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Using Photo ID to Examine Injuries in Eastern Pacific Gray Whales
From Calving to Feeding Grounds and Along the Migratory Corridor

Laura Conner
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Abstract:

The Eastern Pacific population of gray whales (*Eschrichtius robustus*) migrates along the entire west coast of North America every year; this migration brings them into close contact with shipping lanes and fishing operations which present major anthropogenic (human caused) threats to gray whales. The purpose of this study is to use photo ID of the whales from their feeding and calving grounds, and their migratory corridor to study which body regions are susceptible to both natural and anthropogenic injury and examine the most common types of injury to the whales. In order to do this, photos were collected from each location and analyzed. Study sites include Bahía Magdalena, BCS, Mexico, Flores Island, BC, Canada, and Redondo Beach and San Pedro, CA, United States. Photographs were entered into catalogs for photo ID, and then analyzed to determine the body regions and injuries observed. Types of injuries included: scar, wound, rake mark (from attack by killer whale), entanglement, and fluke (injury on tail that does not fall into another category). It was found that scars, rake marks, and entanglements represented the most common types of injuries, each occurring in about 10% of the whales. Rake marks were found more often on the flukes of the whale than the body, but there was no significant difference in locations of wounds or scars when compared between the body and flukes. From examination of the results of other studies (Jensen and Silber 2004, Nelson et al 2007), I estimate that 3-6% of gray whales die from ship strikes. However, because the population is quite large (17,000-22,000 individuals) I conclude that anthropogenic injuries are not representing a significant source of mortality to the Eastern Pacific stock of gray whales. I suspect that anthropogenic injuries are more of a threat to smaller populations of cetaceans such as the Western Pacific gray whales and North Atlantic right whale.
Introduction:

Gray Whale Biology:

Gray whales, *Eschrichtius robustus*, are one of the smaller species of baleen whales, averaging only about 15 meters as adults compared to the gigantic blue whales which can be over 33 m (Reynolds & Rommel 1999). Baleen whales are cetaceans in the suborder Mysticeti; their most identifying characteristic (other than their large size) is their baleen hanging from their upper jaws in place of teeth. Most baleen whales use it to filter out very small food particles (often zooplankton) from the water column (Berta et al 2006).

Gray whales migrate annually from feeding grounds in the Bering and Chuckchi Seas, to their mating and calving grounds in the protected lagoons off the coast of Baja California, Mexico, and then back north a few months later (Moore et al 2003). This is one of the longest mammalian migrations in the world, averaging about 15-20,000 km round trip annually (Berta et al 2006). However, some of the whales do not complete this entire migration; there are estimated to be about 180 individuals that stop their northward migration anywhere between Northern California and Southern Alaska and remain in these locations for the duration of the summer (Calambokidis et al 2002). This subset of the population comprises the pacific coast feeding aggregation. Stopping the migration early significantly reduces the amount of energy required to travel, and allows the whales to spend more time feeding. Gray whales feed during the summer and fast during their migration and the winter when they are in the calving lagoons. Perryman and Lynn (2002) found that gray whales lose about 11-29% of their total body weight during their migration.

Gray whales are unusual in their feeding strategy as they primarily feed on benthic amphipods in the Bering and Chukchi Seas (Moore et al 2003). Gray whales employ a technique called 'mucking' in which they roll to the side and place their mouth a few centimeters above the substrate, they then retract their tongue and expand the throat groves on their chin to
create suction which propels sediment and benthic crustaceans into their mouths (Woodward and Winn 2006). Most gray whales feed on sub-benthic ampeliscid amphipods (Ampelisca spp.) that live in the seafloor sediments (Darling et al 1998). It is estimated that gray whales disturb 5% of the benthos of the Bering/Chukchi Sea regions every summer, and consume 10% of the yearly amphipod production (Rugh et al 1999). Gray whales show strong lateralization similar to humans because in over 97% of their feeding dives the whales will turn onto their right side (Woodward and Winn 2006).

Gray whales have also been noted to be opportunistic feeders. They feed in a variety of environments including shallow sand or mud bays, eel grass, kelp beds, the open water column, and at the surface (Darling et al 1998). Individuals in the pacific coast feeding aggregation have been observed to feed heavily on dense swarms of mysids (primarily Holmesimysis sculpta) that congregate above the seafloor (Stelle et al 2008), and the larvae of pelagic porcelain crabs (Petrolithes eriomerus) (Dunham and Duffus 2002, Darling et al 1998). Mysids are generally found above rocky reefs about 15 m deep, and the pelagic schooling porcelain crab larvae is found over boulders at less than 30 m depth (Dunham and Duffus 2002). In addition, their benthic prey of amphipods occurs along Vancouver Island as do ghost shrimp (Callianassa californiensis), both of which can be found in near shore sediments up to 35 m deep (Darling et al 1998).

Gray whales undergo their long migration so their calves may be born in the warm protected lagoons off the coast of Baja California, Mexico. An additional advantage for having their young in the protected bays of Mexico is that the newborns are protected from predators such as killer whales (Orcinus orca) when they are first born. It is hypothesized that juvenile and non-reproductive whales also make the migration simply because it is more energetically efficient to swim to warmer waters than to put the energy into keeping warm and remain in the arctic during the long cold winter.
Gray whales are estimated to become sexually mature at about 6-12 years of age (Bradford et al 2010), and females tend to bear calves every other year (Jones 1991). Their median calving date is around January 13th (Perryman & Lynn 2002). It has been observed that the percent of whales migrating southward with new calves has been increasing over the past twenty years. Between 1984 and 1990, there was an average of 1.7% of the whales observed with calves as they migrated past Point Vicente, CA, this grew to an average of 3.5% between 1990 and 1993, and then increased again to 4.6% between 1993 and 1999 (Rugh et al 1999). A possible reason for this increase is that there has been a full week delay in the peak timing of the gray whale migration since 1980, which has brought the peak calving data to coincide with the migration (Shelden et al 2004). This delay is important because the newborn whales are at greater risk of orca predation when born outside of the protected Mexican lagoons. The delay may be caused by climate change which has altered the structure of the arctic feeding grounds and increased competition between whales (Shelden et al 2004). This competition has caused the whales to expand their foraging range farther north, which makes their migration even longer (Shelden et al 2004).

