A review of the biology of western North Pacific minke whales relevant to stock structure

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Abstract
Examination of the stock structure of minke whales in the Yellow Sea, Sea of Japan (East Sea), and western Pacific Ocean is difficult because there are no data from the breeding grounds and there are few data from mature females on the feeding grounds, as sampling has been limited to the mid-latitudes (mostly between 35° and 45° North latitude). Most of the data come from the Pacific Ocean, with some information from the northern Sea of Japan and the southern Sea of Okhotsk. There are relatively few data from the Yellow Sea, the Korean coast of the Sea of Japan, and the southern Japanese (Honshu) coast of the Sea of Japan. Nonetheless, some of the available data provides information about stock structure, and a few types of biological data are particularly informative, including conception dates and flipper color types. An examination of migration patterns, whale distribution, and historical whaling areas on feeding grounds, in concert with observations of immature/mature ratios and sex ratios also provides some information on possible stock structure. Several lines of evidence point to the existence of a separate stock of minke whales in the Yellow Sea; mature females with newborn calves are there in summer and there appears to be a distributional hiatus between the central/northern Yellow Sea (a historical whaling ground) and other areas in summer. Most striking of all is that whales from the Yellow Sea only have dates of conception in autumn (July-September), in contrast to other areas which have winter conception (February-March) dates or a mix of autumn and winter conception dates. There is less information to determine whether two stocks exist on either side of the Sea of Japan. Data from the northern Sea of Japan show a mixture of autumn and winter conception dates and of type III and type IV flipper color types, which could be indicative of a mixture of two stocks from either side of the southern Sea of Japan, or of a single stock that has multiple types of both traits. Comparisons between the west and east coasts of Japan (Sea of Japan versus Pacific coast) are complicated due to the possibility of comparing 'J-type' whales in the Sea of Japan with mixture of 'J-type' and 'O-type' whales in the Pacific Ocean. In the Pacific 'J-type' whales are found primarily in coastal waters of the coasts of Honshu and Hokkaido, so comparisons between the Sanriku whaling data (<50nm from the coast) and the northern Sea of Japan data can be used to examine potential differences. 'J-type' whales migrate up both coasts, possibly to separate historical whaling grounds in feeding areas in (1) the northern Sea of Japan and (2) the Pacific Ocean east of Hokkaido and the southern Sea of Okhotsk; this therefore represents either two stocks or a split migration of a single stock. Data from the northern Sea of Japan show a mixture of autumn and winter conception dates and of type III and type IV flipper color types, whereas data from Sanriku on the Pacific coast show only winter conception dates and type IV flipper color types. These data are consistent with either two coastal stocks on either side of Japan, or a single coastal stock on both sides of Japan but the existence of a second stock (presumably) along the Korean coast of the Sea of Japan that mixes with the Japan stock in the northern Sea of Japan. Some differences were found between coastal sub-area 7 whales and Pacific offshore whales in sub-areas 7, 8, or 9. Most striking is that sub-areas 8 and 9 are dominated by immature males whereas coastal sub-area 7 has a majority of females and a higher proportion of mature animals. Whale densities were also much higher along the coast than offshore, suggesting the possibility of a coastal stock. Some differences between coastal and offshore areas were also found in the amount of body scars from cookie cutter sharks and in the concentrations of some contaminants.

Introduction
The biology of minke whales has previously been examined from the perspective of examining population structure between the Sea of Japan ("J-stock") and the Pacific Ocean ("O-stock"), with several differences found. These include the timing of conception or breeding season, coloration patterns of the flipper and baleen, scarring/parasite patterns, and chemical analyses of Persistent Organic Pollutants (POPs) and heavy metals. Apart from the differences noted between those two broad regions, most other genetic and biological studies have mainly examined hypotheses of possible population structure within the western Pacific Ocean, such as the possibility of one stock in sub-area 7 and a second stock in sub-areas 8-9 (Fig. 1, bottom right panel).

Recent genetic analyses have indicated that there may be population structure within the putative J-stock, and that what have been thought of as J-stock whales may occur outside the Sea of Japan, so the picture is more complicated than a simple scenario of a Sea of Japan stock versus a Pacific Ocean stock. Genetic evidence has shown that J-stock type whales are found along the Pacific coast of Japan, and there are other indications of possible genetic differences within the Sea of Japan between the Korean coast and the Japanese coast. In light of these recent genetic results, seven new hypotheses (Fig. 1) were made regarding population structure of minke whales in the Yellow Sea, Sea of Japan, and Pacific Coast of Japan (IWC 61, 2010, Annex G1, Appendix 8).

Although the seven hypotheses depicted in Fig. 1 appear complicated, they simply represent different permutations of four main uncertainties. Investigations of these four issues will help resolve stock structure of minke whales in the western North Pacific, particularly in the Yellow Sea, the East Sea/Sea of Japan, and the Pacific coast of Japan):

1) *Are whales in the Yellow sea part of a population that migrates into the Sea of Japan?*
2) *Are whales along the Korean coast part of the same population as whales that migrate along the Japanese coast?*
3) *Are whales on the east coast of Japan the same population as on the west coast of Japan?*
4) *Is there a coastal population in Subarea 7 (east of Hokkaido and northern Honshu) that is different from offshore minke whales in the Pacific Ocean, even after accounting for Sea of Japan whales that might migrate into this area?*

In this paper, we review and re-examine non-genetic biological data from minke whales in order to more closely examine population structure within the Yellow Sea, Sea of Japan, and Pacific coast of Japan. We also review biological data relevant to population structure in the Pacific Ocean and Sea of Ohkotsk, where many of the whales have been hunted during the last decade.

Methods and Materials

We re-examined available published and unpublished (IWC/SC documents) papers on the biology of minke whales from the western North Pacific in this review.

It should be emphasized that there are two primary data gaps that make interpretation of the data difficult: 1) there are no data from the breeding grounds, and 2) there are virtually no data from mature females on the feeding grounds. Sampling has been limited to the mid-latitudes (most between 35° and 45° North latitude). The season of sampling for scientific whaling has also been limited with most occurring in May through August. Starting in 2004, small-type whalers were allowed to take 120 minke whales within 50 nm of the coast and this effort was earlier and later than the offshore pelagic catches. In the Pacific Ocean this timing means that adult females have already migrated through the area and are found in more northerly waters where whaling does not occur. Thus, many (if not most) of the whales killed in pelagic waters are on migration. The sex and age segregation of minke whales together with the limited sampling times and locations can make for a difficult problem in interpreting the data.

Results and Discussion

Feeding grounds

It has been postulated that there are three components to what has been thought of as the J-stock, based on separate feeding destinations: (1) Yellow Sea, (2) Sea of Japan, and (3) north of Hokkaido and east of Honshu (IWC 1994, Kato and Kasuya 1992). These have been hypothesized from the locations of past whaling grounds together with information on the times of the catches on each of the grounds (IWC 1994). Brownell (1981) noted catches around Korea in all months between 1965 and 1977, although only a few catches occurred in January. Wang (1985) reported catches throughout the year in the Yellow Sea west of the Korean Peninsula. Gong (1982) reported catches off the Korean Peninsula from March to October in 1980, including in the East Sea/Sea of Japan May to October, and in the Yellow Sea from March to September. These authors report catches of whales greater than 7m in summer, indicating mature whales are there during the feeding season.

