# Comparison of the offshore distribution of southbound migrating gray whales from aerial survey data collected off Granite Canyon, California, 1979-96[1]

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ABSTRACT

Aerial surveys provide an assessment of the offshore distribution of gray whales and an estimate of the proportion of whales that migrate beyond the visual range of shore-based observers. Six surveys were conducted concurrent with shore-based surveys during 1979, 1980, 1988, 1993, 1994 and 1996. Annual differences were tested for in the distribution of whales within an area 3 n.miles north and south of Granite Canyon, and it was found that the distributions within 3 n.miles of the shore differed by year but the shifts in the distribution were minor ( < 0.3 n.miles). The inshore ( < 2.25 n.miles) and offshore ( > 2.25 n.miles) distribution of gray whale pods did not differ significantly between survey years. An average of 4.76% (SE = 0.85%) of the whale pods were observed beyond 2.25 n.miles and only 1.28% (SE = 0.07%) beyond 3 n.miles.

KEYWORDS: GRAY WHALE; PACIFIC OCEAN; SURVEY-AERIAL; DISTRIBUTION; MIGRATION

## INTRODUCTION

Since 1977, scientists from the National Marine Mammal Laboratory (NMML) have been monitoring gray whale (*Eschrichtius robustus*) abundance from a shore-based site at Granite Canyon, California (36°26′41″N). Shore-based surveys have been conducted regularly (often annually) during the migration (e.g. see Reilly *et al.*, 1983; Buckland *et al.*, 1993; Buckland and Breiwick, 2002). Without an aerial survey or equivalent approach, the assessment of the gray whale population size from shore-based surveys at Granite Canyon would be contingent on the assumption that all whales migrate within visual range of the observers. Shore-based observers are able to see gray whales as far away as the horizon (8.93 n.miles) under ideal conditions, but most searching is conducted without the aid of binoculars, so whale surfacings occurring at distances of 5 n.miles or greater may go undetected. To assess the importance of this loss in sightings, and to examine the offshore distribution of gray whales, aerial surveys were conducted concurrent with the shore-based surveys in January 1979, 1980 (Reilly *et al.*, 1983), 1988 (Withrow, 1990), 1993, 1994 and 1996.

The results of the 1996 aerial survey are described and the results of all surveys conducted since 1979 are compared to test for annual differences in the distribution of whales within 3 n.miles of the shore and the proportion of whales migrating beyond 2.25 n.miles.

## METHODS

Aerial surveys were conducted 13-24 January 1996 during the peak of the gray whale southbound migration. Two survey aircraft were used: both were twin-engine *Partenavias* (model P68C)[2]. The first aircraft (N3832K), used from 12-19 January, was replaced with the 'observer' model (N6602L), used from 20-24 January. The survey altitude was 305m (1,000ft) and ground speed was 185km/hr (100kts). Each aircraft was equipped with a global positioning navigation system (GPS)[2], radar altimeter and bubble windows at the left and right observer positions. High wings allowed for a clear line of sight beneath and forward of the aircraft. The field of view for each observer was restricted to 19° below the horizon, which defined a strip width of 1 n.mile (0.5 n.miles on each side) at the flight altitude of 305m. The flight crew consisted of the pilot, two observers and a computer operator. One to four flights were conducted each day, with a 1-1.5hr interval between adjacent surveys to allow most of the observed whale pods to move south of the survey area.

Data were collected using a portable laptop computer with positional data downloaded from the GPS unit. Environmental conditions (Beaufort state, visibility, glare and percent cloud cover) and sighting information (observer, species, pod size and behaviour) were updated throughout the flight. A numerical waypoint was designated for the start and end of each trackline.

