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Variation in a color pattern of white patch on the flippers of North Pacific common minke whales: Potential application for their interoceanic difference.

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Abstract : We investigated growth related changes, sex-based differences, and variation in the white flipper patches of 240 North Pacific minke whales *Balaenoptera acutorostrata*. Previously reported photographic data of North Atlantic minke whales (n =13) were also used for interoceanic comparison. In the North Pacific specimens the size of the white patch was larger in males (33.8%) than in females (31.8%). The relative area of the white patch decreased during development, and tended to be larger in the males. The relative length of white patch to flipper length (33.4%) and area of the white to flipper area (38.8%) in North Pacific specimens were significantly smaller than the corresponding length (40.7%) and area (55.5%) in North Atlantic specimens. Although the proximal boundary contour of the white patch was straight in North Atlantic specimens, it was meandering in North Pacific specimens. The findings in this study suggest that the morphology of the white flipper patch can be applicable to the elucidation of common minke whale speciation.

Keywords : Common minke whales, *Balaenoptera acutorostrata*, flipper, morphology

Introduction

The common minke whale, *Balaenoptera acutorostrata*, is the smallest species in family Balaenopteridae. They are widely distributed in the world and are considered to be an important marine resource, especially given their large stock size. North Atlantic minke whales are a commercial whaling target species in Norway and Iceland, and North Pacific minke whales have a long history of sustainable use in Japan. This species is currently the subject of whale research programs conducted in accordance with Article VIII of the International Convention for the Regulation of Whaling.

Common minke whales are currently classified into two subspecies: *B. a. scammoni* in the North Pacific and *B. a. acutorostrata* in the North Atlantic. In the Southern Hemisphere there is a distinctive population of "dwarf" minke whales *B. a.* subsp., however, its taxonomical classification is still debated (RICE, 1998). It has also been recommended that the North Pacific minke whales be further divided into several subspecies (KATO *et al.,* 1992, KANDA *et al.,* 2009), which demonstrates

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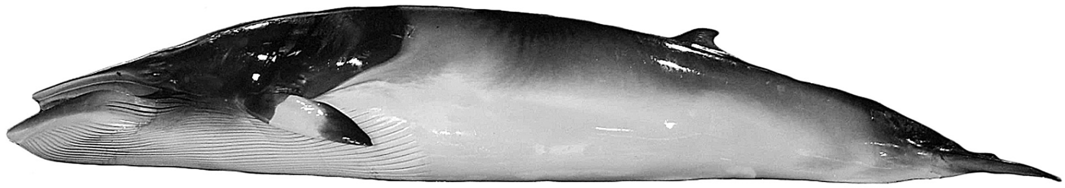

Fig. 1. Lateral view of the North Pacific common minke whale with a clear white patch on the flipper

the complexity associated with the classification of *B. acutorostrata*. Minke whales have a white patch on their pectoral flippers, a feature that has not been observed in any other whale species (Fig. 1). External appearance is an important classification criterion, and previous studies have investigated intra-oceanic variation (KATO *et al.,* 1992) and made interoceanic comparisons (OMURA and SAKIURA, 1956) of these white flipper patches. Compared with North Pacific minke whales, white patches in dwarf minke whales are much larger, reaching the shoulder, and thereby significantly differentiate the subspecies (ARNOLD *et al.,* 1987; KATO and FUJISE, 2000; ARNOLD *et al.,* 2005). Furthermore, preliminary studies have shown that the boundary contour of the white patch at the base of the flipper varies between the North Pacific and North Atlantic minke whales (OMURA and SAKIURA, 1956; HORWOOD, 1989).

Despite the preliminary investigation of interoceanic variation of white patches in common minke whales, such findings have not been used to identify their subspecies, because of the lack of fundamental information such as the extent of intra-oceanic variation and growth related changes in the North Pacific minke whales. In this study, we therefore investigated the features, variation, and sex-based differences in the morphology of the white flipper patch of North Pacific minke whale specimens, with the aim of establishing classification indexes from our findings for the North Pacific stock in future studies. We also compared North Pacific and North Atlantic specimens to reveal the morphological variation in white patches within the same species and to evaluate the utility of using white patch morphological features to identify common minke whale populations.

Materials

North Pacific minke whales

We used 237 North Pacific minke whales (151 males, body length: 3.70–8.16 m; 86 females, body length: 3.84–8.68 m) collected from offshore waters near Japan in 2012 and off Sanriku and Kushiro, Japan, in 2012–2013 during the Japanese Whale Research Program under Special Permit in the Western North Pacific-Phase II (commonly known as JARPN II) survey, which was conducted in accordance with Article VIII of the International Convention for the Regulation of Whaling and Japanese law (Fig. 2). Even for minke whales inhabiting the same ocean, it is necessary to investigate intra-species variation among the subspecies inhabiting Pacific coastal regions and those offshore. In this study, however, we placed priority on the comparison between larger geographical regions to elucidate interoceanic species variation and will investigate intra-oceanic variation in future studies.

North Atlantic minke whales

In this study, comparative analysis was performed using photographs of North Atlantic minke whales taken in the ocean, which were available online. We made efforts to provide all specific locations where photographs of whales were taken; however, some whales were considered to be North Atlantic minke whale for the purposes of this study even if that information was unavailable. We selected 13 whales where the front of the flipper was photographed (Table 1).

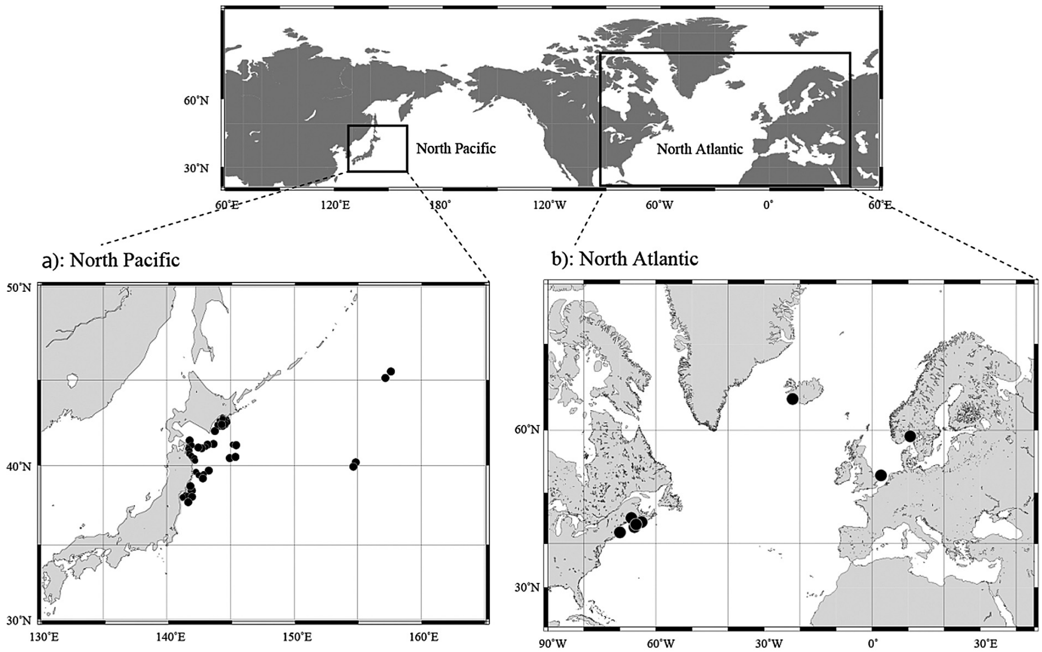

Fig. 2. Geographical locations (a) where North Pacific common minke whales were collected and (b) where North Atlantic common minke whales were photographed

