Interyear re-identifications of bowhead whales during their spring migration past Point Barrow, Alaska, 1984-1994

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ABSTRACT

As a part of a review of bowhead whale (*Balaena mysticetus*) stocks, a study was conducted to evaluate how much mixing occurs in the whales' spring migration, a period which immediately follows the mating season. This study has used aerial photography of bowhead whales during their spring migration near Point Barrow, which has resulted in 5,800 images, primarily from 1984 through 1994. These photographs included 40 different whales seen in at least two years, and of these, two were seen in three different years, making for a pair-wise sample size of 42 matches between years. Differences between dates of initial sightings and subsequent sightings (i.e. resightings) ranged from -31 to +23 days comparing month and day only, irrespective of year. These resightings were well dispersed across most of the bowhead spring migration; 98% of the photographs were taken across 45 days from 19 April through 2 June. Models for predicting resighting date from initial sighting date, whale length, presence of a calf, year of initial sighting and year of subsequent sightings were considered, and the best model was chosen using Akaike's Information Criterion (AIC). The best model included most predictors but did not include initial sighting date. Thus, all of the available evidence indicates that individual mature bowheads do not have a consistent migration timing past Barrow; instead, in subsequent years they may appear on almost any date within the normal migratory period. This wide mixing and near-random distribution of resighting dates throughout the spring migration is indicative of a single stock of whales that have a somewhat plastic schedule.

KEYWORDS: BOWHEAD WHALE; ARCTIC; NORTH AMERICA; DISTRIBUTION; MIGRATION; PHOTO-ID

INTRODUCTION

In preparation for the intensive review of bowhead whale (*Balaena mysticetus*) stock structure conducted by the International Whaling Commission Scientific Committee (IWC SC) in 2007, a large research programme was developed that coordinated a variety of studies covering many aspects of bowhead biology. This included: (1) research planning and hypothesis testing; (2) genetics sampling and analysis; (3) animal mixing and abundance; (4) spatial distribution and abundance; and (5) migration patterns (George *et al*., 2007). The focus was on bowhead whales in Alaskan waters, referred to as the Bering-Chukchi-Beaufort (BCB) stock. Some concern had been raised when evidence suggesting multiple stocks (Jorde *et al*., 2007) was found in microsatellite DNA data from BCB bowheads sampled via subsistence hunts during the spring and autumn migration. As a part of the evaluation of stock discreteness, data from aerial photographs of bowhead whales were reviewed. Individual bowhead whales have unique markings, some of which are genetically acquired, and some of which are acquired through trauma such as contact with sea ice or the seafloor. In many cases, markings on dorsal surfaces are distinct enough to be recognised in aerial photographs (Koski *et al*., 1992; Rugh, 1990; Rugh *et al*., 1992a). Data from individually identified bowhead whales have been used in population abundance estimates (da-Silva *et al*., 2000; Rugh, 1990; Schweder, 2003), survival analysis (da-Silva *et al*., 2007; Zeh *et al*., 2002), determination of calving intervals (Miller *et al*., 1992; Rugh *et al*., 1992b) and photogrammetric analyses of whale lengths and growth (Angliss *et al*., 1995; Koski *et al*., 1992; 1993; Koski *et al*., 2006).

This paper examines dates of reidentifications for bowhead whales photographed in different years during their spring migration past Point Barrow, the northernmost tip of Alaska. The spring migration near Barrow has been more thoroughly and systematically surveyed on more years than other seasons or places, thus it serves as a measure of whale migratory timing[1]. In particular, differences in passage dates of the same whales in different years provide a measure of variation in behaviour of individual whales, perhaps as a function of the presence of a calf, sea ice conditions, interactions with predators (including humans) or availability of prey. Variation in migratory dates of individual whales can provide an indication of how much mixing there might be within the stock of bowheads photographed near Barrow. That is, if there is little variation in migratory dates, there is a lowered probability that whales will mix between years, but if each whale migrates on a wide variety of dates, there is an increased probability that there is genetic mixing during the spring migration because March to May is when mating occurs (Koski *et al*., 1993; Nerini *et al*., 1984), dates which overlap or occur only shortly before the spring migration (April to early June) (Moore and Reeves, 1993).

