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Potential for bowhead whale entanglement in cod and crab pot gear in the Bering Sea

John J. Citta,[1] Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701, U.S.A.; **John J. Burns**, Alaska Department of Fish and Game (retired), PO Box 83570, Fairbanks, Alaska 99708, U.S.A.; **Lori T. Quakenbush**, Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701, U.S.A.; **Vicki Vanek**, Alaska Department of Fish and Game, 211 Mission Road, Kodiak, Alaska 99615, U.S.A.; **John C. George**, North Slope Borough, Department of Wildlife Management, PO Box 69, Barrow, Alaska 99723, U.S.A.; **Robert J. Small**, Alaska Department of Fish and Game, 1255 West 8th Street, Juneau, Alaska 99811-5526, U.S.A.; **Mads Peter Heide-Jørgensen**, Greenland Institute of Natural Resources, ℅ Greenland Representation, Strandgade 91, 3, Postboks 2151, DK-1016 Copenhagen, Denmark; **Harry Brower**, North Slope Borough, Department of Wildlife Management, PO Box 69, Barrow, Alaska 99723, U.S.A.

Abstract

Bowhead whales (*Balaena mysticetus*) of the western Arctic stock winter in ice-covered continental shelf regions of the Bering Sea, where pot fisheries for crabs (*Paralithodes* and *Chionoecetes* spp.) and Pacific cod (*Gadus macrocephalus*) pose a risk of entanglement. In the winter of 2008–2009 and 2009–2010 the spatial distribution of 21 satellite tagged bowhead whales partially overlapped areas in which pot fisheries for cod and blue king crab (*Paralithodes platypus*) occurred. However, these fisheries ended before whales entered the fishing areas, thus avoiding temporal overlap. A fishery for snow crab (*Chionoecetes opilio*) typically runs from January to May and provides the greatest potential for bowhead whales to encounter active pot gear. Tagged whales did not enter the area of the snow crab fishery during this study and generally remained in areas with >90% sea ice concentration, which is too concentrated for crab boats to penetrate. Pack ice sometimes overruns active fishing areas, resulting in lost gear, which is the most likely source of entanglement. The western Arctic stock of bowhead whales was increasing as of 2004; as such, incidental mortality from commercial pot fisheries is probably negligible at this time. Regardless, entanglement may increase over time and should be monitored.

Key words: bowhead whale, *Balaena mysticetus*, Bering Sea, commercial pot fisheries, pot gear, entanglement, Bering Sea-Aleutian Island Crab Rationalization Program, Pacific cod.

Entanglement in fishing nets and lines is a documented source of injury and mortality for baleen whales worldwide, including North Atlantic right whales (*Eubalaena glacialis*; *e.g.*, Knowlton and Kraus 2001, Johnson *et al.* 2005, Knowlton *et al.* 2012),

[1]Corresponding author (e-mail: john.citta@alaska.gov).

North Atlantic and North Pacific humpback whales (*Megaptera novaeangliae*; *e.g.*, Robbins and Mattila 2001, 2004; Johnson *et al.* 2005; Neilson 2009), and gray whales (*Eschrichtius robustus; e.g.*, Bradford *et al.* 2009).

In Alaska, approximately 10% of bowhead whales (*Balaena mysticetus*) harvested by subsistence whalers have rope scars indicative of entanglement (Reeves *et al.* 2012). While a small number of scars might be due to harpoon lines attached to whales that were previously struck but lost, all observed entanglements implicate commercial pot fisheries. To date, at least six beach-cast, two harvested, and three swimming bowhead whales have been observed tangled in lines. Three of these whales, two beach-cast and one harvested, were confirmed to be tangled in commercial pot gear. The remaining whales were tangled in line consistent with that used as buoy lines in commercial pot fisheries (Philo *et al.* 1992; George 2010; Reeves *et al.* 2012; North Slope Bureau, unpublished data). This stock of whales, known as the Western Arctic or the Bering-Chukchi-Beaufort stock, summers primarily in the Beaufort and Chukchi seas and winters in the Bering Sea (Moore and Reeves 1993, Quakenbush *et al.* 2010, Citta *et al.* 2012). Intensive fall and winter pot fisheries occur in the Bering Sea, but currently no commercial pot fisheries occur in the Beaufort or Chukchi seas.

Bowhead whales are usually found north of the shelf break in the Bering Sea (Moore and Reeves 1993, Citta *et al.* 2012). Pot fisheries currently found north of the shelf break include red king crab (*Paralithodes camtschaticus*) in Bristol Bay and Norton Sound, blue king crab (*Paralithodes platypus*) near St. Matthew Island, and snow crab (*Chionoecetes opilio*) (Fig. 1). The snow crab fishery is the largest and geographically most extensive, ranging from southeast of the Pribilof Islands to St. Matthew Island. There is also a fall pot fishery for Pacific cod (*Gadus macrocephalus*), which extends from the Aleutian Islands along the shelf break to the central Bering Sea and on to the vicinity of St. Matthew Island. A Tanner crab (*Chionoecetes bairdi*) fishery was open east of 166°W in 1999, but was closed in 2010. Similar fisheries occur in Russian waters. Blue king, snow, and Tanner crabs are all found in shelf waters south and southeast of Cape Navarin (Slizkin and Safronov 2000, Pereladov and Miljutin 2002). In general, the Russian fisheries are active from spring through late fall rather than during winter.[2] More specific information on the Russian pot fisheries is unavailable.

In the American fisheries discussed above, pots are set individually as opposed to multiple pots tethered to a long ground line. Pots are constructed of steel pipe and heavy nylon web. They are rectangular, typically with a top and bottom of 198 × 198 cm to 244 × 244 cm, and sides of 70–99 cm (Zhou and Kruse 2000). Weight of empty pots ranges from approximately 270 to 320 kg (Burns 1993, Blau 1997). All pots are required to have a panel of biodegradable web to insure that if lost they cannot continue to catch and retain crabs or fishes.

