An update of aerial photography of bowhead whales conducted during the 2003-2005 spring migrations.

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ABSTRACT

Aerial photographic surveys were conducted near Point Barrow, Alaska, from 12 April to 6 June in 2003 and from 18 April to 7 June in 2004 and in the Bering Sea, Alaska, from 9 April to 2 May 2005. Approximately 1,157, 1,443 and 454 photographs containing 1,561, 2,098 and 861 images, respectively, were obtained. The 2003 survey had the most complete photographic coverage of the whales passing Barrow during spring of any survey to date, and the 2004 survey covered the main migration well although poor weather resulted in poor coverage of the mother/calf migration late in the season. The photographs from these studies will permit calculation of a population estimate for comparison with the estimate from ice based counts (George *et al.,* 2004) and better precision in the calculation of bowhead whale life-history parameters. The 2005 survey was successful at photographing bowheads during the later part of the bowhead migration, which includes a higher proportion of medium- and large-sized whales that are well marked. These photographs will be compared to photographs obtained in 1981–2003 to determine whether the recapture rate for the 2005 Bering Sea bowheads differs from the rate at Barrow in 2004. Sizes of recaptured whales and their timing in those two areas will also be examined. A power analysis indicates that we will not be able to reliably detect the existence of a second stock that makes up less than 30% of the Bering Sea photographs unless photograph quality is better than in past years.

KEYWORDS: BOWHEAD WHALE; ARCTIC; NORTH PACIFIC; PHOTO-ID; POPULATION ESTIMATION; PHOTOGRAMMETRY; RECAPTURE; MIGRATION; TIMING

INTRODUCTION

The photographic database of the Bering-Chukchi-Beaufort Seas (BCBS) population of bowhead whales (*Balaena mysticetus*) contains 12,100 images for the years before 2001 (Koski *et al*., 2004). About 85% (10,345) of these images were obtained during slightly more than a decade of relatively intensive photographic surveys from 1982 to 1992. About 54% of the 10,336 images that have been classified for image quality to date are of adequate quality to determine if the whales are marked. All of the images in the database, but particularly the better quality images, have provided useful information on life-history parameters including calving intervals (Miller *et al*., 1992; Rugh *et al*., 1992a), growth rates (Koski *et al*., 1992, 1993), population structure (Davis *et al*., 1983; Koski *et al*., 1993; Angliss *et al*., 1995; Koski *et al*., 2004), population size (Rugh, 1990; da Silva *et al*., 2000; Schweder, 2003) and survival rates (Whitcher *et al*., 1996; Zeh *et al*., 2002). On-going studies continue to use these data to further describe various parameters of bowhead whale life history and population dynamics.

The size of the bowhead photographic database has increased to the point where collection of new photographs results in a relatively high probability of re-sighting a previously photographed marked whale. This

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is because the proportion of the population that has been photographed has increased, and consequently, the likelihood of photographing a whale that has been photographed during previous studies has increased dramatically. Thus new photographs at this time provide much more information on individual whales than the same number of photographs did during the early years of bowhead whale photography studies. This point is emphasized by the substantial information provided by the relatively small photographic effort during the 1998-2000 bowhead feeding study (15 new inter-year re-identifications spanning 4 to 15 years among photographs of 70 different marked whales).

Aerial photographic studies have been conducted during the spring migration period during each year 2003–2005. The major objective of the 2003–2004 aerial photography project was to obtain a population estimate that can be compared to the 2001 ice-based census of bowheads (George *et al*., 2004). The major objective of the 2005 project was to determine if some whales that migrate through the northern Bering Sea in spring do not pass Barrow. Mark-recapture analysis of the 2003–2004 photographs (da Silva *et al*., 2000) will provide a completely independent abundance estimate to compare to the current "best" estimates (George *et al*., 2004; Zeh and Punt, 2004). The aerial photography approach to estimating abundance is less sensitive to vagaries in ice cover than is the ice-based survey, yet both methods provide estimates with similar accuracy: SE = 1,450 - 1,915 for ice-based results in 1985 and 1986 and SE = 1,696 - 2,017 for photographic results in the same years (da Silva *et al*., 2000). Secondary objectives of the project were to obtain a length-frequency distribution of the population to compare with earlier length-frequency distributions estimated by Angliss *et al*. (1995) and Koski *et al*. (2004) and to obtain additional photographic data that can be used to refine existing estimates of life-history parameters such as calving intervals, growth rates and survival rates.

Aerial photographs from the 2005 study will be compared to photographs from previous studies. The recapture rates and sizes of recaptured whales in the Bering Sea photographs from 2005 will be compared with the corresponding recapture rates and sizes in the 2003 and 2004 photographs from Barrow. Differences in the recapture rates or the sizes of whales that are recaptured will be used to assess whether different bowheads are present in the two different areas. In addition, the timing of passage past Barrow will be compared to timing past St Lawrence Island for whales that are photographed in the two areas. The timing information may provide hints about different stocks or sub-populations, if they exist.

METHODS

The 2003–2005 spring aerial photography studies were conducted jointly by LGL Limited (LGL), the North Slope Borough Department of Wildlife Management (NSB-DWM) and the National Marine Mammal Laboratory (NMML). The methods were similar to those of earlier studies (Koski *et al*., 1992; Angliss *et al*., 1995). Surveys were conducted in an Aerocommander 680FL or 690 with bubble windows at all observer positions and a camera port in the floor. The aircraft flew at an air speed of ~180–200km/h and an altitude of ~137m (450ft, cloud ceiling permitting) and passed directly over bowheads. Photographs were taken through the aircraft's ventral camera port with one of two hand-held Pentax medium-format cameras (6cm×7cm film size), each with a 105mm *f*2.4 lens, pointed directly downward. Shutter speed was usually 1/1000th second. We used Fujichrome Provia 400F colour positive film with ISO (ASA) 400. Aircraft altitude was read manually from a digital readout at the moment the camera shutter tripped and was recorded on data sheets. During 2004 and sometimes during 2005 altitude was also recorded on a laptop computer. One (2003) or two (2004 and 2005) laptop computers recorded the aircraft location every 2-6s. Photographs and altitudes were (or will be) linked to the GPS and radar altimeter files based on time. Calibration targets of known dimensions were deployed once (2005) or twice (2003-4) each season and photographed with each of the cameras used during that season. These photographs were taken from the same altitudes as were flown during whale photography sessions.

