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Interactions, injuries, and mortalities of killer whales (*Orcinus orca*) observed during fishing operations in Alaska

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Abstract—Fishery observer records from 2001 through 2016 were examined to document interactions, injuries, and mortalities of killer whales (*Orcinus orca*) associated with fishing operations in Alaska. Although widespread throughout Alaska, the highest numbers of such events occurred in the southeastern Bering Sea. Killer whales of the resident ecotype feeding on catch or discarded catch and fishermen using whale deterrence measures represented 96% (number of interactions [n]=3110) of all interactions examined in this study (n=3245). We found that 87% (n=2817) of all interactions occurred during longline operations. Both minor and serious injuries were documented. Twenty-seven killer whales were reported dead, but additional mortalities are assumed. Most whales killed were residents; however, 3 transient whales were also taken. Because killer whale populations are relatively small, a low level of mortality may significantly affect populations, especially if multiple sympatric stocks are shown to exist. Given the long history (i.e., over 6 decades) that Alaska killer whales have had with fishing operations, it is likely that these interactions will continue.

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Throughout the world's oceans, interactions of killer whales (*Orcinus orca*) with fishing operations have been well documented (Visser, 2000; Purves et al., 2004; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Clark and Agnew, 2010; Tixier et al., 2010; Belonovich and Burkanov, 2012; Tixier et al., 2016). In Alaska, Japanese fishermen first reported depredation by killer whales on longline catches of groundfish in the early 1960s (Dahlheim[1]). Throughout the 1980s, fishermen operating in the United States reported depredation by killer whales on their longline catches (Dahlheim[1]), with additional reports provided by both industry and fishery observers. Interactions have included depredation of longline-caught fish by killer whales, the presence of killer whales feeding off discards in other fisheries, and instances of fishermen using deterrence (Dahlheim[1]).

Killer whales are widely distributed and commonly encountered throughout the waters of Alaska (Braham and Dahlheim, 1982; Zerbini et al., 2007). Three ecotypes of killer whales have been reported from Alaska: resident, transient, and offshore ecotypes. Ecotypes differ in external morphology, acoustic behavior, and prey preferences (Baird and Stacey, 1988; Baird and Dill, 1995; Ford et al., 1998; Dahlheim et al., 2008). External morphology (i.e., fin or saddle shape) combined with natural and human-induced scaring allows for individual, and therefore group, and ecotype identification (Bigg et al., 1990; Emmons et al., 2019). Animals with such identifiable marks can be tracked through time, allowing researchers to document injuries to individual whales, assess individual and group movements, and identify the ecotype involved in specific fishery interactions.

Interactions between killer whales and fisheries affect both fishermen and the individuals or pods of killer whales

[1] Dahlheim, M. E. 1988. Killer whale (*Orcinus orca*) depredation on longline catches of sablefish (*Anoplopoma fimbria*) in Alaskan waters. NWAFC Processed Rep. 88-14, 31 p. [Available from Alsk. Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.]

that are involved in the interactions. Financial losses are incurred by fishermen as a result of lost or damaged gear, lost fishing time due to having to wait for depredating killer whales to leave the vicinity of fishing gear, catch degradation due to increased gear soak time, and overall reduction in harvest of fish (Yano and Dahlheim, 1995; Tixier et al., 2020). In addition to negative effects to the fishing industry, direct interactions between killer whales and fishing vessels have resulted in whales being seriously injured or killed.

Here we summarize data collected by the National Marine Fisheries Service (NMFS) North Pacific Observer Program on fishery interactions of killer whales in the waters of the Bering Sea, Aleutian Islands, and Gulf of Alaska (GOA) during 2001–2016.

Materials and methods

Background

The Marine Mammal Protection Act of 1972, Public Law 92-522, title 1, section 118, requires the NMFS to classify all U.S. commercial fisheries into 1 of 3 categories based on the level of incidental mortality and serious injury of marine mammals occurring in those fisheries (Marine . . . 2020). There are 23 groundfish fisheries operating in the Bering Sea, Aleutian Islands, and GOA that are defined in the List of Fisheries (LOF; see Breiwick, 2013) for which marine mammal bycatch must be estimated (for additional information, see table 1 in the NMFS Office of Protected Resources List of Fisheries Summary Tables, available from website). These fisheries target different fish species by using trawl gear (9 fisheries), longline gear (10 fisheries), and pot gear (4 fisheries). We used this LOF and data from the NMFS North Pacific Observer Program to assess fisheries interactions with killer whales from 2001 (the earliest year in which observer data can be assigned to a particular fishery) through 2016.

Observer program data collection

The North Pacific Observer Program is the largest fisheries observer program in the United States (NMFS, 2013). The NMFS Alaska Fisheries Science Center's Fisheries Monitoring and Analysis Division is responsible for administering this program, which includes observer training, logistics, data management, and analyses. Up to 220 observers are deployed at any one time to collect data for use by the NMFS in managing the Alaska groundfish fisheries. The collected data are critical to NMFS fish stock assessments and to efforts to monitor commercial fishing activities throughout the U.S. exclusive economic zone in the North Pacific Ocean (Fig. 1) as required by the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens . . . 2020). At the request of the Alaska Fisheries Science Center's Marine Mammal Laboratory (MML), observers record information on sightings of marine mammals and document fishery interactions, injuries, and mortalities of killer whales.

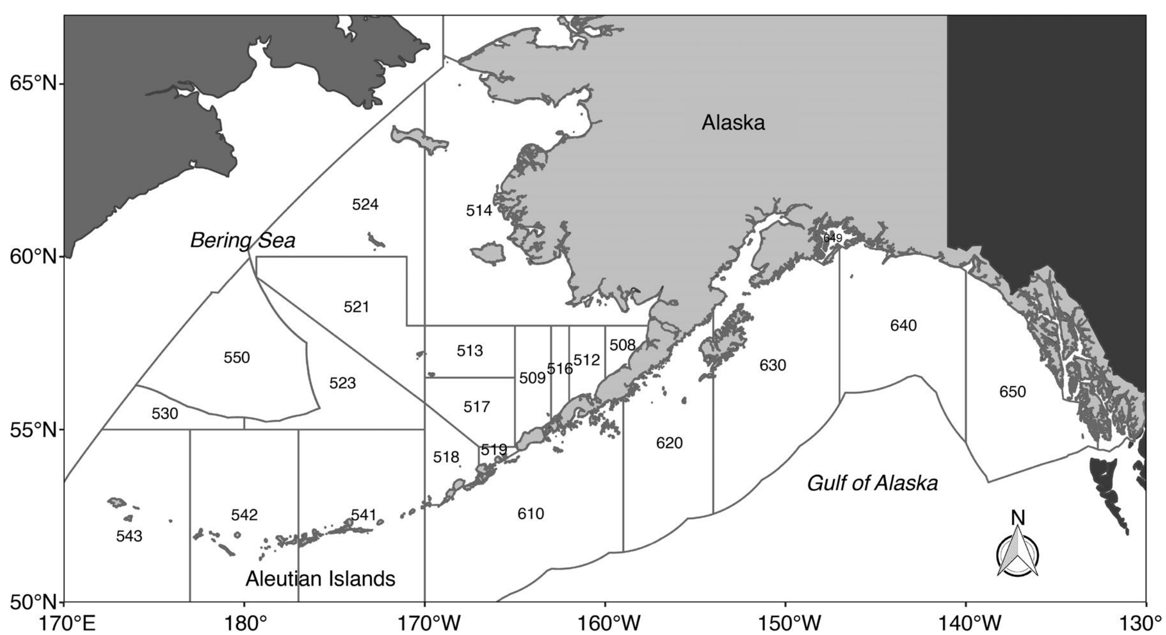

Figure 1

Map of the National Marine Fisheries Service reporting areas in the U.S. exclusive economic zone in the North Pacific Ocean, identified by numbers and outlined with gray lines, where commercial fishing activities are monitored.