As described in a general profile of the fishery (NPFMC 2012), each pot has a short bridle generally made of 2.54 cm (1 in.) diameter buoyant polypropylene line. Buoy line is attached to this bridle and includes multiple lengths of 1.9 cm (¾ in.) buoyant polypropylene line, each 60 m long. These sections do not extend to the sea surface. The topmost section is a length of 1.9 cm (¾ in.) nonbuoyant line to which two surface buoys are attached; the main buoy and 4–5 m after it, at the end of the line, a "trailing" buoy. In this configuration, buoyant line prevents snagging on the seafloor

[2]Personal communication from Vladimir I. Radchenko, Deputy Director General, Pacific Scientific Research Fisheries Center (TINRO-Center), 4 Shevchenko Alley, Vladivostok 690950, Russian Federation, 27 November 2012.

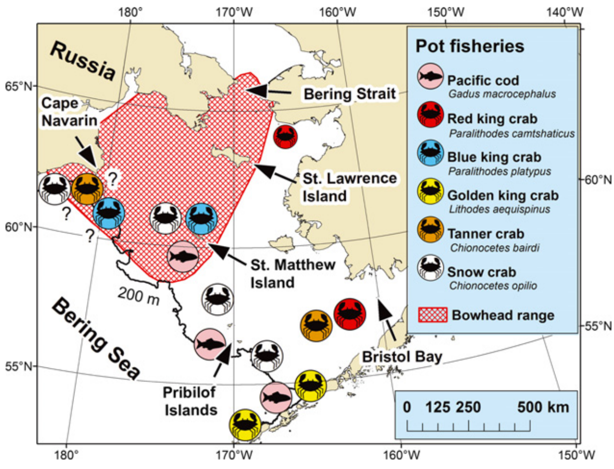

Figure 1. General areas of fall and winter pot fisheries in the Bering Sea during 2008–2011. Approximate primary winter range of bowhead whales is shown in red crosshatching and the 200 m isobath denotes the shelf break. Pot fisheries in Russian waters are poorly documented and are denoted with question marks.

or on submerged hazards. Nonbuoyant line at and near the surface is important to avoid interfering with vessels or their propellers. A pot is retrieved by snagging the "trailing" line between the buoys, using a hand-thrown grapple hook. Gear modifications to reduce entanglement of marine mammals, such as "weak links" connecting lines to buoys that are designed to break if a whale entangles (*e.g.*, Higgins and Salvador 2010), are currently not required.

Here, we examine the spatial and temporal overlap among the locations of 21 bowhead whales instrumented with satellite transmitters during the winters of 2008/2009 (n = 11) and 2009/2010 (n = 10), the distribution of the crab and cod fisheries, and the concentration/dynamics of sea ice. Sea ice is an important factor because it may affect the distribution of pot fisheries and whales (albeit in opposite ways). We limit our consideration to three pot fisheries: snow crab, St. Matthew Island blue king crab, and Pacific cod. Fisheries beyond the known winter range of bowhead whales (*e.g.*, Bristol Bay and Norton Sound red king crab fisheries; Fig. 1), those for which more detailed information is not available (*e.g.*, the Russian pot fisheries), and fisheries that are within the winter range of whales, but are currently closed, were not considered. Closed fisheries include those for the Pribilof Islands Tanner and blue king crabs, due to depleted stocks, and the Pribilof Islands red king crab fishery, due to concerns regarding bycatch of Pribilof Islands blue king crabs. Although the St. Matthew Island blue king crab fishery was closed prior to the 2009 season due to depleted numbers, this fishery reopened during the winter of 2009 and is included in this analysis.

Materials and Methods

Whale Tagging

We used the satellite-linked transmitter attachment and deployment system developed by the Greenland Institute of Natural Resources (Heide-Jørgensen *et al.* 2001,

2003) to deploy tags manufactured by Wildlife Computers (Redmond, WA). Dimensions of the tags are described in Quakenbush *et al.* (2010). Tags were deployed using a 2 m or 4 m long fiberglass pole as a jab-stick (Heide-Jorgensen *et al.* 2003). Due to permitting requirements, calves <1 yr of age and cows with calves were avoided. Of the 21 whales used in this study, all were tagged in fall; three near Atkinson Point, Canada (69.94ºN, 131.42ºW), and 18 near Point Barrow, Alaska (71.29ºN, 156.79ºW).

Location Processing

Transmitter locations were derived using signals received by Argos satellites when whales were at the surface. Location error was estimated by the Argos system and characterized by "location classes" (see the Argos User's Manual for a complete description, available at http://argos-system.org/manual/). Location classes (B, A, 0, 1, 2, 3) are only an approximate representation of location accuracy (*e.g.*, Vincent *et al.* 2002). Instead of using only the locations representing the highest accuracy (2 or 3), we chose to use all available location classes and a location filter developed by Freitas *et al.* (2008) in R version 2.5.1 (available at http://R-project.org) to remove less accurate locations. Successive whale locations that resulted in swim velocities of >1.94 m/s were removed unless they were ≤5 km from the previous location. The threshold velocity of 1.94 m/s is the maximum observed swim speed of bowhead whales not fleeing vessels or assisted by currents (*e.g.*, Zeh *et al.* 1993). The location filter also included an angular component to account for locations with a high degree of location error that fall far from the line of travel, forming acute angles between adjacent locations (*e.g.*, Keating 1994, Freitas *et al.* 2008). We used default settings to define the angular components of the location filter. Locations within 2.5 km of the trackline that resulted in angles <15º were removed and locations between 2.5 and 5 km of the track line were removed if they resulted in angles <25º. We then removed locations that fell on land to establish the final set of locations used in analyses.

