DISTRIBUTION AND ABUNDANCE OF GRAY WHALES

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TABLE OF CONTENTS

List of Figures 297

List of Tables 299

ABSTRACT 301

INTRODUCTION 302

METHODS 303

Aerial Surveys 303
Approach 303
Timing and Number of Surveys 303
Survey Aircraft 303
Survey Procedure 305

Ship-based Observations 306

RESULTS 306

Aerial Surveys 306

Distribution 306
Population Estimation Procedures 312
Survey Models 312
Uncorrected Estimates of Numbers Present in Study Area 317
Corrections for Submerged Gray Whales 321
Duration of Potential Detectability 321
Calculation of Correction Factors 322
Corrected Abundance Estimates 323
Detectability of Feeding Plumes 323
Alternative Population Estimate Using Sightings of Mud Plumes 326

Shipboard Observations of Gray Whales 327

DISCUSSION 327

ACKNOWLEDGMENTS 331

LITERATURE CITED 331

LIST OF FIGURES

Figure 1. Planned transects for aerial surveys. Dashed and solid lines depict the two sets of six randomly-selected transects (see text).

Figure 2. Survey lines and sightings of gray whales during aerial surveys on 10-17 July 1982.

Figure 3. Survey lines and sightings of gray whales during aerial surveys on 9-10 September 1982.

Figure 4. Aerial survey lines and sightings of mud plumes from feeding gray whales, 10-17 July 1982.

Figure 5. Aerial survey lines and sightings of mud plumes from feeding gray whales, 9-10 September 1982.

Figure 6. Aerial survey lines and whale sightings used to estimate gray whale abundance in July 1982. Sightings along opportunistic transects and at lateral distances <100 m or >2100 m are excluded (see text).

Figure 7. Aerial survey lines and whale sightings used to estimate gray whale abundance in September 1982.

Figure 8. Distribution of lateral distances of gray whales sighted during aerial surveys.

Figure 9. Fit of Fourier series probability density functions to lateral distances of gray whale sightings in July and September 1982.

Figure 10. Distribution of lateral distances of mud plumes created by gray whales and sighted during aerial surveys.

Figure 11. Gray whales observed during shipboard observations in the Chirikof Basin and near St. Lawrence Island during July and September 1982. Observations and estimates made in September are in parentheses. Area estimates in the Chirikof Basin include animals counted during nearby station scans and transect observations.

LIST OF TABLES

Table 1. Line transect estimates of the abundance of gray whales in July and September 1982.

Table 2. Parameters used to estimate duration of potential detectability of a whale (t) for surveys 1 and 2.

Table 3. Calculation of the probability that an average whale within the surveyed area will be at the surface while within an observer's field of view. All times are in seconds.

Table 4. Sightings of gray whales and mud plumes during each aerial survey.

Table 5. Level of effort and numbers of whales observed during shipboard observations in the Chirikof Basin and near St. Lawrence Island during the summer of 1982.

ABSTRACT

Aerial surveys of the Chirikof Basin in mid July and early September 1982 showed that gray whales were concentrated in a north-south band across the center of the basin. Aerial and shipboard surveys also found concentrations along the west, south and east coasts of St. Lawrence Island. Many additional gray whales were present west of the U.S./U.S.S.R. Convention Line. These results are consistent with results from studies in previous years.

Raw line transect estimates of gray whale abundance in the Chirikof Basin (excluding the concentrations around St. Lawrence Island and in Soviet waters) were 540 in July and 215 in September. Our data on surfacing/dive cycles permitted us to correct these raw estimates to include whales that were below the surface and hence not visible when the survey aircraft flew over. The corrected estimates were 1929 for July and 601 for September. Similar values were obtained using sightings of mud plumes created by feeding gray whales to correct the raw survey results for whales below the surface.

INTRODUCTION

An understanding of the distribution and number of gray whales utilizing the Chirikof Basin in summer is a prerequisite for an analysis of the relationships between feeding gray whales and their prey. The most comprehensive previous information on distribution and numbers of gray whales in the study area has come from aerial surveys (e.g., Nerini 1980; Ljungblad et al. 1982). Additional information has come from shore-based and shipboard observers. A major limitation in most previous studies, particularly those based on aerial surveys, has been underestimation of numbers of whales present because of inability to detect whales that were below the surface.

In this study, we conducted both ship-based and aerial surveys to determine the distribution and numbers of gray whales in the study area in 1982. Aerial surveys were used because they offered the advantage of sampling large areas in a relatively short period of time, including areas where little or no ship-based work was planned. Ship-based observations both at benthic sampling stations and while steaming between stations provided additional information. Of major relevance to this study was the collection of data on the surfacing-dive cycle of the gray whale (Würsig et al., this report). Through use of those behavioral data and the analytical procedure of Davis et al. (1982), it was possible to estimate the proportion of the whales that were submerged (and, therefore, undetected) during the aerial surveys.

The distributional and abundance data presented here are used by Thomson and Martin (this report) to assess the interactions between gray whales and their prey organisms.

METHODS

Aerial Surveys

Approach

We conducted systematic aerial surveys to determine the distribution and estimate the abundance of gray whales in the study area. In order to sample the area in a systematic manner, we divided it into six bands of equal width by establishing seven lines (33.3 km apart) east of and parallel to the U.S.-U.S.S.R. Convention Line. These lines ran northeast from the St. Lawrence Island region to the Seward Peninsula. We randomly selected two sets of survey lines, each consisting of one line in each of the six bands we intended to sample. These two sets of survey lines, and additional lines designed to sample the distribution of gray whales in coastal waters off St. Lawrence Island, are shown in Figure 1. Lines flown to connect end and start points of successive lines (not shown in Fig. 1) were surveyed on an opportunistic basis to provide additional distribution data.

Timing and Number of Surveys

We originally planned to survey the study area during three different periods in 1982: mid July, late July to early August, and early September* Bad weather prevented us from conducting the second proposed survey; thus, surveys were conducted only during mid July and early September. During mid July, both sets of survey lines across the Chirikof Basin were surveyed. During early September only one set of lines could be completed. Additional surveys would have been desirable, but were impractical because of weather and logistical limitations.

Survey Aircraft

Two aircraft were used in these surveys. The first (mid July) survey was conducted from a Grumman Goose supplied by the Office of Aircraft Services, Anchorage, with the cooperation of the Naval Ocean Systems Center, San Diego. The second survey was conducted from a deHavilland Twin Otter

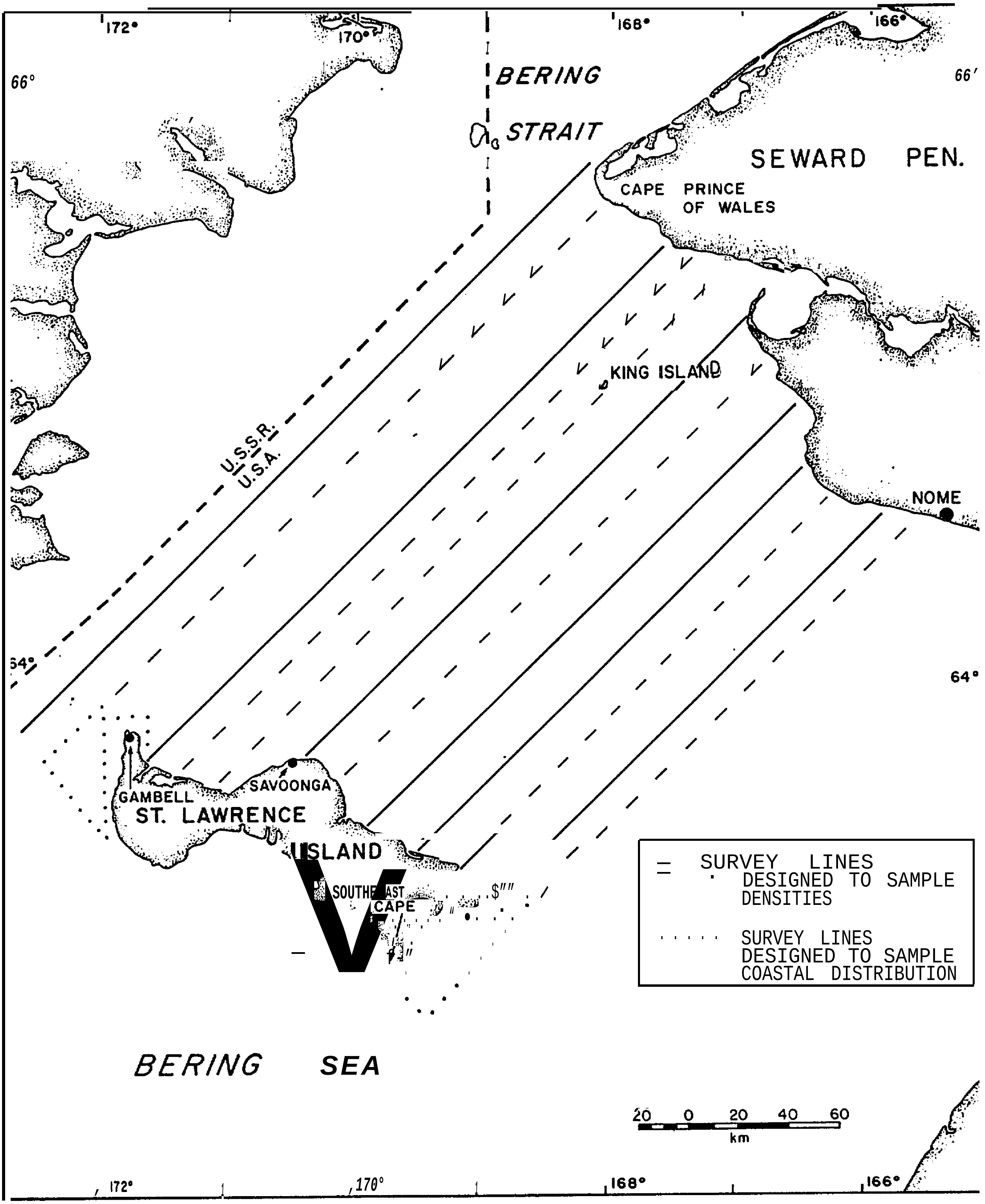

FIGURE 1. Planned transects for aerial surveys. Dashed and solid lines depict the two sets of six randomly-selected transects (see text).

operated by Evergreen Helicopters, Anchorage. Each aircraft was equipped with a VLF navigation system (GNS-500) for accurate offshore navigation, and a radar altimeter for accurate determination and maintenance of survey altitude.