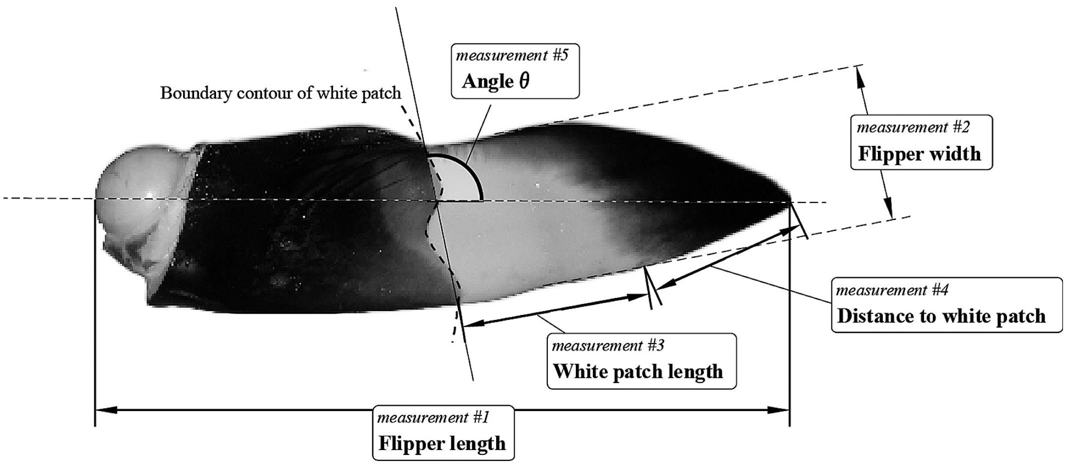

Fig. 3. Measurement points on the flipper

Methods

Measurements of the length of each measurement points

Body length of North Pacific minke whales were measured in a straight line between the tip of the snout and the notch of the flukes down to the centimeter scale. Another measurement points on the flipper, *measurement* #1 through 4 were conducted on resected flippers down to the millimeter scale using a stainless steel caliper or a measurement tape as described in Fig. 3. In the North Atlantic specimens,

Table 1. URLs of various websites with published photographs of North Atlantic common minke whales and the shooting locations

ID	Location	URL
NA-1	North A tlantic	http://www.projectminke.com/pgjminkesco02.jpg
NA-2	Campobello Island, New Brunswick, Canada	http://1.bp.blogspot.com/-syZ_usMTayM/ThoKVNg4DCI/AAAAAAAAD14/pDbvidzmCnc/s400/265932_624155920585_1214036622_3430023_7497371_o.jpg
NA-3	North Atlantic	http://uk.whales.org/sites/default/files/styles/flexslider_full/public/species/balaenoptera_acutorostrata-aishling_hefferna.jpg?itok=WTOtd5iN
NA-4	Stellwagon Bank, Cape Cod, Massachusetts	http://fc05.deviantart.net/fs70/i/2011/219/e/9/the_oceanic_puppy_by_silvervulpine-d45skfn.jpg
NA-5	Gulf of Maine, Canada	http://www.healthywildlife.ca/wp-content/uploads/2012/07/minke-whale-in-fishing-gear.jpg
NA-6	Stellwagen Bank, Massachusetts	http://www.wheretowatchbirdsandotherwildlifeintheworld.co.uk/images/minke.jpg
NA-7	Norway	http://www.marefa-whaleresearch.org/wp-content/uploads/2012/12/minke3-copyright.jpg
NA-8	Gorleston, norfolk, United Kingdom	http://whalesandmarinefauna.files.wordpress.com/2013/07/minke-whale-norfolk.jpg
NA-9	Norway	http://www.bulandet-grendalag.org/images/Kval/BrukKval2.jpg
NA-10	Norway	http://awionline.org/sites/default/files/imagecache/awi-quarterly-cover/images/press-releases/minke%20on%20Norwegian%20boat%20steve%20morgan%20pic.jpg
NA-11	Reychabic, Iceland	http://online.wsj.com/news/articles/SB121984941913476621?mg=reno64-wsj&url=http%3A%2F%2Fonline.wsj.com%2Farticle%2FSB12198494191346621.html&fpid=2.7.121.122.201.401.641.1009#5
NA-12	Martinique Beach, HRM, Nova Scotia	http://i235.photobucket.com/albums/ee253/Accentor/Mammals/Minke-Whale-deceased-06.jpg
NA-13	North Atlantic	http://whalesenseblog.files.wordpress.com/2013/03/2927_70869334631_4497029_n.jpeg?w=604&h=314

measurement values on flipper were calculated using image processing software Canvas X, because their measurement values were not available online.

i) *measurement* #1: Flipper length (a straight line connecting the tip of flipper and the head of the humerus)

ii) *measurement* #2: Flipper width (the widest point of the flipper)

iii) *measurement* #3: The length of the white patch along the anterior margin of the flipper

iv) *measurement* #4: The length between the tip of flipper and the starting point of the white patch along the anterior margin of the flipper

v) *measurement* #5: The angle between the axis of the flipper and the mean black/white borderline between the flipper base and the white patch (Angle θ)

