

Presence of an interparietal bone and morphological variation in the vertex of the skull in North Pacific common minke whale

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Abstract: The vertex of the skull is regarded as one of the most important categorical traits in taxonomy in baleen whales. However the previously reported species-specific characteristics for the North Pacific common minke whale, were based on only a very limited number of specimens. Therefore, we aimed to assess the efficacy of these morphological characteristics as categorical traits, based on specimens of North Pacific common minke whales collected from the JARPNII survey ($n=106$). The frontal border of the nasal bones, as well as the positional relationship of the end of premaxilla and the nasal bones, were varied widely by individual, indicating that these traits are not appropriate for species classification. However, the end of the maxilla was located posteriorly to the end of the premaxilla and the nasal bones in all whales surveyed. Therefore, we conclude that this characteristics can serve as universal species-specific morphological characteristics for the North Pacific common minke whales. Furthermore, we found an interparietal bone in all whales surveyed. This bone has been regarded as one of the specific character of "dwarf" minke and have not been reported from any common minke whales in the North Pacific.

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

Introduction

The common minke whale *Balaenoptera acutorostrata* is the smallest species of Balaenopteran whale, and is regarded as an important cetacean resource in Japan as well as in Northern Europe

such as Norway and Iceland. 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 also a distinctive population of "dwarf" minke whales *B. a.* subsp. however, the taxonomical classification of this population remains under debate (RICE, 1998). For managing whales appropriately, the population estimates of the subspecies or stocks levels are required. Therefore, taxonomy is one of the most important concerns for the whale management. Genetic information has recently become a major key for classification in many animals. However,

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especially in cetaceans, even though their genetic differences were not clear, some morphological differences were clearly observed between stocks or populations in different oceans (MIYAZAKI, 1994). Morphological characteristics therefore still remain an important key for classification in cetaceans.

The vertex of the skull is the highest part of the skull, and all dorsal skull bones aggregate at this point (Fig. 1). This shift in the bones' position, generally called as "telescoping" is the result of adaptation to an aquatic lifestyle (MILLER, 1923), and can be used as an important categorical characteristic for taxonomy in baleen whales, especially Balaenoptera (OMURA *et al.*, 1970; 1981; OMURA and KASUYA, 1976; WADA *et al.*, 2003; MEIRELLES and FURTADO-NETO, 2004; MAGALHÃES *et al.*, 2007).

Morphological comparison of the bones in the vertex of the common minke whale and the Antarctic minke whale *B. bonaerensis* have been performed by several authors (OMURA, 1975; ARNOLD *et al.*, 1987; HORWOOD, 1989; ZERBINI and SIMÕES-LOPES, 2000). Schematic illustration of the vertex showing interspecific differences have described (HORWOOD, 1989). A convex frontal border of the nasal bones (viewed dorsally), the posterior end of the nasal bones being located more anteriorly to the end of premaxilla, and the end of maxilla being located posterior to the nasal bones were all species-specific morphological characteristics for North Pacific common minke whales (OMURA, 1975). However, Omura's study was based on only 6 whales, including juvenile animals. Therefore, there still remains the uncertainty that these results are due to individual variation or growth-dependent changes, and a greater number of individuals should be examined to confirm the consistency of these differences. Furthermore, based on photographs in OMURA (1957), ZERBINI and SIMÕES-LOPES (2000)