The North Pacific Observer Program uses a stratified, hierarchical sampling design to monitor fishing activities in the U.S. exclusive economic zone in Alaska. From the development of domestic fisheries in the early 1990s until the restructuring of the North Pacific Observer Program in 2013, large vessels over 38.1 m (125 ft) in length overall were required to carry an observer on all fishing trips (this group of vessels is the *full-coverage* pool) and vessels between 18.2 m (60 ft) and 37.9 m (124.5 ft) length overall were required to carry observers on approximately 30% of their fishing days (this group of vessels is the *partial-coverage* pool). The restructuring of the North Pacific Observer Program in 2013 redefined these pools such that the full-coverage pool consists primarily of vessels that process catch at sea (catcher-processors and motherships) and vessels that participate in catch share programs regardless of vessel size and such that the partial-coverage pool consists primarily of vessels that deliver their catch to shoreside processors and are over 12.2 m (40 ft) length overall (NPFMC[2]). Observer deployment rates for partial-coverage vessels have varied with management needs for various fisheries and are set each year in an annual deployment plan (e.g., NMFS[3]). These changes over time are one of the reasons that analyses and results are presented separately for the full-coverage and partial-coverage pools.

Once an observer is on a vessel, a subset of hauls are randomly selected to be sampled for catch composition and other biological catch data (Cahalan et al., 2014; Cahalan and Faunce, 2020). If a marine mammal is caught, the observer records this event regardless of whether the animal is within the selected hauls; for marine mammal bycatch, observers record all known mortalities. Sightings of and fishery interactions with marine mammals are also recorded; whenever the observer becomes aware of the presence of a marine mammal, data for the interaction or sighting are recorded.

Interactions of marine mammals with fishing vessels and fishing gear are recorded by observers according to the 7 broad categories defined in the observer manual (e.g., AFSC[4,5]). These categories are as follows: 1) some form of deterrence was used to discourage nearby mammals from interacting with fishing operations, 2) a mammal was entangled and released without trailing gear, 3) a mammal was entangled and released with trailing gear, 4) a mammal was lethally removed (from gear that was not trailing), 5) a mammal boarded the vessel, 6) a mammal was feeding on catch that had not yet been landed, and 7) a mammal was feeding on discards.

During the course of this study (2001–2016), observers used all of these interaction categories with the exception of the category for mammals feeding on discards because it was not introduced until 2008. Observers also used additional interaction categories recorded as *other* (i.e., observations that did not fit the 7 categories listed above) and *unknown* (i.e., interactions observed by the vessel crew but not seen by the observer). In addition, mortalities were recorded and classified as follows: 1) killed by gear, 2) killed by propeller, 3) removed lethally from trailing gear (crew killed a mammal entangled in gear), or 4) removed lethally from gear that was not trailing (in spite of efforts by the crew to release the mammal, the animal died). For whales entangled in gear and subsequently released, an assessment was made by scientists at the MML to determine if the injury sustained would result in the whale's death. If there was a high probability that the entanglement would result in the death of the whale, the incident was listed as a serious injury (serious injury criterion are further described in NMFS[6]).

Analysis of fisheries interactions

The data on fisheries interactions and marine mammal sightings collected by observers were summarized within sampling strata and fisheries as defined in the LOF. The fishery in which a haul or set occurs is determined by the NMFS reporting area (Fig. 1), gear type, and trip target code (dominant species retained; for additional detail, see Cahalan et al., 2014). Additional information collected for an interaction with one or more marine mammals may include the date, year, latitude, longitude, number of animals, vessel and observer identifiers, indication of whether photographs were taken, and indication of whether tissue samples were taken (Breiwick, 2013).

Between 2001 and 2016, the number of hauls monitored by observers fluctuated with varying coverage rates and fishing effort; however, these changes were not always consistent with changes in fishing effort. Therefore, numbers of sampled hauls for which associated interactions with killer whales have been recorded have to be considered in the context of these changes in sampling intensity (for summary of annual sampling intensity, see table 1-1 in AFSC and ARO[7]). As a result, some

[2] NPFMC (North Pacific Fishery Management Council). 2011. Environmental assessment/regulatory impact review/initial regulatory flexibility analysis for proposed amendment 86 to the fishery management plan for groundfish of the Bering Sea/Aleutian Islands management area and amendment 76 to the fishery management plan for groundfish of the Gulf of Alaska. Restructuring the program for observer procurement and deployment in the North Pacific, 239 p. North Pac. Fish. Mange. Counc., Anchorage, AK. [Secretarial review draft.] [Available from website.]

[3] NMFS (National Marine Fisheries Service). 2017. 2018 annual deployment plan for observers and electronic monitoring in the groundfish and halibut fisheries off Alaska, 20 p. Natl. Mar. Fish. Serv., Juneau, AK. [Available from website.]

[4] AFSC (Alaska Fisheries Science Center). 2001. North Pacific groundfish observer manual, 571 p. [Available from North Pac. Groundf. Obs. Program, Alsk. Fish. Sci. Cent., Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle, WA 98115.]

[5] AFSC (Alaska Fisheries Science Center). 2021. 2022 observer sampling manual, 496 p. Fish. Monit. Anal. Div. and North Pac. Groundf. Obs. Program, Alsk. Fish. Sci. Cent., Natl. Mar. Fish. Serv., Seattle, WA. [Available from website.]

[6] NMFS (National Marine Fisheries Service). 2014. Process for distinguishing serious from non-serious injury of marine mammals. Natl. Mar. Fish. Serv. Policy Directive 02-238, 4 p. [Available from website.]

[7] AFSC (Alaska Fisheries Science Center) and ARO (Alaska Regional Office). 2018. North Pacific Observer Program 2017 annual report. AFSC Processed Rep. 2018-02, 136 p. [Available from website.]

fisheries, gears, vessel types, and years are represented in the database at higher rates because of differential rates of observer deployment (full coverage versus partial coverage or interannual changes in coverage; see AFSC and ARO[7]). Combining data from different sampling strata without correcting for coverage rates will result in biases toward those areas of the fishery with higher observer coverage.

Because of these differential coverage rates and the limited information on fishing effort from the unobserved portion of the fisheries, it is not possible to use the number of sampled hauls (nor the number of sampled trips) and the total number of hauls (nor the total number of trips) to obtain a direct estimate of the total number of interactions that occur for all fisheries. A proxy for the ratio of sampled hauls to total hauls has been used to estimate mortality of marine mammals by assuming that the weight of groundfish from sampled hauls (as determined by the observer during sampling), as a fraction of the total groundfish weight landed and reported on fish tickets for the stratum (year, fishery, area, and marine mammal species), is equal to the ratio of the number of sampled hauls to the total number of hauls in the stratum. This approach is typical for estimating incidental mortality in an observed fishery (Breiwick, 2013); however, we have not used this approach in this analysis for several reasons detailed later in the text.

Our focus was to examine only interactions that occurred on observed hauls, not to estimate the total number of the various interaction types in each fishery. Interactions recorded by observers may occur on hauls that are not scheduled for sampling but during which the crew notifies the observer of an interaction. The number of hauls monitored for interactions includes these hauls in addition to hauls randomly selected to be sampled (and monitored for interactions with mammals), and as a result the number of monitored hauls may be greater than the number of sampled hauls, increasing the nominal monitoring rate relative to the rate associated with the randomized sampling design. Although the number of animals involved is recorded by the observer, some animals present might not be observable (e.g., swimming below the surface or otherwise out of sight of the observer). In addition, multiple animals may be involved in any interaction, and some animals may be included in counts associated with different interaction types. Lastly, interactions are not necessarily independent of each other on a haul or within a trip. For example, in cases where deterrence is used to decrease depredation by mammals on the catch, feeding on catch or feeding on discards may also be recorded (i.e., for a single haul, 3 interactions, each of a different type and each involving multiple animals, may be recorded).

For the reasons given in a previous paragraph, we have not used ratio estimates based on groundfish weights to make inferences about interactions of marine mammals with fishing gear for all fishing events in Alaska. We have, however, summarized the frequency of interactions, taking into account the changes that occurred in observer coverage throughout the years by comparing the percentage of monitored hauls in which interactions were documented for the full-coverage and partial-coverage strata separately, although sampling rates in partial-coverage strata have varied between years after 2013 and varied by gear types in 2016 (AFSC and ARO[7]).