The search technique near Barrow in 2003-2004 was similar to earlier NMML surveys near Barrow, but differed in one respect. We did not attempt to minimize obtaining duplicate photographs of whales. The aircraft frequently returned to locations where whales had been photographed earlier in the day to maximise the number of photographs. This approach was based on recommendations in Rugh *et al*. (1998). Similar to earlier NMML surveys, we tended to search along constricting ice structures and leads, or other openings in the ice, to maximize the probability of finding and photographing whales.

The search technique in the Bering Sea in 2005 was concentrated in the area north of Gambell and Savoonga, St Lawrence Island, for three reasons. Firstly, data from earlier surveys frequently found bowheads in that area. Secondly, some of the bowheads harvested near Gambell suggested genetic evidence of belonging to a separate sub-population or stock; whereas, those harvested by Savoonga hunters at Southwest Cape did not. Thus, the most likely place to find photographic evidence of a second sub-population or stock was near Gambell, or along the migration corridor of whales passing Gambell. Thirdly, the aircraft was based at Nome because aircraft fuel was not available on St Lawrence Island. A higher proportion of the aircraft time could be spent attempting to photograph whales if the search area was north of St Lawrence Island and closer to Nome than if the search area was south of St Lawrence Island.

Following the 2003 and 2004 field seasons, the film was developed, labelled, duplicated and stored in acid-free archive sheets for future analyses. The data documenting each photograph were entered into an Excel spreadsheet for future integration into the "Bowhead Whale Photography Database" described in Koski *et al.* (2004). During the 2004 field season, images obtained in 2003 were digitized at 4000 dots per inch; some of the digitized images were cropped and printed to nearly fill 12.7cm × 17.8cm (5in. × 7in.) colour prints (Table 1), which are suitable for comparing photographs to identify matches (Rugh *et al.*, 1992b). During February and March 2005, the 2004 images were digitized and cropped so that they are ready to print. Processing of the film from the 2005 study is not completed, but the position and time data for all 2005 photographs have been entered into an Excel spreadsheet.

RESULTS

2003-4 Barrow studies

Flights to photograph bowhead whales were conducted on 51 of 55 days from 12 April to 6 June in 2003 and 87% of the days during the field season had good conditions for photography (48 of 55 days). There was no period longer than one day when photography was interrupted by weather. A total of 161.8h and were flown to find and photograph bowhead whales in 2003. About 1,157 photographs containing 1,561 bowhead images were obtained during spring 2003.

Flights were conducted on 41 of 50 days from 18 April to 7 June in 2004, and 64% of the days during the field season had good conditions for photography. A total of 142.5h were flown to find and photograph bowheads in 2004. About 1,443 photographs of 2,098 bowhead images were obtained during spring 2004. There was good coverage during the main migration, with no period longer than 3 days without good photographic conditions, but poor weather from 22 May–3 June resulted in poor coverage of most of the mother/calf migration. Further details of the 2003 and 2004 photography projects can be found in Koski *et al*. (2004).

2005 Bering Sea study

Flights were conducted on 19 of 25 days from 8 April to 2 May 2005 (Fig. 1). A total of 83.2h were flown to find and photograph bowheads in the Bering Sea in 2005. The flight lines are shown in Fig. 2, and as indicated earlier, most effort to find whales was conducted north of Gambell and Savoonga.

Most of the bowhead sightings occurred near the 50m contour although considerable effort was made to find whales in adjacent waters (Figs 2 and 3). About 454 photographs of 861 whales were obtained (Figs 1 and 3). The majority of the photographs were taken during a 6-day period from 10–15 April (Fig. 1) when large numbers of whales were present in the survey area. The majority of photographs appear to have been of medium- to large-sized whales, but no mothers and calves or mothers and yearlings were photographed. On 13 April a large dispersed group of several hundred to a thousand or more bowheads was found resting, slowly travelling and engaged in sexual activity along narrow leads in the heavy pack ice that was present at that time. The majority of animals in this group appeared to be medium-to-large size, sexually mature animals, and this sighting is the largest aggregation of breeding bowheads that has been documented.

Fig. 4 shows the area surveyed by U.S. Fish and Wildlife biologists conducting photographic surveys of walruses from about 760m (2500ft) altitude. Although U.S. Fish and Wildlife biologists were not targeting bowheads, they were looking for them and should have seen some bowheads if they were present in significant numbers in the survey area; none were seen.

Power analysis

We have conducted a power analysis to determine whether we are likely to be able to detect differences between recapture rates among our 2004 Barrow photographs and our 2005 Bering Sea photographs. Table 2 is based on examination of data from photographs collected between 1976 and 2000 and on the number of images for 2003, 2004 and 2005 given in Table 1 (1561, 2098 and 861 respectively). Here we define marked whales as those scored as marked (at least M-) in at least one body region (rostrum, back, lower back or fluke). The protocol for scoring photo quality and whale identifiability was described by Rugh *et al*. (1998). Different definitions of marked whales are required when the photographs are to be used in a capture-recapture analysis, where it is critical that no matches (recaptures) be missed (da Silva *et al*., 2000; Zeh *et al*., 2002). Here our objective is to compare the proportion of recaptures in the 2005 sample with the proportion in the 2004 sample. It seems reasonable to assume that missed matches will be no more likely in one of these samples than in the other, so a comparison of the two proportions should not be compromised by missed matches. Recaptured whales are those matched to whales first captured in previous years. We have assumed for purposes of these calculations that whales identified in the 2003 sample will be added to the database, so 2004 and 2005 photographs will be compared with all photographs collected between 1976 and 2003.

