Geographical variations in the external body proportions of Baird's beaked whales (*Berardius bairdii*) off Japan

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ABSTRACT

The use of morphometrics in stock identification studies for cetaceans has been widely employed. In this study, 14 measurements of external body proportions of 172 Baird's beaked whales caught by small-type whaling operations off the Pacific coast of Japan, the Sea of Japan and the Sea of Okhotsk from 1988 to 2004 were examined using canonical discriminant analysis (CANDISC) and ANCOVA with body length as a covariate. The canonical variates obtained from the CANDISC could discriminate between whales from the Pacific coast and the Sea of Japan for both males and females, although some overlap was observed. The flipper size (maximum width and straight length) of the Pacific coast whales was significantly larger (3.9-8.3%) than that of the Sea of Japan whales. The canonical variates of the Sea of Okhotsk whales were located in the middle area between the Pacific coast and the Sea of Japan and a significant difference was not observed, however the Sea of Okhotsk samples consisted of data measured by several researchers and so a sampling error may have been introduced. The morphological differences observed between the Pacific coast and the Sea of Japan whales suggest different stocks occur in these two waters.

KEYWORDS: BAIRD'S BEAKED WHALE; SMALL-TYPE WHALING; MORPHOMETRICS; PACIFIC OCEAN; SEA OF JAPAN; SEA OF OKHOTSK; NORTHERN HEMISPHERE; ASIA; MIGRATION; DISTRIBUTION

INTRODUCTION

Baird's beaked whale (*Berardius bairdii*) belongs to the family Ziphiidae and attains an adult body length of 10-12m (Balcomb, 1989). This species is found in the North Pacific, from the Pribilof Islands and Alaska south to southern California in the east and from Kamchatka and the Sea of Okhotsk to southeast Japan in the west (Balcomb, 1989). In and around the waters off Japan, the existence of three putative stocks (Pacific coast off Japan, the southern Sea of Okhotsk, and the Sea of Japan) has been suggested from earlier studies based on sighting records and whaling operations data (Kasuya, 1986; Kasuya and Miyashita, 1997; Omura *et al*., 1955), but final conclusions have not yet been reached due to a lack of biological materials and data, especially for whales in the Sea of Japan.

This species is a target species for small-type whaling conducted in the coastal waters off Japan. The current annual quota for this species permitted by the Fisheries Agency of Japan is 66 whales (52 in the Pacific coast off Japan, 4 in the Sea of Okhotsk, and 10 in the Sea of Japan), which was set for 2005 onwards (Kishiro, 2005). For effective management of these fisheries and the populations of these whales, it is necessary to clarify its stock structure.

A comparison of multi-measurements of body proportions has been commonly used to obtain information on stock structure for several cetacean species, including fin whales (*Balaenoptera physalus*), common minke whales (*B. acutorostrata*), Bryde's whales (*B. edeni*) and Dall's porpoise (*Phocoenoides dalli*) (Amano and Miyazaki, 1996; Christensen *et al*., 1990; Jover, 1992; Kato *et al*., 1992; Kato and Yoshioka, 1995). In this study, this method is applied to Baird's beaked whales.

MATERIALS AND METHODS

Measurement data

Since 1988, the National Research Institute of Far Seas Fisheries (NRIFSF) has examined almost all harvested Baird's beaked whales at whaling land stations and collected biological data and samples including external measurements. To minimise problems because of measurements being taken by different people, only data collected by the author have been used in the Pacific coast samples (collected from 1992 to 2001) and the Sea of Japan samples (from 1999 to 2004), although for the Sea of Okhotsk samples, small sample sizes mean that data measured by several researchers and held by the NRIFSF were used (those data were collected from 1988 to 2004). The number of samples used in this study are summarised in Table 1. Fig. 1 shows the catch locations of those whales.