Sea Ice

To generate monthly average sea ice concentrations, we used data from the Advanced Microwave Scanning Radiometer (AMSR) instrument aboard NASA's Earth Observing System AQUA satellite (known as AMSR-EOS or, more commonly, AMSR-E). AMSR-E data are currently available through the National Snow and Ice Data Center at http://nsidc.org/data/amsre/. We calculated monthly average concentrations using a sample of daily ice concentrations and the "cell statistics" tool within ArcMap 10. Starting on the first day of each month, we sampled the ice concentrations every fourth day.

Location of Pot Fisheries

Location of the pot fisheries was based on the latitude and longitude from multiple pots sampled by onboard observers. Regulations adopted by the Alaska Board of Fisheries in 1999 authorized the Alaska Department of Fish and Game (ADF&G) to place observers onboard any vessel participating in the Bering Sea/Aleutian Island crab fisheries (Boyle and Schwenzfeier 2002, Bowers *et al.* 2008). Regulations required all vessels that process *Chionoecetes* spp. (including Tanner and snow crabs), red king crab, blue king crab, or golden king crab (*Lithodes aequispinus*) at sea to have observers onboard. Regulations also authorized ADF&G to place observers on fishing vessels, as needed, for collecting data necessary for fishery management (*e.g.*, incidental catch of nontarget species, age composition of the catch, *etc*.). In practice, the percent of fishing vessels with observers ranged from 30% for the extensive snow crab fishery to 100% for smaller fisheries, such as the one for St. Matthew Island blue king crab. Observers collected data from a sample of the catch, including the sex and size class of crabs and the geographic locations of sampled pots. The Pacific cod pot fishery in the Bering Sea is managed by the National Marine Fisheries Service (NFMS). Under the North Pacific Groundfish Observer Program (U.S. Federal Register 2010), observers were placed on board all pot fishing vessels ≥18.3 m in length that fished longer than 3 d. Data, including latitude and longitude, were recorded for at least 30% of the cod pot sets. The boundaries of all pot fishing areas (cod and crab) were mapped as polygons to maintain the confidentiality of the locations of individual pot sets.

Results

During the winter of 2008/2009, the 11 southward migrating whales (Table 1) entered the Bering Sea over an approximate two month period from 7 November to 11 January ($\bar{x}$ = 14 December). Movement of whales into the Bering Sea was correlated with the formation and expansion of sea ice (Fig. 2). The cod pot fishery closed in September 2008. The snow crab fishery opened in November and continued

Table 1. Number of satellite locations of 21 bowhead whales in the Bering Sea, by winter and month. These are the locations that are presented in Figures 2–5.

Winter	Whale ID	Sex	Length (m)	Month: November	December	January	February	March	April
2008–2009	B08-01	F	11		15	63	23	9	13
2008–2009	B08-03	?	15	107					
2008–2009	B08-06	?	10			419	359	181	
2008–2009	B08-07	M	10		76	252	319	305	68
2008–2009	B08-08	?	10		30	262	272	110	
2008–2009	B08-09	M	9		21	52	127	231	133
2008–2009	B08-10	F	10			185	336	409	112
2008–2009	B08-11	M	10	22	50	207	367	377	199
2008–2009	B08-12	M	>9			124	154	199	306
2008–2009	B08-13	?	10		38	207	130	39	
2008–2009	B08-14	M	>14	12	1	183	209	204	80
2009–2010	B09-01	F	15	342	321				
2009–2010	B09-02	?	14	44	75	53			
2009–2010	B09-03	?	12	38	37				
2009–2010	B09-04	M	10		64	74	81	74	56
2009–2010	B09-05	M	10	21	156	110	111	68	31
2009–2010	B09-08	M	14	2	11	5			
2009–2010	B09-09	?	14	38	248	124	105	134	61
2009–2010	B09-13	F	8	47	179	123	62	88	79
2009–2010	B09-15	F	11	27	123	81	17	33	12
2009–2010	B09-16	M	13		17	90	135	27	69