Gray Whale Status:

Fossils indicate that gray whales are an ancient species that was once distributed in the North Atlantic as well as the North Pacific Ocean (Barnes & McLoed 1984). There have been at least eight other species of the family Eschrichtiidae identified from fossils dating back over 51,000 years, all of which are now extinct except *E. robustus* (Barnes & McLoed 1984). Due to intense whaling, gray whales were made extinct in the Atlantic about three hundred years ago, and nearly became extinct in the Pacific in the early to mid 1900s. Estimates of the minimum abundance of the Eastern Pacific stock in 1900 are between 4-5,000 individuals, but possibly fewer than 2,000 (Swarts et al 2006). The Western Pacific population, living around Russia and Japan, remains critically endangered with only about 120 individuals surviving (Bradford et al 2009).
The Eastern Pacific gray whale was listed on the US Endangered Species Act (ESA) in 1970, and also protected internationally by the 1986 IWC moratorium on whaling (Keller 2004). Through these combined conservation efforts and bans on whaling, the Eastern Pacific stock has recovered and on the 16th of June, 1994, the US Fish & Wildlife service removed the Eastern Pacific stock from the endangered species list (Moore & Clarke 2002). This was the first marine mammal ever delisted from the ESA (Keller 2004). It is estimated that the Eastern Pacific gray whale population throughout the 1990s was roughly 20,000 individuals, peaking in 1997/98 to 26,000 (Hobbs et al 2004). However, the population has been declining for the past few years and is now estimated to be roughly 17-22,000 individuals (Hobbs et al 2004). This decrease represents a population decline of nearly one third (Keller 2004).

In a report by Moore et al (2003) they postulated that the reason for the decline is a coupling between the gray whale population hitting their carrying capacity, and changes in their prey species abundance. However, they also point out that it is surprising that so many whales appeared emaciated due to the gray whale’s ability to feed on a variety of prey. A study by Alter et al (2007) found that the genetic diversity of gray whales suggests a pre-whaling population size of about 76-118,000 individuals. This has sparked a debate of whether or not the population is actually as fully recovered as it was thought to be. Some fear that the gray whale population is still too fragile throughout the entirety of its range and it was removed from the endangered species act too early. The California Gray Whale Commission has petitioned the National Marine Fisheries Service (NMFS) to perform a reevaluation of the gray whale status to determine if the population should be listed as depleted under the Marine Mammal Protection Act (Arnold 2010). However, NMFS refused the petition on the grounds that the population is not below its maximum net productivity level (Cottingham 2010)

**Whale Injuries:**

As a coastal species, gray whales may be more vulnerable to injuries caused by human activities than other species of whale with a more pelagic distribution (Kraus 1990). Nearly all of
the gray whale's 15,000-20,000 km migration passes within 10 km of shore (Berta et al 2006). Therefore, gray whales are susceptible to mortality or serious injury from vessel collisions and entanglement throughout the entirety of their range (Yakovlev & Tyurneva 2003). Potential threats for gray whales are similar to the threats for other marine mammals and include: commercial fishing and vessel traffic, whale-watching and scientific research, offshore oil and gas development, noise pollution, and more (Moore & Clarke 2002).

A study of the influence of whale-watching traffic on gray whales found that they did not show significant avoidance of the boats during their southward migration, but did appear to avoid boats on the northward migration if the boat approached the whale head-on (Heckel et al 2001). This is a problem for the whales primarily because it could force them to go out of their way to avoid boats which wastes energy, a precious resource to the whales during their migration. Oil and gas development are mainly problems because of the noise that is produced. Extremely loud noises can affect marine mammals either by making them change their path to avoid the sound, or by disorienting them and causing them to surface too quickly which can cause the whale or dolphin to develop nitrogen poisoning and strand (Filadelfo et al 2009). However, there are no reports of such noises affecting gray whales. Gray whales also do not appear to show avoidance to natural oil seeps along the California coast, and were observed passing through the oil slick of the Exxon-Valdez spill, therefore it is thought that oil pollution would be of greatest concern if it was contaminating the whale's food sources (Rugh et al 1999).

I will be focusing this study on direct interactions that cause physical injuries to the whales.

Collisions between whales and vessels were rare before the 1950s, possibly due to smaller and slower ships and decreased stocks of large whales caused by whaling (Laist et al 2001). However, the incidence of such collisions has been on the rise as ships get larger and faster. The chance of a ship-strike being fatal approaches 100% as the speed of the ship increases to 15 knots (Vanderlaan & Taggart 2007). Of 24 instances of gray whales being struck by ships in a study by Jensen and Silber (2004), 16 were recorded mortalities (a mortality
rate of 66.7%), and 4 (16.7%) obtained injuries. A study by Bradford et al (2009) on the western population of gray whales, found that 20% of the whales had evidence of anthropogenic interactions. Eighteen percent of those whales had scars from entanglement, and 2% had scars caused by vessel collisions (Bradford et al 2009). Between the years 1990 and 1999 there were 47 known cases of Eastern Pacific gray whale entanglements of which 13 survived (Rugh et al 1999). During this same time period, there were a total of 250 strandings involving gray whales off the coast of CA, OR, WA, and AK, 6 strandings off of BC in 1999, and between 1975 and 1999 there were 518 recorded strandings in Mexico (Rugh et al 1999).

A study by Nelson et al (2007) found that 133 out of 417 (31.9%) reported events involving whales on the east coast of the U.S. were confirmed entanglements of which 26 (19.5%) were mortalities, and 42 (10.1%) were confirmed ship strikes which resulted in 27 (64.3%) known mortalities. These data showed that humpback, right, fin, sei, blue, brydes, and minke whales were all susceptible to such injuries (Nelson et al 2007). Baird and Gorgone (2005) studied false killer whales around Hawaii and found that 3.75% of them had severe fin disfigurement from interaction with the long-line fishery of the area.