Survey Procedure

Survey procedure was standardized to the extent possible; however, the use of two different aircraft required different survey speeds and different seating positions during the two surveys. We attempted to maintain a ground speed of 240 km/h when flying in the Grumman Goose. When surveying from the Twin Otter (second survey) it was practical to maintain a ground speed of about 205 km/h.

In the Grumman Goose the observers occupied seats opposite one another in the rear of the aircraft. The observers surveyed through a large window offering some forward and rearward visibility. Thus , the two observers had equal visibility when in the Goose. In the Twin Otter, one observer was seated in the front left (co-pilot's) seat. The second observer occupied a seat on the right side of the aircraft, two behind the pilot, and observed through a standard side window. During this survey the observer occupying the co-pilot's seat had better forward visibility than did the rear observer.

All surveys were flown at an altitude of 152 m. Fog caused occasional deviations from this altitude; however, when these deviations became prolonged the survey was terminated.

Surveyors recorded all observations onto audio tapes. Information for each sighting included species, number, group type, behavior (including description of activity, direction of movement), sighting cue, and presence or absence of feeding plumes and/or associated flocks of birds. An inclinometer (Suunto PM-S/360S) was used to determine the angle of depression of the line to the animal when it was directly to the side of the aircraft. Lateral distances of gray whales from the flight path were later calculated based on the sighting angle and aircraft elevation.

Position along the transect route was interpolated by the use of an interval timer system, digital watches, and the aircraft's VLF navigation system. The interval timer was reset to zero at the start of each transect and, thereafter, at 2-rein intervals it produced a sound audible to all observers. This division of transects into 2-rein transect segments permitted us to map gray whale sightings at intervals of approximately 6-8 km along each transect. During all surveys, weather (fog, rain, snow), sea state and sun glare intensity were recorded for each transect segment.

Ship-based Observations

During the gray whale benthic ecology and behavior cruises in July and September, 1982, a systematic watch for marine mammals was kept from the flying bridge of the MILLER FREEMAN (12 m above water), and from the flying bridge or "aloft conning tower" of the DISCOVERER (15 m and 23 m above water, respectively). One to three whale biologists scanned the sea with unaided eyes and with 9x30 binoculars, Distance of visibility varied with weather conditions and size of marine mammal, but the observers believed that they were usually able to sight blows of gray whales within five km of the vessel. Marine mammal sighting information included time, ship's position and heading, weather, species, number of animals, and distance of sighting from the ship.

When the ship was on station during benthic sampling, systematic binocular-aided scans were conducted for 10 min of every hour. In this way, estimates of number of whales within sight of the ship were made. These estimates, as well as the overall sighting effort, are presented in the Results.

RESULTS

Aerial Surveys

Distribution

We flew two sets of survey lines during the first survey period (10-17 July), totalling 3709 km. Coverage was virtually complete, except that Federal Aviation Administration regulations prevented us from flying lines we had laid out in the westernmost of the six survey bands. Seventy-six gray whales were sighted (20.5/1000 km of survey line) on the regular survey lines, and a total of 79 gray whales (21.3/1000 km) were seen. The survey lines flown and the distribution of all sightings recorded in July are shown in Figure 2. Sea states were generally good during the survey, ranging from Beaufort 2 to 4.

The distribution of sightings in July suggests that gray whales were concentrated in a broad swath extending (roughly) from Cape Prince of Wales on the Seward Peninsula south to Northeast Cape on St. Lawrence Island. Few gray whales were seen in offshore areas to the east or west of the swath. Gray whales were also found in substantial numbers in nearshore waters to the east and west of St. Lawrence Island.

Only one of the two sets of survey lines was flown during the second survey period (9-10 September) totalling 1933 km. Twenty-seven whales were recorded (14.0 whales/1000 km of survey line; Figure 3). Sea states were higher than observed in July, ranging from Beaufort 3 to 4 (average 3.5). The general distribution of whales appears to have been similar to that observed in July with the exception that no whales were seen north or west of King Island during the September survey. However, the lack of sightings in that area may be an artifact of the lower sampling effort during the second survey.

Feeding gray whales often bring considerable amounts of mud to the surface, which remains visible after the whale has dived. Thus, the distribution of mud plumes provides additional information about gray whale distribution beyond that provided by sightings of whales themselves. The distributions of all feeding plumes seen are plotted in Figures 4 and 5. These distributions correspond very closely to the distributions of whale sightings (Figs. 2 and 3). Thus, it appears that gray whales were feeding throughout all of the areas in which they were recorded. (For more details on the relationships between sightings, feeding plumes and gray whales see later section--Detectability of Feeding Plumes.)

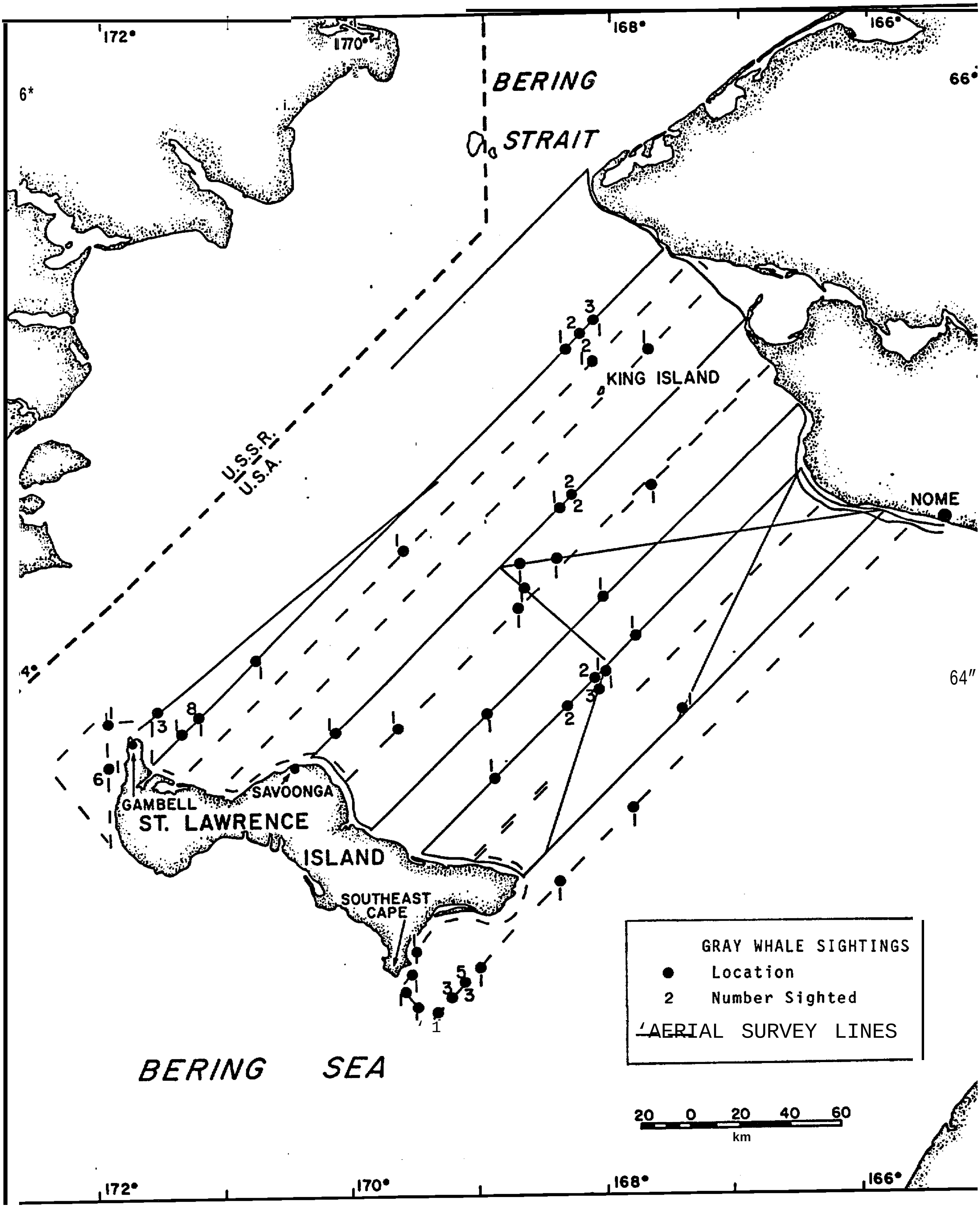

FIGURE 2. Survey lines and sightings of gray whales during aerial surveys on 10-17 **July** 1982.

