HUMPBACK WHALE (*MEGAPTERA NOVAEANGLIAE*) ENTANGLEMENT IN FISHING GEAR IN NORTHERN SOUTHEASTERN ALASKA

By

Janet L. Neilson

RECOMMENDED:

Christine M. Gabriele

Janice M Straley

Susan Hills
Advisory Committee Chair

Thomas Weingartner
Head, Program in Marine Science and Limnology

APPROVED:

Dean, School of Fisheries and Ocean Sciences

Susan M. Henrichs
Dean of the Graduate School

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Date

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A

THESIS

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By
Janet L. Neilson, B.S.

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Abstract

The prevalence of non-lethal entanglements of humpback whales (*Megaptera novaeangliae*) in fishing gear in northern southeastern Alaska (SEAK) was quantified using a scar-based method. The percentage of whales assessed to have been entangled ranged from 52% (minimal estimate) to 71% (conditional estimate) to 78% (maximal estimate). The conditional estimate is recommended because it is based solely on unambiguous scars. Eight percent of the whales in Glacier Bay/Icy Strait acquired new entanglement scars between years, although the sample size was small. Calves were less likely to have entanglement scars than older whales and males may be at higher risk than females. The temporal and spatial distribution of commercial fisheries is complex and difficult to correlate with these results. The percentage of whales with entanglement scarring is comparable to the Gulf of Maine where entanglement is a substantial management concern. Consequently, SEAK humpback whale-fisheries interactions may warrant a similar level of scrutiny.

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Introduction

Entanglement of marine mammals in fishing gear has been documented widely and may affect a significant proportion of some populations of baleen whales (Kraus 1990; Lien 1994; Volgenau *et al*. 1995; Knowlton and Kraus 2001; Robbins and Mattila 2001, 2004; Knowlton *et al*. 2005). In recent years an increasing number of humpback whales (*Megaptera novaeangliae*) has been reported entangled in Alaska according to unpublished data from the National Oceanic and Atmospheric Administration (NOAA) Fisheries Alaska Regional Office. There have been no systematic efforts to quantify the problem, although reports of entangled whales are compiled by NOAA Fisheries in a stranding database. In 2001, NOAA Fisheries acknowledged the pressing need for a detailed assessment of humpback whale entanglement in Alaska.[1] The goal of this thesis is to elucidate the prevalence of non-lethal entanglements and the distribution of commercial fisheries in northern southeastern Alaska (SEAK) with the ultimate goal of informing management discussions of the entanglement issue for the Central North Pacific (CNP) stock of humpback whales.

Population size and status of humpback whales in Alaska

The humpback whales in Alaska are part of the CNP stock, mainly wintering in the Hawaiian Islands and migrating in the summer to northern British Columbia and Alaska west to Unimak Pass (Baker *et al*. 1990; Perry *et al*. 1990; Calambokidis *et al*. 1997, 2001). Like all stocks in U.S. waters, this stock is listed as endangered under the U.S. Endangered Species Act (ESA) and as depleted under the U.S. Marine Mammal Protection Act (MMPA). The most recent population estimate for the CNP stock based on photo-identification data was 4,005 whales (CV = 0.095) in 1993 (Calambokidis *et al*. 1997) with a current rate of increase of 7% per year (Mobley *et al*. 2001).

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[1] Unpublished presentation by Kaja Brix, NOAA Fisheries Alaska Regional Office, PO Box 21668, Juneau, AK 99802, to the Marine Mammal Commission, 2001.

Within Alaska, seasonal aggregations of feeding humpback whales from the CNP stock form in several areas including SEAK, Prince William Sound, Kodiak and the Shumagin Islands (Baker *et al*. 1986; Calambokidis *et al*. 1997, 2001; Waite *et al*. 1999; Witteven *et al*. 2004). These aggregations are relatively isolated with minimal interchange documented among feeding areas (Baker *et al*. 1986; Waite *et al*. 1999; Calambokidis *et al*. 1997, 2001). For example, out of 287 whales photographically identified in SEAK between 1991 and 1993, only three individuals were re-sighted in other feeding areas in Alaska (Calambokidis *et al*. 2001). Based on the discreteness of the SEAK feeding aggregation, NOAA Fisheries is considering formally designating these whales as a separate stock under the MMPA (Angliss and Outlaw 2005).

Many of the whales in SEAK show a high level of fidelity to relatively small summer feeding areas such as Glacier Bay or Sitka Sound (Straley 1994; Straley *et al*. 2002). Using data collected in Glacier Bay, Sitka Sound and Frederick Sound from 1994 through 2000, Straley *et al*. (2002) estimated that 74% – 81% of the whales returned to the same feeding area.

The most recent population estimate for northern SEAK was based on photo-identification data and yielded an estimate of 961 (95% CI: 657, 1,076) individuals in 2000 (Straley *et al*. 2002). This is considered a minimum population estimate for SEAK because no data were collected in southern SEAK (Straley *et al*. 2002).

Legal mandates regarding marine mammal-fisheries interactions in the U.S.

The 1994 amendments to the MMPA (16 U.S.C. 1361 *et seq.*) define a framework for determining when the number of marine mammals seriously injured or killed incidental to commercial fishing operations jeopardizes the sustainability of a stock. The process involves estimating the maximum number of animals (not including natural mortalities) that may be removed annually from a marine mammal stock while still allowing the stock to reach or maintain its optimum sustainable population size. This threshold, known as the Potential Biological Removal (PBR), is calculated from the species' estimated population size, net productivity rate and status under the ESA (50 CFR 229.2).

Although it is one of management's key driving forces, a 'serious injury' is defined vaguely as "[a wound or other physical harm] that will likely result in mortality" (50 CFR 229.2). In the absence of a more specific definition for serious injury, each humpback whale entanglement in fishing gear is assessed by a panel of experts on a case-by-case basis to determine if the whale's injuries were likely to be fatal.[2] The estimated number of serious injuries is then added to the number of confirmed mortalities to determine if PBR for the stock has been exceeded.

If PBR is exceeded, the MMPA mandates that a take reduction plan (TRP) be developed to determine ways to reduce the serious injury and mortality rate to below PBR within six months. Within five years of the implementation of the TRP, the number of marine mammals seriously injured or killed incidental to commercial fishing operations is to be reduced to "insignificant levels", defined as less than 10% of PBR, which is called the Zero Mortality Rate Goal (ZMRG).

Initially, the PBR framework was established to address serious injuries and mortalities resulting from commercial fisheries interactions, but it has evolved to incorporate other human-caused serious injuries and mortalities (*e.g.*, ship strikes, subsistence/sport fisheries interactions, etc.). However, there is no systematic effort to monitor non-commercial fishery related takes (National Research Council 2005) and they are not addressed through the TRP process.

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[2] Personal communication from Robyn Angliss, National Marine Mammal Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115, April 2005.

As an integral part of the PBR framework, NOAA Fisheries must categorize all U.S. commercial fisheries annually based on the level of serious injury and mortality of marine mammals caused by each fishery (16 U.S.C. 1387 (c)(1)). Category I fisheries are those in which the amount of annual serious injury and mortality of a marine mammal stock is greater than or equal to 50% of PBR; Category II fisheries are those in which the amount of annual serious injury and mortality of a marine mammal stock is greater than 1% and less than 50% of PBR; and Category III fisheries are those in which the amount of annual serious injury and mortality of a marine mammal stock is less than or equal to 1% of PBR.

Owners of vessels or gear involved in Category I or II fisheries are required to register with NOAA Fisheries and obtain authorization to take marine mammals incidentally. If requested by NOAA Fisheries, participants in Category I and II fisheries are required to accommodate observers onboard their vessels to monitor incidental mortality and injury of marine mammals (50 CFR 229.7). Observers may be placed on vessels participating in Category III fisheries if there is evidence that the fishery is causing "immediate and significant adverse impact" on a threatened or endangered marine mammal species (50 CFR 229.7). Vessel owners or operators engaged in any commercial fishery (Category I, II or III) must report all mortalities and/or injuries of marine mammals that occur in the course of commercial fishing operations (50 CFR 229.6).

Applying the MMPA to humpback whale-fisheries interactions in SEAK

Currently, PBR for the SEAK portion of the CNP stock of humpback whales is 3.0 whales per year (Angliss and Outlaw 2005). If this PBR were exceeded, then the ZMRG would be 0.3 whales per year. The only Category I commercial fisheries that have been identified within the typical annual range of SEAK humpback whales are the Hawaii longline/set line fisheries for broadbill swordfish (*Xiphias gladius*), tuna (*Thunnus* sp., *Katsuwonus pelamis*), billfish (*Makaira* sp., *Istiophorus* sp., *Tetrapturus* sp.), mahimahi (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*) and oceanic sharks (primarily

Prionace glauca). These fisheries are classified as Category I primarily due to interactions with false killer whales (*Pseudorca crassidens*). Two Category II commercial fisheries have been identified within the typical annual range of SEAK humpback whales: the SEAK salmon drift gillnet fishery and the SEAK salmon purse seine fishery. These fisheries are classified as Category II based on the cumulative serious injury and mortality to multiple marine mammal stocks, including humpback whales. All other commercial fisheries in SEAK and Hawaii with which SEAK humpback whales are likely to interact are classified as Category III fisheries.

Based on a multi-year average of Alaska-Hawaii federal fishery observer program data, self-reported commercial fisheries records and Alaska-Hawaii stranding records, the serious injury and mortality rate incidental to commercial fisheries in SEAK is estimated to be 2.7 whales per year (Angliss and Outlaw 2005). While this rate is considered an underestimate because not all entangled whales are found or reported, it may also be an overestimate because 1) any serious injury or mortality in which the gear type could not be determined is counted as a commercial fisheries interaction[3] and 2) all records from Hawaii are counted, even though some of the whales may have come from feeding grounds other than SEAK. Omitting the Hawaii records yields a serious injury and mortality rate incidental to commercial fisheries of 1.65 whales per year. Regardless of which rate is more accurate for SEAK, neither exceeds the PBR of 3.0 whales per year but both exceed the ZMRG of 0.3 whales per year.

From a management perspective, an accurate measure of the serious injury and mortality rate due to fisheries interactions in SEAK is clearly needed but difficult to obtain. The remoteness of the Alaska and northern British Columbia coastline and the rarity with which humpback whale carcasses are found and reported[4] make it difficult to examine

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[3] Personal communication from Robyn Angliss, National Marine Mammal Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115, September 2005.

[4] Personal communication from Jan Straley, University of Alaska Southeast, 1332 Seward Ave., Sitka, AK 99835, October 2003.

dead humpback whales for evidence of lethal fisheries interactions. Alternatively, if every live entangled whale or piece of lost fishing gear were found and tracked, then accurately calculating the rate of lethal entanglements might be possible, but the cost and effort required to undertake this level of monitoring are prohibitive.

In the absence of more comprehensive data, reports of live entangled whales provide much of the information that managers use to gauge the level of serious injury and mortality incidental to commercial fisheries in SEAK. Assessing whether or not an entangled whale's injuries are likely to be fatal is subjective, especially with the incomplete information that accompanies most reports. The quality of an assessment improves with the experience level of the person conducting the assessment; those with more experience disentangling whales are generally better at interpreting whether an entangled whale's injuries are likely to be fatal over time. Some whales are able to self-release (*i.e.,* shed the entangling gear without human intervention) but the factors that allow them to do so are poorly understood. Every entanglement is potentially lethal when the whale first becomes entangled because the nature of each entanglement continuously changes as the whale attempts to free itself, the gear shifts and/or the animal grows. In addition, an entangled whale with trailing gear is susceptible to snagging more gear. Unless all of the gear is removed from the whale, an entanglement assessed on one day as minor may evolve into a serious injury or mortality.

Assessments of entangled whales are further complicated by the fact that extensive external injuries are not always present in entangled humpback whales that eventually die (Robbins and Mattila 2004). Superficially, entangled animals may appear healthy, but chronic exposure to stress in cetaceans (such as the stress presumably induced by an entanglement that is not immediately lethal) may cause an imbalance in metabolic regulation which can lead to death (Angliss and Demaster 1998).

A scar-based approach to assessing non-lethal entanglements

A more feasible approach for assessing the magnitude of fisheries interactions in a stock is to examine living humpback whales for evidence that they have been entangled previously. This approach was pioneered in the western North Atlantic where researchers studying northern right (*Eubalaena glacialis*) and humpback whales noted that wounds resulting from entanglements may remain visible as distinct scars long after the entanglement event (Kraus 1990; Robbins and Mattila 1999, 2001, 2004; Knowlton and Kraus 2001; Knowlton *et al*. 2005). Photographic studies of entanglement scars offer the opportunity to non-invasively sample a large number of animals to make inferences about the frequency of entanglements in a population on a cumulative and annual scale.

The short- and long-term biological implications of non-lethal entanglements are unknown and presumably vary depending on the severity of the incident. Female humpback whales in the Gulf of Maine that survived being entangled were less likely to be lactating than females that had not been entangled, suggesting that non-lethal entanglements may have an impact on reproductive success (Robbins and Mattila 2001). However, the short length of the study period may have confounded this analysis (Robbins and Mattila 2001).

A study of 30 humpback whale entanglements documented in the western North Atlantic revealed that 53% of the whales had gear attached at the posterior caudal peduncle (the narrowing of the body at the insertion point of the flukes), 43% had gear attached at the mouth and 4% had gear attached at the flipper(s), body or the exact location was unknown (Johnson *et al*. 2005). Although entanglements often involved multiple body parts, 30% involved only the caudal peduncle and 20% involved only the mouth (Johnson *et al*. 2005). The propensity for gear to wrap around the caudal peduncle also has been documented in gray whales (Heyning and Lewis 1990) and some right whales (Kraus 1990). Heyning and Lewis (1990) speculated that the gear starts out wrapped further forward on the body, then slips posteriorly where it eventually snags at the base of the flukes. Because whales are often entangled around their caudal peduncles, this is a good place to look for evidence that they have been entangled.

In the Gulf of Maine, Robbins and Mattila (1999, 2001) developed a systematic method to measure the frequency of non-lethal entanglements in humpback whales by assessing high resolution photographs of scarring patterns on living whales' caudal peduncles (although they also included the leading edges of the whales' flukes.) Humpback whales frequently raise their tails as they dive, making the caudal peduncle a relatively easy part of the body to photograph consistently and then examine for wrapping scars, linear notches and other tissue damage consistent with a previous entanglement. After ground-truthing the method with documented entanglements in their study area, Robbins and Mattila (2001, 2004) concluded that 48% – 65% (no variances calculated in original) of the humpback whales photographed annually between 1997 and 2002 in the Gulf of Maine (n = 569) had a high likelihood of having experienced at least one entanglement involving the caudal peduncle. A comparison of photographs of the same individuals between years revealed that 8% – 25% of the whales acquired new entanglement scars each year (Robbins and Mattila 2004). Using a similar scar-based approach, Kraus (1990) concluded that 57% of North Atlantic right whales bear caudal peduncle entanglement scars.

In 2002, Robbins and Mattila (2004) applied the caudal peduncle scar analysis method to humpback whales in Hawaii (n =157) and found that 14% of the animals had a high likelihood of having been entangled (Robbins and Mattila 2004). Based on these results, entanglement of humpback whales appeared to be much more common in the Gulf of Maine than in Hawaii. No comparative data were available for humpback whales in Alaska, although historic photographs collected by Glacier Bay National Park & Preserve (GBNPP) biologists include numerous opportunistic caudal peduncle photographs (Appendix 1). This thesis represents the first systematic attempt to quantify the number of humpback whales in Alaska that have been entangled.

Humpback whale entanglements in Alaska

Prior to 1955, several entanglements of large whales in submarine telecommunications cables were reported in the Pacific Ocean (Heezen 1957), but since the mid-1950s no whales have been documented entangled in submarine cables, presumably due to advances in cable building and laying technology (Norman and Lopez 2002).

Entanglement records were not collected systematically by the NOAA Fisheries Alaska Regional Office until 1997. From 1997 through 2004, 52 humpback whales were reported entangled in fishing nets and/or lines in Alaska (or were reported elsewhere and were confirmed to be entangled in Alaskan fishing gear.) Seventy-seven percent of the reports involved SEAK humpback whales.[5] This could either mean that entanglement rates are higher in SEAK and/or that the reporting rate in SEAK is higher than in more remote coastal areas of the state. The majority of entangled animals in SEAK were reported in July and August (Fig. 1), although temporal patterns in stranding reports are confounded by seasonal changes in the number of boaters/observers on the water.

The majority of the entanglements reported in Alaska have not been documented fully, making it difficult to quantify how often different body parts are involved or how similar the patterns of entanglement are between Alaska and the Gulf of Maine. However, two unusually well-documented entanglements in Alaska involved whales with gear wrapped around the caudal peduncle (Fig. 2, 3) in a manner analogous to what has been documented in the Gulf of Maine.[6] Both whales also had conspicuous wrap marks anterior to the caudal peduncle, indicating that the gear probably started out wrapped farther forward on their bodies and then slipped posteriorly to the location where it was photographed.

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[5] Unpublished data, NOAA Fisheries Alaska Regional Office, PO Box 21668, Juneau, AK 99802.

[6] Personal communication from Jooke Robbins, Provincetown Center for Coastal Studies, PO Box 1036, Provincetown, MA 02657, September 2005.

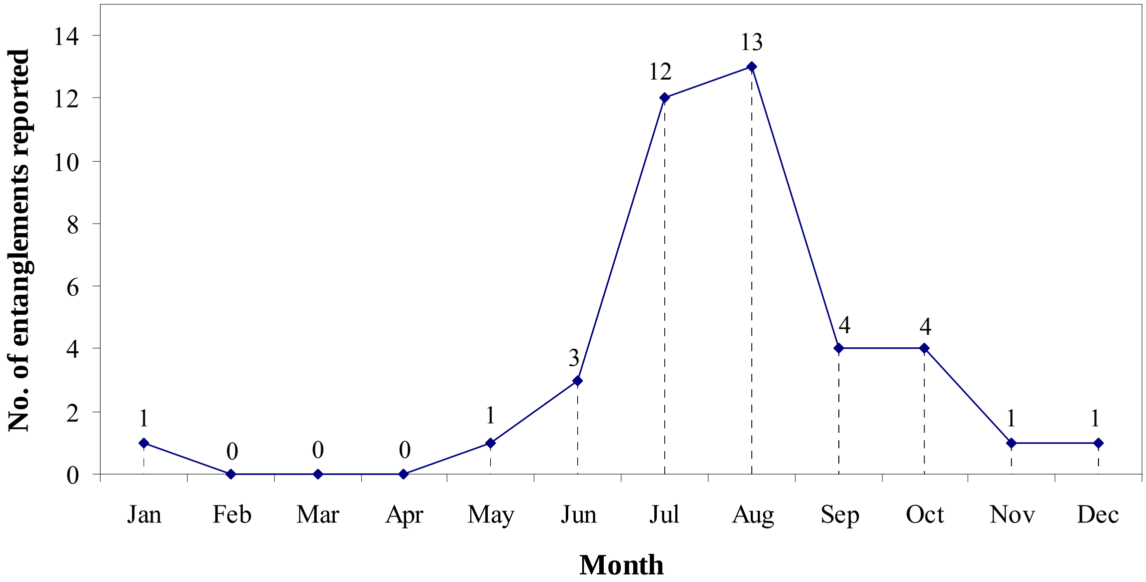

Figure 1. Number of entangled humpback whales by month either reported in SEAK or sighted elsewhere, but confirmed to be entangled in SEAK fishing gear, 1997 – 2004 (*n* = 40).[7]

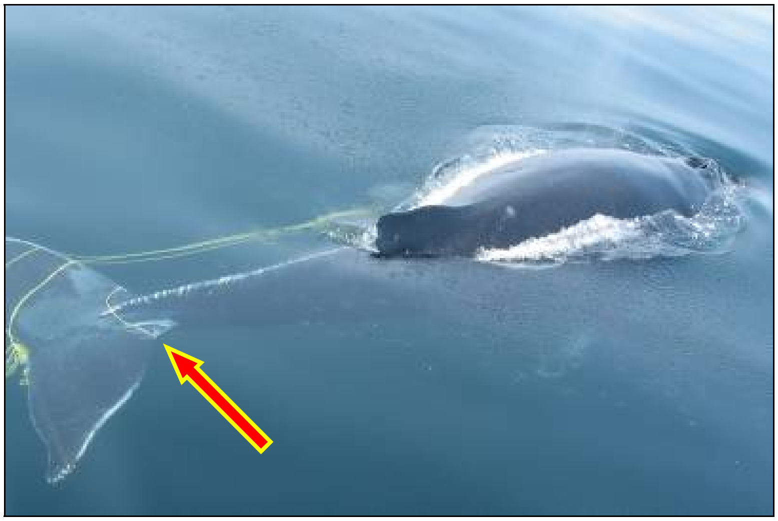

Figure 2. Humpback whale calf with line entangled around its caudal peduncle in Frederick Sound, AK in July 2004. The calf also appears to have line entangled around its left pectoral fin (photo courtesy of John McNally).

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[7] Unpublished data, NOAA Fisheries Alaska Regional Office, PO Box 21668, Juneau, AK 99802.

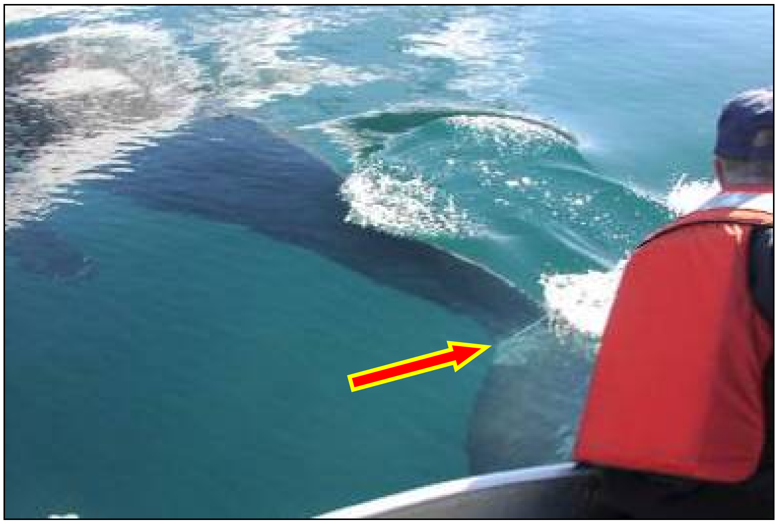

Figure 3. Humpback whale with line entangled around its caudal peduncle near Homer, AK in March 2005 (photo courtesy of NOAA Fisheries Enforcement Officer Jim Wisher).

In 2004, extensive scarring documented on calf #1846's flukes and caudal peduncle (Fig. 4) illustrates the distinct difference between scars created by entangling gear and those

Figure 4. Calf whale #1846 with extensive caudal peduncle and fluke scarring presumed to be from an attack by a killer whale or false killer whale.

created by a predator. The parallel rake marks observed on the calf are consistent with a killer whale (*Orcinus orca)* or false killer whale attack (Naessig and Lanyon 2004). These scars are distinct in several respects from the wrapping marks and linear notch scars characteristic of a previous entanglement. Most notably, the rake marks consist of linear, parallel scars spaced a few centimeters apart (matching the dentition of a killer whale or false killer whale (Naessig and Lanyon 2004)) with no scars wrapping around the caudal peduncle, as would be expected if they had been produced by entangling gear.

When an entangled whale is reported, NOAA Fisheries records the gear type involved in the entanglement based on observations made by the reporting party (Fig. 5). Nearly half

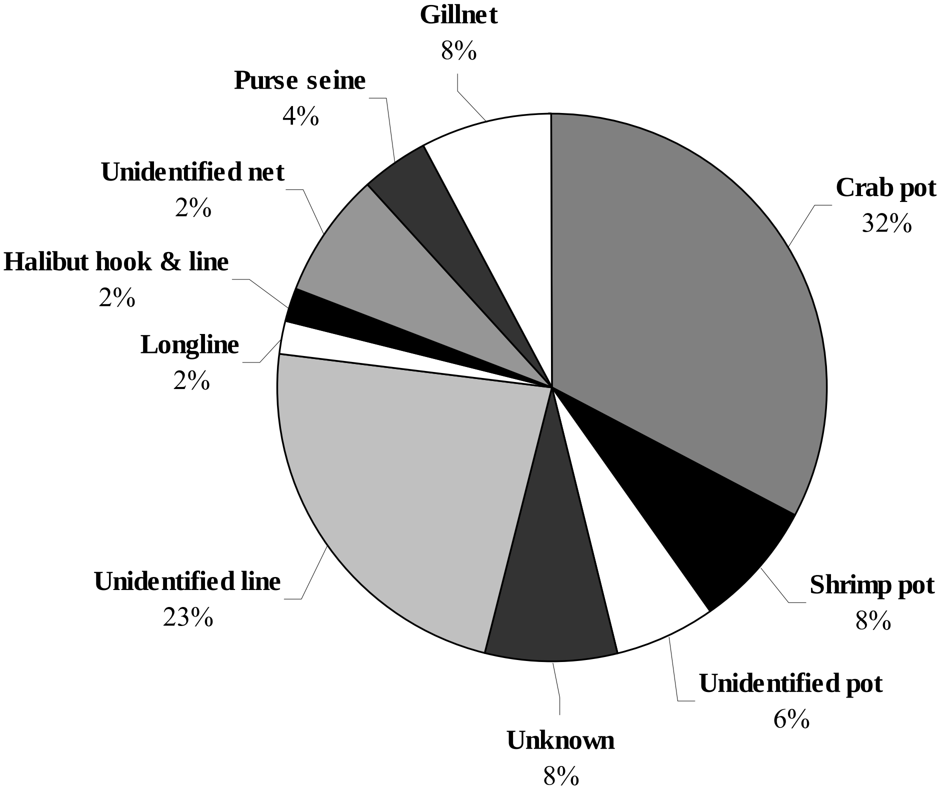

Figure 5. Fishing gear types involved in humpback whale entanglements in Alaska, 1997 – 2004 (*n* = 52).[8]

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[8] Unpublished data, NOAA Fisheries Alaska Regional Office, PO Box 21668, Juneau, AK 99802.

(46%) of all the entanglements reported have involved pot gear (Appendix 2). However, only one pot fishery in Alaska, the Bering Sea sablefish pot fishery, is classified as Category II[9] and it is far from the typical range of SEAK humpback whales. In 48% of all reported entanglements, the whales collided with gear that appears to have originated in Alaska and/or British Columbia (*i.e.*, crab pot, shrimp pot, unidentified pot, sport halibut hook & line).[10] The other gear types (*i.e.,* longline, purse seine, gillnet, various other lines and nets) are used broadly throughout the annual range of humpback whales; thus it is not always possible to pinpoint the geographic origin of these entanglements. Humpback whales sighted around the Hawaiian Islands in winter have been reported entangled in fishing gear originating from Hawaii and Alaska fisheries (Mazzuca *et al*. 1998)[11], and throughout their annual range humpback whales encounter miscellaneous synthetic marine debris of wide geographic origin.

The reliability of gear reports depends on the expertise of the observer and how closely they could examine the gear. Distinguishing between commercial, sport and subsistence fishing gear is often difficult unless surface buoys are marked with information identifying the owner, or the gear is of a variety that is used only commercially (*e.g.,* purse seine). Despite many shortcomings in the gear data, it appears that the fishing gear types most often implicated in entanglements in Alaska (pot gear and gillnets) match the general gear types most often implicated in the western North Atlantic, where 41% of entangled humpbacks (n = 22) were entangled in pot gear and 50% were entangled in gillnets (Johnson *et al*. 2005, also see Lien 1994).

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[9] This fishery was elevated from Category III to Category II on the 2005 List of Fisheries (71 FR 2) based on interactions with the central and western North Pacific stocks of humpback whales (69 FR 231).

[10] From the late 1970s through 1999, a limited entry (15 permits) pot fishery targeting spiny lobster (*Panulirus marginatus*) and slipper lobster (*Scyllarides squammosus*) occurred in the northwestern Hawaiian Islands. The fishery has been closed since 2000 (50 CFR 660).

[11] Unpublished data, NOAA Fisheries Pacific Islands Regional Office, 1601 Kapiolani Boulevard, Suite 1110, Honolulu, HI 96814.

While some entanglements are short-term (lasting only hours or days), others may last months or even years (Robbins and Mattila 2001), confounding attempts to pinpoint the entanglement site. In rare cases, the geographic origin of the fishing gear is unambiguous. For management purposes, NOAA Fisheries assumes that an entanglement occurred where the whale was reported unless the type of gear indicates otherwise (Angliss and Outlaw 2005). An example of the latter occurred in 1997, when the U.S. Coast Guard in Hawaii disentangled a humpback whale from sport crab pot gear that the whale had carried from Juneau, Alaska (Angliss and Lodge 2004)[12], a distance of at least 2,500 mi. Whales may be entangled in multiple gear types, making it difficult if not impossible to implicate a specific fishery as the initial source of the entanglement. For instance, in March 2005 at least 21 different types of lines and nets were identified in a mass of gear weighing >50 lb that was removed from a humpback whale in Hawaii.[13]

The current reporting rate of entanglements in SEAK is certainly an underestimate of the true entanglement rate because it is based upon observed incidents reported to NOAA Fisheries. Each year, whale researchers hear about entangled whales in SEAK from local boaters that are never reported to NOAA Fisheries[14,15] and some entangled whales are likely never observed by humans. In the Gulf of Maine, only 3% of the humpback whales assessed to have been entangled between 1997 and 1999 were reported as entangled whales (Robbins and Mattila 2001). The reporting rate of entanglements to the NOAA Fisheries Alaska Regional Office stranding database is unknown and cannot be calculated because photographic identifications of those entangled whales were not obtained.