Most scars from entanglements are located on the peduncle (location where the body joins the fluke) of the whales because this region is easier to get tangled in nets and lines. Kraus (1990) found that 57% of north Atlantic right whales had scars from entanglements in this region. Kraus also found that 7% of the whales had major wounds on their backs, all of which were attributed to ship strikes.

Juvenile whales may be more susceptible to entanglement than adults (Bradford et al 2009). This could be because juveniles either become entangled or struck by boats more often, or because it is more often fatal when they are entangled or struck. This follows the prediction that newborn mortality is higher than adult mortality for most mammals. In Kraus' study (1990) of North Atlantic right whales (*Eubalaena glacialis*), mortality rates were estimated to be 17% for
the first year or life, and decreased to 3% for each of the next three years. Of 89 stranded whales examined by Rugh et al (1999), 28% were juveniles or newborns.

Another study found that 1% of the bowhead whales had scars from ship collisions, and 4-8% had scars from attacks by killer whales, which is a lower percentage than has been found in other studies of different species (George et al 1994). Kraus (1990) found that 9% of north Atlantic right whales had evidence of killer whale attacks on the tips of their flukes. It is also estimated that transient (mammal-eating) killer whales consume up to 35% of the average annual calf production of gray whales (Barrett-Lennard et al 2005).

It is expected that rake marks from killer whales will be most common on the flukes and flippers of whales (George et al 1994). Killer whales leave parallel scars that are 2.5-5.1 cm apart, and range from 5-20 cm in length (George et al 1994). Rice and Woolman (1971) hypothesized that killer whales will seize the flukes and flippers of gray whales in order to immobilize and drown them. Sharks may also attack whales, but the scars left by sharks look very different than those from orcas. Shark scars usually have multiple penetrations in an oval shape from the shark's knife-like teeth (George et al 1994).

Another potential source of natural injury is the gray whale's feeding strategy. Scars that occur on or around the head of right whales are likely caused by collisions with the bottom substrate of the ocean (Kraus 1990). This probably accounts for most of the scars on the head of gray whales as their primary method of feeding is to swim to the bottom of the ocean and scoop up sediment in their mouth. This would bring them into close contact with any rocks or sharp objects that could cause injuries. I would expect these injuries to be more prevalent on the right side of the gray whale's head as they primarily roll onto their right side to feed (Woodward and Winn 2006). Many scars on the body and flukes of gray whales could be from similar collisions with the ocean floor obtained while feeding.
Photo ID:

During the 1950s and 60s, artificial marking of individuals, such as tagging or attaching radio transmitters, was thought to be required for behavioral research (Würsig & Jefferson 1990). However, marking is often disruptive or even potentially harmful for the animal. For many species, it was discovered that individuals could be identified by their natural markings; this is especially true of large or long-lived species such as whales (Würsig & Jefferson 1990). Thus, it was found that using photographs to identify individuals is a comparatively non-invasive alternative to tagging (Rangelova et al 2004). Photo ID has been used with marine mammals since the early eighties (Würsig & Jefferson 1990). Interestingly, the first animals that photo ID was used to identify were humans. Beginning in 1915, photographs were a required component of U.S. passports (www.articlesbase.com).

Photo ID uses unique natural markings or features such as notches, scars, patches, blotches, etc. that are on the animal's body to identify individuals. For example, the edges of dolphin dorsal fins, whale flukes, and sea lion flippers have unique shapes that can be used for identification (Gope et al 2005). In addition, scars caused by anthropogenic interactions can make it easier to use photo identification (Bradford et al 2009). The longevity of markings on gray whales is at least eleven years; therefore it is possible to identify individuals based on scarring patterns between years (Darling 1984). With enough high quality photographs, a large portion of the population of almost any cetacean population can be individually identified.

Photo identification can be used to study a variety of characteristics, including group composition, individual 'fidelity' to a group, area distribution, short-term movement patterns, migrations, respiration cycles, behavior patterns, and population size (Würsig & Jefferson 1990). Photo ID is commonly used to estimate population size by using the mark-recapture method in which an animal that is photographed is considered to be 'marked', and if it is re-photographed on a different day it is 'recaptured'. When used in conjunction with longitudinal behavior studies, photo ID can show age at sexual maturity, calving intervals, length of nursing, reproductive and
total life span, and even disease or mortality (Würsig & Jefferson 1990). Though photo ID is an excellent tool, it cannot reach its full potential for providing information about cetaceans when used individually. Photo ID is most beneficial when used in conjunction with other data-gathering techniques such as focal animal studies, or capturing animals for blood, hormone, or chromosome analysis (Würsig & Jefferson 1990).

There are several ways to perform the analysis of photo identification data. One can individually examine photos by hand or use computer programs to aid in finding matches. Curve matching is a method of photo ID in which the outline of the fluke, flipper or fin is extracted from the photo and compared to other such extracted outlines to try to find a match. This method generally requires computer analysis both to extract the fluke, and to match it to another photograph (Gope et al 2005). This method is insufficient to match photos of gray whales because they have no dorsal fin, they do not always fluke, and their dorsal knuckles do not appear to show enough individually distinguishing characteristics to be useful as the sole means of matching individuals.

There is another computerized method being developed by Rangelova et al (2004) to identify the pigmentation patterns on the flukes of humpback whales. Each fluke photo is processed by a program that extracts the light and dark patterns as part of a grid that covers the entire fluke then compares them to other extracted samples looking for similarities. This program does not completely match photos but it narrows down the options to those that are similar for the human researcher to examine (Rangelova et al 2004). Because gray whales do not often fluke, their identification cannot rely solely on their flukes. The coloration patterns of gray whales are also more subtle than those of humpbacks with more shades of gray as opposed to stark black and white, therefore this method would not be as effective if used for the backs of gray whales. Therefore, our gray whale photo ID data was all examined and matched by hand.

Objectives:
Studies of injuries have been performed for other species of whales, but never for the Eastern Pacific population of gray whales. It is important to study both the natural and anthropogenic injuries on gray whales due to the uncertain status of the gray whale population. Because the population may not be fully recovered from the impacts of whaling, it is important to know how anthropogenic factors are still affecting the whales.