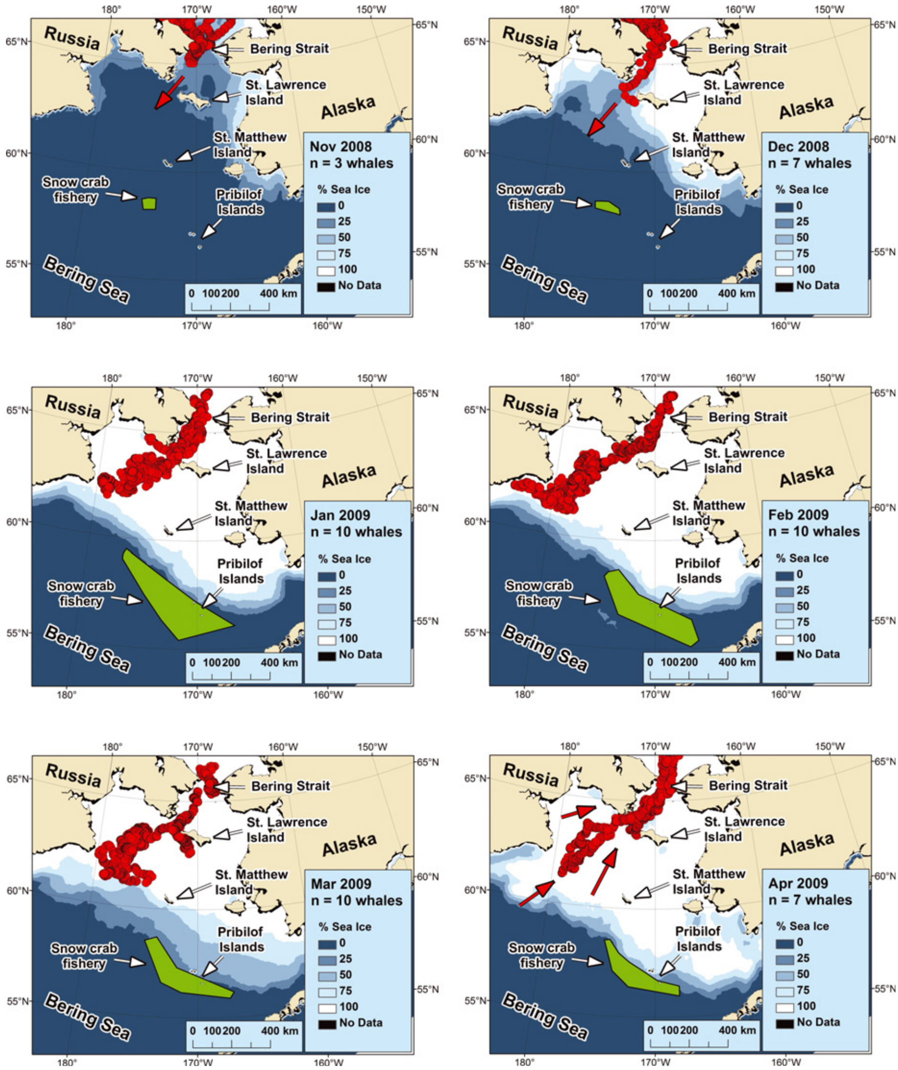

Figure 2. Bowhead whale locations (red circles; monthly sample size, *n*, of tagged whales is for the Bering Sea), sea ice concentration (%), and location of the snow crab fishery in U.S. waters (green polygons) between November 2008 and April 2009. Red arrows denote the general direction of whale movement.

through April. The geographic extent of the snow crab fishery was relatively limited in November and December (Fig. 2) but expanded between January and April. At maximum extent, the snow crab fishery extended from approximately 166°W to 177°W, along the shelf break, generally south of the ice edge. Tagged bowhead whales remained north of the ice edge and west of the snow crab fishery. Tagged whales never overlapped pot fishing areas in U.S. waters before migrating north in April 2009 (Fig. 3) and were never closer than 290 km to the nearest fishery, which was for snow crab.

In 2009/2010 the 10 tagged bowhead whales (Table 1) migrated into the Bering Sea over a period of less than one month. Entry dates ranged from 14 November to 4 December ($\bar{x}$ = 26 November). Tagged whales ranged farther east than during the winter of 2008/2009 (compare Fig. 2 and 4). Of six transmitters that functioned until the spring migration, five transmitted within 100 km of St. Matthew Island. As in spring 2009, the northward migration began the first week of April. Tagged whales never came closer than 210 km of an active pot fishery in U.S. waters (Fig. 4). There was, however, considerable overlap of whale locations and both the Pacific cod and the St. Matthew blue king crab pot fishery areas (Fig. 5). The cod pot fishery occurred west of St. Matthew Island in September 2009 and the St. Matthew blue king crab fishery occurred in the vicinity of St. Matthew Island in November and December 2009 (Fig. 5). Four of ten tagged whales entered the region where cod pots had previously been fished in September. Six of ten tagged whales entered the region where the pots set for St. Matthew blue king crab were previously fished in November and December.

Discussion

Although there was some spatial overlap of bowhead whales and active pot fisheries, there was no temporal overlap. Bowhead whales range mainly north of the ice edge, while pot fishing boats set gear south of the ice edge (Fig. 2, 4). We have only a general understanding of Russian pot fisheries in the western Bering Sea, yet conversations with Russian scientists indicate those fisheries near Cape Navarin end in December due to thickening and advancing sea ice, and do not reopen until the following spring. In U.S. waters, tagged whales did not enter any of the pot fishing areas until the end of December. Hence, entanglements are due either to whales venturing south of the ice edge into active pot fishing areas in Alaskan waters (presuming there are no winter pot fisheries in Russian waters) or are due to lost gear.

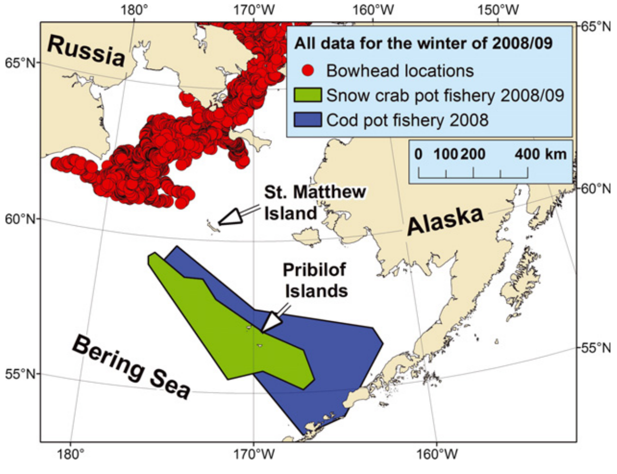

Figure 3. Locations obtained from 11 bowhead whales in relation to pot fisheries in U.S. waters between November 2008 and April 2009.