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[12] Personal communication from Christine Gabriele, GBNPP, PO Box 140, Gustavus, AK 99826, October 2005.

[13] Unpublished data, Hawaiian Islands Humpback Whale National Marine Sanctuary, 726 South Kihei Road, Kihei, HI 96753.

[14] Personal communication from Fred Sharpe, Alaska Whale Foundation, 4739 University Way NE #1239, Seattle, WA 98105, October 2005.

[15] Personal communication from Jan Straley, University of Alaska Southeast, 1332 Seward Ave., Sitka, AK 99835, October 2005.

Fisheries in SEAK

Fisheries in SEAK include commercial, subsistence and sport fishing gear. A description of the current distribution of fishing gear in SEAK was undertaken to improve understanding of interactions between whales and fisheries and to help inform management actions aimed at preventing entanglements. Quantitative datasets describing the distribution and quantity of commercial, subsistence and sport fishing gear in use in SEAK on a fine geographic scale do not exist. However, unlike subsistence and sport fisheries, most commercial fisheries in SEAK are managed under a limited entry system and harvest levels (lb) are tabulated systematically by management areas. These commercial fishery datasets describing harvest levels by area constitute the only information currently available to approximate the distribution of fishing gear in SEAK. This reality, coupled with the MMPA's focus on commercial fisheries interactions, made commercial fisheries the focus of this study.

Objectives

This thesis describes a study of non-lethal entanglement of humpback whales in fishing gear in northern SEAK. The objectives of the study were to: 1) estimate the percentage of humpback whales in northern SEAK that have been non-lethally entangled using the caudal peduncle scar analysis methods developed by Robbins and Mattila (1999, 2001); 2) analyze the entanglement scar data in conjunction with existing long-term humpback whale demographic data to identify any particularly vulnerable segments of the humpback whale population; and 3) describe the distribution of scarred humpback whales in relation to the distribution and amount of commercial fishing in the study area.

Methods

Study area

The main study area encompassed the near shore waters of northern southeastern Alaska, approximately 57° – 59° North latitude (Fig. 6). This region is characterized by an extensive network of glacial fjords, bays, channels and inlets surrounded by temperate rainforest. The primary survey areas were Glacier Bay, Icy Strait and Frederick Sound. In addition, lower Lynn Canal, Chatham Strait, Seymour Canal, Peril Strait and Sitka Sound were surveyed.

Whale surveys and data collection

Data collection in Glacier Bay and Icy Strait occurred concurrently with humpback whale surveys conducted as part of a long-term humpback whale monitoring program sponsored by GBNPP. These surveys occurred approximately four to five days per week from June 1 – August 31 in 2003 and 2004, and one to two days per week in May, September, October and November 2003 and 2004. Other parts of northern SEAK were surveyed intermittently, with most of the effort occurring during two 10-day surveys in August 2003 and August 2004. Christine Gabriele (GBNPP), Betsy Wilson (Southeast Alaska Wilderness Exploration, Analysis and Discovery) and Jan Straley (University of Alaska Southeast) assisted with whale surveys and data collection.

Survey effort was summarized according to Alaska Department of Fish and Game (ADF&G) salmon and shellfish fishery statistical area districts (Fig. 7), hereafter referred to as ADF&G districts. These units of area were chosen because 1) the majority of reported humpback whale entanglements in SEAK involve gear from shellfish and salmon fisheries (*i.e.*, pot gear and gillnets), and 2) organizing the data by ADF&G district allows for comparisons of the percentage of whales with entanglement scars in each district with relative levels of fishing in each district. The ADF&G districts that overlap with the study area are: District 9 (‘eastern Frederick Sound’), District 10

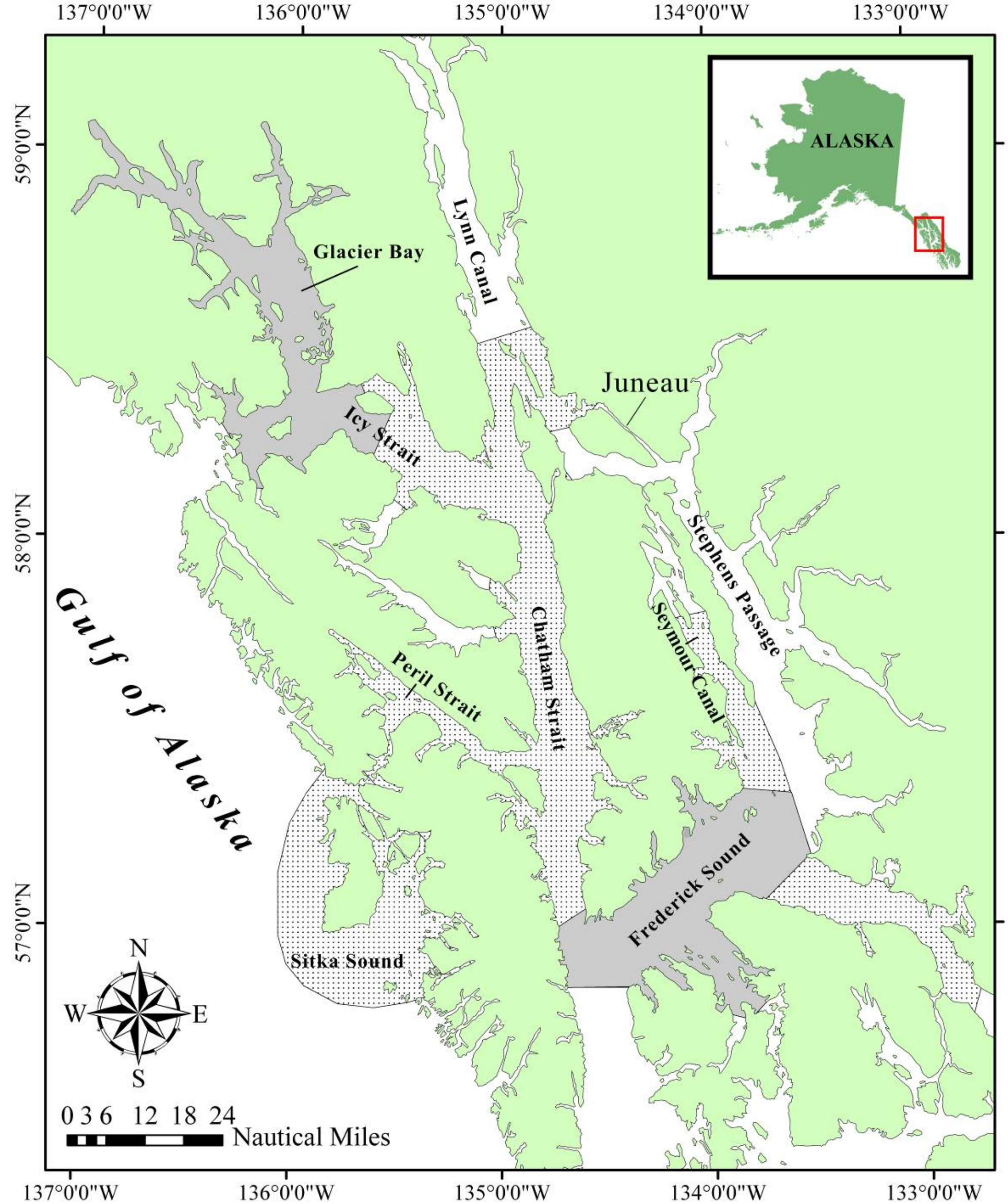


Figure 6. Map of the study area in northern SEAK. Data were collected in the stippled and shaded areas in 2003 and 2004. The primary survey areas are shaded.

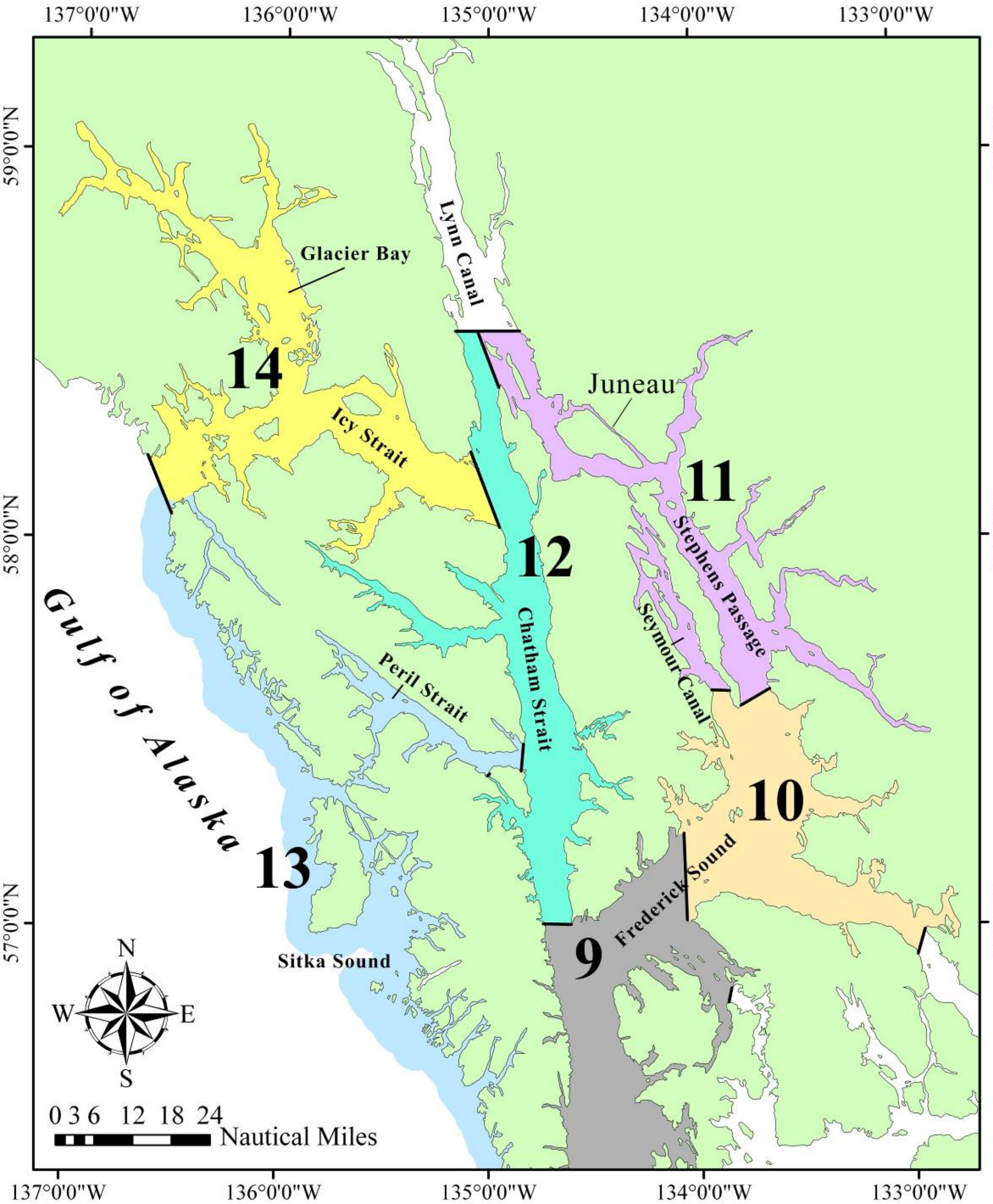


Figure 7. ADF&G salmon and shellfish fishery statistical area districts ('ADF&G districts') that overlap with the study area. Each district is indicated in color and numbered.

(‘western Frederick Sound’), District 11 (‘Stephens Passage’), District 12 (‘Chatham Strait’), District 13 (‘Sitka Sound/Peril Strait’) and District 14 (‘Glacier Bay/Icy Strait’).

Humpback whales were approached and photographed from outboard-driven motorboats 4 – 6.5 m in length. The whales were photographed with single lens reflex (SLR) cameras equipped with 300mm or 70 – 210mm lenses. In 2003, the majority of photographs were taken with a 35mm Nikon N90 camera using Kodak TMAX 3200 black and white print film shot at 1600 ISO. In addition, some color images were taken with a 6.1 megapixel Nikon D100 digital camera in RAW file format shot at 400 ISO. In 2004, all images were collected with the digital camera. Photographs were taken of each whale’s caudal peduncle by operating the boat parallel and slightly forward of each whale as it dove. When conditions allowed both the left and right side of each whale’s caudal peduncle were photographed. Occasionally, photographs of the dorsal side of a whale’s caudal peduncle were taken opportunistically as a whale dove head-on towards us. To avoid bias towards scarred whales, caudal peduncle photographs were taken of all suitably positioned whales, regardless of whether any entanglement scarring was visible. In addition, photographs were collected of the pigmentation and morphology of the ventral surface of the flukes, as well as the shape and scarification of the dorsal fin, for individual identification (Jurasz and Palmer 1981, Katona and Whitehead 1981, Blackmer *et al*. 2000). Waterproof plastic datasheets were used to record the date and latitude/longitude (determined with a Global Positioning System (GPS)) where each whale was encountered.

Photographic data analysis

Panda Photographic Laboratories, Inc., Seattle, WA processed the 35mm film and printed a 21.6 x 27.9 cm contact sheet for each roll. Preliminary data analysis was performed by examining the contact sheets with a 4x magnifying loupe and by using Microsoft Photo Editor v.3.0 (Microsoft Corp., Redmond, WA) to view and enlarge the digital images. Preliminary data analysis consisted of identifying each whale by matching its fluke and/or dorsal fin photograph(s) to catalogs of individual humpback whales previously identified in the Central North Pacific (Appendix 3). Jennifer Cedarleaf (University of Alaska Southeast) assisted with the photographic identification of whales.

Caudal peduncle photographs and digital images were grouped by year and individual whale. A 35mm negative film scanner (Nikon Coolscan 4000ED with Nikon Scan v.3.1.2 software (Nikon, Inc., Melville, NY)) was used to create digital images at 4000 dots per inch (dpi). Microsoft Photo Editor v.3.0, ThumbsPlus v.6.0 and v.7.0 (Cerious Software, Inc., Charlotte, NC) and Nikon View v.6.1.0 (Nikon, Inc., Melville, NY) were used to adjust the lighting, contrast, exposure and dimensions of each scanned or original digital image.

The entanglement scar analysis method of Robbins and Mattila (2001) was applied to the digital caudal peduncle images of individual whales. Each whale's caudal peduncle was divided into six areas with minor revisions in terminology (dorsal peduncle, ventral peduncle, right leading edge of flukes, left leading edge of flukes, left lateral peduncle (equivalent to Robbins and Mattila's 'left flank') and right lateral peduncle (equivalent to Robbins and Mattila's 'right flank')) (Fig. 8).

Scar codes (S-codes) after Robbins and Mattila (2001) were assigned based on the presence/absence of entanglement-related scarring in each area (Table 1) and then an overall entanglement status code (E-code) was assigned to each individual whale (Table 2, Fig. 9). Some entanglement scars are obvious even in very poor photographs but to avoid biasing the analysis towards scarred whales, E-codes E0 – E4 were assigned only to whales with adequate photographic coverage in at least two of the six caudal peduncle coding areas. E-codes E0 – E4 were equivalent to those used by Robbins and Mattila (2001) except that whales coded as E2 were referred to as "ambiguous" instead of as "uncertain". A new E-code, EX, was created and assigned to whales with coverage in fewer than two areas and/or if the quality of the caudal peduncle photographs was

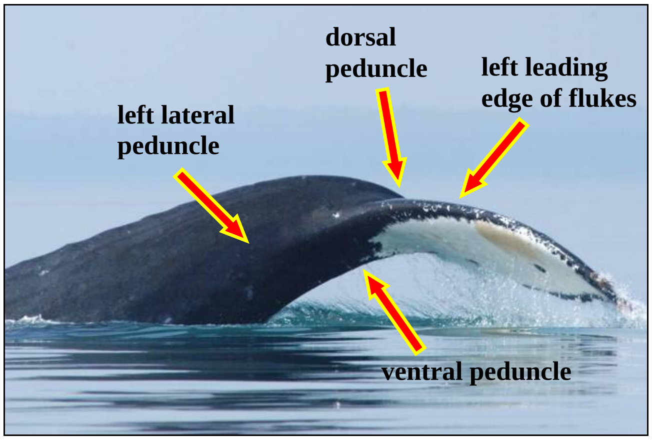


Figure 8. Example caudal peduncle photograph illustrating four of the six areas used in coding (after Robbins and Mattila 2001).

Table 1. Summary of scar codes (S-codes) (after Robbins and Mattila 2001). Each whale's caudal peduncle was divided into six areas and assigned an S-code depending on the marks observed.

Code	Scar Code (S-Code) Description
S0	No visible marks
S1	Non-linear marks or apparently randomly oriented linear marks
S2	Linear marks or wide areas lacking pigmentation, which did not appear to wrap around the feature
S3	Linear or wide scars which appeared to wrap around the feature
S4	At least one visible linear notch or indentation (generally on the dorsal or ventral peduncle)
S5	Extensive tissue damage and deformation of the feature
SX	Feature could not be coded due to lack of photographic coverage or inadequate photo quality

Table 2. Summary of entanglement status codes (E-codes) (after Robbins and Mattila 2001). The six S-codes assigned to each whale's caudal peduncle resulted in an overall E-code for that whale.

Code	Likelihood of Past Entanglement	Entanglement Status Code (E-Code) Description
E0	NONE	No evidence of entanglement (no marks present)
E1	LOW	Marks were observed, but did not suggest a previous entanglement. Scar codes did not generally exceed S2 in any documented region.
E2	AMBIGUOUS	Entanglement-like elements were present, but there was no consistent pattern. At least one region was generally assigned a scar code of S3 or higher.
E3	HIGH	Marks appeared to be entanglement-related and minor tissue damage was evident. At least two regions were generally assigned scar codes of S3 or higher.
E4	HIGH	Marks appeared to be entanglement-related and major tissue damage was evident. At least two regions were assigned scar codes of S3 or higher. At least one region was coded as S5.
EX		Whale could not be assigned an entanglement status code due to lack of photographic coverage or inadequate photo quality.

inadequate (*i.e.*, blurry, too distant, or taken at an angle that obscured the caudal peduncle) (*e.g.*, Fig. 9, 10). Thus E-code EX was assigned to some whales despite clear signs that they had been entangled previously. Robbins and Mattila (2001) eliminated whales from their sample using identical criteria but did not assign an E-code to these whales.

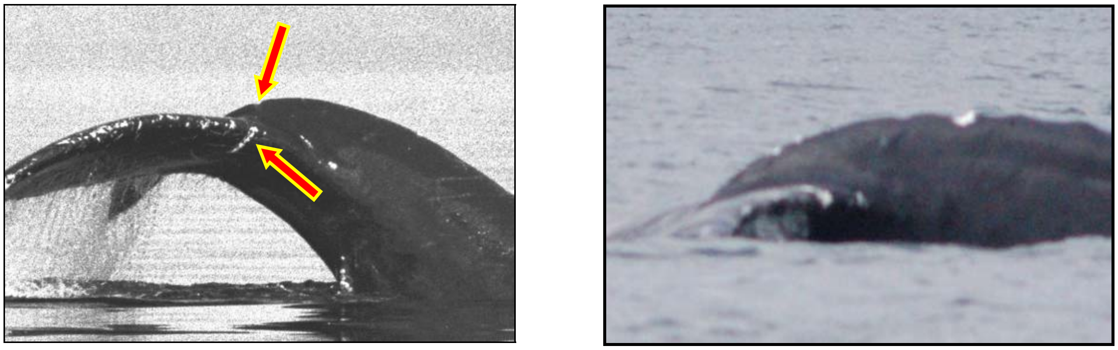
Whales with E-codes E3 and E4 had a high likelihood of having been entangled at least once in the past. To assign E-codes E3 and E4, a consistent, plausible entanglement scarring pattern had to be present across at least two areas. The observed marks had to indicate that gear had wrapped *around* the caudal peduncle, otherwise the whale could have acquired the scars from a source other than entanglement. For example, if a whale had a scar that appeared to wrap across one area, but there were no correlating wrapping

Example of E-code **E0**
Likelihood of past entanglement: *NONE*

Example of E-code **E1**
Likelihood of past entanglement: *LOW*

Example of E-code **E2**
Likelihood of past entanglement: *AMBIGUOUS*

Example of E-code **E3**
Likelihood of past entanglement: *HIGH*



Example of E-code **E4**
Likelihood of past entanglement: *HIGH*

Example of E-code **EX**
Likelihood of past entanglement: *UNKNOWN*

Figure 9. Example caudal peduncle photographs collected during this study illustrating E-codes. Arrows highlight key features and do not represent the total number of entanglement scars observed.

Figure 10. Example of E-code EX due to limited photographic coverage (only one of the six caudal peduncle areas is visible). This is the same calf shown in Fig. 2 approximately one hour after being disentangled from line. Note white linear wrapping scars on the calf's dorsal peduncle and tissue damage indicated by arrow.

or linear notch scars in at least one other area, then E-code E2 was assigned (*i.e.*, entanglement-like elements were present, but there was no consistent pattern).

The caudal peduncle entanglement scar analysis method was mastered during four independent attempts at coding the 2003 sample of images. Between the second and third attempts, I compared my E-codes with J. Robbins, who had assigned all of the entanglement status codes to the whales in the Gulf of Maine study (Robbins and Mattila 2001, 2004). E-codes were assigned independently to 49 individual whales that represented difficult cases because the appropriate code was not obvious and/or the image quality was questionable. When different E-codes were assigned to the same whale, Robbins' E-codes were used when these whales were assigned E-codes in the third attempt at coding. In the fourth (final) attempt at coding the 2003 sample, E-codes were assigned independently without Robbins' input; any E-codes that were found to be different from Robbins' E-codes were not changed in the final coding.

Before assigning E-codes to the 2004 sample of images, each whale was given a random identification number to reduce bias in assigning codes to whales that had also been in the 2003 sample.

Percentage of whales with non-lethal caudal peduncle entanglement scars

Three methods were used to estimate the cumulative percentage of whales with non-lethal caudal peduncle entanglement scars:

$$\text{Minimal Entanglement Scarring Percentage} = \frac{\Sigma E3 + \Sigma E4}{\Sigma E0 + \Sigma E1 + \Sigma E2 + \Sigma E3 + \Sigma E4}$$

$$\text{Conditional Entanglement Scarring Percentage} = \frac{\Sigma E3 + \Sigma E4}{\Sigma E0 + \Sigma E1 + \Sigma E3 + \Sigma E4}$$

$$\text{Maximal Entanglement Scarring Percentage} = \frac{\Sigma E2 + \Sigma E3 + \Sigma E4}{\Sigma E0 + \Sigma E1 + \Sigma E2 + \Sigma E3 + \Sigma E4}$$

Where E0, E1, E2, E3 and E4 = the number of whales assigned E-codes E0, E1, E2, E3 and E4, respectively.

The minimal entanglement scarring percentage, hereafter referred to as the minimal scarring percentage, only includes whales with a high likelihood of previous entanglement (E-codes E3 and E4) in the numerator. This approach is likely to underestimate the true percentage of entangled whales because some of the whales coded as ambiguous (E-code E2) may have been entangled. The minimal scarring percentage approach was used by Robbins and Mattila (2001, 2004) when they estimated the cumulative percentage of previously entangled humpback whales in the Gulf of Maine and Hawaii. The conditional entanglement scarring percentage, hereafter referred to as the conditional scarring percentage, has the same numerator but no ambiguous whales (E-code E2) are included in the denominator; therefore this approach is based solely on individuals with unambiguous caudal peduncle scars. However, this decreases the sample size. The maximal entanglement scarring percentage, hereafter referred to as the maximal scarring percentage, includes whales with a high likelihood of previous entanglement (E-codes E3 and E4) and ambiguous whales (E-code E2) in the numerator. This approach is likely to overestimate the true percentage of entangled whales because it is unlikely that all of the ambiguous whales were entangled.

When the data from both years were combined, whales that were seen in both years were counted once. If there was a difference in the E-codes between years, then the 2004 E-code was used (unless the 2004 E-code was EX, in which case the 2003 E-code was used).

Annual rate of entanglement scar acquisition

The E-codes and images of individual whales that were sampled adequately in both years were used to estimate the annual rate of entanglement scar acquisition between 2003 and 2004. The whale's caudal peduncle images from both years were compared and assessed to estimate the amount of new entanglement-related scarring occurring between 2003 and 2004. This rate was calculated by dividing the number of whales in 2004 with an increase in entanglement scarring by the total number of individuals with adequate photographic coverage in both years.

Identification of vulnerable segments of the population

Sex and birth year for individual whales previously identified in SEAK were obtained from databases maintained by long-term humpback whale monitoring programs based at GBNPP in Gustavus, AK and at J. Straley Investigations in Sitka, AK. Sex was determined by genetic analysis of skin samples (Lambertsen *et al.* 1988; Bérubé and Palsbøll 1996) and/or photographs of the genital slit (Glockner 1983). In addition, any whale that has been observed in close association with a calf on one or more occasions was considered to be a female. The number of whales for which sex was determined only from genetic sampling was calculated to determine if the sample was biased towards one sex. Calves were defined as whales less than one year old and juveniles were defined as whales over one year old but less than five years old (Clapham 1992).

GPS locations of the whale observations were grouped according to ADF&G Districts. If a whale was photographed in multiple districts, it was assigned randomly to one district in analyses of the percentage of whales in each district with entanglement scars. If a whale was documented multiple times within the same district, it was assigned randomly to one of the GPS locations where it was seen so that it could be included on descriptive maps showing where whales were sampled.

Commercial fisheries in northern SEAK

The goal of this part of the study was to describe the commercial fisheries that humpback whales are most likely to encounter in the study area and to compare the entanglement scar results with the spatial and temporal distribution of these fisheries. The following fisheries were considered: pot fisheries for Dungeness crab (*Cancer magister*), red king crab (*Paralithodes camtschaticus*), golden king crab (*Lithodes aequispinus*), Tanner crab (*Chionoecetes bairdi*) and shrimp (*Pandalus* spp.); drift gillnet and purse seine fisheries for Pacific salmon (*Oncorhynchus* spp.)[16]; and longline fisheries for Pacific halibut (*Hippoglossus stenolepis*) and sablefish (*Anoplopoma fimbria*).[17,18]

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[16] Purse seines and set gillnets are used to target Pacific herring (*Clupea pallasi*) in northern SEAK. These fisheries are not included in this analysis because presumably humpback whales are less likely to encounter these fisheries because a) sac roe herring fishery openings (purse seine and gillnet) are typically very short (*e.g.*, ~2 – 24 hours) and occur over just a few days each spring immediately preceding the major herring spawn events and b) although the winter food and bait herring fishery (purse seine) is more protracted (typically opening early December and closing late February), this fishery is highly localized in northern SEAK in Tenakee Inlet (District 12) and to a lesser degree in the Hobart Bay/Port Houghton/Windham Bay area (District 10) with very few participants (generally less than three vessels in recent years). (Personal communication from Dave Harris, ADF&G Commercial Fisheries Division, PO Box 240020, Douglas, AK 99824, March 2006).

[17] Longlines are also used to target Pacific cod (*Gadus macrocephalus*) and demersal shelf rockfishes (*Sebastes spp.*) in SEAK. These fisheries are not included because harvest levels are low compared to longline fisheries for halibut and sablefish and this analysis only includes the major commercial fisheries of SEAK.

For each ADF&G District, the level of fishing in each major commercial fishery was calculated to compare with the entanglement scar results from each district. Harvest levels (lb) were used as a proxy for fishing effort because no data are available on the amount of fishing gear deployed or how long it is in the water. Annual harvest data for each ADF&G District were obtained from ADF&G and were averaged over the period 1995 through 2004 for each fishery. Harvest data from this period were not available for two fisheries; shrimp pot data were averaged over the period 1995 – 2002 and sablefish longline data were averaged over the period 1999 – 2003. For the drift gillnet and purse seine fisheries, harvest data were only compiled from the traditional common property fishery [*i.e.,* harvest data from terminal harvest areas and hatchery cost recovery areas (Appendix 2) were not included.] According to ADF&G policy, when fewer than three vessels participate in a fishery, the harvest data are confidential; in these cases, the harvest level was treated as missing. Harvest data for the halibut and sablefish longline fisheries were not readily available by ADF&G District because the halibut fishery is managed by the International Pacific Halibut Commission (IPHC) based on IPHC statistical areas[19] and the sablefish fishery is managed by ADF&G based on ADF&G groundfish statistical areas.[20] Therefore, to compare the halibut harvest data by ADF&G District, the rough equivalent of each ADF&G district was defined in terms of overlapping IPHC statistical areas (Table 3) and the halibut harvest data were summarized using these criteria. Similarly, to compare the sablefish harvest data by ADF&G District, the rough equivalent of each ADF&G District was defined in terms of overlapping ADF&G groundfish statistical areas (Table 4).

In addition, a brief summary of each fishery was compiled describing the current location of the main fishing grounds, the timing of the fishery and the type of gear used

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[18] Troll fisheries for salmon (*Oncorhynchus* spp.) and lingcod (*Ophiodon elongates*) are not included in this analysis because trolling gear is not one of the gear types reported in humpback whale entanglements in SEAK in recent years (Fig. 5).

[19] See Appendix 2 for a map of IPHC statistical areas in the study area.

[20] See Appendix 2 for a map of ADF&G groundfish statistical areas in the study area.

Table 3. Approximate equivalents between ADF&G Districts and IPHC statistical areas in the study area.