Tracklines were positioned perpendicular to the shoreline in close proximity to the shore-based site at Granite Canyon, with the southernmost tracklines flown first on each series (tracklines were numbered sequentially from south to north). This reduced the chance that a southbound whale would be seen on more than one trackline. In 1979 and 1980, 16 tracklines (each up to 10 n.miles offshore and 1 n.mile apart) with a 0.5 n.mile strip width were surveyed between Point Sur and Point Lobos (Reilly *et al.*, 1983; Fig. 1a). For the 1988 and 1993 surveys, transects were flown between the same two points but the distance between the tracklines was increased to 2-2.5 n.miles, thereby halving the number of tracklines surveyed (Withrow, 1990; Fig. 1b). To better characterise the distribution of whales near the shore-based site, the survey area was narrowed to within 3 n.miles north and south of the site in 1994 (Fig. 1c). In general, flights consisted of six tracklines (between 10 and 20 n.miles in length) with a maximum strip width of 0.5 n.miles on each side of the aircraft. The 1994 survey design was modified only slightly for the 1996 survey (Fig. 1d). Two types of transects were conducted throughout the sampling period in 1996, one consisting of six tracklines each 10 n.miles long,

[1] A version of this paper was originally presented as SC/48/AS11.
[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

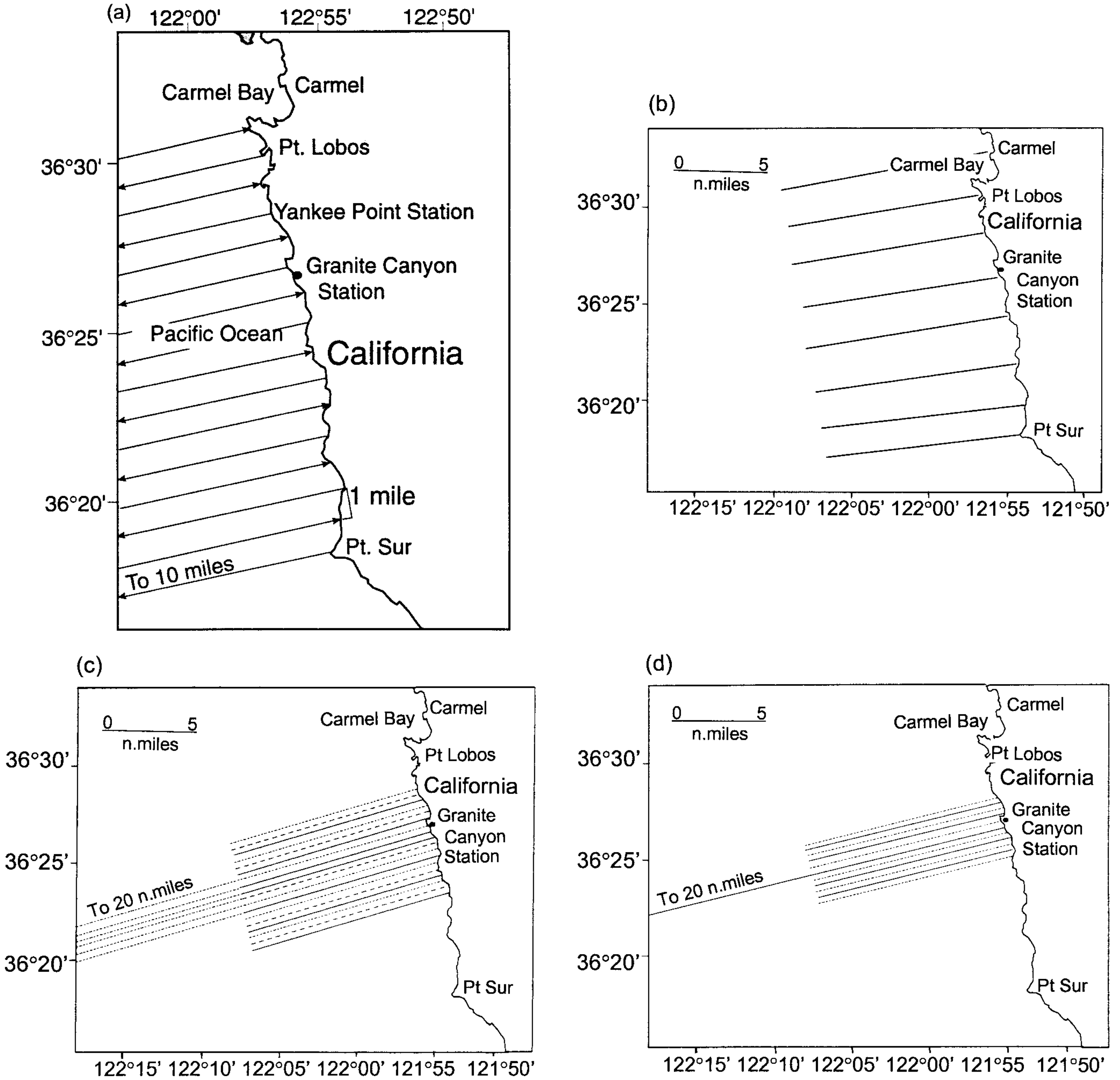


Fig. 1. Survey tracklines flown between Pt Sur and Carmel Bay, California, in January during the southbound migration of gray whales: (a) 1979 and 1980 (modified from Reilly *et al.*, 1983); (b) 1988 and 1993; (c) 1994; and (d) 1996.

the other with four 10 n.mile tracklines and two 20 n.mile tracklines (Fig. 1d). The 20 n.mile tracklines overlapped each other and started or ended directly over the Granite Canyon site. If sightings were made on the inbound leg, within the outer 10 n.mile zone, they were examined for potential duplication with sightings on the outbound leg. Duplication was not expected within the inner 10 n.mile zone because whales, travelling at the average speed of three knots (Swartz *et al.*, 1987), would have had sufficient time to move south of the transect strip. Likewise, 10 n.mile tracklines were separated by 0.66 n.miles between inbound and outbound legs, and pairs of legs were separated by 1 n.mile. This spacing allowed a contraction of the survey to within 2.5 n.miles north and south of the shore-based site, such that duplication of observations within 5 n.miles of the shore was not expected.

