Thesis for the Degree of Master of Science

Study on skinny western gray whales (*Eshrichtius robustus*) in relation to environmental changes in the North Pacific

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서부귀신고래(*Eshrichtius robustus*)의 야윈 개체 출현과 북태평양의 환경 변화에 관한 연구

Advisor: Prof. Suam Kim

by
Hyun Woo Kim

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ABSTRACT

The population size of western gray whales (*Eschrichtius robustus*) in the western Pacific is estimated to be approximately 120 individuals and they are listed by The World Conservation Union as critically endangered. Most individuals of the western population are observed off Piltun Lagoon on the northeastern coast of Sakhalin Island, Russia, during the summer feeding season. Since 1995, a collaborative Russia-U.S. research program has been conducting individual monitoring of western gray whales summering off Piltun Lagoon by use of photo-identification methods. Body condition of individual whales was determined using a photo-based method that specifically examined the relative amount of subcutaneous fat in three body regions surrounding the head, shoulders and flanks. Loss of fat in these regions suggests some degree of abnormal nutritional stress. Since the body condition of western gray whales varied interannually, as apparent by the total number of individuals observed to be "skinny" in any given year, we hypothesized that this variability was likely to be linked with changes in the oceanic environment and climate of the North Pacific. To address this question, counts of skinny whales in their summer feeding area between 1997 and 2005 were compared to their environmental conditions such as sea surface temperature (SST) and amphipod biomass in the feeding ground, the Pacific Decadal Oscillation (PDO) Index, and Southern Oscillation Index (SOI). The results show that when the -6 months lagged PDO was in a positive phase the number of skinny whales observed was lower than in years when the index was in a negative phase during which time higher numbers of skinny whales were observed. In contrast, -1 year lagged SOI was positively correlated with percentage of skinny whales. It means, 1 year after El Niño, the number of skinny whales was increased.

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INTRODUCTION

1. Population status and distribution of western gray whale

Gray whales (*Eshrichtius robustus*) occur along the western and eastern coast areas of the North Pacific as geographically and genetically isolated two populations (LeDuc *et al*., 2002; Lang *et al*., 2004). They are nominally called western gray whales (WGW) and eastern gray whales (EGW) or Korean stock and Californian stock respectively. The population size of EGW is comparatively bigger than that of WGW, and more knowledge on distribution and biology of EGW has been accumulated compare to western stock. The summer feeding area of the WGW is supposed to have extended to northern part of the Okhotsk Sea. However, most WGW distribute off northeastern Sakhalin Island in feeding season. The whales migrate along Korea and Japan to winter breeding area. The winter breeding area of the WGW is not defined clearly yet. But it is supposed to presumably somewhere around coastal waters of southern China (Zhu and Yue, 1998; Zhu, 2002).

They were overexploited from the 19th century and close to extinct. But EGW were protected under a ban on commercial whaling since 1937, as a result, the present population is thought to approximately 20,000 individuals and appears to be approaching the carrying-capacity of its environment (Rugh *et al*., 2004). In contrast to the population recovery of EGW, the WGW still remain critically endangered population. Nowadays, the total population size is estimated to be approximately 120 individuals (Cooke *et al*., 2006).

There was a perfunctory protection policy about WGW in Korea. Korean Cultural Heritage Administration had declared its migration route lying along the eastern coast of Korea as a natural monument No. 126, named "Ulsan Gray Whale Migration Waters" in 1962. Even though this population has been protected by the law in Korea, they were extremely depleted already at that time. The last sighting record of Western gray whales in Korea was two individuals that had been migrating to southward on 3rd January, 1977, 5 miles in front of Bang-eo jin, Ulsan (Park, 1995).

The International Whaling Commission (IWC) and the World Conservation Union (IUCN) have expressed serious concerns about the status of this population and have called for urgent measures to be taken to help ensure its protection (Hilton-Taylor, 2000; IWC, 2002a, 2002b, 2004a; Reeves et al., 2005).

2. Gray whale biology and skinny phenomenon

While most mysticetes filter prey from the water column, gray whales have unique benthic feeding behavior. They sieve benthic invertebrates from the sediment of sea floor. Their principal prey is known amphipods that live in mud and sand (Rice and Wolman, 1971; Nerini, 1984). In EGW exhibit surface skimming and engulfing behavior for prey such as ghost shrimp (*Callianassa sp.*), mycid shrimp (*Holmesimysis sp.*) and pelagic crab (*Pleuroncodes sp.*) from the water column (Rice and Wolman, 1971; Darling, 1977; Swartz and Jones, 1981; Murison *et al*., 1984; Nerini, 1984; Oliver *et al*., 1984; Würsig *et al*., 1984; Darling *et al*., 1998). However, in western population, a few data are available about feeding behavior from water column (Mizue, 1951). The gray whale population seems to rely primarily upon the shallow benthic communities, especially amphipod, of the northern sea as feeding ground for its annual food supply (Nerini, 1984).