During much of the migration period, bowheads are thought to be moving through the survey area in a continuous manner so that residence time in a given area is

[1] Although many aerial photographic surveys have been conducted prior to and during the fall migration of bowhead whales, these surveys have been across much of the Beaufort Sea and lack the geographic focus that is available near Barrow in the spring migration. Therefore, the migratory timing of individual whales is harder to determine in the fall when sighting dates over a wide range of locations must be considered.

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usually only one day; however, later in the spring, residence time and availability to photograph may be as long as several days, perhaps as a function of feeding opportunities. Consequently, time differences of more than a day through most of the migration period indicate variation in behaviour from year to year. This paper considers the observed pattern of variation and the effect of measured whale length (as a proxy for age) and the presence of a calf on timing and variation in migration. Finally, it examines whether the observed variation is consistent with an assumption that individuals (1) may appear at random within the migrating population or (2) tend to vary more narrowly around each individual's mean migration date.

METHODS

Aerial photographs of bowhead whales have been collected systematically during the spring migration near Point Barrow in many years during the past two decades, particularly from 1984 to 1994. Procedures for collecting these aerial photographs have been described in Rugh (1990), Rugh *et al.* (1992a) and Koski *et al.* (1993). Techniques for categorising images and reidentifying individual whales have been summarised by Rugh (1990) and Rugh *et al.* (1992a; 1998). Following each field season, systematic searches were conducted among the images to find whales photographed more than once; comparisons were then done between years. No equivocal matches are included in the data set (13 potential matches were not included because they were not definitely of the same whale). Each match was confirmed by three different researchers (DJR, WRK and Gary Miller of LGL Ltd). Data used in this study were limited to the area near Point Barrow (between 160°W and 153°W longitude; from the coast north to 72°N; see Fig. 1) during the spring migration (April-June).

Bowhead images obtained near Point Barrow during spring migration were binned relative to the respective 'week' (<23 April, 23-29 April, 30 April-6 May, 7-13 May, 14-20 May, 21-27 May and >27 May) of the migration as given in table 6 of Koski *et al.* (2006). The first and last 'weeks' are more than 7 days long. The dates defining the weeks are based on the temporal distribution of sighting data from the ice-based census of bowhead whales near Point Barrow in the spring (George *et al.*, 2004). Hypotheses related to these weeks as well as hypotheses concerning the differences between dates of initial sightings and subsequent sighting (i.e. resightings) were tested.

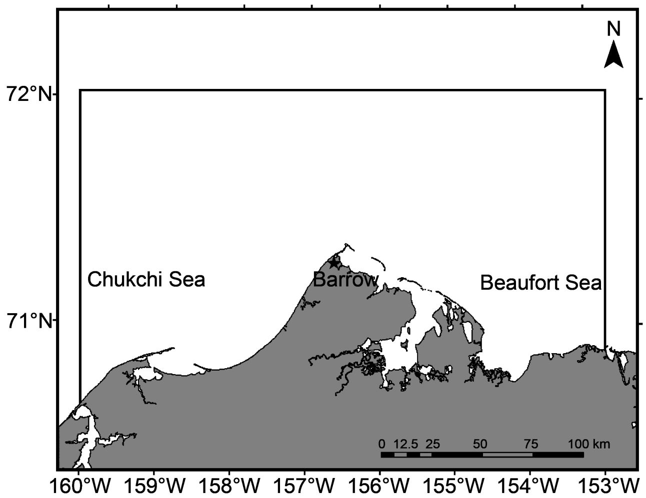

Fig. 1. Map of the sample area where aerial photographs of bowhead whales were taken during the spring migration past Barrow, north of Alaska.

