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Short Note

Prevalence of Killer Whale Tooth Rake Marks on Gray Whales off Sakhalin Island, Russia

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Killer whales (*Orcinus orca*) attack nearly all species of baleen whales, some more regularly than others (Weller, 2018). Although observations of killer whale attacks on large whales are relatively infrequent, the common observation of rake marks left by the teeth of killer whales that are found on the bodies, flippers, and flukes of individuals in many populations indicate that attacks occur relatively frequently. Baleen whales are dangerous adversaries and difficult to kill, requiring extended effort and coordination between members of a killer whale group. A typical hunting and handling strategy employed by killer whales consists of first fatiguing their prey by active pursuit and then delivering a debilitating assault. Killer whales on the attack have been observed using their teeth to grasp large whales by the flukes and pectoral flippers in an attempt to slow or stop their movement or perhaps drown their prey by pulling or pushing them under water (Silber et al., 1990; Melnikov & Zagrebin, 2005; Ford & Reeves, 2008). While the significance of killer whale predation on baleen whales has been questioned by some researchers (e.g., Rice & Wolman, 1971; Clapham, 2001; Mehta et al., 2007), others have suggested that such interactions are likely to have influenced the behavioral patterns and life history traits of particular species (Andrews, 1914; Reeves & Mitchell, 1988; Finley, 1990; Corkeron & Connor, 1999; Barrett-Lennard et al., 2011).

A number of long-term research studies on baleen whales have used photographic and sighting data to examine the occurrence and prevalence of rake marks from killer whales. Mehta et al. (2007) examined killer whale-related tooth scarring on humpback (*Megaptera novaeangliae*), blue (*Balaenoptera musculus*), and pygmy blue (*B. brevicauda*) whales in 24 regions worldwide. This study found considerable geographic variation in the proportion of whales with rake marks, ranging from 0 to 40% in different areas. Humpback whales off New Zealand (37.5%), New Caledonia (31.3%), and Mexico (40.1%), and pygmy blue whales off western Australia (42.1%) had the highest reported prevalence rates. Of the photographs collected from individual humpback whales throughout the North Pacific, 15% contained evidence of rake marks from killer whales with overall averages for wintering areas and feeding areas of 18% (range = 6 to 31%) and 9% (range = 5 to 20%), respectively (Steiger et al., 2008). Images of North Atlantic humpback whale flukes were examined for the presence of killer whale rake marks, and it was found that scarring frequencies ranged from 2.7 to 17.4% and differed significantly among five geographic regions, with Canada having the highest prevalence rate (McCordic et al., 2014). Finally, a study of eastern Australian humpback whales found that 17% had predator-related scarring and that most attacks appeared to occur early in life (Naessig & Lanyon, 2004).

The frequency of killer whale-inflicted scars on bowhead whales (*Balaena mysticetus*) in the western and eastern Arctic has also been examined. The prevalence of scarring on the Bering-Chukchi-Beaufort Seas stock, as measured from inspection of whales landed by native hunters, ranged from 4.1 to 7.9% (George et al., 1994, 2017), and it was mostly large whales (mean length of 15.4 m) that had killer whale-related scarring. In contrast, Finley (1990) found a much higher prevalence of killer whale scarring (31%) in a photogrammetric study of bowhead whales of the Davis Strait stock, although a lower proportion (10.2%) of whales were reported to have scars from killer whales when a similar analysis was expanded to include additional areas within the eastern Canadian Arctic (Reinhart et al., 2013).

Of all the species hunted by killer whales, attacks on gray whales (*Eschrichtius robustus*) are observed most often (Jefferson et al., 1991; Reeves et al., 2006; Weller, 2018). The relative abundance of these reports is most likely because the coastal/shelf distribution of gray whales overlaps with high-density areas of killer whales and, as such, increases the likelihood of attacks being observed by humans. Early reports of killer whales attacking gray whales came from observations on the Pacific coast of Baja California in the spring of 1858 (Scammon, 1874) and off the coast of Korea in 1909-1910 (Andrews, 1914). Existing and ever-increasing recent evidence suggests that predation by killer whales is not exceptional but, rather, a recurring aspect of their existence (Reeves et al., 2006; Weller, 2018), with somewhat regular reports of attacks occurring in wintering areas off Baja California, along the coastal migration route between Mexico and Alaska, and on the feeding grounds in the Bering and Chukchi Seas (Baldridge, 1972; Goley & Straley, 1994; Melnikov & Zagrebin, 2005; Reeves et al., 2006; Barrett-Lennard et al., 2011; Matkin & Durban, 2013). On a predictable basis each spring, killer whales attack gray whales off known "hunting grounds" that include California (Monterey Bay), Alaska (Unimak Island), and Far East Russia (Chukotka). Young calves and juveniles are particularly vulnerable, but other age classes, including adults, are also attacked. The level of predation on gray whales off Unimak Island is apparently so extreme that it has been speculated to have possible population-level consequences (Barrett-Lennard et al., 2011). Predation by killer whales in just this one region may account for the deaths of anywhere from 8 to 50% (averaging around 35%) of gray whale calves in a given cohort (Matkin & Durban, 2013). If this level of calf mortality due to killer whale predation occurs annually, it is remarkable that the abundance of the eastern North Pacific gray whale population has been able to continue to increase, nearing 27,000 whales in recent years (Durban et al., 2015, 2018).