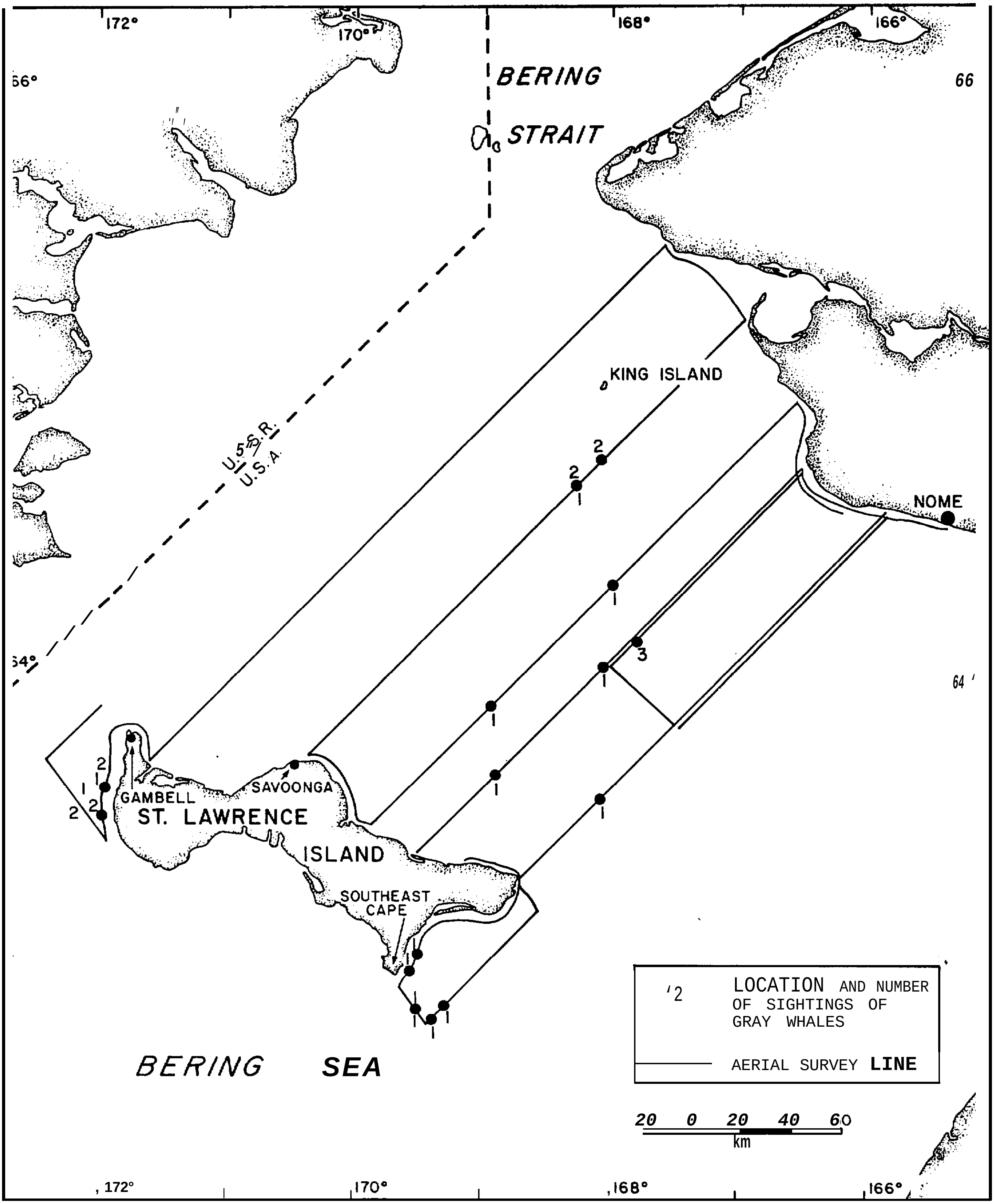

FIGURE 3. Survey lines and sightings of gray whales during aerial surveys on 9-10 September 1982.

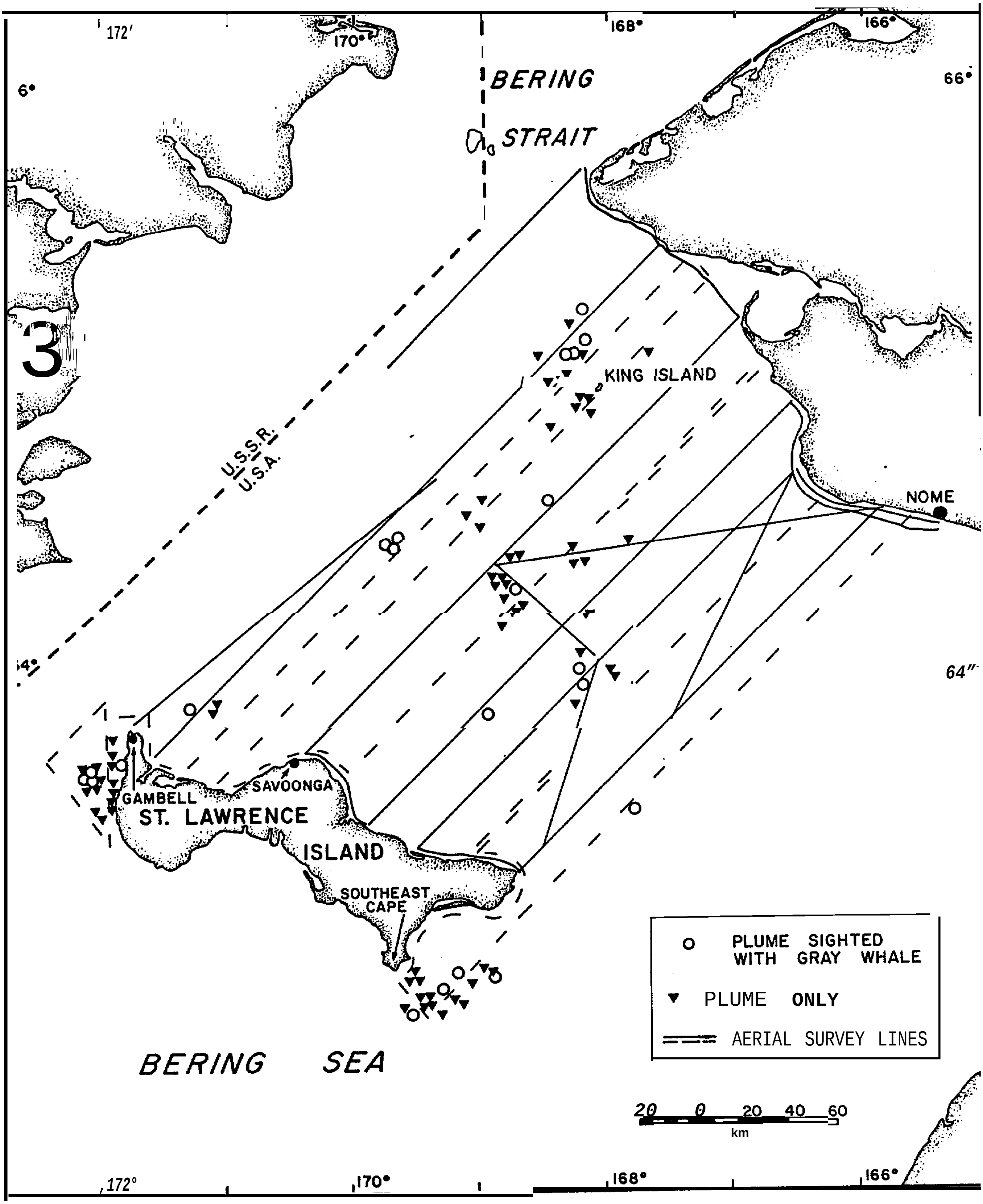

FIGURE 4. Aerial survey lines and sightings of mud plumes from feeding gray whales, 10-17 July 1982.