Whale density

There are no true distributional hiatuses for minke whales. However, a density index (IWC 2001 Fig. 2) calculated from JARPN data revealed high densities along the coast declining to near zero at 147° E followed by relatively constant low densities offshore. A similar pattern is seen in the JARPN2 data (Konishi et al. 2009). This density pattern is consistent either with a high-density coastal stock and a low-density offshore stock or with a single stock that occurs at higher densities near the coast. Whale densities have not been calculated in a similar way in either the Sea of Japan or the Yellow Sea. However, recent surveys in the Yellow Sea show a relatively high density of minke whales in the central Yellow Sea but very few in the southern Yellow Sea (e.g, An et al. 2009), suggesting a hiatus in distribution (during that season) between Yellow Sea whales and whales in other locations.

Migration patterns
Omura and Sakiura (1956) analyzed catches from small-type commercial whaling during 1948-1954. The operation had no regulation until 1951, but it was limited to 6 months (February-July) since 1952. They show peaks in minke whale catches moving from the Sea of Japan coast of Honshu in March), to northern Kyushu in April, and to the Sea of Japan coast of southern Hokkaido in June (Omura and Sakiura 1956, Fig. 18). In the Sea of Japan, the minke whale was the only important target of the fishery (Baird's beaked whale was also taken but was less preferred), so the peaks in catches should represent their migration, although it might be skewed to some degree by the operation off Sanriku (Pacific coast) in June and July (because the same whaling vessels moved from one ground to another).

Pastene et al. (2000) reviewed length and maturity data from catches in the Pacific and describe a migration pattern where females move through sub-area 7 early in spring, arriving in the southern Sea of Ohkotsk (sub-area 11) to feed in May, moving further north in the Sea of Ohkotsk in summer. They concluded that males arrive in sub-area 7 later, with many apparently remaining in sub-area 7 in coastal and offshore waters for the summer to feed.

Whales in the northern Sea of Okhotsk, sampled in July-September, were bigger than whales to the south (Kato et al. 1992). Sample was 60% males, whereas southern Sea of Okhotsk had more females (19 of 30). The Sea of Japan and Pacific coast of Japan samples were also skewed to males, so the northern Sea of Okhotsk apparently had larger whales than those locations. This could be interpreted as being because older, larger whales have migrated further north, though it is not clear that the percentage of mature whales increases from May to August in all sub-areas (Zenitani et al. 2002, Fig. 5).

Wang (1985) describes a movement of whales into the northern Yellow Sea during spring and summer. Brownell (1981) showed that catches of minke whales from Korean waters occurred in all months of the year, though only a few were in January between 1965 and 1977.

Immature/mature ratios
In summer there appear to be a higher percentage of mature whales further north, on average, than immature whales. From small-type commercial whaling catches, Kato (1992) showed that the majority of catches of males from the whaling grounds east of Hokkaido, the southern Sea of Okhotsk, and the northern Sea of Japan (mainly west of Hokkaido) were mature whales (Fig 2). Catches further south off Honshu on the Sanriku whaling ground were mainly immature whales.

In those small-type whaling catches, the majority of female whales in all areas were immature. However, the same pattern was seen where there were fewer mature whales in the south. On the Sanriku whaling ground, only 7% of the females were mature. That percentage rose to 38-40% on the other whaling grounds (Fig. 3).

The maturity composition in offshore waters appears somewhat different. Zenitani et al. (2002) reported the majority of whales in sub-areas 7, 8 and 9 in the JARPN/JARPN2 catches were mature males. The percentage of mature males increases from May to August in sub-area 9W, and maybe in 7, but does not increase in sub-areas 8 and 9E. The small-type commercial whaling catches in sub-area 7 do show an increase in the percentage of adult males from April to August.

Taylor and Martien (2003) noted the ratio of immature to mature does not vary between sub-areas 7 and 9, and concluded that the sex and age ratios appear to be relatively constant across sub-areas in the mid-latitudes when month is accounted for. They also pointed out there was a very low proportion of immature females in all of the samples from areas 7, 8 and 9 and that there was no difference in the proportion of immature females by longitude in the samples. Thus, the lower proportion of immature females in areas to the east of 7W indicates that the sampling is missing a high proportion of the population no matter what stock structure model is assumed.

Wang (1985) reported that in summer most of the whales in the northern Yellow Sea were adults.

Sex ratio
It has been noted several times that nearly all the minke whales in waters of the Pacific during summer are dominated by males. From small-type commercial whaling catches, Kato (1992) showed that catches from the whaling ground east of Hokkaido were 80% male, whereas catches in the southern Sea of Okhotsk were only 30% male (Fig. 4). Catches further south off Honshu on the Sanriku whaling ground were 68% male. Catches in the northern Sea of Japan (mainly west of Hokkaido) were 61% male.

Using JARPN catches only, Zenitani et al. (2000) found no differences in sex ratio between sub-areas 7, 8, and 9, which were dominated by males; sex ratio in all sampled months in all sub-areas was at least 74% male, and was at least 85% male in summer, and overall, roughly 90% of the individuals in sub-areas 7, 8, and 9 in May to August were males (Taylor and Martien 2003).

Using JARPN and JARPN2 catches, Zenitani et al. (2002) calculated sex ratios by area. Additional catches from small-type commercial whaling in sub-area 7 were also used; those catches on average occurred much closer to the coast than the JARPN/JARPN2 catches taken in sub-area 7, and so represent a more coastal signal. The JARPN/JARPN2 catches in sub-area 7 were from both the more coastal area where the small-type commercial whaling occurred but also included many samples from much further offshore. The proportion of females in the sub-area 7 small-type whaling catch had a much higher proportion of females (30%) (Fig. 5). In all the JARPN/JARPN2 catches the percentage of females was less than 15% (Figure 5), including sub-area 7. This suggests there could be a stock in Pacific coastal waters as more females are present there (rather than migrating further north). In April the percent females killed in small-type whaling in was 52% (n = 661) indicating more females are present early in the season along the Pacific coast of Japan (Zenitani et al. 2002).

This dominance of males in the Pacific in all areas accept the coastal area indicates that none of the stock structure hypotheses in the Pacific Ocean include the possibility that the mid-latitudes entirely contain any stock during the whaling period. The females are thought to be further north in the summer, as shown by data from the Sea of Okhotsk where the majority of whales are female. Some whales from sub-areas 8 or 9 may also migrate to the eastern side of Kamchatka; it may also be true that females dominate in that region as well, but no data are available to examine that. A study off the Chukotka Peninsula (latitude 63-67) found minke whales present in April in years when ice conditions were favorable (Melnikov et al. 2000). They report that after mid-May minke whales are “already fairly numerous off the Bering Sea coast of Chukotka”, so it is possible some of these whales could be arriving from sub-areas 8 or 9. The sex ratio information does not provide any information regarding stock structure between sub-areas 7, 8, and 9, other than that the stock or stocks in those sub-areas also occur in waters further north, because of a lack of females at mid-latitudes.