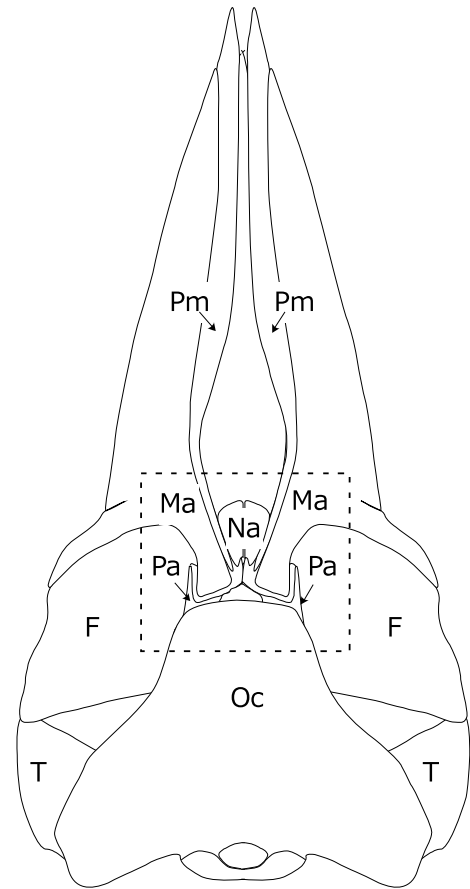


Fig. 1. Dorsal view of the skull of common minke whale and the vertex of the skull (surrounded by dotted line). F: Frontal, Ma: Maxilla, Na: Nasal, Oc: Occipital, Pa: Parietal, Pm: Preamaxilla, T: Temporal.

pointed out that the North Pacific minke whales also might possess an interparietal bone, which has not been reported previously in this species.

Against this background, in the present study we focused on the form of the frontal border of the nasal bones, the positional relationships of the end of premaxilla, maxilla, and the nasal bones, and the existence/nonexistence of an interparietal bone, which have been held to be possible species-specific characteristics. We examined in-

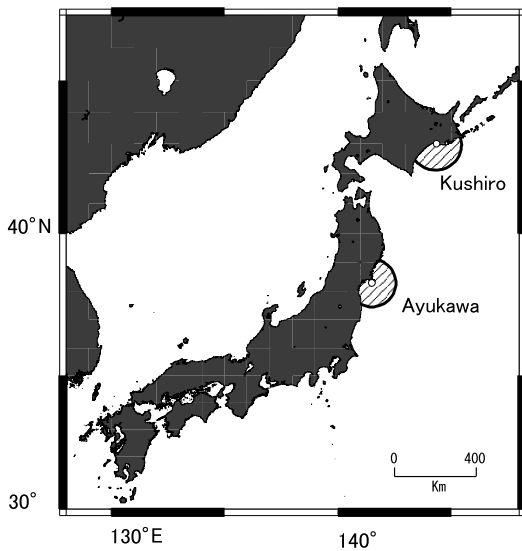


Fig. 2. Sampling area. Research was conducted in coastal waters off Ayukawa, Miyagi prefecture and Kushiro, Hokkaido prefecture. The areas are 50 nautical miles from each port (illustrated by circle).

dividual variation, sexual differences, and growth-dependent changes in these morphological characteristics to assess their efficacy as categorical traits for classifying whale species.

Materials and Methods

We used 106 North Pacific minke whales (64 males, body length: 1.68–8.05 m; 42 females, body length: 3.73–8.55 m) collected from water off Ayukawa, Miyagi pref. and Kushiro, Hokkaido pref. Japan, in 2009–2012 during the Japanese Whale Research Program under Special Permit in the Western North Pacific-Phase II (commonly known as JARPN II) survey (Fig. 2), conducted under the special permit from the government of Japan in accordance with Article VIII of the International Convention for the Regulation of Whaling (GOVERNMENT OF JAPAN, 2002). Body length was recorded as the length between the

tip of rostrum and the notch of the fluke.

After flensing, any flesh or connective tissue remaining on the skull was completely removed manually by knife and the skull was then observed. The below characteristics were chose for the present analysis in order to elucidate individual variation, sex differences, and growth-dependent changes in morphology. Each characteristic was classified based on form or position (Fig. 3). To avoid the effect of growth related morphological changes, the fetus was used only for the observation of the existence/nonexistence of the interparietal bone. Animals with unclear morphological characteristics, due to the incompleteness of removing connective tissues were removed from analysis.

1. Shape of the frontal border of the nasal bones (Fig. 3-1)

Animals were classified into 3 types based on form of the frontal border of the nasal bones: convex, flat, or concave.

2. Relative location between the posterior end of the nasal bones and the premaxilla (Fig. 3-2)

Animals were classified into 3 types based on whether the end of the nasal bones was positioned anterior, equal, or posterior to the end of the premaxilla.

3. Relative location between the posterior end of the maxilla and the nasal bones and premaxilla (Fig. 3-3)

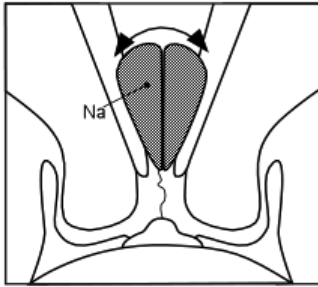
Animals were classified into 3 types based on whether the posterior end of the maxilla was positioned anterior, equal, or posterior to the end of the other two characteristics (the nasal bones and premaxilla).