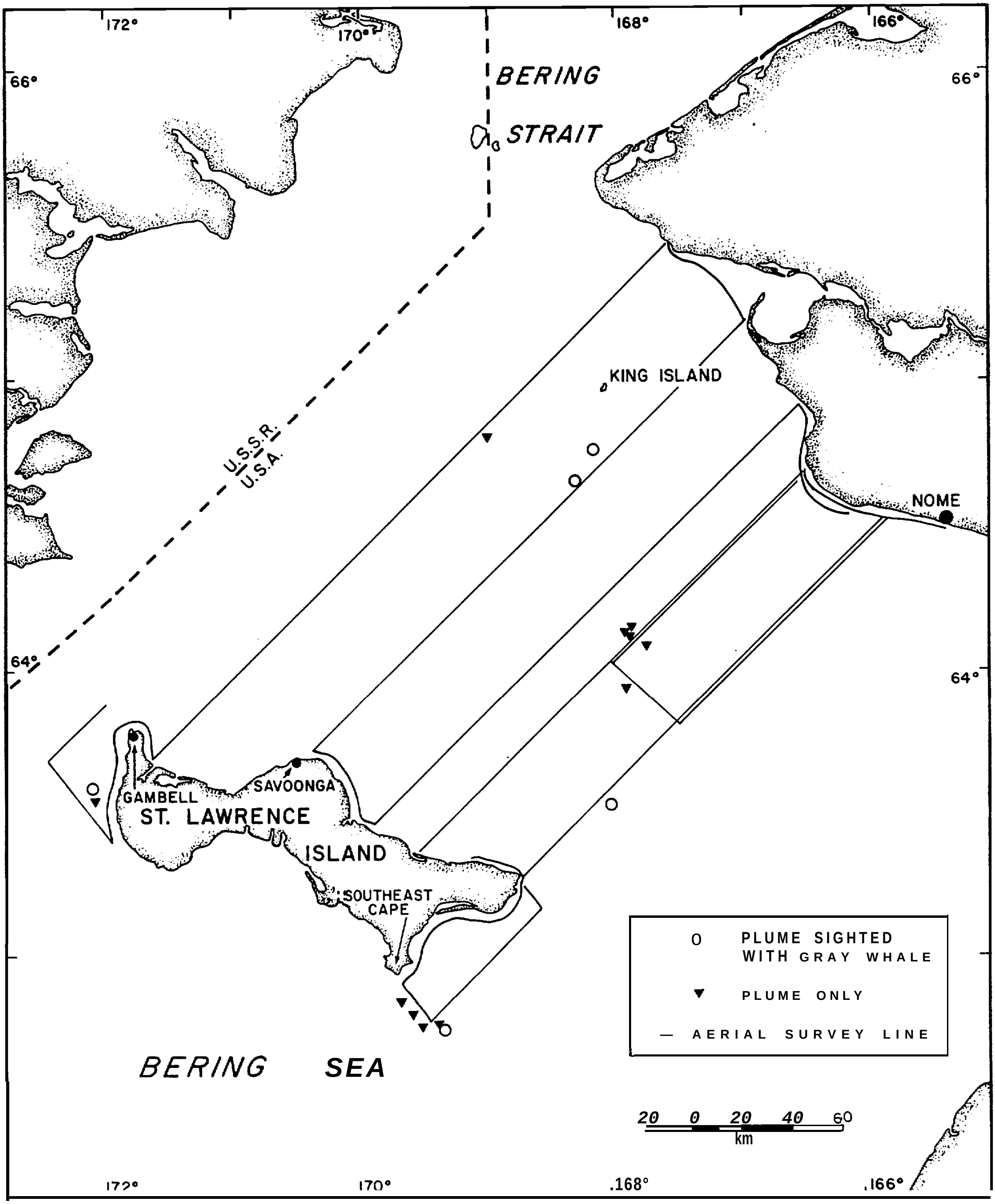

FIGURE 5. Aerial survey lines and sightings of mud plumes from feeding gray whales, 9-10 September 1982.

Population Estimation Procedures

In a later section we estimate the size of the gray whale population inhabiting the study area during the two surveys. The estimates are based on the gray whale sightings along the straight-line transects across the Chirikof Basin (see Figs. 6 and 7 for the July and September transects and sightings used in calculations). Line transect procedures were used to obtain 'raw' estimates of gray whale densities. In order to derive population estimates, we applied correction factors to the raw densities. These correction factors accounted for gray whales that were submerged and therefore not visible to the observers. The 'corrected' densities were applied to the area within the six survey bands (Fig. 1) to estimate the number of whales within those bands.

Survey Models

Use of inclinometers enabled us to estimate the perpendicular distance from the flight path to each whale we sighted. The availability of these estimates allows us to calculate gray whale densities according to either strip transect or line transect models, both of which are used commonly in aerial censuses of marine mammals (Eberhardt et al. 1979).

The choice of which of these two models to use depends on a number of factors, especially the distribution of lateral detection distances from the flight path. The lateral detection distances of gray whales sighted on the pre-established survey lines are plotted separately for July (n = 41) and September (n = 13) in Figure 8. We compared the lateral distances at which gray whales were observed during the two surveys, lumping sighting distances into categories of 0-500, 500-1000, 1000-1500 and 1500+ m from the flight path of the aircraft. No significant difference was found between the two surveys (chi^2 = 3.40, df = 3, $p>0.30$).

The median distances at which gray whales were sighted did differ considerably between July (470 m) and September (860 m), however, and some possible explanations for this difference are discussed below.

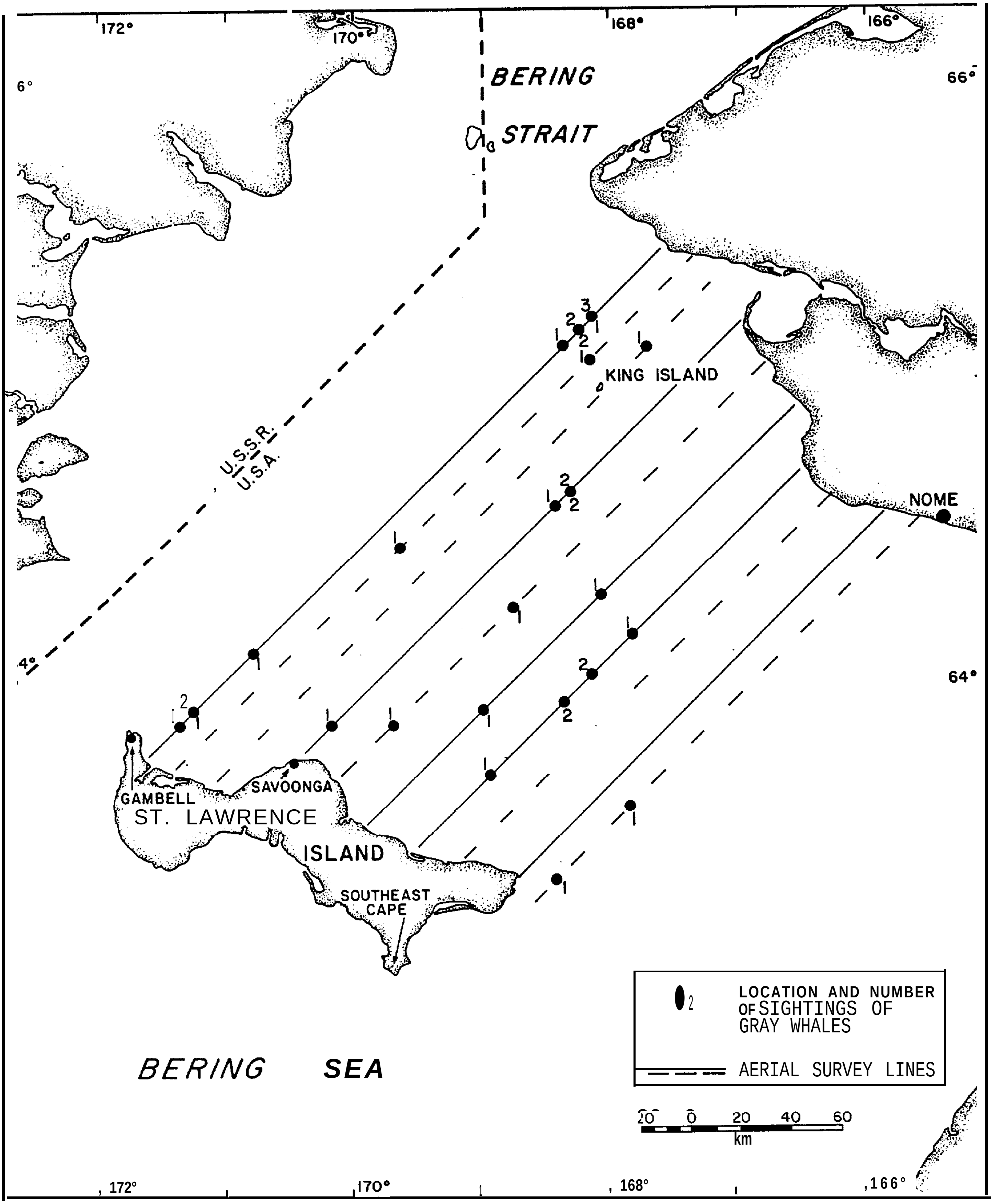

FIGURE 6. Aerial survey lines and whale sightings used to estimate gray whale abundance in July 1982. Sightings along opportunistic transects and at lateral distances <100 m or >2100 m are excluded (see text).

