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ABSTRACT
This paper provides abundance estimate for western North Pacific common minke whales (*Balaenoptera acutorostrata*) based on dedicated sighting surveys conducted in 2013, 2015, 2016, 2017 and 2018 with IWC oversight. The common minke whale abundances in sub-areas 7, 8, 9, 10E and 11 were estimated by standard methodology following the 'Requirements and Guidelines for Conducting Surveys and Analysing Data within the Revised Management Scheme'. These estimates are presented for possible use in conditioning of the current *Implementation Review* for western North Pacific common minke whale.

INTRODUCTION

At the first Workshop on *Implementation Review* for western North Pacific common minke whale, it was strongly recommended that estimates for all surveys over 2013 to 2018 be prepared for tabling at the 2019 meeting of the Scientific Committee (IWC, 2019). This paper provides abundance estimation for the common minke whales based on dedicated sighting surveys during 2013-2018. These estimates are presented for possible use in conditioning of the current *Implementation Review* for western North Pacific common minke whale.

MATERIALS AND METHODS

Sighting surveys

Dedicated sighting surveys under JARPNII were conducted in 2013, 2015, 2016, 2017 and 2018 with IWC oversight. Survey areas and survey periods for these surveys are shown in Table 1. Plot of primary sightings and searching effort for the surveys in 2013, 2015, 2016, 2017 and 2018 are shown in Figures 1, 2, 3, 4 and 5, respectively. Survey design of these surveys and analytical procedures applied followed the IWC guidelines (IWC, 2012).

Analytical Procedure

It is assumed that g(0)=1. Truncation distance is 1.5 n.miles. The truncated distance was chosen because the distance is same as the previous analyses from line transect surveys (e.g. Hakamada and Matsuoka, 2016) Abundance and its variance were estimated based on a Horvitz-Thompson like estimator of abundance expressed by formula (1) and (2), respectively.

$$P = \frac{A}{2WL}\sum_{i=1}^{n}\frac{s_i}{p_i(z_i)}$$

$$= \frac{A}{2L}\sum_{i=1}^{n} s_i \hat{f}(0|\boldsymbol{z}_i) \qquad (1)$$

where P is abundance estimate, A is area size of the surveyed area, W is truncation distance (1.5 n.miles for the common minke whales) L is searching effort, n is the number of schools detected within perpendicular distance of W, s_i is school size of ith detection, $p_i(z_i)$ is the probability that school i is detected given that it is within the perpendicular distance W and given the covariate z_i. $f(0|z_i)$ is conditional probability density function of distance 0 given covariates z_i.

$$var(P) = \left(\frac{A}{2WL}\right)^2 \left\{\frac{1}{L(K-1)}\sum_{k=1}^{K} l_k \left(\frac{P_{Ck}}{l_k} - \frac{P_C}{L}\right)^2 + \sum_{j=1}^{r}\sum_{m=1}^{r} \frac{\partial P_C}{\partial \theta_j}\frac{\partial P_C}{\partial \theta_m} H_{jm}^{-1}(\theta)\right\} \quad (2)$$

where K is the number of transect, l_k is searching distance in kth transect, P_{Ck} is abundance estimate in covered region (within W n.miles from track line surveyed) in kth transect, P_C is abundance estimate in the covered region, $H_{jm}^{-1}(\theta)$ is the jmth element of inverse of Hessian matrix of detection function for covariate θ.

Multiple Covariate Distance Sampling (MCDS) Engine in DISTANCE program was used (Thomas *et al*., 2010). Hazard rate (Equation (3)) and Half normal (Equation (4)) models were considered as candidate models for the detection function. Full model of the two detection functions were provided by

$$g(x) = 1 - \exp\left\{-\left(x/_{a\exp(Size + Beaufort + Vessel)}\right)^{-b}\right\} \quad (3)$$

$$g(x) = exp\left[-x^2/_{2a^2\, exp\{2(Size + Beaufort + Vessel)\}}\right] \quad (4)$$

where x is perpendicular distance, a and b ($b \geqq 1$) are parameters, *Size* is observed school size, *Beaufort* is categorical variable for Beaufort sea state (good: 0-3, bad: 4-5) and *Vessel* is categorical variable for whether research vessel used is *Yushin-maru* type or not. Because the number of primary sightings is low, primary sightings occurred during 2008-2012 were added to 2013-2018 data in order to estimate the detection function better. AIC was used to select the best model to estimate detection probability.

