AERIAL SURVEY OF PACIFIC WALRUS, 1980

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SUMMARY

The second coordinated U.S. - U.S.S.R. aerial survey of walruses was completed in September 1980. The first was undertaken in September - October 1975. In 1980, surveys undertaken by the U. S. side were done on 10 to 20 September. Purposes of the surveys were to: develop an estimate of, or index to, the size of the Pacific walrus population; obtain additional knowledge of walrus distribution and changes in distribution; and to evaluate the effectiveness of aerial surveys in population assessment.

In 1980, flights were made on 10, 11, 15, 16, 18, 19 and 20 September. On the 10th and 11th, we located the edge of the ice pack and flew some transects east of Pt. Barrow. From 15 to 20 September, 40 parallel north-south oriented transects were flown and these provided the basis for population calculations and most other conclusions. The transects were located every 30 seconds longitude beginning at 153° W and continued through 172°30' W between latitudes 71° N and 73° N. Transects were of varying length between the southern edge of pack ice and the northern end where ice cover was about 100%. While flying these transects, 24,096 walruses were sighted, 10,522 of them within the 1/2-nautical mile (nm) sample strips located on each side of the flight path. The data were tabulated and analyzed using programs developed by scientists at the National Marine Fisheries Service Marine Mammal Laboratory at Seattle, Washington. Density and population estimates were developed using the same methods used by Estes and Gilbert (1978) for the 1975 survey data.

Walruses were found throughout the areas surveyed and the distribution showed extreme clustering with an area of high density between longitude 166° W and 171° W. The density estimate for this 4,300 nm^2 area was about 20 visible walruses per nm^2. For the remainder of the area surveyed, the estimated density was less than 1 per nm^2.

The results of this survey indicate that there were an estimated 140,000 plus walruses east of 173° W longitude at the time of the survey. A concurrent survey undertaken in regions west of 173° W by Soviet scientists resulted in an estimate of 130,000 to 150,000, suggesting a total estimate of 270,000 to 290,000 Pacific walruses in 1980. This estimate is consistent with previous estimates based on aerial surveys which, in combination, indicate a more than doubling of the population during the past two decades. We have great confidence in the indicated population trend, but little confidence in the accuracy of the estimates. The data base from which estimates of density and total numbers were calculated is highly variable and there is no basis for estimating the number of walruses that are not visible because they were feeding within the survey area or were in the open water south of the ice. Even though we have little confidence in the accuracy of the population estimate, it is likely that the actual population is greater than our estimate. Without additional data on haul out-feeding cycles, particularly a measure of daily variability in the number of walruses hauled out on the ice, we cannot complete assessment of the value of aerial surveys as a population monitoring method. However, it is unlikely that even with the best of conditions aerial surveys can be expected to detect changes of less than

25% with a probability of 95%. Because there is a critical need to monitor the walrus population but no means other than aerial surveys are presently evident, we recommend that these joint surveys be continued, at least until the method can be more thoroughly evaluated.

INTRODUCTION

The Pacific walrus (Odobenus rosmarus divergens) population has long been an important resource to inhabitants of the Chukchi Peninsula and western Alaska. Prior to the middle of the 19th century catches by the coastal dwelling natives presumably had an insignificant effect on the size of the walrus population. However, the population was reduced rather quickly when whalers turned to walruses as a source of oil and ivory in about 1860, after they had reduced bowhead whale populations. During the first half of the 20th century the walrus population remained at a relatively low level, but by the late 1950's conservation measures by Soviets and Alaskans sufficiently reduced the take and the population began to increase. From 1960 through 1975, several aerial surveys were made in an attempt to estimate the size and to follow the increase of the walrus population. The results of these surveys and other estimates have been summarized by Fay (1982) and are presented in Table 1. Passage of the Marine Mammal Protection Act in 1972 obligated the Fish and Wildlife Service to submit to Congress an annual report of the status of the Pacific walrus. This obligation provided an additional stimulus to continue monitoring the walrus population. In 1973 and 1974, the Marine Mammal Working Group of the US/USSR Agreement on Conservation of the

Environment agreed that the two countries should conduct joint aerial walrus surveys at 5-year intervals, the first in 1975.

By 1975, a substantial amount of information had accumulated which identified sources of variability and unmeasurable bias affecting precision and accuracy of results from aerial surveys. In a report of results of the 1975 survey, Estes and Gilbert (1978) addressed these problem areas in some detail. The three factors creating the greatest difficulties were found to be: (1) the vast area occupied by walruses during the survey time period; (2) the gregarious habit of walruses which results in compact groups with most individuals in contact and these groups forming large aggregations sometimes containing many thousands of animals; and (3) the haul out and feeding cycles that appear to be synchronous within large aggregations. Because only hauled out walruses are readily visible during surveys, the proportion of animals hauled out must be known to extrapolate survey results to a total population estimate. The effect of these factors is that population estimates based on aerial surveys are of unknown accuracy and are exceedingly imprecise. Because the estimate does not include a correction for walruses in the open water south of the pack ice and those in the water in the pack ice have a low probability of being sighted, an estimate resulting from aerial surveys underestimates actual population size.

Since 1975, there has been little progress in solving these problems. Studies of males at Round Island, Bristol Bay, Alaska, have shown that the haul out-feeding cycle is quite synchronized for the entire aggregation of males hauling out there (S. J. Taggart and C. Zabel, pers. comm.), but essentially nothing is known of the patterns of walrus use of ice floes for hauling out. Walruses utilizing ice in late summer-early autumn are predominantly females, calves, and immatures. Consequently, there was considerable discussion of the merits of carrying out the aerial survey scheduled for the fall of 1980, the second joint US and USSR survey. Although there were impressive arguments against doing the survey in 1980, the lack of alternative techniques to monitor population status and the increasing need to do so in the face of indications that suggested the population was approaching its maximum size, were sufficient to bring about a decision in the late summer of 1980 that the survey should be done as planned.

Realizing that a reliable point estimate of the total walrus population was impossible without additional knowledge of the haul out-feeding cycle, the primary objective of the survey was to develop an estimate of the lower limit to population size. Also, additional data for evaluating walrus population enumeration techniques would be obtained.

METHODS

The methods used in an aerial survey can be conveniently divided into three categories: the physical characteristics and constraints of the aircraft, the distribution of sampling effort or basic survey design, and data collection and analysis. The major details of the survey are listed in Table 2.

Flight characteristics:

There are few suitable aircraft available for the surveys. For this survey, a Conquest (Cessna 441) was finally selected (Fig. 1). The positive characteristics of the plane included: forward-looking radar with a display that showed the ice floes; a Global Navigation System (GNS-500); a wide range of flying speeds from about 120 to about 300 knots; twin turbine engines; de-icing equipment; pressurized cabin and a maximum flight altitude in excess of 30,000 ft; comfortable seating for observers and recorder; and a relatively low cabin noise level. However, the aircraft was less than ideal because the main observers had only limited forward visibility through the side windows and there was no photographic capability.

The 500-foot altitude and the 120-140 knots speed selected for the survey have been standard on most of the previous aerial surveys and both were satisfactory. If the base of the cloud layer was less than 200 feet, we stopped the survey, but otherwise flew at the altitude providing the best visibility between 200 and 500 feet. Most transects were flown at the 500-foot altitude.

Survey Design:

During late summer and fall walruses haul out on ice floes from east of Pt. Barrow west along the loose pack to the vicinity of Wrangle Island and the Chukchi Coast. An unknown proportion apparently go south of the ice to feed, but the number in the open water may be small (Estes and Gilbert 1978). We did not sample the open water south of the ice.

Our initial intent was to fly 1 or 2 days to locate the edge of the solid pack and the open water and to determine the area of the greatest density. Then the sample space was to be surveyed by locating transects so that 60% to 70% of the effort would be in the area of greatest density. Estes and Gilbert (1978) suggested that the optimum allocation of sampling effort was about 70% in the high density area. Because visibility was poor, after 4 days we had no basis for stratifying the area on the basis of walrus density. However, we had located the edge of the solid pack and open water. Since autumn storms are frequent and time was a significant constraint, we decided to survey the entire area from 153°00' W to 172°00' W longitude with systematically located north-south transects located every 30', or about 10 nm apart (Fig. 2). So far as possible, westernmost transects were completed first to minimize the possibility of recounting animals passively moving westward with the drifting ice. The north-south limits of the transects were to be solid pack and open water. No effort was assigned to open water because of the low probability of sighting walruses there and the 1975 survey indicated few walruses were in the open water south of the ice edge. After all transects were completed, if time permitted, some transects were to be replicated to measure daily variability. The sample space, or area for which an abundance estimate was to be developed, was the area enclosed by connecting the ends of the transects (Fig. 3).