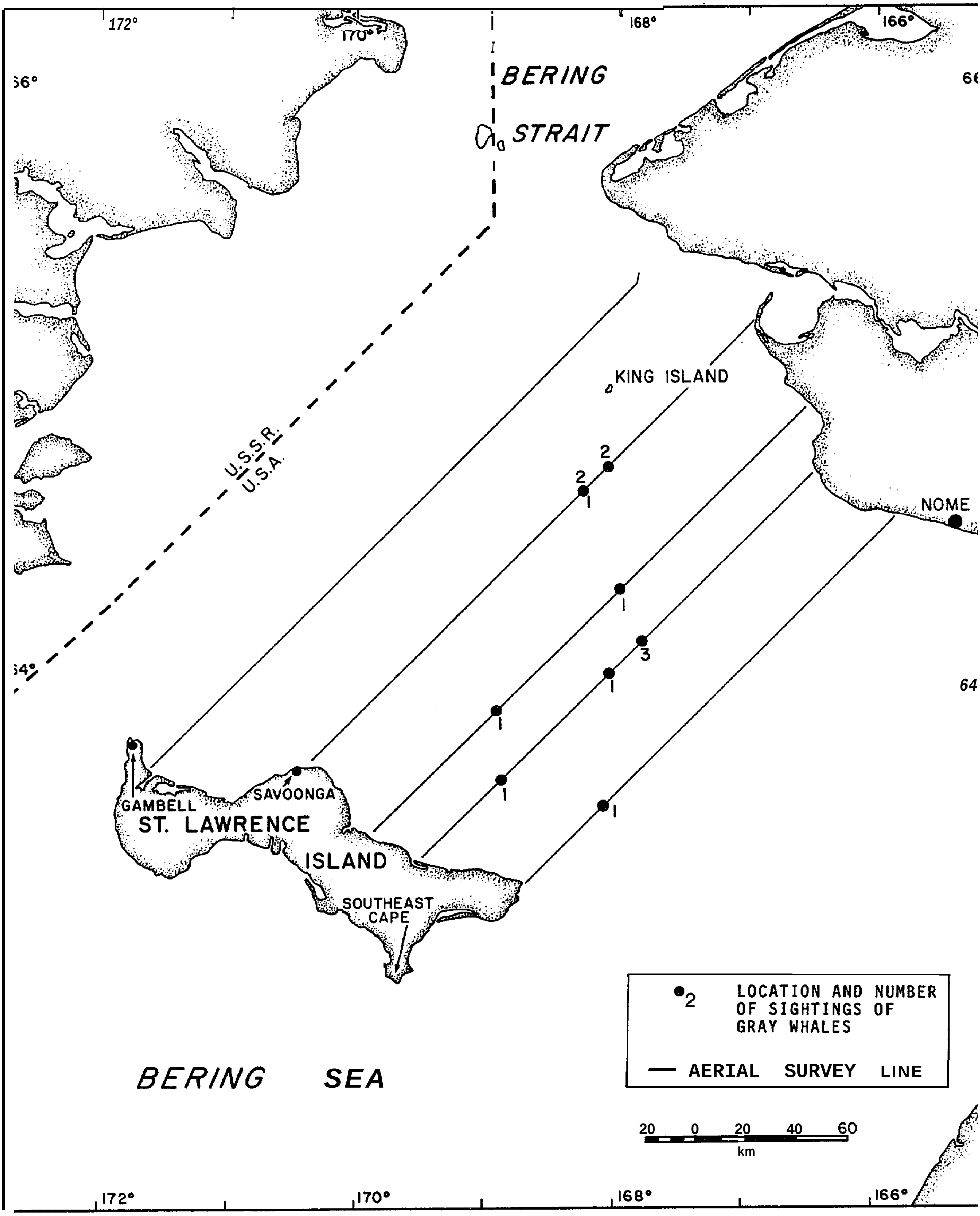

FIGURE 7. Aerial survey lines and whale sightings used to estimate gray whale abundance in September 1982.

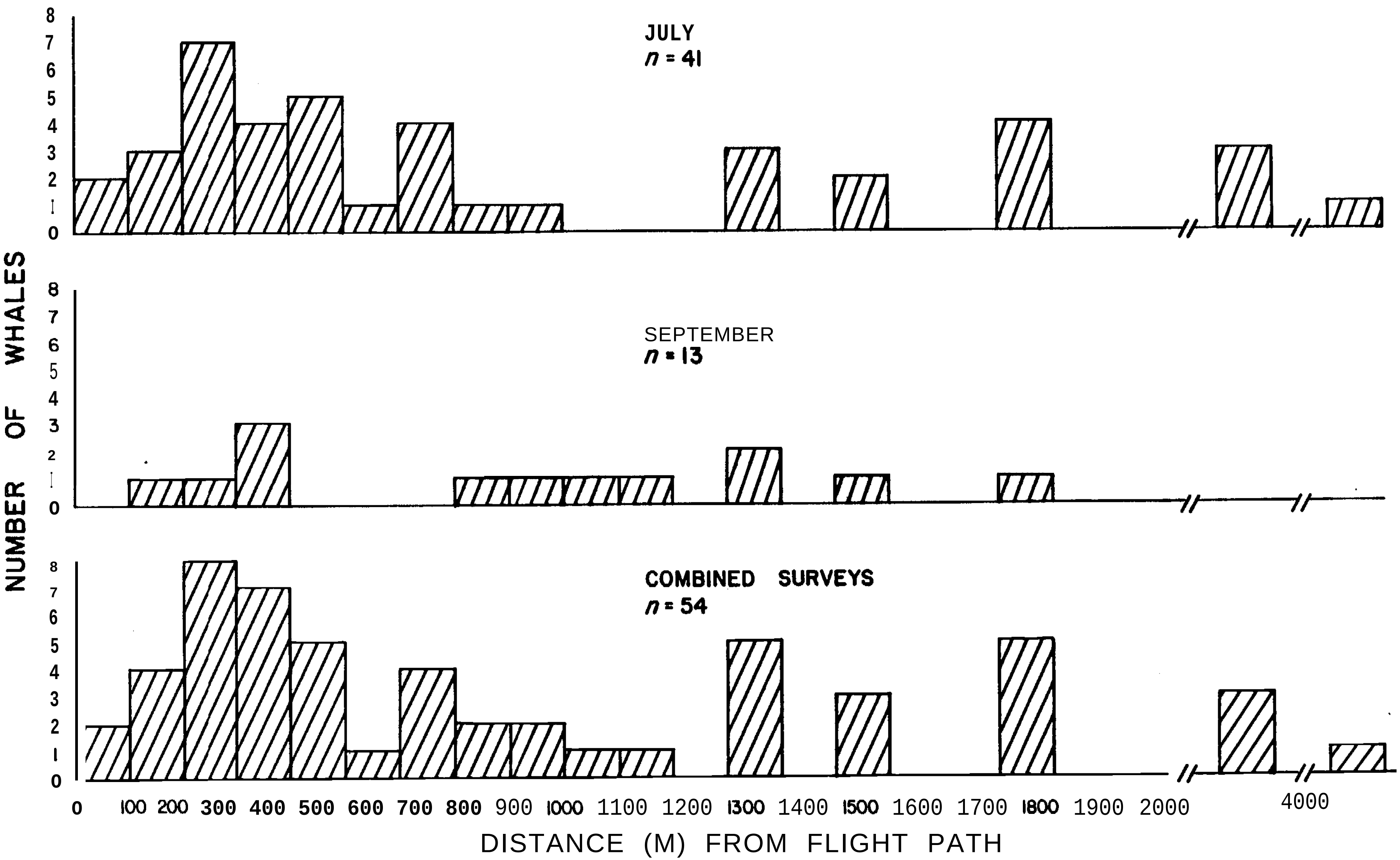

FIGURE 8. Distribution of lateral distances of gray whales sighted during aerial surveys.

The sample sizes for both the July and September surveys were small (41 and 13, respectively) and sampling error may account for some of the observed difference. Of the other variables that might conceivably account for differing lateral sighting distances (aircraft type, seating position, aircraft speed and weather and sea state conditions), sea state seems to be the most likely cause.

Sea states were generally higher in September than in July and this may have affected the sighting cues that the aerial observers relied on to spot and recognize gray whales. The aerial observers recorded, when possible, the sighting cues that first brought their attention to a gray whale. These cues included the whale itself (body, back, flukes), feeding plumes, aggregations of feeding birds, and blows (exhalation) from the whale. Blows tended to be visible at greater distances than other sighting cues. For example, in July the mean lateral distance of whales whose sighting cues were blows was 1803 m (n = 13) compared to 441 m for all other cue types (n = 20). In September, the comparable distances were 1223 m (n = 6) and 517 m (n = 6).

Although, intuitively, it may seem that higher sea states would decrease the likelihood of seeing whales at a distance, this may not be the case for whales that are sighted with a blow as the cue. Blows are conspicuous even in moderately high sea states. The probability of sighting a whale's back or body definitely deceases with increasing sea state because white caps, spray and swells tend to conceal such cues. The moderately higher sea states encountered in September may have decreased the sightability of whales near the aircraft, but left the sightability of whales farther from the aircraft, where blows are the most important sighting cue, relatively unchanged. In September, blows were the sighting cue for 50% (6 of 12) of the whales recorded compared to 29% (8 of 27) in July. Thus, in September, fewer whales may have been recorded and the distribution of lateral sighting distances may have been biased toward whales farther from the aircraft. This bias makes the estimating procedure more conservative and results in a lower population estimate for September.

A fundamental assumption underlying the strip transect model is that animals be equally detectable in all parts of the transect. To test this assumption we examined the combined (n = 54) distribution of lateral distances for surveys 1 and 2 (Fig. 8). Based on these data it would be difficult to choose a transect width that would satisfy the assumption of equal detectability. There appears to be a zone close to the aircraft (0-100 m from flight path) where few gray whales were detected. If we exclude this region and consider a hypothetical 1000 m transect width from 100 to 1100 m from the aircraft, we find that 71% (25) of the gray whales sighted were in the inner half (100-600 m) of the transect and only 29% (10) were in the outer half. This difference is statistically significant (binomial test, $p<0.05$). Thus, these data do not appear to be appropriate for strip transect analysis.

In the following section we use the line transect method to estimate the 'raw' density of gray whales in the survey area. The advantage of the line transect method is that animals in all parts of the transect need not be equally detectable. The line transect model assumes that all animals at the center of the transect (i.e. at zero distance from the survey line) are detected, and that the detectability of animals decreases with increasing distance from the line.

Uncorrected Estimates of Numbers Present in Study Area

We calculated uncorrected density estimates for each of the two surveys according to the line transect method of Burnham et al. (1980) using a computer program which they developed (TRANSECT version 1.1; Laake et al. 1979). The sightings used in the program are those shown in Figures 6 and 7. The line transect model assumes that all animals at zero lateral distance are recorded by the observers. Our data (Fig. 8) suggest that whales closest to the transect lines (0-100 m) were less likely to be seen than whales farther from the lines (100+ m). This is to be expected because it was impossible to detect whales directly below either of the survey aircraft that were used. To compensate for this, we eliminated two sightings of whales seen at distances of 90 m from the transect line and assumed that our transect began at 100 m from the aircraft flight path. All sighting distances were accordingly decreased by 100 m for the purpose of using the computer program. We truncated the sighting distances at 2100 m, eliminating a further four sightings beyond that distance. Two pairs of whales were treated as single sightings because the line transect method requires independent sightings. The resulting sample sizes used in the analysis were 33 and 13 sightings for the first and second surveys, respectively, based on a transect width of 0-2000 m (originally 100-2100 m).