The objective of this study is to examine photographs of gray whales from their feeding and calving grounds, and their migratory corridor to see: (1) what body regions are most often injured, (2) what types of injuries are most frequently observed, (3) if there are differences in injury abundance between the feeding and calving locations and the overall population during the migration, and (4) if the types and locations of injuries observed in eastern Pacific gray whales resemble those found in other marine mammals.

The results found in this study are intended to represent a minimum level of injury and anthropogenic interactions because not all body regions of each whale can be photographed and fatal injuries are not documented by this method. I would expect the true incidence of anthropogenic interactions to be higher than can be reported from a study of this kind; however, this study can be used as the foundation for future research on the abundance and types of injuries and the types of human activities that should be altered to reduce the risk to whales. Such activities may include the proximity and speed of boats approaching the whales, or the use of specific types of fishing gear.
Methods:

Study Area: Mexico

Baja California is a 1,250 km long peninsula in which there are three main bays and lagoons that gray whales migrate to every winter: Laguna Ojo De Liebre, Laguna San Ignacio, and Bahía Magdalena (Pérez-Cortez et al 2004). Roughly 53% of the gray whales go to Laguna Ojo de Liebre, which is farther north along the peninsula. 37% disperse through other bays and lagoons and the remaining 10% distribute themselves in an area called the Bahía Magdalena Lagoon Complex, which includes: Banderitas, Bahía Magdalena, and Bahía Almejas (Pérez-Cortez et al 2004). Bahía Magdalena is located about 900 km south of the US/Mexico border on the western coast of the peninsula. The study region fell between 24°32'31"N, 112°02'28"W and 24°45'98"N, 112°07'10"W.

Bahía Magdalena is a transition zone between temperate and tropical faunal regions due to its location at the intersection of the California current (which brings cold nutrient-rich waters south from Alaska), and the California countercurrent. The countercurrent exerts its influence primarily in the fall and winter making the waters slightly warmer, and transforming the various bays of Baja (including Bahía Magdalena) into perfect nurseries and wintering grounds for gray whales (Bizzarro 2008). Humpback (Megaptera novaenlæa) and killer whales (Orcinus orca) are also found in the area, but were never observed within the bays.

There are three primary regions of the Bahía Magdalena Lagoon Complex, the narrow and shallow area called Banderitas in the north, Bahía Almejas in the south, and Bahía Magdalena in the center (see figure 1A), which is relatively large with a maximum depth of 44m (Bizzarro 2008). Whales are generally found more densely congregated in narrower regions of the bays (Banderitas) where there are more cow-calf pairs, and single whales are usually found in a higher proportion in Magdalena and Almejas bays (Pérez-Cortez et al 2004).
Figure 1: Study Areas. Stars represent ports of departure. Insets: A) Bahía Magdalena, Mexico. B) Flores Island, Canada. C) Redondo Beach and San Pedro, California.
Study Area: Canada

Flores Island is off the western coast of Vancouver Island, British Columbia, Canada (see figure 1B). The study area was a 20 km² region of gray whale foraging habitat off of the southwest coast of the island located between 49°14'36"N, 126° 6'10"W and 49°18'51"N, 126°14'30"W (Feyrer 2010). The dotted line in figure 1B represents the path of the transects, which were performed every two to three days (weather permitting) from July 17 to August 24, 2010. The foraging location is bounded to the north and south by deep inlets that are not productive feeding grounds for gray whales, and the 30 m depth contour to the southwest (Feyrer 2010). This narrow range of area is critical feeding habitat because the gray whale’s sub-benthic (amphipods and ghost shrimp), hyper-benthic (mysids), and pelagic (porcelain crab larvae) prey are generally found in these nearshore areas up to depths of 35m (Dunham and Duffus 2002). Humpback whales and harbor porpoises also inhabit these waters, but the humpbacks are usually found slightly farther off shore than gray whales. Killer whales visit occasionally, but are not permanent residents.

Study Area: California

Data was also collected as the whales pass by southern California during the migration. Whale watching boats that departed from King Harbor at Redondo Beach and San Pedro Harbor were used as research platforms (figure 1C). The study site fell between 33°31.747N, 118°13.852W and 33°50.516N, 118°36.070W. This region has no protective bays as seen in Mexico, and while mysids are found in the area, it is not a common foraging ground. The depth throughout the region ranges from 10-800 m within about 1 km of shore (Wolf and Gutmacher 2004). Blue, fin, humpback and killer whales can all be found in the area, as well as several species of dolphins, seals and sea lions.

Photograph Collection:

Small boats (<10m) are best for photo ID because they are more maneuverable and allow for a low angle for photograph collection (Würsig & Jefferson 1990). High speeds were
avoided because they cause spray and can influence the animals to change their behavior (Würsig & Jefferson 1990). Eight meter fiberglass pangas were used to perform transects and as platforms for photo ID in Mexico, and in Canada an 8 m aluminum motorboat was used as well as an 11 m converted fishing boat. The boats used in California were commercial whale watching boats and average 18-20 m. In all locations, data were only collected on relatively calm days (Beaufort 3 and below, with minimal wind and fog). In Mexico both transects and point surveys were performed from February through March 2010. Within Bahía Magdalena and Banderitas, there was no set transect line, instead transects were performed at random throughout the bay to cover the most area possible. When performing transects, the boat traveled at a constant slow speed of roughly 6 knots. In Canada, there was a set course that was followed (see figure 1B). When a whale was observed, the boat left the transect line and approached as close as possible to the whale in order to collect photographs and record an exact location. Because we had no control over where whale watching boats would travel, there were no transects performed in California; instead, we simply recorded the locations in which the boats traveled.

I used a digital SLR camera (Nikon D40) with a 70-300mm manual focus zoom lens to photograph whales, and others used their own personal or lab cameras. Photographs from Mexico were collected by untrained university students at the School for Field Studies. Photos in Canada were taken by trained researchers at the UVIC Whale Lab, and photos in California were collected by trained researchers as well as Earthwatch volunteers. The photograph number was recorded as well as the time, GPS location, behavior, and other comments for each whale. An example of the data sheet used is given below in figure 2.
Figure 2: Photo ID and Transect Data Sheet. Information recorded includes sighting
codes, time, location, sighting number, species, number of animals, photo numbers,
behaviors, and weather.

