Further examination of the distribution of western North Pacific minke whales applying a logistic regression analysis for reproductive data collected by the JARPN surveys

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ABSTRACT

In the Workshop in the JARPN review meeting held in February 2000, it was recommended that biological data should be further analyzed (IWC, 2000) in order to clarify the sexual and reproductive segregation of western North Pacific minke whales. In response to the recommendation, we applied a logistic regression analysis for some biological parameters (proportion of males, sexual maturity rates of males and females) using biological data obtained during the JARPN surveys. For the present analyses, we used biological data of 419 males and 79 females collected in sub-areas 7, 8, 9 and 11 through the JARPN surveys in May to September in 1994 to 1999. The logistic regression analyses for the proportion of males, sexual maturity rates of males and females show the following. (1) There was a clear difference in the proportion of males between sub-areas on the Pacific side and the Okhotsk side. Though females were present in relatively high proportion in the Okhotsk side sub-area, males dominated in the Pacific side sub-areas. In the research area, mature males were dominant and the number of immature males was very small. (2) The proportion of immature males was higher in May, June and September in comparison with midsummer. The proportion of mature males was highest in July and then decreased. These data indicate a seasonal change in distribution. (3) It was revealed that there is a possibility that the maturity rate of females changed by the month, though the sample size of females was very small. In the JARPN review meeting, with reference to the pending problem that where immature animals distributed mainly as the number of immature animals were very small and mature males were dominant in the research. Based on the previous reports of migration pattern of immature animals and the stranding and incidental take records in Japan, it is reasonable to assume that the majority of immature animals are distributed near the Pacific coast of Japan.

KEYWORDS: NORTH PACIFIC MINKE WHALE, JARPN, BIOLOGICAL PARAMETER, SEGREGATION

INTRODUCTION

Many authors have already reported that there is sexual and reproductive segregation related to time and area among minke whales distributed in the waters around Japan (Matsuura, 1936; Omura and Sakiura, 1956; Ohsumi, 1983; Wada, 1989; Kato, 1992; Hatanaka and Miyashita, 1997). The JARPN surveys provided useful data on distribution of North Pacific minke whales in the research area with segregation depending on sex and reproductive status. The following results were presented to the JARPN review meeting (Zenitani *et al.*, 2000): (1) minke whales distributed in sub-areas 7, 8 and 9 of the Pacific side in spring (May to June) to summer (July to September) formed incomplete composition (dominant mature males, few mature females and few immature animals); (2) the proportion of immature animals in sub-area 7, 8 and 9 were slightly higher in spring than in summer; (3) mature females were present in relatively high proportion in July and August in sub-area 11 compared with other sub-areas in the Pacific side; (4) there was no case when all composition (mature males, mature females, immature males, immature females) of minke whales were found in the same area; (5) incomplete composition of sex and sexual status in sub-areas and seasons indicates that an independent stock unit in each sub-area was not existed.

During the JARPN review meeting, in discussion of the incomplete composition of sex and sexual status, it was noted that: (1) males dominated in sub-areas 7, 8 and 9, and mature females in sub-areas 8 and 9 might be distributed in the northern part (in the Russian EEZ) of these sub-areas; (2) it was not clear where immature animals area distributed.

The Workshop indicated the possibility that the different sample sizes by months and by sub-areas influenced the low proportion of immature animals, and recommended a multivariate statistical analysis of these data. The present made further analysis using the logistic regression analyses for some biological parameter (proportion of male, sexual maturity rates of males and females).

MATERIALS AND METHODS

Biological data used in the present study

Table 1 indicates the number of samples collected through the JARPN surveys in 1994 to 1999 by sub-area and month. The present study used the biological data obtained from 80 individuals (47 males and 33 females) in sub-area 11, 139 individuals (122 males and 17 females) in sub-area 7, 91 individuals (86 males and 5 females) in sub-area 8, and 188 individuals (164 males and 24 females) in sub-area 9.

Determination of sexual maturity

Sexual maturity for males was determined by examination of histological status of testis tissues. Males with seminiferous tubules over 100 μm diameter or spermatid in the tubule were determined to be sexually mature (Kato, 1986; Kato *et al.*, 1990, 1991). Sexual maturity for females was determined by the presence of at least one corpus luteum or albicans in both ovaries.

