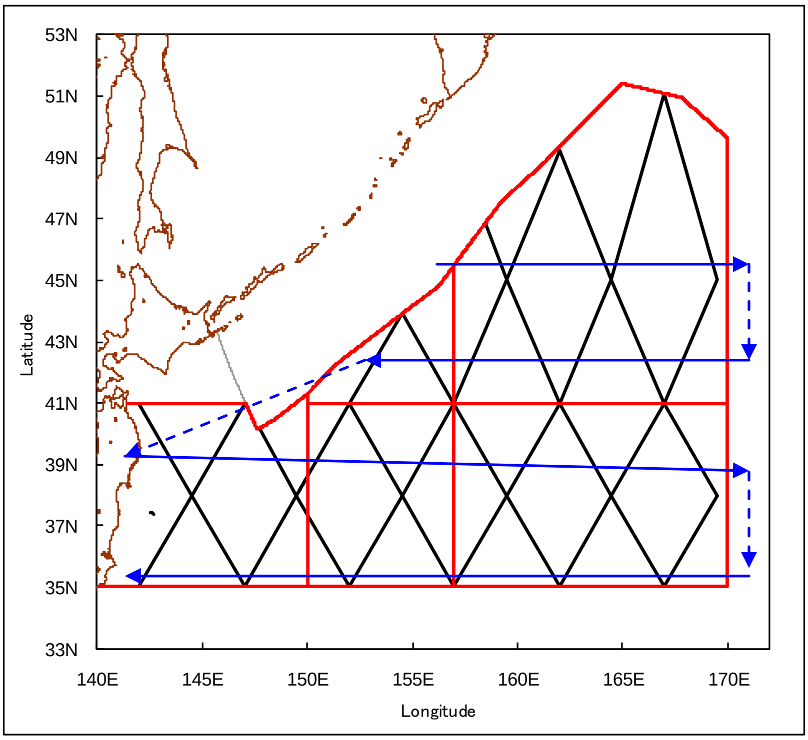


Figure 22. Survey order in 2007 JARPN II.

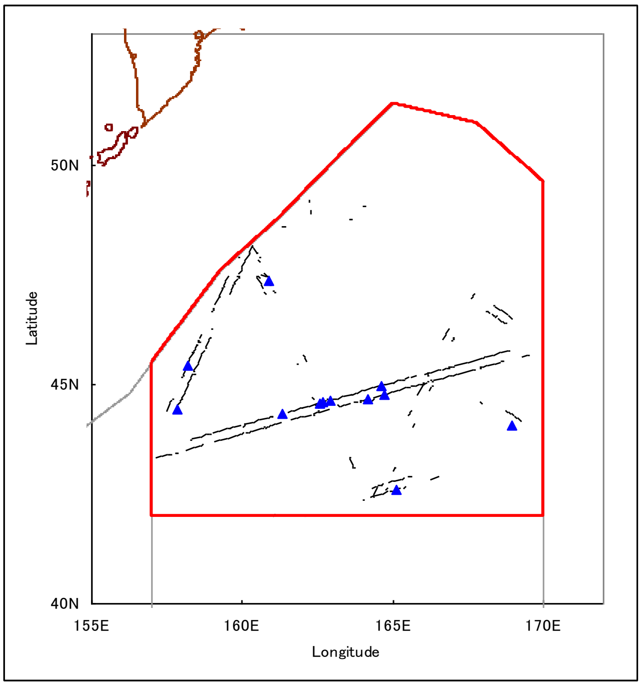


Figure 23. Track line actually surveyed and primary sighting positions of common minke whale schools in sub-area 9 in the first half of 1994 JARPN. Blue triangle indicates the position.