During the field survey, unusually thin whales referred to as "skinny whales" were regularly observed (Weller et al., 2002b). This condition could be noticed, in most cases, within several minutes of approaching individuals by small boat for photo-identification purposes. Initial laboratory analysis of photographs and video collected between 1997 and 2005 revealed several morphological attributes correlated with a particular individual being described as skinny.

Diagnostic features varied between individuals, but consisted of at least one of the following (Brownell and Weller, 2001; Weller *et al*., 2002a):

(1) Obvious protrusion of the scapulas with associated thoracic depression at the posterior and anterior insertion point of the flipper.

(2) The presence of noticeable depressions or concavities around the post cranial region.

(3) Pronounced depression along the neural/dorsal spine of the lumber and caudal vertebrae resulting in the appearance of a bell-shaped body.

It has been noticed number of skinny whales varied interannually. The most likely cause of this condition is nutritional stress, but the underlying reason has been not defined exactly.

3. Climate change impacts on cetaceans

The consequences of the climate change affect both sea surface temperature regimes and temperature driven current pattern throughout the oceans. Climate change is also thought to affect the composition and structure of ecological communities, including cetacean species. There is an increasing evidence for impacts of large-scale climate variation on ecological processes in animal populations (Ottersen *et al*., 2001; Stenseth *et al*., 2002), but the underlying mechanisms often remain unclear (Stenseth *et al*., 2003), especially on cetacean community as well. The effects of climate variations on higher trophic levels can be difficult to understand because they involve several non-liner relationships. There may also be lags in responses to local climate (Hallett *et al*., 2004), which make it hard to determine these complex associations. Studies of the influence of climate change on body condition of the whales may provide important insights into causal links between these large-scale processes and population dynamics. However, it can be difficult to quantify meaningful body condition indices of the whales and collect long term data sets.

4. Purposes and hypothesis

To explain nutritional stress that affects body condition of WGW, any of the following factors may be contributing alone or in combination: 1) disease; 2) stress induced metabolic shifts; 3) habitat perturbation by anthropogenic activities; 4) prey availability affected by environmental change of the feeding ground.

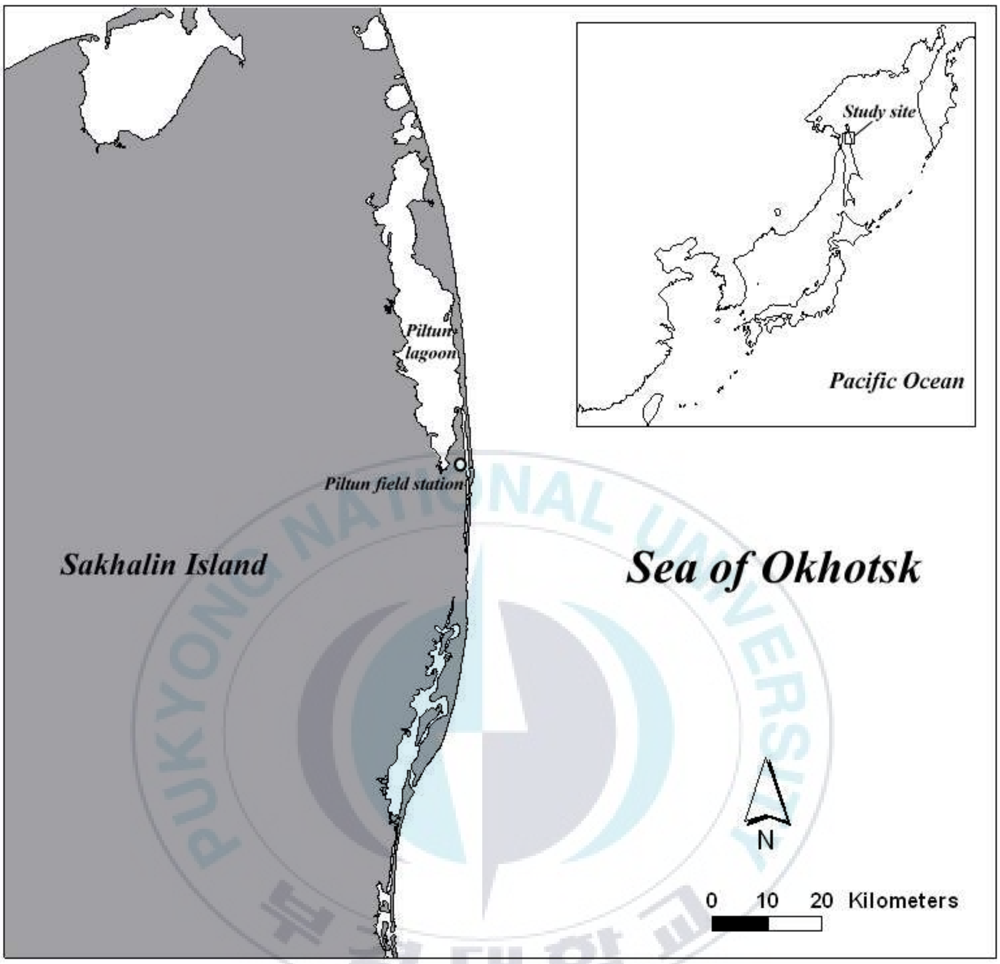
This research aims to figure out the relationship between oceanic environments and body condition of WGW. The hypothesis is that the skinny phenomenon was likely to be linked with prey availability from oceanic environment changes in the feeding area associated to climate changes of the Pacific Ocean.