A multivariate statistical analyses used

In order to extract the real trends in the proportion of males and the sexual maturity rate of males and females, we applied the following logistic regression model and examined which of the categorical variables (sub-areas, months of sampling and years of sampling) significantly affect the proportion of males and sexual maturity rate of males and females using stepwise model selection.

$$\log (p/1\text{-}p) = \alpha + \beta\,(\text{sub-area}) + \gamma\,(\text{month}) + \varepsilon\,(\text{year})$$

where p is the biological parameter, such as the proportion of males, on the sexual maturity of rates of males and females. In order to select the best model, we used the AIC (Akaike Information Criterion). However, as it is known that the AIC tends to be a conservative criterion in that a model with more parameters results than when using the BIC or likelihood ratio test (Quinn and Deriso, 2000), as needed the BIC (Bayesian Information Criterion) was used to select the best model. The AIC and the BIC are given by

$$AIC = -2 \log (L) + 2p$$
$$BIC = -2 \log (L) + p \log (n)$$

where L is the maximized likelihood function (Quinn and Deriso, 1999), p is the number of parameters, and n is sample size.

When the model with the variable of sub-area was selected, we assume the sub-area groupings and select the best model:

1. four groups: sub-area 11, sub-area 7, sub-area 8, sub-area 9;
2. one group (all sub-areas combined): sub-area 11=7=8=9;
3. two groups
   (1) three sub-areas combined: for example (a) sub-area 11, sub-area 7=8=9,
   (b) sub-area 9, sub-area 8=9=11,
   (c).....etc.
   (2) two sub-areas combined: for example (a) sub-areas 11=7, sub-area 8=9,
   (b) sub-areas 11=9, sub-area 7=8,
   (c)....etc.;
4. three groups (two sub-areas combined): for example (a) sub-area 11, sub-area 7, sub-area 8=9,
   (b) sub-area 11, sub-area 9, sub-area 7=8,
   (c).....etc..

RESULTS

Proportion of male minke whales

Table 2 shows the proportion of male minke whales by sub-areas and months. If we compare the proportion of males between sub-areas, the values in sub-areas 7, 8 and 9 (87.2-94.5%) are high while the value is low in sub-area 11 (58.8%). This shows a clear difference in the proportion of males between sub-areas on the Pacific side and the Okhotsk side. The proportion of males in sub-area 11 in July to August was 56.0-63.3%. This is lower than that of sub-areas 7, 8 and 9. The proportion of males was high in sub-areas 7, 8 and 9 in May to September (sub-area 7: 86.5-100.0%, sub-area 8: 87.5-100.0%, sub-area 9: 74.1-100.0%). These values in sub-areas 7, 8 and 9 tend to be slightly lower in spring (May to June) than in summer (July to September).

Then, we applied a logistic regression model. Through the stepwise model selection, the model using sub-area as the categorical variable was selected as the best model by the AIC. This model revealed that the proportion of males is related to sub-area. The parameters estimated by the best model with sub-area are shown in Table 3. The proportion of males estimated is 0.588-0.945 and the value in sub-area 11 (0.588) is lower than that for other sub-areas (Fig. 1).

We further examined the difference of proportion of males among sub-areas using the AIC and the BIC. The results are shown in Table 4. Though model Ⅲ (sub-area 11, sub-area 8, sub-area 7=8) was selected as the best model by the AIC (AIC = 400.0689), this value of the AIC is similar to the value of AIC of the other two models Ⅰ (sub-area 11, sub-area 7, sub-area 8, sub-area 9) and Ⅱ (sub-area 11, sub-area 7=8=9) (the value of AIC: model Ⅰ = 402.0480, model Ⅱ = 402.2113). Therefore we selected the best model using the BIC. Model Ⅱ is selected the best model (BIC = 410.6325) however the BIC of this model is also similar to that of model Ⅲ (BIC = 412.7007). The AIC and the BIC of model Ⅳ (sub-area 11 is same to other areas) is clearly different from those of models Ⅰ, Ⅱ and Ⅲ (sub-area 11 is not same to other areas). However the AIC and the BIC of models Ⅱ and Ⅲ combined sub-area 7, 8 and 9 indicate also similar each other. Though there is clear difference in the proportion of males between sub-area 11 and other sub-areas on the Pacific side, the difference in the proportion of males among sub-areas 7, 8 and 9 is small. The proportion of males estimated by the best model using the BIC in sub-area 11 of the Okhotsk side is 0.587 and on the Pacific side is 0.890 (Table 5). This suggests that the proportion of males is low and that females are present in relatively high proportion in the Okhotsk side area.