Comparisons of survey data between years were restricted to tracklines flown within a 3 n.mile perimeter north and south of the shore-based site. This included tracklines 4-9 for the 1979 and 1980 surveys, tracklines 4-6 for the 1988 and 1993 surveys, and all tracklines from the 1994 and 1996 seasons. Original survey records and raw data from the earlier surveys were obtained for the analysis. Chi-square contingency tests were used to examine changes in whale migration patterns within 3 n.miles of shore (four bins of 0.75 n.miles each) and proportion nearshore (within 2.25 n.miles) *versus* offshore (beyond 2.25 n.miles). The comparison within 3 n.miles of shore was arbitrarily established, as that distance was the expected outer viewing limit of shore-based observers (Withrow, 1990). To achieve reasonable power for the inshore-offshore comparison, 2.25 n.miles was chosen as the cutoff because few aerial observations were made beyond 3 n.miles.

The power of the chi-square test for the inshore-offshore comparison was computed empirically by repeatedly (1,000 times) simulating data under the alternative hypothesis and tallying the rejection frequency of the null hypothesis. Two types of alternative hypotheses were considered in the power calculations: (1) that the true offshore proportions for whales passing beyond 2.25 n.miles in each year were the measured values; and (2) that the proportions were random variables drawn from a uniform distribution with a lower bound of 0.02 and upper bounds of 0.09, 0.12, 0.15 and 0.22. In each case, the number of offshore pods for a year was a binomial random variable with parameters $N_y$, the sample size observed during that year and $p_y$, the probability specified by the alternative hypothesis. The probability ($P^*$) that the largest order statistic from the distribution (Mood *et al.*, 1974) was less than or equal to the observed maximum percentage during the six survey years was computed for each uniform distribution alternative.