The sex ratio of the Japanese bycatch in sub-area 6 is nearly even (48% male) (Baker et al. 2010). The sex ratio from the Korean bycatch data also show a strong bias towards males (66% male, Baker et al. 2010). No information is available on changes in sex ratio by season. In the northern Yellow Sea, off China the sex ratio was 74.3% females (Wang 1985).

Life History: Conception date

Differences in conception date between populations can perhaps be viewed as evidence the populations differ on an evolutionary time scale, but it should be remembered that not finding differences does not constitute evidence against there being stock structure. Kato (1992) noted that the timing of conception in North Pacific minke whales (estimated from foetal length data and a mean growth curve) was not uniform geographically (Table 1). Samples from the Pacific Ocean (Sanriku and east of Hokkaido) had a peak of conception in winter, the northeastern Sea of Japan (east coast of Hokkaido) had a bimodal distribution with the largest peak in autumn and a smaller peak in winter, and the southern Sea of Okhotsk (north coast of Hokkaido) also had a bi-modal distribution with a large winter peak and a smaller autumn peak (Figure 6). This information, along with isozyme genetic data from Wada (1991) (showing differences between the Sea of Japan and the Pacific, and a mixture of types in the Sea of Okhotsk), were used by Kato and Kasuya (1992) to suggest stock boundaries. They proposed two stocks, representing a Sea of Japan stock and a Pacific Ocean stock, with apparent overlap of the stocks in the southern Sea of Okhotsk. It should be noted that the samples from the Sea of Japan in Kato (1992) come from the northern Sea of Japan, so it is possible that there could be a mixing of two stocks there, which might explain the bimodal distribution of conception dates. Alternatively, if those are all whales from one population, there are two peaks of conception during the year in that population. Note that Kato and Kasuya (1992) included waters west of Hokkaido in the ‘Pacific Ocean’ stock, and left it ambiguous which stock whales in the center of the northern Sea of Japan belonged to, so they did not propose a complete division between the Sea of Japan and the Pacific Ocean.

Wang (1985) reported that pregnant minke whales caught in the northern Yellow Sea all had estimated conception dates between June and August using a power function curve, but the lack of samples of embryos in the late autumn means there is some uncertainty in those estimates. The data themselves imply that conception likely takes place (at least) after July and before December, consistent with an autumn-only conception period. This indicates that either the Yellow Sea (autumn conception) is a different stock than the Sea of Japan stock or stocks (autumn+winter conception), or that the Yellow Sea is part of a stock that also occurs in the Sea of Japan, but that there are at least two stocks in the Seas of Japan (one with autumn conception and one with either autumn+winter conception or winter conception). Wang (1985) reports seeing cows with young calves in summer (May-July) in the Yellow Sea, consistent with an autumn conception and a gestation of ~10 months.

Life History: Age of maturity
Kato et al (1992) examined body length in females versus the number of corpora, and found no significant differences in whales from Sanriku, E. Hokkaido, N. Japan Sea, and the southern Sea of Okhotsk. Whale with one or more corpora were generally greater than 7m long; the average body length of whales with no corpora was about 6m. These numbers are from whaling operations that presumably tended to select larger whales, but it indicates whales greater than 7m are likely to be mature. The mean maximum body length in females was about 8m.

Body size and morphometrics
Differences in body length and morphometrics between populations can perhaps be viewed as evidence the populations differ on an evolutionary time scale, but it should be remembered that not finding differences does not constitute evidence against there being stock structure. Omura and Sakiura (1956) found that whales taken on southern whaling grounds were smaller than whales taken on northern whaling grounds. This could be interpreted as weak evidence for stock structure, but also may be due simply to mature whales being found further north than immature animals (Ohsumi 1983). Ohsumi (1983) did conclude that mature Sea of Japan whales were smaller than those found in the Pacific, and that this was evidence of stock structure.

The body size of the two sexes is similar and if anything, females are slightly larger. Kato et al. (1992) found that Sea of Japan whales had, on average, different body proportions than whales from Pacific coastal Japan ("Sanriku"). Specifically, the distance from the tip of the snout to the blowhole, as a percentage of total body length, is greater in Sea of Japan whales at larger body sizes than in Pacific coast of Japan whales (e.g., adult Sea of Japan whales have a bigger head for a given body size). A caveat is the sample sizes were small. A discriminant function based on body proportions could correctly classify Sea of Japan and Pacific coastal Japan whales 65.2% of the time. If these morphometric differences are correct, they provide evidence consistent with separate coastal stocks on either side of Japan.

Using JARPN samples only, Zenitani et al. (2000) found no differences in the size of males between 'J-stock' and 'O-stock' whales (as identified by mtDNA), but did find that mature 'J-stock' females were significantly smaller than 'O-stock' females. In a comparison between sub-areas in the Pacific, Zenitani et al. (2000) found significant differences at the 0.05 level in body length distributions of all males between sub-areas 7 and 8, but not between other comparisons (i.e., all other pair-wise comparisons between sub-areas 7, 8, 9, and 11). Comparisons of mature males between sub-areas 7 and 8 were significant at the 0.1 level, with a p-value of 0.057 for body length distributions and a p-value of 0.051 for mean body length. Comparisons of mature males between sub-areas 8 and 11 were also significant at the 0.1 level, with a p-value of 0.057 for body length distributions and a p-value of 0.054 for mean body length. The data in Zenitani et al. (2000) therefore provide some evidence of stock differences between sub-areas 7 and 8, as well as between the Sea of Japan and the Pacific Ocean.

Similarly, Hakamada and Bando (2009) found significant differences in 5 different body proportions between the 'J-stock' whales and 'O-stock' whales (as determined by genetics). No statistical test was made between 'J-type' and coastal 'O-type' whales.

Flipper color
Minke whales have been found in some cases to have morphological differences in flipper color patterns. In a study of minke whales in the Sea of Japan, Pacific Ocean, and Sea of Ohkotsk, the most common flipper color was Type IV, a dark flipper with a clear white band through the middle, found in 94% of the whales (Table 2, Fig. 7) (Kato et al. 1992). The only other flipper color type found was Type III, with an obscure white band, which was found only in Sea of Japan whales (18 out of 63) and in a few southern Sea of Ohkotsk whales (2 out of 65). Using only May-July samples, the proportions of flipper color type in the Sea of Japan whales were significantly different from the proportions seen in all other areas, including the Sanriku samples, which means that coastal whales on either side of Japan had different proportions of flipper color types, which indicates a different stock may be found in Pacific coastal waters than what is found in the Sea of Japan.