The formula used to calculate the density of sightings is

$$D = \frac{N \cdot f(0)}{2L}$$

where N is the sample size of observations, L is the total line length and f(0) is the probability density function of the distribution of lateral distances at lateral distance O. TRANSECT used the data to calculate probability density functions based on three different models

1. non-parametric linear (Fourier Series),
2. simple parametric (negative exponential),
3. generalized parametric (exponential power series).

Any of these models will provide a value of f(0) that can be used as an estimator in the above density formula. The values of f(0) determined from the above models are shown in Table 1. The f(0) values derived from the three models for the July survey were very similar, ranging from 1.511-1*587* The f(0) values calculated for the September survey were more variable, ranging from 0.667-1.033 (Table 1).

We used the f(0) values determined from the Fourier Series method for both the July and September surveys. The use of this estimator has been recommended by Burnham et al. (1980) on the basis of its robustness, shape criteria and its estimation efficiency for small samples. The fit of the Fourier Series probability density functions to our data (pooled into four lateral distance categories) is shown in Figure 9. Burnham et al.

Table 1. Line transect estimates of the abundance of gray whales in July and September 1982.

Survey	Model	f(o)	χ^2 probability	D*
July	Fourier Series	1.511	-**	0.01087
	Negative Exponential	1.534	0.474	0.01104
	Exponential Power Series	1.587	0.230	0.01142
Sept.	Fourier Series	0.813	0.953	0.00460
	Negative Exponential	1.033	0.767	0.00584
	Exponential Power Series	0.667	0.610	0.00377

* Raw sighting density (per km^2). July figures must be multiplied by 35/33 to convert to whale density, since two sightings involved pairs of whales.
** There were too few degrees of freedom to determine a chi^2 probability.

(1980) suggest that the Fourier Series performs well with samples as small as 30-40 sightings. Thus, the estimate for July based on 33 sightings may be considerably more reliable than the September estimate based on only 13 sightings.

Substitution of the f(0) values from the Fourier method into the aforementioned formula for density leads to raw density estimates of 0.0109 sightings/km^2 or 0.0115 whales/km^2 in July, and 0.0045 whales/km^2 in September. The difference between the two figures for July results from the fact that two of the 33 sightings involved two whales; the other 31 sightings in July and all 13 sightings in September were of single whales. These densities correspond to raw estimates of about 540 (July) and 215 (September) gray whales in the six survey bands, whose total area was 46,860 km^2.

Use of strip transect methods would have resulted in lower estimates. If we had chosen a 1000 m transect width (100-1100 m) on either side of the aircraft, the resulting raw density for July would have been 26 whales/4586 km^2, or 0.0057 whales/km2. The September density would have been 9 whales/2300 km2, or 0.0039 whales/km^2. Applying these densities to the 46,860 km2 study area results in raw population estimates of 266 (July) and 183 (September) gray whales.

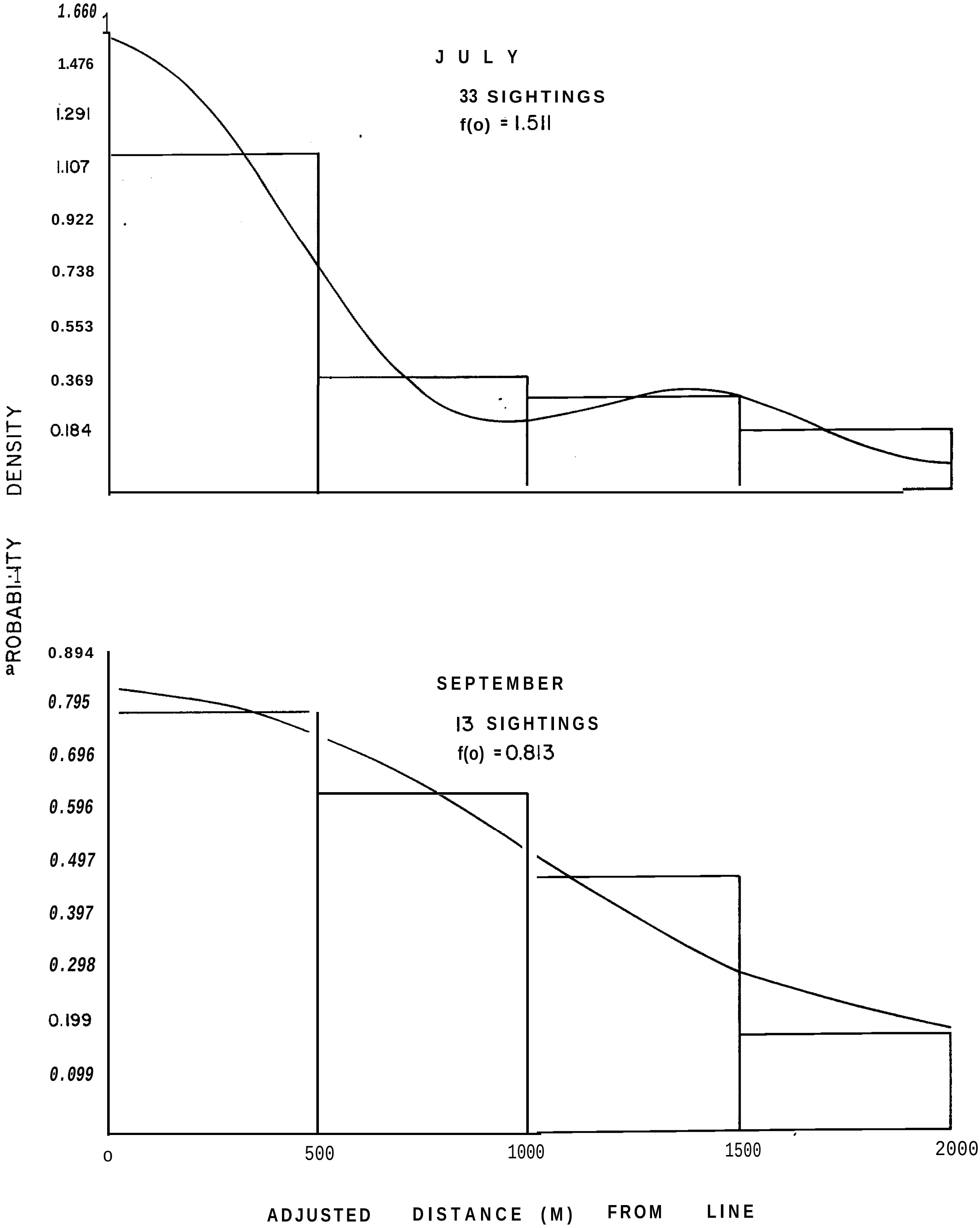

FIGURE 9. Fit of Fourier series probability density functions to lateral distances of gray whale sightings in July and September 1982.

Corrections for Submerged Gray Whales

Feeding gray whales spend large amounts of time below the surface of the water. Submerged whales are invisible to aerial surveyors and aerial survey results must be corrected to account for this if reliable population estimates are to be made. Information on the relative amounts of time gray whales are above and below the surface was obtained from ship-board observations during the present study (**Würsig** et al., this report).

Duration of Potential Detectability.--To correct the raw density estimates for submerged whales, it is necessary to estimate the parameter t, which is the period of time a whale at the surface is potentially detectable from the passing aircraft. The value of this parameter depends on the perpendicular distance between the flight track and the whale, the observer’s horizontal field of view, and the aircraft’s speed. We estimated two ‘*average” values for t, one for the Grumman Goose (first survey), and one for the Twin Otter (second survey) according to the following formula

$$t = \frac{2 \tan \frac{\theta}{2} \cdot x}{v}$$

where θ is the field of view of the observer, x is the median sighting distance from the flight track, and v is the velocity of the aircraft. The parameters used to estimate t are shown in Table 2.

Table 2. Parameters used to estimate duration of potential detectability of a whale (t) for surveys 1 and 2.

Survey	Aircraft Type		x (km)	v(km/s)	t (s)
1	Grumman Goose	110°	0.47	0.067	20
2	Twin Otter	90°	0.86	0.057	30

The estimates of t (20 and 30 s for the Grumman Goose and Twin Otter, respectively) are approximations because of variation in survey speed and rather arbitrary estimates of the viewing angles from the two aircraft. We felt that windows in the Grumman Goose offered the observers a wider field of view than the narrower windows in the Twin Otter. This difference was probably offset to some extent, however, by the fact that one of the two observers in the Twin Otter occupied the co-pilot's seat and had improved forward visibility. The viewing angles we selected may be less than the maximum possible viewing angles: we attempted to estimate a "normal" field of view likely to be exercised by an observer.

<u>Calculation of Correction Factors</u>.--If all surface times are of length s, all dives are of length u and the duration of potential detectability is t, then probability that a whale will be at the surface (or will surface) while within the observer's field of view is

$$P = \frac{s}{s+u} + \frac{t}{s+u} = \frac{s+t}{s+u}$$

(Eberhardt 1978). In the above equation, s/(s + u) is the probability that the whale will be at the surface when its location first comes into visual range, and t/(s + u) is the probability that the whale will surface while its location is in visual range. The uncorrected estimate of the number of animals present should be divided by P to allow for animals that are undetectable because they are submerged when the aircraft passes over.