The percentage of hauls in which interactions with killer whales occurred was computed as the number of hauls in which at least one interaction (of any type) was recorded divided by the number of hauls monitored by observers (multiplied by 100), an estimate of hauls with killer whale interactions per 100 monitored hauls. This estimate is inclusive of hauls that were not sampled but during which the observer or the vessel crew noted an interaction. These percentages were computed for each year and for the partial- and full-coverage strata separately. By presenting the percentage of hauls with interactions for each sampling stratum, the analysis also accounts for differences in sampling intensity. Interactions with killer whales that were recorded for trips that were not associated with a specific haul were not included in this analysis (39 interactions of the 3245 interactions recorded since 2008).

About the tables and figures of this article in which numbers of interactions are used, it should be noted that the number of interactions with killer whales is more than the number of hauls with such interactions. As noted here previously, this difference results from some hauls (fewer than 10%) having multiple interactions recorded (e.g., a killer whale or group of killer whales may be classified as feeding on discards as well as having the vessel crew use a deterrence toward it). The number of interactions in these tables is not adjusted for sampling rate. The mean between-year percentages of hauls with interactions were computed as the simple average between years for a specified set of covariates. For example, the mean percentage of hauls with interactions for each month was computed as the mean between years of the percentage of interactions for each month. Because we are interested in comparisons between months of the expected monthly percentage of hauls where interactions occur, we use the between-year mean, weighting monthly estimates for each year equally. Alternatively, use of a weighted mean would support inferences about the probability of an interaction with a mammal being recorded for a haul in a given month, but that is not our aim here.

Photographic collection and analyses

Beginning in 1986, observers were instructed to take photographs of killer whales that were sighted either close to fishing vessels or actively interacting with fishing operations. We analyzed all photographic materials (in all forms: film, digital, and video) collected from 1986 through 2015 to determine the killer whale ecotype involved in the fishery interactions that occurred in Alaska. A narrative was completed for each interaction, and the narratives include the observer's cruise number, haul number, observer's name, date, location, interaction code, number of whales present, and details summarizing whale behavior.

Only those images that were in focus, had adequate lighting, and were of a quality high enough to accurately identify an individual killer whale or the ecotype involved (i.e., shape of dorsal fin or saddle patch, whale markings, and clearly visible scars) were used in the analyses. Determination of killer whale ecotype was done by examining a whale's external morphology (i.e., fin shape and size and shape of saddle patch), by comparing the photographic data to images of known Alaska killer whale ecotypes (i.e., images in Dahlheim, 1997, and in unpublished catalogs maintained by both the MML and the North Gulf Oceanic Society. In addition, different ecotypes of killer whales do not intermix. If unknown whales are seen with known members of a resident pod, those unknown whales (linked by association) are considered residents. Photographic data were also used to document injuries and mortalities of killer whales. Any dead killer whale (either killed directly in a fishing operation or found floating at sea) was brought on board the fishing vessel to be photographed and examined by the observer. Whenever possible, the dead animal's sex, age class (i.e., calf, juvenile, or adult) was determined and external measurements were collected (AFSC[4,5]). The results of a review of the observer's photographs and associated interaction form provide information on the plausible cause of death.

Tissue collection and genetic analyses

In 1999, the Cetacean Tissue Collection project was initiated by the MML through requests made to observers to collect tissue samples from any dead cetacean brought aboard a fishing vessel by using MML-provided sampling kits; written instructions were included in the observer manual (see AFSC[4]). When possible, an 8-cm^3 sample of skin and blubber was obtained from each carcass. The samples were stored in a vial containing buffered salt solution with dimethyl sulfoxide and labeled with the observer's cruise number and the date, location, and detailed circumstances related to the event (e.g., cause of death when possible, location on the whale's body where sample was taken, whale measurements, and carcass condition). With the exception of 2 tissue collections (biopsies) taken from live whales, all tissues collected were taken from dead whales that were brought on board the vessel.

Genetic samples from killer whales were analyzed at the NMFS Southwest Fisheries Science Center. Genetic results include species verification, sex determination, and when possible, identification of the killer whale ecotype. Results of the analyses were returned to the MML to update the Cetacean Tissue Collection database and to assign the injured or dead animal to a particular stock. Genetic results were also forwarded to staff members of the NMFS Alaska Regional Office to provide them with vital information for assessing the effects to a specific killer whale ecotype or stock.

Results

Fishery interactions

Between 2001 and 2016, observers reported 3245 (2415 in full-coverage strata) fishery interactions with killer whales from 16 NMFS reporting areas ranging from the Bering Sea, throughout the Aleutian Islands, and eastward into Southeast Alaska (Fig.1). There were 3026 hauls (2268 in full-coverage strata) during which at least one interaction occurred (Suppl. Table 1A) out of the 680,872 hauls (534,601 in full-coverage strata) that occurred on observed trips over the 16-year period. The percentage of the hauls for which interactions with killer whales were reported varied by area, with the highest percentage of hauls with interactions occurring in the Bering Sea (Fig. 2, Suppl. Table 1B). Interactions with killer whales also varied by year within each area (Suppl. Table 1, A and B), by month or season (Fig. 3), and by type of interaction (Fig. 4).

Killer whales feeding on catch before the catch was landed, killer whales feeding on discards, and vessel crew members using varied methods of whale deterrence represented 96% of all observed interactions recorded, and these interaction types consistently accounted for higher percentages of affected hauls than other interaction types (Suppl. Table 2, A and B). Feeding on catch that had not yet been landed was the most common interaction documented during this study. Feeding on discards was known to occur prior to 2008, on the basis of records maintained by MML staff; however, this whale behavior was not formally documented by observers until 2008. Figure 4 shows that the use of deterrence methods was relatively low for the years prior to 2008 and that the frequency of deterrent use appears to have increased in more recent years. The areas in which these 3 types of interactions occurred by season is depicted in Figure 5.

We found that 2527 hauls (84%) with at least one interaction with killer whales occurred during longline operations (Suppl. Table 3A). Longline operations in the Bering Sea and Aleutian Islands (BSAI) accounted for 2130 hauls (84%) with interactions, whereas longline fisheries in the GOA represented only 397 hauls (13%) with interactions (Suppl. Table 3A). There were 56 hauls with interactions with killer whales that were assigned to the *unknown* fishery category (for 38 hauls of longlines and for 18 hauls of trawl gear, the collected data corresponds to none of the fisheries in the LOF). An additional 38 hauls could not be categorized to a specific fishery because the necessary data were not available.

Interactions with killer whales were also reported for trawl operations in the BSAI and GOA, during which 322 hauls with interactions (11%) were documented over the 16-year period (Suppl. Table 3A). The greatest number of interactions occurred in the BSAI flatfish trawl fishery (n=272). Few, if any, interactions occurred in the fishery that uses non-pelagic trawl gear.

The operations of the pot gear fishery that targets sablefish in the BSAI logged 82 hauls with at least one interaction over the entire period (Suppl. Table 3A). The number