The ratio of flipper color types has been used in the *Implementation Simulation Trials*, along with other data, to estimate the proportion of J stock animals in sub-area 11, the southern Sea of Ohkotsk. There was not a significant difference in flipper color type proportions between the two Pacific sampling locations (Sanriku and E. Hokkaido) and the Sea of Okhotsk (Kato et al. 1992).

Baleen color-type

Baleen plates were found to be uniformly white accept in some samples offshore of eastern Hokkaido, where 4 of 11 had a thin black band on the outer margin, and the southern Sea of Okhotsk, where 1 out of 45 had the black band (Kato et al. 1992). There is a significant difference between the Sea of Japan samples and the samples from both areas on the Pacific side of Japan (east of Hokkaido and Sanriku). The Sanriku samples appear to be significantly different from the eastern Hokkaido samples; given the Sanriku samples were within ~50nm of the coast and the eastern Hokkaido samples were >60nm from the coast, this would be consistent with the possibility of a Pacific coastal stock and Pacific offshore stock. The Sanriku samples are not different from Sea of Japan samples. A major caveat is that Kato et al (1992) point out that the thin black band occurred on the largest whales, and so may simply be a function of age rather than a morphological difference between populations, and they concluded the baleen plate analysis provided little information on stock identity.

Cookie cutter shark-induced body scars

Cookie cutter shark-induced body scars are evidence that an individual whale has spent time within the range of the sharks. Of particular usefulness is that there is apparently no record of cookie cutter sharks in the East China Sea and Sea of Japan ((Nakano, H., pers. com., as cited in Goto et al. 2009). Goto et al. (2009) examined whales caught in JARPN2 whaling in the Pacific and found significant differences in the amount of body scars between putative 'J-type' and 'O-type' whales (as assigned by microsatellite genetics). Larger (older) whales tended to have more scarring. Goto et al. (2009) also noted that within 'O-type' whales, whales with a larger number of scars tended to occur further north. They suggest that within 'J-type' whales, whales that migrate on the Sea of Japan side of Japan would tend to have no scars, while whales that migrated on the Pacific coast side of Japan would have scars. Although Goto et al (2009) did not examine the data this way, it appears that within whales assigned as 'O-type', the degree of scarring increased offshore moving east (Fig. 8). Taylor and Martien (2003) noted the ratio of immature to mature does not vary between sub-areas 7 and 9, and concluded that the sex and age ratios appear to be relatively constant across sub-areas in the mid-latitudes when month is accounted for. If that is the case, the decrease in the number of body scars in whales moving offshore suggests that whales come from different breeding areas (and are thus exposed to different densities of cookie cutter sharks). If the density of cookie cutter sharks decreases as one moves east in the Pacific, that could result in this pattern. It does suggest a lack of complete mixing of 'O-type' whales between coastal and offshore Japan, and is therefore consistent with a hypothesis of O_E and O_W stocks.

Contaminants

There were large differences between both Cd and Hg levels in an early comparison of males from subareas 7 (n = 23) and 9 (n = 109) (Fujise SC/48/NP22). Although no statistics were done to compare these areas, these preliminary results are consistent with Figures 1-4 that reveal higher levels of contaminants in offshore animals (Yasunaga et al. 1999).

In persistent organic pollutants (POPs), Nakata et al. (2000) compared sub-area 11 with sub-areas 7E (offshore), 8, and 9. No significant differences were found but sample sizes were small. PCBs and CHLs were higher in 7E-9. In a Principal Component Analysis, 4 samples were strongly segregated from all samples; they interpreted these to be whales from the J stock.

Fujise et al (2000). Using JARPN data, some whales had higher levels of PCBs and DDTs in the Sea of Ohkotsk than in the Pacific Ocean, but lower concentrations of mercury (Hg). They also concluded there were no differences between sub-areas 7, 8, and 9, but an examination of their table 2 shows the sample size in sub-area 7 was very small (n=6) and 5 of the samples came from 7E, so there are no data in their study to examine a Pacific coastal versus offshore stock. From whales killed during JARPN2 Yasunaga and Fujise (2009b) examined PCB levels between subareas 7, 8, and 9. PCB values were generally lower in sub-area 9 but the differences were not significantly different.

From JARPN2 data, Yasunaga and Fujise (2009a) found a significant decline through time in mercury levels in minke whales in sub-areas 8 and 9, Kushiro and Sanriku, but not in sub-area 7. No tests were done between sub-areas, and sample sizes were small in each year, but an examination of mercury levels in the last 3 years of the study (2005-07) indicates mercury levels were higher in sub-area 7 (Kushiro and Sanriku) than they were in sub-areas 8 and 9.

Stable isotopes

Carbon stable isotope values were lower and nitrogen stable isotope values were higher in subarea 11 than in subareas 7 and 8. This again indicates either a different stock in the Sea of Ohkotsk, or a mixing of stocks there in subarea 11 (Mitani et al. 2000). No comparisons were made to samples from the Sea of Japan.

Conclusions

As mentioned before, examination of stock structure in the Yellow Sea, Sea of Japan, and Pacific Ocean is difficult because there are no data from the breeding grounds and there are virtually no data from mature females on the feeding grounds, as sampling has been limited to the mid-latitudes (mostly between 35° and 45° North latitude). Most of the data come from the Pacific Ocean, with some information from the northern Sea of Japan and the southern Sea of Okhotsk. Much of the information is not informative about stock structure, particularly because of limited data available (in particular) from the Yellow Sea, the Korean coast of the Sea of Japan, and the southern Japanese (Honshu) coast of the Sea of Japan. Nonetheless, some of the available data provide information about stock structure, and a few types of biological data are particularly informative (e.g, conception dates and flipper color types). Here we examine the four uncertainties described in the introduction in light of the biological information summarized here.

1) *Are whales in the Yellow sea part of a population that migrates into the Sea of Japan?*
Separate feeding grounds (and whaling grounds) exist in the Yellow Sea, the Sea of Japan, and the Pacific Ocean (east and north of Hokkaido), and these may represent the migratory destination of different stocks. Whales migrate north both into the Yellow Sea and into the Sea of Japan, and mature whales, and cow/calf pairs, are seen in the Yellow Sea in summer, indicating an independent stock could be found there. The sex ratio in the northern Yellow sea is 74% female, whereas the Korean bycatch is 34% female. Yellow Sea whales have only autumn conception dates, whereas minke whales in the northern Sea of Japan have a bimodal distribution of conception dates, with peaks in both autumn and winter, suggesting either different stocks in the two areas, or a mixture of two stocks in the northern Sea of Japan. All of the available data shows evidence of differences between the two areas or is consistent with the hypothesis of two stocks. No direct evidence links whales from the Yellow Sea with whales in the Sea of Japan. In summary, the available data suggest there may be a different stock of minke whales in the Yellow Sea.