Male maturity rate

Table 6 shows the sexual maturity rate of males by sub-areas and months. If we compare the maturity rate of males between sub-areas, the value in coastal sub-area 7 (82.0%) is slightly lower than that in the other sub-areas 8 ,9 and 11 (90.7-91.5%). Sexual maturity rate of males in sub-area 11 in July to August was 89.5-92.9%. Sexual maturity rate of males in sub-area 7 from May to September was 69.2-93.3%. This value is high in August (93.3%) and low in September (69.2%) and slightly lower in May to June than in August. Sexual maturity rate of males in sub-areas 8 and 9 are high (sub-area 8: 84.8-100.0%, sub-area 9: 79.6-100.0%) and the values in sub-areas 8 and 9 tend to be slightly lower in May to June than in July to August.

In order to extract the real trends in the sexual maturity rate of males, a logistic regression model was applied. The results are shown in Table 7. Through the stepwise model selection, the model with the categorical variable of month was selected as the best model by the AIC (AIC = 292.7084). The model revealed that the maturity rate of males is related to the month of sampling. The estimated parameters from this model are shown in Table 8. The maturity rate of males in May to September is very high (0.765-0.962). The maturity rate of males is highest in July and then decreases (Fig 2). This suggests that the proportion of immature males is slightly higher in May, June and September in comparison with those in July and August.

Female maturity rate

Table 9 indicates the sexual maturity rate of females by sub-areas and months. The sexual maturity rate in sub-areas 7, 8, 9 and 11 is 47.1-63.6%. Those in sub-area 11 in July to August are 63.6%. Although sample size is small for comparison, the maturity rate in spring in sub-areas 7, 8 and 9 tends to be lower than in summer.

As was done for males, a logistic regression model was applied. The results are shown in Table 10. Through the stepwise model selection, the model containing only the constant was selected as the best model by the AIC. However, the AIC of this model (109.9806) is almost the same as that of the model with the categorical variable of month (109.9817). This indicates that the month of sampling did not affect the maturity rate of females. It is probable that the small sample size of females influenced these analyses. Therefore, we applied a logistic regression using the sub-area as a string variable. Next, the model with the string variable of month was selected as the best model and the values of the intercept and coefficient were estimated as follows:

$$\log (p/1-p) = -3.233 + 0.529 \text{ (month)}$$

This indicates that there is a possibility that the month of sampling had a light influence on the maturity rate of females (Fig. 3).

An additional analysis using samples excluding J stock animals

It was known that both O and J stocks are mixed in sub-area 11 (Wada, 1991; Kato, 1992; Best and Kato, 1992), and the JARPN surveys also clarified that O and J stock animals are mixed in sub-area 11 in July and August (Goto and Pastene, 1997; Pastene *et al.*, 1998; Fujise *et al.*, 2000). Therefore, based on genetic identification (O stock or J stock) on individual minke whales based on mtDNA analyses carried out by Goto *et al.* (2000), we also examined the distribution of O stock animals which J stock animals were excluded applying the same logistic regression analyses.

The proportion of males in sub-area 11 was different from that in sub-areas of the Pacific side. O stock females presented in a relatively high proportion in sub-area 11, and males were dominant in the sub-areas of the Pacific side. The sexual maturity rate of males was highest in July and then decreased, and the proportion of immature males tended to increase in May, June and September in comparison with that of July and August. These results are similar to that above obtained applying a logistic regression analyses of all samples.

DISCUSSION

Using biological data collected in the JARPN surveys and applying a logistic regression analysis, it was clarified that: (1) There was a clear difference in the proportion of males between sub-areas in the Pacific side and in the Okhotsk side. The proportion of males in sub-area 11 was low and high in the Pacific side (sub-areas 7,8 and 9). (2) The sexual maturity rate of males was high in the research area. The proportion of mature males was highest in July and then decreased. Seasonal changes in the proportion of mature males was observed. (3) It was revealed that there is a light influence of the months of sampling on the maturity rate of females. However, sample size of females was very small and possibly influenced this analyses.