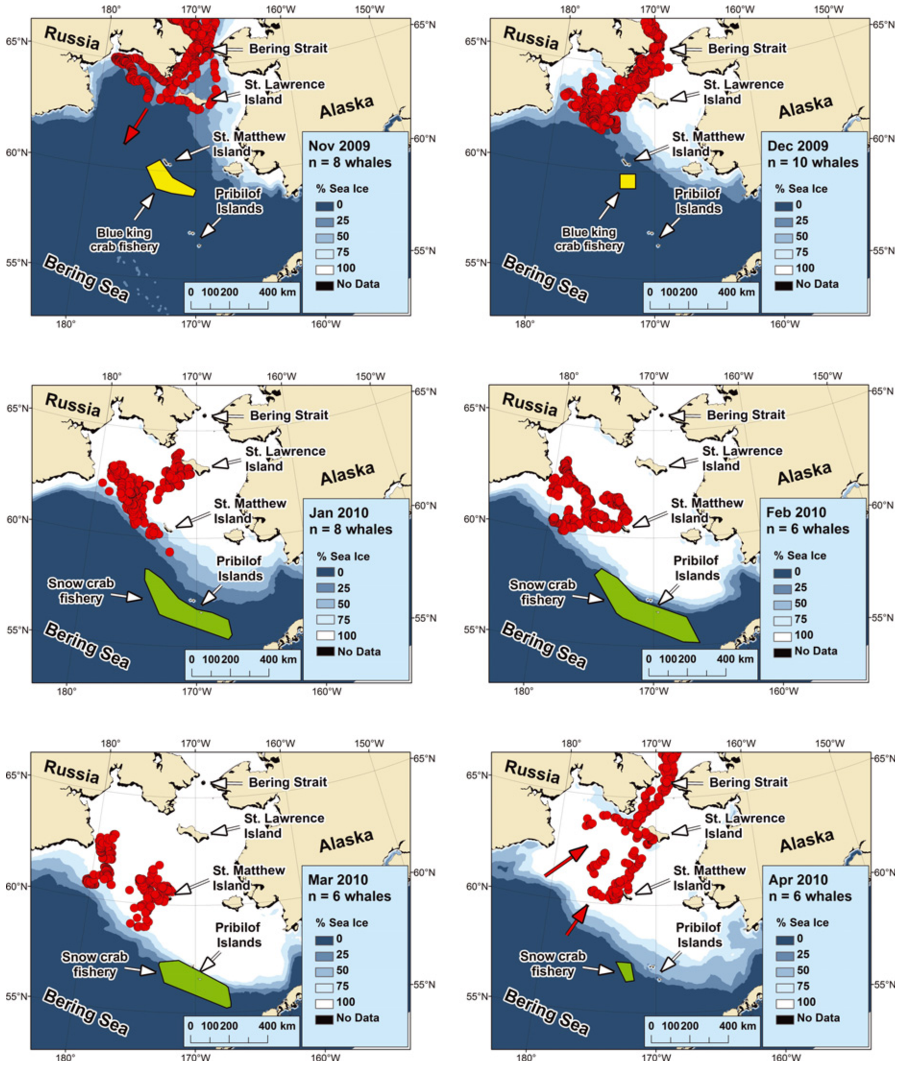

Figure 4. Bowhead whale locations (red circles; monthly sample size, *n*, of tagged whales is for the Bering Sea), sea ice concentration (%), and location of the blue king crab fishery (yellow polygon) and snow crab fishery (green polygon) in U.S. waters between November 2009 and April 2010. Red arrows denote the general direction of whale movement.

The locations of tagged whales can be used to identify where most whales winter, yet satellite tag data underestimate the entire distribution of bowhead whales in the Bering Sea. Bowhead whales have been sighted near the Pribilof Islands (Braham *et al.* 1980) and are detected on passive acoustic recorders as far east as 164.057°W (~350 km east of the Pribilof Islands) in some winters (Stafford and Mellinger 2009). Furthermore, although none of the whales we tagged ventured south of the marginal ice edge (Citta *et al.* 2012), bowhead whales have been observed adjacent to the

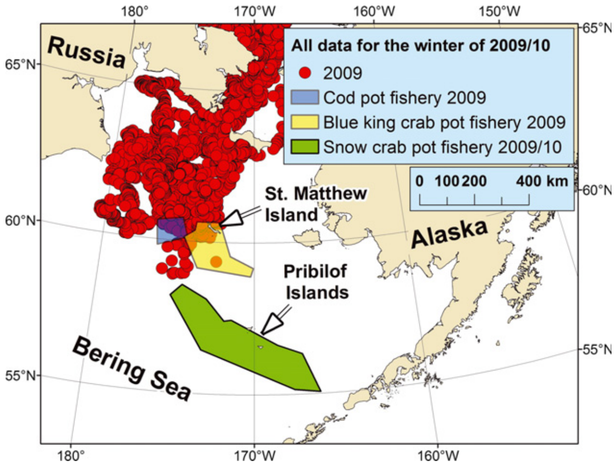

Figure 5. Locations obtained from 10 bowhead whales in relation to pot fisheries in U.S. waters between November 2009 and April 2010. There was spatial overlap between whales and pot fisheries but no temporal overlap.

marginal ice edge in open water (*e.g.*, Braham *et al.* 1980, Brueggeman 1982, Ljungblad 1986). Pots are set near the ice edge during the snow crab fishery (Fig. 2, 4), and if whales venture south of the ice edge near the Pribilof Islands they may encounter active pot sets.

Lost Pot Gear and the Bering Sea-Aleutian Island Crab Rationalization Program

In the Bering Sea, pot gear is sometimes lost during episodes of rapidly advancing sea ice. The southern extent of ice is largely determined by wind; strong or prolonged wind from the north can cause the pack ice in the Bering Sea to rapidly advance southwards (Niebauer and Schell 1993) overrunning large numbers of pots, some of which are not recovered (Burns 1993). Such an event occurred in January 2012 (after this study), when sea ice covered 562,000 square km of the Bering Sea, ~23% more than the 1979 to 2000 average (NSIDC 2012), and the severe ice conditions resulted in the loss of ~800 crab pots (~6% of the total number set) during the snow crab fishery.

How long lost pots are capable of entangling whales is unknown. Sea ice may quickly crush and sink buoys or detach buoy lines, lowering the risk of entanglement. However, buoy lines commonly have breaking strengths in excess of 3,000 kg and buoy eyelets commonly have breaking strengths greater than 450 kg. Therefore, pots may simply be dragged and redistributed by moving sea ice. We think that unless buoys are damaged and sink, the attached lines pose some risk for entanglement and suspect most entanglements may occur under the sea ice following rapid ice advance (Burns 1993).