As shown in Fig. 2, a total of 18 external measurements were collected from the whales landed at the whaling land stations at Ayukawa, Miyagi prefecture and Wadaura, Chiba prefecture (Pacific coast samples), Hakodate, Hokkaido (Sea of Japan samples) and Abashiri, Hokkaido (Sea of Okhotsk samples). All measurements except for V12 to V18 were measured on a straight and parallel plane to the body axis. Measurements V13, V14, V15, and V16 were excluded from the geographic comparisons due to the small sample size (those parts of the animal were often cut off by fishermen before measurements could be taken) and the difficulty in obtaining an exact measurement, which might result in bias. After outliers were excluded by plotting the data against body length (V1), all values were log-transformed to minimise the size differences between the absolute values of different measurements.

Multivariate comparison

To examine the difference between the morphological features among whales on the Pacific coast, the Sea of Japan, and the Sea of Okhotsk, a multivariate approach was used. In order to address the effect of the difference of body size by geographical area (sampling groups), a principal component analysis (PCA) was first conducted using 14 variables (measurements V1 to V12, V17 and V18). The PCA transforms the original variables into new variables that have zero intercorrelation and new variables (principal components) which have positive values in all eigenvectors;

Table 1

Number of samples used in this study.

Area	Year	Male	Female	Total	Researcher* (No. of whales measured)
Pacific coast of Japan	1992-2001	47	31	78	TK (78)
Sea of Japan	1999-2004	21	20	41	TK (41)
Sea of Okhotsk	1988-2004	34	19	53	HK (9), HY (2), JiT (2), JT (19), KK (2), MA (2), MY (2), RO (4), SK (2), ST (2), TH (2), TI (2), TK (1), TN (2)

*HK: Hidehiro Kato; HY: Hideyoshi Yoshida; JiT: Jiro Takeuchi; JT: Junko Taguchi; KK: Koichi Kimura; MA: Mika Aoki; MY: Mineo Yamamoto; RO: Ryosuke Okamoto; SK: Satoko Kawazu; ST: Shigeo Tabata; TH: Takanori Hara; TI: Tatsuya Isoda; TK: Toshiya Kishiro; TN: Tomoko Nakazato.

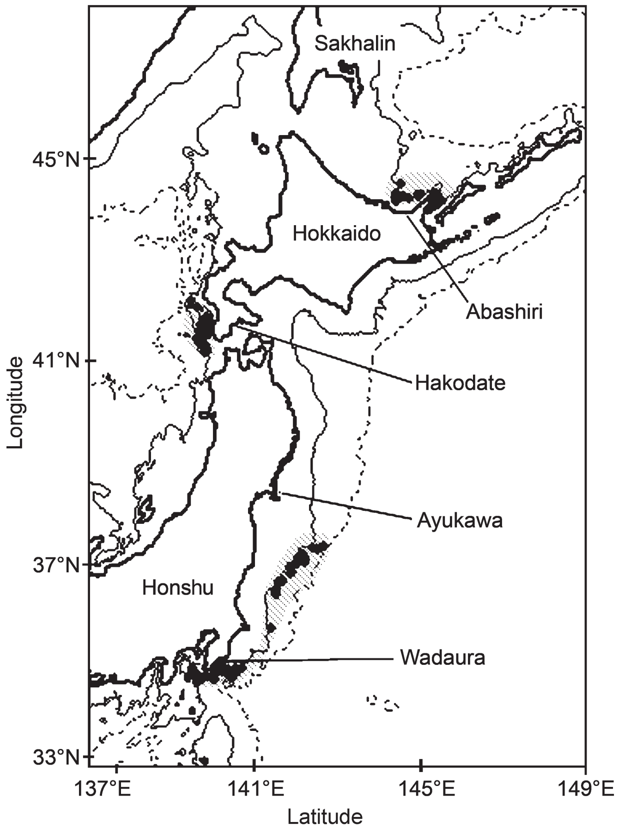

Fig. 1. Catch positions of Baird's beaked whales used in this study. Shaded areas indicate the small-type whaling grounds. Solid and dotted lines indicate the 1,000m and the 3,000m depth contour lines, respectively.