2) *Are whales along the Korean coast part of the same population as whales along the eastern Japanese coast?*
Survey data show minke whales distributed throughout the Sea of Japan, not just along the coasts, so there is no obvious hiatus in distribution between the two coasts. On the other hand, separate feeding grounds (and whaling grounds) exist for 'J-type' whales in the Sea of Japan and the Pacific Ocean (east and north of Hokkaido), and these may represent the migratory destination of different stocks; it is possible that whales from the west coast of Japan move into the Pacific Ocean, whereas whales from the East Sea along the Korean coast move north into the northern Sea of Japan. Alternatively, these could be two feeding grounds for one stock. Sex ratios are significantly different along the two coasts; the Korean bycatch is 34% female whereas the Japanese bycatch in sub-area 6 is 52% female. No conception date data are available from the southern Sea of Japan; whales in the northern Sea of Japan have a bimodal distribution of conception dates, with peaks in both autumn and winter, which is consistent either with a mixture of two stocks in that area or a single stock with two peaks in conception during the year. Two different flipper color patterns are seen in the northern Sea of Japan; again, this is consistent either with a mixture of two stocks in that area or a single stock with two color patterns. No direct evidence links whales from the coast of Korea with whales from the eastern coast of Japan. In summary, the available data suggest it is plausible there are different stocks on either side of the Sea of Japan, but data are lacking to make definitive or even preliminary conclusions.

3) *Are whales on the east coast of Japan the same population as on the west coast of Japan?*
Comparisons between these two areas are complicated due to the possibility of comparing 'J-type' whales in the Sea of Japan with 'O-type' whales in the Pacific Ocean. However, 'J-type' whales are found in coastal waters of the Pacific coasts of Honshu and Hokkaido, so comparisons between coastal waters can be examined. Separate feeding grounds (and whaling grounds) exist for 'J-type' whales in the Sea of Japan and the Pacific Ocean (east and north of Hokkaido, and southern Sea of Okhotsk), and these may represent the migratory destination of different stocks; it is possible that whales from the west coast of Japan feed only in the northern Sea of Japan, whereas whales from the Pacific coast of Japan move to feeding grounds east of Hokkaido and in the southern Sea of Okhotsk. Alternatively, these could be two feeding grounds for one stock. More immature whales were found in Sanriku than in the northern Sea of Japan, but the catches from the Pacific coast were taken further south. Bycatch is close to the coast on both sides of Japan, and so provides a direct comparison of coastal whales in both areas. Sex ratios from bycatch are close to 50% in the Sea of Japan bycatch (sub-area 6), whereas bycatch in sub-areas 2 and 7 (Pacific coast of Japan) have a majority of females, particularly in the south (>70%). Whales from Sanriku (Pacific coast of Japan) have only winter conception dates, whereas minke whales in the northern Sea of Japan have a bimodal distribution of conception dates, with peaks in both autumn and winter, suggesting either different stocks in the two areas, or a mixture of two stocks in the northern Sea of Japan. Using only May-July samples, the proportions of flipper color type in the Sea of Japan whales were significantly different from the proportions seen in the Sanriku catches (Pacific coast), which means that coastal whales on either side of Japan had

different proportions of flipper color types, which indicates a different stock may be found in Pacific coastal waters than what is found in the Sea of Japan. In summary, a comparison between the two coasts of Japan is complicated (in part because of the lack of data and the possible mixing between "J" and "O" stocks in Pacific coastal waters), but it is plausible that there are different "J-stocks" on either coast of Japan, and some evidence suggests this is the case.

4) *Is there a coastal population in Subarea 7 (east of Hokkaido and northern Honshu) that is different from offshore minke whales in the Pacific Ocean, even after accounting for Sea of Japan whales that might migrate into this area?*

Some 'O-type' whales occur in summer on feeding grounds in sub-area 7 (coastal Japan), whereas whales in sub-areas 8 and 9 are thought to migrate to feeding grounds further north in the Sea of Okhotsk or Pacific Ocean, as few females are seen in sub-areas 8 and 9 in summer. The catches from the small-type whaling grounds (Sanriku and Kushiro), which are on average closer to the coast than offshore Pacific catches, have a much higher percentage of females, whereas offshore catches are heavily dominated by males. Similarly, sub-area 7 bycatches (which occur close to the coast) are 57% female. Densities of minke whales are much higher along the Pacific coast than in offshore waters; this density pattern is consistent either with a high-density coastal stock and a low-density offshore stock or with a single stock that occurs at higher densities near the coast. One study found morphometric differences between sub-areas 7 and 8, but other studies have not found differences. Within 'O-type' whales, coastal animals have fewer body scars from cookie cutter shark bites than offshore animals. Some differences in contaminant values have been found between sub-area 7 and sub-areas 8 and 9, but other studies show no differences. Whales in sub-area 11 (Sea of Okhotsk) had different stable isotope values than whales from sub-area 7, which would be consistent with different feeding grounds, but the interpretation of this is confounded by a lack of information about where sub-area 11 whales specifically come from. In summary, a comparison between the coastal and offshore waters in the Pacific is complicated (in part because of the lack of data and the possible mixing between "J" and "O" stocks in Pacific coastal waters), but it is plausible there is a coastal "O-stock" on the Pacific coast of Japan that is different from the "O-stock" in pelagic waters, and some evidence suggests this is the case.

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Table 1. Estimated conception date by month for four areas in the Sea of Japan, Pacific Ocean, and Sea of Ohkotsk. Data are from Kato 1992, including data from both (1) small-type whaling 1977-1987 (Kato 1992, Figure 5, numbers estimated from the plot) and from (2) the factory-catcher boat Miwa Maru in 1973-75 (Kato 1992, Table 9). Conception date data were pooled across those two data sources in this table. Note that in Fig. 5 of Kato (1992) the sampling areas are not labelled; here it was assumed that the sampling areas, from top to bottom, were S. Okhotsk, E. Hokkaido, Sanriku, and N. Japan Sea, based on a comparison to reported sample sizes in Table 4 of Kato (1992).

Location	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
S.Okhotsk	1	5	5	4	28	37	57	8	5	3	1	1
Sea of Japan	0	3	1	0	0	2	1	1	0	0	0	0
E. Hokkaido	0	0	2	2	4	13	21	6	2	2	0	0
Sanriku	0	0	1	3	1	3	4	1	1	0	2	0

Table 2. Incidence of animals with different flipper color types for 5 areas within the Sea of Japan, Pacific Ocean, and Sea of Ohkotsk, by month. Hyphens represent no catch or no observation. Data are from Kato et al. (1992).