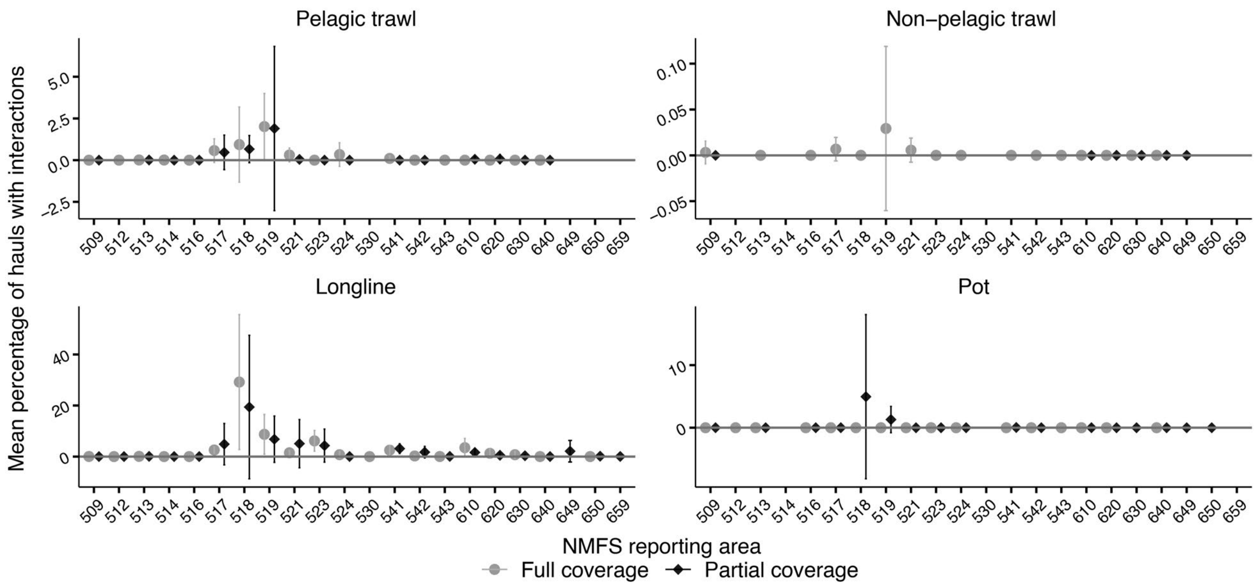

Figure 2

Mean percentage of monitored hauls with recorded interactions of killer whales (*Orcinus orca*) with fishery operations across the years of 2001–2016, by gear type, category of observer coverage (full and partial), and National Marine Fisheries Service (NMFS) reporting area in the U.S. exclusive economic zone in the North Pacific Ocean. Error bars indicate ±1 standard deviation. Note that the scale of the *y*-axis (percentage of monitored hauls) varies among panels.

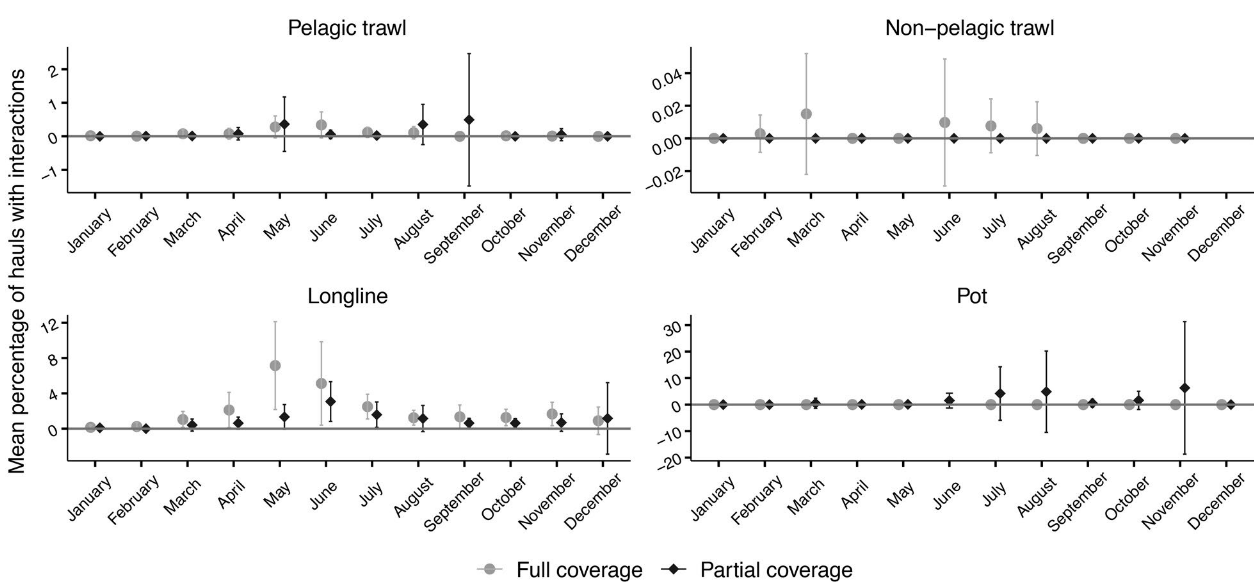

Figure 3

Mean percentage of monitored hauls with recorded interactions of killer whales (*Orcinus orca*) with fishery operations across the years of 2001–2016, by gear type, category of observer coverage (full and partial), and month, in the waters of the Bering Sea, Aleutian Islands, and Gulf of Alaska. Error bars indicate ±1 standard deviation. Note that the scale of the *y*-axis (percentage of monitored hauls) varies among panels.

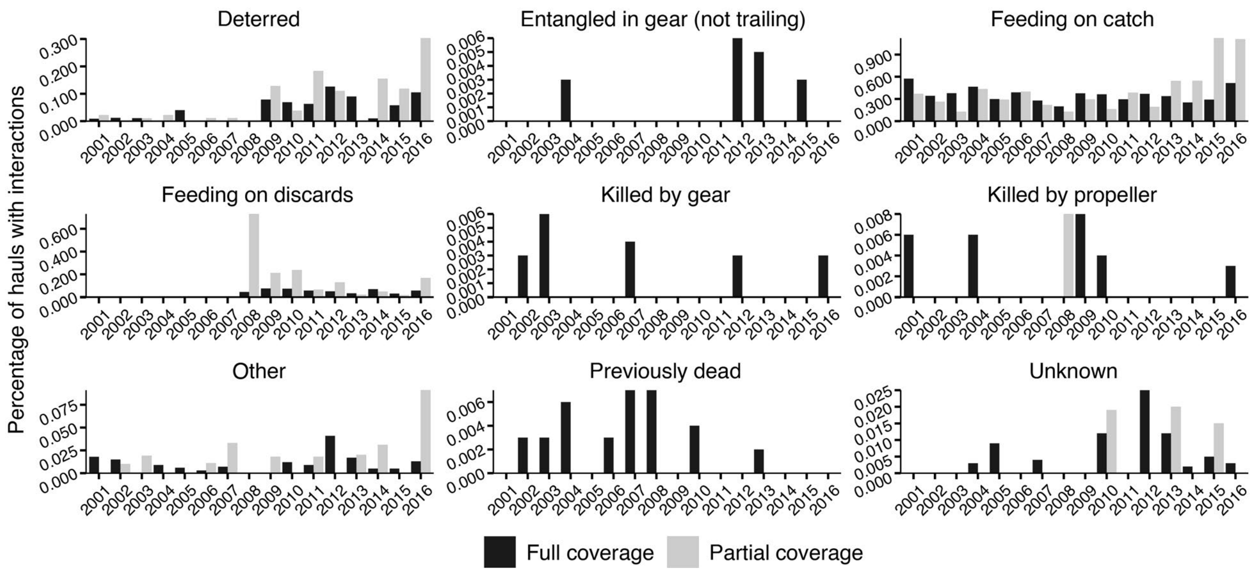

Figure 4

Percentage of monitored hauls with recorded interactions of killer whales (*Orcinus orca*) with fishery operations from 2001 through 2016, by type of interaction, category of observer coverage (full or partial), and year, in the waters of the Bering Sea, Aleutian Islands, and Gulf of Alaska. Note that the scale of the *y*-axis (percentage of monitored hauls) varies among panels.

of hauls with interactions with killer whales in the pot gear fishery notably increased after 2008 because of the inclusion of a new interaction code (i.e., feeding off discards) that was reported from a few pot vessels.

The number of monitored hauls varied by year and sampling stratum. Given the low numbers of hauls that were monitored during their operations, the BSAI rockfish longline fishery (137 hauls for all years), GOA flatfish longline fishery (43 hauls for all years), and GOA rockfish longline fishery (28 hauls for all years) were not included in the fishery-specific graphs presented here. The following fisheries for which no interactions were reported were also excluded from the analysis: the BSAI Pacific cod pot, GOA pollock trawl, Alaska GOA rockfish trawl, and GOA Pacific cod pot fisheries. Data for all fisheries are summarized in Supplementary Table 3, A and B, and in Figures 6 and 7.

Injuries

Photographic images were reviewed to document the types of injuries seen on Alaska killer whales. Relatively few injuries were directly witnessed by observers, and most of the photographs depicted old injuries. Similar to the injuries observed in other populations of killer whales, the minor injuries we documented include the following: body scratches or nicks on the trailing edge of the dorsal fin that resulted from interactions with either conspecifics or prey items; wounds caused by attachments of cookiecutter sharks (*Isistius brasiliensis*), Pacific hagfish (*Eptatretus stoutii*), or barnacles; and small wounds made during prior biopsy sampling or satellite tagging research. Killer whales with more severe injuries were also photo-documented by observers. The top of the dorsal fin of several killer whales appeared to be injured or missing. At least 3 large males were seen with dorsal fins that were completely flopped over; one of these whales also had severe spinal damage. Most injuries appeared to be healed, indicating that a previous injury had occurred. However, the most severe injury was that of a killer whale whose dorsal fin had been completely cut off and who had severe damage to its head and lateral region; photographs of this animal were collected as it fed on discards (Fig. 8, A and B).