4. Existence/nonexistence of an interparietal bone and any individual variation (Fig. 3-4)

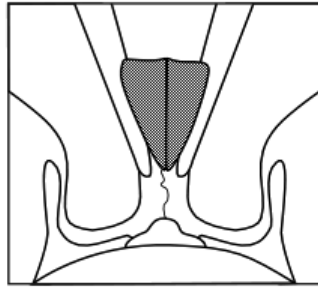
By removing any flesh or remaining connective tissue carefully, especially around the parietal

1. Shape of the frontal border of the nasal bones (Na).

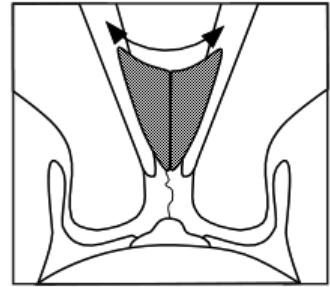
A. Convex



B. Flat

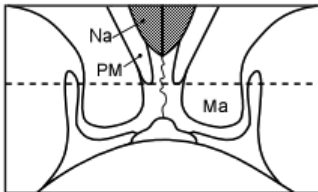


C. Concave

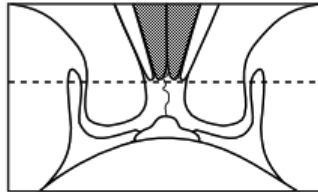


2. Relative location between the posterior end of the nasal bones (Na) and the premaxilla (PM).

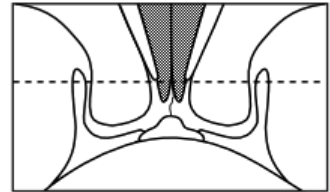
A. Anterior



B. Equal

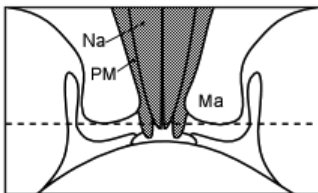


C. Posterior

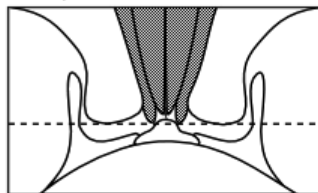


3. Relative location between the posterior end of the maxilla (Ma) and the nasal bones and the premaxilla (Na and PM).

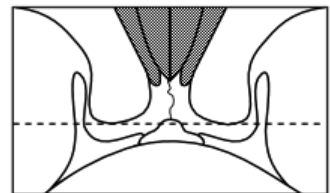
A. Anterior



B. Equal

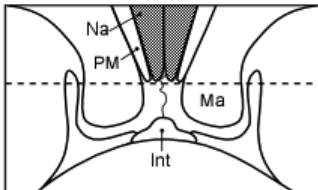


C. Posterior



4. Existence/nonexistence of an interparietal (Int) bone.

A. Exist



B. Non exist

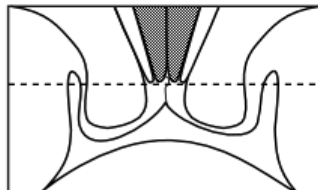


Fig. 3. Basis for the classification of each character.

Table 1. Frequency and sex ratio of each types of the frontal border of the nasal bones.

	Types of the frontal border of the nasal bones		
	Convex	Flat	Concave
Male (<i>n</i> =53)	73.6% (<i>n</i> =39)	22.6% (<i>n</i> =12)	3.8% (<i>n</i> =2)
Female (<i>n</i> =39)	89.7% (<i>n</i> =35)	10.3% (<i>n</i> =4)	0.0% (<i>n</i> =0)
Total	80.4% (<i>n</i> =74)	17.4% (<i>n</i> =16)	2.2% (<i>n</i> =2)

Table 2. Frontal border types of the nasal bones in each body length class.