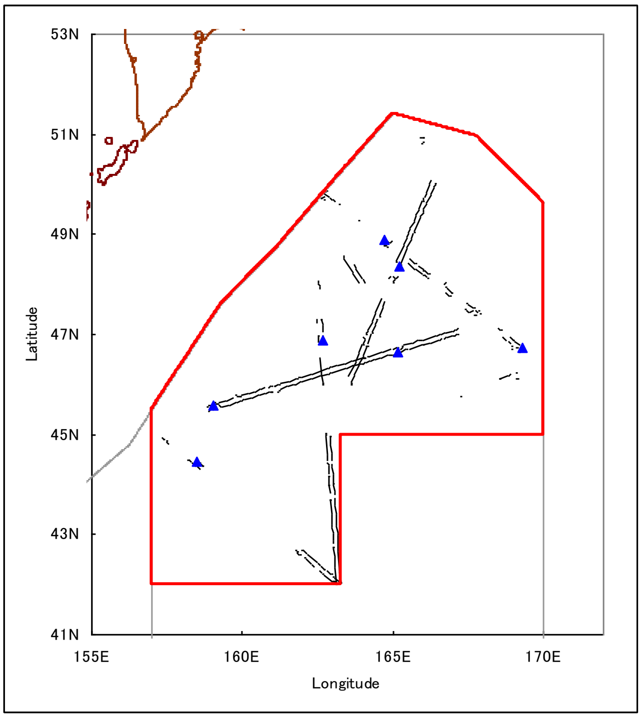


Figure 24. Track line actually surveyed and primary sighting positions of common minke whale schools in sub-area 9 in the second half of 1994 JARPN. Blue triangle indicates the position.

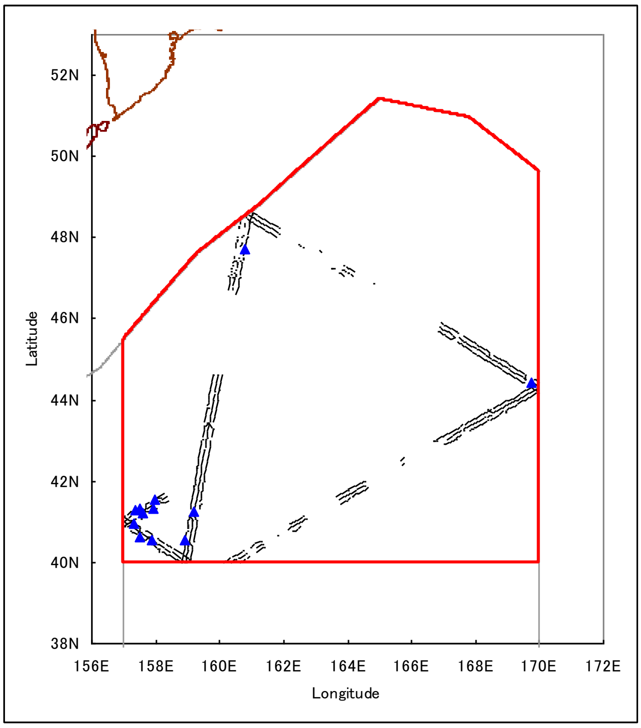


Figure 25. Track line actually surveyed and primary sighting positions of common minke whale schools in sub-area 9 in the first period of 1995 JARPN. Blue triangle indicates the position.

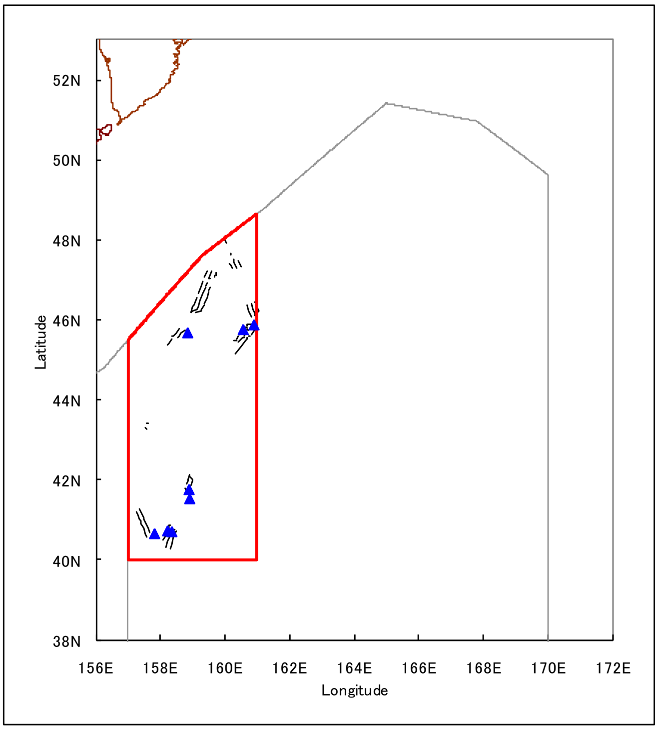


Figure 26. Track line actually surveyed and primary sighting positions of common minke whale schools in sub-area 9 in the second period of 1995 JARPN. Blue triangle indicates the position.