Data Record and Analyses:

The longitude of each transect was predetermined with the eastern limit determined from results of preliminary flights and the southern limit of ice was approximately known. The daily procedure followed a general pattern. The first transect of a flight began by locating the southern limit of the ice, by use of radar or visually. When the aircraft was at the beginning of the transect, the time and location were recorded and the transect was flown. The north end of transect was approximately the southern limit of the solid pack. At both ends and periodically along the transect, time and location were recorded. At the end of a transect, the plane turned east or west and flew to the beginning of the next transect. Thus, in most instances, the direction of flight along transects alternated from south to north and north to south.

The survey crew included: an observer in the co-pilot position that observed ice conditions on the radar screen or visually, and gave the pilot and recorder location of transects and positions along transects; a recorder, two primary observers, and an alternate (Fig. 1). The primary observers were in the main cabin on each side of the plane looking through side windows. All marine mammals sighted were counted and reported to the recorder along with the perpendicular angle from the flight path. Inclinometers were used to determine the angles (Fig. 4). The recorder noted the time to the nearest 1/10 second, recorded the species, number in group, sight angle and time. The amount of ice cover was recorded periodically, or when it changed.

When walruses were in groups of more than about 20 or when numerous groups formed large aggregations, the numbers of walruses in groups were estimated in multiples of 5's or 10's. Also, when large aggregations were encountered, it became impossible to determine the sighting angle to each group from the aircraft. Therefore, under these conditions, groups of walruses were recorded as being within sectors A, B, or outside. Sectors A and B were the first and second quarter mile wide strips in view on each side of the aircraft (Fig. 4). It had been determined during previous surveys that walruses within a 1/2-mile strip on each side of the aircraft had about equal probability of being sighted (Kenyon 1972, Estes and Gilbert, 1978).

Scientists at the National Marine Fisheries Service, Marine Mammal Laboratory, Seattle, have made numerous aerial surveys in the recent past and have developed data record sheets and programs for data analyses. We used the same techniques of recording the data and they assisted with the analyses.

RESULTS

Data collected during the aerial survey were analyzed at the University of Washington Academic Computer Center. Output included figures and tables showing the distribution of marine mammals sighted and the number sighted. For walruses, the output included estimates of density and population along with associated variances. The number of sightings of marine mammals other than walruses was low (Table 3) and population estimates were not developed for these. The results of walrus sightings will be discussed first.

Distribution:

Knowledge of walrus geographic distribution is improving and the data suggest that there is a general westerly movement of the center of abundance through August and September. Three ship expeditions along or within the southern fringe of the late summer pack ice have indicated the presence of high concentrations of walruses.

From August 2 to September 1, 1973, the R/V Alpha Helix cruised within and along the ice fringe from Long Strait north of Chukchi Peninsula, eastward to Point Barrow. A daily marine mammal sighting log maintained during that traverse of northern Chukchi Sea showed low numbers of walruses ($\bar{x}$ = 3.88) sighted per day between 175° W and 165°15' W. The numbers sighted increased greatly between 164°30' eastward to 161° W, with daily counts being 153 animals on 28 August (noon position at 164°15'), 564 animals on 29 August (noon position at 162°25') and more than 700 animals on 30 August (exact counts not possible due to heavy seas at the water/ice interface, noon position 161°15'). On 31 August, walruses sighted decreased to nine (noon position 159°55') and remained low eastward to Point Barrow which was reached on 1 September (Burns, field notes).

Between August 1 and 6, 1977 the U.S. Coast Guard Icebreaker Glacier operated in and along the ice margin from the vicinity of Point Barrow (156°38' W) to 164° W. Again, walruses were highly clumped with several thousand being sighted between 158°30' W and 161°30' W. Few walruses were sighted east or west of these longitudes (Burns, field notes).

Another traverse of the ice fringe from Point Barrow westward to Herald Island was made between 4 and 15 August 1978, aboard the Soviet sealing/research vessel Zubarevo. Due to other tasks, no mammal sighting log was maintained. However, a general daily assessment of relative abundance was made (Burns, field notes). Walruses were common though not numerous between longitudes of 159° W and 161° W. They were abundant in the water and on the ice from 161°30' W to about 165° W; present but not numerous from 165°39' W to 172° W and few were sighted from 172° W to 175°32' (the farthest west position reached on the cruise).

During each of these three cruises, sightings were of those walruses in the ice fringe and north for 2 to 4 miles. Walruses well within the pack ice were not visible to shipboard observers.

The U.S. walrus survey conducted in 1975 provided information of walrus distribution. That survey effort (Estes and Gilbert, 1978) confirmed that high concentrations of walruses occurred near the ice margin of eastern Chukchi Sea with greatest abundance being between 162° and 165° W longitude. Further, it confirmed that in comparison to the large number of walruses sighted on the ice, relatively few were seen on transects south of the ice margin. Within the pack ice, walruses occurred in all categories of ice cover (8/8 being complete cover) though 98.6% were observed in the first 6 deciles of the transects, beginning at the ice margin to 74 km north of it. Of 3,777 walruses counted within strip transects over ice, 1,264 (34.5%) were in ice of coverage of 1/8 to 3/8 of the sea surface, 2,279 (60.3%) in 4/8 to 7/8 ice cover and 234 (6.2%) in 8/8 ice cover. Of a total of 3,869 walruses counted, both in open water immediately south of the pack ice and on the ice, only 88 (2.3%) were in that portion of transects south of the ice margin (Estes and Gilbert 1978 Table 1).

A well-known attribute of walruses is their uneven distribution. Not only do they occur in well defined groups of two to several hundred, with all animals essentially in contact within each group, but these groups form larger aggregations that on occasion contain several thousands and even tens of thousands of animals (Krogman et al. 1979). Our data show a similar pattern of distribution. During the 1980 survey, walruses were sighted from about 153°30' W to 172°30' W longitude, the western boundary of the sample space. The density of walruses ranged from 0 to 43.9 per nm^2 within the sample strips (Table 4). Transects between 166°30' W and 170°30' W longitude revealed aggregations of several thousands of animals sufficiently close to each other to allow visual and/or auditory contact among groups. Actually, 85% of the total walruses sighted within the sampling strips were in this area which contained about 18% of the total sample space. The average density within this 4,300 nm^2

area was about 19 walruses per nm^2 and the estimated total number was 84,398 (Table 5). During aerial surveys in 1975, walruses were most abundant from 162° W to 165° W longitude and Estes and Gilbert (1978) reported 1.43 per km^2 (4.9 per nm^2) in their high density area.

In addition to these longitudinal differences in density, the latitudinal distribution of walruses along the transects was not uniform. The pattern was somewhat different from that observed in 1975. In 1975, the sightings increased to the maximum level in the second decile of transects beginning at the edge of open water. The numbers then decreased gradually to about the center of the transects, with few walruses sighted in the northern half of the transects. In 1980, walruses also were not distributed uniformly along the transects ($P < 0.01$-chi square). The number of walruses in the 1st, 2nd and 10th deciles from the ice edge were less than expected and approximately equal numbers were sighted in the north and south halves of the transects (Fig. 5). There was no clear longitudinal change in this pattern. However, where the ice edge was close to shore, there was a high density of walruses at the very southern edge of the ice.

Sightings along adjacent transects support the conclusion that walruses generally occur in large aggregations. Frequently, where walruses were sighted along a transect, walruses were sighted at about the same latitude on adjacent transects (Figs. 5 and 6). Distribution and relative size of these aggregations are shown in Figure 6.

Even though walruses show extreme clustering of groups, no really large groups were sighted (Table 6). The largest group contained about 450 walruses and only 35 groups larger than 100 were seen. Estes and Gilbert (1978) also saw few large groups. The lack of large groups, although consistent with other observations in September, is surprising in view of the gregarious habits of walruses and the high density of small groups in some areas.