Our power calculations are based on the data through 2000 and consequently are only approximate. They will be refined when we know the number of marked whales added to the photographic database from the 2003 survey and the actual number of marked whales and sizes of all the whales photographed in 2004 and 2005. The sizes of the whales photographed in 2005 will provide information on what part of the migration the 2005 sample represents, since the bowhead migration is size-structured (Angliss *et al*., 1995). Since larger whales have more markings than smaller whales and tend to migrate later, we will need to reduce the 2004 sample, which covered the whole migration, to the part comparable to that sampled in 2005. Otherwise, for example, the 2004 sample might include more small whales that are not well marked and therefore are less likely to be recaptured, and the 2004 and 2005 proportions of recaptured whales would not be comparable.

For purposes of power calculations, we assumed that the 2005 sample represented the second half of the migration. Data from the ice-based censuses in 1985 and 1986 provided estimates that the second half of the migration in those years began on May 19 and May 11, respectively. Both those years had late migrations, particularly 1985. In 1989-1992 and 1994 there were also photographic surveys at Barrow during the spring migration from which photogrammetric measurements of whale length were made. None of these years had successful ice-based censuses, so we used data from 1988, 1993 and 2001 to estimate the average start of the second half of the migration as May 7 for 1989-1992 and 1994. The images obtained in the second half of the migrations in the years with photographic surveys constituted 62.1% of the total images obtained in the surveys. We therefore estimated the number of images in the second half of the 2004 migration as 2098 × 0.621 = 1303. By examining the total number of photographic images obtained and the sum over the survey years of the numbers of marked whales captured during the second half of the migration, we could estimate factors by which to multiply a number of images to obtain a number of marked whales. These factors were 0.174 if the images included calves as in 2004 and 0.196 if there were no images of calves as in 2005. Thus we estimated the number of marked whales photographed in 2004 as 1303 × 0.174 = 227 and in 2005 as 861 × 0.196 = 169. Similarly, we estimated the number of marked whales photographed during the entire 2003 migration as 1561 × 0.158 = 247, where 0.158 is the factor estimated from the whole migration in the earlier surveys instead of the second half only.

Next we needed to estimate the proportion recaptured under the null hypothesis that the 2003 and 2004 surveys sampled a single stock migrating past Barrow in the spring. The 2005 survey, under the alternative hypothesis, represents two stocks, only one of which migrates past Barrow in the spring.

The database records 1,307 individual marked bowheads photographed between 1976 and 2000. Of these, 827 (63%) were first photographed in 1986 or before. Consequently, even given the high adult survival rate of bowheads (Zeh *et al*., 2002), some of these whales will have died before the 2003 and subsequent surveys. By projecting forward from the year each whale was first photographed, using the median survival rate of 0.988 from the posterior distribution given by Zeh *et al*. (2002), we estimated the expected number of the marked bowheads in the database still alive in 2003 as approximately 1,080.

By using only good quality images (2+ or better for all four body regions, Rugh *et al*., 1998) we estimated that 47% of bowheads are marked as defined in this paper. However, this may overestimate the percentage typically recognized as being marked in the database, so we also carried out calculations assuming that 40% of the population is marked. We assumed a 2001 population size of 10,500 (George *et al*., 2004; Zeh and Punt, 2004) and a 3.4% rate of increase (George *et al*., 2004) to project 2003 population size as 11,200, giving about 5,300 marked whales if 47% are marked. We therefore expect a recapture probability of 0.20 = 1,080/5,300. This value is close to the observed recapture probability in 1998-2000 of 15/70 = 0.21, as it should be. Therefore we expect the 2003 photographs to yield 0.80 × 247 = 198 newly captured whales. If the percentage of marked whales is 40%, the corresponding calculations give 0.76 × 247 = 188 newly captured whales. In either case, the sum of the expected number of marked whales in the database surviving in 2003 and the number newly captured in 2003 is around 1,300. Similar calculations give a recapture probability of 0.236 or 0.277 in 2004.

If whales from a second stock not represented in the database of whales photographed during spring migration past Barrow or in summer in the Beaufort Sea were among those photographed in 2005, the recapture probability in 2005 is reduced because some of the 169 bowheads photographed near St Lawrence Island in 2005 cannot possibly be matched. We therefore computed reduced recapture rates for percentages of a second stock in the 2005 sample ranging from 1% to 50% and the corresponding power to detect the reduction from the 2004 rate with a one-sided test comparing two binomial proportions and using a normal approximation to the arcsine transformation (http://calculators.stat.ucla.edu/powercalc/). We table only percentages of the second stock from 20% to 50% because power was very low for smaller percentages. If tests are done at the 0.1 level, power is acceptable (68% or more) for all but the lowest percentage shown.

Data analyses

To date, the limited funding for analyses of the photographs has been provided by the NSB with a minor contribution by MMS. The main funding for analysis is pending through NOAA. Nonetheless, significant progress has been made by utilizing field staff to enter data, check data entry, scan film, crop scanned images and print whale images during days when surveys were not conducted or were curtailed by poor weather (Table 1). A small grant from MMS allowed the 2004 film to be digitized and images cropped and prepared for printing. A small number of the 2003 images have been printed, filed, scored for image quality and identifiability, and some of these have been compared to find within-year recaptures of the same whales (Table 1).