Fortunately, the number of pots lost has declined over time. Before 2006, crab fisheries in Alaska were managed as a "derby" system where boats competed for a limited harvest in an open access fishery during short predetermined open fishing periods. The season closed when the total quota of crabs was harvested. As a result of this race for crabs, seasons were typically short, often a week or two in duration, and some boats set pots in extreme weather. In March 2005, new federal regulations were promulgated that established the Bering Sea-Aleutian Island Crab Rationalization Program. The new management regime was in accord with the provisions adopted by the North Pacific Fishery Management Council as Amendments 18 and 19 of the Fishery Management Plan for the commercial king and Tanner crab fisheries (U.S. Federal Register 2005). The Crab Rationalization Program established a quota system for allocating the entire harvest in each of the Bering Sea-Aleutian Island crab fisheries to qualifying vessels. ADF&G now sets an annual total allowable catch (TAC) for each fishery according to state regulations and NMFS distributes the TAC as quota shares to qualifying fishermen as individual fishing quotas (IFQ).

There are currently fewer vessels and pots in the crab fisheries, partly due to the Crab Rationalization Program and partly due to overfishing prior to the implementation of the program. In the snow crab fishery there was an annual average of 222 registered vessels and 46,162 registered pots from 1990 to 2005. In contrast, after implementation of the Crab Rationalization Program there was an average of 73 registered vessels and 12,364 registered pots from 2006 to 2011. A similar pattern is observed in the St. Matthew blue king crab fishery. Between 1990 and when the fishery was closed due to a depleted population in 1999, there was an average of 101 registered vessels and 8,697 registered pots. This fishery reopened in 2009, but is relatively small. There were only 7 registered vessels (1,022 registered pots) in 2009 and 11 registered vessels (1,615 registered pots) in 2010. The Tanner crab fishery was even more extensive than the snow crab fishery before it was closed in 1997 due to population depletion. Between 1990 and 2007, there was an annual average of 235 registered vessels and 67,852 registered pots. The Tanner crab fishery has not reopened west of 166ºW and the current fishing area is mostly east of the winter range of bowhead whales. Hence, there are fewer vessels setting fewer pots in all the winter crab fisheries.

Fewer pots are also being lost in these fisheries. Because of the IFQs and a vessel "cap," each vessel has a maximum catch limit and there is no longer need for a very short season. Vessel operators can choose when they want to fish within what is now a much longer open season and thus avoid setting pot gear when weather and ice forecasts are unfavorable. As a result, fewer pots are lost under the Crab Rationalization Program than were lost under the derby system. Prior to 2006, data on lost pots were collected sporadically by ADF&G and can only be approximated. Those data suggest 10%–20% of all pots fished under the derby system were lost annually, perhaps 5,000–10,000 per year. By comparison, between 2006 and 2011, 1%–4% of pots were lost per year in the snow crab fishery and 1.5% were lost during the 2009/2010 St. Matthew blue king crab fishery (ADF&G, unpublished data). Although the percentage is low, the total number of lost pots is not trivial, especially for the more extensive pot fisheries. Cumulatively, between the 2006/2007 and 2009/2010 seasons, approximately 1,400 pots were lost during the snow crab fishery, compared to the loss of 15 pots during the 2009/2010 season for the small St. Matthew blue king crab fishery. Pot loss statistics are not kept for the Bering Sea cod fishery. This fishery usually closes by the end of September, well before both the formation of seasonal sea ice near the shelf break and the arrival of bowhead whales near the cod fishing area. The number of cod pots lost is reportedly low but, unfortunately, unknown.

The Bering Sea-Aleutian Island Crab Rationalization Program was originally implemented to improve the conservation of crab species, reduce bycatch, reduce excess harvesting and processing capacity (*i.e.*, there were not enough crabs for all harvesters and processors), create more economic stability for harvesters, processors, and coastal communities, and to promote human safety at sea (NPFMC 2004). An unanticipated benefit of this program is an almost certain reduction in the number of cetacean entanglements by decreasing the number of lost pots.

Entanglement Mortality and Serious Injury

Under Section 117 of the Marine Mammal Protection Act, the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) are required to summarize mortality and "serious injury" incidental to commercial fishing. The intent is to reduce mortality and serious injury to insignificant levels approaching a zero rate (U.S. Federal Register 2004). Serious injury was defined by Angliss and DeMaster (1998) as an injury likely to result in death or one that impairs reproduction. Current NMFS policy is to interpret the regulatory definition of serious injury as "any injury that is more likely than not to result in mortality, or any injury that presents a greater than 50% chance of death to a marine mammal." Injuries known to result in mortality in more than 50% of documented cases are considered serious injuries. When such data do not exist, expert opinion is used (NMFS 2012). For harvested and beach-cast whales entangled in pot gear, observers can assess the severity of entanglement. For harvested whales, the health of the animal can also be assessed. Whales with healed line scars are no longer likely to die from entanglement, and thus their previous entanglement can no longer constitute serious injury. However, most line scars are found on older whales (North Slope Borough, unpublished data). Perhaps some calves and younger whales did not survive entanglements long enough to be seen with attached lines or to be harvested. Within North Atlantic right whales, calves and juveniles are known to have a higher incidence of serious entanglements than adults (Knowlton *et al.* 2012) and the same may be true for bowhead whales. Alternatively, because fewer pots have been lost in recent years, many of the scars observed may be the result of entanglements that occurred before 2006, when the Crab Rationalization Program was implemented.

It is also important to know which fishery is responsible for entanglements. The Marine Mammal Protection Act authorizes NMFS to manage incidental take of marine mammals in domestic commercial fisheries through regulation. However, regulating U.S. fisheries will not reduce the number of entanglements that occur in foreign fisheries and may pose an unnecessary hardship on domestic fishermen. As such, determining whether bowhead whale entanglement occurs predominantly in Russian or U.S. waters is important. If most entanglements occur when whales encounter intact pot gear under sea ice and if most of this gear is lost during episodes of advancing ice, then it is reasonable to assume that most entanglements result from winter fisheries. Russian pot fisheries are not thought to be active in winter, so there is no reason to assume that entanglements only occur in Russian waters. Rather, the opportunity for entanglement is probably greatest due to the winter snow crab fishery, which occurs in U.S. waters.