## RESULTS

### 1996 survey

In 1996, a total of 108 tracklines 10 n.miles in length and 12 tracklines 20 n.miles in length were run (22.2 flight hours). On-effort sightings included 171 gray whale pods (325 individuals), of which 10 were cows with calves. Pod sizes ranged from one to seven individuals with the largest percentage of pods (52%) consisting of only one animal. The mean number of pods observed per flight (six tracklines) was 9 (SE = 1.04, median 8, range 1-23), and the average sighting distance offshore was 1.21 n.miles (SE = 0.06, median 1.14 n.miles, range 0.16-8.46 n.miles). Within 3 n.miles of shore, sightings occurred at an average distance of 1.13 n.miles (an area referred to as the 'migration corridor' by shore-based observers; Table 1). No sightings occurred beyond 10 n.miles.

Table 1

Offshore distribution of gray whale pods within 3 n.miles of shore near Granite Canyon, California, in January of each year (**bold** font indicates cells that contributed to the overall significance of the chi-square test). Column percentages (b) are derived from the corresponding columns in (a).

| Bin width (n.miles) | 1979 | 1980 | 1988 | 1993 | 1994 | 1996 | Totals |
|---|---|---|---|---|---|---|---|
| **(a) Number of pods** | | | | | | | |
| 0.00-0.74 | 15 | 26 | **43** | **5** | **32** | 31 | 152 |
| 0.75-1.49 | 36 | 47 | 101 | 45 | 159 | 113 | 501 |
| 1.50-2.24 | 17 | 26 | **15** | 21 | 67 | 22 | 168 |
| 2.25-2.99 | 3 | 1 | **11** | 4 | 9 | 2 | 30 |
| Totals | 71 | 100 | 170 | 75 | 267 | 168 | 851 |
| **(b) Column percentages** | | | | | | | |
| 0.00-0.74 | 21.13 | 26.00 | 25.29 | 6.67 | 11.99 | 18.45 | 17.86 |
| 0.75-1.49 | 50.70 | 47.00 | 59.41 | 60.00 | 59.55 | 67.26 | 58.87 |
| 1.50-2.24 | 23.94 | 26.00 | 8.82 | 28.00 | 25.09 | 13.10 | 19.74 |
| 2.25-2.99 | 4.23 | 1.00 | 6.47 | 5.33 | 3.37 | 1.19 | 3.53 |
| **(c) Expected counts** | | | | | | | |
| 0.00-0.74 | 12.68 | 17.86 | 30.36 | 13.40 | 47.69 | 30.01 | |
| 0.75-1.49 | 41.80 | 58.87 | 100.08 | 44.15 | 157.19 | 98.90 | |
| 1.50-2.24 | 14.02 | 19.74 | 33.56 | 14.81 | 52.71 | 33.16 | |
| 2.25-2.99 | 2.50 | 3.52 | 5.99 | 2.64 | 9.41 | 5.92 | |
| **(d) Migration corridor location** | | | | | | | |
| Median | 1.15 | 1.12 | 1.13 | 1.39 | 1.28 | 1.12 | |
| Mean | 1.20 | 1.14 | 1.07 | 1.35 | 1.25 | 1.13 | |
| SE | 0.06 | 0.05 | 0.04 | 0.05 | 0.03 | 0.03 | |

Weather conditions varied from flight to flight as storm fronts moved through the survey area during the sampling period. Beaufort states ranged from 2 (as far as 20 n.miles offshore on some flights) to 6. Of the twelve 20 n.mile legs, 8 were flown during Beaufort 2-3 states, 2 during Beaufort 4-5 and 2 during Beaufort 6. Light penetration and water clarity were generally good enough to view whales clearly beneath the surface.

Other species observed during the survey included one killer whale (*Orcinus orca*), Risso's dolphins (*Grampus griseus*: in groups ranging from 5-100+ animals, sometimes including calves), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*: with group sizes of 5-20 animals, some with calves), common dolphins (*Delphinus delphis*: in groups of 350 to over 1,000), northern right whale dolphins (*Lissodelphis borealis*: in mixed schools with Risso's and Pacific white-sided dolphins), and one minke whale (*Balaenoptera acutorostrata*).