The western gray whale subpopulation is endangered and remains at low numbers (about 200 individuals) despite slow but steady population growth during the past 20 years (Cooke, 2018). Historical evidence indicates that the coastal waters of eastern Russia, the Korean Peninsula, and Japan were once part of the migratory route and that areas in the East and South China Seas may have been used as wintering grounds (Weller et al., 2002, 2013). Present day records of gray whales off Japan (Nambu et al., 2010; Nakamura et al., 2017a, 2017b) and China (Wang, 1984; Zhu, 2002; Wang et al., 2015) are occasional, and the last known record from Korea was in 1977 (Park, 1995; Kim et al., 2013) or possibly 2015 (Kim et al., 2018). In the past two decades, observations of gray whales off Japan, mostly from the Pacific coast, have been increasing (Nakamura et al., 2017b).

Information from tagging, photo-identification, and genetic studies show that some whales identified in the western North Pacific off Russia have also been observed in the eastern North Pacific, including coastal waters of Canada, the U.S., and Mexico (Lang, 2010; Weller et al., 2012; Urbán et al., 2013; Mate et al., 2015). Despite the cross-basin movements observed for some individuals, significant differences exist in both mitochondrial and nuclear DNA between whales sampled in the eastern North Pacific and those sampled off Sakhalin Island in the western North Pacific (LeDuc et al., 2002; Lang et al., 2011). A recent population assessment of gray whales in the western North Pacific concluded that whales summering off Sakhalin Island and southeast Kamchatka appear to represent a demographically self-contained population segment (Cooke et al., 2017).

Given the ongoing conservation concern about gray whales in the western North Pacific, determining the prevalence of killer whale attacks is important, particularly with respect to better understanding how this selective pressure may be influencing population recovery. This article provides an analysis of the prevalence of rake marks from killer whales on gray whales photo-identified off Sakhalin Island, Russia, including an assessment of how this prevalence varies by sex and between calves and non-calves.

From 1997 to 2007, following an opportunistic effort in 1994 and a pilot study in 1995, gray whale photo-identification surveys were carried out annually during summer months off the northeastern coast of Sakhalin Island, Russia, in the nearshore waters proximate to Piltun Lagoon. Further information about the study area and a detailed description of the photo-identification data collection and analysis protocols can be found in Weller et al. (1999). From 1994 to 2007, 337 photo-identification surveys were conducted, resulting in 5,167 sightings of 169 individual whales. A sighting consisted of at least one high-quality photo-identification image, although usually multiple images were collected. Additionally, 14 sightings of 11 of these individuals were obtained in 2002 during a survey of a feeding area approximately 60 km southeast of Piltun Lagoon. Overall, 34,030 film and digital images from 5,181 sightings of 169 photo-identified western gray whales were examined in the present analysis. The sex of 142 of these individuals is known from genetic analyses of biopsy samples collected in coordination with photo-identification efforts.

A protocol employed to quantify anthropogenic scarring of western gray whales (Bradford et al., 2009) was extended to assess killer whale tooth rakes on these whales (Figure 1). As the aim of the scar quantification approach was to provide a minimum estimate of killer whale interactions, the entire photo-identification dataset was utilized, even though (1) photographic coverage is unequal across body regions within and between individuals and (2) the target body region for photo-identification may not be particularly vulnerable to scarring. Therefore, all available images of an individual gray whale were examined for the presence of killer whale rake marks in 21 defined regions spanning the entire body (Figure 2). Specifically, for each survey sighting of a gray whale, one or more of the designated codes (Table 1) were assigned to all body regions of that individual. Thus, a line of recorded data consisted of 21 cells, each comprised of one or more codes indicating if the body region of that whale during that sighting was either (1) without killer whale scarring, (2) with killer whale scarring, (3) partially visible with or without killer whale scarring, or (4) not visible.