ADF&G District	Approximate IPHC statistical area equivalent
9	stat area 161 + approximately 1/3 of stat area 162
10	stat area 163 + approximately 2/3 of stat area 162
11	stat area 173
12	stat area 171
13	stat areas 160 + 170 + 181 + 174
14	stat areas 182 + 184

Table 4. Approximate equivalents between ADF&G Districts and ADF&G groundfish statistical areas in the study area.[21,22]

ADF&G District	Approximate ADF&G groundfish statistical area equivalent
9	stat areas 345702 + 345631 + 345603
10	stat area 335701
12	stat areas 345803 + 345731 + 345701

(Appendix 2). Maps showing the location of the fishing grounds were generated using information from various sources, including ADF&G reports and consultations with commercial fishermen. Descriptions of the open season for each fishery were compiled from ADF&G and IPHC management plans and reports. Descriptions of legal gear were obtained from Alaska state law (05 AAC 29.001 – 05 AAC 35.590). When available, information pertaining to historic changes in the timing or gear types used in a fishery was noted to provide a broader perspective on the fisheries that humpback whales were likely to have encountered in the past in northern SEAK. NOAA Alaska Sea Grant provided illustrations of commercial fishing vessels and gear configurations. ArcGIS 9

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[21] ADF&G Districts 11, 13 and 14 were not considered because over 99% of the sablefish catch in the study area comes from the equivalent of ADF&G Districts 9, 10 and 12 (Richardson and O'Connell 2004).

[22] Longlining for sablefish occurs offshore of the study area in the eastern Gulf of Alaska (Appendix 2); however these ADF&G groundfish statistical areas were not included in the summary of harvest data because they do not overlap with the study area.

(Environmental Systems Research Institute, Inc., Redlands, CA) was used to create maps of the locations where whales were photographed and the locations of the fishing grounds.

Statistical analyses

Ninety-five percent confidence intervals were calculated according to Zar (1999) on the entanglement scarring percentages. Fisher's exact tests of independence (Zar 1999) were used to test for significant differences between percentages. For example, when testing the difference between minimal scarring percentages, the pooled frequencies of E-codes E3 and E4 were compared to the pooled frequencies of E-codes E0, E1 and E2.

Results

Whale surveys and data collection

A total of 1,139 hours were spent searching for, approaching and photographing humpback whales in northern SEAK (Table 5).

Table 5. Summary of survey effort, 2003 – 2004.

	2003		2004		2003 + 2004	
Location (ADF&G District)	# days	# hours	# days	# hours	# days	# hours
W. Frederick Sound (9)	2	17	5	26	7	43
E. Frederick Sound (10)	2	15	4	27	6	42
Stephens Passage (11)	4	14	1	10	5	24
Chatham Strait (12)	3	20	2	10	5	30
Sitka Sound/Peril Strait (13)	2	4	2	16	4	20
Glacier Bay/Icy Strait (14)	68	447	80	533	148	980
Total	81	517	94	622	175	1,139

Note: On some days surveys were conducted in more than one district; these were counted as one survey day in each district.

Photographic data analysis

Caudal peduncle images of 152 and 224 unique whales were obtained in 2003 and 2004, respectively. Seventy-three whales were photographed in both years resulting in 303 unique whales in the combined 2003 – 2004 sample, the majority of which were sampled in Glacier Bay, Icy Strait and Frederick Sound (Fig. 11).

The amount of photographic coverage obtained of each whale's caudal peduncle varied. Fifty-three percent (*n* = 160) of the whales in the 2003 – 2004 sample were whales with photographs of both the right and left sides of the caudal peduncle (# sides = 2); 6% (*n* = 17) were whales with photographs of one side of the caudal peduncle (left or right) and opportunistic photographs of the dorsal caudal peduncle as the whale dove head-on

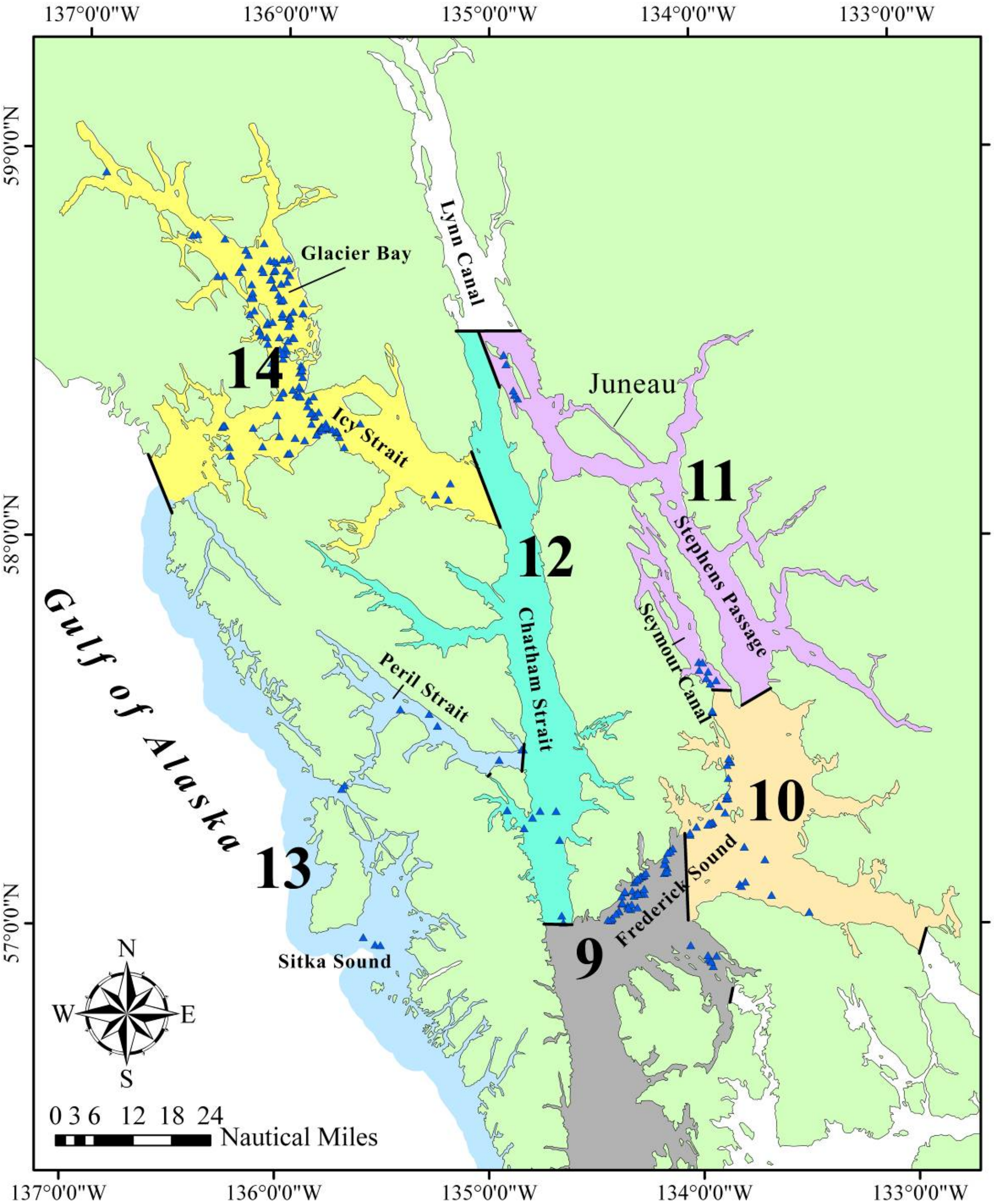

Figure 11. Locations of sampled whales, 2003 – 2004 (*n* = 303). ADF&G Districts are indicated in color and numbered.

towards the survey vessel (# sides = 1.5); 36% (*n* = 109) were whales with photographs of just the left or the right side of the caudal peduncle (# sides = 1); 4% (*n* = 12) were whales with photographs of only the dorsal caudal peduncle as the whale dove head-on towards the survey vessel (# sides = 0.5); and 2% (*n* = 5) were whales with photographs of small portions of the caudal peduncle that qualified as inadequate quality (# sides = 0) (Table 6). The less photographic coverage that was obtained of a whale, the more likely it was to be assigned E-code EX. All of the whales with 0 and 0.5 sides of coverage were assigned E-code EX (Table 6) because the minimum criterion necessary to assign E-codes E0 – E4 was not met (fewer than two of the caudal peduncle coding areas were visible).

Table 6. Number of whales assigned to each E-code based on how much photographic coverage of the caudal peduncle was obtained for both years combined.

No. of sides	*n*	E0	E1	E2	E3	E4	EX	% EX
2	160	1	24	30	74	2	29	18%
1.5	17	0	4	3	2	0	8	47%
1	109	1	9	14	16	0	69	63%
0.5	12	0	0	0	0	0	12	100%
0	5	0	0	0	0	0	5	100%

Using the minimal scarring percentage approach, whales with adequate photographic coverage of one side of the caudal peduncle were significantly less likely to be assessed as having been entangled than whales with adequate photographic coverage of both sides of the caudal peduncle (*P* = 0.035, one-tailed Fisher's exact test) (Table 7). This bias did not exist when the maximal or conditional scarring percentage approaches were followed; whales with photographic coverage of one side of the caudal peduncle did not have significantly lower maximal or conditional scarring percentages than whales with

Table 7. Entanglement scarring percentages of whales with adequate photographic coverage of one *vs.* two (*i.e.*, both) sides of the caudal peduncle for both years combined (95% confidence intervals).

No. of sides	*n*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
2	131	58% (49%, 67%)	81% (73%, 87%)	101	75% (66%, 83%)
1	40	40% (25%, 57%)	75% (59%, 87%)	26	62% (41%, 80%)

photographs of both sides of the caudal peduncle ($P = 0.273$ and $P = 0.126$, respectively, one-tailed Fisher's exact tests).

Adequate photographic coverage was obtained of 47% ($n = 72$) of the whales in the 2003 sample and of 61% ($n = 137$) of the whales in the 2004 sample (Table 8). In total, the entanglement status of 180 unique individuals was determined. Twenty-four percent of each annual sample consisted of whales with an ambiguous entanglement history (E-code E2).

Table 8. E-codes of all whales with adequate photographic coverage, 2003 – 2004. The numbers for the two years cannot be added directly because some whales were seen in both years.

Year	*n*	E0	E1	E2	E3	E4
2003	72	1	15	17	37	2
2004	137	1	30	33	73	0
2003 + 2004	180	2	37	47	92	2

The number of caudal peduncle photographs per individual whale appeared to influence the E-code (Fig. 12). The more photographs that were obtained of a whale, the more likely it was that the whale was assigned E-code E3 (*i.e.*, marks appeared to be entanglement-related and minor tissue damage was evident). The mean number of

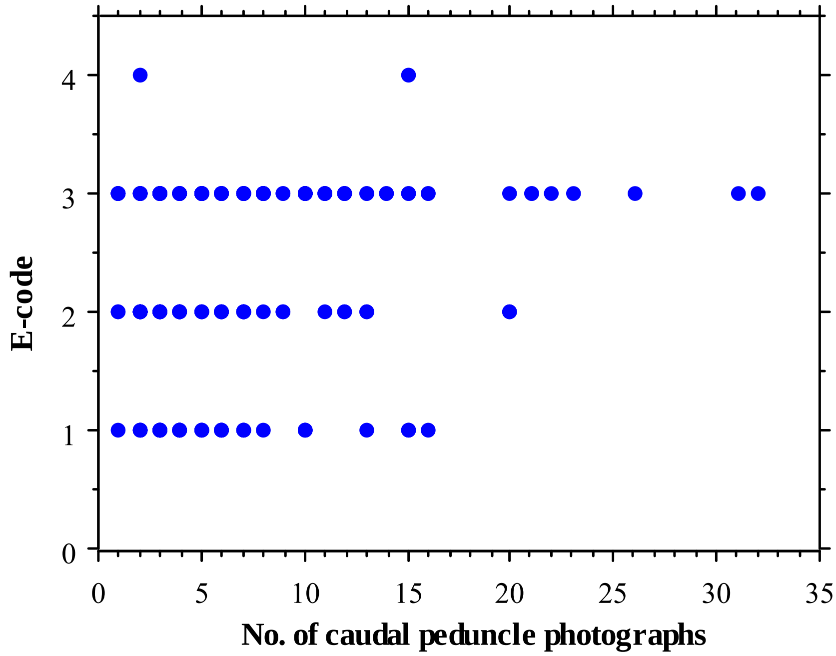

Figure 12. Number of caudal peduncle photographs collected per individual whale *vs*. E-code for whales with adequate photographic coverage for both years combined (*n* = 180).

photographs of whales assessed to have a high likelihood of previous entanglement (E-codes E3 and E4) (8.4 photographs per whale) was higher than the mean number of photographs of whales assessed to have no, low or an ambiguous likelihood of previous entanglement (E-codes E0 – E2) (5.8 photographs per whale) and the difference was significant (unpaired t-test, $t = 3.31$, df = 178, $P = 0.001$).

Whales with fewer than 10 caudal peduncle photographs had significantly lower minimal and conditional scarring percentages than whales with 10 or more caudal peduncle photographs ($P = 0.003$ and $P = 0.037$, respectively, one-tailed Fisher's exact tests). However, whales with fewer than 10 caudal peduncle photographs did not have a significantly lower maximal scarring percentage than whales with 10 or more caudal peduncle photographs ($P = 0.133$, one-tailed Fisher's exact test) (Table 9, 10).

Table 9. Number of whales assigned E-codes E0 – E4 by number of caudal peduncle photographs per individual whale for both years combined.

No. caudal peduncle photographs	*n*	E0	E1	E2	E3	E4
< 10	133	2	30	40	60	1
≥ 10	47	0	7	7	32	1
All whales	180	2	37	47	92	2

Table 10. Entanglement scarring percentages of whales with fewer than 10 caudal peduncle photographs, whales with 10 or more caudal peduncle photographs and all whales for both years combined (95% confidence intervals).

No. caudal peduncle photographs	*n*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
< 10	133	46% (37%, 55%)	76% (68%, 83%)	93	66% (55%, 75%)
≥ 10	47	70% (55%, 83%)	85% (72%, 94%)	40	83% (67%, 93%)
All whales	180	52% (45%, 60%)	78% (72%, 84%)	133	71% (62%, 78%)

The number of whales that I assigned to each E-code category varied with each attempt that I made at coding the 2003 sample (Fig. 13). The greatest variation occurred in the assignment of E-codes E3 and EX. As I learned to recognize the subtleties of entanglement scar patterns, the percentage of whales coded E3 (*i.e.*, marks appeared to be entanglement-related and minor tissue damage was evident) increased with each coding attempt. As I became more familiar with the minimum photographic quality and coverage needed to assign E-codes E0 – E4, I became more selective and therefore the number of whales coded EX (*i.e.*, whale could not be assigned an entanglement status code due to lack of photographic coverage or inadequate photo quality) increased with each coding attempt. There was 90% agreement between the E-codes that I assigned during my third and fourth coding attempts. The entanglement scarring percentages changed the most between my first and second attempts at coding, with less variation in subsequent coding

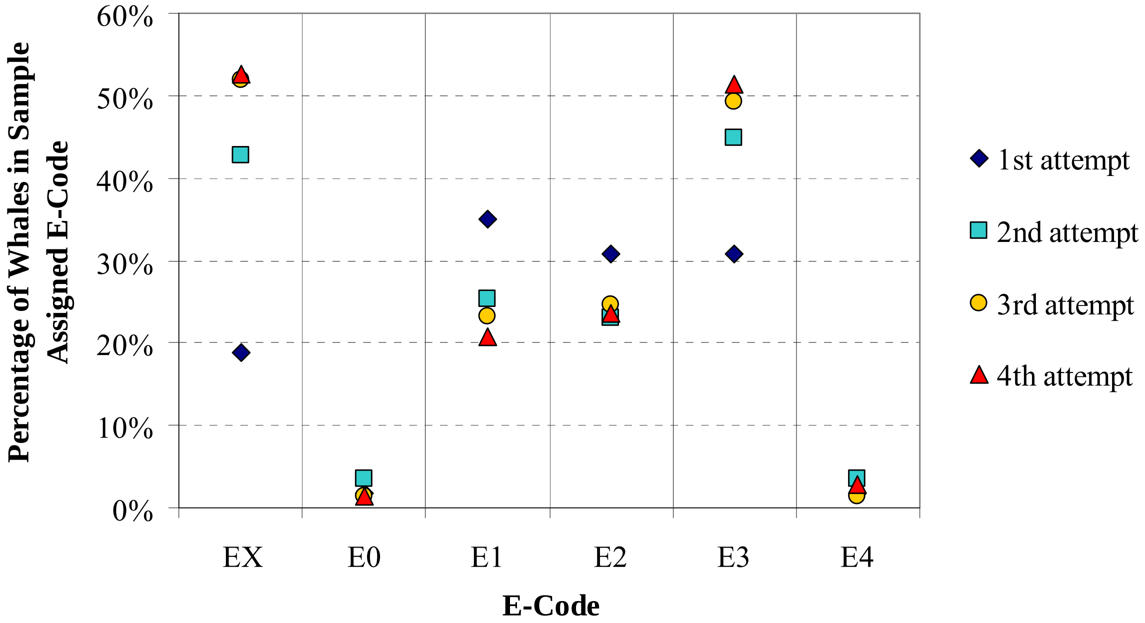

Figure 13. Variation in the percentage of whales assigned to each E-code during four independent attempts at coding the 2003 sample of caudal peduncle photographs. For code EX, the sample size is *n* = 152; for codes E0 – E4 the sample size is *n* minus the number of whales assigned code EX.

attempts (Fig. 14). There was a significant difference in the minimal scarring percentages between my first and second attempt at coding (*P* = 0.029, two-tailed Fisher's exact test); none of the other scarring percentages were significantly different between coding attempts (Table 11).

The comparison of E-codes with Robbins based on photographs of 49 "difficult" whales revealed that we generated similar minimal (Neilson: 37%; Robbins: 41%), conditional (Neilson: 53%; Robbins: 65%) and maximal (Neilson: 67%; Robbins: 78%) scarring percentages. None of these pairs of percentages were significantly different (*P* = 1, *P* = 0.516, *P* = 0.544, respectively, two-tailed Fisher's exact tests) but Robbins' estimates of the percentage of previously entangled whales were consistently higher than mine.

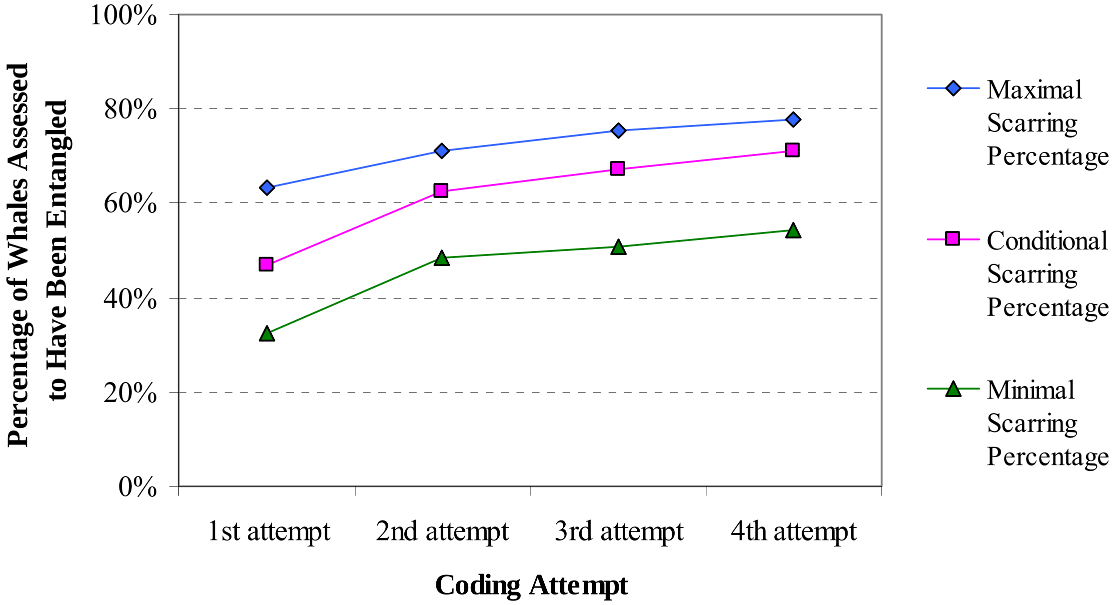

Figure 14. Entanglement scarring percentages during four independent attempts at coding the 2003 sample of caudal peduncle photographs.

Table 11. Results of two-tailed Fisher's exact tests comparing entanglement scarring percentages between four attempts at coding the 2003 sample of caudal peduncle photographs.

Comparison	Minimal Scarring Percentage	Conditional Scarring Percentage	Maximal Scarring Percentage
1st *vs.* 2nd attempt	P = 0.029*	P = 0.069	P = 0.293
2nd *vs.* 3rd attempt	P = 0.874	P = 0.704	P = 0.595
3rd *vs.* 4th attempt	P = 0.872	P = 0.837	P = 0.845

* Indicates significant difference at $\alpha = 0.05$

We assigned the same E-codes 67% (n = 33) of the time and different E-codes 33% (n = 16) of the time. There were no instances in which one of us coded a whale as having been entangled (E3 or E4) that the other person coded as not having been entangled (E0 or E1). The reasons why we assigned different E-codes varied:

In eight cases we disagreed on what constituted adequate quality photographs:

I assigned E-code EX to four whales that Robbins coded E2, E2, E3 and E3;

Robbins assessed four whales as having inadequate quality photographs that I coded E1, E1, E2 and E3.

In five cases we disagreed on the distinction between E-codes E1 and E2:

I assigned E-code E1 to three whales that Robbins coded E2;

Robbins assigned E-code E1 to two whales that I coded E2.

In two cases we disagreed on the distinction between E-codes E2 and E3:

I assigned E-code E2 to one whale that Robbins coded E3;

Robbins assigned E-code E2 to one whale that I coded as E3.

In one case we disagreed on the distinction between E-codes E3 and E4:

I assigned E-code E4 to one whale (#1797) that Robbins coded E3 (Robbins agreed that this was a borderline case).

During my fourth (and final) attempt at coding, I assigned 12 of these 16 disputed whales the same E-codes and four of them different E-codes. The reasons I changed four of the E-codes in the fourth coding were: I assigned E-code EX to one whale that had been E-code E2; I assigned E-code E3 to two whales that had been E-code E2; I assigned E-code E4 to whale #1797, which Robbins and I had both agreed was a borderline E3/E4 case. These changes occurred because of slight differences in my interpretation of the same scars, a problem inherent in the subjective nature of the scar coding method, but in this case accentuated by the fact that these were difficult whales with scarring patterns that did not fit easily into one E-code category.

Percentage of whales with non-lethal caudal peduncle entanglement scars

In 2004, a larger sample of whales with adequate caudal peduncle photographs than in 2003 allowed for greater precision in the estimates of the entanglement scarring percentages (Table 12). The minimal, maximal and conditional scarring percentages in 2003 and 2004 were not significantly different between years ($P = 1$, two-tailed Fisher's exact tests for all comparisons); therefore, the data for both years were pooled (Table 12).

Table 12. Entanglement scarring percentages for all whales, 2003 – 2004 (95% confidence intervals).

Year	*N*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
2003	72	54% (42%, 66%)	78% (67%, 87%)	55	71% (57%, 82%)
2004	137	53% (45%, 61%)	77% (69%, 84%)	104	70% (60%, 79%)
2003 + 2004	180	52% (45%, 60%)	78% (72%, 84%)	133	71% (62%, 78%)

As documented by photographs of the flukes, 73 whales were photographed in both years: 28 had adequate photographic coverage of the caudal peduncle in both years; all were adults. None of these 28 whales exhibited a decrease in entanglement scarring between years, 26 (93%) exhibited stable scars and two (7%) (whales #1489 and #351) exhibited an increase in entanglement scarring. Whale #1489 was assessed as having a low likelihood of previous entanglement (E-code E1) in 2003 and a high likelihood of previous entanglement in (E-code E3) in 2004 based on a definite increase in scarring. Whale #351 gained new entanglement scarring but was assessed as having a high likelihood of previous entanglement (E-code E3) in both years (Fig. 15).

Of the 28 whales photographed adequately in both years, different E-codes were assigned between years in four (14%) cases. One of the four whales with a different E-code was whale #1489; this whale gained new entanglement scars between years. The other three

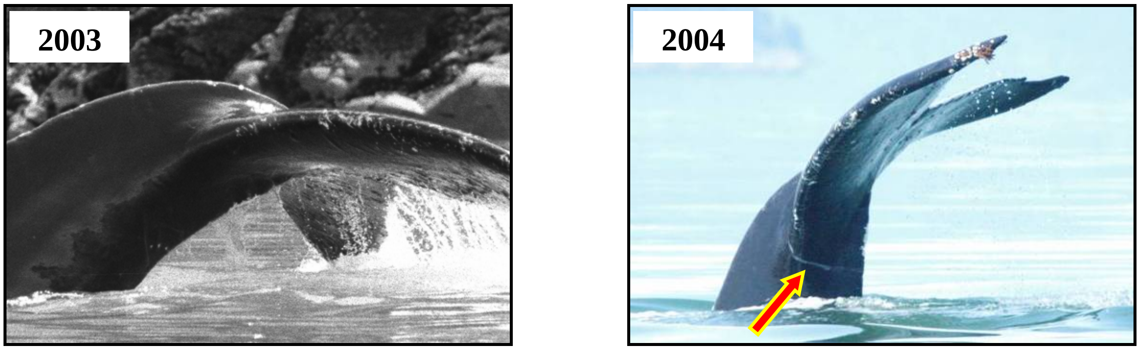

Figure 15. Whale #351 in 2003 (left) and 2004 (right). This whale was assigned E-code E3 in both years but new wrap marks (indicated with arrow) were visible in 2004.

instances (3/28 = 11%) in which whales were assigned different E-codes are attributable to inter-annual differences in photographic quality and/or the angle of the photographs (Table 13).

Table 13. Whales assigned different E-codes in 2003 and 2004 due to inter-annual differences in photographic quality and/or angle of caudal peduncle photographs.

Whale ID	2003 E-code	2004 E-code	Reason for difference
166	E4	E3	An area of major tissue damage that was apparent in 2003 was obscured by the angle of the 2004 photographs. All of the other scars available for direct comparison were stable.
518	E1	E2	Slight differences in lighting and angle of photographs resulted in different interpretations of the same marks between years.
157	E2	E3	Slight differences in lighting and angle of photographs resulted in different interpretations of the same marks between years.

The effects of these kinds of changes in E-codes can be qualified by examining how the changes affect the minimal, maximal and conditional scarring percentages:

1) Interpreting an E4 whale as an E3 whale (*e.g.*, whale #166) does not change the minimal, maximal or conditional scarring percentages; all of the percentages are robust to this type of variation in coding.

2) Interpreting an E1 whale as an E2 whale (*e.g.*, whale #518) does not change the minimal scarring percentage; it is robust to this type of variation in coding. However, it raises both the maximal scarring percentage (by increasing the value of the numerator in the percentage calculation) and the conditional scarring percentage (by lowering the value of the denominator in the percentage calculation). The conditional scarring percentage changes less than the maximal scarring percentage, thus the conditional scarring percentage is more robust than the maximal scarring percentage to this type of change in coding.

3) Interpreting an E2 whale as an E3 whale (*e.g.*, whale #157) does not change the maximal scarring percentage; it is robust to this type of variation in coding. However, it raises both the minimal scarring percentage (by increasing the value of the numerator in the percentage calculation) and the conditional scarring percentage (by increasing the value of the numerator and lowering the value of the denominator in the percentage calculation.) The conditional scarring percentage changes less than the minimal scarring percentage, thus the conditional scarring percentage is more robust than the minimal scarring percentage to this type of change in coding.

Annual rate of entanglement scar acquisition

Twenty-six of the 28 whales that were documented in both years were sampled in Glacier Bay and Icy Strait. Thus these 26 individuals do not represent a random sample from the study area but instead reflect the concentration of survey effort in Glacier Bay and Icy

Strait. Limiting the sample of whales documented in both years to only the 26 whales documented in Glacier Bay and Icy Strait, two (8%) acquired new caudal peduncle entanglement scars between years. By applying an 8% (95% CI: 1%, 25%) annual rate of entanglement scar acquisition to the best population estimate for the humpback whale population in Glacier Bay and Icy Strait (n = 169) (Straley *et al*. 2002), about 12 or 13 (point estimate 12.5) of the whales in Glacier Bay and Icy Strait are estimated to have had non-lethal entanglements and self-released between 2003 and 2004.

Identification of vulnerable segments of the population

Sex

The combined 2003 – 2004 sample consisted of 75 females, 46 males and 182 whales of unknown sex. The higher percentage of females in the combined sample (1.6:1) is reasonable because a greater proportion of the SEAK population has been identified as female because females can be sexed more easily based on the presence of a calf. Limiting the sample to whales whose sex is known from genetic sampling (32 females, 37 males) reveals a sample closer to parity and no female bias. Therefore I conclude that the overall sample is not biased toward females.

In 2003, the whales with adequate photographic coverage (*i.e.*, E-codes E0 – E4) consisted of 14 males, 28 females and 30 whales of unknown sex (Table 14). In 2004, the whales with adequate photographic coverage consisted of 26 males, 47 females and 64 whales of unknown sex (Table 14).

The minimal, maximal and conditional scarring percentages of males, females and whales of unknown sex were not significantly different between 2003 and 2004 (Table 15, 16); therefore, the data from both years were pooled (Table 17, 18).