The target location of a gray whale for photo ID was the region shown above the line in
figure 3. The first dorsal knuckle should ideally be in the middle of the photo. When taking the
photo, it was best to wait as the whale usually breathes 3-4 times before it dives. During its
dive, the whale arched its back more than it would during its previous breaths and more of the
body would be visible. It was important to take a photo at this time to maximize the amount of
whale in the photo.

![Image modified from: sarahcutter.blogspot.com/](image)

Figure 3: Target of Photo ID for Gray Whales is the Region above Line.

In Mexico, the right side of the whale was the target for photo ID in most years, however
in Canada, both sides were targeted. After photographs were obtained of one side in Canada,
the boat driver would maneuver the boat around to the other side of the whale if possible to get photos of both sides. It was usually necessary to wait between four to six minutes for the whale to surface again before getting photographs of the second side. Photos were also collected opportunistically of whale’s flukes (tail) when they were occasionally raised above the surface of the water as the whale dove. Concentrating on capturing photos of one individual at a time was more effective than trying to get multiple at once, and it was helpful to take a blank photo in between different individuals to mark the separation (Sears et al 1980). Photos of the coastline were ideal blanks in case the GPS locations were lost the approximate location could still be determined by examining the coastal features.

Because commercial whale watching boats were the research platform during the migration in California, we were unable to get as close to the whales in order to collect high quality photo ID images and exact locations, and it was generally impossible to obtain photographs of both sides of the whale. However, because the main aim of this research was examining the whales for injuries instead of matching individuals, this did not affect the data.

Data Entry:

When we returned to the field station, the photos were uploaded onto a computer and the recorded data was entered into an Excel spreadsheet. Photos were saved as .jpg for ease of handling. In Canada, the photos were titled by the year, photographer, date, and photo number (ex: 10lc05_0055.jpg). In Mexico, there were a variety of naming schemes existing, but for 2010, all photos were named to include the same data as mentioned above for Canada, but in a different format (ex: 23-03-2010-LC57). Photos from California were named in the same was as those in Mexico except that they included the port of departure as well (Redondo Beach = RB, and San Pedro = SP).

All photos were resized to crop out empty space, take up less memory, and allow them to load faster. In Mexico, photos were cropped using Microsoft Paint, in California they were cropped during creation of the catalog using Microsoft PowerPoint, and in Canada photos were
resized using a program created by Dr. William Megill that used Lab View. This program made all the final images the same size and allowed the image to be moved within a box of static proportions of side size. This made it especially easy to create a catalog of the images afterwards because they all had the same dimensions.

Photograph Quality:

Each photo was evaluated in order to determine which pictures were suitable for use in identification. Factors considered when determining usefulness were: the amount of whale in the photo, the amount of photo that was whale, the angle of the whale to the photographer, photo conditions, and quality. Obviously, if more of a whale can be observed in a photo then it is more useful. The amount of photo that was comprised of whale increased as the photo was taken closer to the whale. This reduced the amount that the photo needed to be zoomed and maintains higher quality. Ideal photos had the whale perpendicular to the observer; however for capturing fluke photos it was best to have the whale parallel and in front of the viewer so the fluke was seen straight-on. Photo conditions include the weather. It was easier to get a good photo if the water was calm and the sun was out, but then you had to be aware of not getting glare on the whale. The final aspect examined was the overall photograph quality. Ideal photos were sharply focused so that all marks could be seen. Most photos had a small amount of blur as it was very difficult to obtain a photo of a moving target from a platform that was also moving. However, if the photo was so blurry that distinguishing marks could not be identified it was not used.

Individual Identification:

Photos of the gray whales were all matched by hand. It was best to match photos soon after returning from the field so they were still fresh in one's mind. Photos were first organized by the individuals seen in a single day based upon the photo number and the notes taken in the field.
In Canada, a new catalog was created that was only for whales seen during the summer of 2010. This was done so that any whales seen could be compared to whales previously seen that summer to speed up the matching process. This reduced the amount of time required for matching because it was no longer necessary to compare every whale seen each day to all three of the UVIC catalogs and the CERF catalog, instead each whale only had to be compared to the small catalog from the summer which was matched to the other catalogs as new whales were added. There has been photo ID data collected from Flores Island every year since 1998 which represents the UVIC catalogs. The CERF catalog was from Cape Caution, which is on the mainland of British Columbia just past the northern tip of Vancouver Island and was collected during a similar time period.

The matching process in Canada was fastest when two computers were used along with a printed copy of the UVIC catalog. One computer had the 2010 database open to an individual whale, then the CERF catalog on the other computer, and the printed UVIC catalog were scrolled through page-by-page for matches. When a match was found it was recorded in an Excel spreadsheet. If no match was found, it was assigned a new UVIC identification number.

Because there was no preexisting catalog to use in Mexico, one had to be created. Photographs were first matched for resightings of individuals, and then afterwards, the catalog was created. In order to perform the matching, a folder titled 'unmatched photos' was created in which copies of all the photos were placed for comparison. Two photos were matched at a time. Two photos would be kept open in windows at the bottom of the computer screen in order to compare them to the other photos. The rest of the photos would be scrolled through and examined individually for comparisons in a larger window in the top half of the screen. 401 photos were examined by this method. When a match was found, it would be recorded in an Excel spreadsheet then the photo would be deleted from the 'unmatched photos' folder. Once the matching was finished, this excel spreadsheet was used to create the database by creating an SFS ID number for each individual whale and making a PowerPoint containing all of the
photos of each whale. The PowerPoint was divided into years so that they were small enough files to load quickly.

A 'resighting' was defined as seeing the same whale on a different day than it was originally photographed. Resightings were recorded for both Canada and Mexico.

During the migration, photos were matched for individuals for each excursion in order to account for seeing the same whale twice in the same day. Otherwise, whales were not matched unless there was a reason to believe it was the same whale. Because these whales were undergoing their migration, we were functioning under the assumption that they would not be spending more time in the area than it takes simply to migrate past, and because I was usually only able to collect data once a week, there should not have been instances in which we saw the same whale more than once.