It is well known that the bowhead migration is length structured (Angliss *et al.*, 1995; Koski *et al.*, 2006). Most notably, small whales (except for calves) pass Point Barrow primarily during the first half of the migration period and cows with calves during the latter half. There are no calves among the resighted whales because they lack sufficient marks to be identified in aerial photographs, but some resightings are of adults accompanied by calves in at least one year. It is also known that the timing of the whole migration might be shifted somewhat from one year to the next (e.g. Koski *et al.*, 2006). It is thus natural to examine correlation between initial and subsequent sighting dates by constructing a model for predicting resighting date based on the initial sighting date, years of the sightings, whale length and presence of a calf.

Koski *et al.* (2006) determined that the 1985 migration was delayed by nine days; accordingly, 9 days were subtracted from 1985 dates. Shifts were also estimated for the other years with >6 sightings among the resighted whales (1986, 1989, 1990, 1991 and 1992). To do this, dummy variables were created; for example, Y_{86}=1 if the resighting year was 1986, 0 otherwise and $Y1_{86}$ =1 if the year of the initial sighting was 1986, 0 otherwise. The date variables represent month and day of the sighting date (*Date1* for initial sighting and *Date2* for a subsequent sighting) in days after 31 March. The variable *Mom* is 1 for a cow accompanied by a calf, 0 otherwise. The variable *Length* is the length of the whale in the year resighted, except for the four cases in which this length is missing; in those cases, *Length* is length in the year of the initial sighting.

The resulting full nonlinear model is $Date2 = Constant + Clength \times Length + Cmom \times Mom + \Sigma_y\ Shift_y \times Y_y + Cdate1 \times (Date1 - \Sigma_y\ Shift_y \times Y1_y)$ where the summations are over the applicable years *y*, with *Y* and *Y1* the dummy variables for years of subsequent and initial sightings, respectively. The best model is defined as the one including the subset of $\{Constant, Clength, Cmom, Cdate1, Shift_{86}, Shift_{89}, Shift_{90}, Shift_{91}, Shift_{92}\}$ that minimises Akaike's Information Criterion (AIC) (Venables and Ripley, 1999). All possible subsets of coefficients were considered.

RESULTS AND DISCUSSION

Aerial photography of bowhead whales has resulted in >12,000 images collected between 1976 and 2000. Over 1,330 individual whales have sufficient marks to be considered unique and identifiable using these techniques, and 157 interyear reidentifications have been made of 118 different whales seen in two different years, 19 seen in three years and 2 seen in four years. Around 5,800 of the photographs were taken from 1984 to 1994 near Point Barrow, Alaska, during the spring migration, all from 15 April to 7 June (median=12 May). Among the 5,800 photographs, there were images of 40 whales seen more than once between years, and two of these whales were seen in three different years, making for a total pair-wise sample size of 42 matches between the first year seen and a subsequent year (Table 1). Fig. 2 traces the matches between paired sightings of the respective whales.

Table 1

Bowhead whales resighted during 1984-1994 spring migrations past Point Barrow, Alaska. Whale numbers are as defined in the database. Differences in dates (ΔT) are subsequent sighting dates minus initial sighting dates, irrespective of year.