MATERIALS AND METHODS

1. Study area

Piltun Lagoon is located on the northeastern shore of Sakhalin Island, Russia (Fig. 1). The lagoon is approximately 80~90 km long and 15 km across at its widest point. A single channel connecting the inner lagoon with the Okhotsk Sea occurs at 52° 50′ N and 143° 20′ E, and has considerable biological influence on the surrounding marine environment. The gray whales are frequently observed near this lagoon. A lighthouse, Piltun field station near the lagoon channel, served as the base for a study. The coastal waters environment of the study area is mostly consisted of sand substrate, characterized by a gradually sloping and broad continental shelf. Water depths within 5 km of shore are mostly less then 20 m deep.

Figure 1. Map of the Piltun study area. Inset shows the location of Sakhalin Island in the Sea of Okhotsk.



2. Photo-Identification

Research designed to examine the behavior and ecology of cetaceans has benefited greatly from the ability to recognize individuals (International Whaling Commission, 1990). The use of distinctive, naturally occurring variations in the appearance of individual cetaceans within a population has been commonly combined with photo-identification techniques (Wüsig and Jefferson, 1991).

Boat-based photo-identification surveys of the WGW have been conducted by international survey team since 1994 with the exception of 1996. Especially, collaborative efforts of Russian-U.S. survey group included the most comprehensive and detailed photographic, genetic, and behavioral data-bases. A photo-Identification method was employed during all good weather days each survey, with the primary objective of encountering and photographically identifying as many whales as possible.

Each gray whale has different and unique patch, spot patterns, and dorsal hump shape on their body (Fig. 2), and is identified individual through these three features (Brownell et al., 1997; Weller *et al*., 1999, 2006a). Attempts were made to simultaneously photograph and videotape the right dorsal flank of each whale, followed then by photos of the left dorsal flank and flukes. However, the majority of whales identified to date now have images of right and left flanks and flukes as well as ventral surface of flukes in the photo-identification catalog, thereby allowing for useful identification images to be collected from nearly any body region.

Photographic surveys involved slow travel in a 4.5 m outboard-powered inflatable boat. The research team consisted of a boat driver, data recorder, digital video camera operator, and digital camera photographer. Systematic visual search by vessel slowed to idle speed, and maneuvered to a vantage point approximately 50 m from the whale (s). From this position, observations on group location (as determined by Global Positioning System, GPS), time, behavior, and number of whales were recorded.

The research vessel was then moved within approximately 30 m of the whale group and individuals were photographed. During the photographic effort, a running commentary regarding the image frame and video counter number as related to particular whales was recorded onto data sheets. Measures of water depth (as determined by digital depth sounder), location (as determined by GPS), and environmental conditions were recorded every 3-5 min. throughout each photographic session.

Figure 2. Pigmentation and other patterns used to photographically identify individual whales, (a) Left side of dorsal flank, (b) Right side of dorsal flank, (c) Downside of fluke.

(a)

(b)

(c)

3. Body condition assessment

Relative amounts of subcutaneous fat in three areas that post cranial area, scapula region, and lateral flank were considered, because loss of subcutaneous fat in these three regions has led to three characteristics relative to normal condition (Fig. 3a). The skinny whales are characterized by post-cranial depression, subdermal protrusion on the scapula (Fig. 3b) and depression along the lateral flank (Fig. 3c). If any one or more of the above criteria were observed and noted in photographs or video data, the subject animal was categorized as a skinny whale for that sighting. The final categorization given to a subject animal is the highest Class number associated with that animal for any given field season. The body condition classes are consisted by 3 digits which indicate poor (1), fair (2), and normal (3) conditions of post-cranial, scapula, and lateral flank respectively.

Basically, since the post-cranial condition is seemingly the more 'standard' measure of body condition, except in the case where the other two conditions are poor. In those cases (i.e., post-cranial = 2, scapula = 1, lateral flank = 1, and 3 1 1), the resulting body condition could be brought down a code (i.e., poor and fair, respectively). However, any other combination after the post-cranial score (e.g., 2 1 X, 3 X X) does not change the code indicated by the post-cranial condition, which ends up being a conservative coding approach. Skinny whale in this study was defined as the animal in categories Poor.

The suggested body condition keys are defined as below:

- POOR: 111, 112, 11X, 121, 122, 1X1, 1XX, 211
- FAIR: 212, 21X, 221, 222, 22X, 21X, 2X2, 2XX, 311
- NORMAL: 312, 321, 322, 32X, 3X2, 3XX
- UNKNOWN: X12, X1X, X21, X22, X2X, XX1, XX2, XXX

Annual body condition of the whales was analyzed from the photo-identification survey 1997-2005. Body condition of the whales is variable depending on their age class or sex deference. Mothers, weaning their calf, are subject to exceptionally high energetic demands during lactation (Weller *et al.*, 2002b). Calves, newborns of the year, have mostly normal condition because of sufficient energy support from their mother. Juveniles, known age between two and four years old, also hardly have poor body condition. Two-sided Chi-square test of independence with adult group (excepted above three groups from total body condition data) was applied, and it was revealed that all the groups were independent from the adult group. Body condition data of mother, calf and juvenile ware removed from total body condition data, and the rest was the animals analyzed.