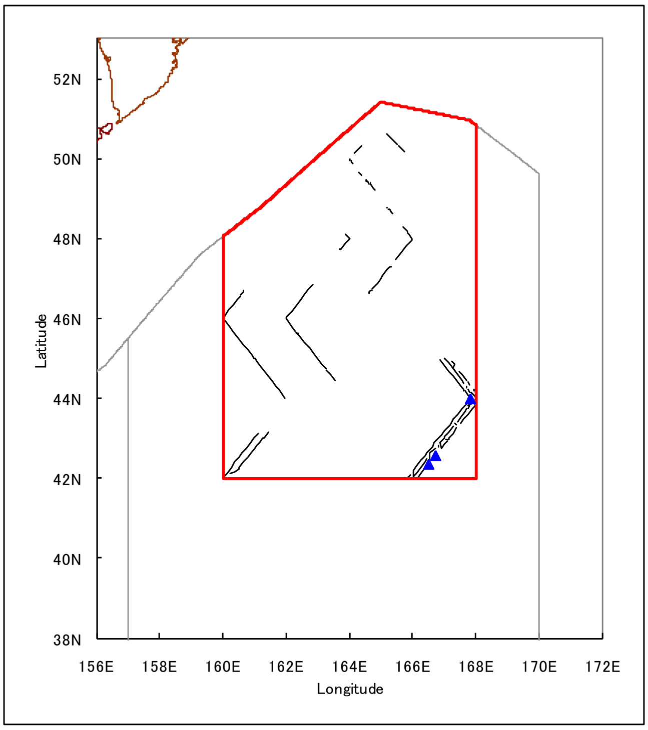


Figure 27. Track line actually surveyed and primary sighting positions of common minke whale schools in sub-area 9 in the third period of 1995 JARPN.

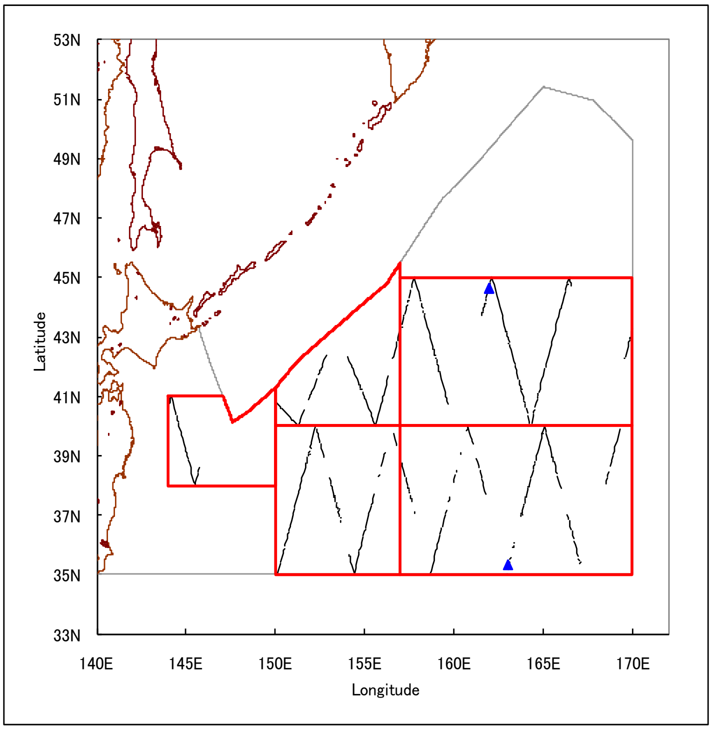


Figure 28. Track line actually surveyed and primary sighting positions of common minke whale schools in the 2002 JARPN II.