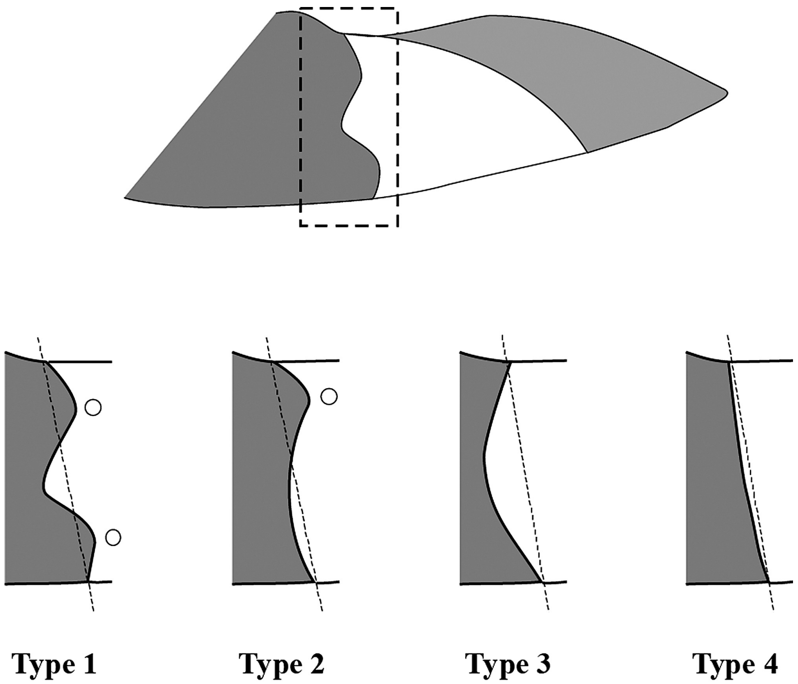

Fig. 4. Morphological typing of the boundary contours at the flipper base

Photographic recording

To measure the angle (angle θ) and area of white patch, the photographic recording of flippers was performed using the raw image function of Nikon D70 and D100 digital cameras, with the Kodak Gray Scale chart to the side, and efforts were taken not to overexpose the black area with flash. The raw image processing program, RAWTherapee (http://www.rawtherapee.com), was used to perform white balance of photographic images and to adjust exposure, and the RGB values at the midpoint of the Kodak Gray Scale chart were also adjusted to R=119, G=119, and B=119. After saving the images as TIFF files, image processing software (Image J; http://imagej.nih.gov/ij/) was used to construct 8-bit grayscale images, and Otsu's binarization method was used to determine the threshold value for discriminating white from black and gray and thus produce binary images. When it was difficult to determine a correct threshold value due to the presence of shadows and light grays, variable thresholding was performed with Open CV in Microsoft Visual C++. After this preprocessing, Image J was used to determine the area of the flipper and white patch. The flipper area was defined as the area between the tip of the flipper and the white patch, and the area of the white patch was defined as the white area after binarization. The area of the white patch relative to the flipper was expressed as a percentage. Angle θ was determined using Canvas X (http://www.poladigital.co.jp/canvas/). Measurement and photographic recording were performed bilaterally; however in general, only left side measurements were used in this study.

Classification of the boundary contour of the white patch

The boundary contours of the white patches at the base of the flipper were grouped based on the pattern of the boundary of the curves along the mean black/white borderline connecting the dorsal and anterior margins (Fig. 4). White patches with an unclear boundary pattern were excluded from this study.

Type 1: 2 curves crossing the mean black/white borderline
Type 2: 1 curve crossing the mean black/white borderline
Type 3: No curves crossing the mean black/white borderline, but a large concave curve toward the base of the flipper
Type 4: The actual boundary being nearly straight and parallel to the mean black/white borderline

Analysis on growth dependent change

The following allometric equation was used to extract growth- and sex-related patterns at each measurement point :

$$Y = \beta X^{\alpha}$$

where X defines flipper length (cm) or body length (m) ; Y, the length at each measurement point (cm) ; α, the allometric coefficient; and β, initial growth constant. To reveal sex-based differences, individual allometric equations were converted into a logarithmic form, and the slope and intercept were compared using the t test. Results were considered statisti cally significant at $p<0.05$. Following YOSHIDA *et al.* (1993), the t test was also conducted to classify growth features at each anatomical point into three patterns: hyperallometry (positive allometry) when the allometric coeffi cient was significantly greater than 1, isometry (isometric allometry), and hypoallometry (negative allometry) when the allometric coefficient was less than 1.

Results and discussion

1. Growth related changes and sex-based differences in the North Pacific minke whales.

Length of the flipper and body length

237 North Pacific specimens (151 males; 86 females) were divided into different groups based on body length: groups divided every 50 cm between 3.5–8.0 m and a group of 8.0–9.0 m due to the small sample number. The minimum, maximum, and mean flipper length and the flipper length relative to body length in individual groups are shown in Table 2. Flipper length increased as growth in both sexes. In males, the mean length increased from 63.0 cm (c.v. = 0.03, n=2) in the 3.5 m group (3.5–4.0 m) to 127.1 cm (c.v. = 0.02, n=3) in the 8.0 m group (8.0–9.0 m), whereas the mean length of female whales increased from 59.5 cm (n=1) to 134.1 cm (c.v. = 0.03, n=6), respectively.

The mean proportion of the flipper length to the body length dropped from 16.3% (c.v. = 0.04, n=2) in the 3.5 m group to 15.5% (c.v. = 0.03, n=16) in the 4.5 m group in males and from 16.2% (c.v. = 0.04, n=7) in the 4.0 m group to 15.7% (c.v. = 0.03, n=17) in the 4.5 m group in females. The mean proportion peaked at 16.5% (c.v. = 0.03, n=35) for males and 17.3% (n=1) for females in the 7.0 m group before decreasing again, showing that the proportional length of the flipper changes with body length. No statistically significant difference by sex was observed in any of the body length groups (Mann-Whitney's U-test, $p<0.01$).

In mammals, the relative growth patterns of the four limbs reflect the ecology and life history of individual species and may vary between sexes or over different developmental stages. In *Homo sapiens*, the length of four limbs relative to the body increases during development (BOGIN and VARELA-SILVA, 2010). However, the relative proportion of leg length decreases in crab-eating macaques, (*Macaca fascicularis*), and at age 3 years, male-female differences in relative growth pattern starts to emerge, with a lower or higher relative proportion in females and males, respectively (SHIMIZU *et al.,* 1991). Although the length between the tip and base of the flipper relative to the body decreases in the Dall's Porpoise (*Phocoenoides dalli*), another marine mammal, the corresponding measurement in fin whales (*B. physalus*), which belong to the same genus as common minke whales, is constant (OHSUMI, 1960; AMANO and MIYAZAKI, 1993). In common minke whales, the relative length of the flipper to the body decreased by approximately 0.8% during the 3.5–4.5 m developmental stages, but peaked at the 7.0–8.0 m developmental stage before making another decline, demonstrating an inconsistent growth pattern. Such fluctuation in the proportions is thought to be due to differences in the growth rates of the flipper and body. Whales use their flippers to acquire buoyancy and change direction (FISH *et al.,*

Table 2. Actual length of the flipper in *measurement #1* and the length relative to the body length in the North Pacific common minke whales