Whale no.	Sighting 1	Length 1	Sighting 2	Length 2	ΔT
1890	05/08/1984	N/A	04/23/1992	13.37	-15
1921	05/02/1985	10.15	05/05/1990	10.55	3
1937	05/11/1985	13.23	04/27/1992	13.36	-14
2024	05/14/1985	10.37	05/12/1986	N/A	-2
2037	05/17/1985	14.97	05/29/1986	15.17	12
1058	05/18/1985	13.46	05/13/1986	12.88	-5
2200	05/22/1985	16.31	05/26/1991	16.16	4
2217	05/23/1985	14.63	05/10/1991	14.49	-13
2246	05/26/1985	13.39	05/06/1989	14.05	-20
2247	05/26/1985	13.38	05/17/1989	N/A	-9
2291	05/27/1985	13.50	05/18/1989	N/A	-9
2312	05/29/1985	14.59	05/19/1990	13.71	-10
2347	05/31/1985	14.56	05/11/1986	14.67	-20
2371	06/01/1985	15.05	05/26/1992	15.46	-6
2374	06/01/1985	13.88	*05/29/1986	14.29	-3
2384	06/02/1985	12.97	05/15/1989	14.01	-18
2392	06/02/1985	14.45	05/22/1986	13.97	-11
2392	06/02/1985	14.45	#05/18/1989	14.66	-15
2403	06/02/1985	14.34	05/19/1986	13.98	-14
2428	06/06/1985	16.70	05/27/1989	16.01	-10
7946	05/06/1986	12.99	05/03/1989	13.60	-3
3963	05/11/1986	9.80	05/14/1992	11.26	3
4020	05/11/1986	13.33	05/06/1989	13.79	-5
8002	05/11/1986	13.44	05/10/1991	14.17	-1
8015	05/11/1986	13.51	*06/02/1990	13.80	22
8026	05/11/1986	N/A	05/16/1992	13.71	5
8033	05/11/1986	14.60	05/19/1990	14.72	8
8090	05/14/1986	N/A	04/19/1989	12.84	-25
8622	05/19/1986	13.55	*05/26/1989	13.94	7
8135	05/22/1986	13.65	04/21/1989	13.05	-31
8142	05/22/1986	13.78	05/19/1990	13.34	-3
8250	05/04/1987	N/A	05/11/1990	14.56	7
1184	05/07/1987	N/A	04/23/1992	15.17	-14
8288	05/08/1987	N/A	*05/25/1991	16.03	17
8312	05/18/1987	N/A	05/11/1990	13.76	-7
8744	04/20/1989	12.61	05/13/1992	13.56	23
8824	04/25/1989	12.75	05/14/1992	14.57	19
9304	05/31/1989	N/A	05/29/1990	14.18	-2
9304	05/31/1989	N/A	#*05/10/1991	14.95	-21
1880	05/08/1991	13.59	05/13/1992	N/A	5
10573	05/11/1991	14.68	05/26/1992	15.26	15
5149	05/09/1992	13.57	05/25/1994	14.45	16

*Accompanied by a calf. #Third sighting.