Location		Total	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Sea of Japan	Type III	18 29%	0	2	2	14	-	0	-	-
	Type IV	45 71%	3	12	9	19	-	2	-	-
Sanriku (Pacific coastal Japan)	Type III	0 0%	-	-	0	0	-	-	-	-
	Type IV	34 100%	-	-	32	2	-	-	-	-
East of Hokkaido (Pacific offshore)	Type III	0 0%	-	-	-	-	-	-	0	0
	Type IV	43 100%	-	-	-	-	-	-	31	12
South Okhotsk	Type III	2 3%	-	-	-	2	0	0		
	Type IV	63 97%	-	-	-	5	23	35		
North Okhotsk	Type III	0 0%	-	-	-	-	0	0	0	-
	Type IV	96 100%	-	-	-	-	60	20	16	

Table 3. A summary of evidence for or against the four uncertainties about stock structure in the Yellow Sea, Sea of Japan, and the Pacific coast of Japan (see text for a description of the four questions being addressed). A dash ('-') indicates there was no information about stock structure from that type of data.

	Q1. Yellow Sea vs Sea of Japan	Q2. Korea coast vs west Japan coast	Q3. West coast Japan vs. east coast Japan	Q4.Coastal SA7 vs O Stock
Feeding grounds	Differences	Consistent with 1 or 2 stocks	Consistent with 1 or 2 stocks	Differences
Whale density	-	-	-	Differences
Migration patterns	Differences	Consistent with 1 or 2 stocks	Consistent with 1 or 2 stocks	Consistent with 1 or 2 stocks
Imm/mature ratio	Consistent with 2 stocks	-	Differences (but confounded)	Consistent with 1 or 2 stocks
Sex ratio	Differences	Differences	Differences	Differences
Conception date	Differences	Consistent with 1 or 2 stocks	Differences	No Differences
Age of maturity	-	-	No Differences	No Differences
Morphometrics	-	-	Differences	Mixed Results
Flipper color	-	Consistent with 1 or 2 stocks	Differences	No Differences
Baleen color	-	-	-	-
Cookie cutter scars	-	-	-	Differences
Contaminants	-	-	-	Differences
Stable isotopes	-	-	-	-

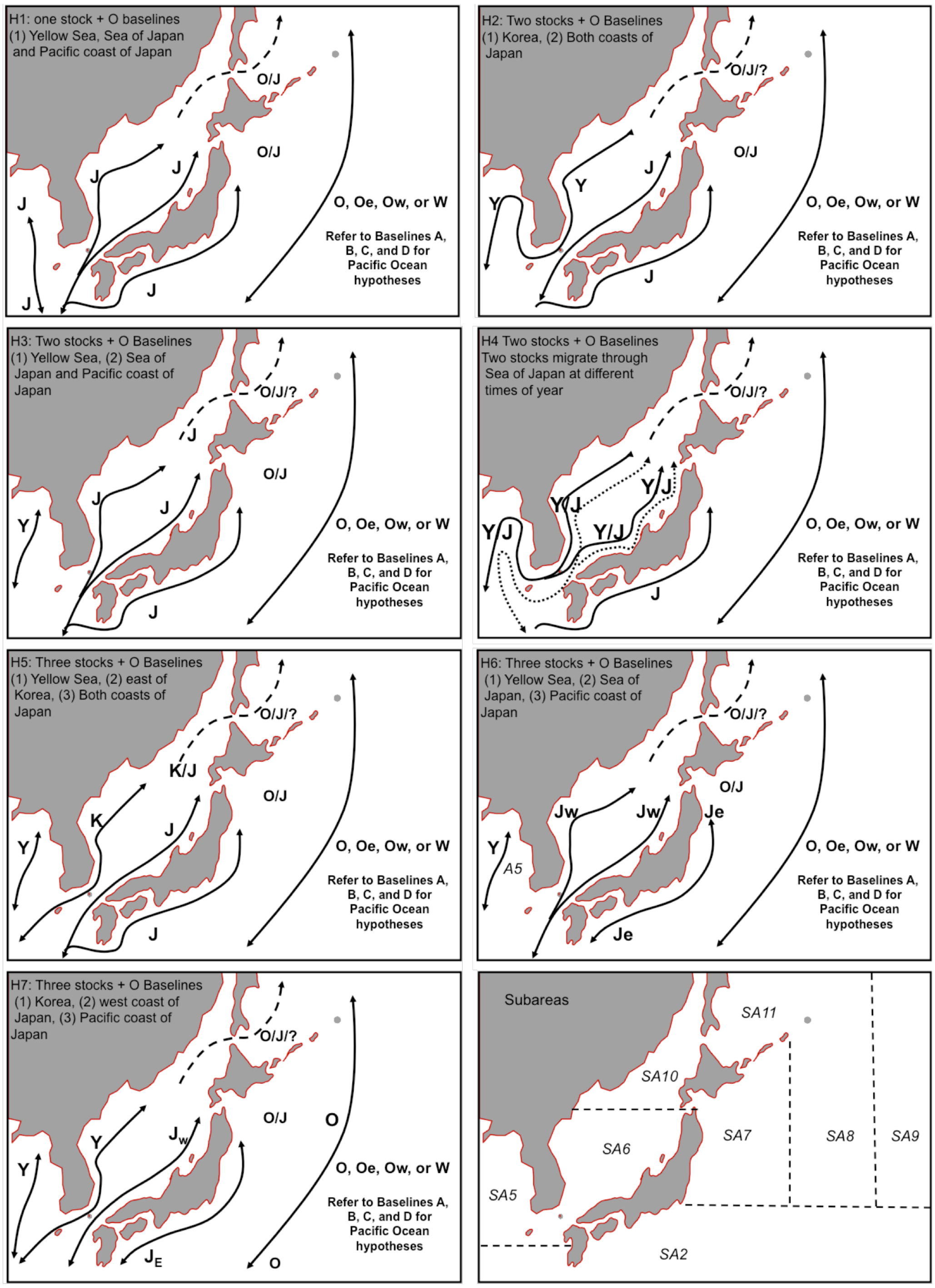

Figure 1. A description of 7 hypotheses for the stock structure of minke whales in the western North Pacific. Note that all permutations of stock structure in the Pacific Ocean are not shown; hypotheses of stock structure in the Pacific have previously been described as Baselines A, B, C, and D. Note that the hypothesis of a coastal stock on the east (Pacific) coast of Japan (‘J_E’) may or may not be similar to the hypothesis of a coastal Pacific Ocean stock (‘O_E”). Sub-areas 2, 5, 6, 7, 8, 9, 10, and 11 are shown in the lower right panel; sub-area boundaries are approximate.