These data for each survey sighting were then collapsed to produce an annual killer whale scar composite of each whale for use in subsequent summaries and analyses. An annual killer whale scar composite was thus one line of data containing all information (i.e., presence of killer whale scarring and degree of visibility) gleaned about each body region of a whale during a given year. Note that while the described protocol systematically quantified the presence of killer whale scarring, it could not enumerate scarring events. All coding was conducted by one analyst (ALB) as recommend for consistency in scarring analyses (Neilson, 2006). However, it was previously demonstrated that this protocol could be used by more than one researcher to achieve similar results (Bradford et al., 2009). Killer whale rake mark determinations in the present analysis followed descriptions from other studies on baleen whales (e.g., George et al., 1994; Naessig & Lanyon, 2004; Mehta et al., 2007; Steiger et al., 2008).

The 5,181 survey sightings were collapsed into 844 annual scar composites representing 169 photo-identified western gray whales, with a median of four composites per whale (range = 1 to 11). Of the 169 photo-identified individuals, 74 whales (43.8%; 39 males, 26 females, and nine of unknown sex) were found to have evidence of at least one killer whale encounter based on the presence of visible rake marks (Figure 3). At least 22 of these whales (29.7%; 14 males, six females, and two of unknown sex) were determined to have been attacked at some point during the study period. These male and female whales included both calves and non-calves, although relatively few attacks on calves were identified (Figure 4). In eight of these cases, the approximate timing of the interaction was determined in the following manner: (1) for non-calves, when a body region was coded as fully visible without scarring in the year preceding a newly acquired rake mark; and (2) for calves, when their first observation in the study area revealed existing rake marks, indicating that those scars were acquired sometime between the time of their birth and when they were about 6 to 7 mo old and first arrived to the Sakhalin feeding area. Of these occurrences, interactions with killer whales occurred in the months prior to the 1999 (one calf of unknown sex), 2000 (one male non-calf), 2001 (one male non-calf and one female calf), 2002 (one male calf), 2003 (two male non-calves), and 2007 (one male calf) field seasons. Most of the killer whale rake marks were found on the left and right tips and trailing edges of the flukes (BR12, BR14, BR17, and BR18), followed by the left and right back and dorsal ridge (BR5, BR6, BR7L, and BR7R) (Figure 5).

The prevalence of killer whale scars on western gray whales (43%) documented in the current study is the highest reported for any baleen whale species, including the populations of humpback, blue, pygmy blue, and bowhead whales reviewed herein. Although both mammal- and fish-eating killer whales are somewhat common in the gray whale feeding ground off Sakhalin Island, little aggression between the two species has been observed. Therefore, predatory advances of killer whales that result in rake marks are likely to be occurring elsewhere within the migratory or wintering range of these gray whales. Two lines of reasoning suggest that these attacks may be taking place during migration: (1) despite the possibility that the gray whale migratory corridor off Korea is no longer or only seldomly used (Kim et al., 2013, 2018), Andrews (1914) found rake marks from killer whales on the flukes and "fins" (presumed to be flippers) of a majority of the gray whales killed by whalers off Korea in 1909 and 1910 and documented numerous accounts of killer whales attacking both dead and living gray whales during whaling operations in Korean waters; and (2) the western to eastern North Pacific cross-basin migratory movements of some whales feeding off Sakhalin (see Weller et al., 2012; Mate et al.,

Figure 1. An individual western gray whale (*Eschrichtius robustus*) photographed off Sakhalin Island, Russia: killer whale inflicted tooth rakes posterior to the eye and on the throat and flipper (A), and a close-up view of the rake marks posterior to the eye (B). (Photographs by D. Weller, NOAA Fisheries)