Sightability:

Kenyon (1972) concluded from his aerial surveys that walruses hauled out on ice within 1/2-mile strips on each side of the midline of transect had a near 100% probability of being seen. Estes and Gilbert (1978) also limited their record of observations to walruses within the 1/2-mile strips on each side of the midline and found equal probability of sighting within the strip. We recorded all walruses sighted and for most sightings recorded the perpendicular angle to calculate the distance of walruses from the flight path. We calculated the frequency of sightings by groups and numbers of walruses for each 1/8-nm strip (Tables 6, 7 and 8). From these data, it is clear that the number of walruses sighted drops off rapidly beyond 1/2 nm. Also, group size and number of walruses sighted in the first four 1/8-nm strips (= 1/2-nm sample strips) differed significantly ($p < 0.05$-chi square), i.e., the number of individual walruses and group size increased with increased distance from the flight path in this 1/2-nm strip. Few single walruses were sighted beyond 1/4 nm. The forward observer and pilot observed that walruses near the transect line sometimes entered the water when the plane was nearly overhead. Apparently, groups that had entered the water were unnoticed by the primary observers in the main cabin and this is the likely reason for the lower numbers of groups sighted in the first three 1/8-nm strips compared to the fourth 1/8-nm strip. Even though observers apparently missed walruses near the flight path, it is clear from the data in Tables 6 and 7 that groups of all sizes had a lower probability of being sighted beyond 1/2 nm.

Daily Variation:

Even though we were unable to replicate transects to determine daily variation, we did get a hint of the variability that exists among days. On 10 September, we flew an irregular transect in the area east of Barrow (Fig. 7). During approximately 280 nm of transect flown, we sighted 1,833 walruses with numerous sightings in the area bounded by 71°35' N--71°50' N and 154°15' W--155°15' W. On 11 September, we flew a series of transects located parallel to the edge of open water in the same area (Fig. 8) and only 88 walruses were sighted on transects totaling 440 nm even though two transects intersected the high density areas of 10 September. In fact, the transect which intersects the other transects (Fig. 8) was the last one flown on 11 September and intentionally passed through the highest density areas of 10 September. Also, on 20 September, this area was surveyed by flying systematic north-south transects covering 380 nm and only 26 walruses were sighted. Additional data showing the great variability among days was obtained from a transect located at

$164^{\circ}30'$ W. On 16 September, the north end of this transect was flown, but poor visibility and a low ceiling disrupted the flight after 28 nm. On this section, 1,767 walruses were sighted, 308 of these within the 1-mile-wide sample strip. On 18 September, the entire transect, 81.4 nm long, was flown and 117 walruses were seen, 115 of these within the sample strip. It is clear from these data and other sources (Kenyon 1972, Estes and Gilbert 1978, Wartzok and Ray 1980) that the proportion of walruses visible varies greatly from day to day. We suspect this is because the number of walruses hauled out on the ice varies greatly. It is unlikely that normal daily movement to other ice flows or movement of the ice would have been sufficient to explain the great differences in these counts, especially those in the area east of Pt. Barrow on 10 and 11 September.

It is hypothesized that the underlying reason causing this variability is the more or less synchronous hauling out-feeding cycles of aggregations. For example, the approximately 15,000 male walruses hauling out on Round Island during the summer and early fall have a predictable haul-out cycle that results in counts as low as a few hundred and highs of about 12,000 with approximately 10 days between high counts (S. J. Taggart and C. Zabel, pers. comm.). During the high counts of the cycle, 80% or more of the marked individuals were present, suggesting that at times most of the animals using the area for hauling out were hauled out. Observations of the activity of walruses hauling out on ice floes also suggest a synchronous pattern and further, that the length of the cycle on ice is probably about 40 hours (Wartzok and Ray 1980), but this estimate is based on very limited data and apparently the time is quite variable.

Estimates of Abundance:

Problems associated with estimating abundance from aerial survey data were discussed at length by Estes and Gilbert (1978). The unknown and so far unpredictable proportion of the walruses hauled out on ice, and thus readily visible, creates the greatest difficulty when attempting to estimate abundance. It is known that this proportion varies substantially with time, as discussed in the previous section.

Methods used to estimate abundance were described by Estes and Gilbert (1978). They used two methods: first, a ratio estimator to estimate density per unit area which was then expanded to the total sample space (Method 1); and second, a method using the number of walruses on a transect, the transect being a sampling unit. The average number sighted per transect was expanded by the total number of transects possible within the sample space (Method 2). For each method two estimates were developed, one using the counts of individuals to estimate density, and the second using mean group size and the number of groups. The estimates resulting from both methods were identical but had different variances.

We used these same methods for developing estimates from our data. The equations are in Table 9. The point estimates of abundance, estimated standard deviations and coefficients of variations (COV) are given in Table 10. Because of the difference in sightability of walruses in sectors A and B, estimates were developed for each sector and for the pooled data.

Method 2, using transects as the sampling unit, is appropriate only if the number of walruses sighted on a transect and the area (length) of the transect are independent. There was a slight negative correlation in our data but the correlation was weak ($r = 0.257$; $P = 0.11$). This negative relationship was caused primarily by a few long transects at the western end of the sample space within which walrus density was low. Ice was widely scattered at the southern edge of this area and there were few walruses. We do not think that the length of north-south transects and the number of walruses sighted are dependent.

It should be noted that the estimates are not of the total number of walruses east of longitude 172°30' W, but are of the number of walruses visible under the conditions of the survey and there is no correction for walruses not sighted. The coefficients of variation of our estimates were somewhat less than those of Estes and Gilbert (1978). Because of our sampling design, it is not appropriate to develop estimates from the data collected each day since they are generally area specific.

A primary objective of the survey was to obtain data to make a minimum estimate of the total number of walruses east of 172°30' W longitude. To obtain this estimate, we took the estimate based on sectors A and B combined (101,213) (Table 10) and added to it the estimated 15,000 male walruses in the eastern Bering Sea, using Round Island (Bristol Bay) as a haul-out area (S. J. Taggart and C. Zabel, pers. comm.) giving a total minimum estimate of approximately 115,000.

It seems appropriate to point out what we consider to be the best estimate from the data. To obtain this estimate, we assumed that the higher density observed in sector B is an appropriate estimate for the probable density. This gave an estimate for the sample space of 125,858 (Table 10). Adding the estimated 15,000 males from Bristol Bay gives an estimate of about 140,000 walruses east of 172°30' W.

We have no means to correct the estimates for bias. The various sources of bias all tend to increase the magnitude of the underestimate. Estes and Gilbert (1978) flew some transects over water south of the ice edge and saw some walruses. We did not fly transects over water and therefore did not include the area of open water in our sample space. Also, it appears that even in sector B the probability of sighting is less than 1, thus reducing our estimate. When these known sources of bias are added to that resulting from the unknown proportion of walruses in the water and not visible, the potential underestimate may be large.

Scientists from the USSR surveyed the Pacific walrus population in the area west of 172°30' W longitude at approximately the same time as our survey. We do not have a report of their results but were informed (Dr. Fedoseev, pers. comm.) that they estimated 130,000 to 150,000 Pacific walruses in their survey area. Assuming that their estimate is reasonable and adding our "best" estimate, we conclude that the Pacific walrus population is no less than 250,000 and perhaps near 300,000.

Other Marine Mammal Sightings:

Generally, the observations of marine mammals other than walruses were too infrequent to provide significant new biological information. At the elevation flown, 500 ft, probably the only species that could be detected with high reliability were belukha whales near the flight path. A large concentration of belukhas was observed on 11 September near the edge of the solid pack (the very northern portion of the survey area) north and east of Pt. Barrow. Eleven polar bears were sighted. Several of these were at or in the vicinity of unidentifiable carcasses that were partially eaten.

DISCUSSION

Joint US-USSR aerial surveys of walruses were made in September of 1975 and 1980. The primary objectives of these surveys were to determine walrus distribution along the edge of the ice pack, to estimate walrus abundance, and to evaluate aerial surveys as a means of determining walrus abundance. Survey results are adequate to show distribution but it is obvious that two factors, the extremely clustered distribution of walruses and the unpredictable and seemingly highly variable proportion of walruses visible, make it impossible to develop accurate population estimates. Both of these factors contribute to the lack of precision in survey results and the second factor results in an underestimate of abundance. Our knowledge of walrus haul-out activity, though meager, leads us to conclude that in the near future, it is unlikely that we will be able to accurately predict the proportion of walruses visible and therefore counted during a survey. To do so will require a much better understanding of this activity than seems possible at this time. Assuming that this is correct, aerial surveys cannot be used to develop reliable point estimates of abundance. However, they may provide a usable index of population size. Knowing the approximate duration of the haul out-feeding cycle and determining if areas with observed low density are in fact low density areas is essential to further the evaluation of aerial surveys.

Causes of variability in density estimates needs to be considered in greater detail. There are at least three factors that contribute to variability in density: the gregarious habits causing the clumped distribution (a species characteristic); the spatial distribution of aggregations, probably related to availability of food; and the daily or periodic changes in the proportion of walruses hauled out on ice and therefore visible, probably the result of synchronous haul out feeding cycles.