Whether additional regulation or modification of pot gear is currently warranted is unclear. This stock of bowhead whales has been increasing (George *et al.* 2004, Zeh and Punt 2005) despite the observed entangled whales, the observed incidence of whales with rope scars, and a subsistence hunt in which ~40 whales are landed annually (Suydam and George 2004). Thus, if any mortality is caused by entanglement from the Bering Sea crab and cod pot fisheries, the level of that mortality appears negligible. As defined by the NMFS, a "negligible impact" is one that "cannot be reasonably expected to, and is not reasonably likely to, adversely affect the species or stock through effects on annual rates of recruitment or survival" (50 CFR 216.103).

We recommend continued monitoring for evidence of entanglement on beach-cast whales, floating dead whales, and on whales landed in the subsistence harvest. The spatial and temporal overlap of commercial fisheries and bowhead whales may increase over time, possibly leading to more entanglements. How a warming climate, changes in the distribution of sea ice, or changing oceanography may affect the distribution of crabs, cod, and bowhead whales is unclear, as is how those factors may affect entanglement of whales. Even a low number of entanglements may become unacceptable if other sources of mortality, such as ship strikes, increase.

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Literature Cited

Angliss, R. P., and D. P. De Master. 1998. Differentiating serious and non-serious injury of marine mammals taken incidental to commercial fishing operation. Report of the Serious Injury Workshop, 1–2 April 1997, Silver Spring, MD. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-OPR-13.

Blau, S. F. 1997. Alaska king crabs. Alaska Department of Fish and Game, Juneau, AK. Available at http://www.adfg.alaska.gov/static/education/wns/alaska_king_crabs.pdf.

Bowers, F. R., M. Schwenzfeier, S. Coleman, *et al*. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 08-02, Anchorage, AK.

Boyle, L., and M. Schwenzfeier. 2002. Alaska's mandatory shellfish observer program, 1988–2000. Pages 693–704 *in* A. J. Paul, E. G. Dawe, R. Elner, *et al*., eds. Crabs in cold water regions: Biology, management, and economics. University of Alaska Sea Grant College Program AK-SG-02-01, Fairbanks, AK.

Bradford, A. L., D. W. Weller, Y. V. Ivachenko, A. M. Burdin and R. L. Brownell, Jr. 2009. Anthropogenic scarring of western gray whales (*Eschrichtius robustus*). Marine Mammal Science 25:161–175.

Braham, H., B. Krogman, J. Johnson, *et al*. 1980. Population studies of the bowhead whale (*Balaena mysticetus*): Results of the 1979 spring research season. Report of the International Whaling Commission 30:391–404.

Brueggeman, J. J. 1982. Early spring distribution of bowhead whales in the Bering Sea. Journal of Wildlife Management 46:1036–1044.

Burns, J. 1993. Epilogue. Pages 745–764 *in* J. J. Burns, J. H. Montague and C. J. Cowles, eds. The bowhead whale. Special Publication Number 2. The Society for Marine Mammalogy.

Citta, J. J., L. T. Quakenbush, J. C. George, *et al*. 2012. Winter movements of bowhead whales (*Balaena mysticetus*) in the Bering Sea. Arctic 65:13–34.

Freitas, C., C. Lydersen, M. A. Fedak and K. M. Kovacs. 2008. A simple new algorithm to filter marine mammal Argos locations. Marine Mammal Science 24:315–325.

George, J. C., J. Zeh, R. Suydam and C. Clark. 2004. Abundance and population trend (1978–2001) of Western Arctic bowhead whales surveyed near Barrow, Alaska. Marine Mammal Science 20:755–773.

George, J. C. 2010. Dead bowhead found tangled in commercial pot gear. The Nome Nugget, November 4, 2010, p. 5. Available at http://www.nomenugget.net/archives/2010/11.4.10%20nn.pdf.

Heide-Jørgensen, M. P., L. Kleivane, N. Øien, K. L. Laidre and M. V. Jensen. 2001. A new technique for deploying satellite transmitters on baleen whales: Tracking a blue whale (*Balaenoptera musculus*) in the North Atlantic. Marine Mammal Science 17:949–954.

Heide-Jørgensen, M. P., K. L. Laidre, Ø. Wiig, *et al*. 2003. From Greenland to Canada in ten days: Tracks of bowhead whales, *Balaena mysticetus*, across Baffin Bay. Arctic 56:21–31.

Higgins, J., and G. Salvador. 2010. Guide to the Atlantic large whale take reduction plan. Protected Species Division, NOAA Fisheries Service. Available at http://www.nero.noaa.gov/whaletrp/.

Johnson, A., G. Salvador, J. Kenney, J. Robbins, S. Kraus, S. Landry and P. Clapham. 2005. Fishing gear involved in entanglements of right and humpback whales. Marine Mammal Science 21:635–645.

Keating, K. A. 1994. An alternative index of satellite telemetry location error. Journal of Wildlife Management 58:414–421.

Knowlton, A. R., and S. D. Kraus. 2001. Mortality and serious injury of northern right whales (*Eubalaena glacialis*) in the western North Atlantic Ocean. Journal of Cetacean Research and Management (Special Issue) 2:193–208.

Knowlton, A. R., P. K. Hamilton, M. K. Marx, H. M. Pettis and S. C. Kraus. 2012. Monitoring North Atlantic right whale *Eubalaena glacialis* entanglement rates: A 30 yr retrospective. Marine Ecology Progress Series 466:293–302.