### 1979-96 survey comparisons

The distributions of gray whale pods within 3 n.miles (Table 1) differed between years ($\chi^2 = 57.61$, df = 15, $p << 0.001$). Partitioning the table yielded similarities between the surveys conducted in 1979 and 1980 ($\chi^2 = 2.45$, df = 3, $p = 0.48$) and 1993 and 1994 ($\chi^2 = 2.32$, df = 3, $p = 0.51$). The 1988 and 1996 distributions were different ($\chi^2 = 10.16$, df = 3, $p = 0.02$), and each differed from the other surveys ($p < 0.005$ in all comparisons).

The nearshore (< 2.25 n.miles) and offshore (> 2.25 n.miles) distribution of gray whale pods (Table 2) did not differ significantly between survey years ($\chi^2 = 5.91$, df = 5, $p = 0.31$). The average percentage of pods beyond 2.25 n.miles was 4.76% (SE = 0.85%). The largest contributor to the chi-square statistic was the 1993 offshore cell. With the sample sizes obtained for the inshore-offshore comparison, the power of the chi-square test was reasonably good for small differences in the proportions offshore (0.02-0.09). For the alternative that the true offshore proportions are the measured values, the power was 0.45. Power calculations for the alternatives described by uniform distributions (Table 3) suggest that it was very unlikely that the proportion offshore varied by more than 0.02-0.15.

Table 2

Nearshore (within 2.25 n.miles) and offshore (beyond 2.25 n.miles) distribution of gray whale pods during the southbound migration near Granite Canyon, California, in January of each year.

| Bin width (n.miles) | 1979 | 1980 | 1988 | 1993 | 1994 | 1996 | Totals |
|---|---|---|---|---|---|---|---|
| **(a) Number of pods** | | | | | | | |
| 0.00-2.24 | 68 | 99 | 159 | 71 | 258 | 166 | 821 |
| 2.25-20.00 | 3 | 4 | 11 | 7 | 11 | 5 | 41 |
| Totals | 71 | 103 | 170 | 78 | 269 | 171 | 862 |
| **(b) Column percentages** | | | | | | | |
| 0.00-2.24 | 95.77 | 96.12 | 93.53 | 91.03 | 95.91 | 97.08 | 95.24 |
| 2.25-20.00 | 4.23 | 3.88 | 6.47 | 8.97 | 4.09 | 2.92 | 4.76 |
| **(c) Expected counts** | | | | | | | |
| 0.00-2.24 | 67.62 | 98.10 | 161.91 | 74.29 | 256.21 | 162.87 | |
| 2.25-20.00 | 3.38 | 4.90 | 8.09 | 3.71 | 12.79 | 8.13 | |

Table 3

Power calculations for the alternative hypothesis of a uniform distribution of tail probabilities with varying ranges and the probability ($P^*$) that a maximum of 9% (observed during the 1979-1996 aerial surveys) or less would be observed from the distribution.

| Range | Power | $P^*$ |
|---|---|---|
| 2-9% | 0.38 | 1.000 |
| 2-12% | 0.60 | 0.120 |
| 2-15% | 0.70 | 0.020 |
| 2-22% | 0.82 | 0.003 |

## DISCUSSION

To investigate what is occurring in the distribution of gray whales near the Granite Canyon station, the comparison of offshore distributions was restricted to within a narrow area north and south of the site. This reduced the sample sizes collected in all years except 1994 and 1996 and made comparisons between the results presented here and those in other publications (e.g. Reilly *et al.*, 1983; Withrow, 1990) inappropriate.

Even though significant differences between years were found in the distribution within 3 n.miles, this result should not be over-interpreted. First, the differences amount to no more than a 0.2-0.3 n.mile shift in the median distance (Table 1). Second, variations in distributional data within 3 n.miles of shore may, in part, result from differences or errors in methods used to gather positional data. In 1979 and 1980, the locations of whales relative to shore were 'calculated from the time difference between their position and the shore edge, and the plane's speed' (Reilly *et al.*, 1983, p.271). In 1988 and 1993, positions were determined by 'dead-reckoning' (Withrow, 1990); based on trackline starting time/position and ending time/position, with the position of the pod computed from the time of the sighting. GPS positions were used for the 1994 and 1996 surveys. All positional data were converted to distances relative to the coastline. Prior to 1993, the same way points were used for each survey. In 1994 and 1996, tracklines were staggered along the coast to average out irregularities in the coastline. However, indentations between points of land range from 0.10-0.20 n.miles and the irregularity of the coastline, in addition to the method used to determine pod locations, may account for some of the inter-year differences observed within 3 n.miles.