The above formula assumes that s and u are constant and that $t<u$. Conventionally, s and u are taken to be the mean duration of surfacings and dives. In fact, some dives may be short ($u<t$), and s and u are both highly variable and skewed.

Davis et al. (1982) developed a corrected version of the (s + t)/(s + u) formula that allows for dives that are short in duration ($u<t$). Their procedure also allows for the fact that s and u are variables that may have non-normal distributions. However, they found that this is not a critical factor provided that the cases with $u<t$ are treated separately.

We followed the approach of Davis et al. (1982), and calculated separate correction factors for July and September. The July correction factor was based on observations of 444 paired surfacings and dives during the 12-21 July period (data from Würsig et al., this report). All 444 of these dives were >20 s in duration. The September correction factor was based on observations of 376 paired surfacing/dive cycles in the 12-27 September period. Five of the 376 dives were <30 s in duration. The calculations from which the correction factors for July and September are derived are shown in Table 3. The correction factors by which raw abundance estimates should be divided are 0.280 for July and 0.358 for September.

Corrected Abundance Estimates

Dividing our raw population estimates (540 and 215) by the two correction factors derived above, we calculated corrected population estimates for the 46,860 km^2 survey area of 1929 (July) and 601 (September). Although these estimates allow for whales below as well as at the surface, they may be conservative because no attempt was made to correct for whales at the surface that might have been missed by the observers. Davis et al. (1982) developed such a correction factor for bowheads. They estimated that only 68.5% of the bowheads at the surface in their study were detected by the primary observers.

Had we used conventional strip transect methods, our 'corrected' estimates would have been 950 for July and 511 for September.

Detectability of Feeding Plumes

We examined the distribution of feeding plumes to determine whether they might be used as an index of gray whale abundance.

First, we looked at the limits of detectability of feeding plumes. The lateral detection distances were estimated for 99 of 101 sightings of plumes, separately for July and September surveys (Figure 10). There was a marked decrease in sightability at distances beyond 500 m from the flight path of the aircraft. Only five of 82 (6%) of the feeding plumes sighted

Table 3. Calculation of the probability that an average whale within the surveyed area will be at the surface while within an observer's field of view. All times are in seconds .

Observation period	sun of " dive durations	Sum of surface times	# dives and surfacings	Mean surface time (s)	Mean dive time (u)	s+t / S-hi
12-21 July						
dives <20 s			0			
dives >20s	91,518	23,303	444	52.48	206.12	0.280
Au dives	91,518	23,303	444	52.48	206.12	0* 280
12-27 September						
dives <30 s	86	45	5	9.00	17.20	-
dives >30 s	66,765	19,716	371	53.14	179.%	0.357
All dives	66,851	19,761	376	52.56	177.80	0.358
					corrected*	0.358

* Following the method of Davis et al. (1982), the corrected (s + t)/(s + u) is calculated ss

$$\frac{[(86 + 45) \times 1.01 + [(66,765 + 19,716) \times 0.3571}{(66,851 + 19,761)} = 0.358$$

Using three digits of precision, the corrected result is unchanged from the conventional result--a consequence of the very low percentage of surfacing/ dive cycles for which u<t.

from the Goose and none of the 17 sightings from the Twin Otter were at distances >500 m from the flight path. As with whale sightings, few plumes were seen <100 m from the flight track.

We looked at the number of whales that were accompanied by at least one feeding plume, restricting the tabulation to whales sighted at distances between 100 and 500 m from the flight path (Table 4). The percentages of whales accompanied by at least one feeding plume were 42% (8 of 19) in the July survey, 60% (3 of 5) in the September survey, and averaged 46% (11 of 24) in the combined surveys.

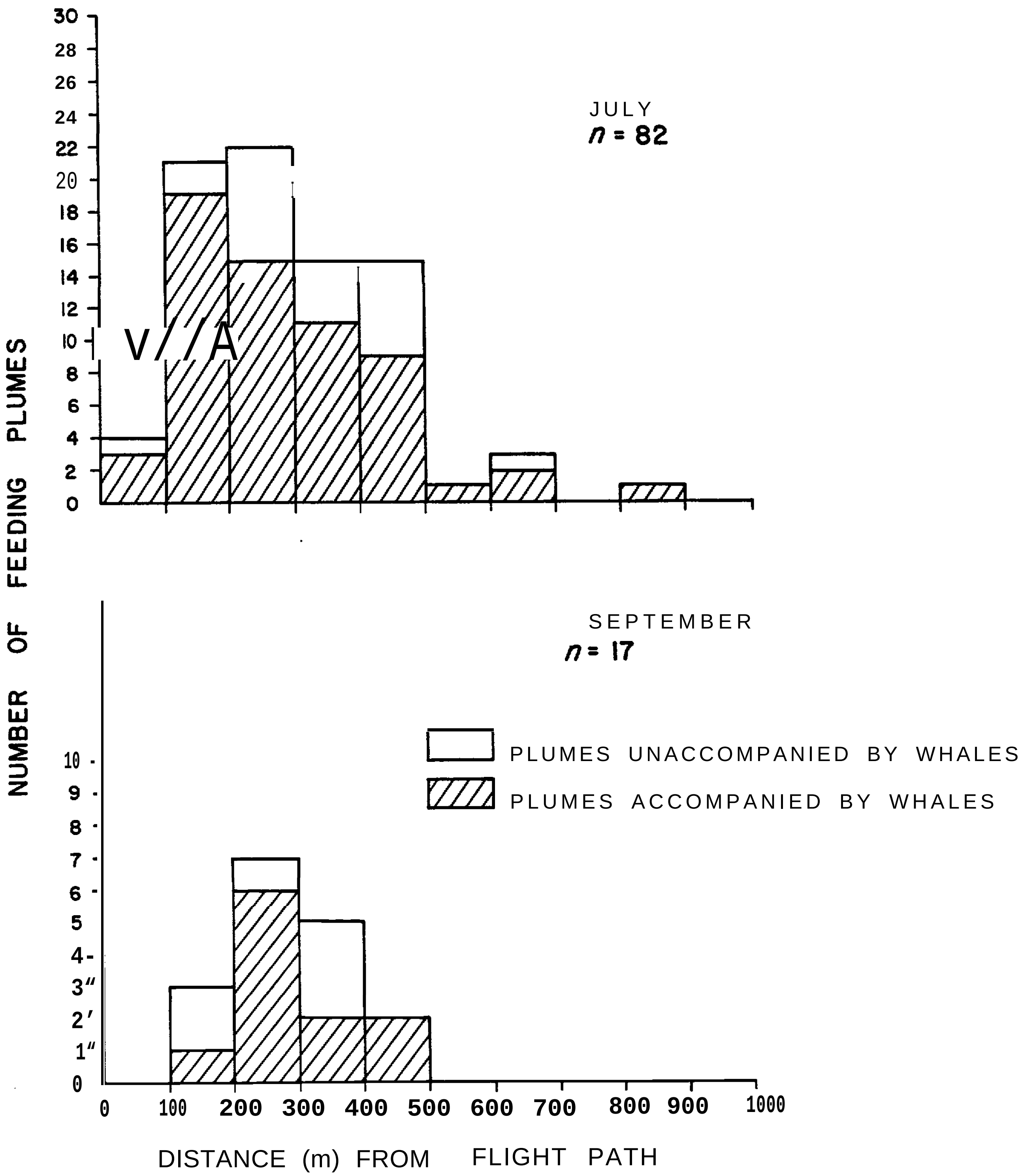

FIGURE 10. Distribution of lateral distances of mud plumes created by gray whales and sighted during aerial surveys.

Table 4. Sightings of gray whales and mud plumes during each aerial survey.

Survey	Whales* Total	Whales* with plumes (%)**	Whales* without plumes (%)	Plumes without whales
1A	13	5 (38.5)	8 (61.5)	4
1B	6	3 (50.0)	3 (50.0)	11
Sub-total	19	8 (42.1)	11 (57.9)	15
2	5	3 (60)	2 (40)	2
Total	24	11 (45.8)	13 (54.2)	17

* Sighted between 100 and 500 m from the flight track.
** Closely grouped plumes that looked as though they might have been the result of a single whale's feeding activities were considered as one plume in this analysis.

Alternative Population Estimate Using Sightings of Mud Plumes

We used the mud plume data to obtain an entirely different estimate of abundance based on the strip transect method. Assuming a 400 m transect width on each side of the aircraft (lateral distance 100-500 m), we counted the number of whales sighted and used the number of unaccompanied plumes to correct for submerged whales.

In survey 1, eight of 19 whales sighted between 100 and 500 m from the flight path were accompanied by feeding plumes. If we *assume* that the same proportion of submerged whales would create plumes, then the number of submerged whales can be estimated by dividing the number of unaccompanied whale plumes by that proportion. In the first July survey, we saw 15 unaccompanied plumes at lateral distances of 100-500 m. Dividing that number by 8/19, we calculate that 35.6 additional submerged whales were present in the transect strip. Thus 54.6 whales (19 + 35.6) were present in the 2293 km of transect (width = 0.8 km) flown. This corresponds to a density of 54.6 whales/1834 km^2 or 0.0298 whales/km^2. Using the same approach for the second survey we calculated a density of 0.0123 whales/km^2. Applying those two densities to the sum of the areas in our six survey bands (46,860 km^2) results in population estimates of 1396 whales during the July survey and 576 whales during September. These estimates are reasonably close to our previously derived estimates of 1929 and 601 based on the line transect method with adjustment for submerged whales.