Even though there is little reason to be optimistic that aerial survey results can be made more precise, with the appropriate design and sufficient survey flight time, the results may be adequate for management purposes. Since aerial surveys appear to be the only direct method of monitoring walrus population size, it cannot be discarded without a thorough evaluation.

The major techniques for overcoming the lack of precision caused by high variance are stratification and increased sampling effort. If we assume that the data from 1975 and 1980 correctly reflect walrus distribution, it is clear that in a given year a major portion, 75% or more, of the walrus population east of 173° W longitude will be found in 25% or less of the total area. In 1975, walruses were most abundant from 162° - 165° W and in 1980 from 166°30' W to 170°30 W. Thus, it appears that during September in any given year, the area from about 162° W to about 171° W is where walruses will be most abundant. This area is about half of the area along the ice east of 173° W. This suggests that the sample space can be stratified prior to beginning a survey and it may be possible to stratify further during the survey. Stratifying the sampling space is an effective means of increasing efficiency of sampling effort. However, it is necessary to determine if the low density of walruses east of 162° W accurately reflects a real condition and not merely an artifact of sampling variability.

Several conditions indicate an increasing need to know the trend of the walrus population. The harvest by Alaskan natives has nearly doubled since 1978 and is likely to continue to increase. The USSR has increased their quota for walruses from 2,000 to 5,000. Oil and gas development within the breeding and calving range of walruses is expected within 5 years. A commercial clam fishery in Bristol Bay may begin in the future. Also, there is speculation that the walrus population may be near its maximum level which, when it is reached, will result in at least a temporary reduction of sustainable yield.

The need to monitor the walrus population is obvious and, presently, there is no method to substitute for aerial surveys. Information such as body condition, reproduction rates, and feeding habits can be obtained from harvested walruses. However, such data cannot be easily interpreted, even if it can be measured with precision. For example, the walrus population can decline yet none of these characteristics would necessarily change. It is likely that they change only at "high" population levels. If the characteristics do change, it can be concluded that production or survival have increased or decreased. However, it would not be clear that sustainable yield had changed, or what management action to take without knowing the population trend. When these factors are considered, along with the lack of an alternative method to monitor population trends, it appears likely that aerial surveys will be continued even though they are imprecise. Resource managers will probably have to be content with direct methods of enumeration that can detect population changes of only 25, or possibly 50% and with a reliability of less than 95% confidence. The actual accuracy with which aerial surveys can detect population change cannot be predicted until we have a better understanding of factors causing variability, particularly those related to the haul out-feeding cycle.

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Table 1--Summary of Estimates of the Size of the Pacific Walrus Population, Derived from Aerial Surveys, 1960 to 1980

	Walruses (thousands)		
Date	Counted	Estimate	Source
February-March 1960	3.9	78 - 119	Kenyon (1960)
April 1960	3.3	73 - 110	Kenyon (1960)
March 1961	4.9	73 - 110	Kenyon (unpublished)
April 1968	8.7	73 - 110	Kenyon (unpublished)
April 1972	9.3	85 - 162	Kenyon (1972)
September-October 1975	UNK	140 - 200	J. A. Estes and N. V. Gol'tsev (unpublished data)
September 1980	27.3	270 - 290	This study

Table 2--Major Details of 1980 Aerial Survey of Walruses

Time Span: 10-23 September 1980 (systematic transects 15-20 September)

Aircraft: Cessna 441 (Conquest)

Base of Operations: Naval Arctic Research Laboratory, Barrow, AK

Survey Team:

Anchorage Regional Office, USFWS:

1. Robert Jones
2. Scott Schliebe
3. Mindy Rowse
4. Timothy Smith

Denver Wildlife Research Center, USFWS:

1. Ancel Johnson
2. William Dusenberry

Alaska Dept. of Fish & Game:

1. John Burns, Research, Fairbanks; (also Chairman, U.S. Planning & Steering Com., Joint US/USSR Agreement on Environmental Protection)

Anchorage Airways:

1. Walt Remele, Pilot.

Flight Characteristics:

1. Maximum duration of a flight--5 hours

2. Altitude--30,000 to 33,000 ft to and from transects; 500 ft on transects

3. Flight speed--about 300 kn to and from transects; 120 to 140 kn on transects

Survey Results:

Dates of transect flights--15, 16, 18, 19, and 20 September, 1980 (Reconnaisance flights on 10 and 11 September)

Total length of all transects--2,462.2 nautical miles (41 transects)

Total walruses sighted--24,096 (an additional 3,206 walruses were sighted during reconnaisance flights or while going to or from transects)

Total walruses within 1 mile sample strip--10,522

Total area in sample space--23,685 square nautical miles

Table 3--Numbers of Each Species of Marine Mammal Sighted During Walrus Survey, September 1980

Species	Date 10	11	15	16	18	19	20	Totals
Walrus	1,833	88	16,826	6,399	1,035	1,095	26	27,302
Polar Bear	1	2	2	3	3	0	0	11
Bearded Seal	1	0	1	2	10	1	0	15
Ringed Seal	3	0	3	4	56	4	0	70
Bowhead Whale	1	0	0	0	2	0	6	9
Belukha	11	124[a]	131	1	9	0	49	325
Total	1,850	214	16,963	6,409	1,115	1,100	81	27,732

[a] Saw a large number of belukhas (in the thousands) on this day but data was not recorded on a regular transect so is not included in computer summarizations.