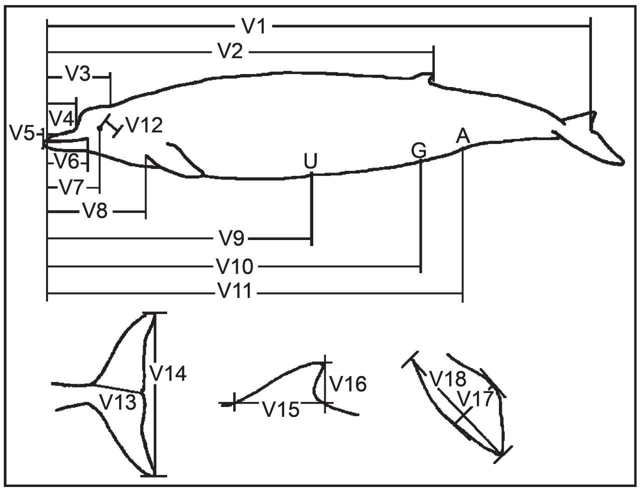

Fig. 2. Schematic diagram of the body proportion measurements of Baird's beaked whales. V1: Body length from tip of snout to notch of flukes; V2: Tip of snout to tip of dorsal fin; V3: Tip of snout to blowhole; V4: Length of snout; V5: Projection of lower jaw beyond tip of snout; V6: Tip of snout to angle of gape; V7: Tip of snout to centre of eye; V8: Tip of snout to anterior insertion of flipper; V9: Tip of snout to umbilicus; V10: Tip of snout to centre of reproductive aperture. V11: Tip of snout to anus; V12: Centre of eye to centre of ear; V13: Fluke length from anterior insertion to notch; V14: Fluke width from tip to tip; V15: Length of base of dorsal fin; V16: Vertical height of dorsal fin; V17: Maximum width of flipper; V18: Straight length of flipper from tip to anterior insertion.

this represents the body size or growth variation of the data (Christensen *et al*., 1990). The remaining components represent the shape variation, and might be not affected by the body size. A canonical discriminant analysis (CANDISC) was then carried out for geographical comparisons, using the scores obtained from the remaining components. Obtained canonical variates were plotted on the first and second axes of the canonical variates by geographic sampling group. Analyses were conducted by sex.

Comparisons of measurements

The comparison of the respective measurements by geographical area (separately by sex) was conducted using an analysis of covariance (ANCOVA) with body length (V1) as a covariate. If no significant relationship with body length was found, an analysis of variance (ANOVA) was conducted. The statistical calculations in this study were conducted using the software package SAS version 8.02.

RESULTS

Multi-measurement comparison

Table 2 shows the mean, standard deviation (SD) and range of respective measurements by sex and geographical area. From the results of the PCA, the first principal component (PRIN1) had positive values in all eigenvectors, and the eigenvalue (ratio of contribution) of the PRIN1 was 42.8% for males and 51.7% for females, respectively. Table 3 shows the canonical variates obtained by the CANDISC using the principal components except for PRIN1. The canonical variate of each whale is plotted in Fig. 3.

The distribution of the canonical variates appeared to reflect the geographic sampling groups in both males and females, although some overlap was observed. In particular, the Pacific coast whales and the Sea of Japan whales were separately distributed along the first canonical axis and the Sea of Okhotsk whales were distributed in and around the middle area between the Pacific coast and the Sea of Japan groups. The squared distance between the geographic areas and the probability of those distances being larger than the Mahalanobis' distance (SAS Institute Inc., 2000) is shown in Table 4. The null hypothesis (that the whales are from same population) was rejected for the comparison between the

Table 2

The sample size, mean, standard deviation (SD) and range of respective measurements by sex and area.