Inter-year comparison of proportions inshore and offshore of 2.25 n.miles is more important in assessing the impact on population estimates than are comparisons of sighting rates within 3 n.miles. If the shore-based observers saw no whales beyond 2.25 n.miles and the proportion exceeding 2.25 n.miles varied between 0.02 and 0.15, with a population of 20,000 gray whales, the estimate would vary from 17,000-19,600. However, shore-based observations to 3 n.miles are used in the abundance estimate, and the decrease in detection probability at larger offshore distances is already incorporated into the estimate (Laake *et al.*, 1994). Ignoring observations beyond 3 n.miles is of little consequence to the abundance estimate or an assessment of inter-year trend because the average percentage of aerial observations beyond 3 n.miles for all years combined was only 1.28% (SE = 0.07%) with a range of 0.0-3.8%.

## ACKNOWLEDGEMENTS

Many individuals made the 1996 field season possible. We thank J. Gilpatrick (SWFSC) and NOAA Corps Officers S. Hill, T. Martin and A. Von Saunder for their participation as observers during the 1996 survey; our pilots B. Hansen (a three-year veteran of these surveys) and T. McLaughlin for their expert flying; the staff of the Monterey Bay National Marine Sanctuary Program, in particular T. Jackson (Manager) and S. Kathey, for their assistance throughout the permit review process and field project; W. Perryman (SWFSC) for his assistance with the aircraft contracting and support during the project; H. Braham and D. DeMaster for providing research direction; and the National Marine Fisheries Service Office of Protected Resources for budgetary support of this project. S. Reilly and D. Withrow provided access to data collected under their supervision. L. Baraff, J. Breiwick, P. Gearin, R. Hobbs, D. DeMaster, P. Wade and J Waite reviewed earlier drafts of this manuscript. We dedicate this paper to the memory of J. Drust, an outstanding pilot without whom our 1994 survey would have been incomplete.

REFERENCES

Buckland, S.T. and Breiwick, J.M. 2002. Estimated trends in abundance of eastern Pacific gray whales from shore counts (1967/68 to 1995/96). *J. Cetacean Res. Manage.* 4(1):41-48.

Buckland, S.T., Breiwick, J.M., Cattanach, K.L. and Laake, J.L. 1993. Estimated population size of the California gray whale. *Mar. Mammal Sci.* 9(3):235-49.

Laake, J.L., Rugh, D.J., Lerczak, J.A. and Buckland, S.T. 1994. Preliminary estimates of population size of gray whales from the 1992/93 and 1993/94 shore-based surveys. Paper SC/46/AS7 presented to the IWC Scientific Committee, May 1994 (unpublished). 13pp. [Paper available from the Office of this Journal].

Mood, A.M., Graybill, F.A. and Boes, D.C. 1974. *Introduction to the Theory of Statistics*. McGraw-Hill, Singapore. 564pp.

Reilly, S.B., Rice, D.W. and Wolman, A.A. 1983. Population assessment of the gray whale, *Eschrichtius robustus*, from California shore censuses, 1967-80. *Fish. Bull.* 81(2):267-81.

Swartz, S.L., Jones, M.L., Goodyear, J., Withrow, D.E. and Miller, R.V. 1987. Radio-telemetric studies of gray whale migration along the California coast: a preliminary comparison of day and night migration rates. *Rep. int. Whal. Commn* 37:295-9.

Withrow, D.E. 1990. Aerial surveys of gray whales off the central California coast during the 1987/88 southbound migration. Paper SC/A90/G3 presented to the IWC Scientific Committee Special Meeting on the Assessment of Gray Whales, Seattle, April 1990 (unpublished). 9pp. [Paper available from the Office of this Journal].