Body length class (m)	Male							Female							Male v.s. Female
	Flipper length (cm)			Proportion of body length (%)			n	Flipper length (cm)			Proportion of body length (%)			n	
	Min–Max	Average	c.v.	Min–Max	Average	c.v.		Min–Max	Average	c.v.	Min–Max	Average	c.v.		
3.5–3.9	61.2–64.7	63.0	0.03	15.6–16.9	16.3	0.04	2	59.5	59.5	0.00	15.5	15.5		1	n.s.
4.0–4.4	64.0–77.8	68.7	0.06	15.2–17.4	16.0	0.04	7	63.8–72.6	69.0	0.04	14.7–17.1	16.2	0.04	7	n.s.
4.5–4.9	67.2–79.4	73.5	0.05	14.3–16.5	15.5	0.03	16	69.2–79.0	74.8	0.04	14.8–16.9	15.7	0.03	17	n.s.
5.0–5.4	74.6–87.3	82.1	0.04	14.9–16.3	15.6	0.03	18	77.0–89.7	83.3	0.04	14.9–16.8	15.8	0.03	22	n.s.
5.5–5.9	82.4–99.8	92.2	0.06	14.7–16.7	15.9	0.04	9	84.3–95.5	91.3	0.04	14.7–16.2	15.8	0.02	12	n.s.
6.0–6.4	93.2–107.1	99.3	0.04	15.1–17.1	15.9	0.04	18	93.0–105.6	100.2	0.05	15.2–17.0	16.1	0.04	9	n.s.
6.6–6.9	103.0–117.1	110.1	0.03	15.6–17.3	16.4	0.03	21	104.0–114.0	110.8	0.03	16–17.1	16.8	0.03	5	n.s.
7.0–7.4	106.2–128.8	119.5	0.04	15.1–17.6	16.5	0.03	35	122.6	122.6	0.00	17.3	17.3		1	n.s.
7.5–7.9	118.1–133.0	126.1	0.03	15.4–17.6	16.5	0.03	22	122.7–135.0	129.0	0.03	16.1–17.3	16.7	0.02	6	n.s.
8.0–9.0	123.4–130.7	127.1	0.02	15.3–16.3	15.7	0.03	3	128–140.6	134.1	0.03	15.9–17	16.4	0.02	6	n.s.
Total	61.2–133.0			14.3–17.6	16.1	0.04	151	59.5–140.6			14.7–17.3	16.0	0.04	86	n.s.

Table 3. Actual and relative values in *measurement #3-5* and the relative area of the white patches in the North Pacific common minke whales

Body length class (m)		*measurement #3*							*measurement #4*							*measurement #5*				Area of white patch			
		Lengh (cm)			Proportion of fipper lengh (%)			*n*	Lengh (cm)			Proportion of fipper lengh (%)			*n*	Angle (°)			*n*	Coverage of white patch to fipper area (%)			*n*
		Min–Max	Average	c.v.	Min–Max	Average	c.v.		Min–Max	Average	c.v.	Min–Max	Average	c.v.		Min–Max	Average	c.v.		Min–Max	Average	c.v.	
Male	3.5–3.9	16.2–27.1	21.7	0.25	26.5–41.9	34.2	0.23	2	19.6–20.4	20.0	0.02	30.3–33.3	31.8	0.05	2	73.1–87.1	80.1	0.09	2	34.8–43.7	39.2	0.11	2
	4.0–4.4	17.8–27.6	23.4	0.12	24.8–38.7	34.2	0.12	7	15.0–24.4	20.2	0.16	23.0–35.5	29.4	0.13	7	74.6–97.2	86.5	0.08	7	35.6–48.7	43.5	0.11	7
	4.5–4.9	18.0–31.1	24.2	0.15	24.2–44.6	32.8	0.17	14	12.8–30.2	21.7	0.20	19.0–38.5	29.4	0.18	16	77.8–104.5	89.1	0.08	16	32.5–61.5	43.7	0.18	13
	5.0–5.4	25.0–35.8	28.5	0.10	29.6–44.5	34.8	0.12	18	16.1–28.7	23.0	0.13	20.8–32.9	27.9	0.11	18	73.4–100.3	88.1	0.09	18	24.7–55.5	43.7	0.19	16
	5.5–5.9	18.7–38.9	29.1	0.20	22.1–40.5	31.4	0.17	8	22.5–36.8	28.4	0.16	25.3–39.3	30.8	0.13	9	75.6–98.4	86.6	0.10	9	24.7–47.1	34.3	0.24	6
	6.0–6.4	24.2–41.0	33.1	0.14	25.4–41.7	33.4	0.14	18	19.3–39.0	30.1	0.18	19.8–36.4	30.2	0.15	18	67.2–98.0	86.1	0.10	18	23.3–57.3	41.9	0.25	12
	6.6–6.9	27.9–45.7	36.2	0.12	24.5–42.3	33.0	0.14	21	25.9–44.5	33.7	0.14	24.0–38.9	30.6	0.13	21	71.3–104.0	87.7	0.09	21	14.5–58.2	39.6	0.28	17
	7.0–7.4	30.1–55.7	42.4	0.15	23.6–46.5	35.6	0.16	34	25.3–50.7	36.2	0.17	22.7–41.7	30.2	0.15	35	67.2–104.1	86.9	0.11	35	16.9–57.4	35.4	0.27	26
	7.5–7.9	30.8–55.3	41.5	0.16	24.8–42.7	32.8	0.16	22	31.7–54.2	40.7	0.13	24.6–45.9	32.3	0.14	22	69.7–99.4	86.9	0.10	22	7.7–58.5	35.4	0.34	16
	8.0–9.0	33.7–41.8	38.8	0.09	27.3–32.2	30.5	0.07	3	43.7–48.0	45.2	0.04	34.4–36.7	35.5	0.03	3	82.2–90.1	86.5	0.04	3				0
	Total	16.2–55.7			22.1–46.5	33.8	0.15	147	12.8–54.2			19.0–45.9	30.3	0.15	151	67.2–104.5	87.2	0.10	151	7.7–61.5	39.3	0.26	115
Female	3.5–3.9	15.6	15.6		26.2	26.2		1	19.2–19.2	19.2		32.3	32.3		1	97.4–97.4	97.4	0.00	1				0
	4.0–4.4	18.4–23.8	21.4	0.08	28.8–33.8	31.1	0.05	7	19.4–25.0	21.5	0.08	26.7–36.0	31.2	0.09	7	86.2–96.1	91.1	0.04	7	17.2–48.3	32.2	0.27	7
	4.5–4.9	17.2–39.2	24.6	0.20	22.5–53.5	32.9	0.21	17	9.6–25.4	20.8	0.18	13.1–34.1	27.8	0.18	17	70.4–102.6	90.9	0.10	17	9.7—52.3	41.1	0.25	16
	5.0–5.4	16.6–39.8	28.4	0.20	20.1–47.0	34.2	0.19	20	16.0–33.4	22.8	0.17	20.4–38.6	27.4	0.16	22	75.8–98.9	88.0	0.08	22	24.9–55.7	45.1	0.20	19
	5.5–5.9	23.0–40.2	28.7	0.17	24.2–44.7	31.4	0.17	12	23.0–34.1	28.1	0.14	25.6–39.7	30.7	0.14	12	65.5–100.2	87.9	0.10	12	8.6–50.9	30.5	0.42	9
	6.0–6.4	17.5–40.4	28.4	0.25	16.6–42.7	28.6	0.27	9	19.5–39.6	30.2	0.09	20.6–38.2	30.0	0.16	9	77.8–100.6	90.2	0.09	9	28.5–43.6	36.6	0.16	8
	6.6–6.9	28.4–42.1	33.4	0.14	25.0–37.2	30.2	0.13	5	28.7–46.4	36.5	0.16	27.6–40.9	32.8	0.14	5	75.1–99.0	87.0	0.10	5	26.5–43.9	33.1	0.20	5
	7.0–7.4	30.8	30.8		25.1	25.1		1	45.0	45.0		36.7	36.7		1	102.9–102.9	102.9	0.00	1	36.1–36.1	36.1	0.00	1
	7.5–7.9	37.5–44.3	41.3	0.07	28.8–34.1	32.0	0.06	6	36.6–46.3	40.8	0.08	27.6–34.3	31.6	0.07	6	71.4–98.7	89.8	0.10	6	30.9–44.9	37.4	0.14	5
	8.0–9.0	25.9–51.5	39.9	0.19	19.5–38.5	29.8	0.19	6	35.8–51.8	45.0	0.12	27.9–39.0	33.5	0.11	6	72.1–104.5	92.7	0.11	9	17.2–27.9	22.5	0.24	2
	Total	15.6–51.5			16.6–53.5	31.8	0.02	84	9.6–51.8			13.1–40.9	29.8	0.16	86	65.5–104.5	89.9	0.10	89	8.6–55.7	38.1	0.28	72
Total		15.6–55.7			16.6–53.5	33.4	0.18	231	9.6–54.2			13.1–45.9	30.1	0.15	237	65.5–104.5	86.6	0.12	240	74.7–61.5	38.8	0.2706186	187