		Pacific coast of Japan					Sea of Okhotsk					Sea of Japan				
Sex	Measurements	n	Mean (cm)	SD	Max.	Min.	n	Mean (cm)	SD	Max.	Min.	n	Mean (cm)	SD	Max.	Min.
Male	V1	47	998.9	37.55	1,090	886	34	997.8	78.82	1,080	700	21	940.3	36.80	1,015	840
	V2	46	717.4	27.19	764	635	22	703.5	68.89	780	505	21	673.1	25.14	713	595
	V3	46	107.3	6.85	119	84	28	107.4	11.10	124	71	21	109.4	5.33	119	95
	V4	46	60.5	4.83	71	46	29	58.0	8.02	75	34	21	60.6	4.04	69	54
	V5	42	7.5	2.10	12	2.7	23	7.2	2.72	13.8	2	21	6.7	1.39	9.3	3.7
	V6	46	59.8	4.47	74	50	27	62.2	6.78	73	42	21	63.2	4.86	72	53
	V7	45	92.4	5.21	103	81	23	93.5	11.04	110	62	21	95.1	6.32	108	82
	V8	46	158.9	10.09	187	140	24	160.4	20.19	191	102	21	155.7	8.42	173	134
	V9	46	440.9	18.29	480	390	24	438.0	33.50	479	350	21	415.4	18.11	440	371
	V10	45	648.8	26.28	711	580	23	641.8	57.23	690	460	21	611.7	22.94	640	542
	V11	46	722.0	28.27	790	635	24	711.4	61.06	773	505	21	678.5	27.28	730	602
	V12	41	21.6	1.31	24	19	22	21.7	1.79	25	17.5	21	21.4	1.11	23.5	19
	V13	36	83.0	7.61	105	65	20	81.5	10.30	103	66	21	79.4	7.53	94	69
	V14	16	280.6	16.21	314	252	10	271.9	15.44	289	245	16	251.6	15.89	280	220
	V15	44	59.1	4.65	70	49	19	58.2	9.35	74	40	21	57.7	5.35	68	49
	V16	45	25.1	3.82	38	19	20	25.1	2.92	30	19	21	22.3	2.42	27	19
	V17	43	42.4	2.02	47	37	19	40.8	3.55	48	31	21	38.9	2.91	44	29
	V18	45	125.0	6.42	141	110	16	123.6	7.56	135	107	21	115.0	4.87	123	106
Female	V1	31	1,023.0	47.26	1,088	899	19	1,008.1	55.34	1,094	874	20	970.2	51.36	1,075	866
	V2	31	738.3	37.33	794	640	14	728.8	41.84	789	640	19	695.2	36.11	756	628
	V3	31	110.9	5.20	119	96	17	114.4	8.58	134	103	20	114.1	7.59	127	100
	V4	31	63.3	4.23	72	56	18	63.2	5.24	72	52	20	63.2	6.35	77	49
	V5	29	7.0	2.08	12.5	4	15	7.5	2.28	11.6	3.4	20	6.7	1.54	10	4.8
	V6	31	62.7	4.09	75	52	18	66.2	5.51	79	58	19	65.8	5.24	73	57
	V7	31	95.7	5.28	107	84	17	98.9	8.44	120	87	20	98.8	6.03	106	85
	V8	30	159.7	11.61	180	138	14	162.1	12.94	183	142	20	163.8	11.14	187	141
	V9	30	446.4	23.68	479	390	15	445.7	30.86	494	401	20	434.3	22.88	491	401
	V10	31	709.3	35.96	750	614	16	694.2	45.37	769	619	20	676.9	36.19	735	609
	V11	31	744.9	39.12	793	644	16	734.9	40.31	790	649	20	706.2	37.41	766	638
	V12	30	21.9	1.44	24	19	16	21.3	1.95	25	18	20	21.3	1.07	24	19
	V13	26	86.5	7.86	100	71	12	78.2	8.26	96	65	20	78.1	6.80	93	65
	V14	7	282.9	14.42	297	255	3	276.3	23.18	303	261	12	258.2	12.73	278	239
	V15	30	63.1	5.12	75	53	12	64.7	7.04	80	55	20	59.9	5.88	78	52
	V16	29	25.3	2.98	32	20	14	26.4	3.05	31	21	20	24.4	3.69	32	17
	V17	31	42.2	2.22	46	36	13	40.7	2.95	45	35	19	38.8	1.42	41	36
	V18	31	125.9	7.92	139	97	9	120.6	8.50	131	108	20	114.9	6.72	129	102

Table 3

The canonical coefficients obtained from the Canonical discriminant analysis using 13 principal components (PRIN2-14) based on the 14 external measurements.