RESULTS

Table 2 shows AIC for each model of the detection functions. The best model is Hazard rate model (i.e. Equation (3)) with *Vessel* covariate using 2008-2018 data. A plot of the best detection model compared to relative frequency of the detection are shown in Figure 6. Figure 7 shows a QQ plot of the detection function, which suggests that points fall nearly close to the 1–1 line, indicating that the model provides a good fit (Burnham *et al*., 2004). The abundances estimated by sub-areas using the best model of the detection function are listed in Table 3. The estimates assume that $g(0)$=1. Areal coverage in each sub-area is shown in Table 3.

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Table 1. Research area, research period, research vessel, searching distance and the numbers of primary sightings for the common minke whales during sighting surveys 2013-2018.

Year	Area	Vessel	Period	Searching Effort (n. milees)	No. of primary sightings
2013	7WR	*YS1*	21 May - 5 Jun	1047.3	1
2013	7E	*YS1*	6 Jun - 21 Jun	598.9	0
2013	8	*YS2*	21 May - 21 Jun	1824.0	5
2015	9	*YS1*, *YS2*	29 Apr - 30 May	2729.3	2
2016	7CS	*YS1*	14 Aug - 3 Sep	754.3	0
2016	7CN	*YS1*	30 Jul - 14 Aug	651.8	8
2016	7WR	*YS2*	31 Jul - 13 Aug	913.7	1
2016	7E	*YS2*	15 Aug - 2 Sep	471.9	0
2017	7CS	*YS3*	1 May - 23 May	970.6	10
2017	7CN	*YS1*	30 Apr - 26 May	1052.0	11
2018	11	*YS2*	14 May - 22 May	502.8	12
2018	10E	*YS2*	24 May - 22 Jun	1103.0	17
2018	7CS	*KY7*	26 May - 5 Jun	615.9	3
2018	7CN	*KY7*	12 May - 25 May	648.2	4

Table 2. AIC for each model of the detection function. Third column indicates AIC for 2008-2018 sighting data. The forth column indicates sum of AIC for the 2008-2012 data and for the 2013-2018 data. S is a covariate for school size, B is a covariate for Beaufort Sea state and V is a covariate for vessel type (See text for more detail.).

Formula	Covariates	AIC	
		2008-2018	2008-12, 2013-18
Hazard rate	No	17.055	21.042
	S+B	19.596	27.019
	S	19.046	24.778
	B	17.630	23.408
	V	**14.847**	18.856
	S+B+V	17.910	23.704
	S+V	38.423	31.344
	B+V	16.035	20.148
Half normal	No	38.404	40.390
	S+B	31.150	36.205
	S	39.042	43.018
	B	30.196	33.127
	V	37.383	28.690
	S+B+V	32.616	22.624
	S+V	38.423	31.344
	B+V	31.519	19.692

Table 3. Abundance estimates by sub-areas for the best detection function model based on sighting survey data during 2013-2018. A is the area size of the sub-area, L is searching distance, n_s is the number of the primary sightings, n_w is the number of the primary detected whales, P is the abundance estimate, CV(P) is the coefficient of the variance for P, 95%LL is the 95% lower limit of the P and 95% UL is the 95% upper limit of the P.

Year	Stratum	Month	Areal coverage	A	L	n_s	n_w	n_w/L*100	CV(n_w/L)	P	CV(P)	95%LL	95%UL
2013	7WR	May-Jun	89%	72,991	1047.3	1	1	0.095	0.998	**65**	1.007	9	464
2013	7E	Jun	57%	48,208	598.9	-	-	-	-	-	-	-	-
2013	8	May-Jun	65%	162,789	1824.0	5	5	0.274	0.628	**413**	0.586	130	1,307
2015	9	Apr-May	87%	499,235	2729.3	1	1	0.037	0.983	**140**	0.963	18	1,099
2016	7CS	Aug-Sep	100%	26,826	754.3	-	-	-	-	-	-	-	-
2016	7CN	Jul-Aug	75%	16,171	651.8	8	8	1.227	0.402	**185**	0.423	77	448
2016	7WR	Jul-Aug	89%	72,991	913.7	1	1	0.109	1.054	**75**	1.062	9	616
2016	7E	Aug-Sep	57%	48,208	471.9	-	-	-	-	-	-	-	-
2017	7CS	May	100%	26,826	970.6	10	11	1.133	0.480	**284**	0.497	105	769
2017	7CN	Apr-May	75%	18,281	1052.0	11	11	1.046	0.353	**179**	0.377	84	379
2018	11	May	35%	9,749	502.8	12	13	2.585	0.462	**235**	0.481	91	606
2018	10E	May-Jun	100%	40,648	1103.0	17	18	1.632	0.459	**620**	0.478	243	1,578
2018	7CS	May-Jun	100%	26,826	615.9	3	3	0.487	0.739	**245**	0.828	56	1,073
2018	7CN	May	75%	18,281	648.2	4	4	0.617	0.689	**212**	0.784	52	867