Mortalities

Between 1991 and 2016, 24 dead killer whales were reported by NMFS observers, and all of these dead animals were observed in the Bering Sea, 23 of them in the full-coverage stratum. Of the 24 dead whales, 14 animals were killed by fishing gear and 10 whales were killed by propellers (Table 1). Of the 14 mortalities associated with fishing gear, 7 deaths resulted from entanglements in longline gear (Fig. 9) and 7 deaths occurred during trawling operations. For the 10 killer whales killed by propellers, all mortalities resulted from interactions with flatfish, rockfish, or Atka mackerel trawl operations. Deaths of killer whales were reported for 6 of the 23 observed fisheries: the BSAI flatfish trawl, BSAI pollock trawl, BSAI rockfish trawl, BSAI Atka mackerel trawl, BSAI Greenland turbot longline, and BSAI Pacific cod longline fisheries.

Five reports documented live killer whales entangled in gear (Table 2). In all cases, the killer whales were

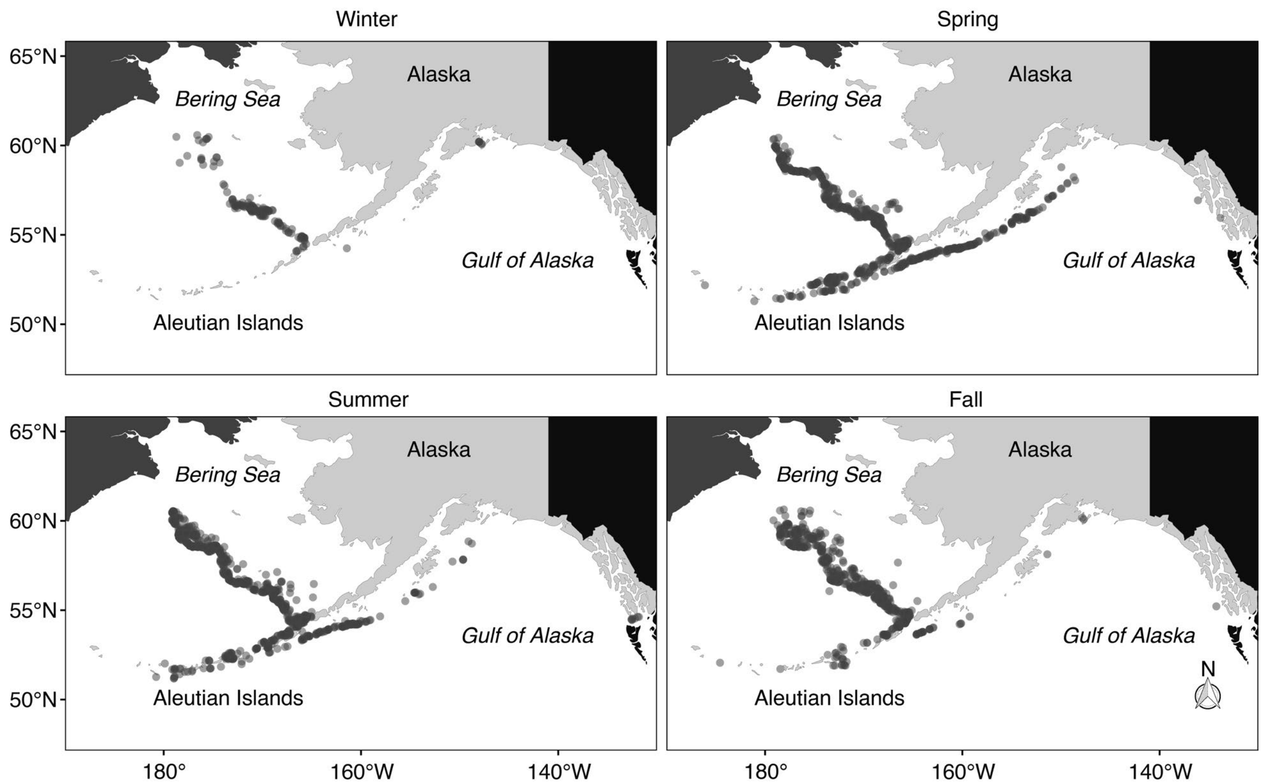

Figure 5

Map of locations, by season, where observers on board fishing vessels recorded that killer whales (*Orcinus orca*) were feeding off catch or discards or that deterrence was used during 2001–2016 in the waters of the Bering Sea, Aleutian Islands, and Gulf of Alaska. The seasons are as follows: December, January, and February (winter); March, April, and May (spring); June, July, and August (summer); and September, October, and November (fall).

subsequently released with the hopes that they would survive. A determination of serious injury (i.e., an entanglement that ultimately results in the death of the whale) was made for 3 whales caught in trawl gear, raising the total number of dead killer whales to 27 for the period between 1991 and 2016.

In addition to the deaths documented as a result of killer whales interacting with the fishery, observers reported 16 dead killer whales (Table 1) that had died prior to the recorded fishery interaction. Three of these whales were observed during longline operations, and 13 were reported during trawl operations. The level of decomposition of the previously dead whales varied from minor (suggesting the whale recently died) to considerable decomposition.

Ecotype

From 1986 through 2015, a total of 9828 photographs of killer whales (2643 images of sufficient quality for analysis) were collected during 375 observed cruises and were reviewed to determine the killer whale ecotype. During longline fishing operations, photographs of killer whales were collected during 266 cruises in the same period (1986–2015), and 1955 images of sufficient quality were reviewed. For the examined photographs from longline cruises, all depredation events were associated with the resident killer whale ecotype. Individuals from all age classes (from calves to adults) and from both sexes of killer whales can be seen close to the vessels in photographs taken during these depredation events.

For the 109 cruises that occurred in 2008–2014, after the interaction type for feeding on discards was added, 688 images of killer whales of sufficient quality were reviewed. The resident killer whale ecotype accounted for all the discard interactions associated with fishing operations. Again, individuals from all age classes and both sexes of killer whales can be seen close to the vessel in photographs taken during these events of discard feeding. No photographs of killer whales of the live transient ecotype were collected during this study.

Genetic analysis

Seven samples from killer whales representing animals killed by gear or by propeller were collected and available for genetic analysis (Table 3). Genetic analysis identified