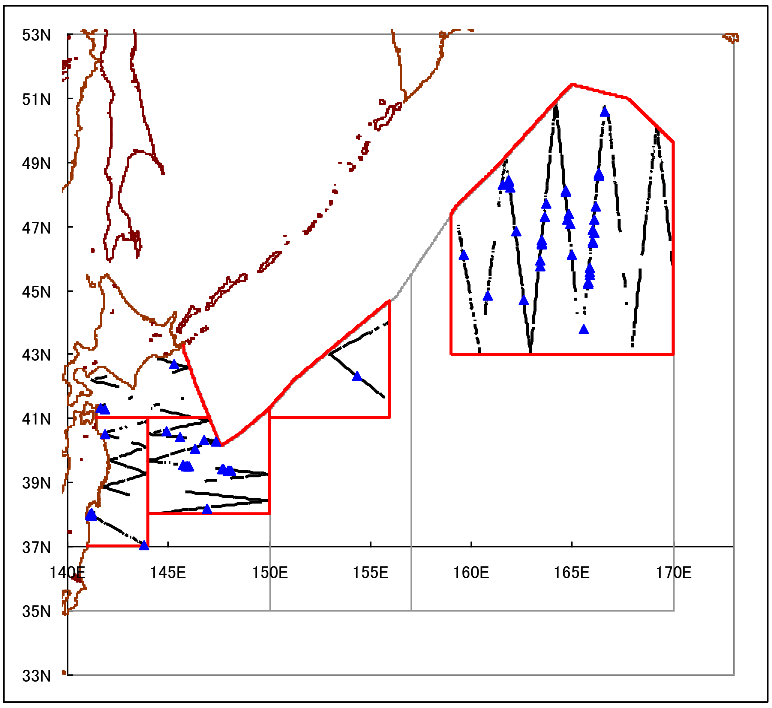


Figure 29. Track line actually surveyed and primary sighting positions of common minke whale schools in the 2003 JARPN II.

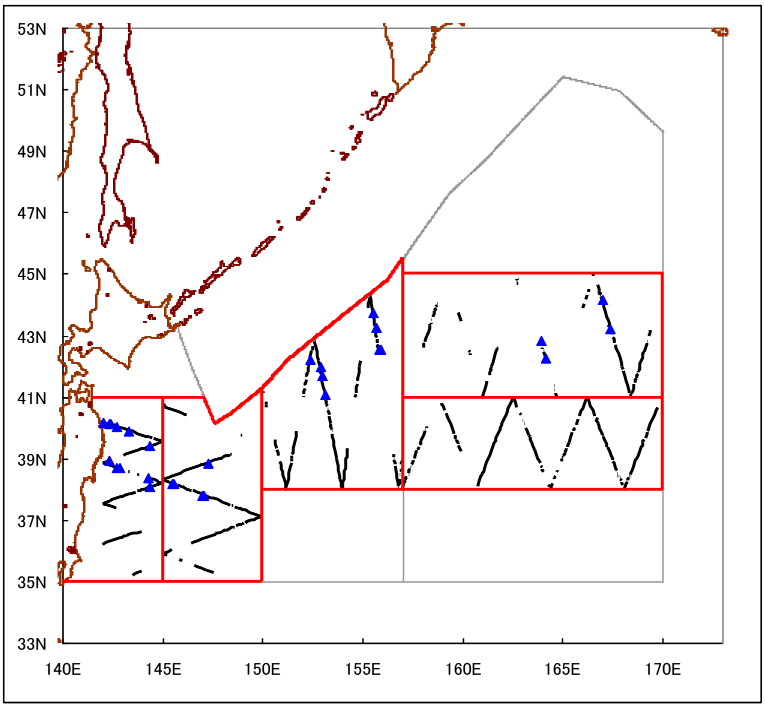


Figure 30. Track line actually surveyed and primary sighting positions of common minke whale schools in the 2004 JARPN II.