	Male		Female	
Variable	1st Canonical variate	2nd Canonical variate	1st Canonical variate	2nd Canonical variate
PRIN2	0.5731	0.2021	0.6334	0.1949
PRIN3	-0.0489	0.3865	-0.2641	0.4539
PRIN4	0.2159	0.0222	0.9820	0.1076
PRIN5	-0.7411	0.1609	0.4361	-0.8428
PRIN6	0.2024	-0.1880	0.8443	-0.0613
PRIN7	-0.1401	0.1771	-0.3544	-0.2609
PRIN8	-0.5336	0.5086	-0.2245	0.0227
PRIN9	-0.1189	0.5943	-0.2018	0.2050
PRIN10	-0.6265	-0.1482	0.0795	-0.7011
PRIN11	-0.1917	-0.4298	-0.3169	1.3358
PRIN12	-0.5115	-1.7969	0.3363	0.4149
PRIN13	1.9044	-1.5993	-0.4152	2.7024
PRIN14	1.0454	-2.4695	0.4682	-3.8847

Pacific coast and the Sea of Japan groups ($p<0.01$), but accepted for the Pacific coast and the Sea of Okhotsk and for the Sea of Japan and the Sea of Okhotsk groups respectively.

Difference in respective body parts

The number of measurements compared by the ANCOVA was five (V2, V8, V9, V10 and V11) for males and six (V2, V9, V10, V11, V17 and V18) for females. Table 5 shows the least square mean of the measurements obtained from the ANCOVA between the three waters. Results indicated that measurement V17 (the maximum width of the flipper) from the Pacific coast females was significantly longer than those of both the Sea of Japan and the Sea of Okhotsk females, and measurement V18 (the straight length of the flipper from anterior insertion to tip) from the Pacific coast females was also significantly longer than those of the Sea of Japan females (Tukey-Kramer's test, $p<0.05$).

Results of the ANOVA for the rest of the measurements are shown in Table 6. In males, measurements V17 and V18 from the Pacific coast were significantly longer than those from the Sea of Japan, whilst V17 from the Sea of Okhotsk was also significantly longer than for the Sea of Japan (Tukey-Kramer's test, $p<0.05$).

The measurements for which a significant difference was observed both involved the flipper (V17 and V18). Based on the least square means, the Pacific coast females had 3.9% (V17) to 4.3% (V18) larger flippers than those of the Sea of Japan, and the mean length of the flipper of the Pacific coast males was 8.0% (V18) to 8.3%(V17) larger than that of the Sea of Japan.

DISCUSSION

The morphological differences between the geographical areas observed in this study can be summarised as follows:

(1) morphological features based on the multi-measurements were significantly different between the Pacific coast whales and the Sea of Japan whales;
(2) the Pacific coast whales had 3.9-8.3% larger flippers than those of the Sea of Japan whales for both sexes.

Some measurements of the flippers of the Sea of Okhotsk whales were also significantly different from those from the Pacific coast and the Sea of Japan whales. However, the results of the multi-measurement comparisons showed no significant difference between the Sea of Okhotsk and other waters. As shown in Fig. 3, the Sea of Okhotsk whales were located between the Pacific coast and the Sea of Japan whales, with a large overlap with the Sea of Japan whales. One possibility is that this reflects some migration of whales from the Sea of Japan to the Sea of Okhotsk and the presence of more than one stock in these waters. However, the Sea of Okhotsk samples used in this study included data measured by a variety of researchers, most of whom were temporary persons with little experience of field surveys. The inclusion of these data might explain the large SD observed for the Sea of Okhotsk samples (Table 2) and makes it difficult to reach a reliable conclusion for the Sea of Okhotsk whales.