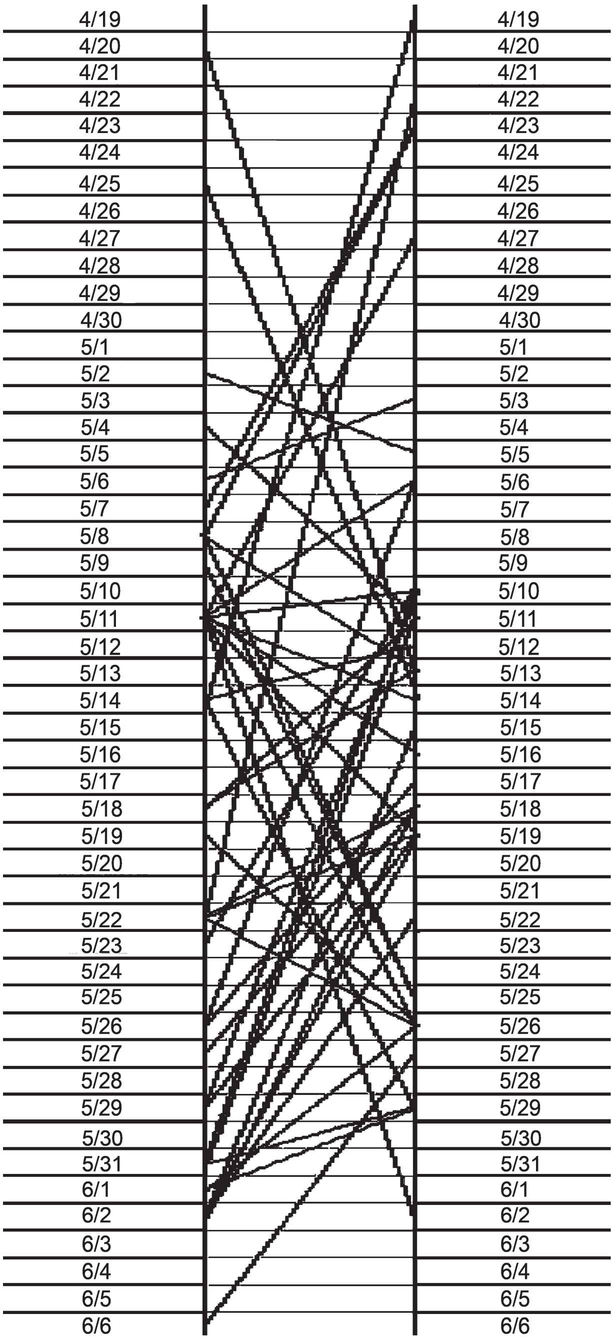

Fig. 2. Differences in dates when individual bowhead whales were photographed migrating past Point Barrow, Alaska, through the spring migration. The lines connect the pair of dates for resightings of each whale. The left column represents the initial sighting date, and the right column represents the resighting date.

Differences between dates of initial sightings and subsequent sightings ranged from -31 to +23 days, comparing dates irrespective of year. The range of the differences did not depend on whether the 1985 dates were shifted by nine days, but the mean was closer to zero (0.7 compared to -3.3), and the standard deviation was somewhat smaller (12.3 compared to 13.1) with the shift. Only three whales were resighted within two days of their original sighting date, but many (52%) were resighted within ten days (Fig. 3). This is not surprising given that more than half of the photographic images (53%) were obtained within a two-week period from 7 to 20 May in a typical year (Table 2).

When lengths were compared relative to absolute differences (|ΔT|) in sighting dates (Fig. 4), it appears that smaller, immature whales (<12m) may be less variable in the date that they pass Point Barrow (|ΔT| = 2-3 days) than larger whales (>12m), which have a wide range in dates (|ΔT| = 1-31 days). Although the sample size of resighted immature whales is very small (n=3), if it is representative, it supports the consistent observation that immature whales tend to pass Barrow early in the migration (Angliss *et al*., 1995; Koski *et al*., 2006; Nerini *et al*., 1984; Rugh, 1990; Zeh *et al*., 1993). However, these data suggest that the migration is less structured than previously thought. Since bowhead whales acquire marks over time, young whales have a low probability of being identifiable in aerial photographs. It is likely that there are unrecognised resightings of immature whales among our photographs.

As shown in Table 1, five resightings were of an adult with a calf. These resightings had differences in migration dates that ranged from -21 to +22 days, which is similar in range (-31 to 23 days) for the other 37 resightings of whales without calves. Whether or not an adult was accompanied by a calf did not seem to affect inter-year differences in

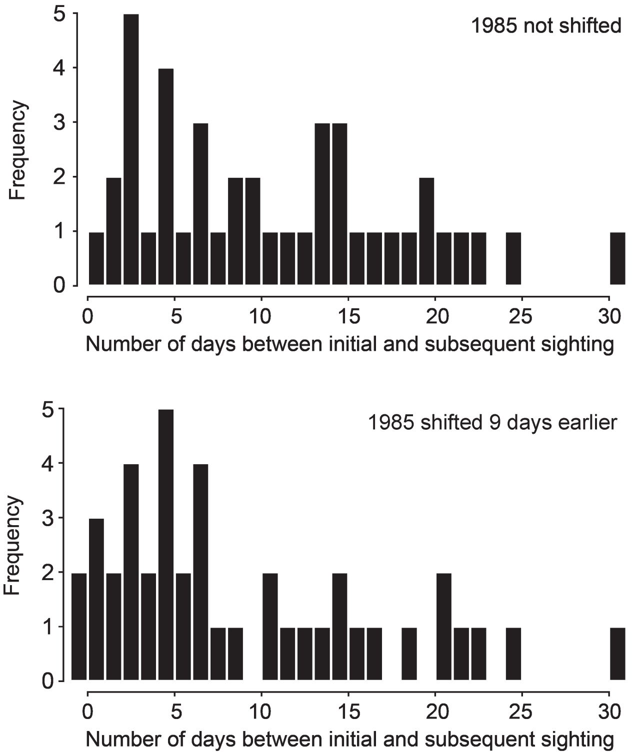

Fig. 3. Histograms showing ΔT in days between the initial sighting of a bowhead whale in the spring migration near Barrow and its resighting in a subsequent year. The top panel shows ΔT with uncorrected dates, and the lower panel shows ΔT based on a −9 day shift of dates in 1985 because that year the migration was late.