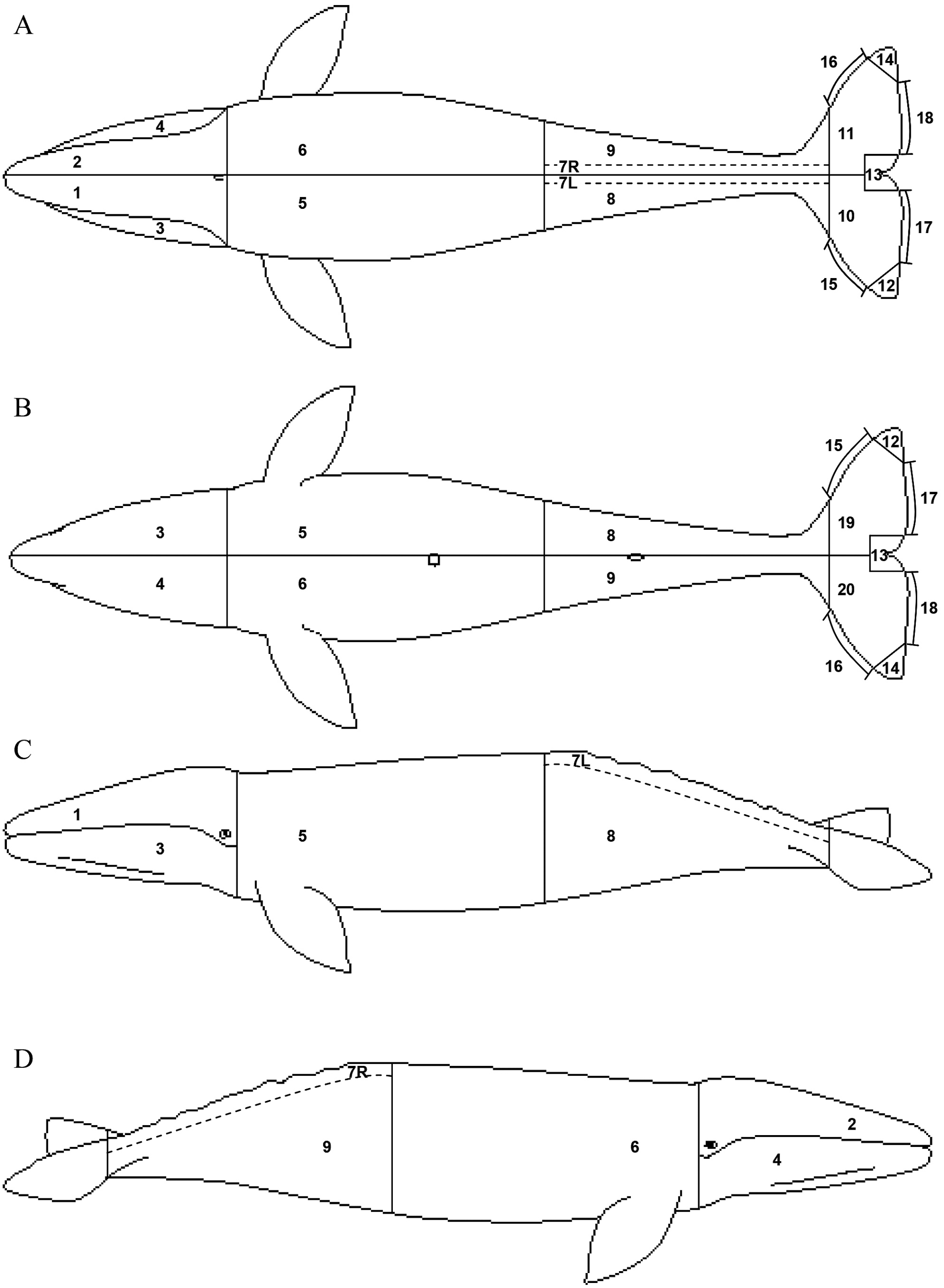

Figure 2. Dorsal (A), ventral (B), left side (C), and right side (D) views of western gray whale body regions (n = 21) examined for killer whale scarring. Note that while body regions are numbered 1 through 20, number 7 is divided into separate right (R) and left (L) regions. Gray whale outlines courtesy of J. L. Sumich.

Table 1. Scar codes assigned to western gray whale (*Eschrichtius robustus*) body regions during image analysis as adapted from Hamilton et al. (1998) in Bradford et al. (2009)

Code	Definition	Description
N	No scar	No killer whale scars visible
*	New scar	Used in combination with the killer whale scar code to indicate the first sighting of a scar
O	Killer whale rake marks	Highly structured scars in the form of thin, white parallel lines
P	Partially visible	Used in combination with the killer whale scar code to denote that the body region is only partially photographed or is too dark, out of focus, or distant in the image to completely assess scarring[a]
X	Not visible	Body region was not photographed at all or is too dark, out of focus, or distant in the image to assess scarring

[a]The ventral portions of the following body regions (BR) were assumed never to be visible: BR5, BR6, BR8, and BR9. Thus, a "P" was not assigned in these regions unless parts of the dorsal surface were obscured or not photographed.