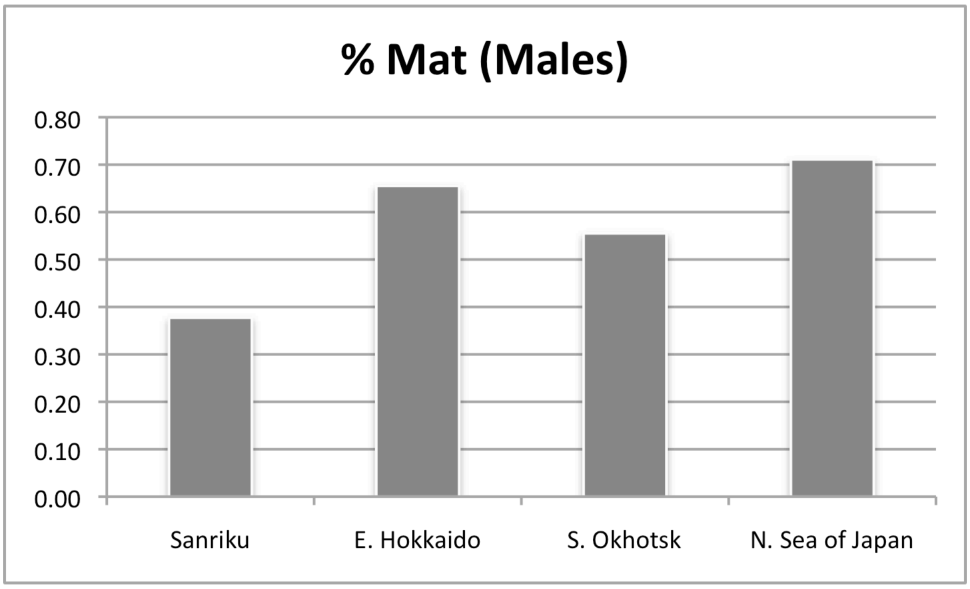

Fig 2. Percent mature whales for males. Data are from small-type commercial whaling 1977-1988 (Kato 1992).

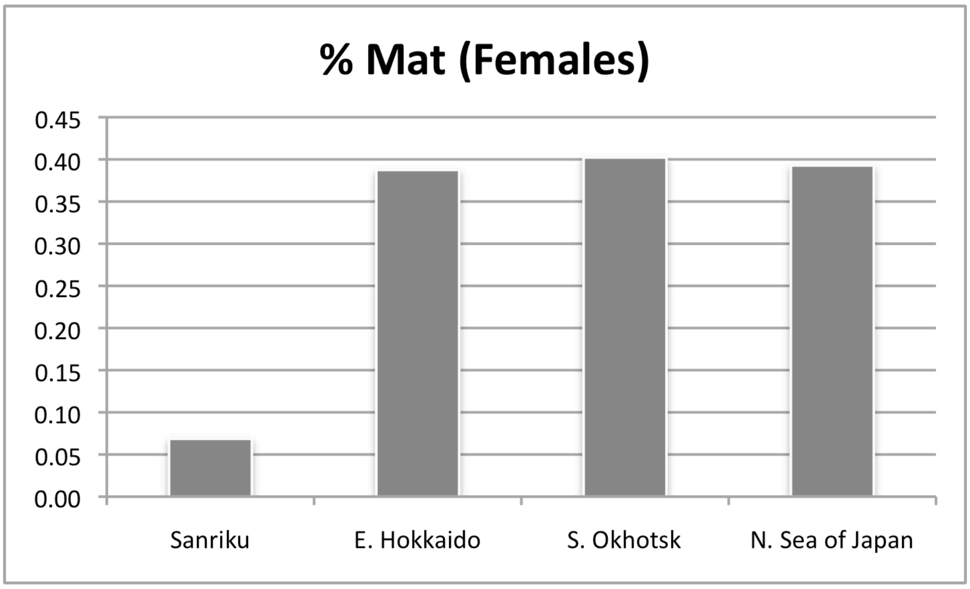

Fig 3. Percent mature whales for females. Data are from small-type commercial whaling 1977-1988 (Kato 1992).

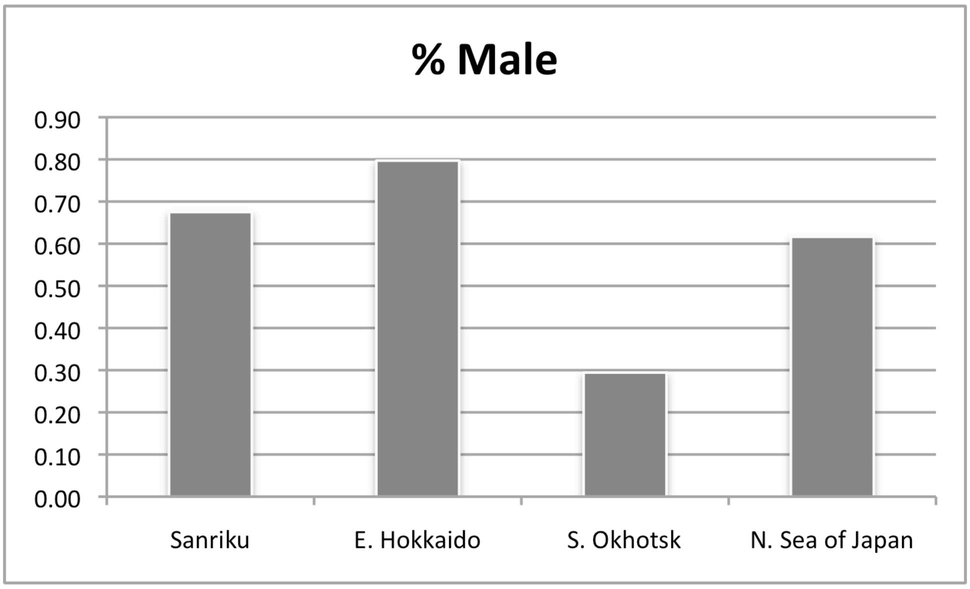

Fig 4. Percent of whales in that catch that were males on different whaling grounds. Data are from small-type commercial whaling 1977-1988 (Kato 1992).

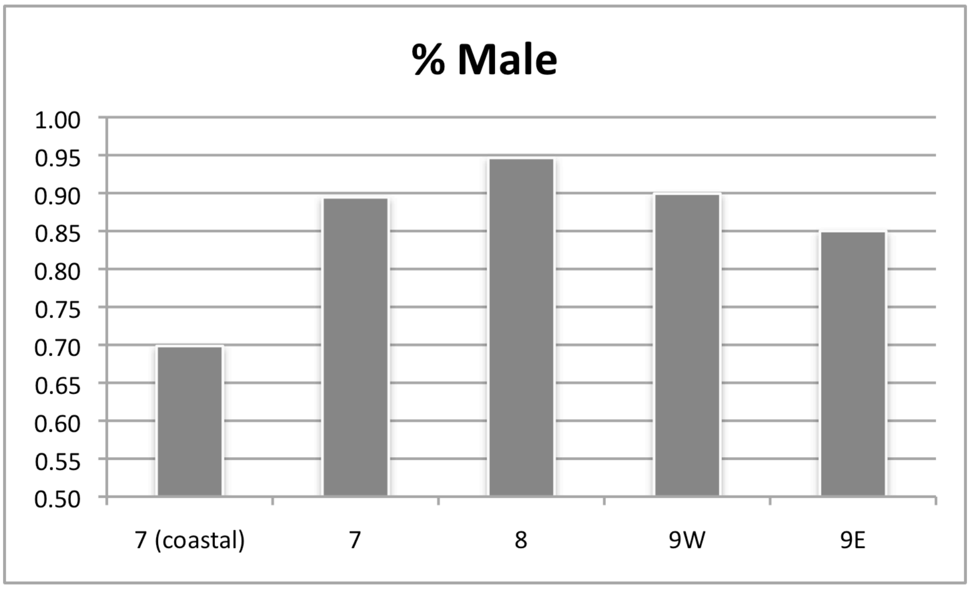

Figure 5. Sex ratio from Zenitani et al. 2002. All data are from JARPN and JARPN2 samples, except for ‘7 (coastal)’, which were data from the small-type commercial whaling, which on average occurred much closer to the coast than the JARPN/JARPN2 samples from sub-area 7.