Shipboard Observations of Gray Whales

In July, approximately 291 gray whales were observed during station scans, transect counts and other shipboard operations in the nearshore waters of St. Lawrence Island (Table 5). Similarly, 116 gray whales were observed in September. In intensively worked areas and areas where whales were numerous, the same whales may have been counted several times. In these areas, the observers estimated the total. number of whales present. These area estimates (Fig. 11) include whales observed along transects and during station scans.

High densities of whales were found off Southeast Cape, the south and west coasts of St. Lawrence Island, in the south central Chirikof Basin, and across the international boundary in the northwest part of the Chirikof Basin (observed from U.S. waters on a clear night; Fig. 11). No whales were observed along the north coast of St. Lawrence Island and only two whales were observed in the northern part of the study area between King Island and Nome.

The distribution of whales observed from the ship closely parallels that found during aerial surveys conducted during this study (Fig. 2-5).

DISCUSSION

Northward migrating gray whales arrive at St. Lawrence Island in May and June, and in summer are dispersed to the north and west (Braham in press). Approximately 17,000 whales enter the Bering Sea (Rugh in press). An estimated 7700 to 7800 are found in Russian waters (Zimushko and Ivashin 1980). Ljungblad et al. (1982, 1983) conducted aerial surveys throughout the Chukchi and northern Bering seas in 1981 and 1982 and computed densities of whales for these areas. The regions surveyed during the present study

Table 5. Level of effort and numbers of whales observed during shipboard observations in the Chirikof Basin and near St. Lawrence Island during the summer of 1982.

Day	Location	Type	Level of Effort	No. Whales observed
July:				
10	Approaching southwest coast of St. Lawrence Island	Transect	13.0 h	0
11-14	West coast of St. Lawrence Island	Area estimate	4 d in area	65
15	North coast of St. Lawrence Island	Transect	5.5 h	0
16-21	Southeast Cape of St. Lawrence Island	Area estimate	6 d in area	40
22-23	Chirikof Basin, station 7A to Date Line	Transect	8.6 h	39
		Station scans	4.2 h	43
23	Across international boundary	Area estimate		100
24	King Island	Area estimate	4h in area	4
25	King Island to Nome	Transect	8.1 h	0
		Station scans	2.8 h	0
27	south of Nome	Transect	3h	0
September:				
12	Approaching Southeast Cape of St. Lawrence Island	Transect	6.8 h	21
13-15	Chirikof Basin	Transect	7.0 h	0
		Station scans	1.5 h	2
16	South coast of St. Lawrence Island	Transect	5.3 h	17
		Station scans	1.2h	41
17	East coast of St. Lawrence Island	Station scans	0.5 h	0
18	Boxer Island	Area estimate	1 d in area	15
20-23	Southeast Cape of St. Lawrence Island	Area estimate	4 d in area	20
24	Gambell to Savoonga; north coast of St. Lawrence Island	Transect	2h	0

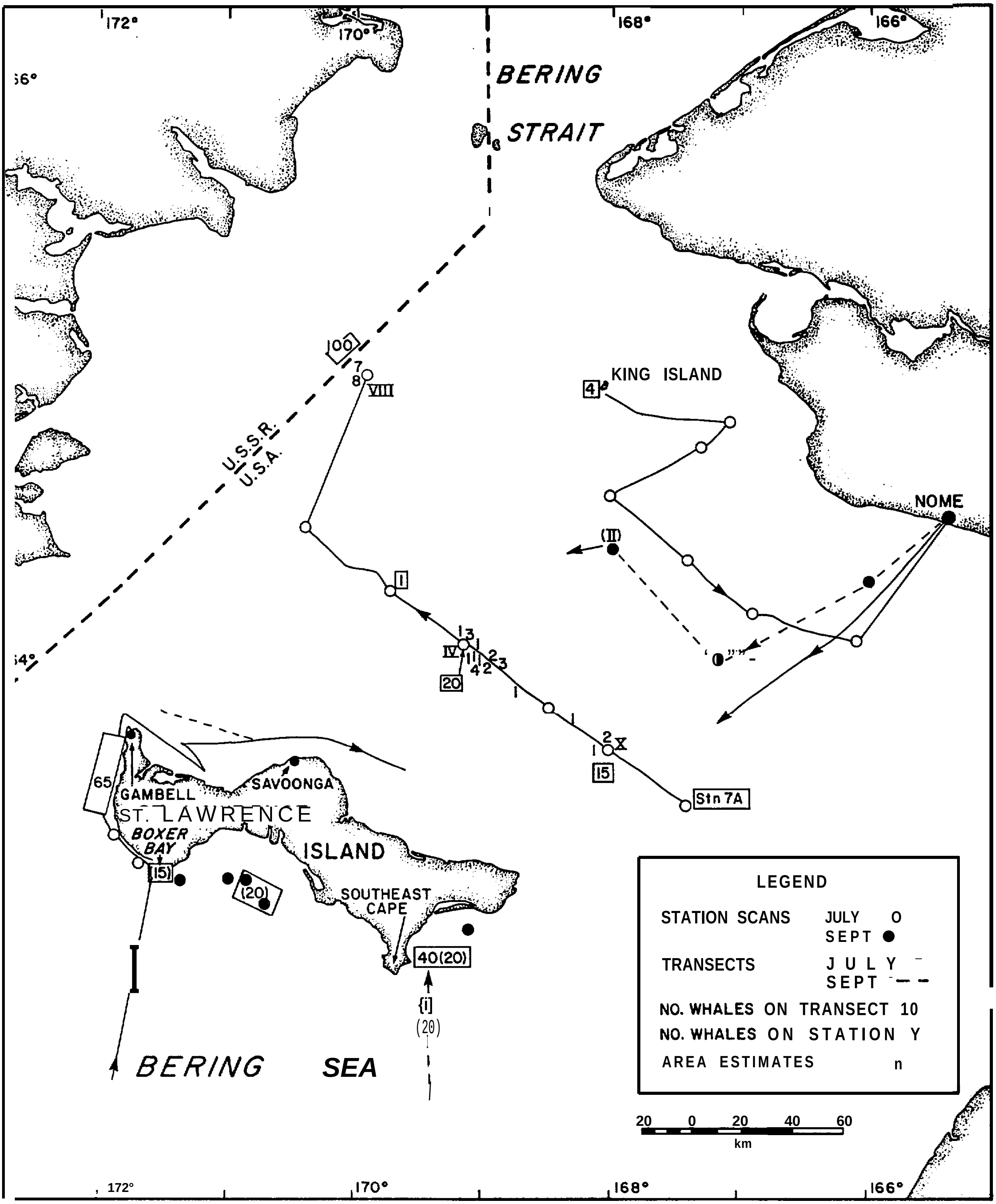

FIGURE 11. Gray whales observed during shipboard observations in the Chirikof Basin and near St. Lawrence Island during July and September 1982. Observations and estimates made in September are in parentheses. Area estimates in the Chirikof Basin include animals counted during nearby station scans and transect observations.

included some or all of blocks 5, 6, 7, 8, 10 and 11 surveyed by Ljungblad et al. (1983; Fig. B-26) in 1981 and 1982. Their mean raw density estimate for the whole area encompassed by these blocks between June and August 1981 was 0.0125 whales/km^2, and their raw mean density estimate for July 1982 was 0.0106 whales/km^2. Total area considered in their estimate was 62,848 km^2, including the Chirikof Basin and the west coast of St. Lawrence Island. Application of our July correction factor for whales below the surface to Ljungblad et al.'s data yields an estimated 2805 whales for 1981 and 2379 whales for 1982. Ljungblad et al.'s raw density estimates are close to the estimate of 0.0115 whales/km^2 found during the present survey. The total area of 46,860 km^2 surveyed during this study was smaller than the area surveyed by Ljungblad et al. and the estimate of 1929 whales/km^2 found during this study in July is correspondingly smaller.

In 1982, 105 gray whales were estimated *to* be in the areas observed from the ship off Southeast Cape and the west coast of St. Lawrence Island in July, and an estimated 76 whales were off the south coast and Southeast Cape in September. These results are also similar to estimates based on Ljungblad et al.'s (1982) data--193 gray whales in the St. Lawrence Island area in 1981. Densities were higher in 1982 (Ljungblad et al. 1983) and application of the correction factor yielded an estimate of 805 whales off Southeast Cape. Ljungblad et al.'s (1983) coverage of the southwest and south coasts in 1982 was insufficient for estimation.

The distribution of whales appears to have been similar in 1981 and 1982. Surveys conducted by Ljungblad et al. (1982: Fig. B-76 and 1983: Fig. B-64) also show high densities of whales off Southeast Cape of St. Lawrence Island, the west coast and in the south central basin, and no whales in the northeastern or southwestern part of the basin, or close to shore along the north coast of St. Lawrence Island.

The area across the international boundary where we estimated 100 whales to be present is *part* of an area referred to as the "large kitchen-garden" by Russian authors. In summer it may harbor up to 400 gray whales (Votrogov and Bogoslovskaya 1980).

Gray whales generally depart Russian waters in mid October to November, and passage out of the Bering Sea is between mid November and mid December (Rugh and Braham 1979; Yablokov and Bogoslovskaya in press). The decline in estimated whale numbers from 1929 in July 1982 to 601 in September 1982 is inexplicable in terms of what is known of their movements. It is not known whether these animals moved north, west or south between July and September.

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