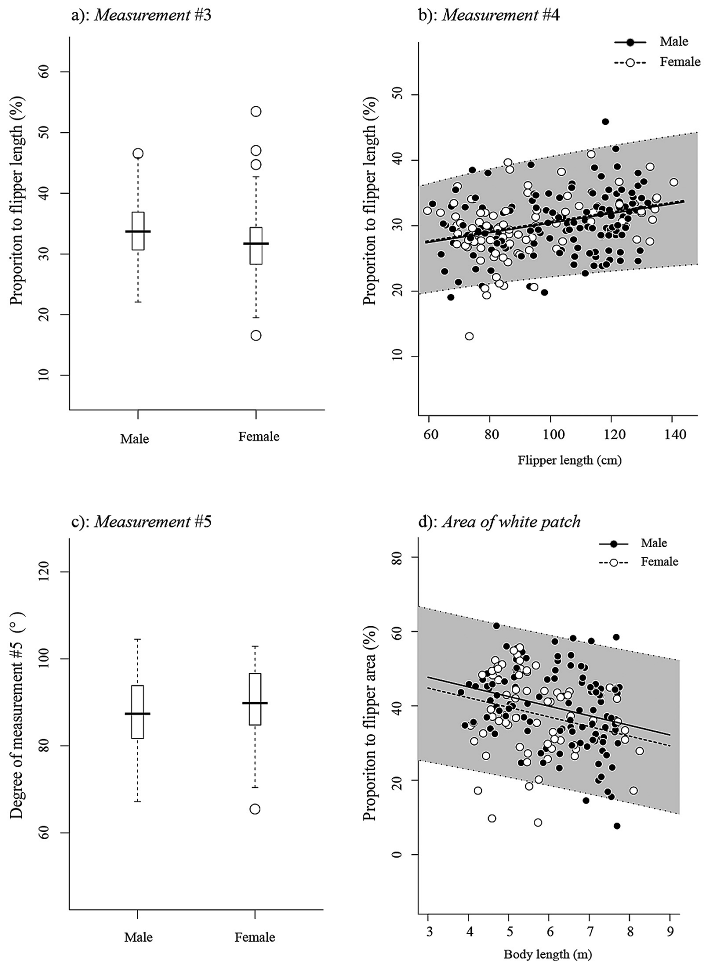

Fig. 5. Growth related changes and sexual differences of each measurement points on the flipper. *Measurement #3* (a), *measurement #4* (b), *measurement #5* (c) and white patch area (d). Boxplots are shown with whiskers extending from minimum (bottom) to maximum (top) values, with a horizontal line as the median value and outliers as circles. Black circle with solid regression line denotes male; white circle with broken line, female and gray area, 95% confidence interval.

2008). The difference in the relative length was approximately 1% in this study, and it is unclear to what extent such a small difference affects flipper function. We plan to investigate this further in a future study by using, for example, computational fluid dynamics simulation.

Anterior white patch on the flipper (measurement #3)

The correlation coefficient (r) was larger for flipper length ($r = 0.636$) than for body length ($r = 0.628$), indicating that the values of *measurement* #3 and therefore growth related changes are affected more by flipper length than by body length (Table 5). We therefore used flipper length as a criterion to assess growth related changes and sex-based differences in *measurement #3*. The allometric equation for each sex is shown below :

Males (n=147) : $y = 0.47x^{0.93}$

Table 4. White patch boundary contour type in North Pacific and North Atlantic common minke whales. In the North Pacific common minke whales, the predominant type was type 1 (two curves), followed by type 2 (one curve) and type 3 (concave boundary contour) . None of the common minke whales were classified as type 4 (straight borderline). Conversely, all North Atlantic common minke whales were classified as type 4 (straight borderline), but not types 1–3.