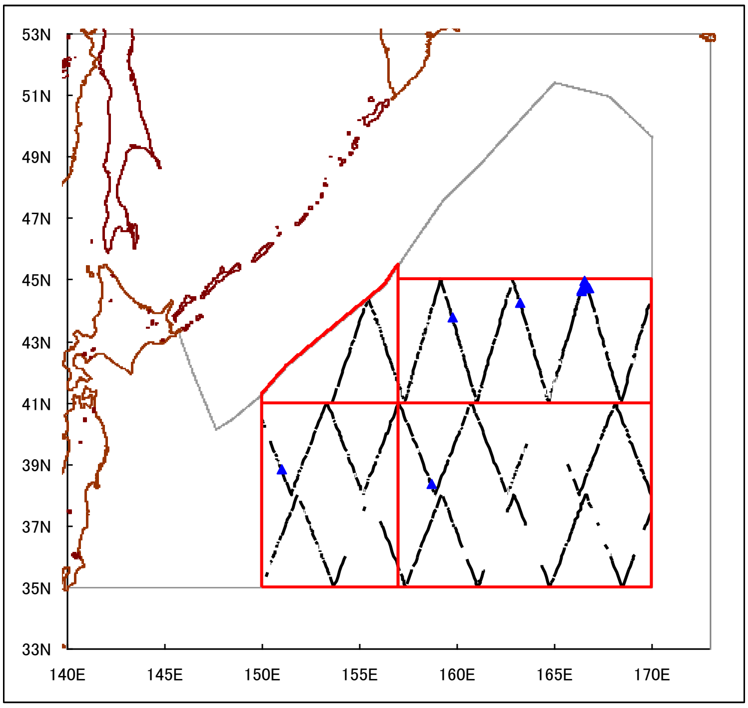


Figure 31. Track line actually surveyed and primary sighting positions of common minke whale schools in the 2005 JARPN II.

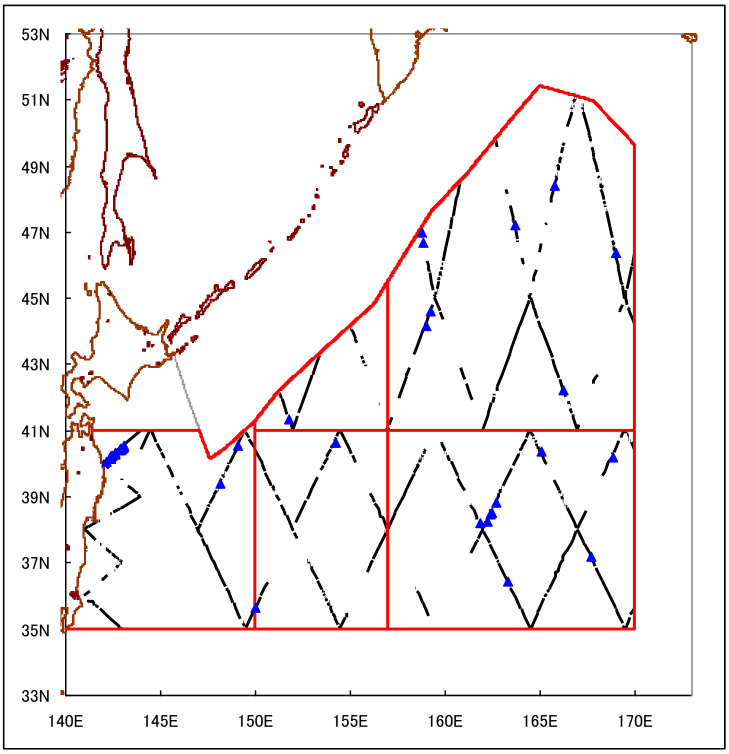


Figure 32. Track line actually surveyed and primary sighting positions of common minke whale schools in the 2006 JARPN II.