Table 4—Summary of Walrus Sightings on Transects 1980 Walrus Survey

	Date surv.	Sector A No. walrus	Sector A No. groups	Sector B No. walrus	Sector B No. groups	Sectors A + B No. walrus	Sectors A + B No. groups	Outside A & B No. walrus	Outside A & B No, groups	Totals No. walrus	Totals No. groups	Length of trans. (nm) •	Dir. flown	Starting pos. Lat. (N)	Starting pos. Long. (W)	Ending pos. Lat. (N)	Ending pos. Long. (W)	Start time	End time	Dens Sec. A+B
st end)																				
	20	0	0	0	0	0	0	0	0	0	0	61.4	N	71°10'	153°03'	72°01'	152°60'	1433	1456	0
	20	0	0	0	0	0	0	0	0	0	0	50.1	S	72°01'	153°31'	71°11	153°31'	1403	1427	0
	20	0	0	0	0	0	0	25	0	25	1	44.2	N	71°16'	154°00'	72°00'	154°00'	1339	1358	0
	20	1	1	0	0	1	1	0	0	1	1	69.2	N	71°12'	154°30'	72°11'	154°31'	1046	1105	.02
	20	0	0	0	0	0	0	0	0	0	0	54.4	S	72°14'	155°02'	71°39'	155°03'	1018	1039	0
	20	0	0	0	0	0	0	0	0	0	0	29.7	N	71°44'	155°29	72°14'	155°30'	958	1012	0
	20	0	0	0	0	0	0	0	0	0	0	41.8	S	72°26'	156°01'	71°44'	156°00	929	953	0
	20	0	0	0	0	0	0	0	0	0	0	61.1	N	71°36'	156°29'	72°27'	156°30	850	925	0
	19	1	1	1	1	2	2	125	6	127	8	64.1	S	72°20'	156°57'	71°26'	157°00'	1608	1633	.04
	19	13	2	8	3	21	5	50	7	71	12	63.2	N	71°17'	157°31'	72°20'	157°29'	1532	1603	.33
	19.	18	3	48	6	66	9	310	16	376	25	69.3	S	72°22'	158°02'	71°13'	158°00'	1455	1527	.95
	19	220	5	173	8	393	13	1	1	394	14	72.2	N	71°09'	158°31'	72°22'	158°30'	1415	1450	5.44
	18	19	8	11	3	30	11	60	2	90	13	49.8	S	71°65'	159°00'	71°05'	159°02'	1909	1932	.60
	18	4	2	203	13	207	15	0	0	207	15	53.3	N	71°02'	159°32'	71°66'	159°30'	1836	1904	3.88
	18	0	0	0	0	0	0	0	0	0	0	46.1	S	71°62'	160°01'	71°06'	160°02'	1810	1831	0
	18	1	1	21	4	22	5	19	7	41	12	46.8	N	71°05'	160°30'	71°51'	160°30'	1743	1806	.47
	18	3	1	38	6	41	7	22	2	63	9	70.4	S	72°15'	161°01'	71°04'	161°01'	1701	1736	.58
	16	0	0	1	1	1	1	1	1	2	2	68.8	S	72°08'	161°32'	71°09'	161°29	1803	1831	.02
	16	1	1	0	0	1	1	745	28	746	29	65.0	N	71°01'	162°02'	72°06'	161°59'	1733	1759	.02
	18	5	2	6	4	11	6	10	4	21	10	67.6	N	71°06'	162°30'	72°14'	162°31'	1613	1648	.16
	18	96	11	12	4	108	15	16	6	124	20	83.3	S	72°35	163°02'	71°12'	163°00'	1347	1424	1.30
	18	9	5	1	1	10	6	211	9	221	15	69.0	N	71°14'	163°32'	72°23'	163°29	1304	1338	.15
	18	76	21	18	6	94	27	52	7	146	34	87.0	S	72°42'	164°00'	71°15'	164°00'	1220	1259	1.08
a	18	91	18	24	11	115	29	2	1	117	30	81.4	N	71°19'	164°30'	72°40'	164°31'	1135	1215	1.41
a	16	0	0	308	19	308	19	1,459	29	1,767	48	28.2	S	72°46'	164°29	72°18'	164°31'	1642	1566	10.92
	16	139	17	0	0	139	17	610	15	749	32	96.8	N	71°12'	165°05'	72°49'	164°56'	1555	1637	1.44
	16	32	12	104	13	136	25	98	6	234	31	82.9	S	72°47'	165°30'	71°24'	165°30'	1207	1249	1.64
	16	19	6	3	1	22	7	281	10	303	17	73.4	N	71°38'	165°59'	72°52'	165°59'	1138	1201	.30
	16	87	13	383	27	470	40	685	13	1,155	53	47.2	S	73°00'	166°31'	72°13'	166°32'	1043	1107	9.96
	16	224	19	355	8	579	27	434	20	1,013	47	50.2	N	72°10'	167°00'	73°00'	166°57'	1019	1039	11.53
	15	399	29	1,639	41	2,038	70	1,249	47	3,287	117	46.4	S	72°59'	167°29'	72°13'	167°30'	1226	1250	13.92
	15	257	14	10	1	267	16	951	32	1,218	48	48.6	N	72°08'	168°01'	72°57'	167°59'	1200	1223	5.49
	15	116	11	531	20	647	31	1,061	29	1,708	60	46.2	S	72°59'	168°32'	72°13'	168°30'	1119	1145	14.00
	15	322	13	1,053	43	1,375	56	614	24	1,989	80	40.7	N	72°19'	169°00'	73°00'	168°58'	1053	1115	33.78
	15	0	0	553	20	553	20	1,503	39	2,056	59	46.3	N	72°10'	169°39'	72°56'	169°29'	1612	1633	11.95
	15	1,372	37	684	36	1,956	73	1,604	65	3,640	128	63.6	S	72°55'	170°00'	72°02'	169°59'	1638	1705	36.56
	15	451	20	300	15	751	35	1,082	44	1,833	79	61.3	N	71°32	170°31'	72°34'	170°31'	1724	1753	12.25
	15	1	1	145	11	146	12	99	13	245	25	88.9	S	72°34'	171°01'	71°05'	171°00'	1757	1841	1.64
	19	2	1	8	4	10	5	5	2	15	7	90.6	N	71°04'	171°32'	72°34'	171°31'	940	1010	.11
	19	1	1	1	1	2	2	80	6	82	8	73.8	S	72°35'	171°59'	71°21'	172°01'	1034	1109	.03
	19	0	0	0	0	0	0	30	2	30	2	67.9	N	71°23'	172°32'	72°31'	172°30'	1114	1147	0
west end)																				
Totals		3,900	276	6,642	332	10,522	608	13,574	483	24,096	1,09[illegible]	2,462.2						19.35 h (28.3 min av)		

Table 5--Estimated Number of Walruses Visible in High Density Area ($166^{\circ}30'$ W - $170^{\circ}30'$ W)[a]

	Method 1 (Individuals)			
	Density	Std Error	Estimated No. Walruses	Std Error
Sector A	14.66	5.18	63,094	21715.6
Sector B	24.56	7.14	105,703	29933.1
Sector A + B	19.61	4.64	84,398	18917.2

[a] Nine transects were flown within this area on 15 and 16 September 1980, and provide the data base for these calculations.

Table 6--Walrus Sightings by Group Size and Distance from Flight Path

	Distance From Aircraft - NM						
	<1/4	1/4	1/2	3/4	>1	Total	Total
Group size		1/2	3/4	1		groups	walruses
1	67	28	12	4	4	115	115
2-5	102	138	22	29	62	353	1,139
6-10	19	31	11	15	43	119	1,041
11-25	55	59	22	38	74	248	4,804
26-50	17	49	24	20	46	156	6,035
51-100	13	15	15	4	18	65	4,775
100+	3	12	5	4	11	35	6.187
						1,091	24,096

Table 7--Walrus Sightings by Distance from Flight Path, with Those Assigned to Sectors A or B Deleted

Strip number[a]	Number groups	Number walruses	Mean group size
1	115	897	7.8
2	124	2,145	17.3
3	144	2,463	17.1
4	157	3,533	22.5
5	46	1,000	21.7
6	55	2,030	36.9
7	94	2,170	23.1
8	20	632	31.6
9	82	2,205	26.9
10	10	317	31.7
11	10	150	15.0
12	29	611	21.1
13	11	171	15.5
15	22	402	18.3
17	4	100	25.0
19	58	1,699	29.3
26	4	110	27.5
30	3	45	15.0
Totals	988	20,681	20.9

[a] Strip = distance from "0" in 1/8 mile increments. For example, strip 1 is 0 - 1/8 mile on either side of plane, strip 2 is 1/8 - 2/8 mile on either side, etc. Sector A = strips 1 + 2; Sector B = strips 3 + 4.

Table 8--Sightings of Walrus Groups with Increasing Distance from Flight Line

Strip number[a]	Number of groups	Percent of total gps.	Accumulated percent of total groups	Number of individuals	Avg. number per group
1	115	10.5	10.5		
Sector A	276	25.3			
2	161	14.8	25.3	3,980	14.42
3	144	13.2	38.5		
Sector B	332	30.4			
4	188	17.2	55.7	6,542	19.70
5	46	4.2	59.9		
6	65	6.0	65.9		
7	94	8.6	74.5		
8	20	1.8	76.3		
9	82	7.5	83.8		
10	10	0.9	84.7		
11	10	0.9	85.6		
12	29	2.7	88.3		
13	11	1.0	89.3		
15	22	2.0	91.3		
17	4	0.4	91.7		
19	58	5.3	97.0		
26	4	0.4	97.4		
30	3	0.3	97.7		
33	25	2.3	100.0		
Overall totals	1,091	100.0%		24,096	22.09
A & B totals	608	55.7%		10,522	17.31

[a] Strip = distance from "0" in 1/8 mile increments. For example, strip 1 is 0 - 1/8 mile on either side of plane, strip 2 is 1/8 - 2/8 mile on either side, etc. Sector A = strips 1 + 2; Sector B = strips 3 + 4.

Table 9. Estimators Used in Data Analysis, 1980 Walrus Survey.

Statistic	Estimator
Method I (Individuals	
Density (R)	$\hat{R} = \Sigma y_i / \Sigma x_i$
Variance (R)	$s_{\hat{R}}^2 = [\Sigma(y_i^2/x_i) - \hat{R}\Sigma y_i]/(n-1)(\Sigma x_i)$
Abundance (Ty)	$\hat{T}_y = A\hat{R}$
Variance (Ty)	$V(\hat{T}_y) = A\ (A - \Sigma x_i)\ s_{\hat{R}}^2$
Method I (Groups)	
Density of Groups (G)	$\hat{G} = \Sigma g_i / \Sigma x_i$
Variance (G)	$s_{\hat{G}}^2 = [\Sigma(g_i^2/x_i) - \hat{G}\ \Sigma g_i]/(n-1)(\Sigma x_i)$
Mean Group Size ($\bar{G}$)	$\bar{G} = \Sigma y_i / \Sigma g_i$
Variance ($\bar{G}$)	$s_{\bar{G}}^2 = [\Sigma(y_i^2/g_i) - \bar{G}\ \Sigma\ y_i]/(n-1)(\Sigma g_i)$
Total Number of Groups (T_G)	$\hat{T}_G = A\hat{G}$
Variance ($\hat{T}_G$)	$V(\hat{T}_G) = A\ (A - \Sigma x_i)\ s_{\hat{G}}^2$
Abundance (T_y)	$\hat{T}_y = \hat{T}_G\ \bar{G}$
Variance (T_y)	$V(\hat{T}_y) = \bar{G}^2 V(\hat{T}_G) + \hat{T}_G^{\ 2}\ V(\bar{G}) + V(\hat{T}_G)V(\bar{G})$
Method II (Individuals)	
Mean Number per Transect ($\bar{y}$)	$\bar{y} = \Sigma y_i / n$
Variance ($\bar{y}$)	$s_{\bar{y}}^2 = [\Sigma y_i^2 - (\Sigma y_i)^2/n]/(n-1)n$
Abundance T_y	$\hat{T}_y = N\bar{y}$
Variance T_y	$V(\hat{T}_y) = N(N - n)s_{\bar{y}}^2$