	North Pacific													**North Atlantic**
	Body length class (m)										Sex		**Total**	
	3.5–3.9	4.0–4.4	4.5–4.9	5.0–5.4	5.5–5.9	6.0–6.4	6.5–6.9	7.0–7.4	7.5–7.9	8.0–9.0	Male	Female		
Type1	2 (66.7%)	10 (71.4%)	22 (68.8%)	26 (68.4%)	15 (75.0%)	16 (61.5%)	21 (80.8%)	24 (70.6%)	13 (50.0%)	6 (66.7%)	99 (68.8%)	56 (66.7%)	**155 (68.0%)**	**0 (0.0%)**
Type2	1 (33.3%)	3 (21.4%)	8 (25.0%)	8 (21.1%)	3 (15.0%)	7 (26.9%)	2 (7.7%)	8 (23.5%)	10 (38.5%)	1 (11.1%)	33 (22.9%)	18 (21.4%)	**51 (22.4%)**	**0 (0.0%)**
Type3	0 (0.0%)	1 (7.1%)	2 (6.3%)	4 (10.5%)	2 (10.0%)	3 (11.5%)	3 (11.5%)	2 (5.9%)	3 (11.5%)	2 (22.2%)	12 (8.3%)	10 (11.9%)	**22 (9.6%)**	**0 (0.0%)**
Type4	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**	**15 (100.0%)**
Total	3	14	32	38	20	26	26	34	26	9	144	84	**228**	**15**

Females (n=84): y=$0.43x^{0.93}$

Here, x and y define flipper length (cm) and *measurement #3* (cm), respectively. The initial growth constants were significantly different between sexes, demonstrating that the values of the length of the white patch along the anterior margin relative to the flipper differ by sex (t-test, $p<0.01$). Moreover, the allometric coefficient (0.93) was close to 1 in both sexes, indicating that the proportion of the length of *measurement #3* to flipper length does not change during development (t-test, $p=0.89$). In fact, the mean proportion in males (33.8%, c.v.=0.15) was about 2% larger than that in females (31.8%, c.v.=0.20), indicating that the relative length of the white patch along the anterior margin in male specimens was higher than the corresponding length in females (Mann-Whitney's U-test, $p<0.01$). However, due to large individual variability of the minimum-maximum values in males (16.2–55.7%) and females (15.6–51.5%), the difference in the length of white patches was not clear enough to discriminate between sexes (Fig. 5-a, Table 3).

The length of flipper from the tip to the white patch along the anterior margin (measurement #4)

The correlation coefficient (r) was larger for the flipper ($r=0.834$) that for the body ($r=0.829$), suggesting that *measurement #4* was affected more by the flipper length (Table 4). Therefore, the length of the flipper was used as the denominator in *measurement #4* to investigate sex-related changes during development. The allometric equation is shown below:

Males (n=151): y=$0.09x^{1.26}$
Females (n=86): y=$0.12x^{1.19}$
Both sexes (n=237): y=$0.11x^{1.22}$

where x and y define the flipper length (cm) and the value of *measurement #4* (cm), respectively.

No significant sex-based differences were observed in the allometric equations or in the initial growth constants (t-test, $p=0.49$). In addition, the allometric equation was larger than 1 in both sexes (1.22) (t-test, $p<0.01$), indicating that the length relative to the flipper of *measurement #4* increases as growth. The 95% prediction interval of the relative values relative to the flipper increased from 19.8–36.4% for a 60 cm flipper to 23.9–43.7% for a 140 cm flipper (Fig. 5-b).

Angle of the mean black/white borderline to the axis of the flipper (Angle θ) (measurement #5)

To investigate growth related changes in the angle between the black/white borderline connecting the anterior and posterior margins of the flipper and the axis of the flipper connecting the tip of the flipper and the head of the humerus (*measurement #5*), 240 North Pacific specimens (151 males; 89 females) were divided into different groups based on body length described above. The minimum, maximum, and mean flipper length and the flipper length relative to body length in individual groups are shown in Table 2.

No difference were observed between body length class both in males and females (*Kruskal-Wallis* test, $p=0.971$). The mean angle of the *Angle* θ was 87.2° (c.v.=0.10, $n=151$) and 89.9° (c.v.=0.10, $n=89$) in males and female, respectively (Fig. 5-c). In female the angle was about 2.7° greater than males (*ANOVA* test, $p<0.05$).

Boundary contour of the white patch

Growth related changes and sex-based difference in the boundary contour of the white patch were investigated after dividing the contours into the four types defined earlier and dividing specimens into groups based on body length (Table 4). Type 1, with two curves was the predominant type in the North Pacific specimens (99 males; 56 females), accounting for 68.0%, followed by 22.4% (33 males; 18 females) for type 2 with one curve and 9.6% (12 males; 10 females) for type 3 with no curves. None of the North Pacific specimens were type 4, with a straight boundary contour. The chi-squared test revealed no sex-based difference (χ^2-test, $p=0.67$).

Comparisons by body length showed that type 1 was predominant type during development, followed by types 2 and 3. The Pearson's chi-squared test did not reveal any difference in compositions between the different developmental stages (Pearson's χ^2-test, $p=0.83$).

Relative area of white patch

To investigate growth related changes and sex-based differences in the area of the white patch relative to the flipper area, we first analyzed whether the relative area was affected more by the length of the body or the flipper. The single regression analysis with the length of body or flipper as the explanatory variable and the relative area of white patch as the objective variable revealed that the correlation coefficient was larger for the body ($r=-0.254$) than for the flipper ($r=-0.256$), indicating that the area of the white patch is affected more by the body length. Therefore, body length was used as the denominator to investigate the growth related changes by sex (Fig 5-d). The intercept on the regression line appeared to be larger for males than that for females, but not significantly so (t-test, $p=0.08$):

Males ($n=115$): $y=-2.58x+55.5$
Females ($n=72$): $y=-2.59x+52.6$
Both sexes ($n=187$): $y=-2.24x+52.3$

Here, x and y define the body length (m) and the relative area of the white patch (%), respectively.

The significantly smaller coefficient (−2.24) indicates that the relative area of the white patch decreases during development (t-test, $p<0.01$). In addition, the 95% confident interval of the relative values to the flipper length decreased from 23.3–63.9% for a 60 cm flipper to 12.8–53.6% for a 140 cm flipper (Fig. 5-d).

Among whales, the white flipper patch is unique to common minke whales, and is thought to play a role in feeding or in recognition of species or sex. We previously investigated the potential contribution of the white patch to the species or sex recognition. Whales are excellent swimmers and migrate long distances across the open ocean. Although the breeding waters of common minke whales have not been fully elucidated, their white patches, which are very visible in the water, may serve as a visual indicator for locating a breeding partner. This study showed that the mean lengths of the white patch differ between sexes. However, the minimum and maximum lengths of the white patch ranged from 22.1–46.5% in males and 16.6–53.3% in females, and because of the large individual variability seen in each sex, sexual dimorphism was not supported by this study. In our analysis, we also combine all specimens collected off the North Pacific coasts of Japan, without investigating intra-oceanic variation. Moreover, the number of large (>7 m) female specimens in this study was

Table 5. Relative values of *measurement #3-5* and actual angles of *measurement #5* of the North Atlantic common minke whales

	Min–Max	Average	c.v.	*n*
measurement #3 (%)	32.7–53.9	40.7	0.15	13
measurement #4 (%)	16.6–35.6	29.7	0.19	13
measurement #5 (°)	45.6–70.6	60.0	0.13	13
Relative area of white patch (%)	43.4–62.2	55.5	0.09	13

relatively small. Therefore, to clarify the actual situation, further studies are needed that include a higher number of female common minke whales and that perform interoceanic comparisons using genetic techniques.