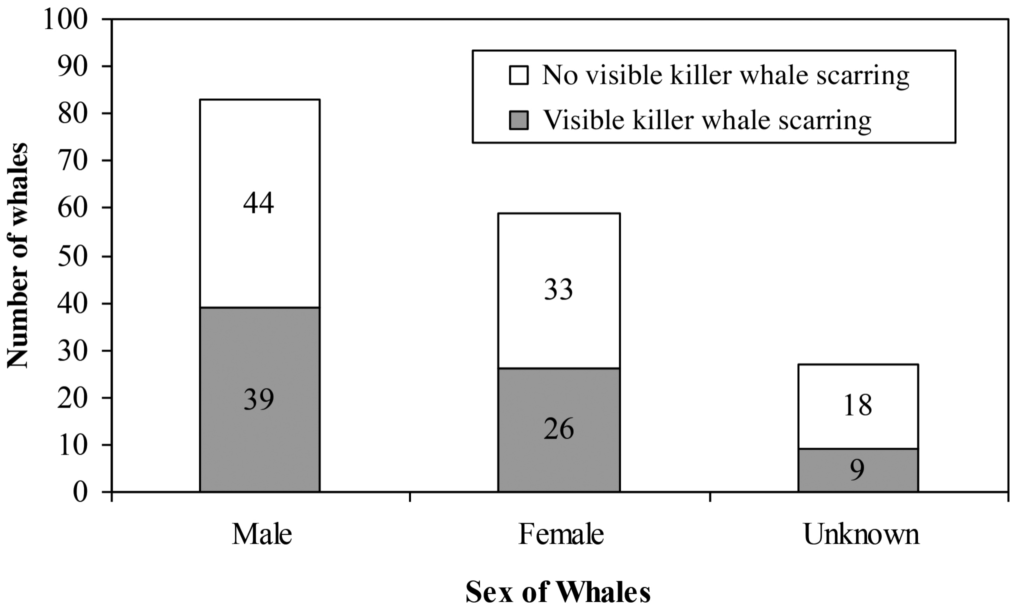

Figure 3. Number of western gray whales (n = 169) with and without visible killer whale rake marks according to sex class

2015) brings them in proximity to the Unimak Island and Monterey Bay areas where killer whale attacks are reported on a regular basis.

Based on the findings presented herein, the acquisition of new scars by gray whales is not limited to calves. That is, known non-calf whales (male and female) acquired new rake marks during the study period. This result stands in contrast to what has been reported for a number of other baleen whale populations, which appear to generally obtain predatory scarring early in life (e.g., Naessig & Lanyon, 2004). New rake marks acquired by non-calf whales in the present study may (or may not) be indicative of a higher vulnerability of some individuals, possibly related to health and condition. Although relatively few attacks on calves were identified in the gray whale data from Sakhalin, this result may be spurious in that attacks on gray whale calves are more likely to be lethal as compared to other age classes. These results are similar to those reported for western Arctic bowhead whales, which also found a prevalence of larger-sized whales with scars from killer whales while fewer calves with scarring were observed (George