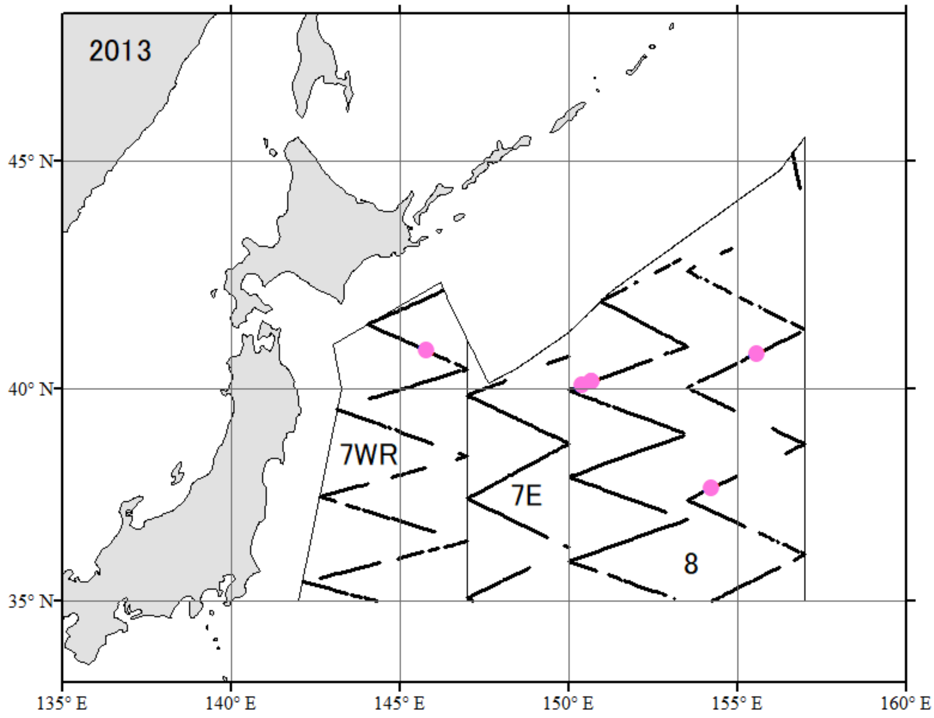

Figure 1. Primary sighting position of the common minke whales (pink circle) and searching effort during sighting survey in sub-areas 7WR, 7E and 8 conducted in 2013.