DISCUSSION

2003-4 Barrow studies

Whales seemed to migrate steadily past Point Barrow throughout the spring period in 2003 with only one major peak of movement which occurred about 2 May (Fig. 2). The lead along the land-fast ice was open throughout the spring period in 2003, and overall good weather conditions permitted us to obtain photographs on 87% of days from 12 April to 6 June. There were no periods longer than one day when we could not survey. Thus the photographic sample obtained in 2003 is the most complete ever obtained and should be representative of the overall migration of whales that passed Barrow that season.

In 2004, bowheads seemed to pass Point Barrow in pulses, which is typical of the spring migration (Carroll and Smithhisler, 1980; Zeh *et al*., 1993; George *et al*., 1995). The first peak occurred on 27-28 April and the second on 11-12 May. Another peak appears to have been associated with the mother/calf migration but poor weather prevented documentation of the timing and magnitude of movements of that segment of the population. In 2004, we had two periods when we were not able to survey or when conditions were too poor to take photographs. During the first period it appears that few whales passed, but during the second period large numbers of mothers and calves passed without being adequately sampled. Thus the 2004 sample of photographs is probably representative of the overall population exclusive of mothers and calves, but it inadequately represents the proportion of mothers and calves in the population during 2004.

In both years, a few bowheads probably passed Barrow before our survey started because we photographed whales during the first several days. Similarly mothers and calves and a few large adults probably continued to pass Barrow after the end of the surveys because moderate numbers of both were sighted during the last few flights.

In summary, the 2003 and 2004 seasons were the two most successful seasons ever in terms of photographing large numbers of whales, and 2003 provided the most consistent coverage of the migration period of any year. The 2003 and 2004 studies started a few days earlier than most previous surveys (12 and 18 April) and continued a few days longer than most previous spring surveys at Barrow (6 and 7 June). Even so, it appears that some whales passed both before and after the survey period. It is unknown whether the migration period has become more protracted as a result of an increasing population size and changes in ice extent (George *et al*., 2004), or whether similar proportions of whales passed before the start and after the end of earlier studies. The 2003 survey more thoroughly covered the migration period than surveys in 1984-1987, 1989-1992 (see Angliss *et al*., 1995) and 2004 because of consistently good weather for photography. These new photographs are a significant contribution to the bowhead whale photographic catalogue. They will permit calculation of a population estimate based on mark-recapture methods similar to da Silva *et al*. (2000) and better precision in the estimation of bowhead whale life-history parameters such as calving intervals, growth rates, population structure and survival rates.

2005 Bering Sea study

The 2005 bowhead photography study in the Bering Sea was highly successful in that it obtained 454 photographs of about 861 whale images. Many of these images are second or subsequent photographs of a particular whale so the number of unique whales photographed is much smaller than 861.

The study was designed to capture the second half of the migration and appears to have been successful in that respect. Few small whales, which make up the majority of the first part of the migration, were seen. It appears that many of the images that were obtained have the potential for re-identification with earlier years because most of the images appear to have been of medium- and large-sized whales. However, no mothers and calves were seen, and so, it is unknown whether the photographs that were obtained represent the last part of the migration. If calving cycles have not changed since the 1980s and early 1990s, then few calves would be expected in 2005 because both 2003 and 2004 were high calving years (Koski *et al*., 2004). Also, the majority of calves are probably born after mid-April (Koski *et al*., 1993) when most whales appear to have passed through our survey area north of St Lawrence Island.

The ice cover was lighter than average at the start of the survey on 8 April in 2005 (Fig. 5), and by the end of the survey on 2 May the only areas with significant ice cover were the Gulf of Anadyr and NE of St Lawrence Island (Fig. 6). It is not known how the light ice conditions influenced the winter distribution and timing of movements of bowheads from the Bering to the Chukchi Sea. At the start of the survey, the only areas that appeared to have suitable bowhead overwintering habitat (heavy consolidated ice with leads) were in the Gulf of Anadyr and north of St Lawrence Island. By the end of the surveys there was mostly open water in the Bering Sea including the area north of St Lawrence Island where most of the bowheads had been seen earlier in the season (Fig. 6).

In summary, the 2005 ice conditions in the Bering Sea were lighter than average, and it is not known how that influenced the distribution and timing of spring movements of bowheads from the Bering to the Chukchi Sea. However, the bowhead photography study that was conducted north of St Lawrence Island was successful in photographing a relatively large number of whales from the later half of the migration. The 2005 photographs can be used to compare recapture rates among Bering Sea bowheads with those at Barrow in 2004 and the sizes and timing of whales recaptured in the two areas. A power analysis assuming the same photograph quality and identifiability as during earlier photographic studies suggests that we could reliably detect a difference if a second population in the Bering Sea made up 30% of the photographs that were obtained in 2005. We have superficially examined the 2003 and 2004 photographs and the photographs from 2004 are much better than average photographs from earlier years. Only a few of the 2005 photographs have been examined and they appear to be about average. Thus our ability to detect a difference between recapture rates among the Barrow and Bering Sea photographs may not be much better than Table 2 suggests. If so, then we are unlikely to be able to reliably identify the existence of a second small stock among the Bering Sea photographs.

ACKNOWLEDGEMENTS

In addition to the authors, Steve McLean of LGL and Devin Bates of the NSB-DWM were the primary observers and data recorders. Darren Ireland and Meike Holst, of LGL, Austin Amasuk of Nome, Merlin Koonooka of Gambell, George Nungwook of Savoonga, Rita Acker, Paula Earp, Crystal Pike and several other members of the NSB-DWM also assisted as observers. Steve McLean was the photographer for 3 days (2–4 May 2003) when WRK was not available. Charles Pike, Marco Colella and Ralph Aiken of Commander Northwest piloted the aircraft. The staff at the NSB-DWM, including Director Charles Brower, were particularly helpful and supportive of the studies.