During the JARPN review meeting, it was not clear where immature animals mainly distributed. It was concluded that the distribution of immature animals was related to month of sampling, not sub-area. The present study clarified that the distribution of immature animals showed seasonal change; that the proportion of immature males tended to increase in May, June and September, and that some immature animals were distributed in the research area in spring and early autumn. However, the number of immature animals in the research area was very small and mature males were dominant, and the main distribution area of immature animals was not directly shown by the JARPN surveys.

Hatanaka and Miyashita (1997) reported on the migration pattern of immature minke whales based on the data obtained through by the small-type whaling operations and test whaling by the *Miwamaru*. These data indicated that: immature males migrated into the southern part of coastal sub-area 7 in April and then dispersed to the northern part of sub-area 7 (the Pacific coast of Hokkaido) and the Okhotsk coast of Hokkaido (sub-area 11) from June; and they remain in these coastal areas until the end of the feeding season; immature females follow a similar pattern to their male counterparts, but larger immature females are also relatively abundant in the Okhotsk coast of Hokkaido (sub-area 11) in May and June. The main distribution area of immature animals reported by Hatanaka and Miyashita (1997) was the southern part of sub-area 7 that the JARPN surveys did not covered.

Furthermore, Ishikawa (1994) reported the stranding and incidental take records of minke whales in Japan, as follows; the majority of stranding and incidental takes of minke whales in the Pacific coast of Japan is comprised small immature animals and there is a high possibility that young animals tend to be distributed in the coastal area.

Based on the above information, it is reasonable to assume that the majority of immature animals are distributed near the Pacific coast of Japan.

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Table 1. Number of samples by sub-area and month collected under the 1994-1999 JARPN surveys.

	Male						Female					
Sub-area	May	Jun.	Jul.	Aug.	Sep.	Total	May	Jun.	Jul.	Aug.	Sep.	Total
11	-	-	28	19	-	47	-	-	22	11	-	33
7	49	45	0	15	13	122	7	7	1	0	2	17
8	7	33	41	5	-	86	1	3	1	0	-	5
9	20	49	62	29	4	164	7	5	7	5	0	24
Total	76	127	131	68	17	419	15	15	31	16	2	79

Table 2. Proportion of male minke whales collected under the 1994-1999 JARPN surveys by sub-area and month.

	Sub-area 11			Sub-area 7			Sub-area 8			Sub-area 9			Combined		
Month	Male	Female	Proportion of male (%)	Male	Female	Proportion of male (%)	Male	Female	Proportion of male (%)	Male	Female	Proportion of male (%)	Male	Female	Proportion of male (%)
May	-	-	-	49	7	87.5	7	1	87.5	20	7	74.1	76	15	83.5
Jun.	-	-	-	45	7	86.5	33	3	91.7	49	5	90.7	127	15	89.4
Jul.	28	22	56.0	0	1	0.0	41	1	97.6	62	7	89.9	131	31	80.9
Aug.	19	11	63.3	15	0	100.0	5	0	100.0	29	5	85.3	68	16	81.0
Sep.	-	-	-	13	2	86.7	-	-	-	4	0	100.0	17	2	89.5
Total	47	33	58.8	122	17	87.8	86	5	94.5	164	24	87.2	419	79	84.1

Table 3. Estimated parameters for the proportion of males using the best model.

Parameter		Coefficient	S.E.	Proportion of males	S.E.
α	constant	1.971	0.259	-	-
β	sub-area 7	0.000	-	0.878	0.028
	sub-area 8	0.873	0.528	0.945	0.024
	sub-area 9	-0.049	0.339	0.872	0.024
	sub-area 11	-1.617	0.344	0.588	0.055

Table 4. Results of sub-area model selection using AIC and BIC for the proportion of male minke whales.

Model	Sub-area	AIC	BIC
Model I	11, 7, 8, 9	402.0480	418.8904
Model II	**11, 7=8=9**	402.2113	**410.6325**
Model III	**11, 7=9, 8**	**400.0689**	412.7007
Model IV	11=7=8=9	437.6491	441.8597

Table 5. Estimated parameters for the proportion of males using the best model.