Table 9 (continued)

Statistic	Estimator
Method II (Groups)	
Mean Number of Groups per Transect	$\bar{g} = \Sigma g_i / n$
Variance $\bar{g}$	$s_{\bar{g}}^2 = [\Sigma g_i^2 - (\Sigma g_i)^2/n] / (n-1)(n)$
Total Number of Groups	$\hat{T}_G = N\bar{g}$
Variance T_G	$V(\hat{T}_G) = N(N - n)\, s_{\bar{g}}^2$
Abundance Ty	$\hat{T}_y = \hat{T}_G\, \bar{G}$
Variance Ty	$V(\hat{T}_y) = \bar{G}^2 V(\hat{T}_G) + \hat{T}_G^2 V(\bar{G}) + V(\hat{T}_G) V(\bar{G})$

where: y_i = number of walruses sighted within 1 nm strip on ith transect;

x_i = length (area) of ith transect;

g_i = number of groups of walruses sighted within 1 nm strip on ith transect

A = Total sample space

n = Number of transects flown, and

N = Total number of sample strips with 100% sampling.

Table 10--Estimates[a] of Numbers of Walruses Visible During Fall Survey, 1980

Method I--Individuals[b]:

	Density	Std. error	Estimated no. walruses visible	Std. error	COV[c]
Sector A	3.233	1.307	76,569	30133	0.39
Sector B	5.314	2.004	125,858	46224	0.36
Sector A + B	4.273	1.452	101,213	32558	0.32

Method I—Groups:

	Estimate	Std. error	COV
Mean group size	17.306	1.335	
Mean density of groups	0.247	0.055	
Total No. of groups	5848	1228	
No. walruses visible	101218	22584	0.22

Method II[d]—Individuals:

	Transect mean	Std. error	Estimated No. walruses visible	Std. error	COV
Sector A + B	256.6	486.81	96,238	26906	0.28

Method II--Groups:

	Estimate	Std. error	COV
Mean group size	17.306	1.335	
Mean No. group per transect	14.829	18.4295	
Total No. groups	5561	1018.614	
No. walruses visible	96238	19,175.874	0.20

[a] Methods of estimating described by Estes and Gilbert (1978).

[b] Total sample space equals 23,685 square nautical miles.

[c] COV = coefficient of variation.

[d] Total number of transects to completely cover sample space is 375.