We thank John Trent, Doug Burn and Marc Webber of U.S. Fish and Wildlife Service for providing their survey track lines for 2005 and for co-ordination during the 2005 surveys. Ted Elliott of LGL produced the maps of effort, sightings and ice conditions.

We especially thank the Whaling Captains Associations at Barrow, Gambell and Savoonga for allowing us to conduct these studies near their villages during the whaling seasons. The NSB-DWM; NOAA Coastal Impact Assessment Program; NMFS; Minerals Management Service and BP Exploration, Alaska, Inc. provided financial support to conduct these studies. The 2003 and 2004 surveys were conducted under Scientific Research Permit 782-1438 issued to NMML under the provisions of the US Marine Mammal Protection Act and Endangered Species Act, and the 2005 survey was conducted under Permit 782-1719.

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Table 1

Status of analyses of bowhead whale photographs obtained during 2003-4 studies near Barrow, AK and the 2005 study in the Bering Sea.

	2003	2004	2005
Film Labelled	All	All	60%
Number of Images	1561	2098	861
Images Scanned	1561	2098	0
Images Cropped	422	2098	0
Images Printed	265	6	0
Images Filed	265	0	0
Images Scored for Quality	265	0	0
Images Scored for Identifiability	265	0	0
Images Compared Within-year	100	0	0
Images Scored for Composite Quality	0	0	0
Images Scored for Composite Identifiability	0	0	0
Images Compared Between 2003 and 2004	1	1	0
Images Compared Between Other Years	0	1	0
Images Measured	0	0	0
Measurements Calibrated	0	0	0
Best Lengths for Each Whale	0	0	0
Data Entered into Database	Up-to-date	Up-to-date	Started

Table 2

Results of a power analysis to determine whether significant differences could be detected between recapture rates in photographs taken near Barrow in 2004 compared to those taken in the Bering Sea in 2005 over a range of assumed percentages of a second stock in the 2005 sample. One-sided tests at two levels α are considered.

	Recapture probability in 2004 = 0.236		Recapture probability in 2004 = 0.277	
Percent 2nd stock in 2005	Power β for α = 0.05	Power β for α = 0.1	Power β for α = 0.05	Power β for α = 0.1
20%	0.30	0.44	0.35	0.49
30%	0.54	0.68	0.61	0.74
40%	0.77	0.86	0.84	0.91
50%	0.93	0.96	0.96	0.98

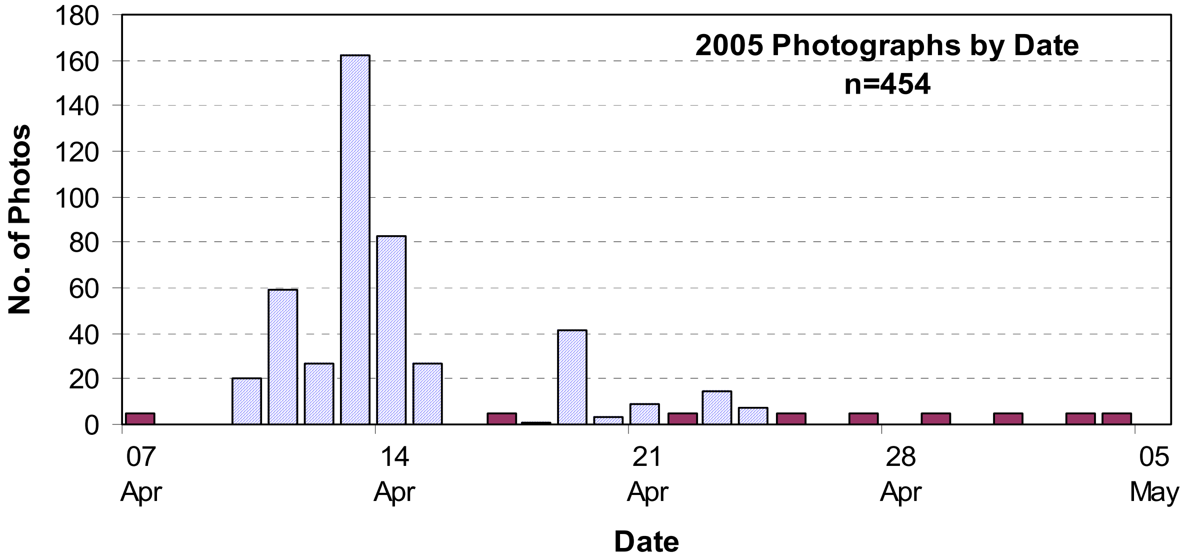

Fig. 1. Photographs obtained by date during the bowhead photography project in the Bering Sea, AK, 8 April – 2 May 2003. Solid bars indicate dates that flights were not made.