With regard to the role of the white patch in feeding, North Pacific minke whales are known to prefer schooling fish to planktonic crustaceans such as copepods and krill (MURASE *et al.,* 2007). North Atlantic minke whales and dwarf minke whales are also known to prey on a large number of fishes (KATO and FUJISE, 2000; Pierce *et al.,* 2004). In addition, Antarctic minke whales (*B. bonaerensis*), a close relative of minke whales that mainly feed on Antarctic krill, do not have a white patch on the flipper. A previous study investigating schooling behavior in fish has shown that their schooling behavior can be controlled by a short light-dark cycle presented as a stimulus (ARIMOTO, 1991). Because the dorsal region of common minke whales is dark gray or black, when they spread their flippers, the white patch is clearly visible from the rear. Because of the high visibility of the white color in water and the high contrast between the white patch and the darker body color, minke whales may be able to use their patch to surprise fish when feeding and induce clumping behavior. Comparative observational studies of feeding behaviors between common minke whales and Antarctic minke whales and the investigation of response behavior of krill and schooling fish toward an artificial whale flipper with a white patch may provide insight into the patch's significance.

2. Comparison between two subspecies.

The above data were used to perform the comparison of common minke whale in two subspecies. Since the values of each measurement showed a significant growth related changes or sex-based difference in the North Pacific minke whales, it would have been appropriate to perform similar measurements considering growth or sex for the North Atlantic minke whales. However, because the information of their body length and sex were not available alongside their photographs, mean values of all specimens were combined and used for comparison. Also the flipper length (the length from the tip of flipper to the end of humer) is not available in the North Atlantic minke whales, this value was estimated from the ratio of flipper width and length in the North Pacific minke whales. In the North Pacific minke whales, the relationship between width and length of the flipper is explained by following equation;

$$y = 4.48x^{0.99} \qquad (n = 224)$$

where x defines the flipper width (cm) and y defines the flipper length. No difference by sex was observed in the initial growth constants or allometric coefficients (t-test, $p > 0.05$). Furthermore, the allometric coefficient (0.99) was close to 1 (t-test, $p > 0.05$), indicating that the flipper width was constant throughout development in both sexes. When both sexes were combined in analysis, the ratio of the length to the width was 4.41 (c.v. = 0.04). So, in the North Atlantic specimens the length of flipper was determined by multiplying flipper width

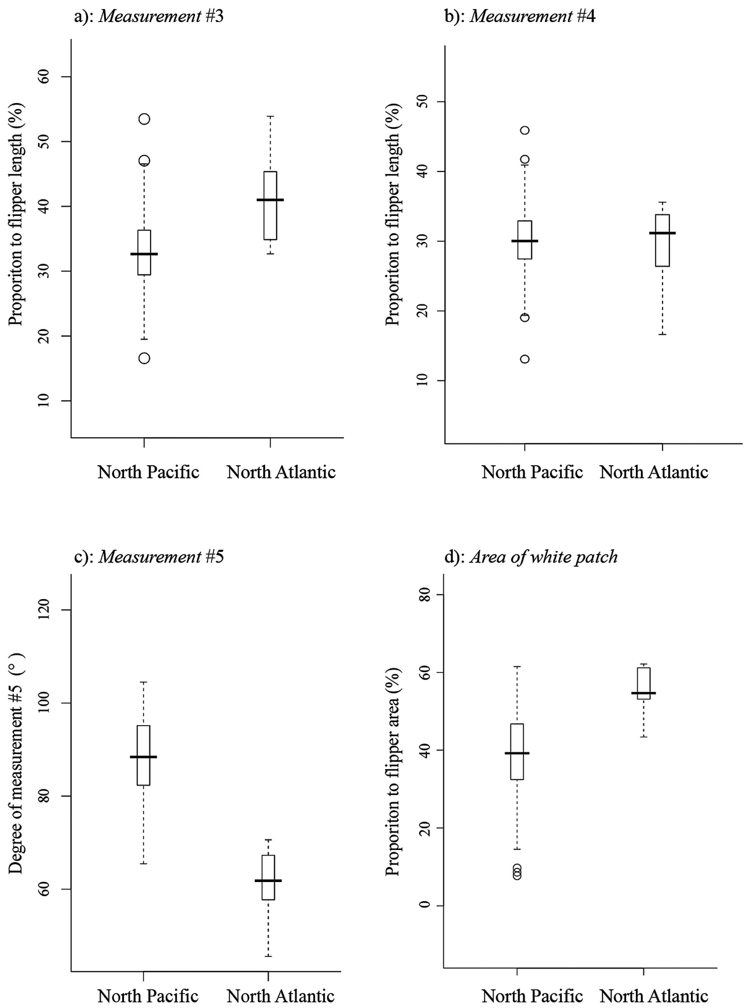

Fig. 6. Interoceanic differences of each measurement points on the flipper. *Measurement #3* (a), *measurement #4* (b), *measurement #5* (c) and white patch area (d). Boxplots are shown with whiskers extending from minimum (bottom) to maximum (top) values, with a horizontal line as the median value and outliers as circles.

by the ratio of length to width (4.41).

Anterior white patch on the flipper (*measurement #3*)

The relative length of the white patch along the anterior margin of the flipper was 40.7% (c.v.=0.15) in the North Atlantic specimens, which was significantly larger than 33.0% (c.v.=0.17) in the North Pacific specimens (Mann-Whitney's U-test, $p<0.01$) (Fig. 6-a, Table 5).

The length of flipper from the tip to the white patch along the anterior margin (*measurement #4*)

The relative length of the flipper from the tip to the white patch along the anterior margin was 29.7% (c.v.=0.19) and 30.1% (c.v.=0.15) in the North Atlantic and North Pacific specimens, respectively, with no significant difference (Mann-Whitney's U-test, $p>0.01$) (Fig. 6-b and 7, Table 5).