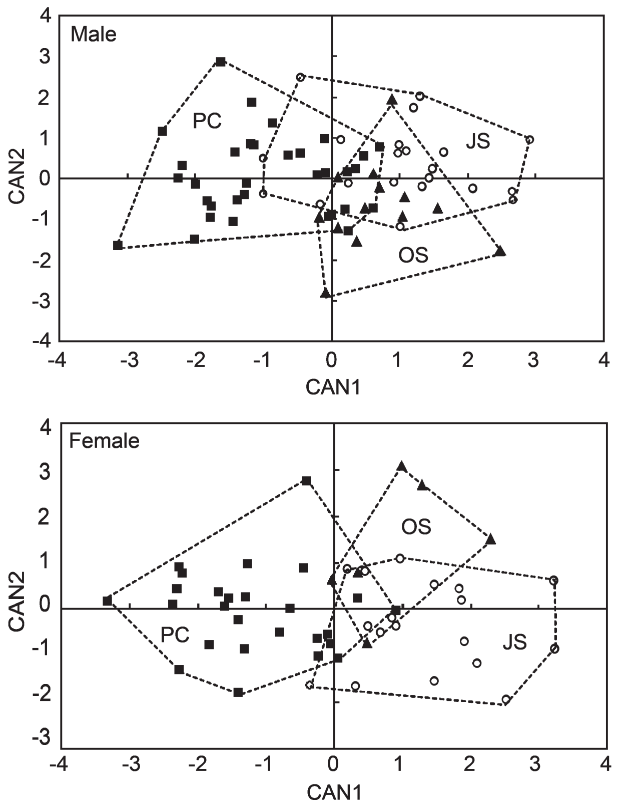

Fig. 3. Distribution of the canonical variates obtained by the canonical discriminant analysis. Open circle: the Sea of Japan sample (JS); closed square: the Pacific coast sample (PC); closed triangle: the Sea of Okhotsk sample (OS).

Although measurement bias may exist even in data collected by a single person, this bias is minimal in the comparison between data and thus the results of the differences found from the comparison between the Pacific coast and the Sea of Japan whales are thought to reflect true differences between stocks.

Omura *et al*. (1955) reported that the body length of Baird's beaked whales caught in the Sea of Japan was about four feet smaller than from other waters, based on catch data collected from small-type whaling between 1948 and 1952. They also reported that the length at sexual maturity of the whales was 32-33 feet for males, and 33-34 feet for females and they proposed that only young whales approached the coast in the whaling ground of the Sea of Japan. If body proportions change with growth then the difference in body proportions will be affected by body size. However, such a change was not detected in the range of body lengths used in this study and body length factor was eliminated as a covariate and/or a principal component. Therefore, those effects are thought to be minimal in the body proportion differences observed in this study. To examine the possible differences in segregation as suggested by Omura *et al*. (1955) requires further studies (e.g. on body length composition and age, growth and sexual or physical maturity) and such work is ongoing by the NRIFSF.

Table 4

The squared distance of the canonical variates between the areas (upper right corner) and the probability of the distance larger than the Mahalanobis' distance with a null hypothesis of same population (lower left corner). Values with underlines indicate significant difference between the areas.

	Male			Female		
Area	Pacific coast of Japan	Sea of Okhotsk	Sea of Japan	Pacific coast of Japan	Sea of Okhotsk	Sea of Japan
Pacific coast of Japan	-	3.264	3.944	-	6.039	6.259
Sea of Okhotsk	0.0515	-	1.291	0.1083	-	3.051
Sea of Japan	0.0015	0.8021	-	0.0008	0.6687	-

Table 5

The least square mean of respective measurements by sex and area obtained from the ANCOVA with body length as covariate. Values with the same superscript are significantly different (Tukey-Kramer test, $p<0.05$).