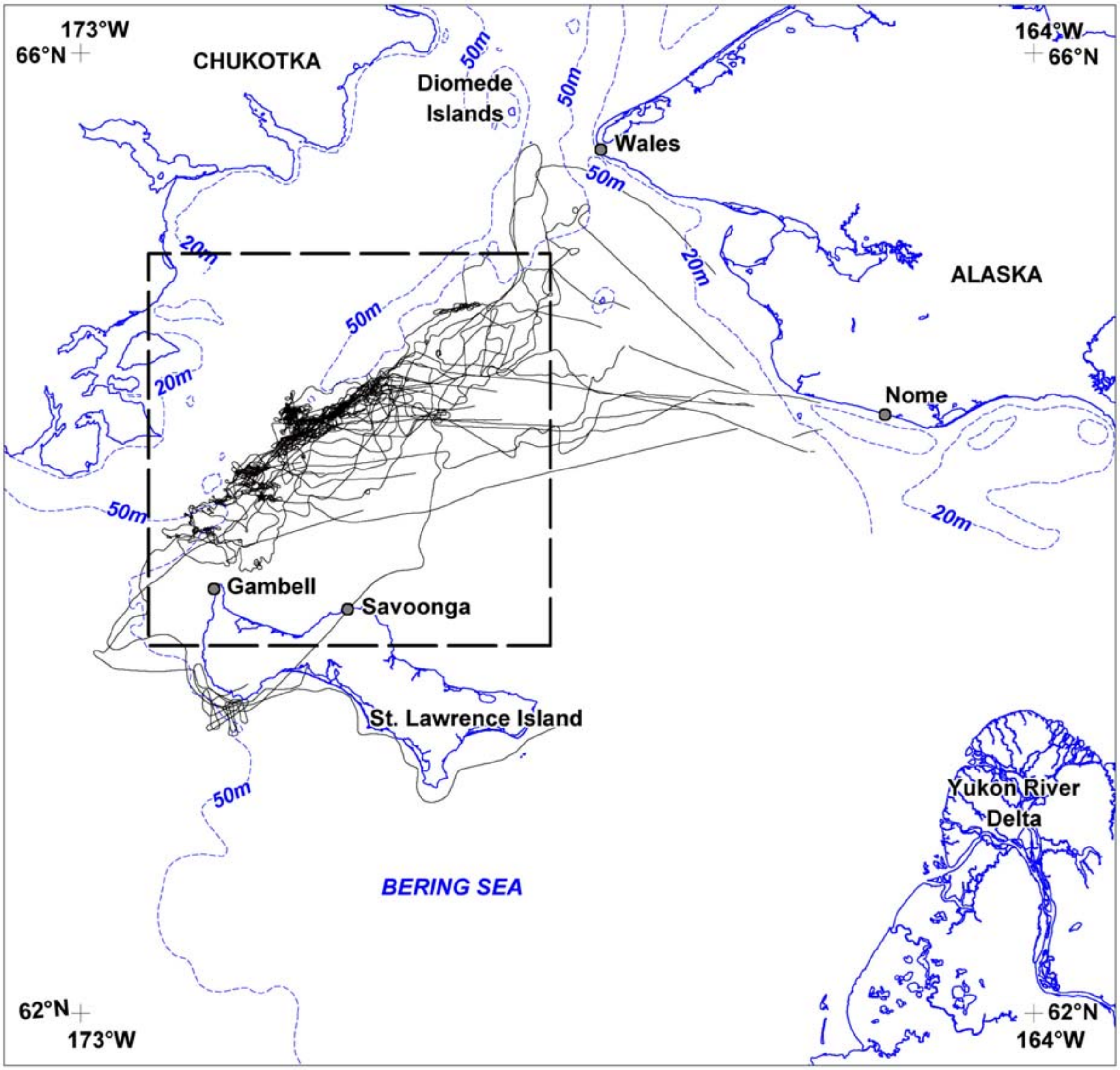

Fig. 2. Survey track lines during the bowhead photography project in the Bering Sea, 8 April–2 May 2005.