For both years combined, the minimal scarring percentage of males (82%) was higher than that of females (55%) and the difference was significant (P = 0.013, two-tailed

Table 14. Number of whales assigned E-codes E0 – E4 by sex and year.

Sex	Year	*n*	E0	E1	E2	E3	E4
Male	2003	14	0	4	1	8	1
	2004	26	0	2	2	22	0
Female	2003	28	0	5	7	16	0
	2004	47	0	12	10	25	0
Unknown	2003	30	1	6	9	13	1
	2004	64	1	16	21	26	0

Table 15. Entanglement scarring percentages by sex and year (95% confidence intervals).

Sex	Year	*n*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
Male	2003	14	64% (35%, 87%)	71% (42%, 92%)	13	69% (38%, 91%)
	2004	26	85% (65%, 96%)	92% (75%, 99%)	24	92% (73%, 99%)
Female	2003	28	57% (37%, 76%)	82% (63%, 94%)	21	76% (53%, 92%)
	2004	47	53% (38%, 68%)	74% (60%, 86%)	37	68% (50%, 82%)
Unknown	2003	30	47% (28%, 66%)	77% (58%, 90%)	21	67% (43%, 85%)
	2004	64	41% (29%, 54%)	73% (61%, 84%)	43	60% (44%, 75%)

Table 16. Results of two-tailed Fisher's exact tests comparing entanglement scarring percentages by sex between 2003 and 2004.

Comparison	Minimal Scarring Percentage	Maximal Scarring Percentage	Conditional Scarring Percentage
Males, 2003 *vs.* 2004	$P = 0.234$	$P = 0.159$	$P = 0.157$
Females, 2003 *vs.* 2004	$P = 0.813$	$P = 0.572$	$P = 0.560$
Unknown sex, 2003 *vs.* 2004	$P = 0.657$	$P = 0.805$	$P = 0.785$

Table 17. Number of whales assigned E-codes E0 – E4 by sex for both years combined.

Sex	*n*	E0	E1	E2	E3	E4
Male	33	0	4	2	26	1
Female	62	0	13	15	34	0
Unknown	85	2	20	30	32	1

Table 18. Entanglement scarring percentages by sex for both years combined (95% confidence intervals).

Sex	*n*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
Male	33	82% (65%, 93%)	88% (72%, 97%)	31	87% (70%, 96%)
Female	62	55% (42%, 68%)	79% (67%, 88%)	47	72% (57%, 84%)
Unknown	85	39% (28%, 50%)	74% (63%, 83%)	55	60% (46%, 73%)

Fisher's exact test). However, this result is influenced by a higher number of caudal peduncle photographs per whale for males (median 8.0) than for females (median 6.0) and more caudal peduncle photographic coverage per whale for males (mean 1.9 sides) than for females (mean 1.7 sides) (Table 19). Males and females did not have significantly different maximal scarring percentages (males 88%, females 79%) ($P = 0.402$, two-tailed Fisher's exact test) or conditional scarring percentages (males 87%, females 72%) ($P = 0.165$, two-tailed Fisher's exact test). The percentage of females with an ambiguous entanglement history (E-code E2) (24%) was higher than the percentage of males with an ambiguous entanglement history (6%) and the difference was significant ($P = 0.046$, two-tailed Fisher's exact test).

The two whales with a definite increase in entanglement scarring between years (#351 and #1489) are males.

Table 19. Number of caudal peduncle photographs per whale (range, median) and average amount of caudal peduncle photographic coverage per whale by sex for both years combined.

	No. of caudal peduncle photographs per whale		Caudal peduncle photographic coverage
Sex	Range	Median	Mean no. of sides
Males	3 - 23	8.0	1.9
Females	1 - 32	6.0	1.7
Unknown sex	1 - 16	4.0	1.7

Age

The sample of juveniles with adequate photographic coverage from both years combined ($n = 3$) was too small to treat juveniles as a separate age class in statistical analyses so they were pooled with older whales. All three known-age juveniles were assessed as having a high likelihood of previous entanglement.

In 2003, the whales with adequate photographic coverage (*i.e.*, E-codes E0 – E4) consisted of two calves and 70 older whales (Table 20). The small sample of calves in 2003 ($n = 2$) generated imprecise entanglement scarring percentage estimates (Table 21). In 2004, the whales with adequate photographic coverage consisted of ten calves and 127 older whales (Table 20). The larger sample of calves in 2004 ($n = 10$) allowed for greater precision in the entanglement scarring percentage estimates (Table 21).

For older whales, the minimal, maximal and conditional scarring percentages were not significantly different between 2003 and 2004 ($P = 1$, two-tailed Fisher's exact tests, for all comparisons); therefore, the data for older whales from both years were pooled (Table 22, 23). For calves, the data from both years were pooled (Table 22, 23) to achieve sufficient sample sizes for statistical testing of differences in entanglement scarring percentages by age class.

Table 20. Number of whales assigned E-codes E0 – E4 by age class and year.

Age Class	Year	*n*	E0	E1	E2	E3	E4
Calves	2003	2	1	0	1	0	0
	2004	10	1	3	4	2	0
Older whales	2003	70	0	15	16	37	2
	2004	127	0	27	29	71	0

Table 21. Entanglement scarring percentages by age class and year (95% confidence intervals).

Age Class	Year	*n*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
Calves	2003	2	0%	50% (1%, 99%)	1	0%
	2004	10	20% (3%, 56%)	60% (26%, 88%)	10	33% (4%, 78%)
Older whales	2003	70	56% (43%, 68%)	79% (67%, 87%)	54	72% (58%, 84%)
	2004	127	56% (47%, 65%)	79% (71%, 85%)	127	72% (63%, 81%)

Table 22. Number of whales assigned E-codes E0 – E4 by age class for both years combined.

Age Class	*n*	E0	E1	E2	E3	E4
Calves	12	2	3	5	2	0
Older whales	168	0	34	42	90	2

Table 23. Entanglement scarring percentages by age class for both years combined (95% confidence intervals).

Age Class	*n*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
Calves	12	17% (2%, 48%)	58% (28%, 85%)	7	29% (4%, 71%)
Older whales	168	55% (47%, 62%)	80% (73%, 86%)	126	73% (64%, 81%)

For both years combined, the minimal scarring percentage of calves (17%) was lower than that of older whales (55%) and the difference was significant (*P* = 0.015, two-tailed Fisher's exact test). In addition, the conditional scarring percentage of calves (29%) was lower than that of older whales (73%) and the difference was significant (*P* = 0.023, two-tailed Fisher's exact test). However, these results are influenced by a slightly higher median number of caudal peduncle photographs per whale for older whales (median 6.0) than for calves (median 4.5) (Table 24). The average amount of caudal peduncle photographic coverage per whale was the same for both age classes (mean 1.8 sides) (Table 24).

Table 24. Number of caudal peduncle photographs per whale (range, median) and average amount of caudal peduncle photographic coverage per whale by age class for both years combined.

	No. of caudal peduncle photographs per whale		Caudal peduncle photographic coverage
Age Class	Range	Median	Mean no. of sides
Calves	2 - 20	4.5	1.8
Older whales	1 - 32	6.0	1.8

The maximal scarring percentage of calves (58%) was not significantly different than that of older whales (80%) (*P* = 0.137, two-tailed Fisher's exact test). The percentage of calves with an ambiguous entanglement history (E-code E2) (42%) was higher than the percentage of older whales with an ambiguous entanglement history (25%) but the difference was not significant (*P* = 0.304, two-tailed Fisher's exact test).

Location

In 2003, 97% (*n* = 70) of the whales with adequate photographs were documented in just one out of the six ADF&G districts and 3% (*n* = 2) were photographed in more than one district and were assigned randomly to one district. None of the whales with adequate photographs were located in Sitka Sound/Peril Strait (District 13). The small samples of whales in 2003 in eastern Frederick Sound (*n* = 3), Stephens Passage (*n* = 3) and Chatham Strait (*n* = 2) (Table 25) generated imprecise entanglement scarring percentage estimates (Table 26).

In 2004, 98% (*n* = 134) of the whales with adequate photographs were documented in just one out of the six ADF&G districts; 2% (*n* = 3) were photographed in more than one district and were assigned randomly to one district. Larger samples from all locations in 2004 (Table 25) allowed for greater precision in the entanglement scarring percentage estimates (Table 26).

Table 25. Number of whales assigned E-codes E0 – E4 by location and year.

Location (ADF&G District)	Year	*n*	E0	E1	E2	E3	E4
W. Frederick Sound (9)	2003	16	0	4	6	5	1
	2004	28	0	9	9	10	0
E. Frederick Sound (10)	2003	3	0	1	1	1	0
	2004	17	0	5	7	5	0
Stephens Passage (11)	2003	3	0	0	0	3	0
	2004	8	0	1	1	6	0
Chatham Strait (12)	2003	2	1	0	0	1	0
	2004	4	0	1	1	2	0
Sitka Sound/Peril Strait (13)	2003	0	0	0	0	0	0
	2004	6	0	0	2	4	0
Glacier Bay/Icy Strait (14)	2003	48	0	10	10	27	1
	2004	74	1	14	13	46	0

Table 26. Entanglement scarring percentages by location and year (95% confidence intervals).

Location (ADF&G District)	Year	*n*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
W. Frederick Sound (9)	2003	16	38% (15%, 65%)	75% (48%, 93%)	10	60% (26%, 88%)
	2004	28	36% (19%, 56%)	68% (48%, 84%)	19	53% (29%, 76%)
E. Frederick Sound (10)	2003	3	33% (1%, 91%)	67% (9%, 99%)	2	50% (1%, 99%)
	2004	17	29% (10%, 56%)	71% (44%, 90%)	10	50% (19%, 81%)
Stephens Passage (11)	2003	3	100% (29%, 100%)	100% (29%, 100%)	3	100% (29%, 100%)
	2004	8	75% (35%, 97%)	88% (47%, 100%)	7	86% (42%, 100%)
Chatham Strait (12)	2003	2	50% (1%, 99%)	50% (1%, 99%)	2	50% (1%, 99%)
	2004	4	50% (7%, 93%)	75% (19%, 99%)	3	67% (9%, 99%)
Sitka Sound/Peril Strait (13)	2003	0	-	-	0	-
	2004	6	67% (22%, 96%)	100% (54%, 100%)	4	100% (40%, 100%)
Glacier Bay/Icy Strait (14)	2003	48	58% (43%, 72%)	65% (79%, 90%)	38	74% (57%, 87%)
	2004	74	62% (50%, 73%)	80% (69%, 88%)	61	75% (63%, 86%)

The minimal, maximal and conditional scarring percentages of whales by location were not significantly different between 2003 and 2004 (Table 27); therefore, the data from

Table 27. Results of two-tailed Fisher's exact tests comparing entanglement scarring percentages by location between 2003 and 2004.

Comparison	Minimal Scarring Percentage	Maximal Scarring Percentage	Conditional Scarring Percentage
W. Frederick Sound, 2003 *vs.* 2004	$P = 1$	$P = 0.739$	$P = 1$
E. Frederick Sound, 2003 *vs.* 2004	$P = 1$	$P = 1$	$P = 1$
Stephens Passage, 2003 *vs.* 2004	$P = 1$	$P = 1$	$P = 1$
Chatham Strait, 2003 *vs.* 2004	$P = 1$	$P = 1$	$P = 1$
Sitka Sound/Peril Strait, 2003 *vs.* 2004	n/a	n/a	n/a
Glacier Bay/Icy Strait, 2003 *vs.* 2004	$P = 0.707$	$P = 1$	$P = 1$

both years were pooled (Table 28, 29). For both years combined, whales in Glacier Bay/Icy Strait and Frederick Sound comprised the majority of the sample (Table 28). Whales assessed to have had a high likelihood of previous entanglement (E-codes E3 and E4) were distributed throughout the study area, with the majority located in Glacier Bay/Icy Strait (Table 28, Fig. 16).

Table 28. Number of whales assigned E-codes E0 – E4 by location of whale for both years combined.

Location (ADF&G District)	*n*	E0	E1	E2	E3	E4
W. Frederick Sound (9)	43	0	13	15	14	1
E. Frederick Sound (10)	18	0	5	8	5	0
Stephens Passage (11)	11	0	1	1	9	0
Chatham Strait (12)	6	1	1	1	3	0
Sitka Sound/Peril Strait (13)	6	0	0	2	4	0
Glacier Bay/Icy Strait (14)	96	1	17	20	57	1

Table 29. Entanglement scarring percentages by location for both years combined (95% confidence intervals).

Location (ADF&G District)	*n*	Minimal Scarring Percentage	Maximal Scarring Percentage	*n*	Conditional Scarring Percentage
W. Frederick Sound (9)	43	35% (21%, 51%)	70% (54%, 83%)	28	54% (34%, 72%)
E. Frederick Sound (10)	18	28% (10%, 53%)	72% (47%, 90%)	10	50% (19%, 81%)
Stephens Passage (11)	11	82% (48%, 98%)	91% (59%, 100%)	10	90% (55%, 100%)
Chatham Strait (12)	6	50% (12%, 88%)	67% (22%, 96%)	5	60% (15%, 95%)
Sitka Sound/Peril Strait (13)	6	67% (22%, 96%)	100% (54%, 100%)	4	100% (40%, 100%)
Glacier Bay/Icy Strait (14)	96	60% (50%, 70%)	80% (71%, 88%)	76	76% (65%, 85%)

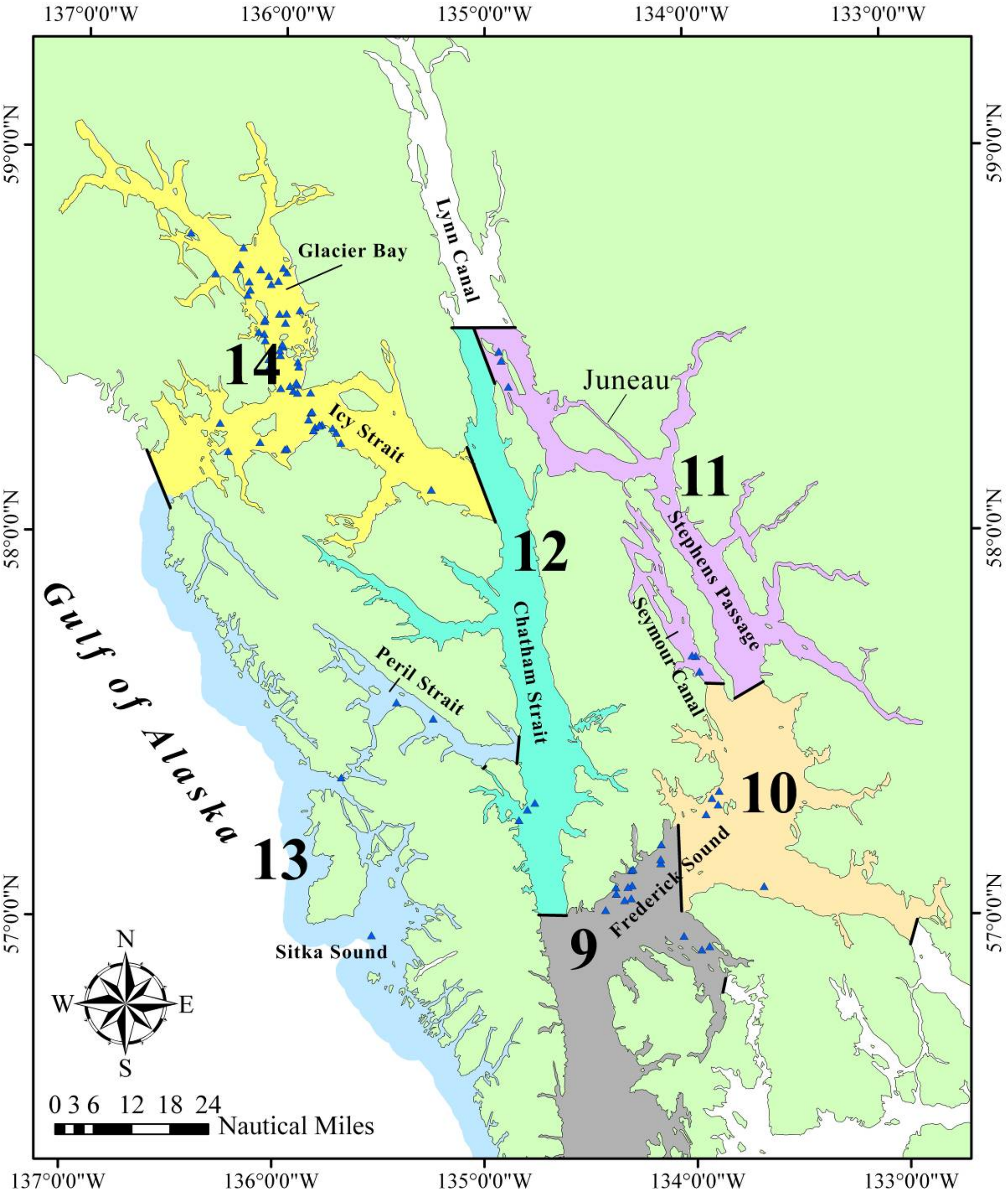

Figure 16. Geographic distribution of whales with a high likelihood of previous entanglement (E-codes E3 and E4) for both years combined ($n = 94$).

The minimal scarring percentage of whales in Glacier Bay/Icy Strait (60%) was higher than the minimal scarring percentages of whales in western Frederick Sound (35%) and eastern Frederick Sound (28%) and the differences were significant (*P* = 0.006 and *P* = 0.018, respectively, two-tailed Fisher's exact tests). Similarly, the minimal scarring percentage of whales in Stephen Passage (82%) was higher than the minimal scarring percentages of whales in western Frederick Sound (35%) and eastern Frederick Sound (28%) and the differences were significant (*P* = 0.007 and *P* = 0.008, respectively, two-tailed Fisher's exact tests). None of the other minimal scarring percentages were significantly different by location for both years combined (Table 30).

Table 30. Results of two-tailed Fisher's exact tests comparing minimal scarring percentages by location for both years combined.

Location	W. FS	E. FS	SP	CS	SS/PS	GB/IS
W. FS	-					
E. FS	*P* = 0.767	-				
SP	*P* = 0.007*	*P* = 0.008*	-			
CS	*P* = 0.656	*P* = 0.362	*P* = 0.280	-		
SS/PS	*P* = 0.190	*P* = 0.150	*P* = 0.584	*P* = 1	-	
GB/IS	*P* = 0.006*	*P* = 0.018*	*P* = 0.204	*P* = 0.682	*P* = 1	-

Note: W. FS = western Frederick Sound; E. FS = eastern Frederick Sound; SP = Stephens Passage; CS = Chatham Strait; SS/PS = Sitka Sound/Peril Strait; GB/IS = Glacier Bay/Icy Strait

* Indicates significant difference at α = 0.05

The conditional scarring percentage of whales in Glacier Bay/Icy Strait (76%) was higher than the conditional scarring percentage of whales in western Frederick Sound (54%) and the difference was significant (*P* = 0.031, two-tailed Fisher's exact test). None of the other conditional scarring percentages were significantly different by location for both years combined (Table 31). None of the maximal scarring percentages were significantly different by location (Table 32).

Table 31. Results of two-tailed Fisher's exact tests comparing conditional scarring percentages by location for both years combined.

Location	W. FS	E. FS	SP	CS	SS/PS	GB/IS
W. FS	-					
E. FS	P = 1	-				
SP	P = 0.059	P = 0.141	-			
CS	P = 1	P = 1	P = 0.242	-		
SS/PS	P = 0.128	P = 0.221	P = 1	P = 0.444	-	
GB/IS	P = 0.031*	P = 0.123	P = 0.447	P = 0.593	P = 0.570	-

Note: W. FS = western Frederick Sound; E. FS = eastern Frederick Sound; SP = Stephens Passage; CS = Chatham Strait; SS/PS = Sitka Sound/Peril Strait; GB/IS = Glacier Bay/Icy Strait

* Indicates significant difference at α = 0.05

Table 32. Results of two-tailed Fisher's exact tests comparing maximal scarring percentages by location for both years combined.

Location	W. FS	E. FS	SP	CS	SS/PS	GB/IS
W. FS	-					
E. FS	P = 1	-				
SP	P = 0.253	P = 0.362	-			
CS	P = 1	P = 1	P = 0.515	-		
SS/PS	P = 0.175	P = 0.280	P = 1	P = 0.455	-	
GB/IS	P = 0.186	P = 0.522	P = 0.685	P = 0.340	P = 0.588	-

Note: W. FS = western Frederick Sound; E. FS = eastern Frederick Sound; SP = Stephens Passage; CS = Chatham Strait; SS/PS = Sitka Sound/Peril Strait; GB/IS = Glacier Bay/Icy Strait

The results indicating a higher incidence of entanglement scarring in whales in Glacier Bay/Icy Strait (and possibly Stephens Passage) than in Frederick Sound are influenced by differences in the number of caudal peduncle photographs per whale and the amount of caudal peduncle photographic coverage per whale. For example, the median number of photographs per whale in Glacier Bay/Icy Strait (8.0) and Stephens Passage (5.0) was higher than in any other location, including Frederick Sound (4.0), and whales in Glacier Bay/Icy Strait had the highest amount of caudal peduncle photographic coverage (mean 1.9 sides) of whales in any location (Table 33).

Table 33. Number of caudal peduncle photographs per whale (range, median) and average amount of caudal peduncle photographic coverage per whale by location for both years combined.

	No. of caudal peduncle photographs per whale		Caudal peduncle photographic coverage
Location (ADF&G District)	Range	Median	Mean no. of sides
W. Frederick Sound (9)	1 - 10	4.0	1.7
E. Frederick Sound (10)	1 - 10	4.0	1.5
Stephens Passage (11)	1 - 8	5.0	1.7
Chatham Strait (12)	1 - 9	4.0	1.4
Sitka Sound/Peril Strait (13)	1 - 9	2.5	1.5
Glacier Bay/Icy Strait (14)	1 - 32	8.0	1.9

Commercial fisheries in northern SEAK

Commercial fishing occurs in all months of the year in northern SEAK, with the greatest number of fisheries open between June and October in the six ADF&G Districts that overlap with the study area (Fig. 17, Appendix 2). The extent of fishing in each fishery is highly variable between districts (Fig. 18), with some fisheries occurring in just one district (*e.g.*, the traditional common property drift gillnet fishery for salmon in District 11) and others widely dispersed over all six districts (*e.g.*, the Dungeness crab pot fishery).

In each fishery there are specific areas within a district where fishing activity is concentrated on the main fishing grounds (Appendix 2). Overall, there are fewer pot fisheries and more longlining for halibut in District 13 (Sitka Sound/Peril Strait) than in the other districts (Fig. 18). District 9 (western Frederick Sound) accounts for 33% of the Dungeness crab harvested from Districts 9 – 14 (Fig. 18) and this fishery occurs for an extended period when humpback whales are generally present (Fig. 17). A unique feature that District 11 (Stephens Passage) and District 14 (Glacier Bay/Icy Strait) share is a high level of fishing effort for Tanner crab; together, these two districts account for the majority (79%) of the Tanner crab harvested from Districts 9 – 14 (Fig. 18). However,

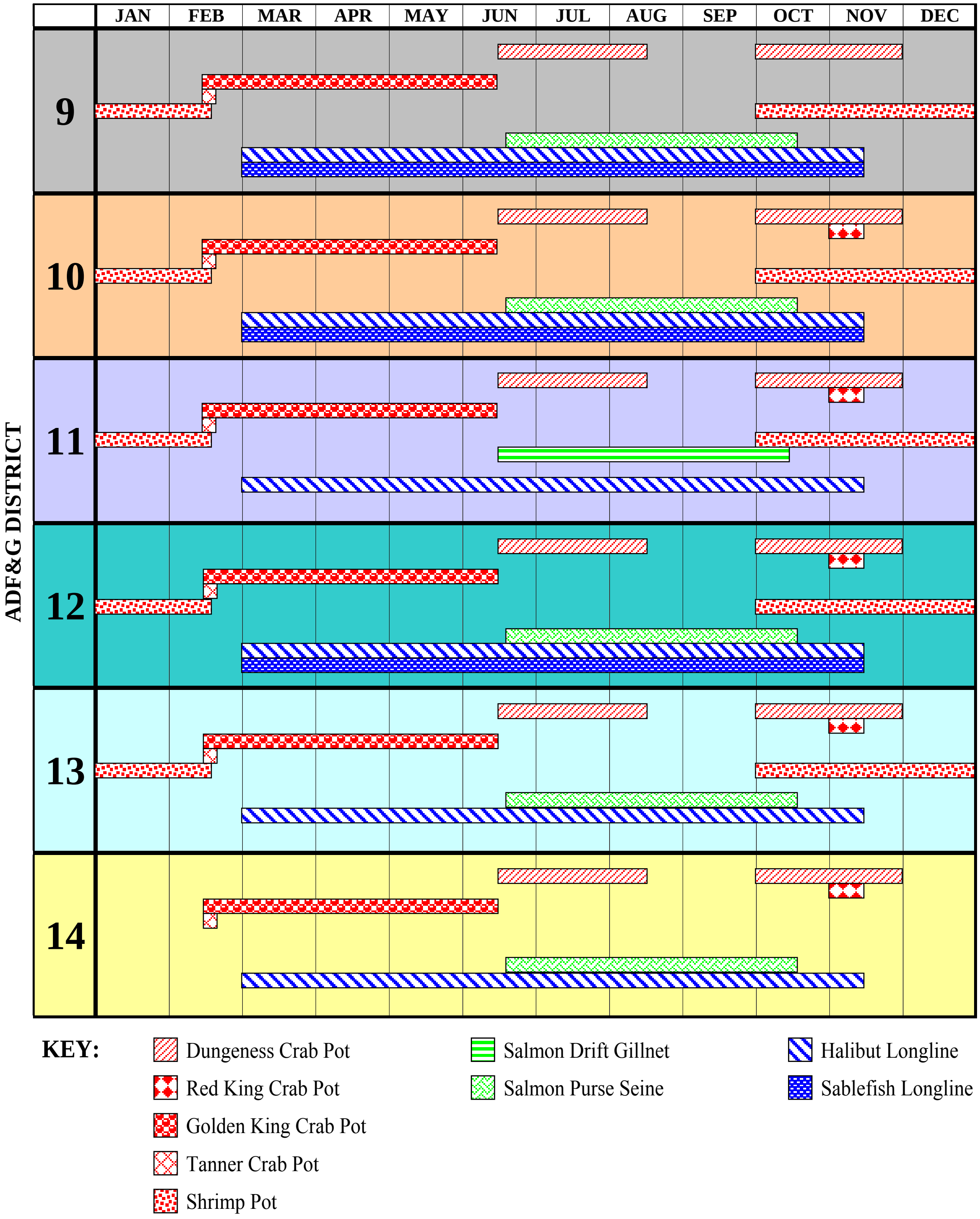

Figure 17. Summary of the general timing of commercial fishing seasons in the study area by ADF&G District. See Appendix 2 for maps showing the location of the main fishing grounds within each district.

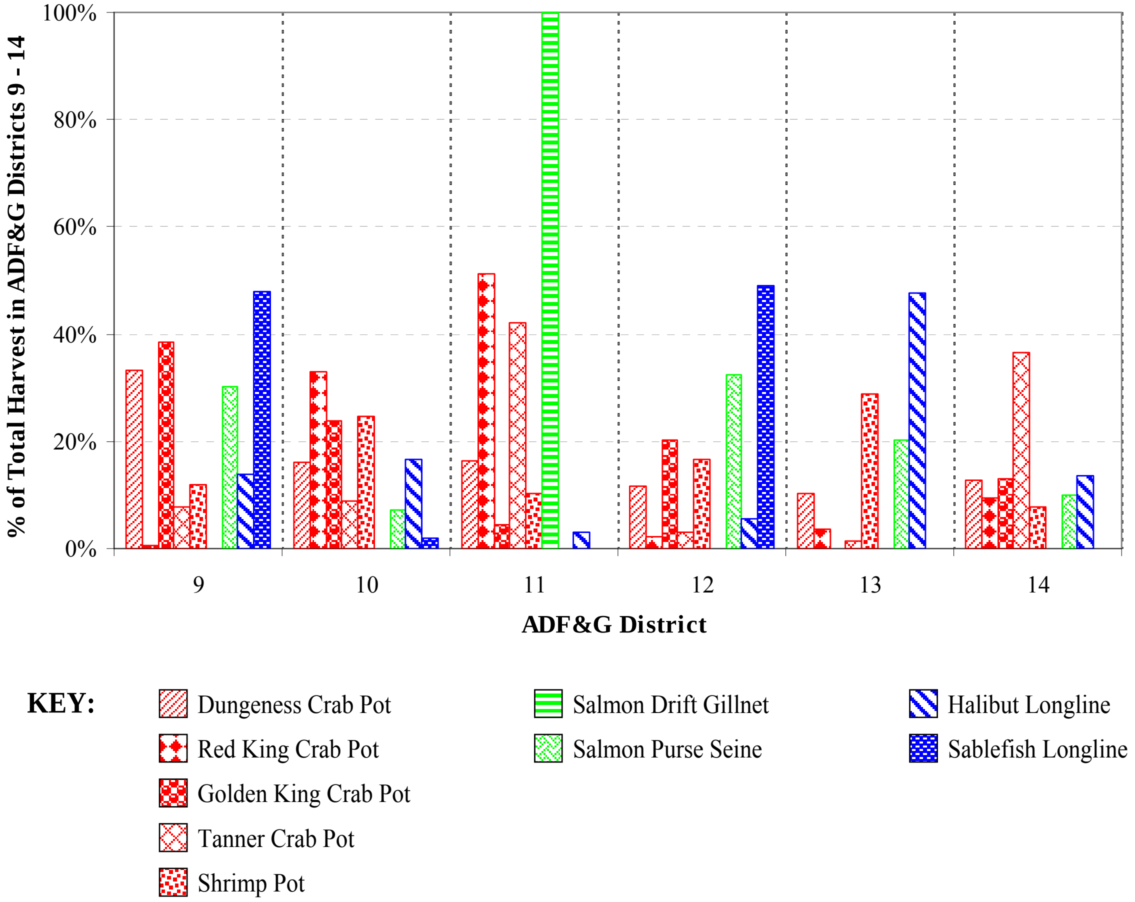

Figure 18. Percentage of total harvest (lb) in ADF&G Districts 9 – 14 for each fishery.

the Tanner crab fishery is only open for a few days in mid-February (Fig. 17), a time of year when few humpback whales are in northern SEAK, so interactions with this fishery alone are unlikely to account for the observed high entanglement scarring percentages in these two districts (Table 29). Districts 9 and 12 account for 97% of the sablefish longline harvested from Districts 9 – 14 and this fishery occurs during months when humpback whales are common (March – November). Districts 10 and 11 account for 84% of the red king crab harvested from Districts 9 – 14 (Fig. 18) but this fishery is only open for a short period in early to mid-November (Fig. 17). However, humpback whales are not uncommon in November, particularly in Seymour Canal (District 11) (Straley 1994), where some of the main red king crab fishing grounds are located (Appendix 2). Since 1999, Glacier Bay (District 14) has been closed to most commercial fishing (except Tanner crab fishing and longlining for halibut) (Appendix 2) which partially explains the relatively low harvest levels in District 14 compared to the other districts.