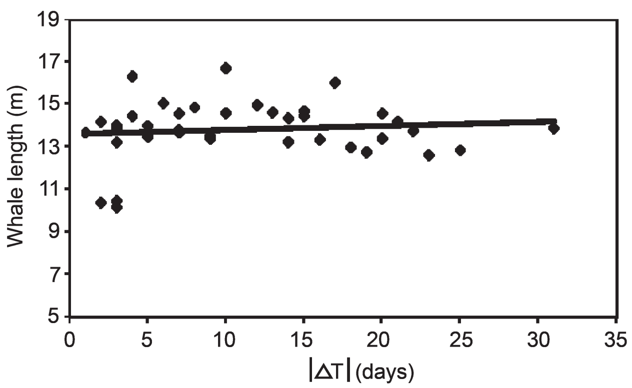

Fig. 4. Bowhead whale length relative to absolute differences (ΔT) in migratory dates determined from aerial photographs taken near Point Barrow. Smaller whales (<11m) appear to be less variable in their migration date (2-3 days) than mature whales (>12m), which range 1-31 days.

migratory timing (*t* test, P=0.29, based on differences corrected for the shift in 1985), in part because all of the bowhead whales had a wide range of date differences.

To test hypotheses regarding the resighting dates in Table 1, week bins were considered (Table 2), showing the number of resighting dates expected in each of these weeks under two different null hypotheses. The first is that resightings are equally likely to occur in any week. The second is that the expected resightings in a week are proportional to the number of photographic images obtained in that week. Not surprisingly, chi-squared tests reject the first of these hypotheses (P=0.043) but not the second (P=0.099) at the 5% level.

Table 2

Proportions of photographic images of bowhead whales by 'week' during the 1984-1994 spring migrations near Point Barrow and expected numbers of resightings under two different null hypotheses. Hypothesis H_{01} is that all weeks are expected to have the same number of resightings. Hypothesis H_{02} is that the expected number of resightings is proportional to the number of photographic images.

		Expected number of resightings	
Weeks	Proportion of images*	H_{01}	H_{02}
15-22 Apr.	0.034	6	1.428
23-29 Apr.	0.129	6	5.418
30 Apr.-6 May	0.119	6	4.998
7-13 May	0.374	6	15.708
14-20 May	0.156	6	6.552
21-27 May	0.150	6	6.300
27 May-7 Jun.	0.038	6	1.596
Total	1.000	42	42.000

*From Table 6 of Koski *et al*. (2006), in which 1985 images are shifted 9d earlier. The H_{02} expected numbers are obtained by multiplying the proportion of images by 42.

The second test is a rather crude test of random resighting dates. A more appropriate test uses a theoretical distribution taking into account that a resighting can only occur in a year subsequent to the year of the initial sighting and only on a day in that year with photographs comparable to those of the resighted whales in terms of quality and identifiability. Fig. 5 shows the empirical distribution function (EDF) of resighting dates and the theoretical distribution under the null hypothesis of random resighting dates. A Kolmogorov-Smirnov test at the 5% level (Birnbaum, 1962) rejects the null hypothesis of random resighting dates. The date with the largest discrepancy between the EDF and the theoretical distribution was 9 May, when young unmarked or marginally marked whales predominate (Angliss *et al*., 1995). The 9 May discrepancy determined the significance of the test. Since two of the resighted whales were scored as nearly but not completely unmarked in two adjacent body parts in their best photo, such whales were considered to be marked in constructing the theoretical distribution function. Such marginally marked whales are less likely to be reidentified than whales scored as at least moderately marked, which may explain the significant test result.

All of the sightings and resightings reported here occurred during the spring migrations from 1984 to 1994. The timing of most of these migrations was about the same, generally starting around the middle of April and continuing into early June with the peak week 7-13 May (Koski *et al*., 2006). However, the migration in 1985 was relatively late (Fig. 6), apparently delayed by nine days (as described earlier), even though the aerial survey provided thorough coverage from 23 April to 6 June.