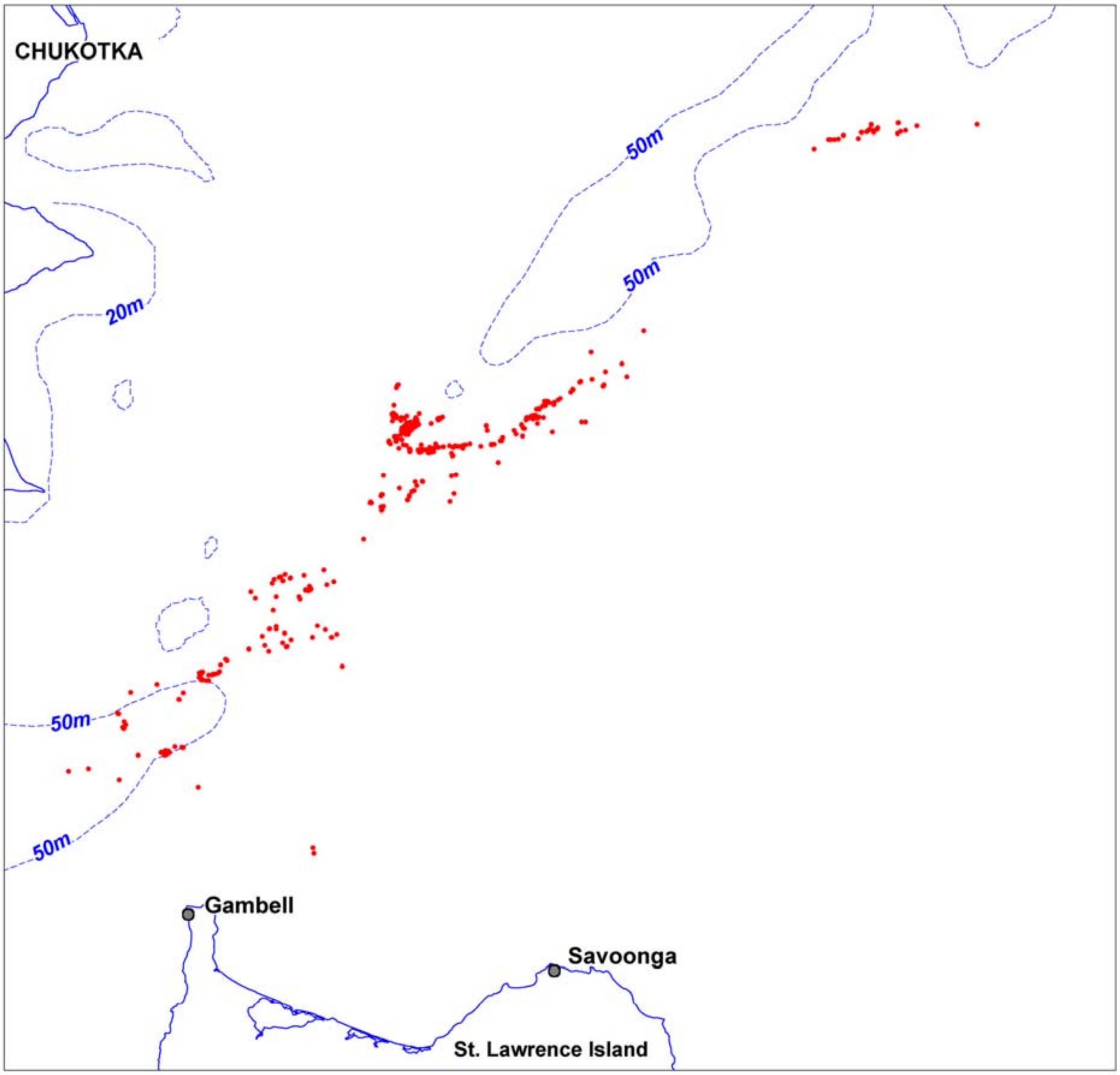

Fig. 3. Locations of photographs of bowhead whales during the Bering Sea bowhead photography project, 8 April–2 May 2005.

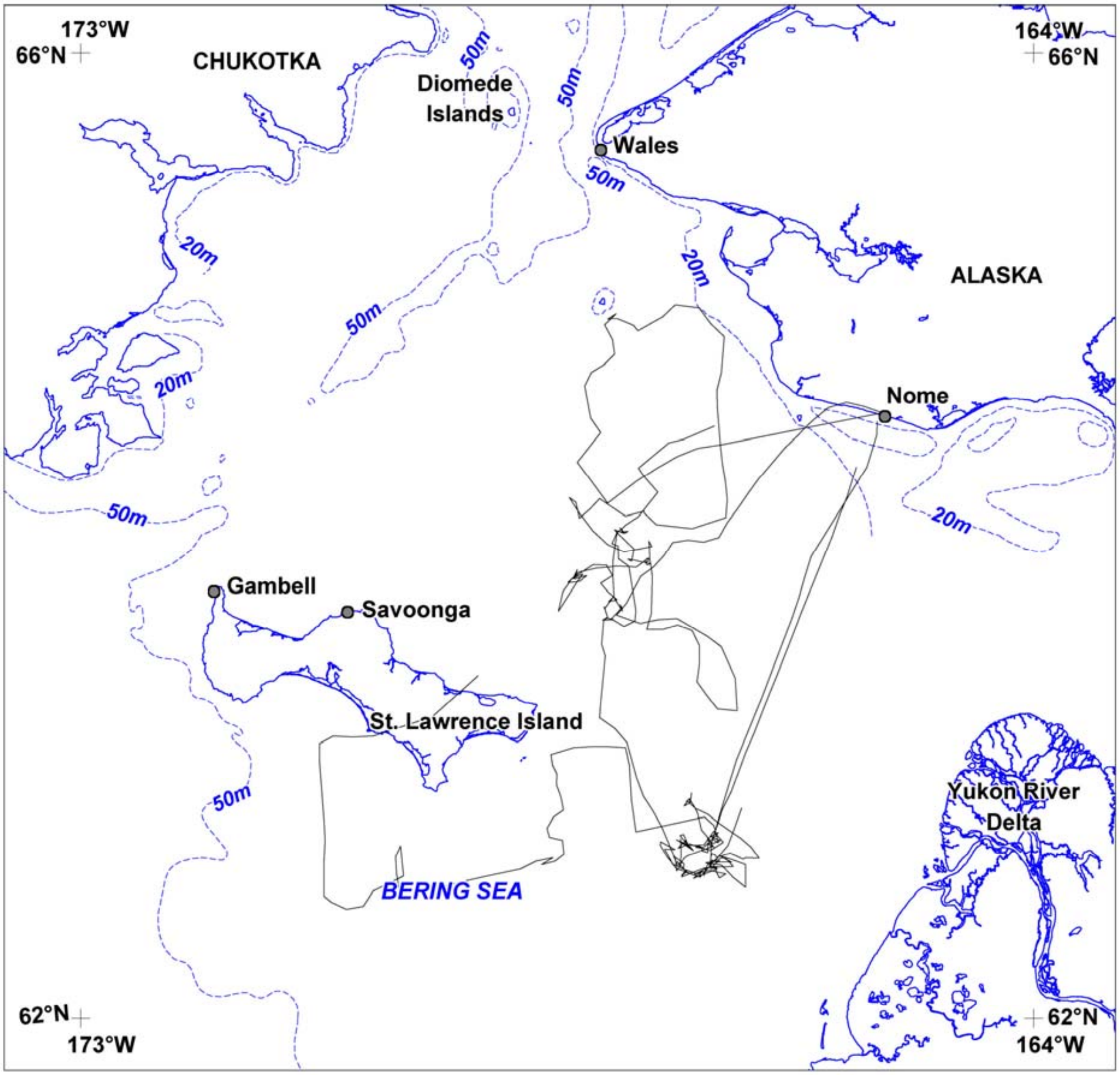

Fig. 4. Survey track lines conducted by U.S. Fish and Wildlife Service during aerial photographic studies of walrus in the Bering Sea, 30 March–10 April 2005.