Discussion

Percentage of whales with non-lethal caudal peduncle entanglement scars

The minimal, conditional and maximal scarring percentages indicate that the majority (52% – 78%) of the humpback whales in northern SEAK have been entangled (Table 12). These cumulative estimates of scarring, combined with the rate at which new entanglement scars were detected between 2003 and 2004 (8%), reveal that entanglements are much more common in northern SEAK than previously thought based on reports of entangled whales. Nevertheless, a scar-based approach is expected to underestimate the true frequency of entanglement because whales that were entangled once were coded the same as whales that were entangled multiple times. In addition, whales with more photographs and/or photographic coverage may be more likely to be assessed as having been entangled, thus the caudal peduncle scar coding method may underestimate the incidence of entanglement for whales with fewer photographs and/or less photographic coverage. Finally, a scar-based approach cannot account for a) whales that died before they could be detected, b) entanglements that did not involve the caudal peduncle and c) entanglement injuries that were so old or faint that they had healed beyond recognition.

Entanglements in SEAK and the Gulf of Maine in similar types of gear appear to cause analogous scar patterns, even though a lack of photographs of entangled whales' caudal peduncles in SEAK prevented me from being able to ground-truth the entanglement scar coding method. The fact that whale #1019 was entangled as a calf (Appendix 1) but was assessed as having a low likelihood of having been entangled based on caudal peduncle scars 16 years later most likely demonstrates that some whales' entanglement scars can heal beyond recognition. Because calves undergo rapid somatic growth, entanglement scars acquired by calves may be even more likely to heal beyond recognition than entanglement scars acquired by adult whales. The pigmentation pattern on the ventral side of humpback whale calves' flukes is less stable than the pigmentation pattern on the ventral side of older whales' flukes (Carlson *et al*. 1990), so scarring patterns on calves' caudal peduncles might be similarly unstable. This hypothesis could be tested by collecting a time series of caudal peduncle photographs of calves and adults with documented caudal peduncle entanglements. Additional caudal peduncle photographs of the calf disentangled in Frederick Sound in 2004 (Fig. 2, 10) would contribute to such a dataset.

The minimal scarring percentages in northern SEAK in 2003 (54%) and 2004 (53%) (Table 12) are similar to the minimal scarring percentages documented in recent years for humpback whales in the Gulf of Maine (1997, 55%; 1998, 48%; 1999, 65%) (Robbins and Mattila 2001), but much higher than the minimal scarring percentage documented for humpback whales in Hawaii in 2002 (14%) (Robbins and Mattila 2004). The median number of caudal peduncle photographs per individual whale in the Hawaii study is unknown, but if it was low, this could have contributed to the lower minimal scarring percentage documented there. Another explanation for the lower value in Hawaii is that Hawaii has a seasonal aggregation of whales from multiple feeding grounds with different levels of fisheries interactions. The high percentage of whales with entanglement scarring migrating to Hawaii from northern SEAK could have been diluted by lower percentages of whales with entanglement scarring migrating to Hawaii from other North Pacific feeding grounds. If whales from some feeding areas have a lower frequency of entanglement scarring, this could mean that they experience fewer entanglements overall, or it could mean that they are entangled fatally more often. Caudal peduncle photographs of humpback whales on feeding grounds across the North Pacific were collected in 2004 and 2005 by researchers participating in the international humpback whale research program, Structure of Populations, Levels of Abundance and Status of Humpbacks (SPLASH) (www.cascadiaresearch.org/SPLASH/splash.htm). These data will be used to determine if entanglement scarring percentages are significantly different between various humpback whale feeding grounds in the North Pacific, allowing a test of this hypothesis. It is not known if entanglement scar tissues heal at comparable rates in different populations of humpback whales. Although there is no reason to believe that they would not, if they did heal at different rates this would confound any comparisons of scarring percentages for whales from different populations.

Conditional and maximal scarring percentages were not calculated in caudal peduncle entanglement scar studies in the Gulf of Maine or Hawaii. However, based on data collected annually in the Gulf of Maine between 1997 and 1999 and presented by Robbins and Mattila (2001), I calculated the Gulf of Maine conditional scarring percentages (1997, 84%; 1998, 68%; 1999, 85%) and maximal scarring percentages (1997, 89%; 1998, 78%; 1999, 88%). These percentages are similar to the conditional and maximal scarring percentages calculated for humpback whales in northern SEAK (Table 12).

The proportion of ambiguously scarred whales in northern SEAK (24%) is comparable to what has been documented on average in the Gulf of Maine (28%) (Robbins and Mattila 2001). Whales with an ambiguous entanglement history (E-code E2) likely represent animals that have experienced less severe entanglements, animals with entanglement wounds that have healed partially and/or animals with wounds from other sources. Presenting a range of entanglement scarring percentages (*e.g.*, minimal, conditional and maximal) allows readers to decide which value they believe is closest to the true percentage of non-lethally entangled whales, depending on how they view whales with an ambiguous entanglement history.

Recommended estimate

The results from this study indicate that the conditional scarring percentage (71%), which excludes whales with ambiguous scars (E-code E2), is the most defensible of the three scarring estimates. Difficulties associated with coding E2 whales (as revealed by comparing E-codes with Robbins), combined with E2 whales' ambiguous entanglement histories (by definition) are compelling reasons to use the conditional approach. In addition, the conditional scarring percentage appears to be more robust than the minimal scarring percentage to variation in the amount of photographic coverage of the caudal peduncle (*i.e.,* one side *vs*. both sides). The conditional scarring percentage is also more robust than the minimal scarring percentage to variation in the number of whales assigned E-code E2 (ambiguous entanglement history) *vs*. E-code E3 (high likelihood of previous entanglement). Finally, the conditional scarring percentage is more robust than the maximal scarring percentage to variation in the number of whales assigned E-code E2 (ambiguous entanglement history) *vs*. E-code E1 (low likelihood of previous entanglement).

One limitation against using the conditional approach is that it results in smaller sample sizes (and wider confidence intervals), but that outcome in this study was inconsequential. In addition, the conditional scarring percentage appears to be less robust to variation in the number of caudal peduncle photographs per individual whale (less than 10 photographs *vs*. 10 or more photographs) than the maximal scarring percentage.

Annual rate of entanglement scar acquisition

Minimal, conditional and maximal scarring percentage estimates offer insight into the cumulative number of animals in a population that have been entangled. However, measuring the number of whales that acquire new entanglement scars over a specific period of time is a more sensitive indicator of the magnitude of the entanglement problem, especially given the long-term stability of some caudal peduncle entanglement scars (Appendix 1; Robbins and Mattila 2001, 2004), the potential for others to heal beyond recognition (*e.g.*, whale #1019 (Appendix 1)) and the fact that whales may be entangled multiple times (*e.g.*, whale #351 (Fig. 15); whale #1018 (Appendix 1)). Eight percent of the whales in Glacier Bay and Icy Strait were estimated to have acquired new entanglement scars between 2003 and 2004, although this estimate is highly uncertain (95% CI: 1%, 25%). Similar rates of annual entanglement scar acquisition were found in the Gulf of Maine from 1997 through 2002 (8% – 25%) (Robbins and Mattila 2004).

Clearly, more whales are being entangled (and self-releasing from gear) in northern SEAK than are reported currently to the NOAA Fisheries Alaska Regional Office.

Overall, the entanglement scarring percentages revealed by this study indicate that the majority of humpback whales in northern SEAK have been entangled at some point in their lives and that most apparently shed the gear on their own, unless whales are being disentangled by humans much more often than is reported. Observations of humpback whales and other cetaceans immediately following entanglement in fishing gear indicate that high energy behaviors such as thrashing, shaking, rolling and breaching are common (Mann *et al*. 1995; Weinrich 1999). Depending on the nature of the entanglement, these behaviors may result in entangled animals successfully shedding the entangling gear by shaking it loose and/or breaking the material so that it falls off. In August 2005, a humpback whale was observed as it became entangled around the caudal peduncle in a shrimp pot line near Sitka, Alaska, but after 3 – 4 minutes of breaching and rapid swimming the whale broke free of the gear.[23] It is not known if an entanglement of such short duration would produce diagnostic caudal peduncle entanglement scarring (no photographs were taken) but this incident clearly demonstrates that some humpback whales are sometimes capable of self-releasing without human intervention.

The reporting rate of entanglements in northern SEAK could not be calculated due to a lack of photographic identifications of entangled whales in this region. The entangled calf in Figures 2 and 10 is the only animal out of 13 whales reported entangled in SEAK in 2003 and 2004 that was photographically identified. If more whales that were reported entangled in SEAK had been photographically identified, then it would have been possible to compare their identities with the identities of the whales that were assessed to have been entangled based on an increase in scarring, and thus estimate the reporting rate of entanglements to NOAA Fisheries. For instance, if 10 individually identified whales gained new entanglement scarring between 2003 and 2004, but only one of these 10

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[23] Personal communication from Barth Hamberg, 206 Shotgun Alley, Sitka, AK 99835, August 2005.

whales was reported to be entangled, then this would equate to a reporting rate of 10%. (Note that calculating the reporting rate hinges on photographically identifying the whales that are reported entangled so that their records can be linked with the entanglement scar data.) In this study, the small sample size of whales with an increase in scarring between years (*n* = 2) would have generated an imprecise estimate of the reporting rate in northern SEAK. Increased efforts to photographically identify entangled whales in SEAK, combined with continued efforts to use caudal peduncle scarring to detect whales that have been entangled over a specific time period, are needed in order to generate an estimate of the reporting rate of entanglements in northern SEAK.

Continuing and expanding efforts to measure the annual rate of entanglement scar acquisition in SEAK offers a systematic way to monitor entanglements in this region. In the event that management initiatives are implemented with the aim of preventing entanglements (*e.g.*, reducing the amount of gear in the water column), the annual rate of entanglement scar acquisition might be an indicator of success; presumably the rate would decrease if prevention is effective. If management initiatives are implemented with the aim of simply reducing the severity of entanglements (*e.g.*, gear modifications such as weak links in fishing lines and/or nets), the annual rate of entanglement scar acquisition may not decrease (Knowlton *et al*. 2005), because even entanglements that last for less than a day can produce diagnostic, persistent scarring (Robbins and Mattila 2004). In fact, the annual rate of entanglement scar acquisition may even increase if whales that previously would have died from entanglements survive to be photographed.

Humpback whales off Newfoundland and Labrador were rarely documented becoming entangled more than once (Lien 1994) but photographs from this study (*e.g.*, whale #351 (Fig. 25)) and the GBNPP archives (*e.g.*, whale #1018 (Appendix 1)) demonstrate that at least some humpback whales in northern SEAK have been entangled multiple times. In a scar-based study of North Atlantic right whales, the number of entanglements per individual (*n* = 447) ranged from zero to six (mean = 1.4 entanglements per animal)

(Knowlton *et al*. 2005). It is not known if entanglements are caused by whales accidentally colliding with gear and/or by whales actively seeking out and investigating gear in their environment. If the former is true, some whales may be at greater risk of multiple entanglements than others if they spend more time in areas with greater quantities of fishing gear or if they have some behavioral or sensory deficit that makes it more difficult for them to detect gear. Alternatively, if some whales are more inquisitive and likely to investigate gear than others, this could explain why some whales get entangled multiple times, others get entangled once and some never get entangled. Humpback whales of all ages have been observed rolling and twisting in beds of kelp, often draping the strands of kelp across different body parts.[24,25]

Identification of vulnerable segments of the population

Sex

The minimal scarring percentages from this study indicate that male humpback whales may be more likely to become non-lethally entangled than female humpback whales (Table 18). Between 1997 and 1999, Robbins and Mattila (2001) also documented a significantly higher percentage of male humpback whales with entanglement scarring compared to females. However, based on recent data they no longer believe that males are more likely to be entangled than females (Robbins and Mattila 2004). They speculate that the distribution of high-risk fishing gear in the Gulf of Maine and/or the geographic foraging patterns of female whales have changed in recent years such that now nearly equal percentages of males and females have entanglement scars (Robbins and Mattila 2004). Knowlton *et al*. (2005) found no significant differences by sex in the number of North Atlantic right whales with entanglement scars from 1980 through 2002.

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[24] Personal communication from Jan Straley, University of Alaska Southeast, 1332 Seward Ave. Sitka, AK 99835, March 2006.

[25] GBNPP unpublished data.

It is unknown why male humpback whales in northern SEAK would have a higher minimal entanglement percentage than females. The fact that males' and females' maximal and conditional scarring percentages were not significantly different indicates that the difference in minimal scarring percentages is attributable to differences in the number of whales of each sex with an ambiguous entanglement history. Thus, the higher proportion of females than males that were assessed to have an ambiguous entanglement history (females 24%; males 6%) explains the observed difference in minimal scarring percentages. The scarring percentage estimates based on sex may also have been influenced by differences in the number of caudal peduncle photographs that were available for males and females (Table 19). It is unknown why the median number of caudal peduncle photographs was higher for males than for females in both years. It was assumed that all whales had an equal chance of being photographed, but there may have been behavioral differences between males and females that made it easier to obtain caudal peduncle photographs of males. For example, many females with calves were present in the study area in 2004 and it is possible that these females were less likely to tolerate close approaches by the survey vessel due to the presence of their calves.

It seems unlikely that my interpretation of caudal peduncle scars on male humpback whales was confounded by breeding ground injuries. Robbins and Mattila (2004) investigated this possibility and concluded that caudal peduncle scars from breeding ground injuries are unique and unlikely to be confused with entanglement scars. While a specific study of age-sex segregation of humpback whales in SEAK has not been conducted, there are no indications that male and female humpback whales select different habitats in SEAK[26,27] where the distribution of fishing gear may pose different levels of risk. However, differences between the sexes in the timing of migration (Gabriele 1992; Craig *et al*. 2003) could potentially expose males to more opportunities

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[26] Personal communication from Christine Gabriele, GBNPP, PO Box 140, Gustavus, AK 99826, November 2005.

[27] Unpublished data, J. Straley Investigations, PO Box 273, Sitka, AK 99835.

for fisheries interactions throughout their annual range. Another possible explanation is that males may be more inquisitive and likely to investigate gear that they encounter than females (*e.g.,* Harris and Knowlton 2001). Male-biased mortality among nonhuman mammals has often been explained in terms of more risky behaviors by males compared with females, but generally these risky behaviors are associated with competition for females (Owens 2002), making this an unlikely explanation for the difference in minimal scarring percentages that I observed.

The reason why more females than males were assessed to have an ambiguous entanglement history (E-code E2) is unclear. If whales assigned E-code E2 represent whales with entanglement scars that have healed beyond recognition, then perhaps male humpback whales "fight" entangling gear more intensely than females, which could produce more severe injuries that are less likely to heal into ambiguous E2-type patterns. Alternatively, if female humpback whales live longer on average than male humpback whales (a pattern documented in many mammalian species (Owens 2002)), then the higher proportion of ambiguous marks on females could be explained by females having a greater chance than males of living long enough to have their entanglement scars heal beyond recognition. Average and maximum life expectancies in humpback whales are poorly understood (Clapham and Mead 1999), making it difficult to determine if this is a contributing factor.

Age

The minimal and conditional scarring percentages suggest that non-lethal entanglement scarring is significantly less common in calves than in older whales (Table 23). It is unlikely that these results were affected by differences in the number of caudal peduncle photographs obtained per whale in each age group because the median number of photographs and amount of photographic coverage were similar between groups (Table 24). A lower incidence of scarring in calves is expected because calves had less time to accumulate entanglement scarring than adults. However, the minimal scarring percentage of calves in northern SEAK (17%) was higher than in the Gulf of Maine, where only 9% of calves were assessed to have been entangled (Robbins and Mattila 2001), but this is not a significant difference. Continued sampling of calves in SEAK would elucidate if the scarring percentages found during this study are typical.

Juvenile humpback whales in the western north Atlantic (Lien 1994; Robbins and Mattila 2001), juvenile North Atlantic right whales (Knowlton *et al*. 2005), juvenile gray whales (Heyning and Lewis 1990) and juvenile northern fur seals (Fowler 1985) appear to have significantly higher rates of entanglement than older animals. In this study, the sample size of juveniles (*n* = 3) was too small to estimate the entanglement scarring percentage. It would be useful to sample more juvenile whales to determine if whales in this age classes are at a higher risk of non-lethal entanglement than whales in other age classes.

It is thought that calves and juveniles probably have a higher mortality rate from entanglements than adult whales because 1) they are growing, so gear is more likely to become embedded, which may lead to lethal infections and/or restricted circulation, and 2) calves and juveniles may not have the strength necessary to break free from entangling gear due to their smaller size (Knowlton *et al*. 2005). If younger animals have a higher mortality rate from entanglements than older animals, this could explain the low incidence of calves bearing entanglement scars in SEAK because a disproportionate number of the calves could have died as a result of being entangled. Humpback whale calves off the Pacific coast of Colombia were significantly more likely to be found dead from entanglement than adults (Capella Alzueta *et al*. 2001). Between 1979 and 1995, the estimated calf mortality rate in the CNP stock was 15% – 24% but the causes of most of these mortalities are unknown (Gabriele *et al*. 2001).

Location

The analysis of scarring percentages by whale location suggests that whales in Stephens Passage and Glacier Bay/Icy Strait may be at a higher risk of entanglement than whales in Frederick Sound (Table 29). These results were likely to have been influenced by differences in the number of caudal peduncle photographs available for whales in different locations, in particular the anomalously high number of photographs available for whales in Glacier Bay/Icy Strait (Table 33).

The ADF&G District where a whale with entanglement scarring was photographed does not mean that this is the location where the whale was entangled. There is no way to know where a whale is entangled unless it is photographically identified at the time it becomes entangled. The high proportion of whales that were documented in only one district supports previous research indicating that the majority of humpback whales in northern SEAK exhibit a high degree of site fidelity to specific local feeding areas (Straley *et al*. 2002). Assuming that most entanglements occur in SEAK (not during the migration and/or on the breeding grounds), the tendency for whales to spend time in the same localized areas in northern SEAK each year means that it may not be unreasonable to draw inferences about where a whale became entangled based on where the whale was sampled in this study.

Identifying where entanglements are occurring could help identify which commercial, sport and/or subsistence fisheries are problematic and could lead to management strategies to reduce the risk of entanglement. One approach that could be useful would be to compare caudal peduncle photographs of individual whales on the breeding grounds with caudal peduncle photographs of the same whales taken within the same year on the feeding grounds. For whales that gain new entanglement scarring, these comparisons could reveal where the whale was when it acquired the new scars (*e.g.,* Hawaii or Alaska), and therefore might help pinpoint which fishery was involved in the entanglement. The caudal peduncle photographs collected as part of the SPLASH program could be used to investigate this question if sample sizes of photographs of the same individual whales from both the breeding and feeding grounds are sufficient.

Commercial fisheries in northern SEAK

Although nearly half of the entanglements reported in SEAK from 1997 through 2004 involved pot gear (Fig. 5), currently the majority of the commercial pot fisheries in SEAK occur during the winter months (Fig. 17), when humpback whale numbers are generally low compared to the summer months. However, based on the number of entanglements reported to involve pot gear, re-categorizing some or all of the commercial pot fisheries in SEAK from Category III to Category I or II may need to be considered. The only commercial pot fishery that consistently overlaps in time with the summer peak in humpback whale presence in SEAK is the Dungeness crab pot fishery. Sport pot gear poses an additional risk of entanglement to humpback whales year-round, especially in the summer months when it is most commonly in use. For example, the summer personal use red king crab pot fishery near Juneau (Appendix 2) may be problematic for some whales, as evidenced by a humpback whale calf that was disentangled from personal use red king crab pot gear that was set near Juneau in September 2005.[28]

It is not known how many humpback whales are in SEAK during the late fall and winter, however some whales are known to be present in the fall and winter and at least 10 individuals have been documented over-wintering near Sitka[29], despite minimal or no photographic identification effort in the winter in most parts of SEAK. Whales that are present in SEAK during the fall and winter are exposed to commercial red and golden king crab, Tanner crab and shrimp pot fisheries, which might put them at a higher risk of entanglement than whales that have left SEAK to migrate to the breeding grounds. With the exception of golden king crab, the commercial fall/winter pot fisheries are generally open for only brief periods, which would presumably lower the probability of entanglement. Nevertheless, entanglements are known to occur when these fall/winter fisheries overlap temporally and spatially with humpback whales that remain on the feeding grounds. For example, in December 2000, a humpback whale was disentangled

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[28] Unpublished data, NOAA Fisheries Alaska Regional Office, PO Box 21668, Juneau, AK 99802.

[29] Unpublished data, J. Straley Investigations, PO Box 273, Sitka, AK 99835.

from a commercial shrimp pot longline after becoming anchored at the surface by the gear near Skagway, Alaska.[30]

This study highlights the need for better data describing the distribution and amount of commercial (as well as sport and subsistence) fishing gear in SEAK. Harvest data were used in the current analysis as a proxy for fishing effort (*i.e.,* amount of gear in the water) because they were the only data available. This information gap is not unique to SEAK; it has been identified in many investigations of cetacean entanglement throughout the world (Lien 1994; Harwood 1999; Lewison *et al*. 2004; Johnson *et al*. 2005; Knowlton *et al*. 2005). Describing the distribution of fishing effort in other parts of SEAK humpback whales' known annual range (*i.e.,* Hawaii, northern British Columbia and the high seas of the Central North Pacific) was beyond the scope of this study, but these data are needed to fully understand the relative levels of risk that humpback whales face from fisheries interactions throughout the year.

It is difficult to make generalizations about the distribution and amount of commercial fishing effort in northern SEAK because of the variation in gear types, fishing grounds and open seasons for each fishery. The synthesis of commercial fishing effort on the basis of ADF&G Districts (Fig. 17, 18) was largely inconclusive and revealed few plausible explanations for the observed differences in entanglement scarring percentages between districts. The drift gillnet fishery in District 11 (Stephens Passage) could have contributed to the high percentage of whales there with entanglement scars (Table 29), but this relationship is only circumstantial without additional evidence. The difficulty of correlating fishery harvest levels with the entanglement scar results is highlighted by the fact that harvest levels in Glacier Bay/Icy Strait (District 14) are relatively low (Fig. 18) but the percentage of whales with entanglement scars there is relatively high (Table 29). For most commercial fisheries, harvest data are available at a finer geographic scale than the units used in this study (*e.g.,* ADF&G sub-districts), however it was beyond the scope

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[30] Unpublished data, NOAA Fisheries Alaska Regional Office, PO Box 21668, Juneau, AK 99802.

of this study to conduct a more detailed analysis of the complex temporal and spatial patterns in commercial fishing activity in northern SEAK.

Given the longterm stability of caudal peduncle entanglement scars, the current distribution and types of commercial fishing gear in SEAK are unlikely to reflect the distribution and types of fishing gear in SEAK at the time many of the scarred whales became entangled. For instance, the distribution of gear in Glacier Bay has changed substantially since many of the commercial fisheries there were closed in 1999 (Appendix 2). In general, it appears that the level of risk posed to whales by commercial fishing gear in SEAK may have been higher in the mid to late 20th century compared to today because many fisheries were open for longer seasons (if not year-round), with fewer restrictions on the amount or type of gear that could be fished (Appendix 2). However, some fisheries may pose a greater risk to whales today than they did historically. For example, with the implementation of halibut and sablefish IFQs in 1995 (Appendix 2), the temporal and spatial distribution of longline gear in SEAK changed dramatically, resulting in a much longer period of time in which whales are exposed to the gear than before 1995. On the other hand, a slower-paced fishery dispersed in time and space may pose less risk.

While the specific circumstances that led to most past entanglements will never be known, a description of the current distribution of commercial, subsistence and sport fishing gear in SEAK which overlaps with areas of high whale numbers seasonally would increase managers' understanding of sources of current potential threats to this population on a regional scale and could help inform management actions aimed at preventing entanglements. This approach would entail identifying areas where humpback whales regularly concentrate in SEAK and examining how these areas overlap with fishing "hotspots" to identify areas that may warrant monitoring and/or special protection.

Although it is beyond the scope of this study to make fishery management recommendations, it would be useful to work with commercial, sport and subsistence fishermen to ground-truth the data describing how often different fishing gear types are involved in humpback whale entanglements in Alaska (Fig. 5). Developing ways for fishermen to report entanglements without fear of retribution are needed to encourage reporting. Another strategy would be to require participants in each fishery to use uniquely colored line that would allow for identification of the gear types involved in entanglements. Also, placing observers on vessels engaged in Category II fisheries in SEAK (*i.e.,* drift gillnet and purse seine vessels) would help ground-truth the relatively low rate of reported entanglements that involve these gear types. Further investigation would be necessary to determine if these measures are feasible.

Fishing gear modifications

Researchers and managers working to reduce right and humpback whale entanglements in the western North Atlantic have identified several fishing practices that have the potential to reduce the frequency and/or severity of entanglements (Johnson *et al*. 2005).[31] Their primary recommendation is to reduce the amount of vertical line in the water column, because having less line and/or slack in the water column presumably reduces the chance that a whale will become entangled. One way to accomplish this would be to replace some floating line with sinking line. Unlike sinking line, the slack in a floating line floats in the water column instead of resting on the ocean floor, posing a potential threat of entanglement to a whale. In recent years, participants in the New England lobster pot and sink gillnet fisheries have reduced the amount of floating line they use by replacing portions of it with sinking line to reduce the risk of entanglement to whales (Kozuck 2003). It remains to be seen if this action results in a reduction in entanglements. In SEAK, commercial Dungeness crab pot and longline fishermen typically do not use floating line. However, floating line is used on commercial red king

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[31] NOAA Fisheries and Marine Mammal Commission Gear Workshop, North Falmouth, MA. October 13 – 15, 2004.

crab, golden king crab, Tanner crab and shrimp pots, as well as sport crab and shrimp pots (Appendix 2). Encouraging these commercial and sport pot fishermen to use sinking line instead may be one way to reduce the risk of entanglement for humpback whales in SEAK.

Lost fishing gear

Lost fishing gear likely poses an additional risk of entanglement to humpback whales, but the quantity and rate of gear losses in SEAK are unknown. Losses may occur for many reasons, including weather, vessel propellers cutting surface buoy lines, vandalism, human error and gear failure (Laist 1996). If a surface buoy line is cut and it is sinking line, presumably the gear sinks to the bottom and poses less of a threat to humpback whales than it would in the water column. But if the surface buoy line is floating line or the gear drifts into deeper water, then the gear may still be vertical in the water column, presumably continuing to pose a risk of entanglement. No systematic efforts exist to quantify the rate of pot loss in SEAK.[32] Surveys from other areas in the United States and Canada indicate that 10% – 30% of the commercial pots used annually are lost (Laist 1996). Pot-loss rates are thought to be significantly lower in SEAK because of the pot limits imposed on the commercial fisheries and because the fishing grounds in SEAK tend to be in waters more protected from storms than the fishing grounds where the other estimates originated.[33] One commercial Dungeness crab fishermen in northern SEAK estimated that he loses approximately 8% –13% of his pots each year for various reasons.[34] Pot-loss rates are reportedly similar in the commercial golden king crab fishery (approximately 10%), and minimal in the commercial red king crab fishery, presumably due to the short length of the season.[35] The IPHC uses logbook data to

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[32] Personal communication from Gretchen Bishop, ADF&G Commercial Fisheries Division, 802 Third St, Douglas, AK 99824, October 2005.

[33] *Ibid.*

[34] Personal communication from Gene Farley, commercial fisherman, PO Box 182, Gustavus, AK 99826, November 2005.

[35] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

estimate the number of halibut longline skates that are lost or abandoned annually; one halibut fishermen in northern SEAK estimated that he loses approximately 1 – 2 skates per year.[36] No systematic efforts exist to quantify the rate of gear loss in sport and subsistence fisheries in SEAK.