Figure 3. Diagnostic features of body condition of gray whale (a) Normal condition of gray whale, (b) A “skinny whale” with two diagnostic features: a post-cranial depression and a protruding scapula, (c) pronounced depression along the flank.

(a)

(b)

(c)

4. Environmental Data

Environmental data sets were collected. Sea Surface Temperature (SST) and amphipod biomass in Piltun feeding ground were available, and large-scale environmental indices over the Pacific Ocean were compared to the interannual variability of skinny whales.

a. Local oceanographic information

The SST data were obtained opportunistically depending on weather condition from the field during the survey. The sample consisted of all SSTs obtained throughout the months of July and August. Sample size varied greatly from year-to-year, ranging from a low of 12 measurements in 2005, to 53 measurements in 1999 (Appendix Ⅰ).

Systematic benthic survey has been conducted since 2001 in the Piltun gray whale feeding ground by Fadeev (2001, 2002, 2003, 2004, and 2005). Quantitative benthic biomass data were available from this survey. Amphipod biomass data were extracted to provide an index of pray of the gray whales from these reports.

b. Large-scale environmental indices

In the North Pacific ecosystem, many ecosystem components were influenced by the changes in environmental factors such as El Niño, SST, or seasonal monsoon.

The Southern Oscillation Index (SOI) and Niño Indices are commonly used to monitor the atmospheric and oceanic aspects of El Niño Southern Oscillation (ENSO). The SOI is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin in tropical Pacific. Sustained negative values of the SOI indicate El Niño episodes. The SOI was obtained on a monthly basis from the Bureau of Meteorology, National Climate Centre, Climate Analysis Section, Australia (ftp://ftp.bom.gov.au/anon/home/ncc/www/sco/soi/soiplaintext.html). To compare and correlate with data on skinny whale phenomenon of the WGW, data on the SOI anomaly were selected during 1997-2005.

Niño Indices are a set of SSTs from Niño 1+2 (0-10° S, 90°W - 80°W) Niño 3 (5°N - 5°S, 50°W - 90°W) Niño 4 (5°N -5°S, 160°E - 150°W) Niño 3.4 (5°N - 5°S, 170 - 120°W) regions. Niño Indices were obtained from Climate Prediction Center, NOAA (http://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices).

The Pacific Decadal Oscillation (PDO) is a reflection of the North Pacific sea surface temperature (Mantua *et al*. 1997). Updated standardized values for the

PDO index, defined as the leading principal component of monthly SST anomalies in the North Pacific Ocean of 20˚ N, were obtained on a monthly basis from the Joint Institute for the Study of the Atmosphere and Ocean (http://jisao.washington.edu/pdo/PDO.latest).

RESULTS

1. Survey effort and sighting trends

Between 1994 and 2005, 150 WGW have been identified during 307 boat based surveys (Table 1). Number of surveys and hours of observation were variable depending on the weather condition of the field. Fifty-five of the whales in the photo-catalog were animals first identified as calves, while the remaining 95 whales were considered non-calves (i.e. adults or subadults). Not all of these whales are alive, however. By excluding mothers and juveniles from the non-calves, WGW were only needed for this analysis (Table 2).

2. Proportion of skinny whales

Based on survey results, the body condition classes of the adult whales, which male and non-weaning female, were classified. Figure 4 shows annual percentage of the each class. Annual percentage of skinny whales fluctuates substantially. In particular, the percentage was higher from 1999 to 2001 and declined in 2003 and 2004.

Table 1. Annual survey effort, groups encountered and whales identified 1994 to 2005.