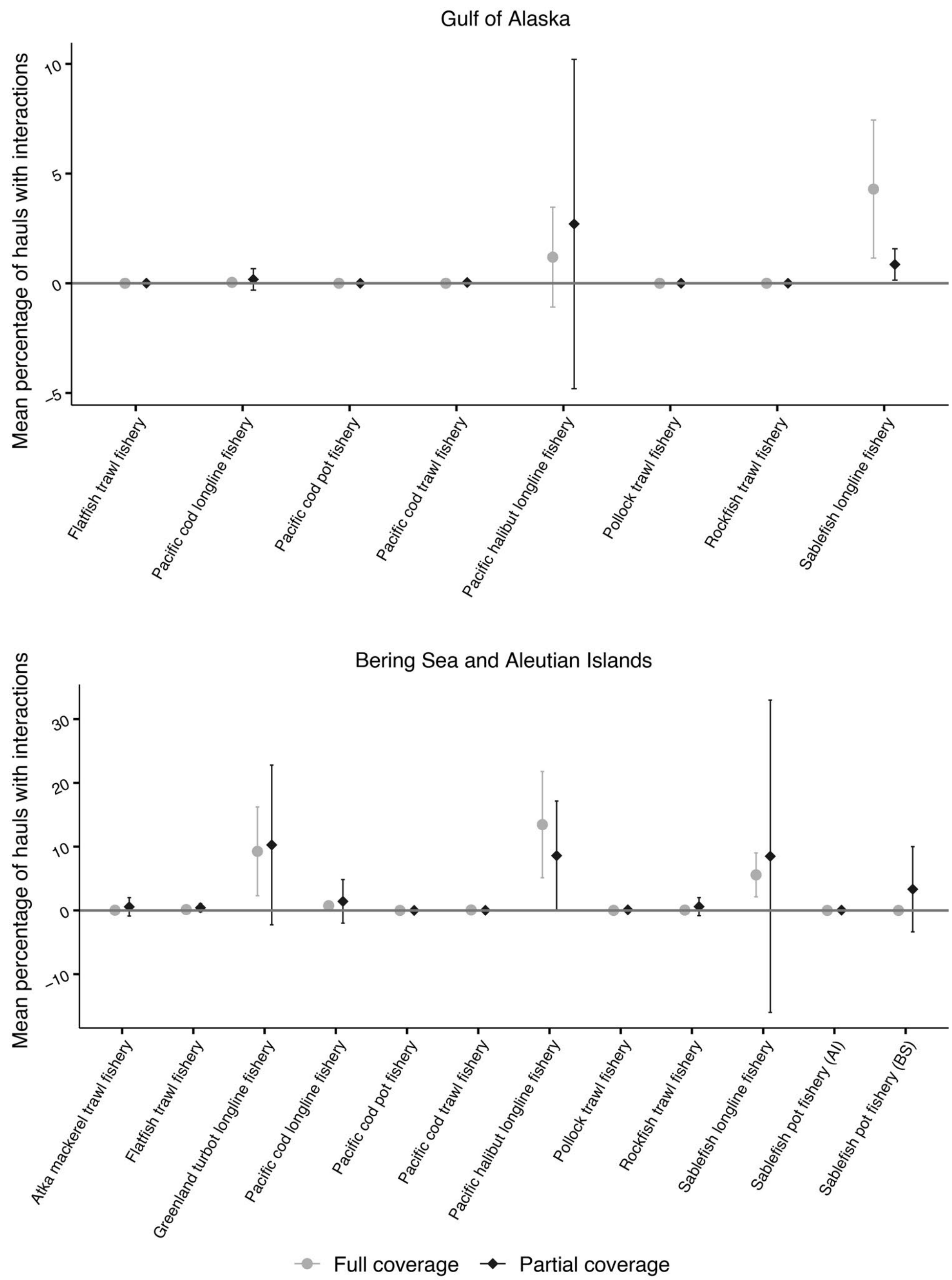

Figure 6

Mean percentage of monitored hauls with recorded interactions of killer whales (*Orcinus orca*) with fishery operations across the years of 2001–2016, by fishery and category of observer coverage (full or partial), in the Gulf of Alaska and in the Bering Sea (BS) and Aleutian Islands (AI). Fisheries are among those groundfish fisheries defined in the List of Fisheries of the Office of Protected Resources, National Marine Fisheries Service. Error bars indicate ±1 standard deviation.

4 of the whales as being from the Alaska resident stock and 3 of the whales as being from the Alaska transient GOA-BSAI stock. Three resident killer whales died as a result of interactions with the BSAI flatfish trawl fishery (killed by propeller), and the other resident whale died during BSAI Pacific cod longline operations (killed by gear). The 3 dead transient whales were killed as a result of interactions with the BSAI pollock trawl fishery (all killed by gear). Six of the animals killed were listed as juveniles of both sexes; the seventh killer whale was an

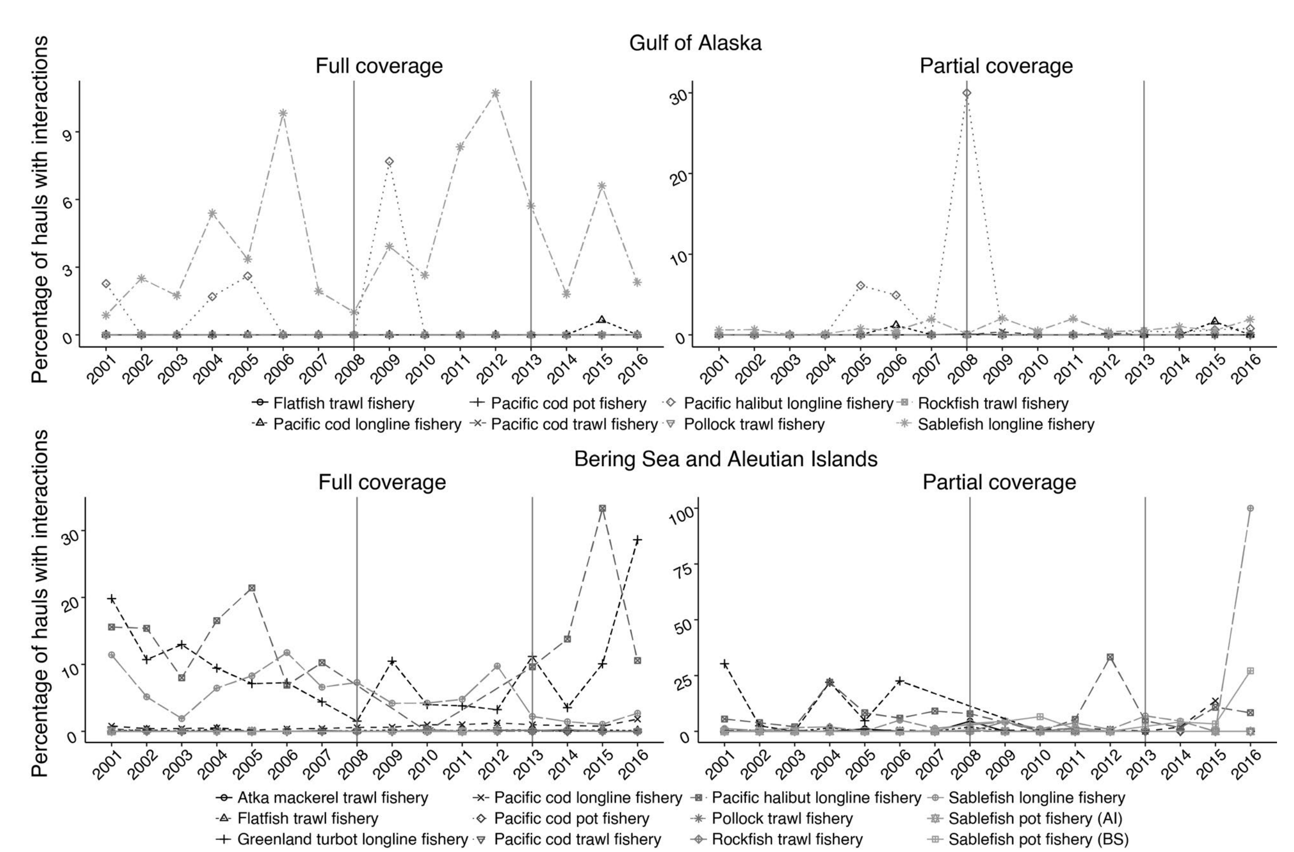

Figure 7

Percentage of monitored hauls with recorded interactions of killer whales (*Orcinus orca*) with fishery operations from 2001 through 2016, by fishery, category of observer coverage (full or partial), and year, in the Gulf of Alaska and in the Bering Sea and Aleutian Islands. Fisheries are among those Alaska fisheries defined in the List of Fisheries of the Office of Protected Resources, National Marine Fisheries Service. Vertical lines are shown as references for the addition in 2008 of "feeding on discarded catch" to the list of interaction types recorded by observers and for the restructuring in 2013 of the North Pacific Observer Program.

adult female (size was not specified). Two tissue samples were also collected from decomposed killer whales that were brought on board the vessel. Results of genetic analysis indicate that both samples were from juvenile males of the resident ecotype.

Additional samples were available for analysis during this study. Staff members of the MML authorized an observer to biopsy killer whales by using darts as they fed on catch during BSAI sablefish longline operations. Two samples were collected; results of genetic analysis confirm that the samples are from killer whales of the resident ecotype.