Lessons learned from applying the scar coding method

Any application of the caudal peduncle scar coding method to other humpback whale populations should be preceded by an initial training period similar to that used in this study (*i.e.*, repetitive attempts by the same person to code a sample of caudal peduncle photographs, combined with a comparison of E-codes with an expert such as Robbins.) Because of the subjectivity inherent in entanglement scar coding, it is essential that the coding be done by as few people as possible to ensure maximum consistency in the assignment of codes. However, a small percentage of cases will always exist in which slight differences in the angle or lighting of photographs influence the coding process (*e.g.,* Table 13; Robbins and Mattila 2004).

The results from this study demonstrate that the amount of photographic coverage and the number of caudal peduncle photographs collected per individual whale may influence the entanglement scarring percentages (Table 7, 10; Fig. 12). It is not surprising that I was more likely to assign E-code EX to whales with less photographic coverage. However, because the minimal scarring percentage is not robust to variation in the amount of photographic coverage of the caudal peduncle (one side *vs.* both sides), if this approach is employed, future efforts to collect data should focus on obtaining photographs of both sides of the caudal peduncle to increase the chances of detecting wrapping marks. More testing is needed to determine the optimum number of caudal peduncle photographs necessary to generate a stable estimate of the percentage of whales with entanglement scars. This could be accomplished by randomly selecting one caudal peduncle

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[36] Personal communication from Paul Barnes, commercial fisherman, PO Box 155, Gustavus, AK 99826, November 2005.

photograph of each whale and assigning an E-code, then adding one photograph at a time (in randomized, blind trials) to determine when the increase in the number of photographs stops significantly influencing the entanglement scarring percentage.

Learning to collect adequate quality caudal peduncle photographs in the field requires practice and this partially explains the increased proportion of adequate quality photographs in the second year of this study. Anyone planning to conduct a caudal peduncle entanglement scar study should practice taking caudal peduncle photographs in advance of attempting a full-scale study. Data collection with a digital camera, not a 35mm camera with black and white film (as historically used in humpback whale photo-identification studies), is recommended. The full conversion to digital data collection in 2004 contributed to the higher proportion of adequate quality photographs in 2004 because of the immediate feedback provided by digital technology. Furthermore, most digital SLR cameras magnify the focal length of the camera lens. For example, a 300mm lens on a Nikon film camera magnifies the subject 6x but the same 300mm lens on a Nikon digital camera magnifies the subject 9x (Nikon, Inc. 2003). Robbins and Mattila (2004) found that color images were preferable to black and white images for the detection of raw entanglement injuries. In some cases, raw injuries offer valuable insights into how recently a whale was entangled; however not all raw injuries are accurate indicators of a recent entanglement, as demonstrated by humpback whales with raw injuries that have persisted for eight (Robbins and Mattila 2004) to 10 years or more (whale #166, Appendix 1).

In an attempt to track the frequency of serious injuries as defined by the MMPA, Robbins and Mattila (2001) defined two types of whales with a high likelihood of previous entanglement: whales with minor tissue damage (E-code E3) and whales with major tissue damage (E-code E4). The proportion of whales in northern SEAK that were assessed to have major tissue damage (0% – 2%) is similar to the proportion documented in the Gulf of Maine (1% – 3%) (Robbins and Mattila 2001). However, recent evidence indicates that whales with minor external injuries may die from fisheries interactions; therefore the frequency of E4 whales is now considered a poor correlate to serious injury and mortality rates (Robbins and Mattila 2004). Based on this finding and also a lack of management applications for distinguishing between E-codes E0 and E1, I recommend simplifying the entanglement scar coding method by reducing the number of E-codes from a total of six categories (likelihood of past entanglement: unknown, none, low, ambiguous, high, high) to a total of four categories (likelihood of past entanglement: unknown, low, ambiguous, high.) This could be accomplished by combining E-codes E0 and E1 into a single 'low' likelihood category and E-codes E3 and E4 into a single 'high' likelihood category, while leaving the 'unknown' and 'ambiguous' categories the same.

Management recommendations

Better photographic documentation of entangled humpback whales in SEAK is needed because photographs have the potential to elucidate the type of material attached to the whale (*e.g.*, net, rope, buoys), the body parts involved in the entanglement, the severity of the whale's injuries, the size of the whale and the identity of the whale. These data are essential to managers and fishermen trying to develop ways to prevent or mitigate the severity of entanglements. In addition, photographic documentation of entanglements has proven invaluable to experts when evaluating the condition of entangled whales, deciding if they are candidates for disentanglement and planning how to attempt to remove the gear.[37] This study would have benefited from having more historic photographs of entangled whales in SEAK because photographs would have allowed for ground-truthing of the entanglement scar coding method for humpback whales in SEAK. Over the long-term, a dataset of photographically identified entangled whales and subsequent sightings of the same whales "gear-free" would allow managers to estimate minimum survival rates of entangled whales and to generate more specific determination criteria for what constitutes a serious injury under the MMPA.

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[37] Personal communication from Jan Straley, University of Alaska Southeast, 1332 Seward Ave. Sitka, AK 99835, November 2005.

Clearly, photographs have the potential to yield important information, but their utility is limited. Photographs rarely reveal the type of fishing gear or which part of the gear (*e.g.*, groundline *vs.* surface buoy line) is entangled on the whale (Johnson *et al*. 2005).[38] These data are essential to managers and fishermen trying to prevent or mitigate the severity of entanglements. In the western North Atlantic, the type of entangling fishing gear was identified 88% of the time when entangled whales were observed by knowledgeable observers (*e.g.*, fishermen, biologists) and/or when the entangling gear was recovered. Thus, expanding the humpback whale stranding and disentanglement response network in Alaska has the potential to greatly increase the quantity and quality of data describing which types of fishing gear and which parts of the gear pose the greatest threats to humpback whales in this region, with the ultimate goal of informing initiatives aimed at preventing entanglements.

The Atlantic Large Whale Disentanglement Network (ALWDN) administered by the Provincetown Center for Coastal Studies in Provincetown, MA, offers a successful model.[39] An ALWDN-style network of "first responders" who are trained to document entangled whales could greatly improve the amount of information available on entanglements in Alaska. Increasing the number of fishermen, biologists and others who are trained and authorized to disentangle whales may not only increase the survival of individual whales by freeing them from gear, but in many cases may also lead to positive identifications and/or recovery of the entangling gear. In recognition of the importance of developing and expanding the entanglement response network in Alaska, NOAA Fisheries sponsored a two-day advanced disentanglement training workshop for whale researchers and state and federal agency personnel in Bartlett Cove, Alaska in September 2005.

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[38] Unpublished data, NOAA Fisheries Alaska Regional Office, PO Box 21668, Juneau, AK 99802.

[39] http://www.coastalstudies.org/what-we-do/whale-rescue/disentanglement-network.htm, accessed November 3, 2005.

Humpback whale-fisheries interactions in northern SEAK may warrant a similar level of management scrutiny as the Gulf of Maine where entanglement has been identified as a substantial management concern, based on similarities in the amount of non-lethal entanglement scarring between the two populations. Additional information is needed to identify the specific fisheries and locations that pose the greatest threats to humpback whales in northern SEAK. Increasing efforts to gather data from entangled whales in northern SEAK and throughout the Central North Pacific could lead to insights into potential preventative measures.

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Appendix 1

Historic Case Studies

Black and white humpback whale photographs from Glacier Bay and Icy Strait collected annually from 1985 through 2002[40] were reviewed to look for case studies that would offer insight into the stability of caudal peduncle scars, the persistence of raw wounds and the occurrence of repeated entanglements of the same individual. Caudal peduncle images of known individuals and ventral fluke photographs of known individuals that showed wrapping injuries along the leading edge of the flukes and/or ventral caudal peduncle were scanned at 4000 dpi using a 35mm negative film scanner (Nikon Coolscan 4000ED with Nikon Scan v.3.1.2 software).

Few adequate caudal peduncle photographs were found, but several historic photographs provided insights into scar longevity (Fig. 19, 20) and the persistence of a raw caudal peduncle wound (Fig. 21). Distinct wrap marks visible in fluke photographs of whale #1018 from 1996 and 2002 illustrate that this female has been entangled more than once (Fig. 22).

One whale was photographed that is known to have been entangled previously. Whale #1019, first documented in 1988 as a calf, was reported to be entangled in a line and towing a buoy in Icy Strait on August 8, 1988. This whale had been sighted July 28, 1988 with no apparent trailing gear, therefore the entanglement was likely less than 10 days old when first reported. On August 10, 1988 GBNPP personnel approached the calf and cut off a hard plastic buoy, trolling and longline gear, including 475 ft of ground line, which was wrapped around the animal’s caudal peduncle (and possibly other body parts).[41]

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[40] Unpublished data, GBNPP, PO Box 140, Gustavus, AK 99826.

[41] Personal communication from Jan Straley, University of Alaska Southeast, 1332 Seward Ave. Sitka, AK 99835, September 2005.

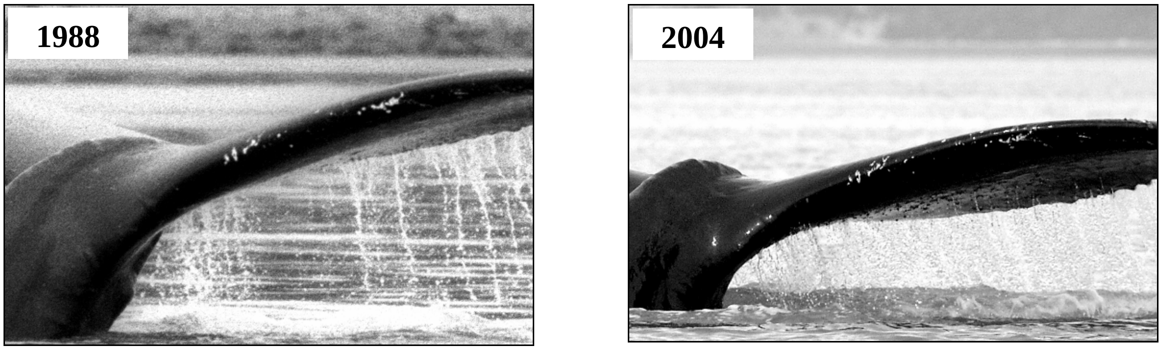

Figure 19. Historic photographs showing whale #232 in 1988 (left) and 2004 (right) showing the stability of the scarring pattern on the leading edge of this whale’s flukes.

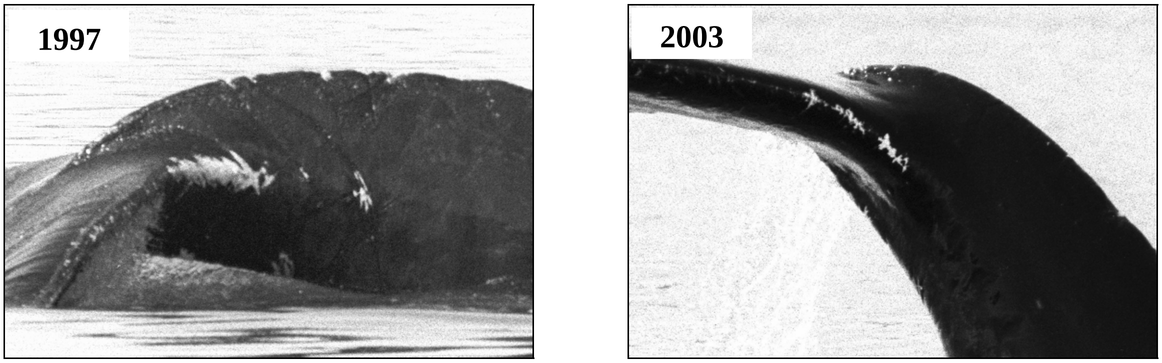

Figure 20. Whale #351 in 1997 (left) and 2003 (right). In 1997 this whale had pink (i.e., raw) entanglement wounds that are not apparent in the 1997 photograph. Many of the wounds had healed or faded beyond recognition by 2003. Nevertheless, there were still enough diagnostic entanglement scars visible in 2003 to assign entanglement status code E3.

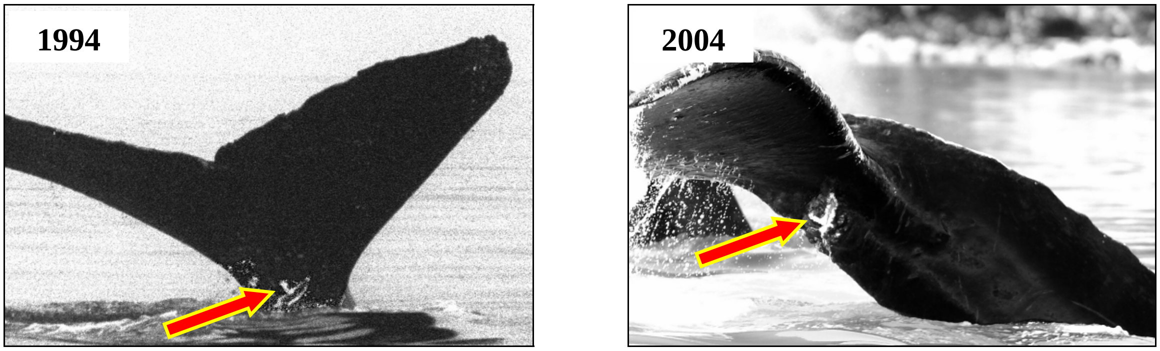

Figure 21. Whale #166 in 1994 (left) and 2004 (right). This whale had a raw caudal peduncle wound in 1994 that was still raw in 2004. The origin of this wound is unknown.

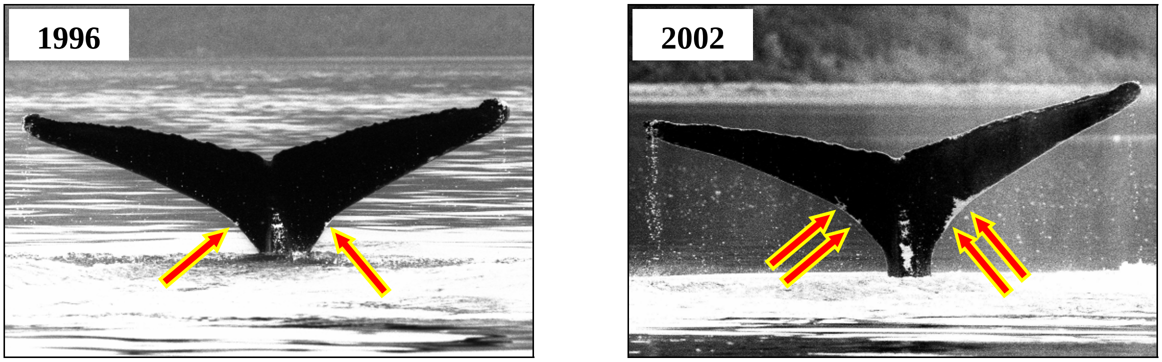

Figure 22. Whale #1018 in 1996 (left) and 2002 (right). This whale already had entanglement scars in 1996 but new entanglement scars, laid on top of the original scars, are visible in the 2002 photograph. Historic caudal peduncle images of this whale show the same general pattern but are of very poor quality.

The original entanglement appeared to have been with the longline which then snagged more gear as it trailed behind the calf. The entanglement was not considered severe.[42] There are no photographs of #1019's caudal peduncle in the GBNPP photo archives from the time of the 1988 entanglement to 2002. In 2003, inadequate quality caudal peduncle photographs were obtained and #1019 was assigned E-code EX. In 2004, adequate photographs were obtained but the marks suggested a low likelihood of previous entanglement (E-code E1).

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[42] *Ibid.*

Appendix 2

Major Commercial Fisheries in Northern SEAK

Dungeness Crab Pot Fishery

Location

Dungeness crabs are harvested in protected bays and inlets throughout the waters of northern SEAK (Fig. 23) at depths of 6 – 60 ft.[43] Glacier Bay and Dundas Bay were closed to commercial Dungeness crab fishing in 1999. Prior to the closure, the harvest of Dungeness crabs from Glacier Bay and Dundas Bay in the early-mid 1990s accounted for 4% – 13% of the total SEAK harvest (Rumble and Bishop 2002).[44]

Season

From the early 1930s through 1955, the fishery was open year-round, except for a closed season for 2 – 4 months between May 1 and September 1. In the late 1950s, the summer closures were lifted. From the late 1960s until 1989, the length of the fishing season varied. From 1989 to the present, the fishery has been open in most of central and northern SEAK in the summer (June 15 – August 15) and fall (October 1 – November 30). Most of the harvest is taken during the summer months (Rumble and Bishop 2002). In addition, a sport pot fishery for Dungeness crab occurs throughout SEAK and is open year-round.

Gear

The majority of fishermen use steel hatbox-shaped pots that weigh 50 – 100 lb each (Fig. 24) (Rumble and Bishop 2002).[45] In 2001, a maximum pot diameter of 50 in. was

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[43] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

[44] GBNPP unpublished data.

[45] Personal communication from Jan Rumble, ADF&G Commercial Fisheries Division, 802 Third St, Douglas, AK 99824, December 2004.

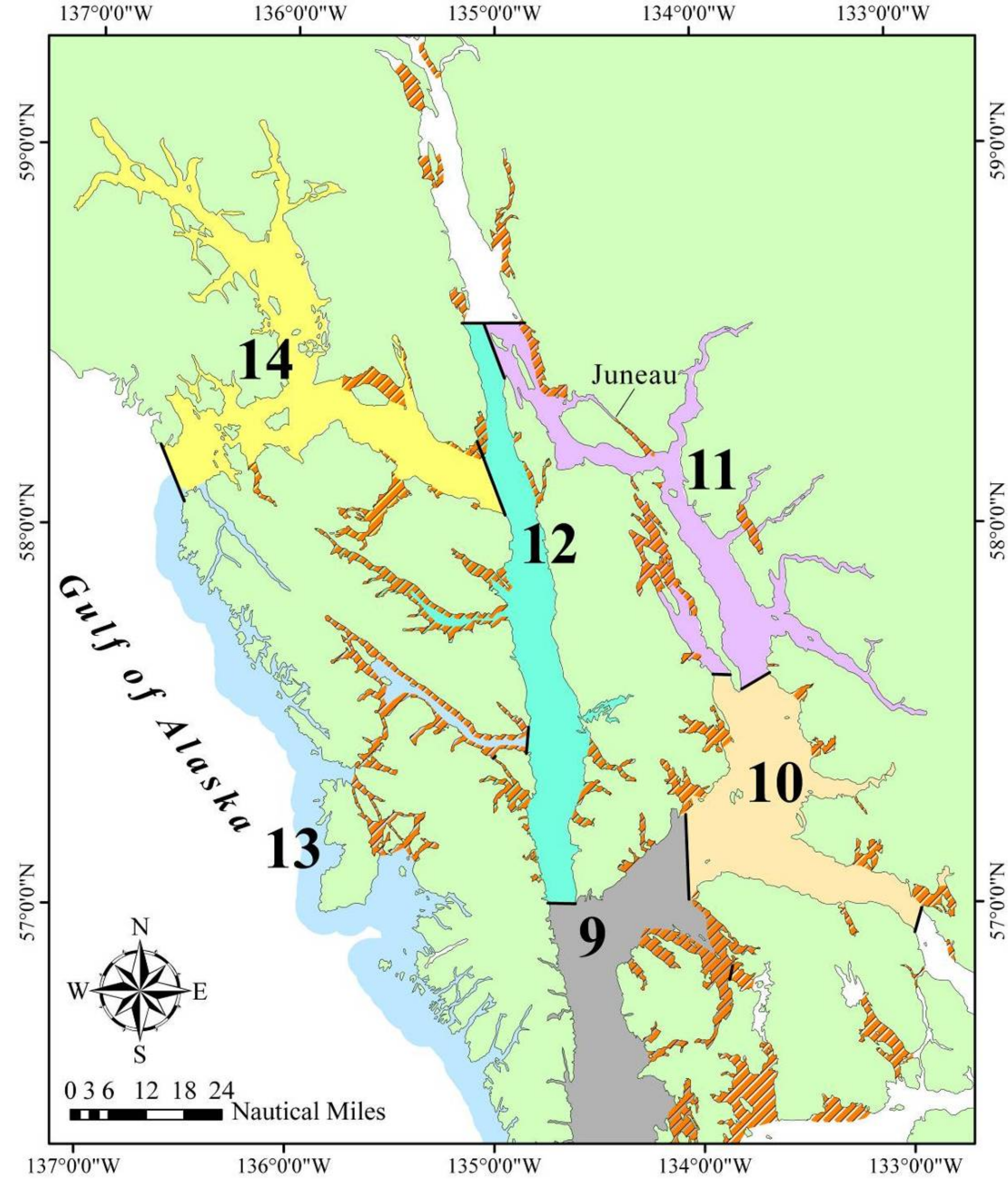

Figure 23. Main Dungeness crab fishing grounds in northern SEAK (hatched areas).[46] ADF&G Districts that overlap with the study area are indicated in color and numbered.

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[46] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

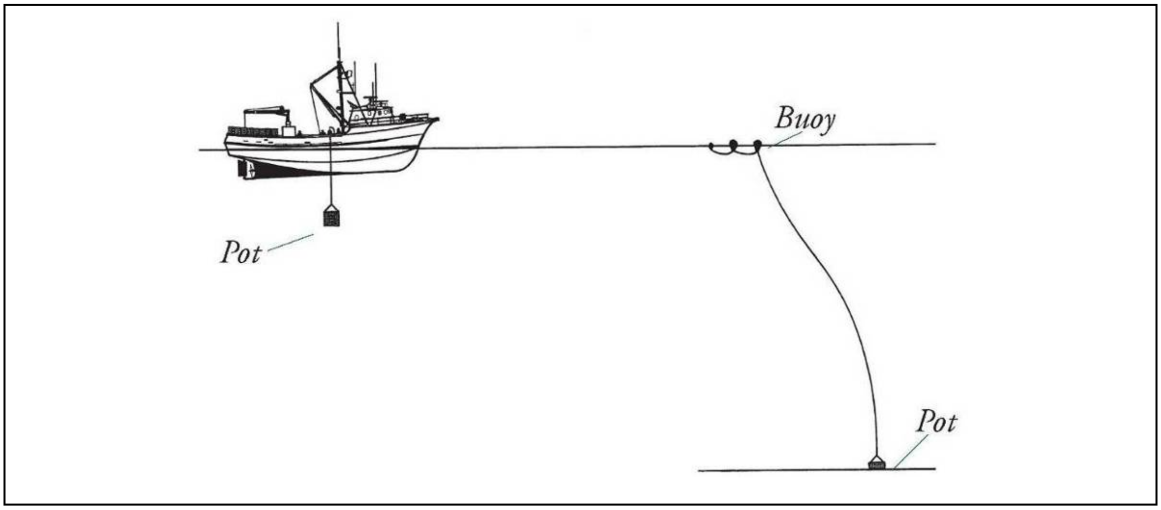

Figure 24. Diagram of generalized pot gear (illustration by Bob Hitz, courtesy of NOAA Alaska Sea Grant).

established. Permits are issued for a maximum of 150 or 300 pots per vessel (05 AAC 32.125). Each pot must be individually marked with a surface buoy; Dungeness crab pots may not be longlined (05 AAC 32.125). At least one buoy on each pot must be labeled with the ADF&G license number of the vessel operating the gear (05 AAC 32.051). Pots are generally soaked for 3 – 5 days.[47] Pots may be stored in the water for up to seven days after the season closes (05 AAC 32.052) in a standard configuration with a surface buoy line. Surface buoy line is typically 3/8-in. to 7/16-in. leaded or 'sinking' (negatively buoyant) line.[48,49] Surface buoys are usually bullet-shaped corks approximately 12 in. long.

In 1997, the Commercial Fisheries Entry Commission (CFEC) implemented a limited entry system for the fishery in SEAK with a maximum effort level of 308 permits,

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[47] *Ibid.*

[48] *Ibid.*

[49] Personal communication from Gene Farley, commercial fisherman, PO Box 182, Gustavus, AK 99826, November 2005.

providing for a maximum of 48,750 commercial Dungeness crab pots (Rumble and Bishop 2002).

Red King Crab Pot Fishery

Location

Red king crabs are harvested primarily in the protected bays, inlets and adjacent shorelines of straits and sounds in northern SEAK in water depths usually less than 900 ft (Fig. 25) (Clark *et al*. 2003, Hebert *et al*. 2005). The majority of the SEAK harvest is taken in ADF&G Districts 9 – 14; generally less than 10% of the harvest comes from southern SEAK (Hebert *et al*. 2005). Glacier Bay was closed to commercial red king crab fishing in 1999; prior to the closure, harvest levels from Glacier Bay were very low (Taylor and Perry 1988).

Season

From 1961 through 1968, the fishery was open year-round. Beginning in the 1969/70 season, the season was restricted to August 15 – March 15. In 1971, the season was shortened to September 1 – January 31. The fishery was closed from the 1985/86 through the 1992/93 seasons due to small stock size. Since 1993, the fishery has been open most years, with intermittent annual closures to allow stocks to rebuild. Currently, the season is open November 1 – January 24, but since the late 1990s the fishery has been closed by November 15 because harvest limits were reached (Hebert *et al*. 2005).

Gear

The majority (~80%) of fishermen in SEAK use pyramid or cone-shaped pots (5 – 8 ft bases) that weigh 200 – 500 lb, the remainder use square pots (7 ft x 7 ft x 30 in.) that weigh approximately 600 lb (Fig. 24) (Clark *et al*. 2003; Hebert *et al*. 2005).[50] From 1961 through 1967, the amount of gear that could be fished was not restricted. From 1968 until

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[50] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

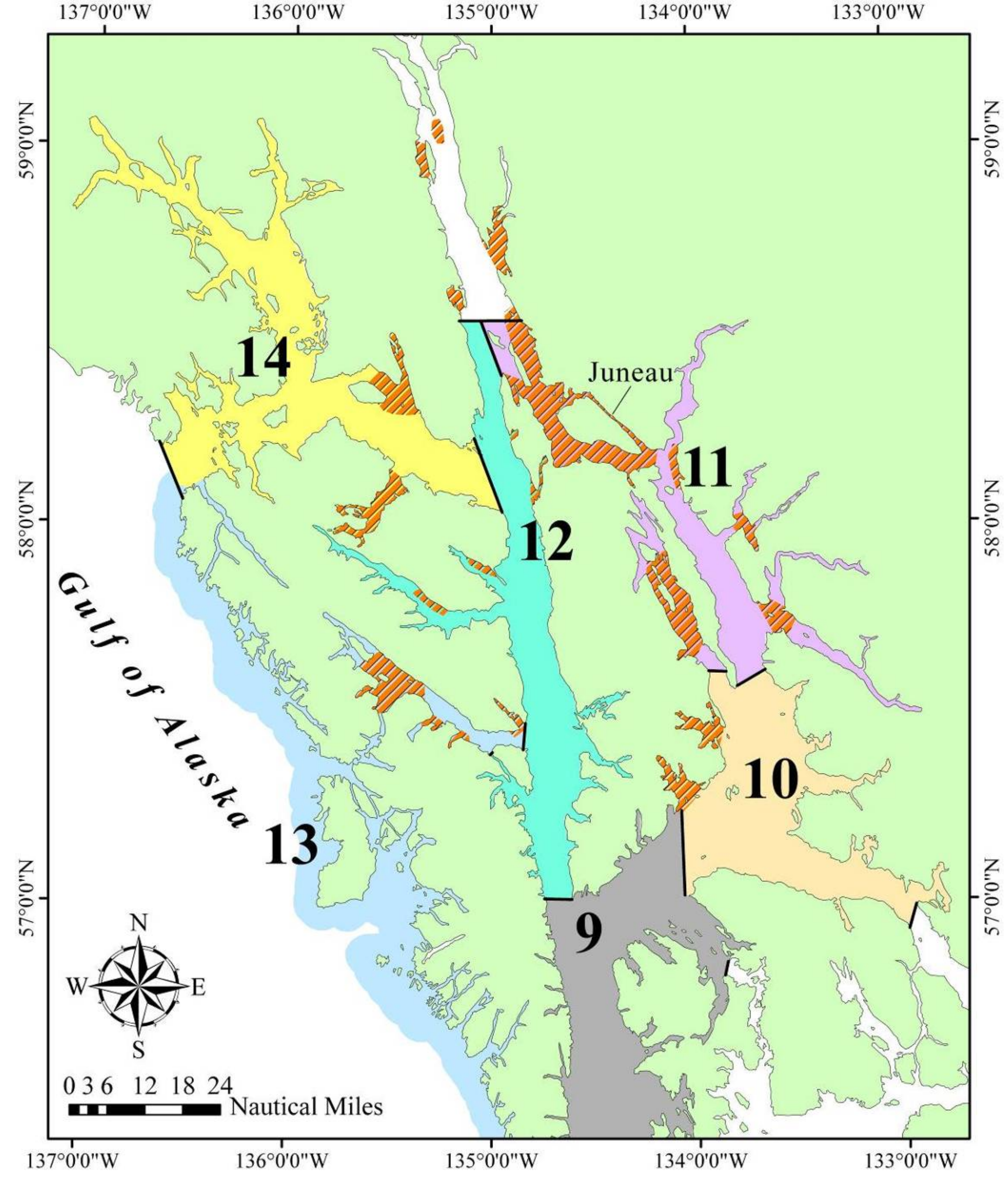

Figure 25. Main red king crab fishing grounds in northern SEAK (hatched areas).[51] ADF&G Districts that overlap with the study area are indicated in color and numbered.

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[51] *Ibid*.