	Body length class				Total
	<5.0m	5.1-6.0m	6.1-7.0m	7.1m <	
Convex	84.0% (<i>n</i> =21)	92.6% (<i>n</i> =25)	87.5% (<i>n</i> =14)	58.3% (<i>n</i> =14)	80.4% (<i>n</i> =74)
Flat	16.0% (<i>n</i> =4)	7.4% (<i>n</i> =2)	12.5% (<i>n</i> =2)	33.3% (<i>n</i> =8)	17.4% (<i>n</i> =16)
Concave	0.0% (<i>n</i> =0)	0.0% (<i>n</i> =0)	0.0% (<i>n</i> =0)	8.3% (<i>n</i> =2)	2.2% (<i>n</i> =2)
Total	25	27	16	24	92

and occipital bones, the existence/nonexistence of an interparietal bone was examined.

Results

1. Shape of the frontal border of the nasal bones

There was variation in shape of the frontal border of the nasal bones. The animals with convex type were dominant (80.4%, *n* =74), however animals with flat (17.4%, *n* =16) or concave border (2.2%, *n* =2) were also observed (Table 1). Such flat or concave borders have not been reported previously. Therefore the shape of the frontal border of the nasal was not uniform and varied individually. Sex ratios within each border type were compared to clarify the presence or absence of sex differences. Proportional differences between each types were not statistically

significant, indicating that there is no sexual differences in the shape of frontal border of the nasal bones (Chi-square test, $df = 2$, $p > 0.05$) (Table 1).

Concave type was observed in only the class with body length > 7 m (*n* = 2). Although it appeared that animals with flat type nasal bones occurred relatively frequently in the > 7 m class, no statistical difference was observed (Chi-square test, $df = 6$, $p > 0.05$) (Table 2)

2. Relative location between the posterior end of the nasal bones and the premaxilla

The end of the nasal bones was positioned anterior (52.9%, *n* =54) or equal (41.2%, *n* =42) to the end of the premaxilla. On the other hand, we also observed a few animals with the end of the nasal bones positioned posterior to the premaxilla (5.9%, *n* = 6), which has not been previously

Table 3. Frequency and sex ratio of position of posterior end of nasal bones to that of the premaxilla.

	Position of posterior end of nasal bones to that of the premaxilla		
	Anterior	Equal	Posterior
Male (<i>n</i> =62)	51.6% (<i>n</i> =32)	43.6% (<i>n</i> =27)	4.8% (<i>n</i> =3)
Female (<i>n</i> =40)	55.0% (<i>n</i> =22)	37.5% (<i>n</i> =15)	7.5% (<i>n</i> =3)
Total	52.9% (<i>n</i> =54)	41.2% (<i>n</i> =42)	5.9% (<i>n</i> =6)

Table 4. Frequency of the position of posterior end of nasal bones to that of the premaxilla, in each body length class.

	Body length class				Total
	<5.0m	5.1-6.0m	6.1-7.0m	7.1m <	
Anterior	48.2% (<i>n</i> =13)	48.0% (<i>n</i> =12)	63.2% (<i>n</i> =12)	54.8% (<i>n</i> =17)	52.9% (<i>n</i> =54)
Equal	40.7% (<i>n</i> =11)	52.0% (<i>n</i> =13)	21.0% (<i>n</i> =4)	45.2% (<i>n</i> =14)	41.2% (<i>n</i> =42)
Posterior	11.1% (<i>n</i> =3)	0.0% (<i>n</i> =0)	15.8% (<i>n</i> =3)	0.0% (<i>n</i> =0)	5.9% (<i>n</i> =6)
Total	27	25	19	31	102

reported (Table 3). Sex ratios were compared between position types to clarify the presence or absence of sex differences. Proportional differences between each types were not statistically significant, indicating that there is no sexual differences in the relative position between the posterior end of the nasal bones and premaxilla (Chi-square test, $df=2$, $p>0.05$) (Table 3).

No clear trends were observed, and there were no statistical differences between each body length classes (Chi-square test, $df=2$, $p>0.05$) (Table 4)

3. Relative location between the posterior end of the maxilla and the nasal bones and premaxilla

The distance from the end of the maxilla and these other two characteristics varied by individual. However, for all animals ($n=106$), the end of

the maxilla was posterior to the end of the premaxilla and the nasal bones.

4. Existence/nonexistence of an interparietal bone and any individual variation

In all animals ($n=106$), we found a bone that was separate from the occipital, frontal, and parietal bones. In the fetal stage, this bone was not fused with other bones; therefore, we concluded it to be the interparietal bone (Fig. 4). The size and shape varied by individual, but no sex differences or growth-dependent change in shape were observed (Fig. 5).