Ljungblad, D. K. 1986. Endangered whale aerial surveys in the Navarin Basin and St. Matthew Hall Planning Areas, Alaska. Appendix E *in* D. K. Ljungblad, S. E. Moore, J. T. Clarke and J. C. Bennett. Aerial surveys of endangered whales in the northern Bering, eastern Chukchi, and Alaskan Beaufort Seas, 1985: With a seven year review, 1979–85. OCS Study, MMS 86-0002. NOSC Technical Report 1111. Minerals Management Service, Alaska OCS Region, Anchorage, AK. 213 pp.

Moore, S. E., and R. R. Reeves. 1993. Distribution and movement. Pages 313–386 *in* J. J. Burns, J. H. Montague, and C. J. Cowles, eds. The bowhead whale, Special Publication Number 2. The Society for Marine Mammalogy.

Niebauer, H. J., and D. M. Schell. 1993. Physical environment of the Bering Sea population. Pages 23–43 *in* J. J. Burns, J. H. Montague, and C. J. Cowles, eds. The bowhead whale, Special Publication Number 2. The Society for Marine Mammalogy.

Neilson, J. L., J. M. Straley, C. M. Gabriele, and S. Hills. 2009. Non-lethal entanglement of humpback whales (*Megaptera novaeangliae*) in fishing gear in northern Southeast Alaska. Journal of Biogeography 36:452–464.

NMFS (National Marine Fisheries Service). 2012. Process for distinguishing serious from non-serious injury of marine mammals. National Marine Fisheries Service Policy Directive 02-238. Available at http://www.nmfs.noaa.gov/op/pds/documents/02/02-238.pdf.

NPFMC (North Pacific Fishery Management Council). 2004. Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement. Available at http://www.fakr.noaa.gov/sustainablefisheries/crab/eis/default.htm#final.

NPFMC (North Pacific Fishery Management Council). 2012. Fishing fleet profiles. Available at http://www.alaskafisheries.noaa.gov/npfmc/PDFdocuments/resources/FleetProfiles412.pdf.

NSIDC (National Snow and Ice Data Center). 2012. Arctic ice extent low overall, high in the Bering Sea. Available at http://nsidc.org/arcticseaicenews/2012/02/arctic-ice-extent-low-overall-high-in-the-bering-sea/.

Pereladov, M. V., and D. M. Miljutin. 2002. Population structure of blue king crab (*Paralithodes platypus*) in the northwestern Bering Sea. Pages 511–520 *in* A. J. Paul, E. G. Dawe, R. Elner, *et al*., eds. Crabs in cold water regions: Biology, management, and economics. University of Alaska Sea Grant College Program AK-SG-02-01, Fairbanks, AK.

Philo, L. M., J. C. George and T. F. Albert. 1992. Rope entanglement of bowhead whales (*Balaena mysticetus*). Marine Mammal Science 8:306–311.

Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small and M. P. Heide-Jørgensen. 2010. Fall and winter movements of bowhead whales (*Balaena mysticetus*) in the Chukchi Sea and within a potential petroleum development area. Arctic 63:289–307.

Reeves, R., C. Rosa, J. C. George, G. Sheffield and M. Moore. 2012. Implications of Arctic industrial growth and strategies to mitigate future vessel and fishing gear impacts on bowhead whales. Marine Policy 36:454–462.

Robbins, J., and D. K. Mattila. 2001. Monitoring entanglements of humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine on the basis of caudal peduncle scarring. Unpublished report to the International Whaling Commission SC/53/NAH25.

Robbins, J., and D. K. Mattila. 2004. Estimating humpback whale (*Megaptera novaeangliae*) entanglement rates on the basis of scar evidence. Report to the Northeast Fisheries Science Center, National Marine Fisheries Service, Contract No. 43EANF030121. Available from the Center for Coastal Studies, Box 1036, Provincetown, MA 02657.

Slizkin, A. G., and S. G. Safronov. 2000. Commercial crabs in nearshore Kamchatka waters. Petropavlovsk-Kamchatskii: "Severnaya Pasifika" Publ. House (in Russian). 180 pp.

Suydam, R. S., and J. C. George. 2004. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos, 1974 to 2003. Unpublished report to the International Whaling Commission SC/56/BRG12.

Stafford, K. M., and D. K. Mellinger. 2009. Analysis of acoustic and oceanographic data from the Bering Sea, May 2006–April 2007. North Pacific Research Board Final Report 719. 23 pp.

U.S. Federal Register. 2004. Authorization for commercial fisheries under the Marine Mammal Protection Act of 1972; zero mortality rate goal. FR 69(138) :43338–43344 (20 July 2004). National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce, Washington, DC.

U.S. Federal Register. 2005. Fisheries of the exclusive economic zone off Alaska; allocating Bering Sea and Aleutian Islands king and tanner crab fishery resources. FR 70 (40):10174–10295 (2 March 2005). National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce, Washington, DC.

U.S. Federal Register. 2010. Fisheries of the exclusive economic zone off Alaska: Groundfish observer program. 75(217):69016–69025. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce, Washington, DC.

Vincent, C., B. J. McConnell, V. Ridoux and M. A. Fedak. 2002. Assessment of Argos location accuracy from satellite tags deployed on captive gray seals. Marine Mammal Science 18:156–166.

Zeh, J. E., and A. E. Punt. 2005. Updated 1978–2001 abundance estimates and their correlations for the Bering-Chukchi-Beaufort seas stock of bowhead whales. Journal of Cetacean Research and Management 7:169–175.

Zeh, J. E., C. W. Clark, J. C. George, D. Withrow, G. M. Carroll and W. R. Koski. 1993. Current population size and dynamics. Pages 409–489 *in* J. J. Burns, J. H. Montague, and C. J. Cowles, eds. The bowhead whale. Special Publication Number 2. The Society for Marine Mammalogy.

Zhou, S., and G. H. Kruse. 2000. Capture efficiency and size selectivity of two types of pots for red king crabs in the Bering Sea. Alaska Fishery Research Bulletin 6:94–103.

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