1988, pot limits varied between 40 and 100 pots per vessel. Today, limits of 20 – 50 pots per vessel are imposed each season depending on stock abundance. Each pot must be individually marked with a surface buoy; king crab pots may not be longlined in SEAK.[52] At least one buoy on each pot must be labeled with the ADF&G license number of the vessel operating the gear (05 AAC 34.051). Pots are generally soaked for 24 hours.[53] Pots may be stored in the water for up to 10 days before the season opens and for up to seven days after the season closes (05 AAC 34.052) in a standard configuration with a surface buoy line.

Surface buoy line is composed of sinking and ‘floating’ (positively buoyant) line spliced together. Typically, ½-in. sinking line is used within approximately 150 ft of the surface. Below this depth, ½-in. floating line is connected to the pot on the ocean floor. Occasionally, heavier lines (9/16-in.) are used.[54] Generally two surface buoys mark each pot: an inflated poly buoy approximately two feet in diameter and a smaller ‘trailer’ buoy (typically a Dungeness crab pot-style cork buoy). The two buoys are connected at the surface with approximately 10 ft of ½-in. floating line.[55]

In 1984, the CFEC implemented a limited entry system for the red king crab fishery in SEAK with a maximum effort level of 61 permits (Hebert *et al*. 2005).

Personal Use Red King Crab Pot Fishery

Although this thesis focuses on commercial fisheries, a significant, well-documented non-commercial fishery for red king crabs occurs in District 11 near Juneau. This fishery is notable because of the large number of participants and because the fishery is open during the summer months. In years when the commercial red king crab fishery is open,

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[52] Personal communication from Gretchen Bishop, ADF&G Commercial Fisheries Division, 802 Third St, Douglas, AK 99824, October 2005.

[53] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

[54] *Ibid.*

[55] *Ibid.*

60% of the total allowable harvest in the Juneau area is allocated to personal use and 40% is allocated to commercial use. In years when the commercial fishery has been closed, the personal use fishery has remained open (Hebert *et al*. 2005).

The personal use season is open July 1 – September 30 (summer) and October 1 – March 31 (winter), with earlier closures if guideline harvest levels are reached. Over 50% of the summer harvest occurs in July and over 90% occurs by the end of August. The majority of the summer harvest (99%) is taken with pot gear. Pot size and shape in the personal use fishery are not restricted but the majority of participants use pyramid-shaped pots (~3 ft x 3 ft bases) that vary in weight up to approximately 50 lb, with a wide range of line types used for surface buoys, including both sinking and floating line.[56]

Personal use permits are required to participate in the fishery. The number of permittees has increased steadily since 1997, with 2,282 personal use permits issued for the summer 2004 season. Beginning in the 1995/96 season, a limit of 4 pots per person or vessel was imposed (Hebert *et al*. 2005). Applying this pot limit to the number of permittees in 2004 equates to up to 9,000 personal use king crab pots in the Juneau area during the summer season.

Golden King Crab Pot Fishery

Location

Golden king crabs are taken from the deeper waters (600 – 2100 ft) of northern SEAK (Fig. 26). The majority of the SEAK harvest is taken in ADF&G Districts 9 – 14; generally less than 10% of the harvest comes from southern SEAK. The fishing grounds tend to be exposed to more adverse weather conditions, stronger tidal exchanges and stronger currents than other crab fishing grounds in SEAK (Hebert *et al*. 2005). Glacier Bay was closed to commercial golden king crab fishing in 1999; prior to the closure,

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[56] Personal communication from Brian Glynn, ADF&G Sport Fish Division, PO Box 240020, Douglas, AK 99824, November 2005.

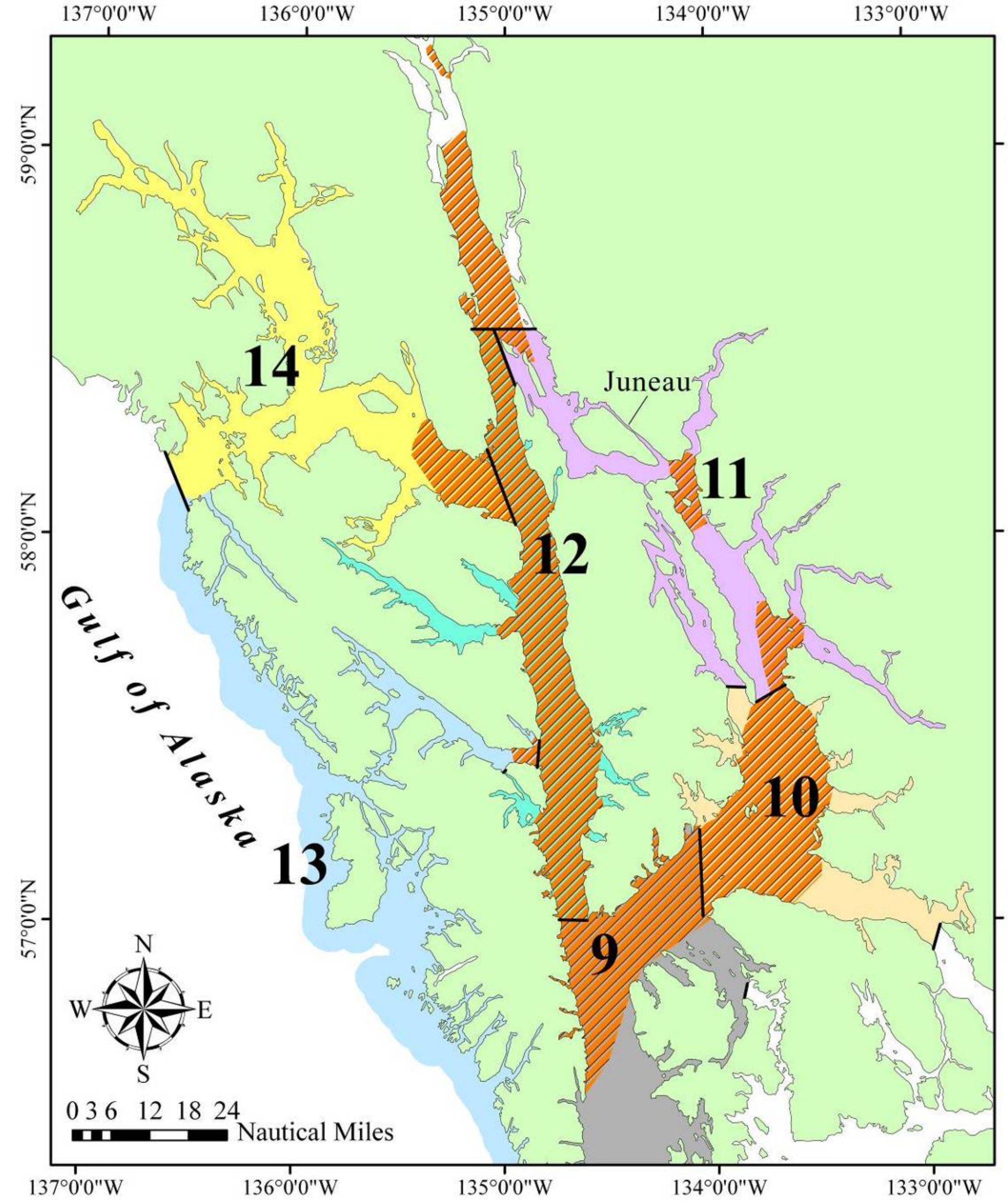

Figure 26. Main golden king crab fishing grounds in northern SEAK (hatched areas) (Hebert *et al*. 2005).[57] ADF&G Districts that overlap with the study area are indicated in color and numbered.

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[57] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

harvest levels from Glacier Bay were very low (Taylor and Perry 1988).

Season

From 1961 through 1968, the fishery was open year-round. Since the 1970s the length of the season has varied. Since 1989 the season has opened on February 15, closing by emergency order when the guideline harvest range is reached. In recent years, the fishery has closed between March and September; most of the harvest is taken in February, March and April (Hebert *et al*. 2005).

Gear

Because golden king crabs are harvested from deeper, more exposed waters, participants tend to use heavier gear and soak times are generally longer compared to other crab pot fisheries.[58] Participants use both square pots (7 ft x 7 ft x 30 in.) that weigh approximately 600 lb and pyramid or cone-shaped pots (5 – 8 ft bases) that weigh 200 – 500 lb (Fig. 24) (Clark *et al*. 2003; Hebert *et al*. 2005).[59] In recent years, the popularity of cone-shaped pots has grown. From 1961 through 1967, the amount of gear that could be fished was not restricted. From 1968 until 1978, pot limits varied between 40 and 60 pots per vessel. In 1978, the limit was raised to 100 pots per vessel; this limit remains in effect today. Each pot must be individually marked with a surface buoy; king crab pots may not be longlined in SEAK.[60] At least one buoy on each pot must be labeled with the ADF&G license number of the vessel operating the gear (05 AAC 34.051). Pots are generally soaked for 3 – 7 days.[61] Pots may be stored in the water for up to 10 days before the season opens and for up to seven days after the season closes (05 AAC 34.052) in a standard configuration with a surface buoy line.

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[58] *Ibid*.

[59] *Ibid*.

[60] Personal communication from Gretchen Bishop, ADF&G Commercial Fisheries Division, 802 Third St, Douglas, AK 99824, October 2005.

[61] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

Surface buoy line is composed of sinking and floating line spliced together. Typically, ½-in. sinking line is used within approximately 150 ft of the surface. Below this depth, ½-in. floating line is connected to the pot on the ocean floor. Occasionally, heavier lines (9/16-in.) are used.[62] Generally two surface buoys mark each pot: an inflated poly buoy approximately two feet in diameter and a smaller 'trailer' buoy (typically a Dungeness crab pot-style cork buoy). The two buoys are connected at the surface with approximately 10 ft of ½-in. floating line.[63]

In 1984, the CFEC implemented a limited entry system for the golden king crab fishery in SEAK with a maximum effort level of 57 permits (Hebert *et al*. 2005).

Tanner Crab Pot Fishery

Location

Tanner crabs are harvested primarily in the waters of northern SEAK at depths of 120 – 600 ft[64] (Fig. 27). In the early 1980s, large crab vessels that were bound for the Bering Sea and Kodiak often fished in SEAK on their way north with a great deal of fishing effort in the Glacier Bay/Icy Strait area (District 14). Harvests peaked in the 1981/82 season, with about two-thirds of the harvest coming from District 14. Beginning in 1985, vessels registered to fish for Tanner crab in SEAK were prohibited from fishing for Tanner crab in any other part of Alaska, which reduced the number of larger vessels fishing in SEAK (Hebert *et al*. 2005).

Season

From 1961 through 1968, the fishery was open year-round. Since the 1970s the length of the season has varied, with most of the openings in the fall and winter months. Since 1989 the season has opened on February 15, closing by emergency order when harvest

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[62] *Ibid.*
[63] *Ibid.*
[64] *Ibid.*

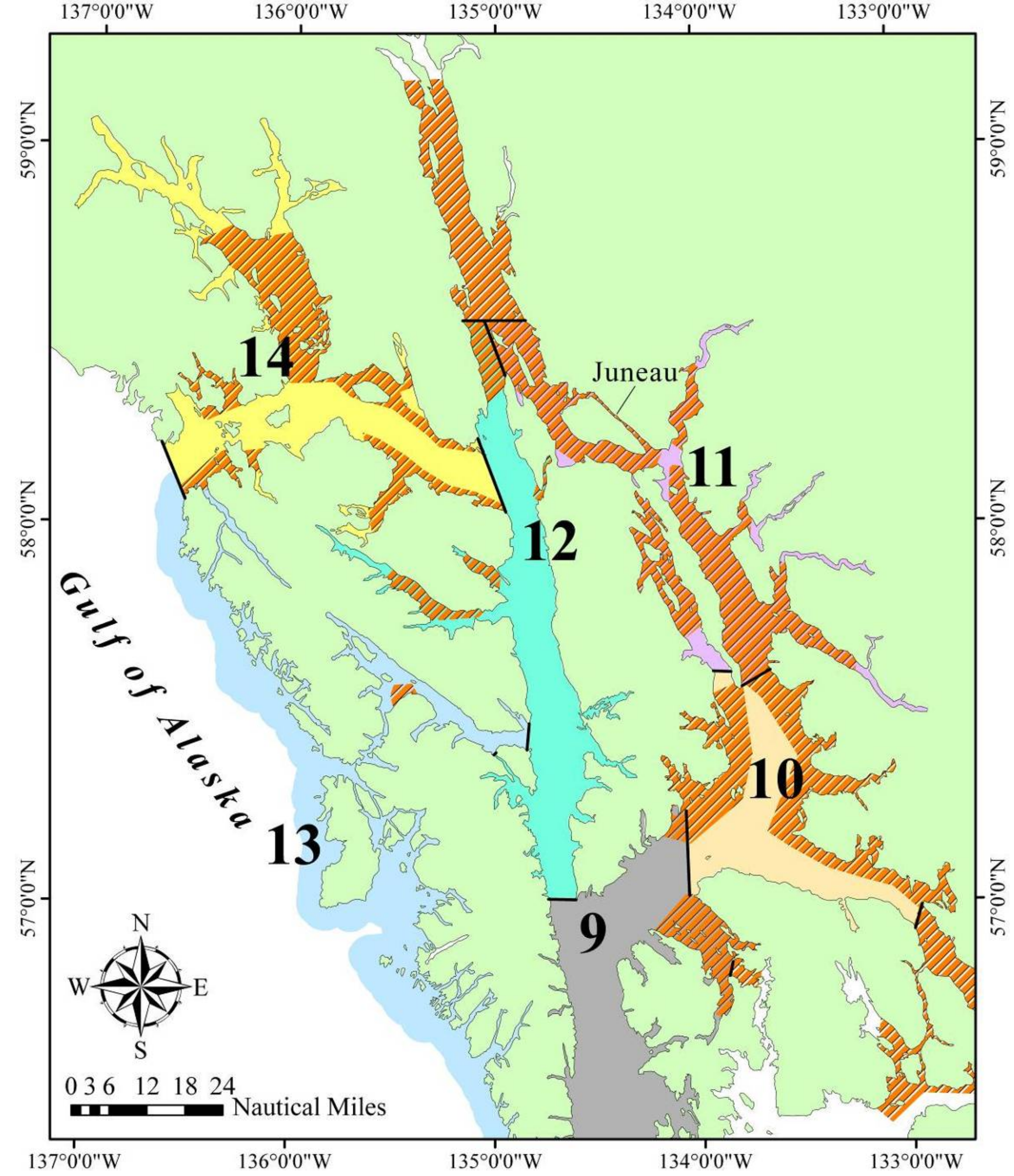

Figure 27. Main Tanner crab fishing grounds in northern SEAK (hatched areas) (Hebert *et al.* 2005).[65] ADF&G Districts that overlap with the study area are indicated in color and numbered.

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[65] *Ibid*.

limits are reached. The average season length has shortened progressively from 9.7 months in the 1970s to 1.6 months in the 1980s to 11.1 days in the 1990s, to 5.75 days in recent years (Hebert *et al*. 2005).

Gear

Most fishermen in SEAK use pyramid or cone-shaped pots (5 – 8 ft bases) that weigh 200 – 500 lb; the remainder use square pots (7 ft x 7 ft x 30 in.) that weigh approximately 600 lb (Fig. 24) (Clark *et al*. 2001; Hebert *et al*. 2005).[66] In 1973, a pot limit of 60 pots per vessel was imposed. In 1977, the limit was raised to 100 pots per vessel. Since 1997, the limit has been 80 pots per vessel. Each pot must be individually marked with a surface buoy; Tanner crab pots may not be longlined in SEAK.[67] At least one buoy on each pot must be labeled with the ADF&G license number of the vessel operating the gear (05 AAC 35.051). Pots are generally soaked for 24 hours.[68] Pots may be stored in the water for up to seven days after the season closes (05 AAC 34.052) in a standard configuration with a surface buoy line.

Surface buoy line is composed of sinking and floating line spliced together. Typically, ½-in. sinking line is used within approximately 150 ft of the surface. Below this depth, ½-in floating line is connected to the pot on the ocean floor. Occasionally, heavier lines (9/16-in.) are used.[69] Generally two surface buoys mark each pot: an inflated poly buoy approximately two feet in diameter and a smaller 'trailer' buoy (typically a Dungeness crab pot-style cork buoy). The two buoys are connected at the surface with approximately 10 ft of ½-in. floating line.[70]

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[66] *Ibid.*

[67] Personal communication from Gretchen Bishop, ADF&G Commercial Fisheries Division, 802 Third St, Douglas, AK 99824, October 2005.

[68] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

[69] *Ibid.*

[70] *Ibid.*

In 1984, the CFEC implemented a limited entry system for the Tanner crab fishery in SEAK with a maximum effort level of 83 permits (Hebert *et al*. 2005).

Shrimp Pot Fishery

Location

Shrimp are harvested in rocky habitats, typically in water depths of 200 – 300 ft (max 600 ft)[71] (Fig. 28). The majority of the harvest in SEAK is taken in southern SEAK (ADF&G Districts 1, 3 and 7); from the 1981/82 season through the 2001/02 season, the annual harvest of shrimp from Districts 9 – 14 only comprised an average of 17% of the total annual SEAK harvest (Love and Bishop 2002). Within northern SEAK, fishing activity is most concentrated in Tenakee Inlet (District 12), Port Houghton (District 10) and Hoonah Sound (District 13).[72] Glacier Bay was closed to commercial shrimp harvest in 1983 (36 CFR 13.65).

Season

Prior to 1970, pot shrimp fishing was generally open May 1 through February 14. From 1970 until 1997, the season was open year-round in ADF&G Districts 9 – 14. In 1997, the season was restricted to October 1 – February 18. If guideline harvest levels are not reached in a district during the regular season, the district may be re-opened by regulation from May 1 – July 31. However, in many areas the guideline harvest level is reached in early October and the fishery is closed by emergency order (Davidson *et al.* 2005). In addition, a sport pot fishery for shrimp occurs in some parts of SEAK and is open year-round.

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[71] Personal communication from Larry Painter, commercial fisherman, PO Box 6181, Ketchikan, AK 99901, November 2005.

[72] Personal communication from Ian Fisk, commercial fisherman, PO Box 240436, Douglas, AK 99824, January 2006.

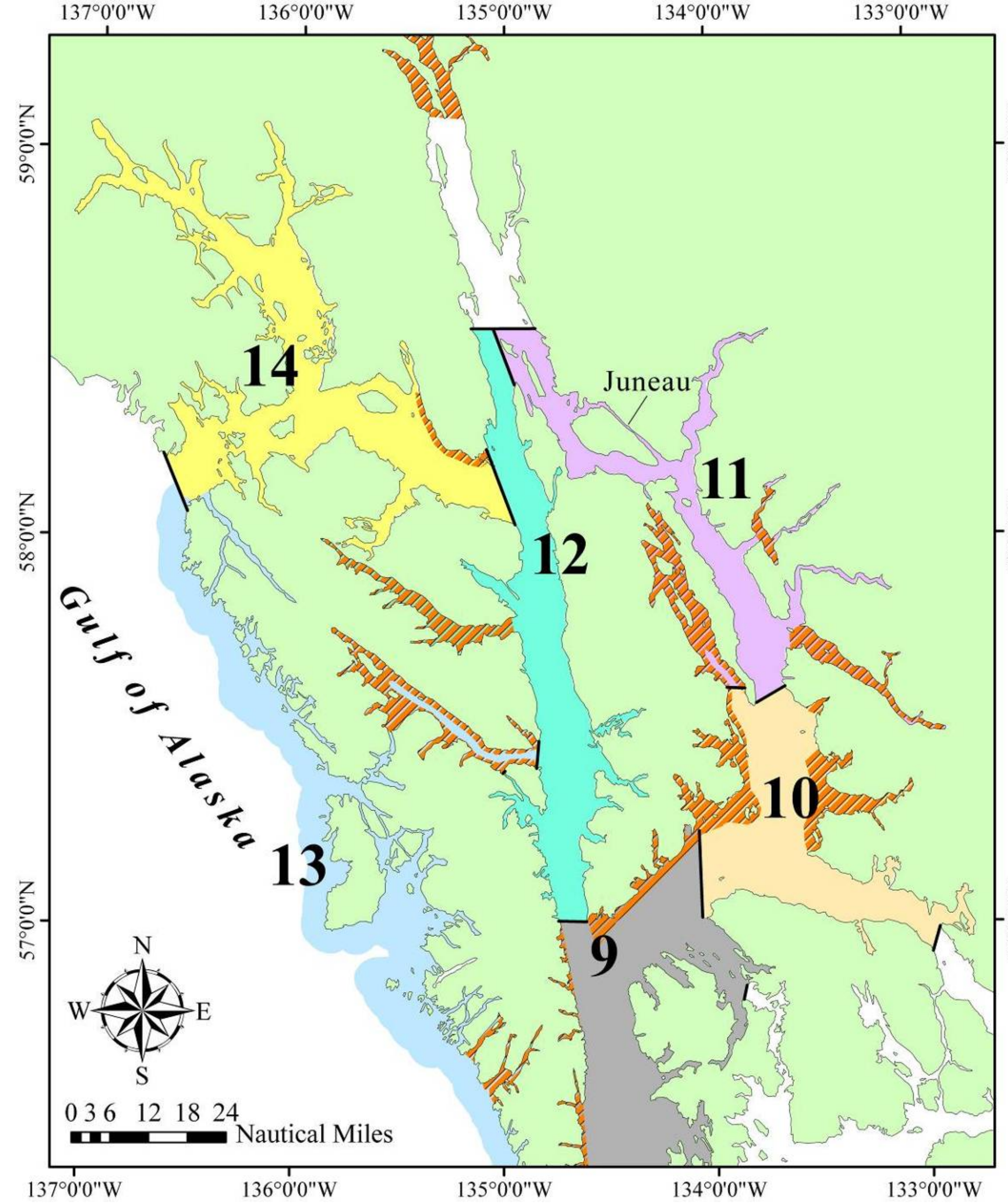

Figure 28. Main shrimp pot fishing grounds in northern SEAK (hatched areas).[73] ADF&G Districts that overlap with the study area are indicated in color and numbered.

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[73] *Ibid*.

Gear

Today most fishermen use cone-shaped pots that weigh 25 – 50 lb[74], but rectangular pots approximately 30 in. x 18 in. x 18 in. used to be common (Fig. 24) (Love and Bishop 2002). Pots are classified as small if the bottom perimeter is less than 124 in. or large if the bottom perimeter is greater than 124 in. (max 153 in.). Pot height may not exceed 24 in. Permits are issued for a maximum of 140 small or 100 large pots per vessel (05 AAC 31.124). Shrimp pots may be fished as single pots or longlined (05 AAC 31.124); most fishermen longline their pots. Typically there are 5 – 20 pots per longline, with the pots spaced 60 – 90 ft apart and connected by a 7/16-in. to ½-in. floating groundline. Pots are generally soaked for 24 hours.[75] Pots may be stored in the water for up to seven days after the season closes (05 AAC 31.052) in a standard configuration with a surface buoy line.

Surface buoy line is composed of sinking and floating line spliced together. Typically, 7/16-in. to ½-in. sinking line is used in the upper half of the water column and 7/16-in. to ½-in. floating line is used in the lower half of the water column.[76] Some fishermen mark both ends of the longline with surface buoys, others mark only one end. Generally two surface buoys are used: an inflated poly buoy approximately two feet in diameter and a smaller 'trailer' buoy (typically a Dungeness crab pot-style cork buoy). The two buoys are connected at the surface with approximately six feet of 7/16-in. to ½-in. floating line.[77] At least one of the buoys must be labeled with the ADF&G license number of the vessel operating the gear (05 AAC 31.051).

Participation in the fishery increased steadily from the 1960s until the early 1990s, when large increases in effort and harvest occurred, leading the CFEC to implement a limited

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[74] *Ibid.*

[75] *Ibid.*

[76] Personal communication from Larry Painter, commercial fisherman, PO Box 6181, Ketchikan, AK 99901, November 2005.

[77] *Ibid.*

entry system in SEAK in 1995 with a maximum effort level of 332 permits (Love and Bishop 2002).

Salmon Drift Gillnet Fishery

Location

One traditional common property drift gillnetting area (Taku/Snettisham (District 11)) and several highly localized terminal hatchery fishing areas and hatchery cost recovery areas overlap with the study area (Fig. 29). Although gillnets may be set anywhere in the open areas, most of the gear is concentrated near shore, with approximately 80% of the nets set within one mile of shore.[78]

Season

Specific periods when the fishery is open are established by emergency order. Openings in SEAK generally occur from mid-June through mid-October with each opening lasting an average of three days.[79] In 2004, participation in the fishery peaked in mid-August.

Gear

Drift gillnets in SEAK may be 50 – 1800 ft long depending on the location where they are fished (Fig. 30). In ADF&G District 11, nets may not be longer than 900 ft until mid-late June, when they may be up to 1200 ft in length (05 AAC 33.331). Most fishermen in District 11 use the maximum allowable net length (1200 ft).[80] Only one gillnet is allowed per vessel (05 AAC 33.331). Gillnet mesh is composed of multi-strand nylon and can be any color, though blue and green are the most common.[81] The maximum legal mesh size is generally six inches (05 AAC 33.331). The top edge of the net is held at the surface of the water by ~½-in. braided floating line attached to cork floats that are spaced

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[78] Personal communication from Richard Gregg, commercial fisherman, PO Box 20669, Juneau, AK 99802, November 2005.

[79] Personal communication from Ted Merrell, commercial fisherman, 3119 Douglas Highway, Juneau, AK 99801, November 2005.

[80] *Ibid.*

[81] *Ibid.*

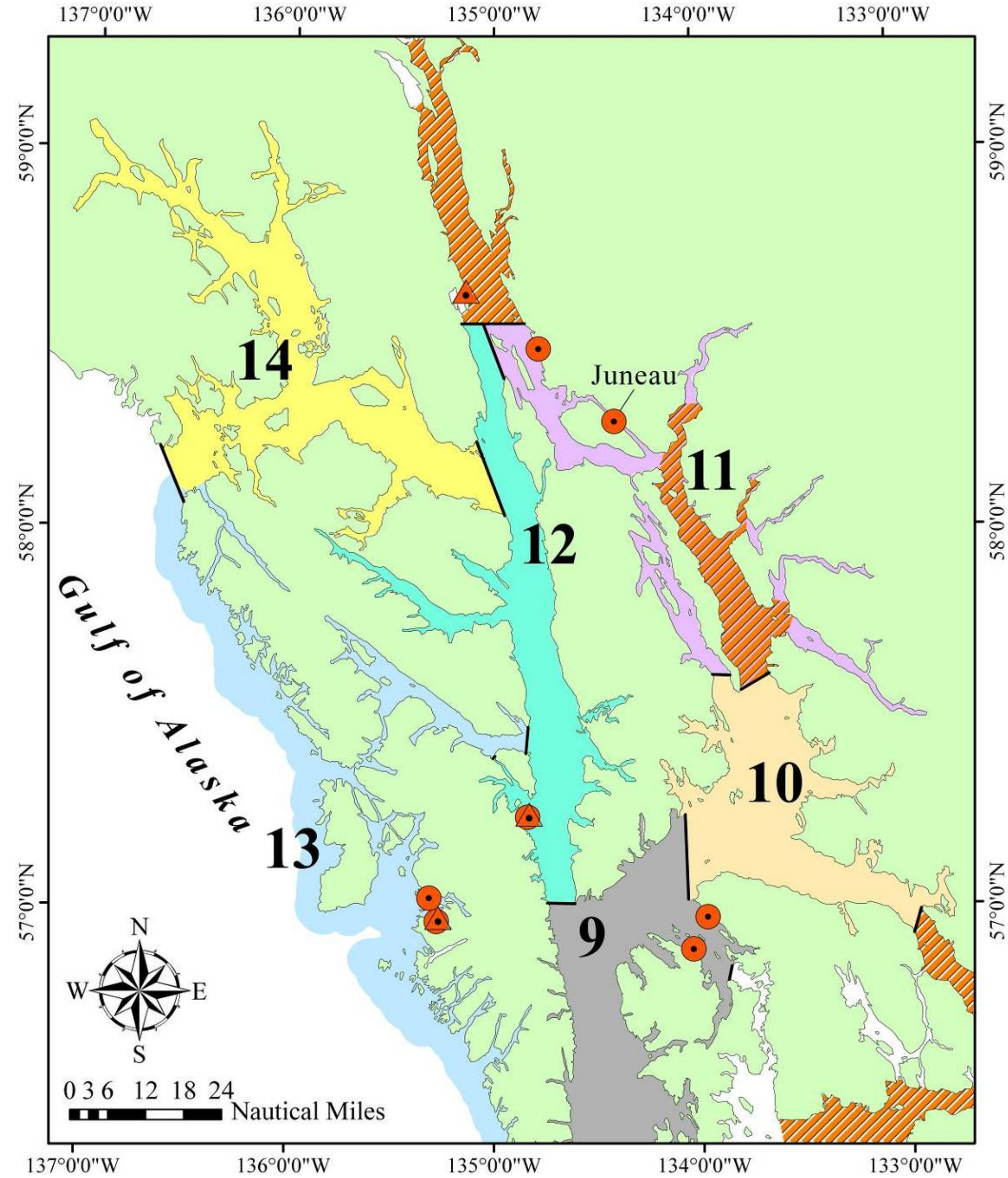

Figure 29. Main drift gillnet fishing grounds for salmon in northern SEAK ((traditional common property (hatched areas), terminal harvest areas (▲), hatchery cost recovery areas (●)) (Bachman *et al*. 2005, 05 AAC 33.350). ADF&G Districts that overlap with the study area are indicated in color and numbered.