**Body Regions:**

The body regions of each whale were also recorded in the photo ID spreadsheet. Body regions were determined according to the numbering scheme created by Bradford et al (2009), in which regions 1-4 represent the head, regions 5-9 are the back and body, and regions 10-20 are different portions of the tail (see figure 4).

![Figure 4: Labeling of Body Regions (Adapted from: Bradford et al 2009).](image-url)
Injury Types:

There were several types of injuries observed in the whales. Table 1 defines the types of injuries scored. Rake marks caused by killer whales are defined as a series of three or more parallel scars that are an even distance of ~2.5 – 5 cm apart (George 1994). These injuries and the body region in which they occurred were recorded in the same photo ID spreadsheet as the previous data. There were no injuries that were conclusively determined to have been caused by sharks; therefore we were unable to examine the prevalence of shark wounds.

Table 1: Descriptions of Injury Types

<table>
<thead>
<tr>
<th>Injury Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scar</td>
<td>Scratch or Scar on body or fluke</td>
</tr>
<tr>
<td>Rake</td>
<td>Set of 3 or more parallel scars caused by attack from a killer whale</td>
</tr>
<tr>
<td>Wound</td>
<td>Serious injury involving: a) cut longer than 1 meter, b) injury deeper than 10 cm, or c) scars covering a surface area ≥ 30 cm² (Kraus 1990)</td>
</tr>
<tr>
<td>Fluke</td>
<td>Flukes missing tips, or with pieces of flesh missing (injuries on flukes that do not fall into another category – no rake marks present)</td>
</tr>
<tr>
<td>Entanglement</td>
<td>Scar around caudal peduncle caused by fishing gear</td>
</tr>
<tr>
<td>None</td>
<td>No observed injury of any sort</td>
</tr>
</tbody>
</table>

Figure 5: Examples of Injury Types. Photographs from UVIC and CERF photo ID catalogs.

Injury Comparison:
In order to estimate the mortality of Eastern Pacific gray whales due to anthropogenic sources (ship strike and entanglement), the results of this study were compared to those found by Nelson et al (2007), and Jensen and Silber (2004). Nelson et al (2007) found that out of 417 events involving large whales, there were 151 (36.2%) entanglements, and 42 (10.1%) ship strikes. Of the 151 observed entanglements, 26 (17.2%) were determined to be the cause of death. Similarly, of the 42 known ship strikes, 27 (64.3%) were fatal. In another study by Jensen and Silber (2004) it was found that out of a total of 292 recorded ship strikes, 68% were fatalities for the whale, 16.4% resulted in injury, 2.4% had no obvious injury, and the results of the rest of the strikes were unknown. The percents of injury vs. fatality found in these two studies were compared to the injury percent for either entanglement or wound (which was assumed to be caused by ship strike) using a ratio to estimate the mortality from those injuries.

Statistics:

Data were primarily analyzed by creating the averages and percentages of injuries in each region. The main statistical method used was a $\chi^2$ test to determine significance in the differences between the locations of different types of injuries, or the different numbers of various types of injury. This test was performed to see if a specific region was more susceptible to a certain type of injury. The calculated values were then compared to the table at: http://www2.iw.psu.edu/irp/chisquar.html to determine significance.
Results:

Photo ID:

Data were collected in Mexico in 1998, 1999, 2003-2005, 2007, 2009, and 2010. Many more photographs were collected than could be used for photo ID due to their poor quality. Out of a subset of four of the years of data collected at SFS (2004, 2007, 2009, and 2010), there were 898 photos collected, of which 235 (26%) were actually useable. From all years combined, a total of 571 photographs were used for matching individuals and compiling the catalog from SFS. There were a total of 325 whales in the catalog, showing that there was an average of 1.76 photographs of each whale. There were between 3 and 96 individual whales identified in each year. There were no resightings of whales from Mexico between years, however within years there were 24 resightings.

In Canada, there were 14 photo ID transects performed during the time of my visit (12 July to 28 August 2010), and a total of 37 whales were observed throughout the summer. There was an average of 13.14 (±5.14) whales observed on each transect (minimum = 4, and maximum = 20). Each whale was observed on an average of 5.14 (±3.1) separate days (minimum = 1, and maximum = 12). Overall, 18 of 37 (48.6%) whales observed during the summer of 2010 had been previously photographed and included in the UVIC and CERF catalogues. I was unable to calculate the percent of photographs useable for this location as I only had access to the catalogs and not the raw photos.

There were a total of 8 days in which I collected photo ID data in California between January 15th and March 13th 2011. There were 19 whales seen, and 11 of those were photographed. I collected a total of 171 photographs of gray whales, of which 62 (36.25%) were useful.
In total, there were 272 whales identified in the catalog from Canada, 325 from Mexico, and 11 in California. This brings the total number of whales examined throughout the study to 608 individuals.

**Body Regions:**

As can be seen in figure 6, the back and sides of the whales (regions 5 to 9) are the most frequently photographed. Body regions 1-4 (the head) are not kept in the catalogs, therefore were not examined for injuries.

![Figure 6: Photograph Coverage of each body region. Body regions that correlate to the back and sides are shown by black bars, and those that are the flukes are represented by hollow bars.](image)

**Injury Types:**

There were a total of 146 injuries observed in 134 whales. There were 10 whales that had two types of injuries, and one that had three. Nine of the whales with multiple injuries were photographed in Canada, and one was in California. There was a higher percentage of whales with injuries found in Canada (29%) than in Mexico (15.4%). The highest percent of injuries, however, was observed in California where 54.5% of the whales had injuries. Overall 22.0% of the whales have injuries, however because 'fluke' and 'entanglement' injuries are specific to
certain body regions, they are underrepresented when compared to the total number of whales. The data in table 2 presents the numbers and percents of whales exhibiting each type of injury, however the numbers of individuals for whom fluke and peduncle photos were obtained was taken into account when calculating the percentages for fluke and entanglement injuries by using the number of individuals for which the fluke or peduncle was observed instead of the overall number of total whales.