Discussion

Although fishery interactions with killer whales were widespread throughout Alaska, most interactions were reported during fishing operations in the southeastern Bering Sea, from the Aleutian Islands north along the shelf break to areas north and west of St. Matthews Island. When comparing this area with locations where interactions occurred during the 1980s and 1990s (Dahlheim[1]; Yano and Dahlheim, 1995), we found that the southeastern Bering Sea continues to be a hotspot for interactions of killer whales with fisheries. Recent data indicate that interactions have occurred as far north as St. Matthews Island and as far west as Agattu Island (just southeast of Attu Island, which like Agattu Island is part of the Near Islands, a group of islands in the Aleutian Islands), with reports from both the Bering Sea and Pacific Ocean sides of the Aleutian Islands. Interactions also occurred along the south side of the Alaska Peninsula into the western GOA near Kodiak, Alaska, with 2 reports as far east as Southeast Alaska. Results of the decadal comparisons of the locations of these interactions indicate that a range expansion could be occurring.

In previous longline depredation studies, killer whales have been reported to consume sablefish (*Anoplopoma fimbria*), Greenland halibut (*Reinhardtius hippoglossoides*), arrowtooth flounder (*Atheresthes stomias*), Pacific halibut (*Hippoglossus stenolepis*), and searcher (*Bathymaster

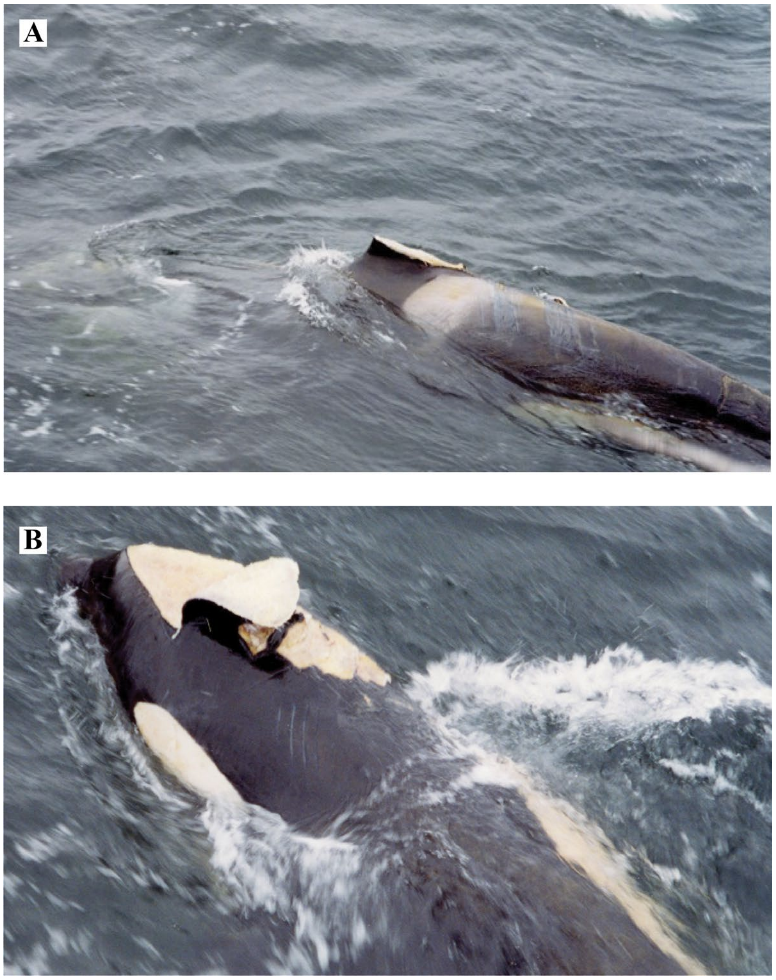

Figure 8

Photographs of a killer whale (*Orcinus orca*) (**A**) with a cut-off dorsal fin and (**B**) with severe head and lateral injuries in the Bering Sea. The photographs were taken as the whale fed off discards during the fishing season in 1994.

signatus) (Dahlheim[1]; Yano and Dahlheim, 1995). Because these data have not been extrapolated to cover interactions for the entire fleet, the number of interactions reported here is an underestimate of the total number of interactions with killer whales occurring in the Alaska groundfish fishery.

During groundfish trawl operations, resident killer whales were seen in close proximity (<3 m) to fishing vessels and feeding off a variety of fish being discarded from the vessels. Group size varied for killer whales, and all age classes were seen taking part in this feeding. We have received multiple reports from fishery observers of both individual and groups of killer whales following vessels for extended periods (i.e., periods ranging from 3 d to 28 d).

Over the past 6 decades (from the 1960s to the 2020s) in Alaska, fishermen have attempted to either reduce or eliminate depredation by killer whales through the use of different deterrence methods (see Dahlheim[1]). Although most deterrence efforts occurred during longline depredation events, reports of killer whales being shot while feeding off discards has also been documented during longline operations. Despite this long-term work by fishermen to protect their catch and reduce their financial losses, interactions continue to occur.

We identified the resident killer whale ecotype as the ecotype responsible for all the interactions reported during this study, on the basis of the external morphologic characteristics of whales of this ecotype, genetic data, photographic matches made to well-known resident killer whales, and the recognition of one distinctly marked individual as a resident killer whale that linked all killer whales by association to that ecotype. Little information is known about the seasonal occurrence and movements of resident killer whales. We documented that interactions were occurring every year and month, with the highest number of interactions reported during the spring and summer months. Given that fishery interactions with resident killer whales are reported throughout the year, we now know that killer whales occur in these northern areas year-round. Photographic matches of individual killer whales collected by observers between 1987 and 2001 (Dahlheim et al., 2002) at locations in the Pacific Ocean and the Bering Sea indicate that resident killer whales moved from south of Unimak Pass, north into the Bering Sea along the shelf break, and then to waters west of St. Matthews Island. Movements by individual killer whales also occurred from Unimak Pass westward to the central Aleutian Islands and then north into the Bering Sea to waters west of St. Matthews Island.

Killer whales occur in high densities throughout Alaska (Leatherwood and Dahlheim[8]). Zerbini et al. (2007), on the basis of surveys of the nearshore waters of the GAO and the Aleutian Islands, estimated abundance of resident killer whales at 991 individuals (coefficient of variation=0.52), with a 95% confidence interval of 380–2585 individuals. Based on photo-identification research conducted by the MML and the North Gulf Oceanic Society in the Bering Sea and western GOA during 2001–2012, a minimum count of western Alaska residents is 1475 killer whales (Muto et al., 2016). Of this total count, the percentage of killer whales or pods involved with fishery interactions

[8] Leatherwood, S. J., and M. E. Dahlheim. 1978. Worldwide distribution of pilot whales and killer whales. Nav. Ocean Syst. Cent., Tech. Rep. 295, 39 p. [Available from website.]

Table 1

Observed mortalities of killer whales (*Orcinus orca*) recorded from 1991 through 2016 by observers aboard vessels in various Alaska Bering Sea and Aleutian Islands fisheries.

	No. of individuals (fishery)		
Year	Killed by gear	Killed by propeller	Previously dead
1991	1 (pollock trawl)		
1992	1 (pollock trawl)		
1993	1 (flatfish trawl)		
1994			
1995	1 (Pacific cod longline)		1 (flatfish trawl)
1996			1 (flatfish trawl)
1997	1 (pollock trawl)		
1998		1 (flatfish trawl)	1 (flatfish trawl)
1999	1 (Greenland turbot longline; 1 (pollock trawl)		1 (pollock trawl)
2000			1 (Pacific cod longline)
2001		2 (flatfish trawl)	
2002	1 (pollock trawl)		1 (flatfish trawl)
2003	1 (pollock trawl); 1 (Pacific cod longline)		1 (pollock trawl)
2004		2 (flatfish trawl)	1 (flatfish trawl); 1 (Pacific cod trawl)
2005			
2006			1 (flatfish trawl)
2007	1 (Greenland turbot longline)		1 (Atka mackerel trawl); 1 (Pacific cod trawl)
2008		1 (flafish trawl)	2 (Pacific cod trawl)
2009		2 (Atka mackerel trawl)	
2010		1 (rockfish trawl)	1 (Pacific cod longline)
2011			
2012	1 (Pacific cod longline)		
2013			1 (Pacfic cod longline)
2014			
2015	1 (Greenland turbot longline)		
2016	1 (Pacific cod longline)	1 (flatfish trawl)	
Fishery type		No. of individuals	
Trawl	7	10	13
Longline	7	0	3
Total	14	10	16

is unknown. Resident killer whales are very social animals that occur in distinct, stable pods. During periods of socialization and foraging, resident pods are known to join other resident pods temporarily (Bigg et al., 1990). During these multi-pod assemblages, individuals can share and subsequently learn certain behaviors (Whitehead, 2007). Over time, it is likely that more groups of killer whales will learn this behavior and begin targeting commercial fisheries where prey are easily located and available.