Parameter		Coefficient	S.E.	Proportion of males	S.E.
α	constant	2.090	0.156	-	-
β	sub-area 7=8=9	0.000	-	0.890	0.015
	sub-area 11	-1.737	0.276	0.587	0.055

Table 6. Sexual maturity rate of male minke whales collected under the 1994-1999 JARPN surveys by sub-area and month.

	Sub-area 11			Sub-area 7			Sub-area 8			Sub-area 9			Combined		
Month	Imm.	Mat.	Maturity rate	Imm.	Mat.	Maturity rate	Imm.	Mat.	Maturity rate	Imm.	Mat.	Maturity rate	Imm.	Mat.	Maturity rate
May	-	-	-	8	41	83.7	0	7	100.0	3	17	85.0	11	65	85.5
Jun.	-	-	-	9	36	80.0	5	28	84.8	10	39	79.6	24	103	81.1
Jul.	2	26	92.9	0	0	-	3	38	92.7	0	62	100.0	5	126	96.2
Aug.	2	17	89.5	1	14	93.3	0	5	100.0	2	27	93.1	5	63	92.6
Sep.	-	-	-	4	9	69.2	-	-	-	0	4	100.0	4	13	76.5
Total	4	43	91.5	22	100	82.0	8	78	90.7	15	149	90.9	49	370	88.3

Table 7. Results of stepwise model selection using AIC for the sexual maturity rate of males.

Model	AIC
α	304.3452
$\alpha + \gamma$ (month)	**292.7084**
$\alpha + \varepsilon$ (year)	299.1320
$\alpha + \beta$ (sub-area)	304.0703

Table 8. Estimated parameters for the sexual maturity rate of males using the best model.

Parameter		Coefficient	S.E.	Sexual maturity rate of males	S.E.
α	constant	1.776	0.326	-	-
γ	May	0.000	-	0.855	0.040
	June	-0.320	0.397	0.811	0.035
	July	1.450	0.560	0.962	0.017
	August	0.757	0.568	0.926	0.032
	September	-0.598	0.658	0.765	0.103

Table 9. Sexual maturity rate of female minke whales collected under the 1994-1999 JARPN surveys by sub-area and month.

	Sub-area 11			Sub-area 7			Sub-area 8			Sub-area 9			Combined		
Month	Imm.	Mat.	Maturity rate	Imm.	Mat.	Maturity rate	Imm.	Mat.	Maturity rate	Imm.	Mat.	Maturity rate	Imm.	Mat.	Maturity rate
May	-	-	-	4	3	42.9	1	0	0.0	5	2	28.6	10	5	33.3
Jun.	-	-	-	5	2	28.6	1	2	66.7	2	3	60.0	8	7	46.7
Jul.	8	14	63.6	0	1	100.0	0	1	100.0	2	5	71.4	10	21	67.7
Aug.	4	7	63.6	0	0	-	0	0	-	2	3	60.0	6	10	62.5
Sep.	-	-	-	0	2	100.0	-	-	-	0	0	-	0	2	100.0
Total	12	21	63.6	9	8	47.1	2	3	60.0	11	13	54.2	34	45	57.0

Table 10. Results of stepwise model selection using AIC for the sexual maturity rate of females.

Model	AIC
α	**109.9806**
$\alpha + \gamma$ (month)	109.9817
$\alpha + \varepsilon$ (year)	115.1000
$\alpha + \beta$ (sub-area)	114.6043