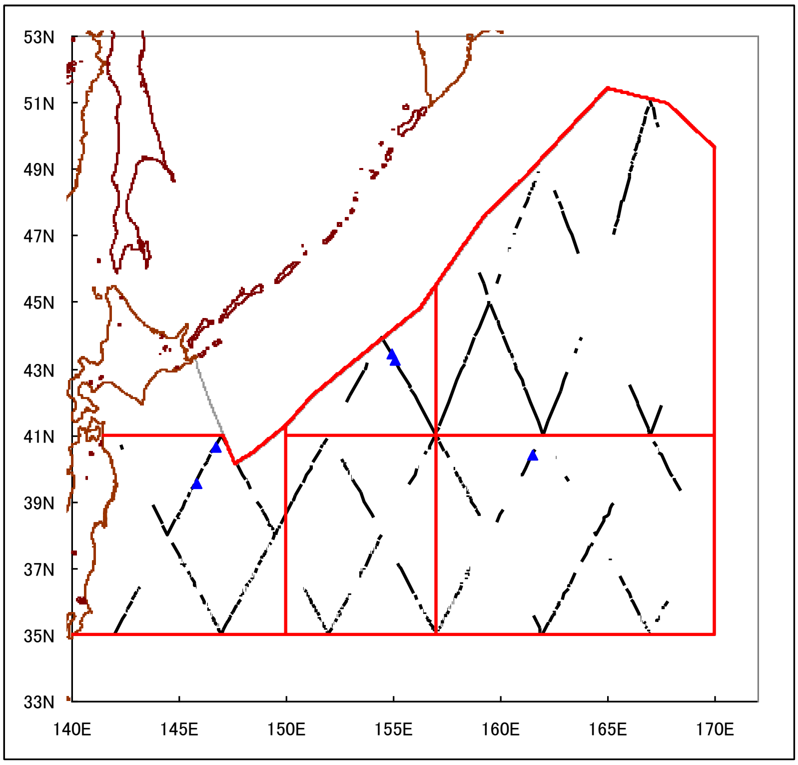
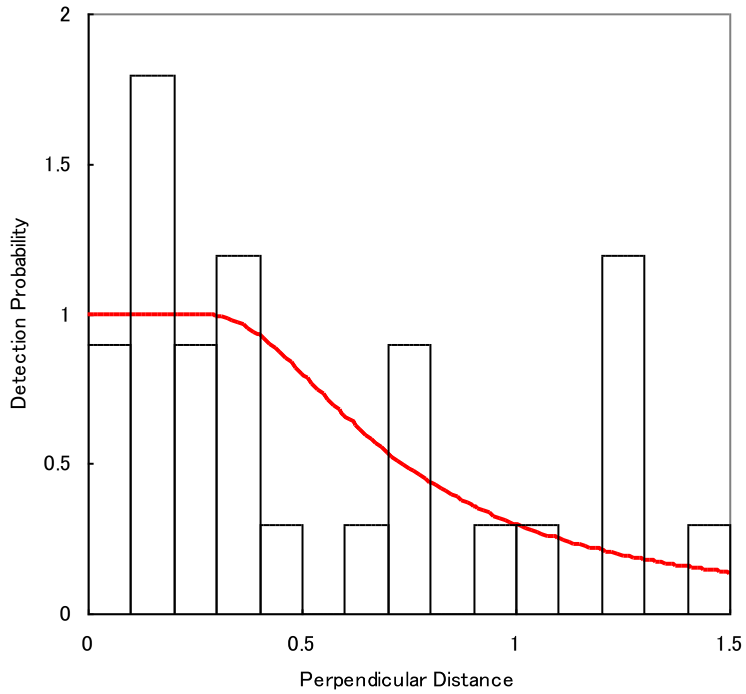
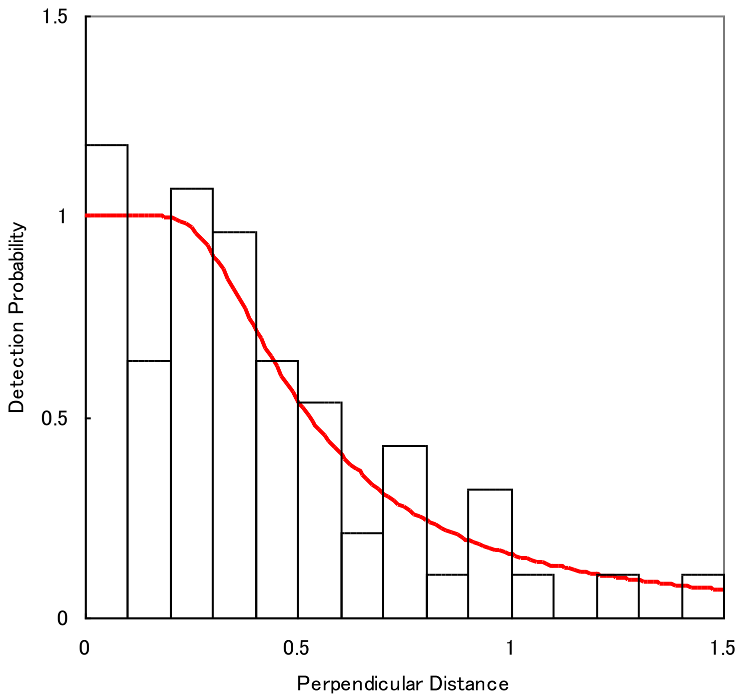


Figure 33. Track line actually surveyed and primary sighting positions of common minke whale schools in the 2007 JARPN II.