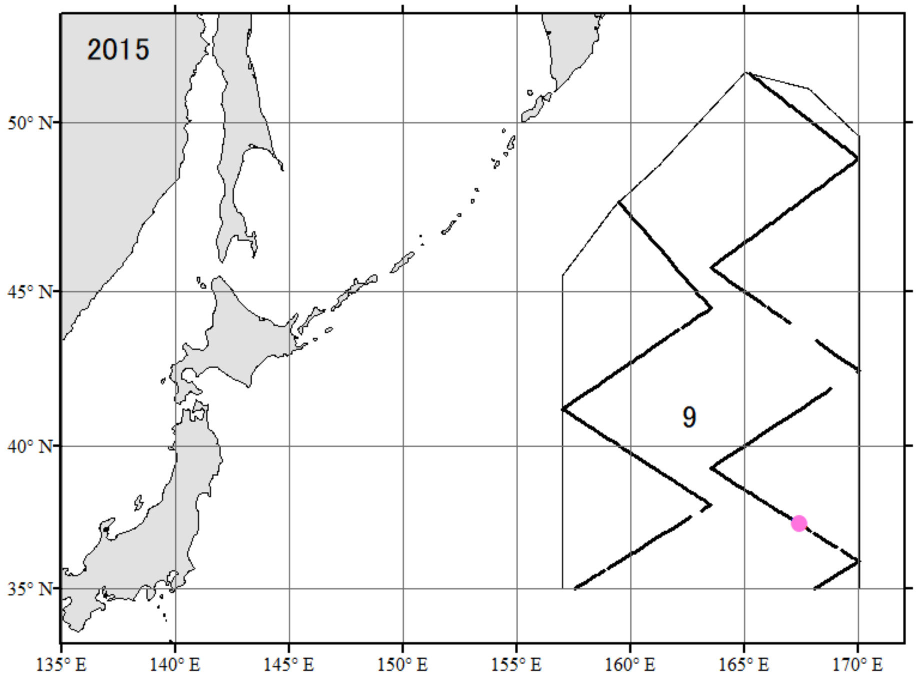

Figure 2. Primary sighting positions of the common minke whales (pink circle) and searching effort during sighting survey in sub-area 9 conducted in 2015.

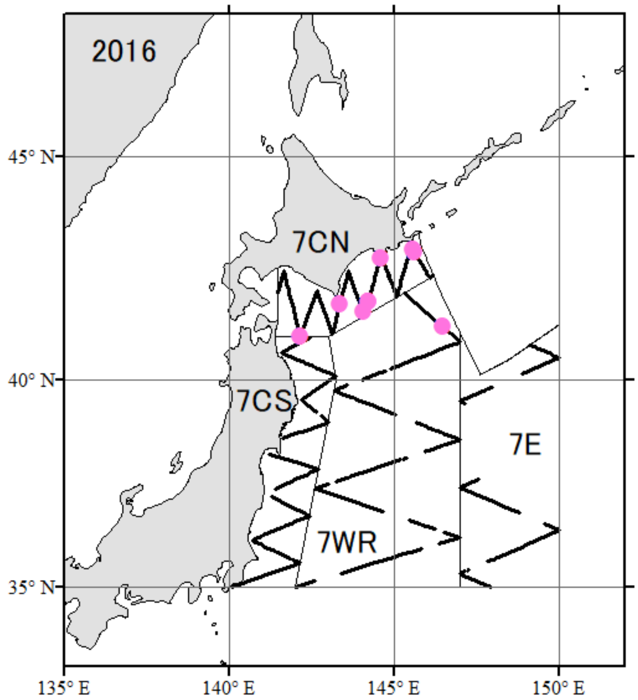

Figure 3. Primary sighting positions of the common minke whales (pink circle) and searching effort during sighting survey in sub-areas 7CS, 7CN, 7WR and 7E conducted in 2016.

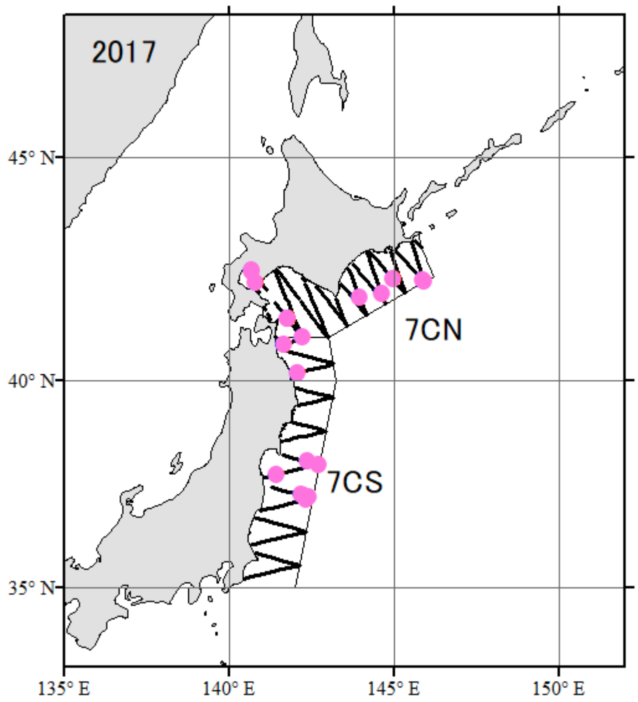

Figure 4. Primary sighting positions of the common minke whales (pink circle) and searching effort during sighting survey in sub-areas 7CS and 7CN conducted in 2017.