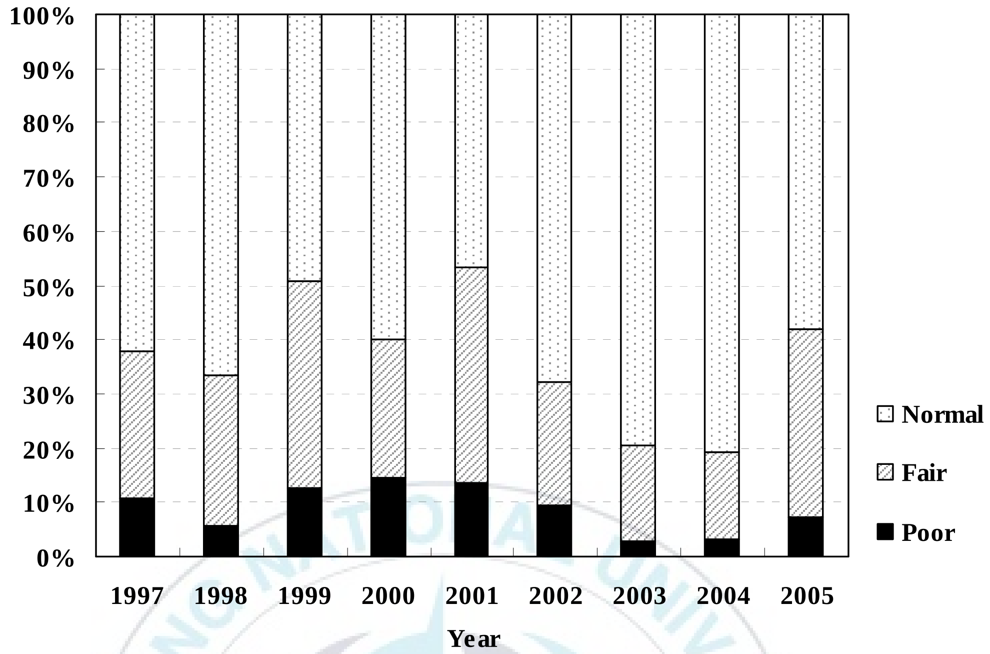
Year	Sampling Period (mo, d)	Number of Surveys	Hours of Observation	Groups Encountered	Whales Identified
1994	09/07 - 09/12	1			10
1995	08/15 - 08/19	5	10.1	23	28
1997	07/09 - 09/08	22	33.4	114	47
1998	07/06 - 09/29	35	50.5	125	54
1999	06/29 - 10/13	56	122	434	69
2000	06/25 - 09/16	40	56.5	365	58
2001	06/25 - 09/25	49	101.8	448	72
2002	06/25 - 09/25	36	75.6	411	76
2003	07/15 - 09/13	22	41.7	219	75
2004	07/29 - 09/12	21	33.8	194	93
2005	07/04 – 09/09	20	40.9	160	92
Overall		307	566.3	2493	150*

Table 2. Annual sighting trends between 1997 and 2005.

Year	Whales Identified	Mothers	Calves	Juvenile	Adults except mother
1997	47	2	2		43
1998	54	7	8	1	38
1999	69	2	3	4	60
2000	58	2	3	4	49
2001	72	6	6	5	55
2002	76	6	7	13	57
2003	75	10	11	11	43
2004	93	6	7	16	64
2005	92	5	6	11	70
Overall	150*	48	55	65	479

* The number of whales identified annually includes relighting of individuals from previous years, resulting in a total of 150 identified individuals.

Figure 4. Annual percentage of the body condition classes of the adult whales.

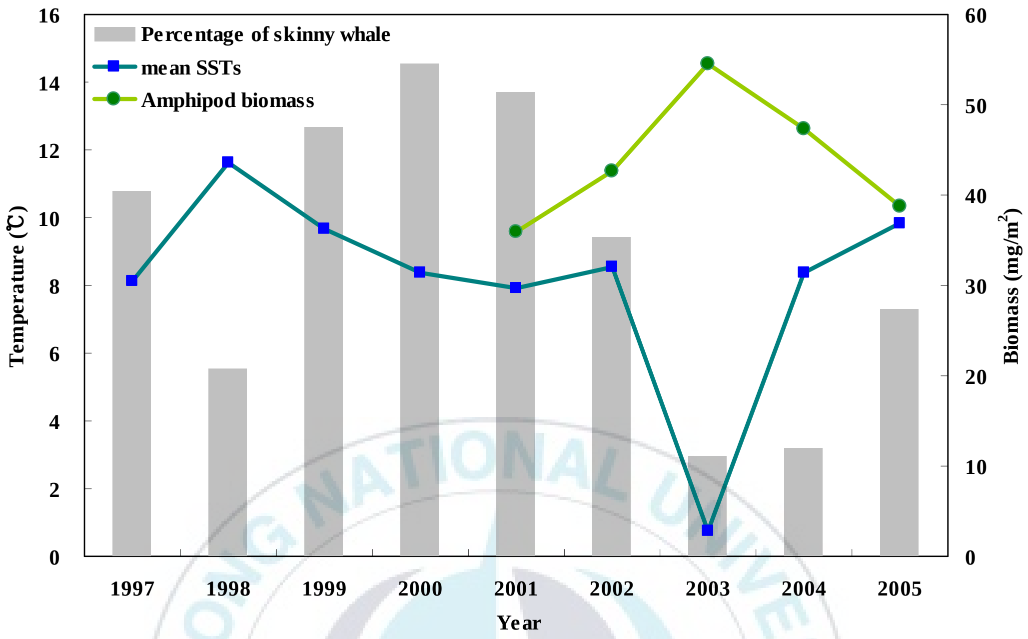


3. Local environments and skinny whales

Mean SSTs during July and August and amphipod biomass from the Piltun field station are shown for the period from 1997 to 2005 in Figure 5. Mean SSTs were highest in 1998 and lowest in 2003, while amphipod biomass was highest in 1998. The cross correlation coefficients between the series of mean SSTs and amphipod biomass was negative ($p = 0.1$, $r = -0.80$).