Table 2: Types and numbers of injuries found on gray whales. Total number of individuals was 608; fluke photos obtained for 156 individuals and peduncle photos for 36 individuals.

<table>
<thead>
<tr>
<th>Injury Type</th>
<th>Mexico</th>
<th>Canada</th>
<th>California</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scar</td>
<td>34</td>
<td>39</td>
<td>6</td>
<td>79</td>
<td>13.0</td>
</tr>
<tr>
<td>Rake</td>
<td>9</td>
<td>28</td>
<td>1</td>
<td>38</td>
<td>6.3</td>
</tr>
<tr>
<td>Wound</td>
<td>3</td>
<td>6</td>
<td>0</td>
<td>9</td>
<td>1.5</td>
</tr>
<tr>
<td>Fluke</td>
<td>4</td>
<td>13</td>
<td>0</td>
<td>17</td>
<td>10.9</td>
</tr>
<tr>
<td>Entanglement</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>8.3</td>
</tr>
<tr>
<td>None</td>
<td>275</td>
<td>194</td>
<td>5</td>
<td>474</td>
<td>78.0</td>
</tr>
</tbody>
</table>

Injury Locations:

Because fluke and entanglement injuries were only observed to occur on the fluke and peduncle respectively, they were not analyzed for location. Scars, rake marks, and wounds were analyzed for difference in location between the body and the tail. After performing a chi squared test, it was found that there were significantly more rake marks on the tail than on the body ($\chi^2=17 \ p<0.001$), but there was no difference in the locations of scars ($\chi^2=0.1 \ p>0.7$) or wounds ($\chi^2=0.4 \ p>0.5$) when compared between the body and the flukes.

A chi squared was also performed to determine if there were more injuries on the right or the left side of the body. It was discovered that there were significantly more injuries on the left side of the whales than on the right ($\chi^2=4.5 \ p<0.05$).
Figure 7: Percent of each body region displaying injury and the types of injury observed.

Injury Comparison:

Jensen and Silber (2004) found that 16.4% of whales struck by ships survived and had injuries afterward; and 67.8% died on impact, and the remaining whales were either uninjured or their fate was unknown. Therefore, assuming that the ratio of survival vs. fatality is similar for gray whales, the following ratio was used to find the percent of gray whales expected to die from ship strikes given the percent that had injuries (1.5%).

\[
\frac{0.678}{0.164} = \frac{X}{0.015}
\]

\[
X = (0.678 * 0.015) / (0.164) = 0.062 \Rightarrow 6.2\% \text{ fatality}
\]

Expected mortality rates from both entanglement and ship strike were also found using the results from Nelson et al (2007) in which 17.2% of whales that stranded with entanglement wounds were conclusively determined to have died from those wounds, and 64% of whales with evidence of ship strikes died from those strikes. Because 17.2% died from entanglement, I assumed that 82.8% survived entanglements, and because 64.3% of ship strikes were fatal,
then 35.7% were not. Similar ratios were set up as shown above, and the results were an expected mortality rate of 2.7% from ship strikes, and 1.7% from entanglement.

\[ X = \frac{(0.643 \times 0.015)}{0.357} = 0.027 \Rightarrow 2.7\% \text{ fatality from ship strike} \]

\[ X = \frac{(0.172 \times 0.083)}{0.828} = 0.017 \Rightarrow 1.7\% \text{ fatality from entanglement} \]
Discussion:

Photo ID:

There were more resightings observed in Canada than in Mexico. This is likely because the whales in Canada belong to a small subset of the overall population that consists of roughly 180 individuals (Calambokidis et al 2002). The number of whales in Bahía Magdalena is much larger, at about 10% of the population or 1,700-2,200 whales (Pérez-Cortés et al 2004). Therefore, it is not surprising that there were more individuals resighted in Canada.

There was also a greater percent of injured whales observed in the UVIC and CERF catalogs than in the SFS catalog. I suspect that this is because the photos from Canada were of higher quality than those from Mexico. This is likely because there has been dedicated photo ID effort in Canada since 1998 by professional researchers or well-trained student assistants using high quality cameras owned by the lab. Photographs in Mexico, however, were collected by untrained students using their own personal cameras, many of which were point and shoot, which are insufficient to collect high quality photo ID images unless the whale is very close.

In California, there was a much higher percent of individuals observed with injury; however I am unable to draw conclusions because of the very small sample size of individuals photographed there.

Body Regions:

As can be seen in figure 7, there are more photographs of the right side of the body. This is because the right side of the whale was the target for photo ID in Mexico for most of the years in which data was collected. In Canada, both the right and left sides of the body were targeted as well as the flukes. The UVIC catalog kept photographs of both the dorsal and ventral sides of the fluke, and the CERF database only had photos of the ventral side. This explains why regions 10 and 11 (the dorsal side of the fluke) have fewer photos than the rest of the regions of the tail. Because the whales do not fluke every time they dive, it is expected that
there will be fewer fluke photos than body pictures. This correlates to what was found by Bradford et al (2009), in which the body was observed more frequently than the tail.

Injuries:

1.5% of the whales were observed to have sustained wounds, all of these were probably due to being struck by boats or ships, and 8.3% of the whales had entanglement, bringing the total for all anthropogenic injuries to at least 9.8%. Natural injuries affected about 30% of the whales.

Overall, the percents of injuries found in this study are slightly lower than those found in other studies of cetacean injuries (Table 3). Bradford et al (2009) found higher percentages of entanglement and ship strikes among Western Pacific Gray Whales, and Kraus (1990) found that there were much higher percentages of North Atlantic right whales displaying entanglements, ship strikes, rake marks and scars. Because the populations of both the Western Pacific gray whale and North Atlantic right whale are very small, and found off the coasts of areas with very dense human habitation (Japan and the East Coast of the US), I do not find it surprising that these populations show higher proportions of anthropogenic interactions. It seems, however, that the right whale should have a similar incidence of rake marks and scars as the eastern gray whale. The increased observance of wounds with the right whales could simply be due to the fact that there are only ~300 whales in that population (Kraus 1990) and there has been a huge amount of effort dedicated to developing a high quality photo ID database for them that includes every animal. If they are able to obtain photographs of all body regions more often, then it makes sense that they see injuries in a higher number of the whales.
Table 3: Comparison of Injuries found in different studies. The ‘wound’ category was changed to ‘ship strike’ under the assumption that most wounds are caused by ship strikes. Bold is my data, 1Bradford et al 2009, 2Kraus 1990, 3George et al 1994, 4Nelson et al 2007.