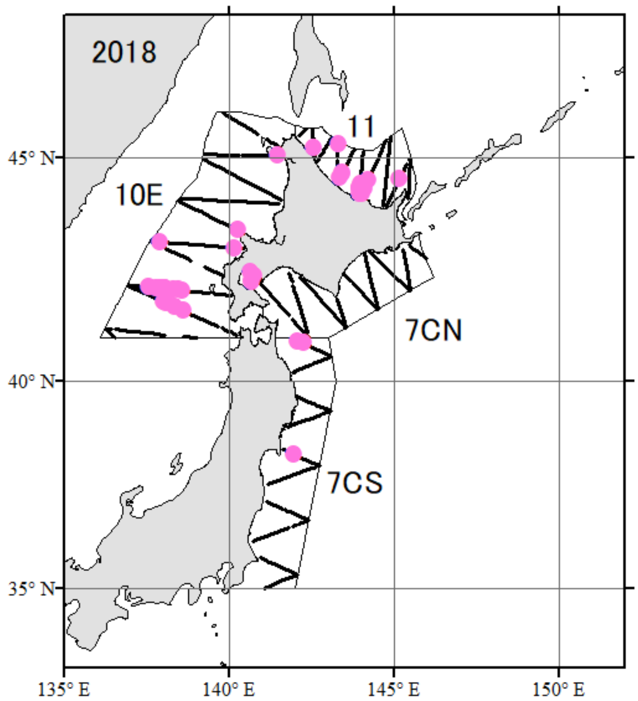

Figure 5. Primary sighting positions of the common minke whales (pink circle) and searching effort during sighting survey in sub-areas 7CS, 7CN, 10E and 11 conducted in 2018.