Although there are only 5 years amphipod biomass dataset, it is helpful to figure out the tendency of correlations between amphipod biomass and the percentage of skinny whales. Figure 5 shows when amphipod biomass was abundant, number of skinny whale had decreased ($p < 0.06$, $r = -0.86$). However, there were no significant correlations between the SSTs and the percentage of skinny whales ($p = 0.32$, $r = 0.39$).

Figure 5. Mean SSTs during July and August and amphipod biomass from the Piltun field station.



4. Large scale environmental indices and skinny whales

The cross-correlation between the percentage of skinny whales and Niño indices indicates similar patterns related to all the Niño areas. The correlation was greatest with -1 year lagged index of Niño 4 region (Fig. 6, $p < 0.001$, $r = 0.95$). Also the percentage of skinny whales were strongly correlated with -1 year lagged SOI (Fig.7, p < 0.001, r = 0.81). It means, 1 year after El Niño, the number of skinny whale was increased and after La Niña, it was decreased.

The fluctuation of skinny whale was also significantly related to the climate index in the North Pacific Ocean. However, it shows opposite tendency with relationship between the percentage of skinny whales and SOI (fig. 7). The cross-correlation coefficients between autumn-winter PDO (September-January) and the percentage of skinny whales were greatest with a time lag of -12 ~ -6 months (Fig. 8, $p < 0.001$, $r = -0.83$). This result shows that when -12 ~ -6 months lagged PDO index was in a positive phase, the percentage of skinny whales were declined. On the other hand, when the index was negatively shifted, the frequency was increased.

Figure 6. Correlation between deviations from the percentage of skinny whales and lagged Niño indices anomalies.

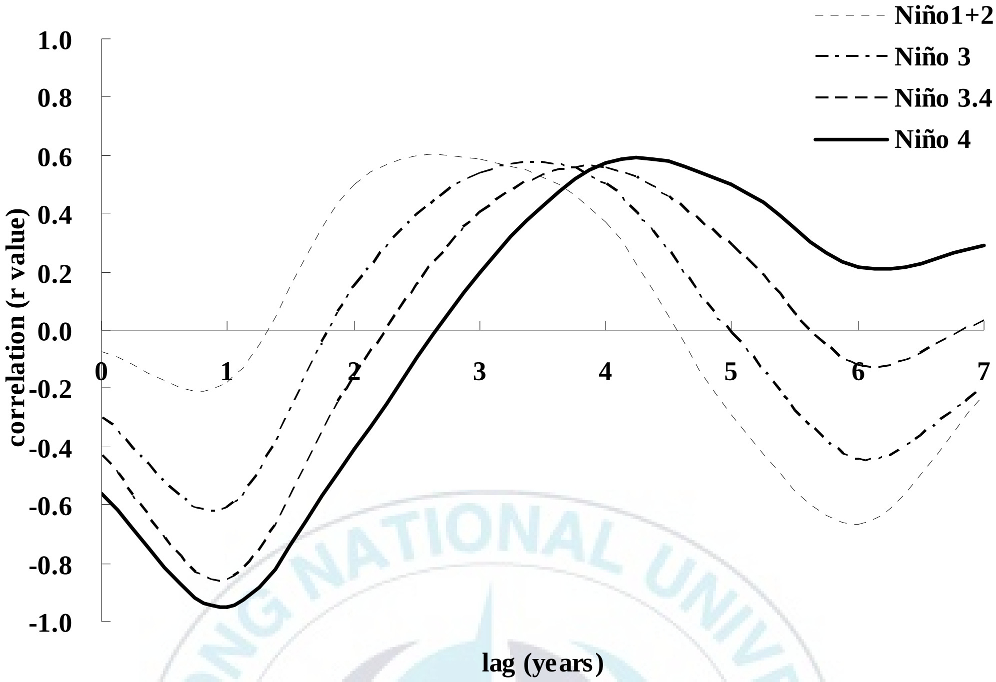


Figure 7. Cross-correlation with a time-lag of SOI and PDO.