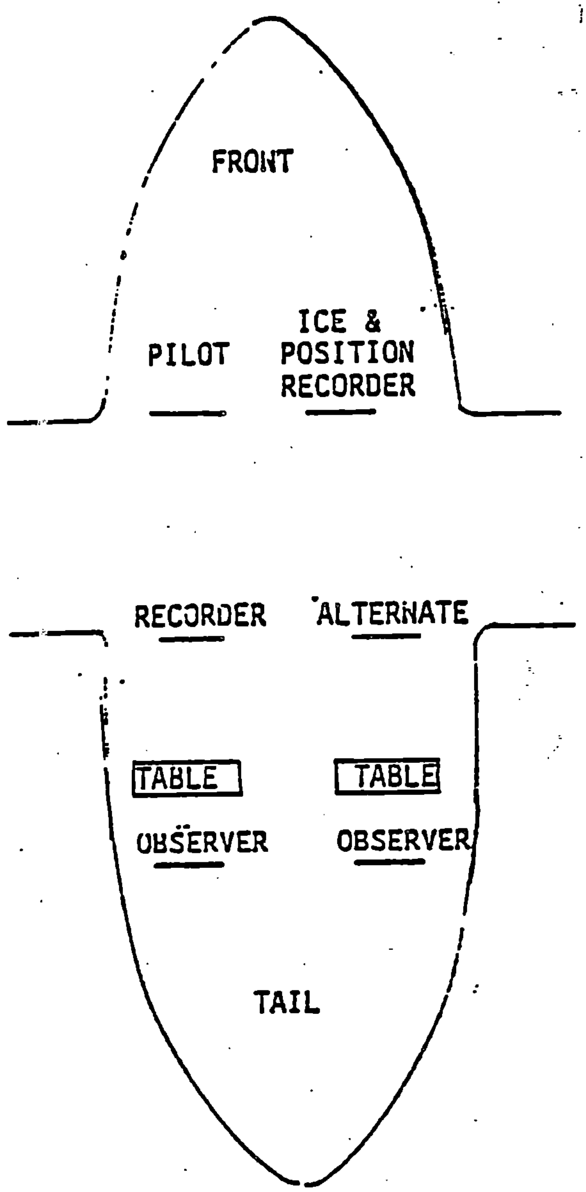


FIGURE 1. OBSERVER POSITIONS IN AIRCRAFT
WALRUS SURVEY 1980

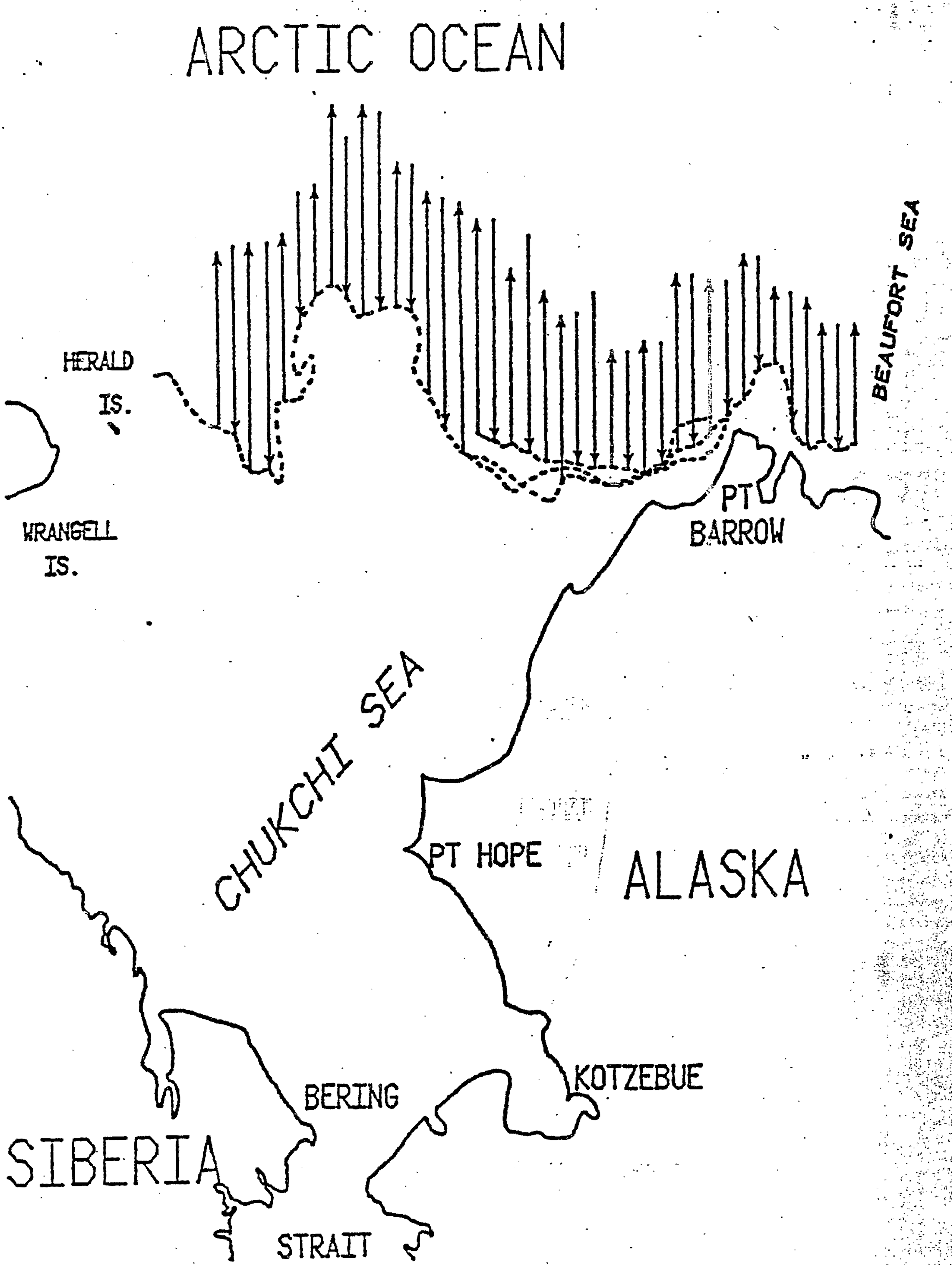


FIGURE 2. LOCATION OF TRANSECTS AND THE DIRECTION FLOWN, DURING 1980 WALRUS SURVEY

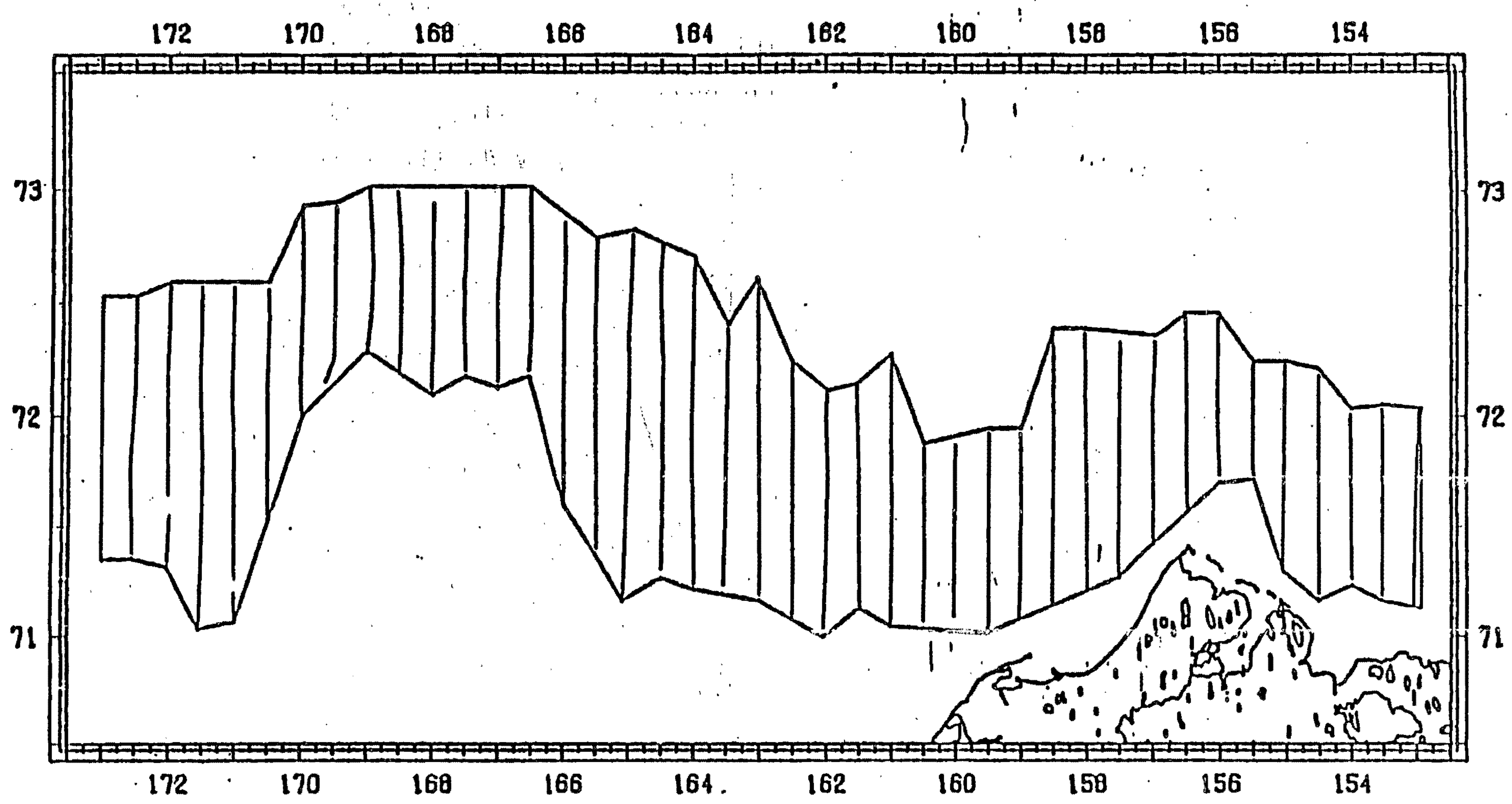
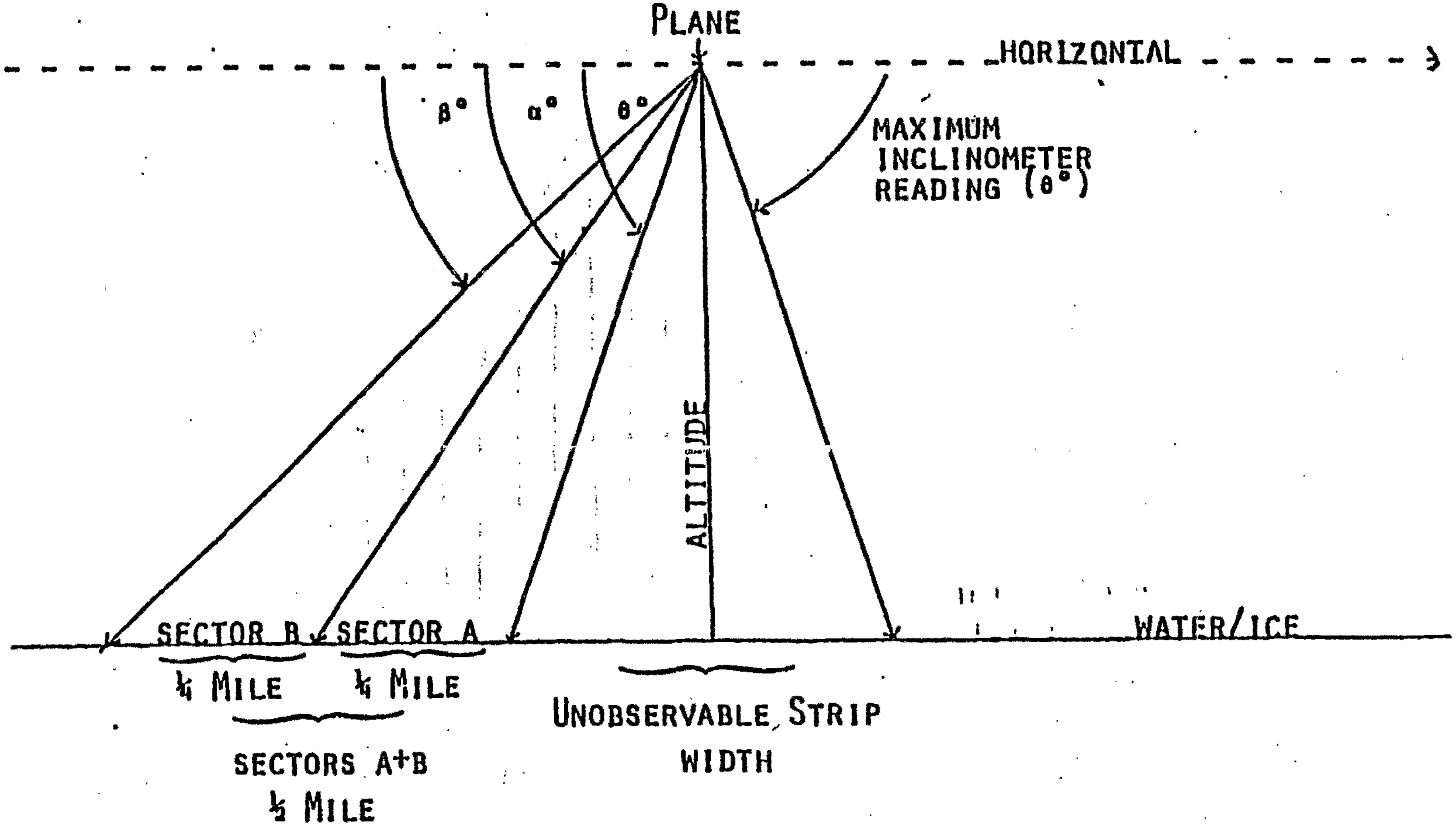


FIGURE 3. THE SAMPLE SPACE FOR THE 1980 WALRUS SURVEY.