<table>
<thead>
<tr>
<th>Injury Type</th>
<th>E. Pacific Gray Whale</th>
<th>W. Pacific Gray Whale 1</th>
<th>N. Atlantic Right Whale 2</th>
<th>Bowhead Whale 3</th>
<th>E. Coast Strandings 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entanglement</td>
<td>8.3</td>
<td>18</td>
<td>57</td>
<td>NA</td>
<td>36.2 (17.2)</td>
</tr>
<tr>
<td>Ship Strike</td>
<td>1.5</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td>10.1 (64.3)</td>
</tr>
<tr>
<td>Rake</td>
<td>6.3</td>
<td>NA</td>
<td>9</td>
<td>8</td>
<td>NA</td>
</tr>
<tr>
<td>Scar</td>
<td>13.0</td>
<td>NA</td>
<td>30</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

The bowhead whales live in the Arctic Ocean, therefore I would expect less ship traffic, and this is indeed what we see. Their incidence of ship strikes is the lowest observed between these studies. The bowheads also fall within a similar range in terms of rake marks as well.

Nelson et al (2007) found that minke, humpback, right, fin, sei, bryde's, and blue whales were all susceptible to entanglements and ship strikes. The results of their study are all for whales that died and were found either washed up on a beach or floating in the ocean, therefore the numbers are presented differently in the last column of table 3. The first numbers represent the percent of stranded whales that exhibited that particular type of injury, and the numbers in parenthesis are the percent of the animals with that injury that were conclusively determined to have died from those injuries. Kraus (1990) estimated mortality rates from entanglement and ship strikes for the North Atlantic right whale to be 4.3% and 19% respectively. The difference between the results of these three mortality studies examined is that Jensen and Silber's results (2004) are the mortality rates after the whale has sustained the injury, and Nelson et al (2007) and Kraus' (1990) results are for the overall population. From applying these results to the gray whales there would be an additional ~3-6% of gray whales expected to die from ship strikes and ~2% from entanglement throughout the Eastern Pacific population.
Injury Locations:

Rake marks were found most often on the flukes of the whales as opposed to the back. I would expect this to be because when the killer whale attacks a gray, the easiest parts to bite are the flukes and the flippers. However, no flipper photos were collected during this study, so I cannot compare to that location. I hypothesize that a large portion of the whales observed with rake marks either acquired them when they were calves and survived the attack, or the whales are mothers who were trying to protect their offspring during an attack.

If wounds are caused by being struck by a boat or ship, then I would expect to see more wounds on the back than on the flukes. However, there was no statistical difference between locations of wounds between the back and flukes. I believe this is primarily due to the small sample size (9 wounds observed).

Because scars have no single source, I am not surprised that they are found in equal distribution throughout the body. I expect that many of the scars on gray whales are caused by collisions with the bottom substrate of the ocean due to their feeding behaviors.

Conclusions:

Because the population of the eastern pacific gray whale is so large (17-22,000 individuals), I suspect that anthropogenic injuries do not represent a significant threat for the continued existence of the population. At least 13% of the whales have survived anthropogenic interactions, and an estimated 3-6% have died from them. This is much less than the 20% of Western Pacific gray whales and the 64% of North Atlantic right whales that have survived such injuries. I expect that anthropogenic injuries represent more of a threat for smaller populations such as the Western Pacific gray whale (~121 individuals, Bradford et al 2009), the North Atlantic right whale (~300 individuals, Caswell et al 1999), and the vaquita (~224 individuals, Agrose et al 2000). Although anthropogenic injuries may not represent a significant threat to the continued existence of the Eastern Pacific population of gray whales, care should still be taken to minimize the incidence of harming the whales. The projected mortality rates of 2-6% would
not likely cause the population to collapse, however they could determine if the population is slowly growing or shrinking.
Future Research:

I am continuing to go on whale watching boats during the northward migration, which is currently ongoing. I am using the same methods and trying to expand the photo ID database from the migratory route. I will also be going to Cascadia Research Collective (CRC) in June in order to examine their gray whale photo ID database to get a larger data set for injury comparisons. The CRC database has roughly 1,000 gray whales; therefore it would greatly increase the amount of data that I have available to analyze. I will also be returning to Flores Island this summer in order to continue the database and the injury research.

I would like to compare the databases from Canada, Mexico, and California to see if there are matches of individuals. I will also be examining a catalog of the Western Pacific gray whales and comparing it to the Eastern Pacific catalogs that I already have in order to determine how much crossover there is between the populations. Comparisons of microsatellite frequencies have shown that the two populations are genetically distinct; however it appears that there could potentially be a small amount of male dispersal between populations (Lang et al 2009). A few months ago a whale from the Western Pacific population was satellite tagged and tracked as it migrated from the Western Pacific (Russia) to the Eastern Pacific (Washington) (Mate http://mmi.oregonstate.edu/Sakhalin2010). This whale was then matched to a whale in the CRC catalog (Calambokidis http://www.cascadiaresearch.org/FLEX_match.htm). I would like to see if there are more whales that cross over between populations.
Acknowledgements:

I would like to thank Dr. Lei Lani Stelle for being a great help during this project, and also Dr. Eduardo Najera-Hillman for selecting me to work with him on gray whales and getting me started. I would also like to thank all the students, researchers, and volunteers who have contributed photographs to the various databases throughout the years. In addition, Dr. William Megill and Benjamin Williamson were very helpful with the labVIEW program used to crop the photos.
References:


Western and Eastern (*Eschrichtius robustus*) gray whale populations using microsatellite markers. SC/62/BRG11