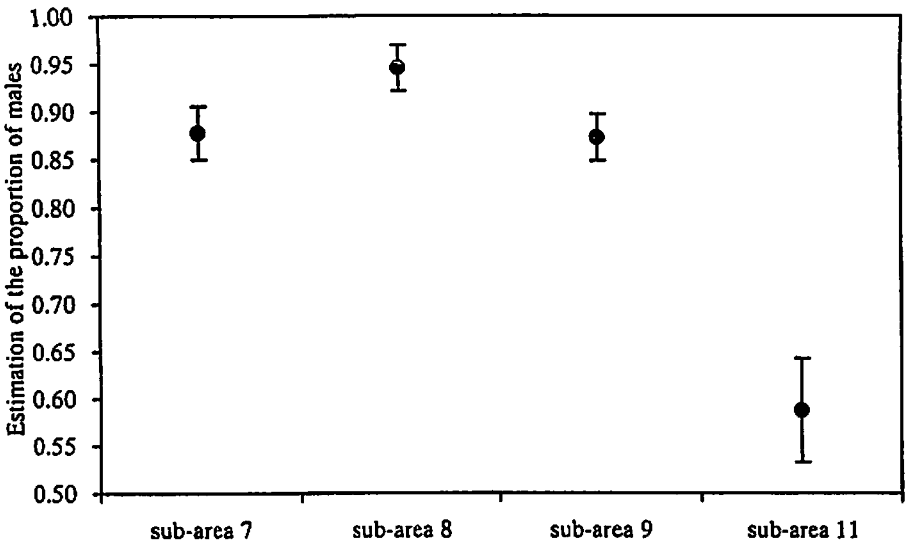

Fig. 1. The estimation of the proportion of males and standard error using the best model.

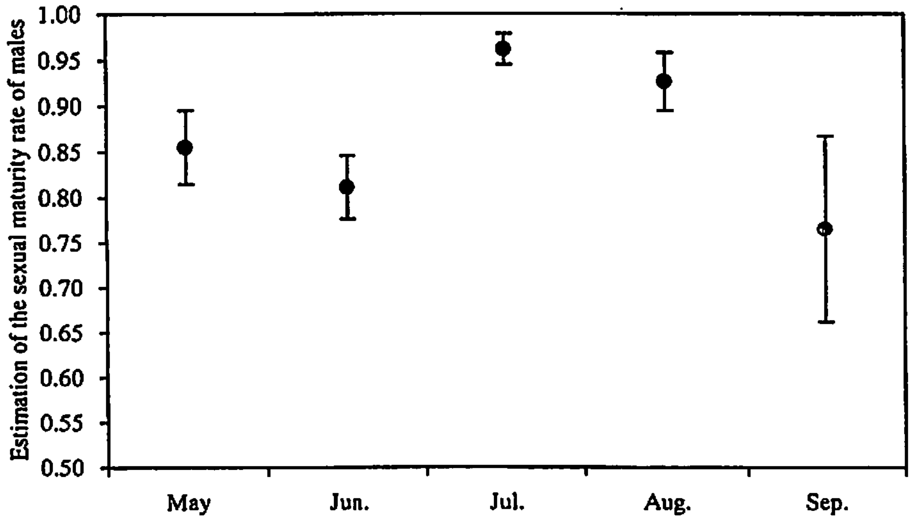

Fig. 2. The estimation of the sexual maturity rate of males and standard error using the best model.

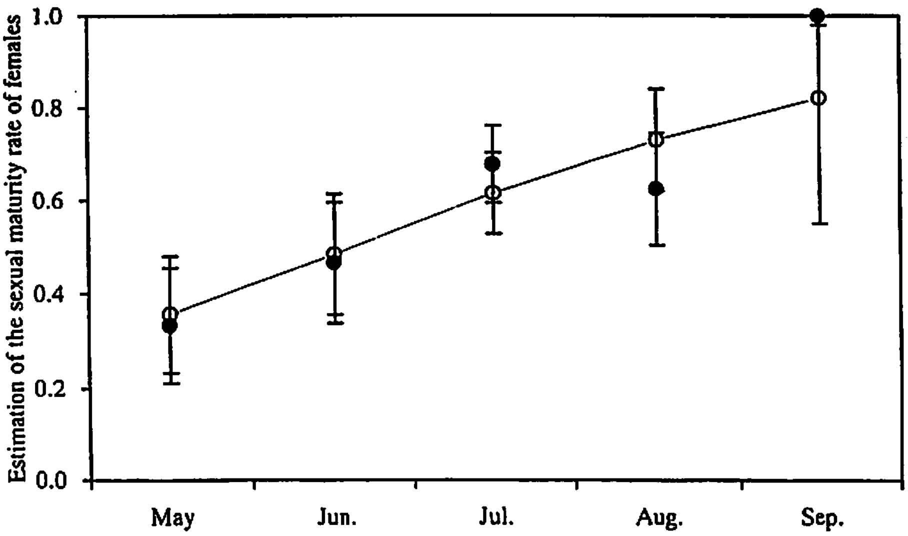

Fig. 3. The estimation of the sexual maturity rate of females and standard error using the best model. (black circle: the categorical variable, open circle: the string variable)