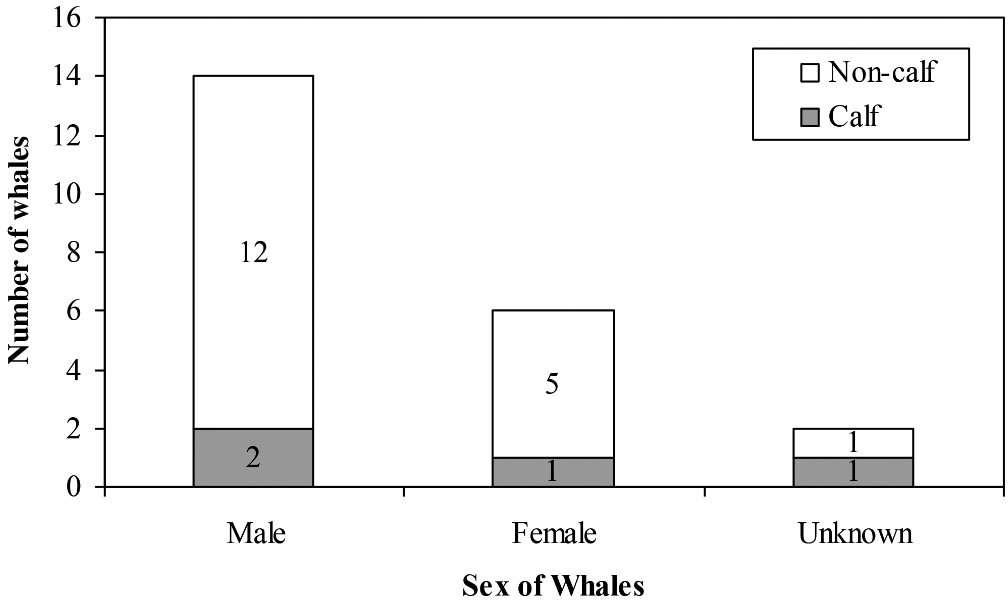

Figure 4. Number of western gray whales (n = 22) determined to have acquired killer whale rake marks during the course of the study according to sex class

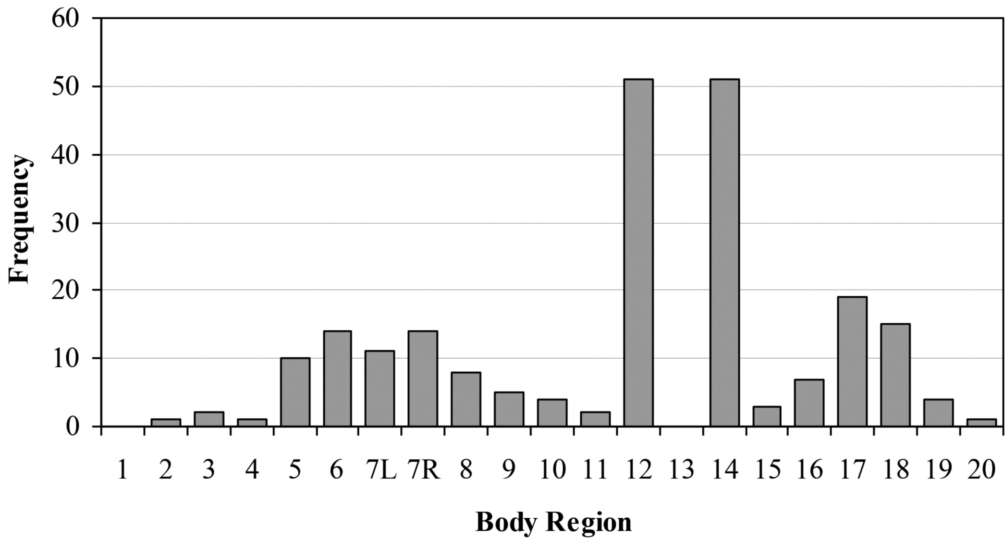

Figure 5. Frequency of killer whale rake mark sets (n = 222) by body region for 169 photo-identified western gray whales. Note that while repeated observations of the same rake marks within a body region are represented only once per individual, individual whales can have rake marks across multiple body regions.

et al., 1994, 2017). Tooth rakes, of course, may not be truly indicative of predation attempts by killer whales but may, instead, represent capture practice or instruction of predatory techniques for younger members of the group. Rake marks may also result from killer whales testing baleen whales to assess the presence of particularly vulnerable individuals (i.e., calves) that may be easily separated from a group and killed. Nevertheless, we suggest that these interactions, fatal or non-fatal, represent attacks in that they are associated with a clear element of physical threat.

The sex ratio observed among gray whales bearing killer whale rake marks, 60% of which were males, was similar to that derived from biopsies (58% of which were male) collected during the same time period (Weller et al., 2008), and the proportion of identified males with scars (47%) was higher than that of females (44%). Given that the majority of rake marks acquired during the study appeared on non-calf whales, it was expected that adult females would have a higher prevalence of scars than adult males if the interactions of non-calf gray whales with killer whales were largely restricted to mothers defending their young. The higher proportion of males bearing rake marks, however, questions this expectation and may be interpreted in two ways: (1) adult male and female gray whales, in addition to mothers with calves, may attempt to defend vulnerable individuals during killer whale attacks as has been observed in humpback whales (Pitman et al., 2015, 2017); or (2) non-calf gray whales (male and female), in the absence of calves, are also attacked by killer whales.

Overall, the results of this study indicate that killer whales are threatening, and probably killing, gray whales in the western North Pacific, but the location(s) and associated level of mortality are unknown. The western gray whale subpopulation is endangered, numbering only about 200 individuals, and the high prevalence of rake marks from killer whale attacks reported herein may represent an important selective pressure regulating its recovery.

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