Discussion

The vertex of the skull has come to be regarded as an important trait for categorizing baleen whales. OMURA (1975) previously described the frontal border of the nasal bone in North Pacific

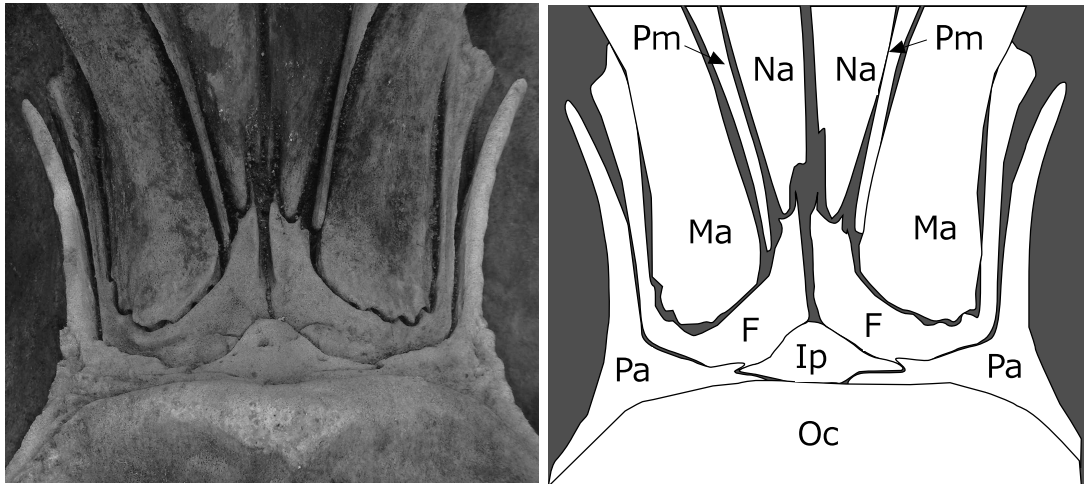


Fig. 4. Photograph (left) and illustration (right) of the vertex of skull of common minke whale. F: Frontal, Ip: Interparietal, Ma: Maxilla, Na: Nasal, Oc: Occipital, Pa: Parietal, Pm: Premaxilla.

minke whales as protruding forward—that is, the border was convex. From the present study, it was clearly indicated that the animals with this convex type of the nasal bones were predominant (80.4%); however, flat-or concave-type animals were also observed. This study furthermore revealed that the positional relationship between the end of the premaxilla and the nasal bones also varied. Because of such wide individual variation, we concluded that the shape of the frontal border of the nasal bones and the positional relationship between the end of the premaxilla and the nasal bone are not an appropriate categorical trait.

The end of the premaxilla and the nasal bones extend more posteriorly and are in line with the maxilla in the Antarctic minke whale, Bryde's whale, and pygmy blue whale (OMURA *et al.*, 1970; 1981; OMURA, 1975). The degree of the telescoping, posterior extension of the rostral bones, in common minke whales tend to be lower than that in other baleen whales. The present study found that the posterior end of the maxilla was located posterior to the end of the premaxilla and the nasal bones in all animals. This positional relation-

ship could therefore be a universal characteristic among North Pacific common minke whales.

Our study also found that all whales surveyed possessed the interparietal bone. The existence of this bone has been reported for dwarf minke whales and Antarctic minke whales, but not for the North Pacific common minke whales (OMURA, 1975; ARNOLD *et al.*, 1987; ZERBINI and SIMÕES-LOPES, 2000). As indicated by ZERBINI and SIMÕES-LOPES (2000), we found the interparietal bone in OMURA's figures (1975). Therefore OMURA (1975) overlooked the existence of this bone, but present study declared that the North Pacific common minke whales also have interparietal bone.