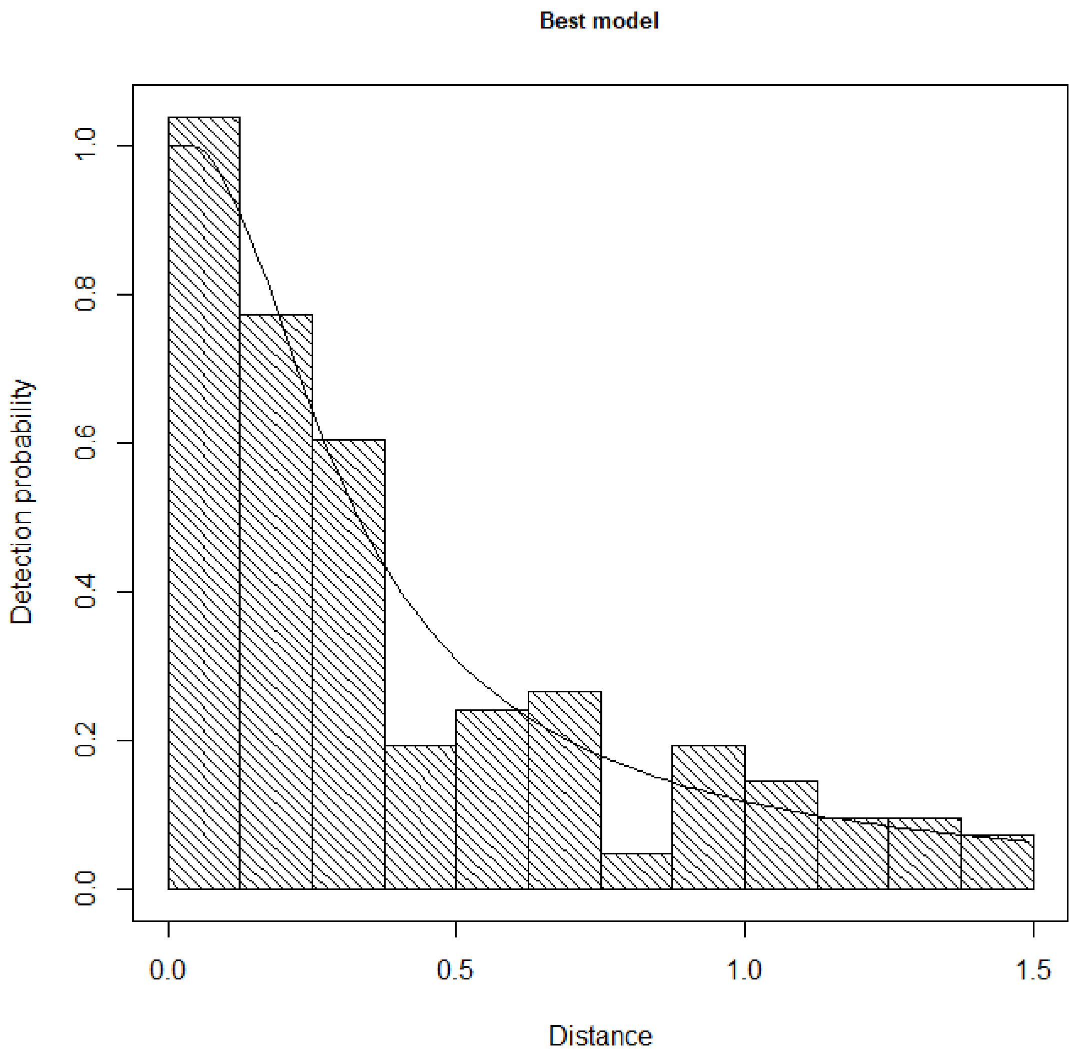

Figure 6. Plot of relative frequency of detection by perpendicular distance and the best detection function model.

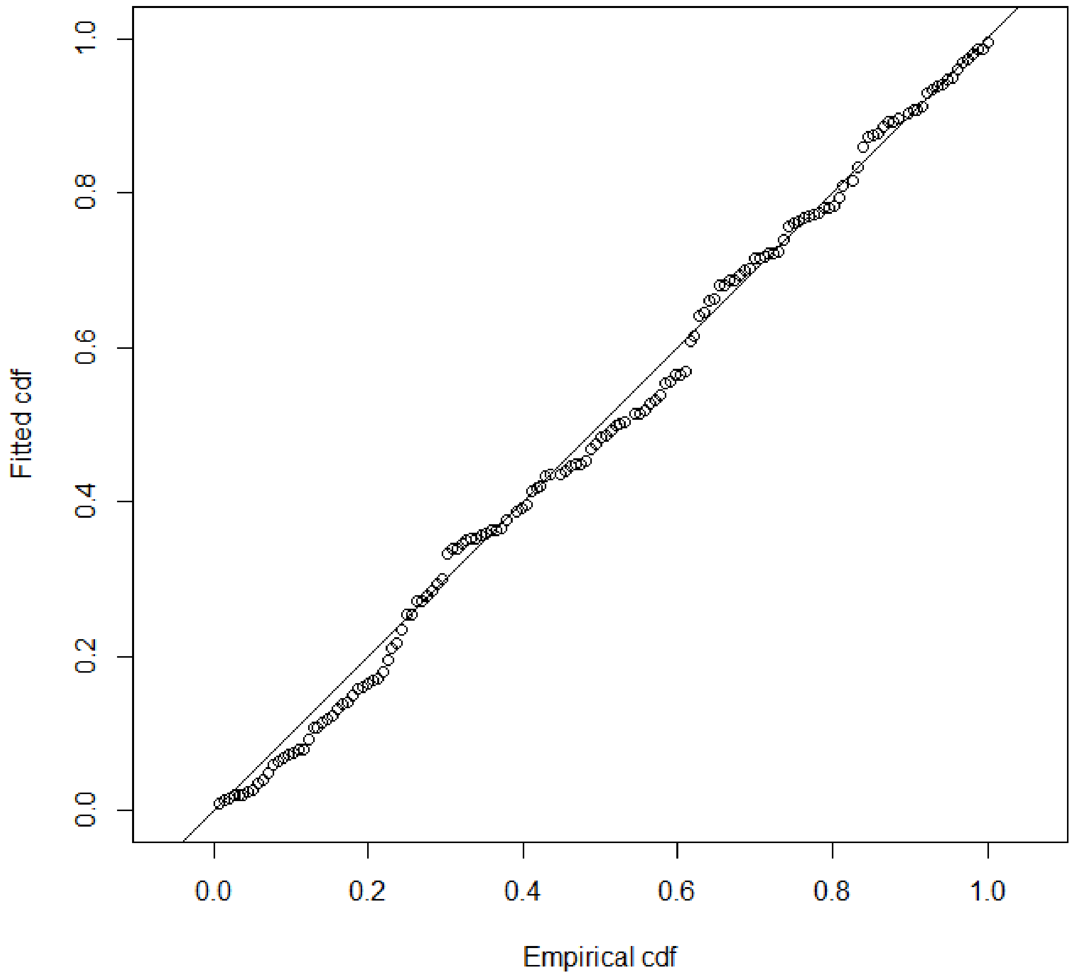

Figure 7. Quantile-Quantile (QQ) plot for the Hazard rate model with vessel covariate (The best model).