	Male			Female		
Measurements	Pacific coast of Japan (cm)	Sea of Okhotsk (cm)	Sea of Japan (cm)	Pacific coast of Japan (cm)	Sea of Okhotsk (cm)	Sea of Japan (cm)
V2	703.9	699.5	700.6	723.0	726.4	717.8
V8	156.0	157.9	162.4	-	-	-
V9	434.4	435.5	429.3	438.4	443.2	446.0
V10	637.2	637.2	636.3	694.5	690.3	699.1
V11	709.1	706.1	706.8	729.4	731.2	729.1
V17	-	-	-	41.5[a,b]	40.4[a]	39.9[b]
V18	-	-	-	123.5[c]	119.3	118.2[c]

Table 6

Comparison of the mean of respective measurements that had no significant relationship with body length. Values with the same superscript are significantly different (ANOVA with Tukey-Kramer test, $p<0.05$).

	Male			Female		
Measurments	Pacific coast of Japan (cm)	Sea of Okhotsk (cm)	Sea of Japan (cm)	Pacific coast of Japan (cm)	Sea of Okhotsk (cm)	Sea of Japan (cm)
V3	107.3	107.4	109.4	110.9	114.4	114.1
V4	60.5	58.0	60.6	63.3	63.2	63.2
V5	7.5	7.2	6.7	7.0	7.5	6.7
V6	59.8	62.2	63.2	62.7	66.2	65.8
V7	92.4	93.5	95.1	95.7	98.9	98.8
V8	-	-	-	159.7	162.1	163.8
V12	21.6	21.7	21.4	21.9	21.3	21.3
V17	42.4[a]	40.8	38.9[a]	-	-	-
V18	125.0[b]	123.6[c]	115.0[b,c]	-	-	-

According to studies on sighting records and whaling operations, Baird's beaked whales appear in early summer off the Boso Peninsula near the southern limit of their distribution range on the Pacific coast off Japan, with numbers peaking in late Autumn off the Pacific coast of Hokkaido (Kasuya and Miyashita, 1997). In the Sea of Japan, past catch records from 1948-1952 indicate the occurrence of whales in Toyama Bay (at about 37°N) and off the Sea of Japan coast off Hokkaido (41-42°N) in June to August (Omura *et al*., 1955) and the majority of the catch in 1999 to 2004 was in the Sea of Japan coast off Hokkaido in May to June. Those whaling grounds are characterised by the presence of deep waters greater than 1,000m near the coast (Fig. 1); the maximum depth of these waters exceeds 3,000m. Baird's beaked whales are known to bottom feed over the continental slope on the Pacific coast at depths between 1,000 and 3,000m (Kasuya and Miyashita, 1997) and mainly feed on damsel fish and squid which are abundant in waters >1,000m (Ohizumi *et al*., 2003; Walker *et al*., 2002). The main prey found in the stomach contents were rat-tails and hakes in the Pacific coast of Japan, while pollock and squid were also important prey in the southern Sea of Okhotsk (Ohizumi *et al*., 2003). This suggests that the topographic features of the sea bottom may act as barriers between stocks. The Tsugaru Strait between the Sea of Japan and the Pacific Ocean comprises waters <200m in depth and Kasuya (1986) proposed that this Strait potentially blocks migration between these waters. Since there are no sightings or catch records for this species in this strait, despite intensive searching effort made during the recent whaling operations based on the land stations at Hakodate, southern coast of Hokkaido in 1999 to 2004, the results of this study are consistent with those of Kasuya (1986). The morphological differences observed in this study between whales from the Sea of Japan and the Pacific Ocean probably reflect the fact that migration between the two stocks can not take place.

The relationships between the whales in the southern Sea of Okhotsk and other waters could not be clarified using the morphological examinations conducted in this study, but should be resolved by other studies such as the genetic examination using samples from the catch or biopsy skin sampling and the direct satellite tracking. These studies will be conducted in the near future.

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