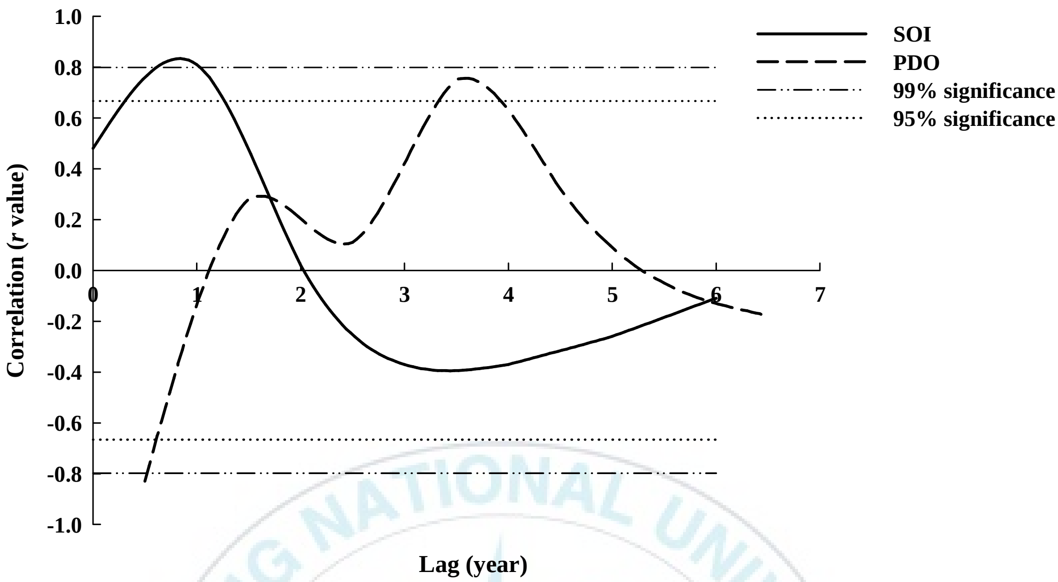


Figure 8. Relationship between SOI (-1 year lagged) and the percentage of skinny whales.

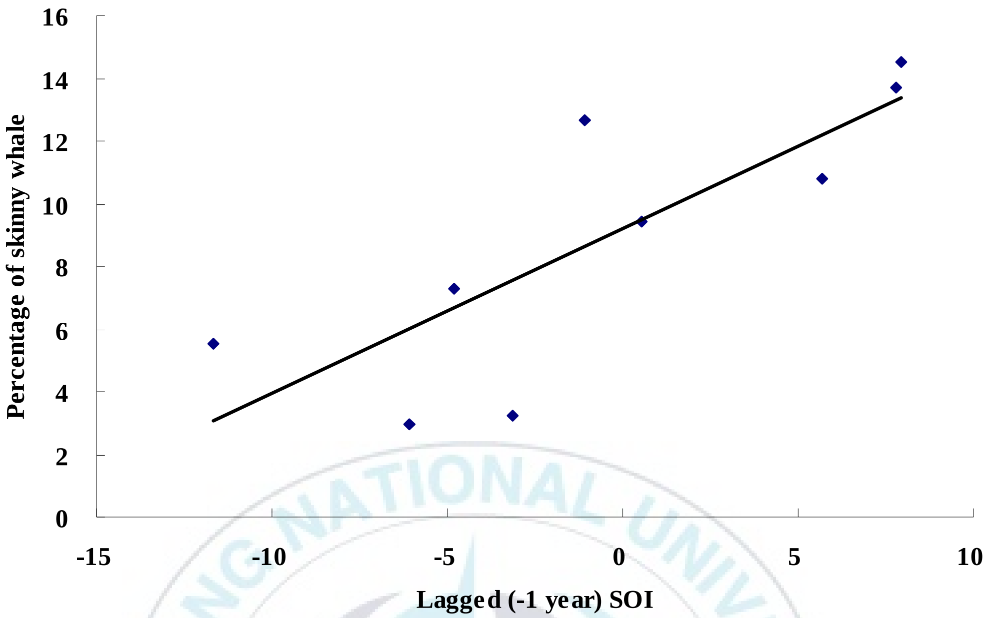
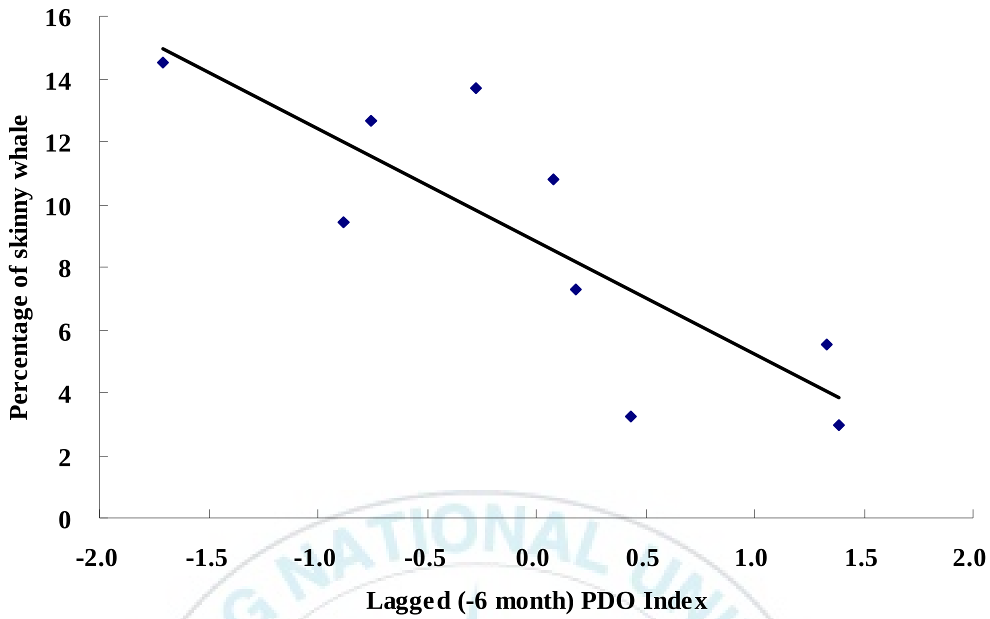


Figure 9. Relationship between autumn-winter PDO Index (-6month lagged) and the percentage of skinny whales.