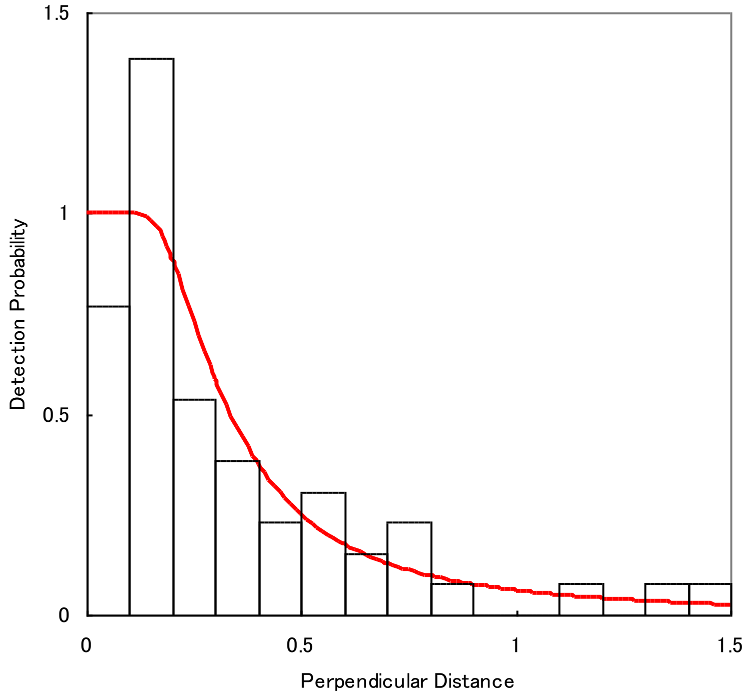


Beaufort state = 1

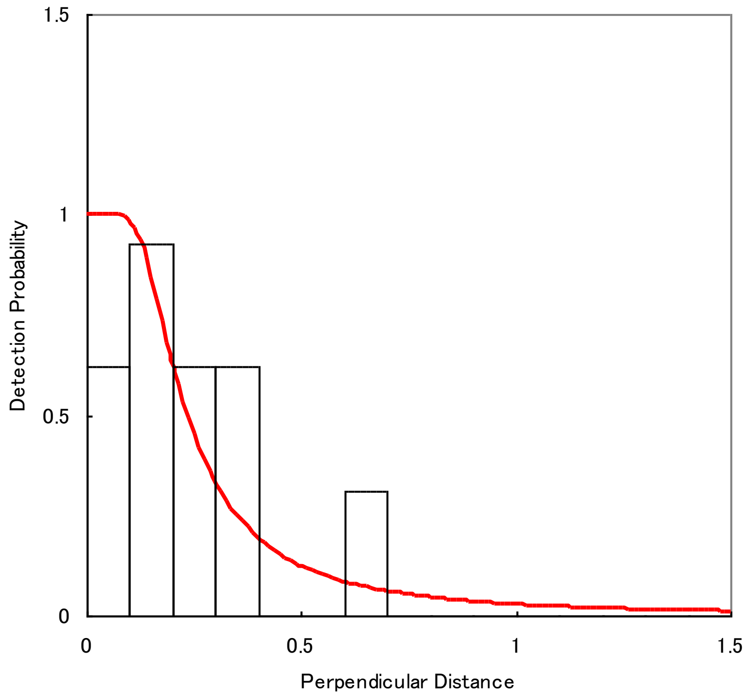


Beaufort state = 2

Figure 34. Plot of the detection function and distribution of the perpendicular distance of the primary sightings for each Beaufort state.



Beaufort state = 3



Beaufort state = 4

Figure 34. (Cont.)