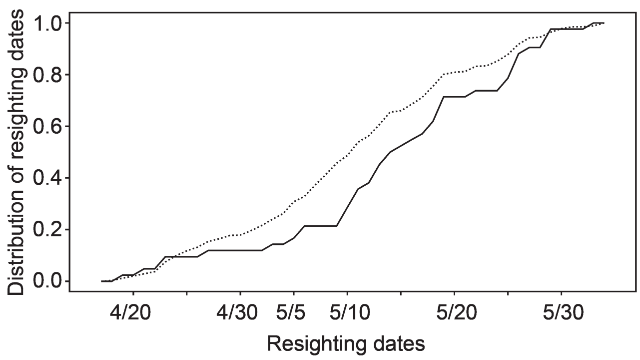

Fig. 5. The empirical distribution function (solid line) and the theoretical distribution function (dotted line) for dates resighted bowhead whales passed Point Barrow during the spring migration.

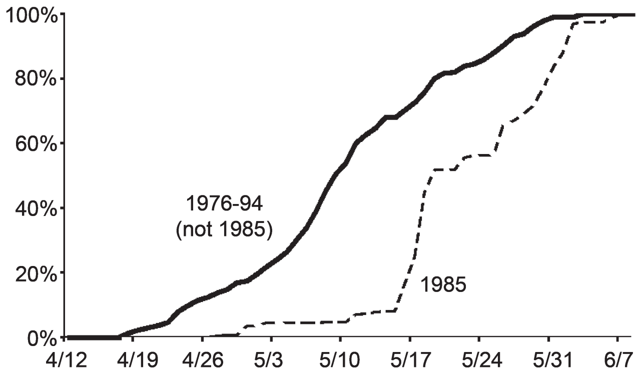

Fig. 6. Cumulative percentile frequencies of bowhead photographs by date showing that the sampled migration in 1985 was significantly later (9 days) than the average of other years.

Comparing dates among the 6 years (1985-86, 1989-92) with sufficient sample sizes (n>6) of whales that have been seen in different years, there were significant differences in passage dates (P=0.001; ANOVA). However, when 1985 dates were either removed or shifted by nine days, differences were no longer significant (P=0.38 for both tests). The mean date for photos of resighted whales in 1985 ($\bar{x}$=25 May; SE=2.1 days) was 11 days later than in 1986-92 ($\bar{x}$=14 May; SE=1.4d). This difference in mean dates is consistent with the shift estimated by Koski *et al*. (2006) from their more comprehensive data set.

A test on the absolute differences $|\Delta T|$ between initial sighting and subsequent sighting dates also provided no evidence for temporal fidelity. In the presence of temporal fidelity, small values of $|\Delta T|$ are expected to be more probable than large ones. The null hypothesis that Pr($|\Delta T| \leq 5$) $\leq$ 0.5 was tested against the alternative that this probability is >0.5. Using $|\Delta T|$ uncorrected for the late 1985 migration, the observed proportion of $|\Delta T| \leq 5$ is 0.31 (P=0.996, exact binomial test). Using the corrected $|\Delta T|$, the observed proportion is 0.43 (P=0.86). Thus, there is no evidence that values of $|\Delta T| \leq 5$ are more probable than larger values.

A problem with a test like the one just described is that the choice of ± 5 days for defining temporal fidelity is arbitrary, and the test does not account for such factors as whale length, presence of a calf and possible less dramatic shifts in migration timing than that observed in 1985. Therefore, a model predicting resighting date from initial sighting date and other relevant factors is a better approach for examining the correlation between initial and subsequent sighting dates. To examine this, the first step was to subtract nine days from all initial sighting dates in 1985; there were no resightings in 1985, subsequently all possible subsets of the potential predictor variables described in our Methods section were considered.