Documented injuries to killer whales range from minor to severe. Although some injuries appear to be life threatening, it is difficult to determine if an injury would lead to mortality of a whale. For example, the killer whale with the cut-off dorsal fin and severe head injury was seen feeding off discards. A killer whale in New Zealand that had its dorsal fin split into 2 parts reportedly lived for 2 years after the injury occurred (Visser and Fertl, 2000). It is unknown whether, but likely that, these severe injuries could be responsible for an early death. With all degrees and types of injuries, healing requires energy that could possibly lower a whale's resistance to disease. The underlying cause of a collapsed dorsal fin is unknown but could be attributable to either an injury or a whale's overall health, including nutritional issues.

Over half of the killer whales that were either killed by gear or killed by propellers and whose ecotype was

Figure 9

Photograph of a deceased adult male killer whale (*Orcinus orca*) entangled in longline gear (whale ID AK218; see Dahlheim, 1997) in the Bering Sea, taken during fishing operations in 2007.

determined through genetic analysis were of the resident ecotype. However, the 3 killer whales killed in net entanglements in the Alaska BSAI pollock trawl fishery, all juveniles, were found to be of the transient ecotype. Given that the diet of transient killer whales consists primarily of other marine mammals, we suggest that these whales were following pinnipeds (e.g., Steller sea lions, *Eumetopias jubatus*) that were in turn attracted to Alaska BSAI pollock trawling operations. The only photographs of transient killer whales collected by observers were taken when transient killer whales were killed and brought on board the vessel. Because transient whales are not targeting fish, their approaches may not be close enough to the boats to make it possible to take photographs usable for identification of ecotype.

It is unusual to find the large number of floating, dead killer whales encountered by observers because this species is thought to typically sink at death, preventing recovery. That a dead killer whale is found floating may indicate that the whale was recently killed (e.g., a whale entangled in gear and subsequently drowned) and then tossed back into the sea. Hence, mortalities could be as high as 43 individuals for this study period if the 16 killer whales found dead prior to fishery interactions are added to the 27 killer whales listed as killed as a result of interactions.

The Alaska groundfish fisheries operate in areas where killer whales are known to concentrate (Braham and Dahlheim, 1982). Major runs of salmon (*Oncorhynchus* spp.)

Table 2

Details about observations of killer whales (*Orcinus orca*) entangled in gear and subsequently released and their level of injury recorded between 2004 and 2013 in various Alaska Bering Sea and Aleutian Islands fisheries.

Year	Fishery	Comments	Level of injury determined
2004	Flatfish trawl	Caught in net, released by crew, and swam away. No injury noted, and no gear trailing.	Detailed data not available; therefore, level of injury listed as undetermined.
2012	Flatfish trawl	Caught in codend. Tried to unzip codend at least 2 times, but whale's fins caught in net. Finally cut whale free. Blood observed on deck, but unsure of level of injury. Whale swam away free of gear.	Serious injury concluded.
2012	Pacific cod longline	Tangled in longline gear. Crew attempted to untangle and cut off groundline. By the time crew got to the other end to view the animal, whale had untangled itself and swam off. No injury witnessed.	Whale not seriously injured.
2013	Flatfish trawl	Large orca caught in net. Took a bit of time to untangle. Whale appeared stunned or shocked, but once back in water it eventually swam back with other whales and was free of gear.	Serious injury concluded.
2013	Flatfish trawl	Small orca caught in net. Crew cut the net open on deck and pushed whale back in water. Whale swam off and back to the pod. No gear trailing.	Serious injury concluded.

Table 3

Details about tissues collected for genetic analysis from dead killer whales (*Orcinus orca*) brought aboard fishing vessels in various Alaska fisheries in the Bering Sea and Aleutian Islands (BSAI) and in the Gulf of Alaska (GOA) from 1999 through 2004. Genetic analysis was used to determine the ecotype of each whale: resident, transient, and offshore. Stock IDs were assigned by using ecotype and the region where the dead animal was sampled. All residents are identified as belonging to a single stock (i.e., the Alaska stock). Transient whales are identified as from either the AT1 stock or the GOA-BSAI stock. The age, sex, and cause of death recorded by observers for each whale are presented. A dash indicates that a whale's age class or sex was undetermined.

Sampling date	Fishery	Stock ID	Whale age class	Whale sex	Comment
20-Aug-1999	Pollock trawl	AT1 transient	Juvenile	F	Killed by gear
11-Aug-2001	Flatfish trawl	Alaska resident	Juvenile	–	Killed by propeller
12-Mar-2002	Pollock trawl	GOA-BSAI transient	Juvenile	–	Killed by gear
20-Mar-2003	Pollock trawl	GOA-BSAI transient	Juvenile	–	Killed by gear
22-Jul-2003	Pollock trawl	Alaska resident	Juvenile	M	Decomposed
9-Sep-2003	Pacifc cod longline	Alaska resident	Juvenile	F	Killed by gear
7-Apr-2004	Flatfish trawl	Alaska resident	Juvenile	M	Decomposed
21-Apr-2004	Flatfish trawl	Alaska resident	Juvenile	F	Hit by propeller
22-Apr-2004	Flatfish trawl	Alaska resident	–	F	Hit by propeller

and other fish species are seasonally available to killer whales in this area. It is no surprise that killer whales would be attracted to fishery operations knowing that food is easily available. Killer whales may not normally consume many of the fish species that they target during fishery interactions. Sablefish are found at depths ranging from 366 m to 1829 m (AFSC[9]), depths believed to be beyond the foraging capabilities of killer whales (Baird et al., 2005). Although an abundance of fish species are available for this ecotype, the availability and reliance on commercially caught fish and discards may likely cause populations of killer whales to increase. If the population level of killer whales is currently sustained by the dependence of whales on food obtained during commercial fishery operations, a significant reduction in the availability of caught fish coinciding with possible decreases in abundance of their natural prey (i.e., salmonids) may cause populations of killer whales to decline.

Conclusions

Our results provide information on the potential effects that commercial groundfish fisheries could have on Alaska killer whales, particularly the fish-eating resident stock. Given that 100% observer coverage is lacking for all fisheries and hauls, the total numbers of interactions, injuries, and mortalities reported here most likely represent underestimates. As currently defined, the Alaska resident killer whale stock ranges from Southeast Alaska to the Bering Sea (Muto et al., 2016). Results of recent studies indicate that the Alaska resident killer whale population may be more finely structured than previously thought, evidence of the likelihood of multiple stocks (Parsons et al., 2013). When compared to those of other cetaceans, populations of killer whales are small with low birth rates (Olesiuk et al., 1990; Dahlheim and Heyning, 1999); therefore, a take level that appears small may significantly affect a population of killer whales, especially if stock structure is found to be more finely structured. Within pods of resident killer whales, individual membership is stable over time and can consist of 2–3 generations. Given this social structure, the loss of a whale or whales from a pod may also have significant implications in how individuals in the pod respond to mortality events (Busson et al., 2019).

Given the long history of killer whales interacting with Alaska groundfish fishery operations (from the early 1960s to the present time) it is likely that interactions of killer whales with Alaska fisheries, events that lead to whale injuries and mortalities, will continue. The range where fishery interactions with killer whales occur may expand, and these interactions may become more frequent over time if the following scenarios occur: 1) the fishery expands in range and duration, 2) natural populations of fish stocks that are normally targeted by killer whales are reduced, 3) populations of killer whales increase, 4) more groups of killer whales learn this depredating behavior and start targeting fishing operations, and 5) killer whales become even more dependent on this reliable food source.

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[9] AFSC (Alaska Fisheries Science Center). 2021. Alaska sablefish fisheries and assessment. Website. [Last modified 27 August 2021.]

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