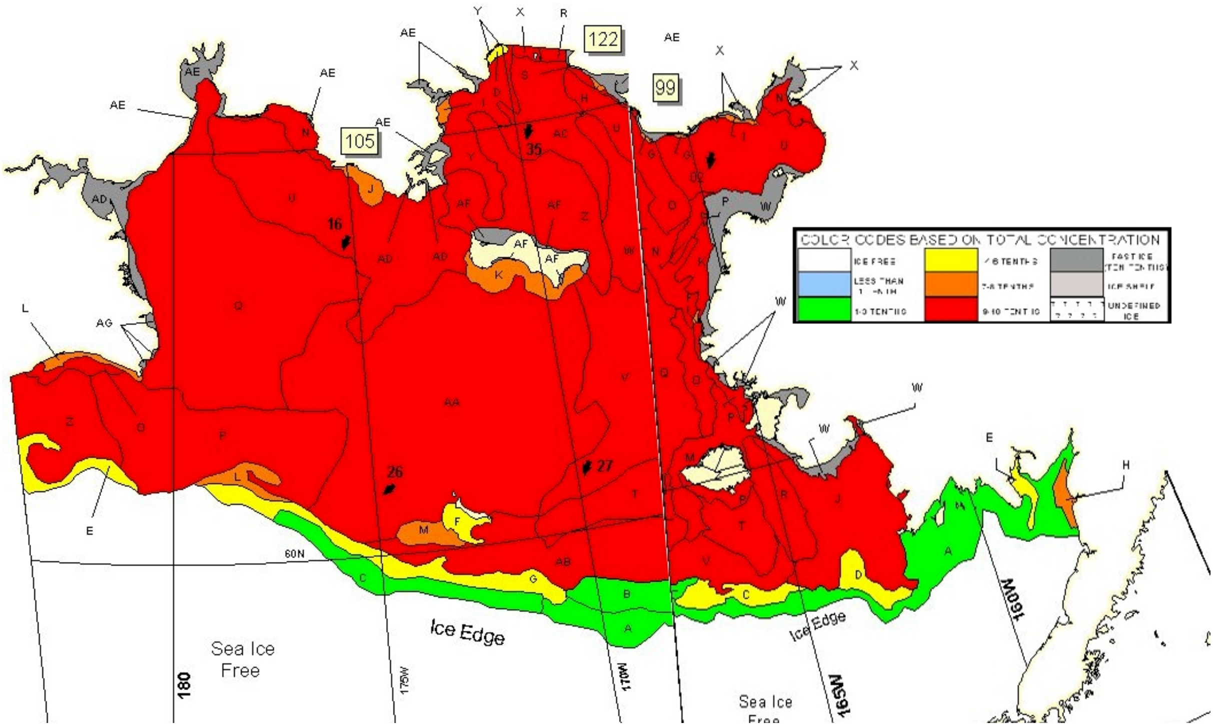

Fig. 5. Ice conditions in the Bering Sea from radarsat imagery collected 8 April 2005. (Prepared from maps provided by the U.S. National Naval Ice Center)

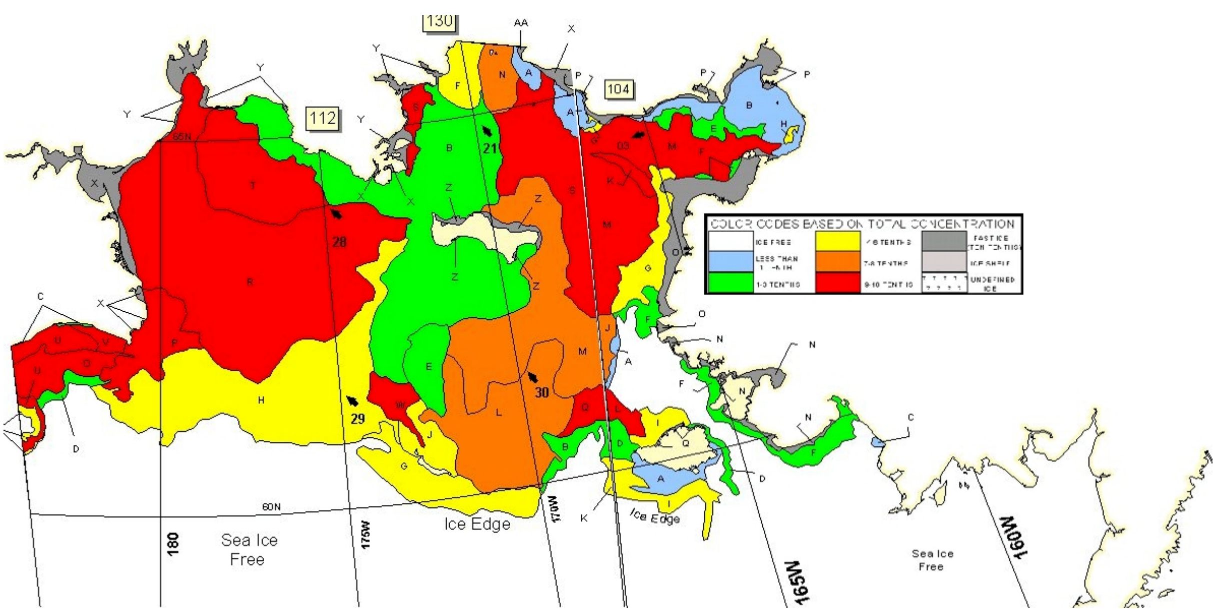

Fig. 6. Ice conditions in the Bering Sea from radarsat imagery collected 1 May 2005. (Prepared from maps provided by the U.S. National Naval Ice Center)