The best single predictor was *Length*, and the best pair of predictors was *Length* and *Mom*; *Length* was present in the best model of each size. The *Constant* term appeared in only the full (9-parameter) model and the best 7-parameter model; it was omitted in the best 8-parameter model and all models with 6 or fewer parameters. Shift parameters for 1986 and 1990 appeared in the best 4-parameter and 3-parameter models, with and without *Mom*, respectively, but they did not appear in the best 7-parameter model. When they appeared, both were positive, suggesting that these years had somewhat delayed migrations, although not as delayed as 1985, relative to the remaining years considered (1989, 1991 and 1992).

The best model was the 5-parameter model $Date2 = Clength \times Length + Cmom \times Mom + \Sigma\ Shift \times Y$, where the summation is over the years 1989, 1991 and 1992. Thus, the best model, like all the models with fewer parameters, does not include *Date1* as a predictor. Although all the models with more parameters included *Date1*, the coefficient *Cdate1* was never statistically significant. The coefficients of the best model are given in Table 3. They suggest that larger whales arrive later than smaller ones, cow-calf pairs arrive late in the migration and the migrations in 1989, 1991 and 1992 were early compared to 1985, 1986 and 1990. The large negative shift coefficient for 1991 was no doubt influenced by the large whale seen with a calf in 1991 on 10 May, earlier than cow-calf pairs are usually seen. Fig. 7 shows $Date2 - \Sigma_y\ Shift_y \times Y_y$ from the best model plotted vs *Length*; cow-calf pairs are shown in black. The residuals from this model had a mean of -0.05 and a standard deviation of 8.55, considerably less than the standard deviation of the differences between resighting and initial sighting dates with 1985 shifted by nine days. Accordingly, this model, which does not incorporate initial sighting date, is considerably more precise than assuming that initial and resighting dates should be similar.

Table 3

Coefficients in the best model for predicting resighting dates, chosen using Akaike's Information Criterion.

	coef	std.err	t.stat	P.value
Clength	3.5213	0.1690	20.8305	0.0000
Cmom	9.4073	4.5933	2.0480	0.0477
Shift89	-9.2327	3.5414	-2.6071	0.0131
Shift91	-10.9451	4.8683	-2.2482	0.0306
Shift92	-8.5546	3.6931	-2.3164	0.0262

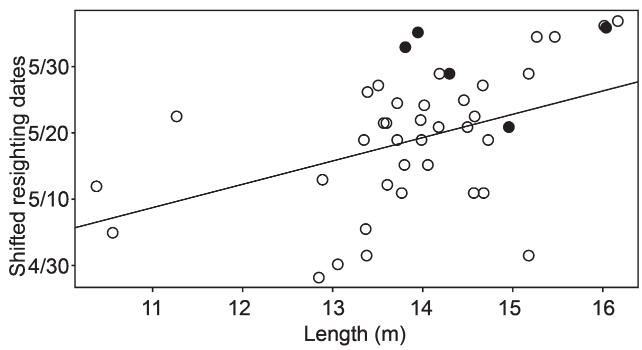

Fig. 7. Resighting dates with resightings in 1989, 1991 and 1992 shifted to reflect the Shift coefficients shown in Table 3. These shifted resighting dates are plotted against whale length, the strongest predictor of resighting date. The line is determined by the Clength coefficient in Table 3. Adults accompanied by a calf are the solid points.

Aerial photography of bowhead whales in the Point Barrow area has occurred as early as 15 April and as late as 7 June, covering much of the spring migration (Table 2). These dates spread across a 54 day period. However, 98% of the photographs have been taken between 19 April and 2 June, a range of 45 days. Some bowhead whales have been photographed as much as 31 days apart in different years. This wide mixing in dates is demonstrated in Fig. 2 (treated here as our null hypothesis with no significant difference from a random distribution). The alternate (failed) hypothesis is that bowhead whales do not significantly change travel dates between migrations, which would mean interyear resightings would be only a few days apart. Instead, the wide mixing and near-random distribution of resighting dates of larger whales throughout the spring migration is indicative of a single stock of whales that have a somewhat plastic schedule[2].

[2] Smaller whales (<12m) might migrate past Barrow in a tighter timeframe than larger (>12m) whales, but we are limited by a small sample size (*n*=3).

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