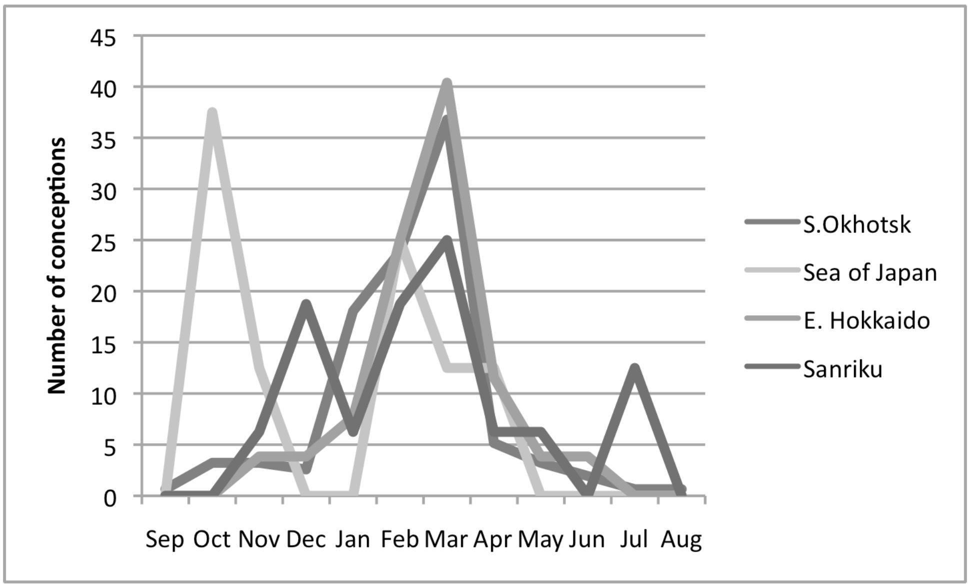

Figure 6. Estimated conception date by month for four areas in the Sea of Japan, Pacific Ocean, and Sea of Ohkotsk. Data are from Kato 1992, including data from both small-type whaling 1977-1987 (Kato 1992, Figure 5, numbers estimated from the plot) and from the factory-catcher boat Miwa Maru in 1973-75 (Kato 1992, Table 9).

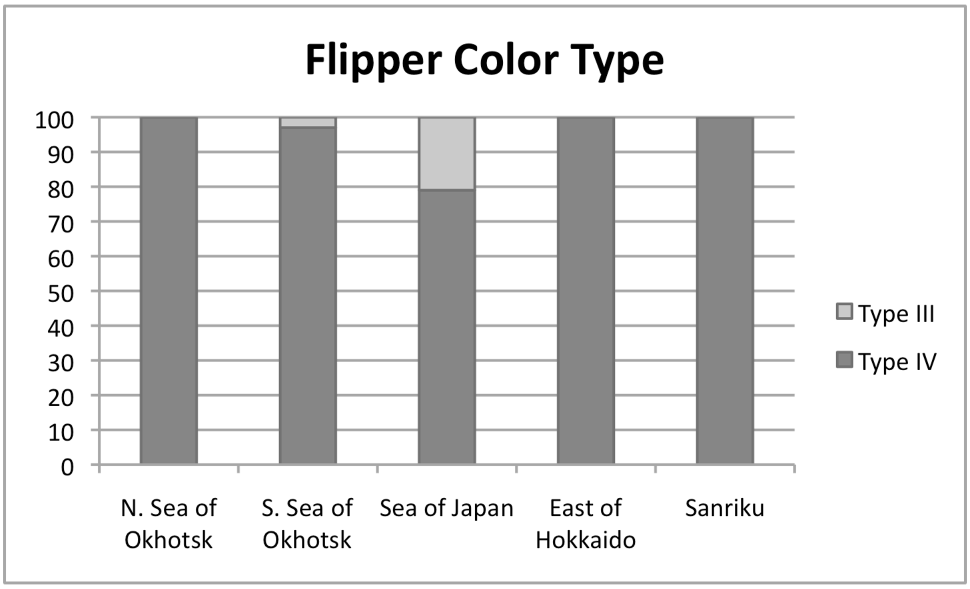

Figure 7. Flipper color types. Kato et al. (1992).

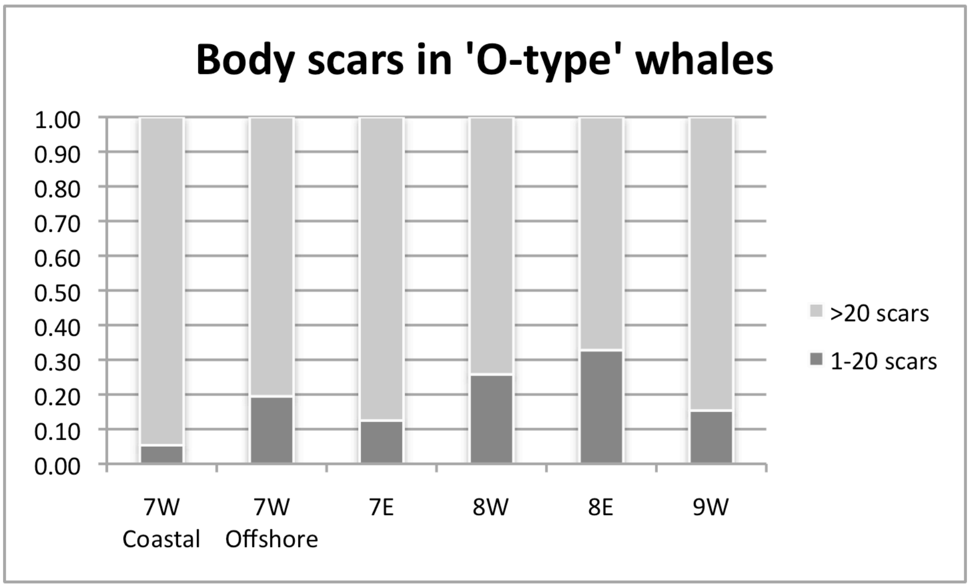

Figure 8. Prevalence of cookie cutter shark-induced body scars in whales identified as 'O-type' whales by microsatellite genetics, plotted from west to east. Data are from Goto et al. (2009, Table 1).