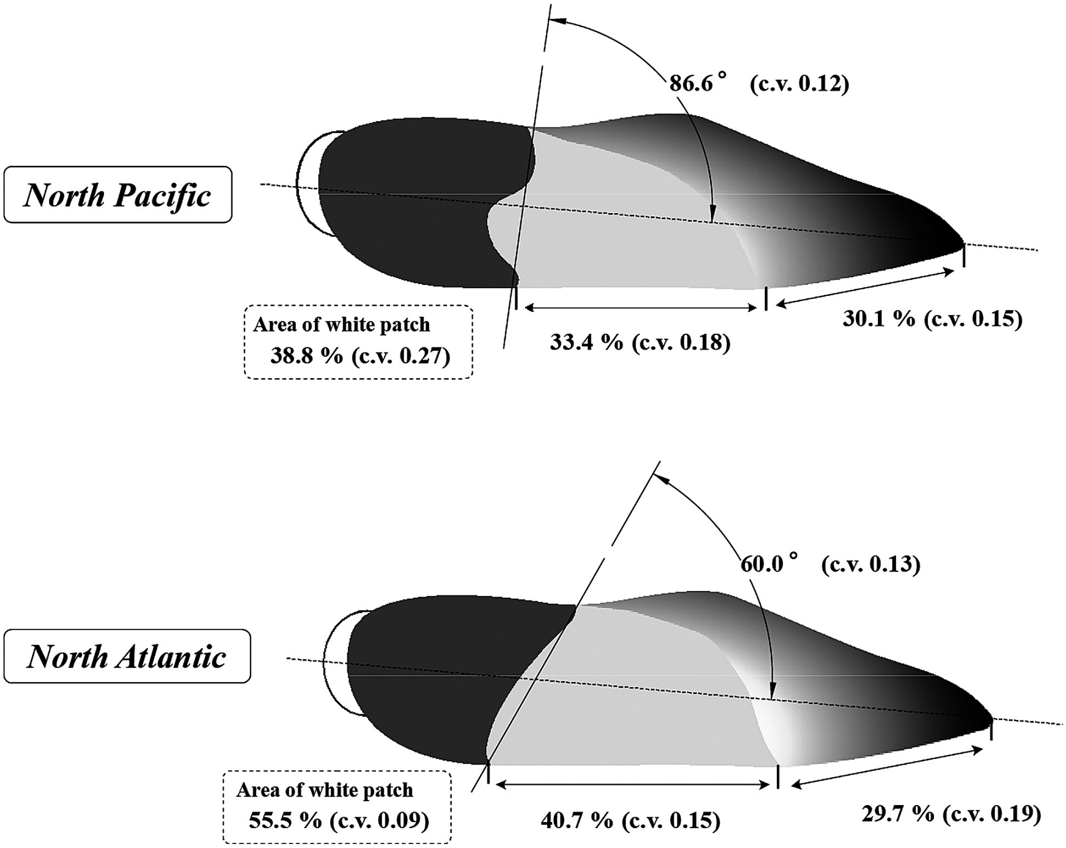

Fig. 7. Relative length of different parts of the flipper, the angle of the mean black/white borderline to the axis of the flipper, and the relative area of the white patch in the North Pacific (top) and North Atlantic (bottom) common minke whales

Measurement # 5: Angle of the mean black/white borderline to the axis of the flipper (Angle θ)

The mean angle was 60.0° (c.v.=0.13) in the North Atlantic specimens and 86.6° (c.v.=0.12) in the North Pacific specimens. This difference in angle by 26.6° indicates that the angle of the mean black/white borderline in the North Atlantic was much more acute in *measurement #5* (Mann-Whitney's U-test, $p<0.01$) (Fig 6-c and 7, Table 5).

Relative area of white patch

The mean area of the white patch was 55.5% (c.v.=0.09) in the North Atlantic specimens, which was significantly larger than 38.8% (c.v.=0.27) in the North Pacific specimens (Mann-Whitney's U-test, $p<0.01$) (Fig. 6-d and 7).

Boundary contour of the white patch

To reveal the difference between whales in the two oceans, the above finding was compared with the boundary contour of the white patch in the North Atlantic specimens. In these specimens, the boundary contour was type 4 with a straight boundary contour, suggesting a clear difference between the two habitats (χ^2-test, $p<0.01$) (Fig. 7). The characteristic features of the boundary contours in North Pacific and North Atlantic whales are summarized in Table 6.

Except for *measurement #4*, which measured

Table 6. Summary of the results and interoceanic comparison

Measurement items	North Pacfic		North Atlantic
Anterior white patch on the fipper (measurement #3)	33.4%	<	40.7%
The length of fipper from the tip to the white patch along the anterior margin (measurement #4)	30.1%	≒	29.7%
Relative area of white patch	38.8%	<	55.5%
Angle of the mean black/white borderline to the axis of the fipper (Angle θ) (measurement #5)	86.6°	>	60.0°
Boundary contour of the white patch	Types 1, 2, 3		Type 4

the relative length of the flipper from the tip to the white patch, all other measurements were clearly different between subspecies. Compared with the North Pacific specimens, the white patch in the North Atlantic specimens was large and well developed at the flipper base. Furthermore, the boundary contours clearly differ between the two subspecies, and no growth related changes were observed in the North Pacific specimens. These findings suggest that the white patch on flipper is an effective anatomical part to use when comparing subspecies, even when those subspecies are geographically distinct.

Because the white patch is a feature unique to common minke whales and unseen in other whale species, it has been useful as a trait for classification. However, it has never been investigated in detail, and this is therefore the first study to quantitatively evaluate the morphology of the white flipper patch. The results revealed growth- and sex-related differences even within the North Pacific species as well as larger-than-expected differences between the North Pacific and North Atlantic subspecies, suggesting that the white flipper patch may serve as a useful feature in common minke whale identification. In particular, the boundary contour of the white patch did not change during development, and the North Pacific and North Atlantic specimens did not share boundary contour features, further supporting the usefulness of the white patch for classification. Although the length of the flipper from the tip to the white patch did not differ between the two subspecies, the clear differences in boundary contour, angle θ, and the length of the white patch between the two subspecies demonstrate that the morphology of the flipper near its base clearly indicates the subspecies of common minke whale. This study showed that North Atlantic minke whale has larger white patch area than North Pacific minke whales. The white patch area of Dwarf minke whales is much larger than that of North Pacific and North Atlantic minke whales, it covers shoulder/flipper region (BEST, 1985; KATO and FUJISE, 2000; ARNOLD *et al.,* 2005). Dwarf minke whales are genetically closer to the North Atlantic minke whales more than North Pacific minke whales (PASTENE *et al.,* 2007). The result that North Atlantic minke whales have large white patch area, might also suggesting that Dwarf minke is evolutionally closer to North Atlantic minke whales. In cetacean, Dall's porpoise *Phocoenoides dalli* shows external difference greater than genetics (HAYANO *et al.,* 2003), therefore external character might changes much faster than genetics. Although genetic variation in North Atlantic minke whales has been reported (PASTENE *et al.,* 2007), differences in the boundary contours of the white patch as shown in this study may serve as a tool equivalent or even superior to genetic testing to elucidate the speciation of common minke whales. It is necessary to further clarify the differences between common minke whale subspecies in different oceans through careful investigation and data collection during commercial whaling of North Atlantic minke whales. Furthermore, crosschecking of the morphological findings and genetic findings regarding the white patch in the North Pacific stock will greatly contribute to the elucidation of the speciation process in the common minke whale clades and their population structure, which can be used for bio resource management.

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