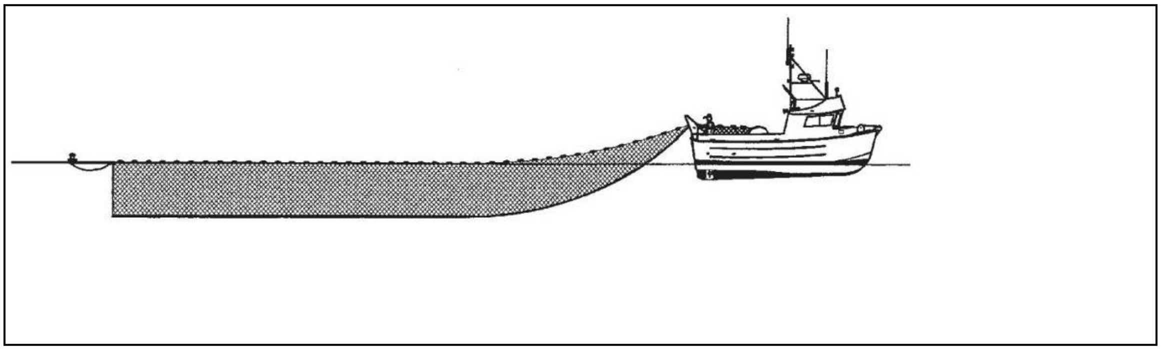

Figure 30. Diagram of generalized drift gillnet gear (illustration by Bob Hitz, courtesy of NOAA Alaska Sea Grant).

approximately three feet apart. The bottom edge of the net is attached to ~½-in. nylon line with a leaded core. The net hangs down in the water like a curtain to a depth of 20 – 23 ft. The total weight of the gear is approximately 500 lb.[82]

Gillnets may be deployed any time of the day or night with soak times varying from 20 minutes to two hours (average one hour). Depending on the weather and currents, fishermen either drift with one end of the net attached to their vessel or they buoy both ends of the net and wait nearby while the net soaks; it is illegal to anchor the net. Gillnetters are often concentrated in the same areas to fish and it is common for 100 vessels to be fishing close to each other.[83]

From 1994 through 2003, the average number of permit holders in the Southeast Alaska and Yakutat drift gillnet fisheries was 481, with an average of 428 permittees actively fishing each year. In recent years, fewer have participated in the fishery: 2004 was the lowest on record with only 351 permittees actively fishing (Bachman *et al*. 2005).

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[82] *Ibid.*

[83] *Ibid.*

Salmon Purse Seine Fishery

Location

Purse seining occurs widely throughout SEAK, with most openings designated as being within two miles of shore (Fig. 31). Although purse seines may be set anywhere in the designated open areas, most of the gear is concentrated close to shore, with approximately 90% of the nets set within one half mile of shore.[84]

Season

Specific periods when the fishery is open are established by emergency order. Openings in SEAK generally occur from June 20 through mid-October with each opening typically lasting 8 hours – 4 days. Peak harvests generally occur from mid-July through mid-August.[85]

Gear

Purse seine nets in SEAK are 900 – 1500 ft long (05 AAC 33.332) and generally hang from the surface to a depth of 90 – 100 ft[86] (Fig. 32). Seine mesh is generally black or dark green in color and is composed of braided or twisted nylon or polyethylene twine with a maximum legal mesh size of 4.5 in. for most of the net (05 AAC 33.332). The top edge of the net is held at the surface of the water by a 1-in. or thicker braided floating line attached to 8 in. to 12 in. cork floats. The bottom edge of the net is weighted with a 1-in. to 1.5-in. line with a leaded core (the 'lead line'). Attached to the lead line are numerous rings through which a 2-in. line (the 'purse line') runs.[87]

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[84] Personal communication from Dave Gordon, ADF&G Commercial Fisheries Division, 304 Lake Street, Rm. 103, Sitka, AK 99835, February 2006.

[85] Personal communication from Michelle Masden, former commercial fisherman, PO Box 7432, Ketchikan, AK 99901, November 2005.

[86] *Ibid.*

[87] *Ibid.*

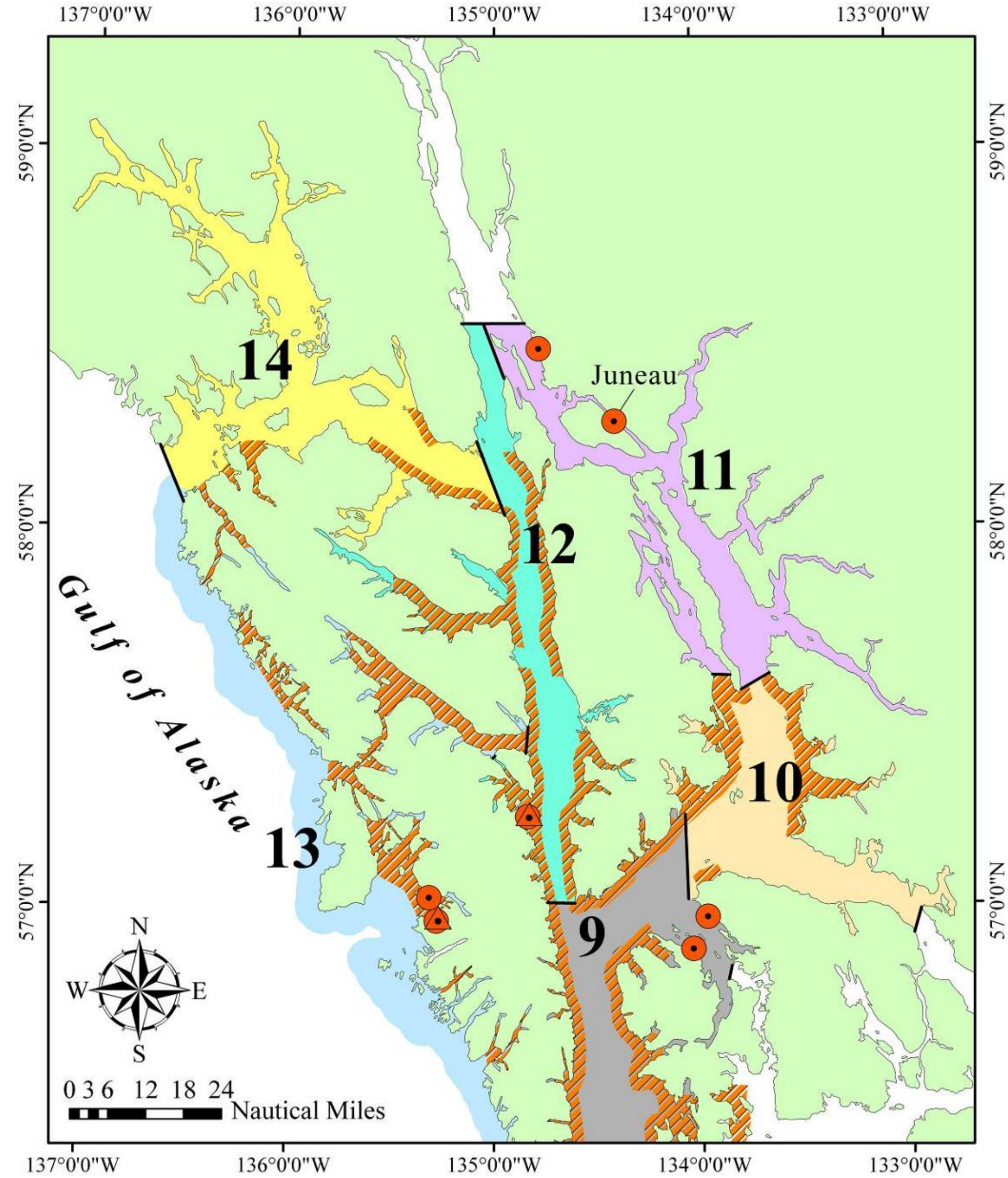

Figure 31. Main purse seine fishing grounds for salmon in northern SEAK ((traditional common property (hatched areas), terminal harvest areas (▲), hatchery cost recovery areas (●)).[88,89,90] ADF&G Districts that overlap with the study area are indicated in color and numbered.

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[88] Personal communication from Dave Harris, ADF&G Commercial Fisheries Division, PO Box 240020, Douglas, AK 99824, January 2006.

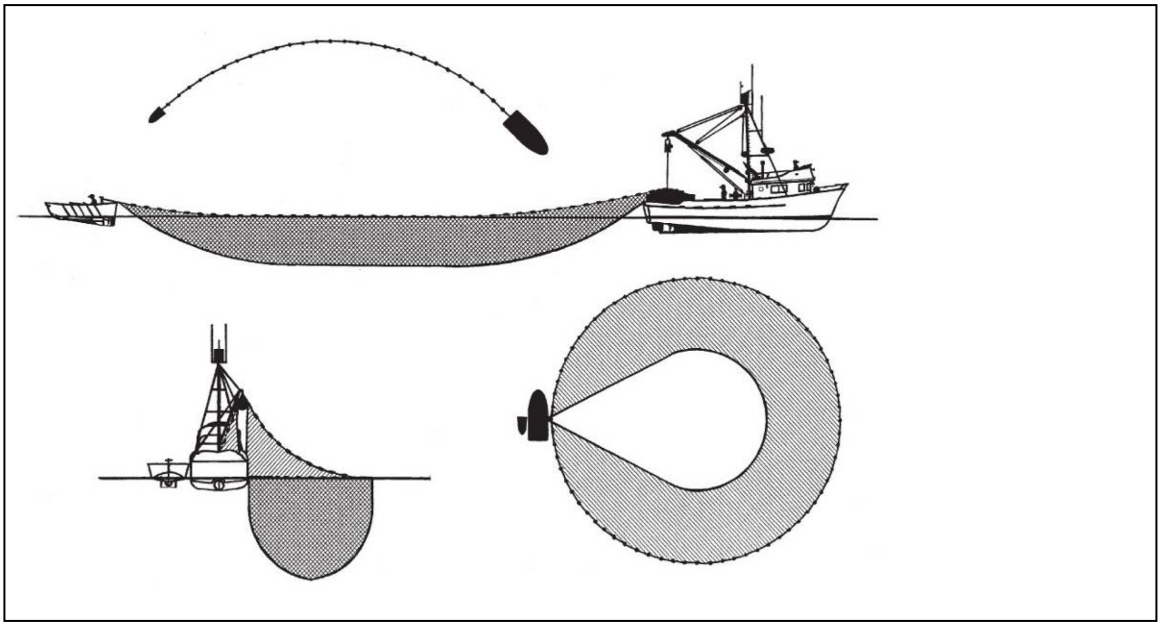

Figure 32. Diagram of generalized purse seine gear (illustration by Bob Hitz, courtesy of NOAA Alaska Sea Grant).

Purse seine nets are generally deployed during daylight hours.[91] The net is deployed off the stern of the fishing vessel. A skiff is used to hold one end of the net in place while the larger vessel maneuvers to encircle the fish with the net. After the net has been deployed for 20 – 30 mins, the purse line is tightened which closes the bottom of the net (Johnson and Byers 2003).[92] The purse line is made of floating line and is generally orange in color. The total weight of the gear is approximately 8,000 – 10,000 lb.[93]

From 1994 through 2003, the average number of permit holders in the Southeast Alaska and Yakutat purse seine fisheries was 416, with an average of 347 permittees actively

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[89] Personal communication from Dave Gordon, ADF&G Commercial Fisheries Division, 304 Lake Street, Rm. 103, Sitka, AK 99835, February 2006.

[90] Personal communication from Troy Thynes, ADF&G Commercial Fisheries Division, PO Box 667, Petersburg, AK 99833, February 2006.

[91] *Ibid.*

[92] *Ibid.*

[93] *Ibid.*

fishing each year (Bachman *et al*. 2005). In recent years, fewer have participated in the fishery: 2004 was the lowest on record with only 211 permittees actively fishing (Bachman *et al*. 2005).

Halibut and Sablefish Longline Fisheries

Location

Halibut are harvested with longlines throughout SEAK, typically in water depths of 60 – 1200 ft[94] (Fig. 33), while sablefish are harvested from deeper waters (Fig. 34) with most of the inshore catch in northern SEAK coming from Chatham Strait (Richardson and O'Connell 2004) in waters below 900 ft.[95] Sablefish are also harvested offshore in the eastern Gulf of Alaska, primarily in water depths of 1,500 – 2,400 ft.[96]

Season

From the late 1960s through 1976, the halibut longline fishery was generally open from May to September. Beginning in 1977, the season was limited to four openings totaling 73 days. In subsequent years, the season was progressively shortened as the number of vessels and the efficiency of the fleet increased. Between 1980 and 1994 the season evolved into a "derby"-like fishery with annual openings totaling 2 – 10 days divided primarily across the months of May, June and September.[97] The inshore northern SEAK sablefish longline fishery followed a similar trend. In the 1960s and 1970s, the season opened between mid-August and mid-September and closed between mid-October and mid-November. However, beginning in the late 1970s, the season was progressively shortened as the number of vessels and the efficiency of the fleet increased. The number of vessels participating in the fishery peaked in the late 1980s and between 1987 and

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[94] Personal communication from Paul Barnes, commercial fisherman, PO Box 155, Gustavus, AK 99826, November 2005.

[95] Personal communication from Vince Shafer, commercial fisherman, PO Box 172, Gustavus, AK 99826, December 2005.

[96] *Ibid.*

[97] IPHC unpublished data.

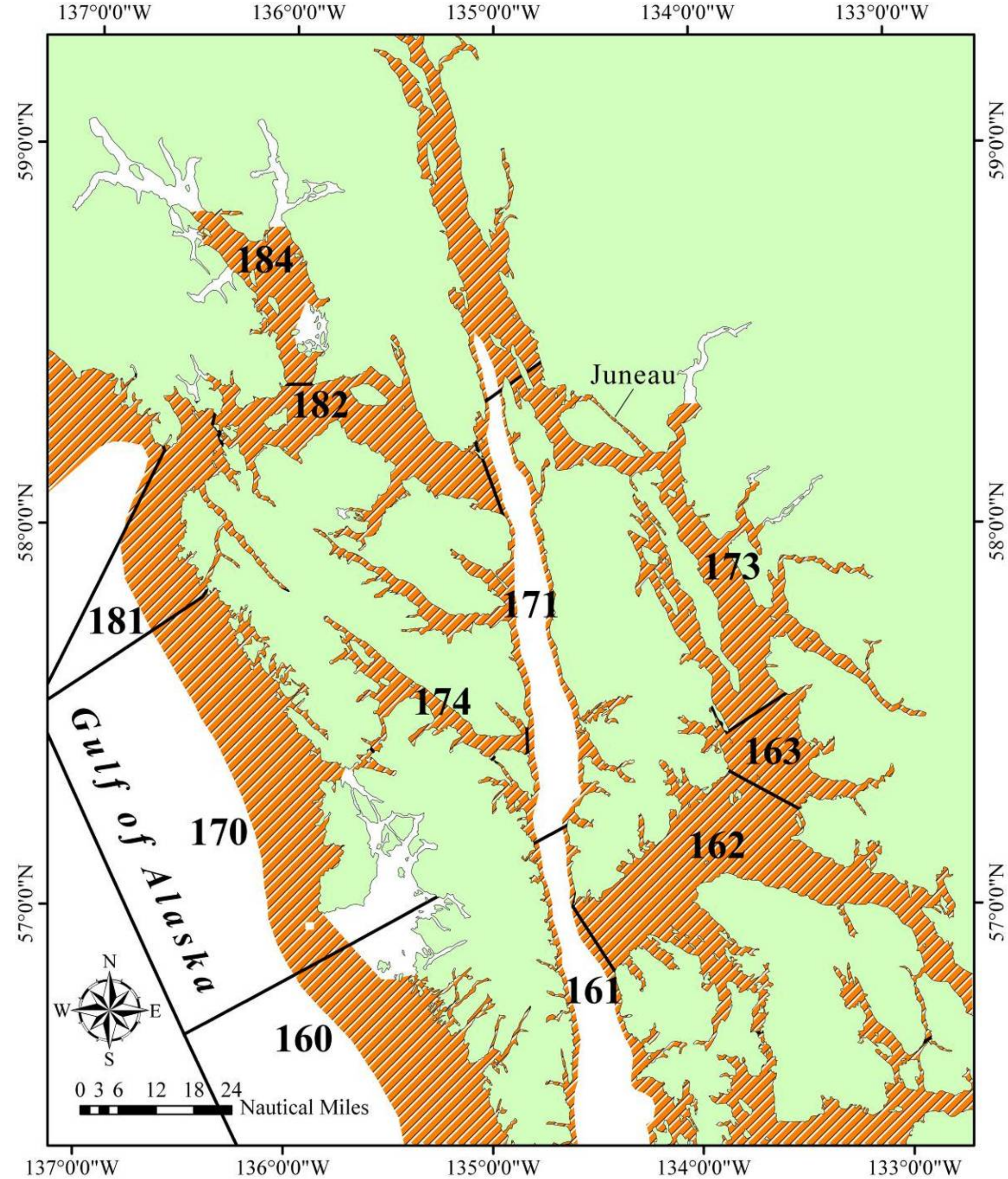

Figure 33. Main longline fishing grounds for halibut in northern SEAK (hatched areas).[98] IPHC statistical areas that overlap with ADF&G Districts 9 – 14 are indicated and numbered.

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[98] Personal communication from Vince Shafer, commercial fisherman, PO Box 172, Gustavus, AK 99826, December 2005.

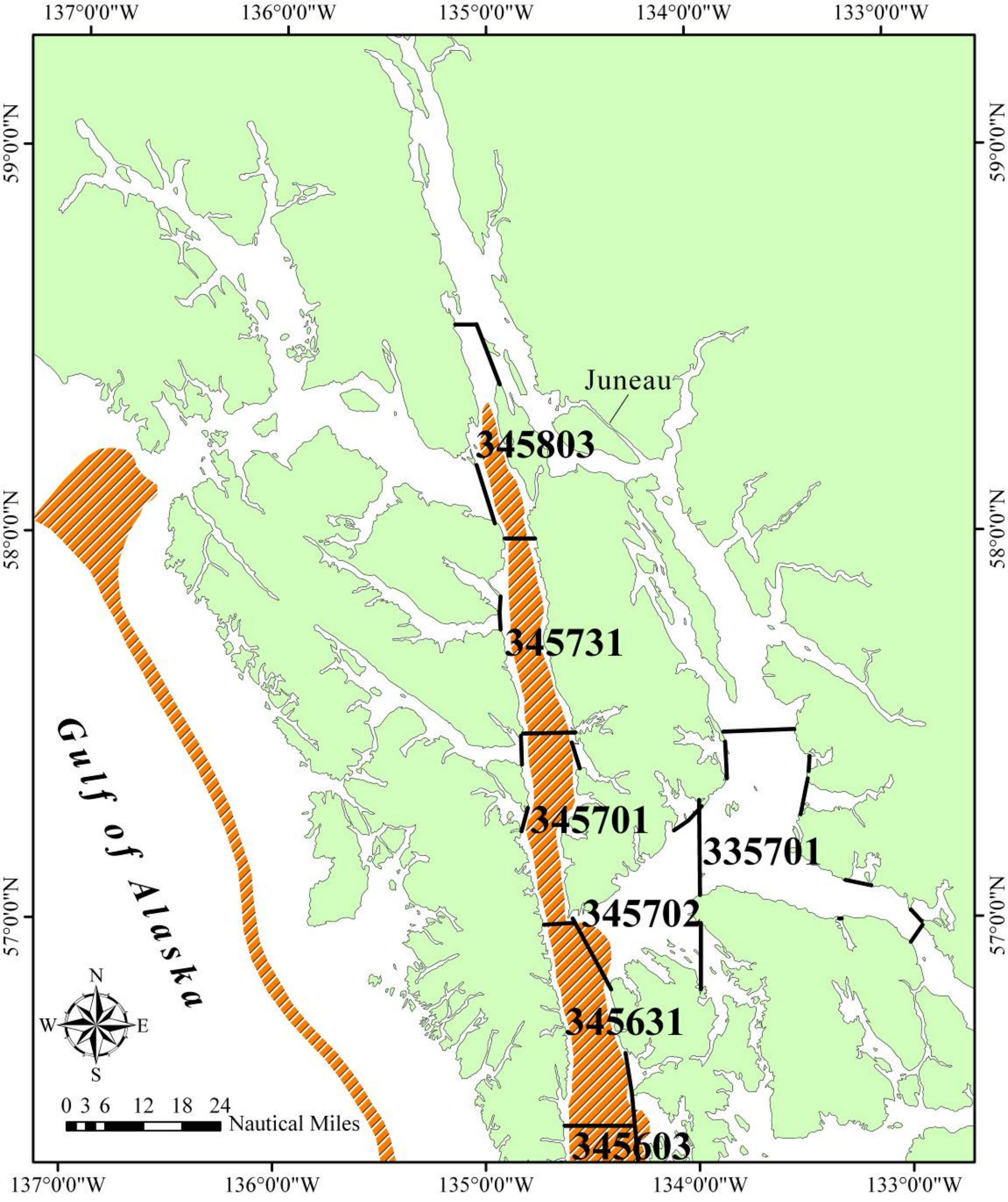

Figure 34. Main longline fishing grounds for sablefish in northern SEAK (hatched areas).[99,100] ADF&G groundfish statistical areas that overlap with ADF&G Districts 9 – 14 are indicated and numbered.

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[99] *Ibid*.

1993 the fishery was open annually for just 24 hours in September (Richardson and O'Connell 2004).

In 1995, the Alaskan Individual Fishing Quota System (IFQ) was implemented for both the halibut and the sablefish fisheries. This eliminated very short, derby-style fisheries, and created an extended 8.5 month season which begins in late February or early March and ends in mid November each year.

In addition, in 2003 a subsistence halibut program was implemented in Alaska, authorizing eligible persons to fish for halibut year-round in SEAK using various gear types, including longlines.

Gear

A longline consist of 1800 ft lengths of groundline; each length is called a 'skate' (Fig. 35). Each skate has 75 – 100 hooks attached via shorter lines called gangions, which are either tied or snapped to the groundline. The total weight of a skate is approximately 60 lb.[101] A "set" typically consists of 5 – 10 baited skates tied together and laid on the ocean bottom for a total length of 3,000 – 6,000 ft per set, with an anchor and a surface buoy attached at each end.[102] The groundline is typically 5/16-in. to 3/8-in. sinking line (*e.g.*, leaded polypropylene or nylon).[103,104,105] The weight of each anchor varies from 30 to 75 lb.[106] The hooks on the groundline are spaced approximately 10 – 20 ft apart for halibut

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[100] Personal communication from Victoria O'Connell, ADF&G Commercial Fisheries Division, 304 Lake Street, Rm. 304, Sitka, AK 99835, February 2006.

[101] Personal communication from Paul Barnes, commercial fisherman, PO Box 155, Gustavus, AK 99826, November 2005.

[102] Personal communication from Vince Shafer, commercial fisherman, PO Box 172, Gustavus, AK 99826, October 2005.

[103] *Ibid.*

[104] Personal communication from Paul Barnes, commercial fisherman, PO Box 155, Gustavus, AK 99826, November 2005.

[105] Personal communication from Pedr Turner, commercial fisherman, PO Box 217, Gustavus, AK 99826, November 2005.

[106] *Ibid.*

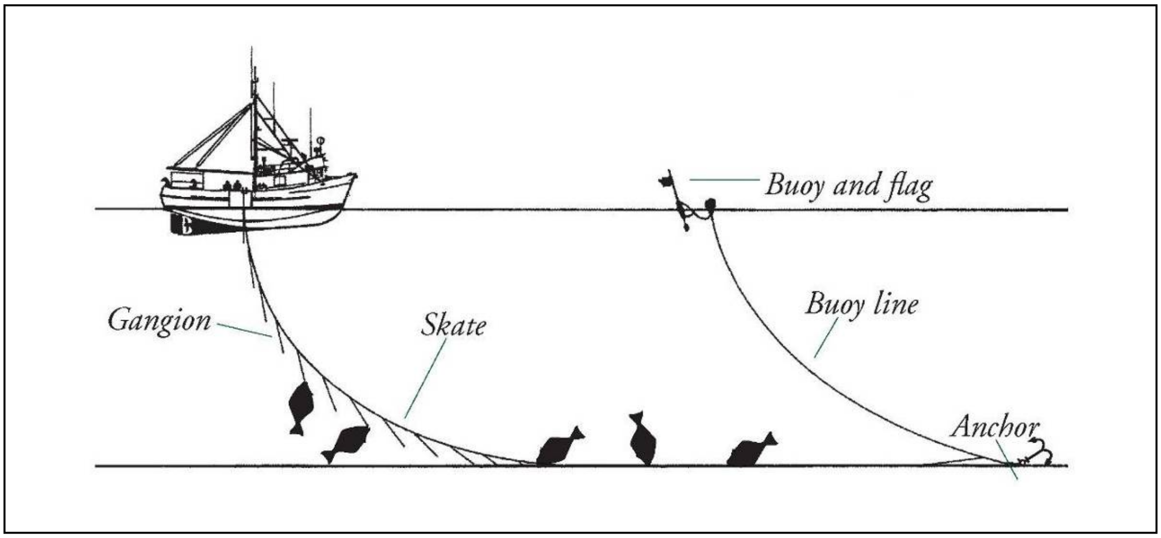

Figure 35. Diagram of generalized longline gear (illustration by Bob Hitz, courtesy of NOAA Alaska Sea Grant).

and 4 – 6 ft apart for sablefish. Soak times vary from 6 – 24 hours for halibut and from 6 – 12 hours for sablefish.[107]

Surface buoy line is typically 5/16-in. to 3/8-in. sinking line (*e.g.*, nylon).[108,109,110] The buoy line is typically composed entirely of sinking line, but it may be a combination of sinking and floating line spliced together. In the latter case, sinking line is used in the upper part of the water column and floating line is used in the lower part of the water column leading to the anchor.[111] The number of surface buoys used to mark each end of a set varies from two to five (or more) depending on the current and other local conditions. Often a combination of inflated poly buoy(s) approximately two feet in

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[107] Personal communication from Vince Shafer, commercial fisherman, PO Box 172, Gustavus, AK 99826, October 2005.

[108] *Ibid.*

[109] Personal communication from Paul Barnes, commercial fisherman, PO Box 155, Gustavus, AK 99826, November 2005.

[110] Personal communication from Pedr Turner, commercial fisherman, PO Box 217, Gustavus, AK 99826, November 2005.

[111] Personal communication from Vince Shafer, commercial fisherman, PO Box 172, Gustavus, AK 99826, October 2005.

diameter and smaller hard plastic buoys are used.[112] Typically, a set has two buoy lines (one at each end of the set); only rarely is a single buoy line used.[113] All buoys must be labeled with the ADF&G license number of the vessel operating the gear (05 AAC 28.050, 05 AAC 28.051).

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[112] *Ibid*.

[113] Personal communication from Paul Barnes, commercial fisherman, PO Box 155, Gustavus, AK 99826, November 2005.

Appendix 3

Humpback Whale Photo Catalogs Used for Individual Identification

CARTWRIGHT, R. Unpublished data. Keiki Kohola Project. Department of Biology, California State University – Channel Islands, One University Dr., Camarillo, CA 93012.

DARLING, J. D. 1991. Humpback Whales in Japanese Waters (Ogasawara and Okinawa) Fluke Identification Catalogue 1987-1990. World Wide Fund for Nature Japan, Minato-ku, Tokyo, Japan.

JACOBSEN, J. Unpublished data. Department of Biological Sciences, Humboldt State University, PO Box 4492, Arcata, CA 95518.

JURASZ, C. M., AND V. P. PALMER. 1981. Censusing and establishing age composition of humpback whales (*Megaptera novaeangliae*), employing photodocumentation in Glacier Bay National Monument, Alaska. Report to the National Park Service, Anchorage, AK, 42 pp.

NATIONAL MARINE MAMMAL LABORATORY. Unpublished data. 7600 Sand Point Way NE, Seattle, WA 98115.

PACIFIC BIOLOGICAL STATION. Photographic Catalogue of Humpback Whales in British Columbia (http://www-sci.pac.dfo-mpo.gc.ca/sa/cetacean/humpbackwhale/default_e.htm), Cetacean Research Program, Pacific Biological Station, 3190 Hammond Bay Rd., Nanaimo, BC V9T 6N7.

PERRY, A., C. S. BAKER, AND L. M. HERMAN. 1985. The natural history of humpback whales (*Megaptera novaeangliae*) in Glacier Bay. Final Report to the National Park Service, Alaska Regional Office, Anchorage, AK, 41 pp.

PERRY, A., J. R. MOBLEY, JR., C. S. BAKER AND L. M. HERMAN. 1988. Humpback whales of the central and eastern North Pacific. University of Hawaii Sea Grant Miscellaneous Report UNIHI-SEAGRANT-MR-88-02, 236 pp.

SHARPE, F. Unpublished data. Alaska Whale Foundation, 4739 University Way NE #1239, Seattle, WA 98105.

STRALEY, J. M., AND C. M. GABRIELE. 2000. Humpback Whales of Southeastern Alaska. Humpback whale fluke identification catalog (3rd printing), National Park Service, PO Box 140, Gustavus, AK.

UCHIDA, S., AND N. HIGASHI. 1995. Fluke Identification Catalogue of Humpback Whales in Japanese Waters off Okinawa 1991-1995. Okinawa Expo Aquarium, Motobu-Cho, Okinawa, Japan 905-03.

VON ZIEGESAR, O., B. GOODWIN AND R. DEVITO. 2004. A catalog of humpback whales in Prince William Sound Alaska 1977-2001, Eye of the Whale Research, PO Box 15191, Homer, AK 99603.