In conclusion, our study found that the positional relationship between the posterior end of the maxilla and the nasal bones and premaxilla is a suitable characteristic for classification of North Pacific common minke whale. The study also established that the North Pacific common minke whale possesses the interparietal bone. It should be noted that the present study was based on only appearance, not quantitative measurements. As for the future study, measurement based

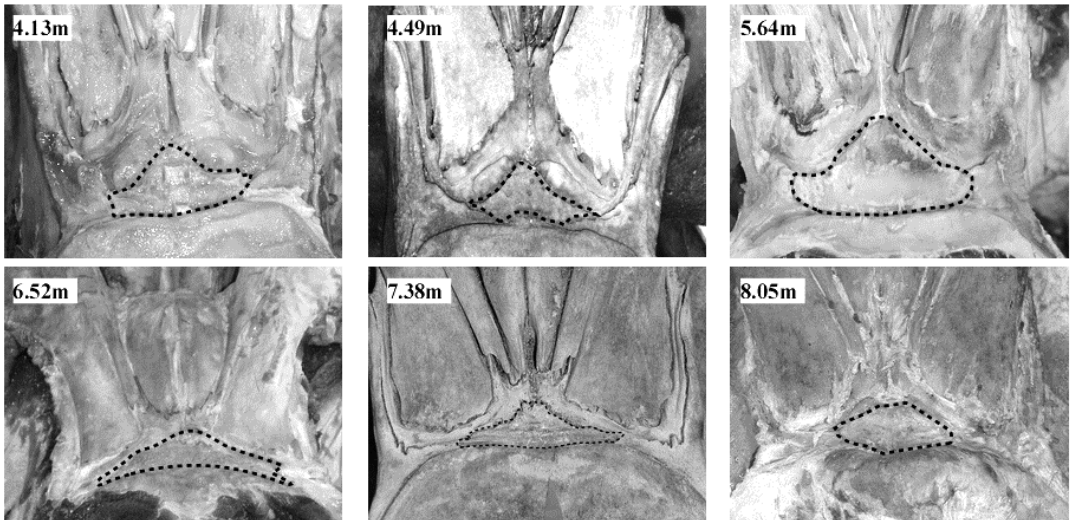
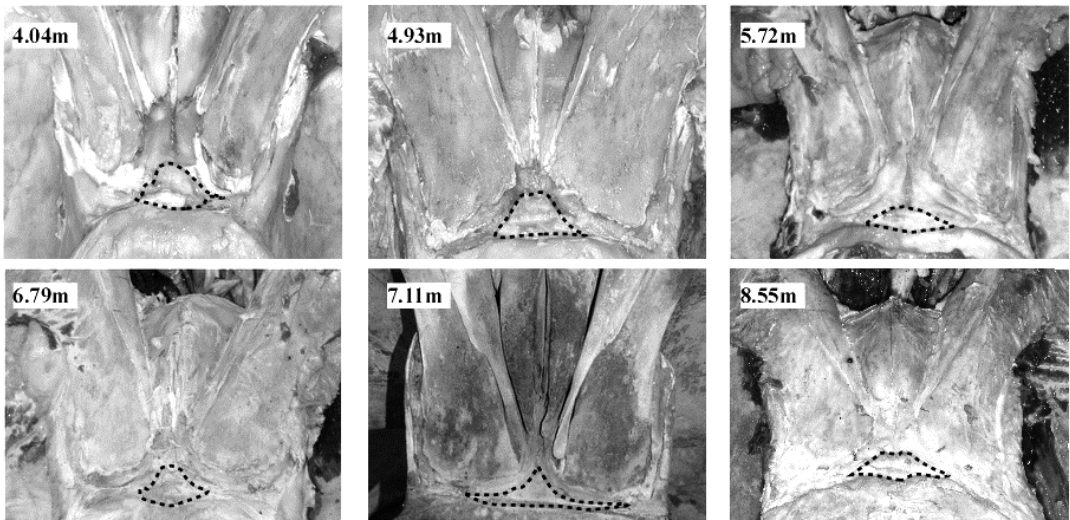
Male**Female**

Fig. 5. Individual variation in size and shape of interparietal of common minke whale. Interparietals are marked by dotted line.

study such as using caliper or 3D scanner would be more effective to evaluate the morphological variation and/or species specific character.

In the North Pacific common minke whales, the existence of two stocks has been reported (KATO *et al.*, 1992). In the present study, we used the samples collected from the coastal waters off

Ayukawa and Kushiro, where the two stocks is mixing (HATANAKA and MIYASHITA, 1997), however we did not consider inter stock differences and therefore still remain the uncertainty that the shape and positional variation includes inter-stock differences. The utility and/or importance of vertex characteristics as categorical traits for

whale classification would be revealed more clearly by future studies using more specific measurements and analyses of size or proportion of these characteristics as well as considering stock information.

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