DISCUSSION

The results presented above show the percentage of skinny whales in western population were recorded the highest value in the 1999, 2000 and 2001 seasons with the 9-year body condition data. Interestingly, at the same time, the eastern gray whale population experienced unusually high mortality of immature and adult whales. The annual stranding rates much greater than reported during the previous years (LeBoeuf *et al*., 2000; Brownell *et al*., 2001; Moore *et al*., 2001). This is contrast to previous years in which mortality was highest among calves, yearlings and juveniles, and adult deaths were rare (Jones and Swartz, 1984; Sanchez Pacheco, 1998).

Coincident with the high mortality, estimates of calf production of eastern population in 1999, 2000 and 2001 were the lowest recorded in an 8-year time series (Perryman and Rowlett, 2003). Similarly, Gross Annual Reproductive Rate (GARR), which is the number of calves expressed as a proportion of the total estimated population, of western population was low in 1999 and 2000 (Weller *et al*. 2006b). It is possible to suppose that body condition and mortality of the gray whales would affect their reproductive rate. Occurring skinny whale phenomenon and low GARR in western population and high mortality and low estimates of calf production in eastern population at the same years suggest that the causes are controlled by large scale climate change.

LeBoeuf *et al*. (2000) hypothesized that principal pray of gray whales, amphipod biomass, had been depleted due to the combined influence of increased annual water temperatures in the Bering Sea and overgrazed by exceeded the carrying capacity of the feeding grounds. The western gray whale population, consisting only about 120 individuals, seemingly cannot be overgrazing their benthic food base or exceeding the carrying capacity of the feeding grounds (Brownell and Weller, 2001).

Highsmith and Coyle (1991) showed amphipods exhibit temperature-dependent growth and maturation rates. In warm temperature, small amphipod species that can reproduce and colonize quickly occupy most of distributing space. And it leads to low amphipod biomass. In other words, cold temperature allows large amphipod species can occupy the space. As a result, the total amphipod biomass would be abundant.

The results are consistent with the hypothesis that the skinny phenomenon was likely to be linked with SST in the feeding area. Although it shows a tendency to relationship between the mean SSTs and amphipod biomass in the feeding ground, it is still insufficient to explain body condition of the whale in relation to local environmental change. Not only, irregularly obtained field SST data and short time series of benthic biomass data, but also unidentified additional local environmental parameters such as primary production, upwelling, sea ice and freshwater flow from coastal lagoon systems near feeding area that considered at least partially responsible among benthic prey communities might make more ambiguous the result. These various environmental factors would affect to benthic prey biomass. However, these environmental data were not available to this study.

The suggested hypothesis is that high water temperature in the feeding ground associated with negative phase of SOI and positive phase of PDO may reduce total amphipod biomass in the area. Because of not enough prey from this process, Number of skinny whales may be increased.

The result is best explained by the basin scale climate change, as represent Niño indices, SOI, and PDO, with the body condition of western gray whales.

ENSO is indicated by Niño indices and SOI. ENSO 1997-98 was one of the strongest ENSOs of the century (Wolter and Timlin, 1998; McPhaden, 1999). Higher than usual sea surface temperatures associated with the ENSO would affect to SST and amphipod biomass of the feeding area. The restrictively available information indicates that mean SST in the feeding area in 1998 was the highest of the nine preceding years. It suggests that if the prey biomass of gray whales was reduced by ENSO, it was due to one single warm year rather than over several years. But this is hard to explain why the percentage of skinny whales fluctuated in response to the climate indices.

The result is also explained by impact of PDO. The PDO positive phase is characterized by a broad expanse of cooler than average temperatures in the mid-latitudes of the central and western Pacific. The negative phase is the inverse of the positive phase with warmer temperatures in the north Pacific (PICES, 2004). PDO showed negative phase between 1998 and 2001. It suggests that western Pacific, including the Piltun feeding area, was warmer then other phase.

Although the result to investigate links between the body condition of gray whales due to high water temperature that lead to inadequate foraging on amphipods in Piltun feeding ground was not significantly correlated, indirect climate indices and circumstantial evidence strongly implies such an association.

The western gray whale population is still at only a small remnant of its original population size. The study indicates the environmental effect on the body condition even at low population levels such as western gray whales. The results show strong evidence of a relationship between global climate change and interannual variability in gray whale body condition.

Small changes in oceanographic conditions in the Pacific Ocean may affect not only body condition of western gray whales, but also their reproduction. Thus identifying the causes and understanding the effects are needed for the conservation of this endangered population.

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APPENDIX

Appendix I. Mean Sea Surface Temperatures 1997 - 2005 in Piltun survey area.

Year	Sample size (*n*)	mean SST (°C)
1997	13	8.1
1998	20	11.6
1999	53	9.7
2000	25	8.4
2001	16	7.9
2002	28	8.6
2003	14	0.7
2004	13	8.4
2005	12	9.8