FIGURE 4. GEOMETRY OF THE SIGHTING ANGLES AND SAMPLING SECTORS.



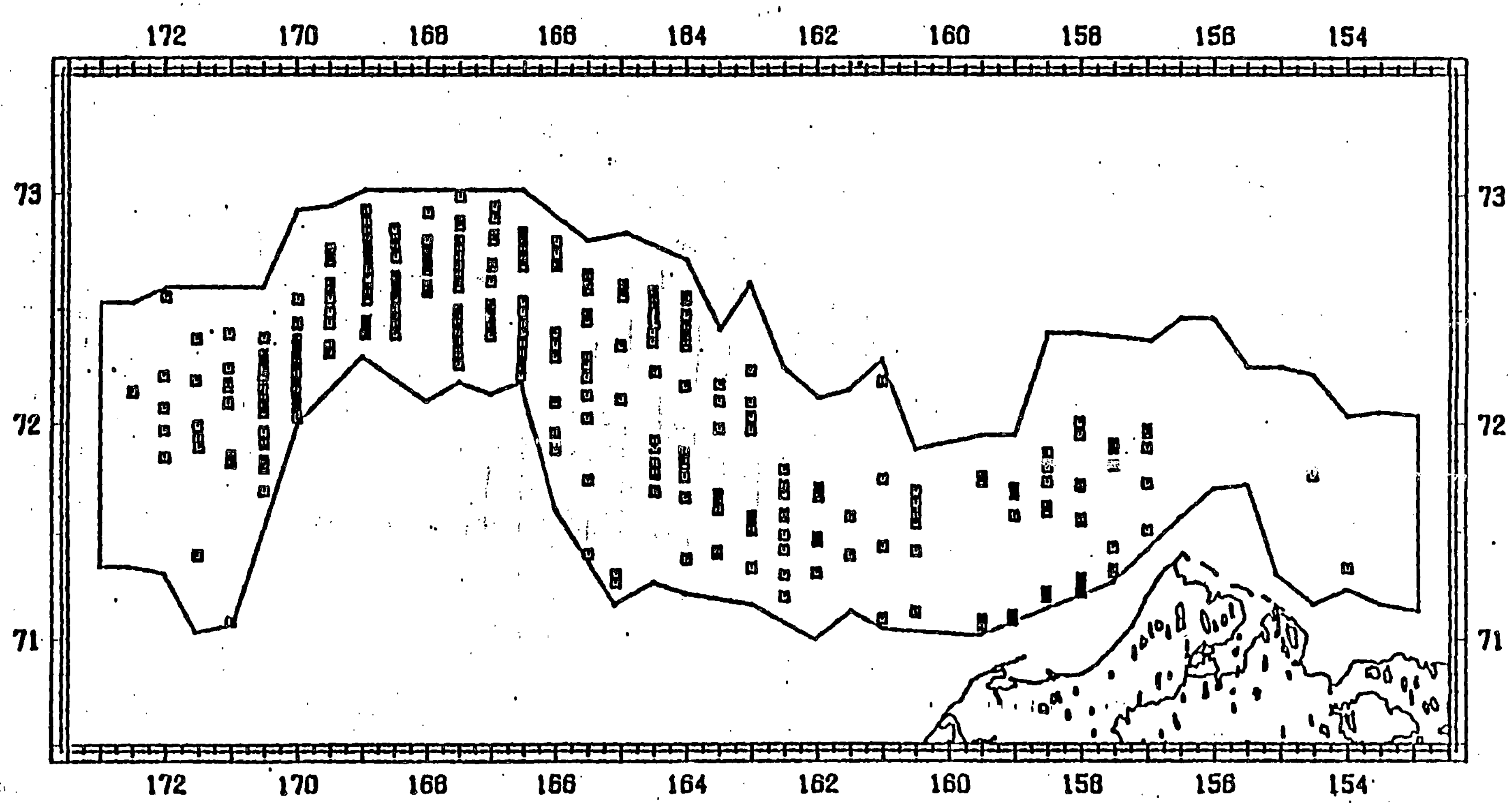


FIGURE 5. LOCATIONS WHERE WALRUSES WERE SIGHTED DURING AERIAL SURVEY, 15-20 SEPTEMBER 1980.

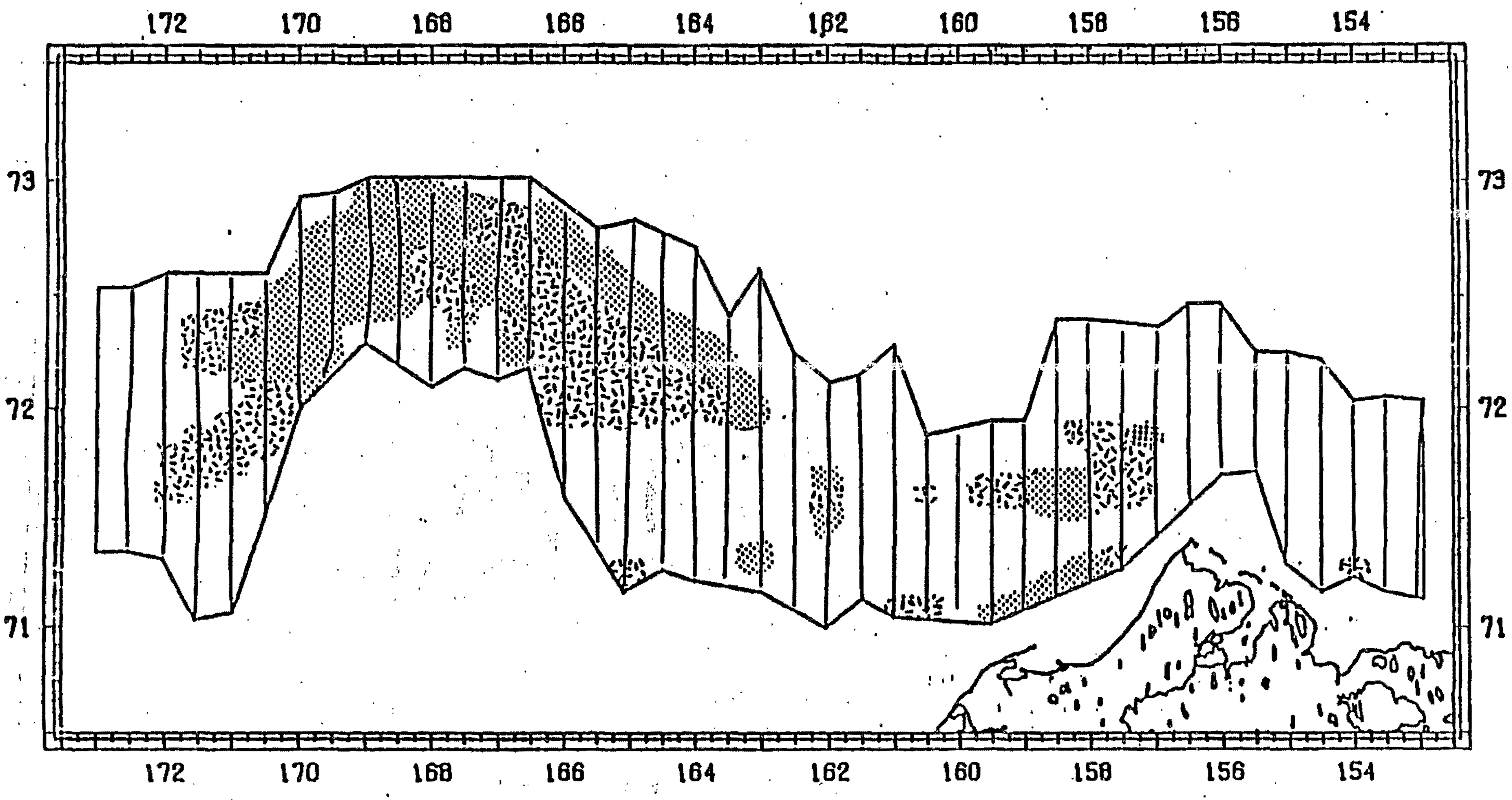


FIGURE 6. APPROXIMATE LIMITS OF WALRUS AGGREGATIONS WITH DENSITY 1-10 per nm^2 (lines) and $\geq$ 10 per nm^2 (dots) 15-20 SEPTEMBER 1980.

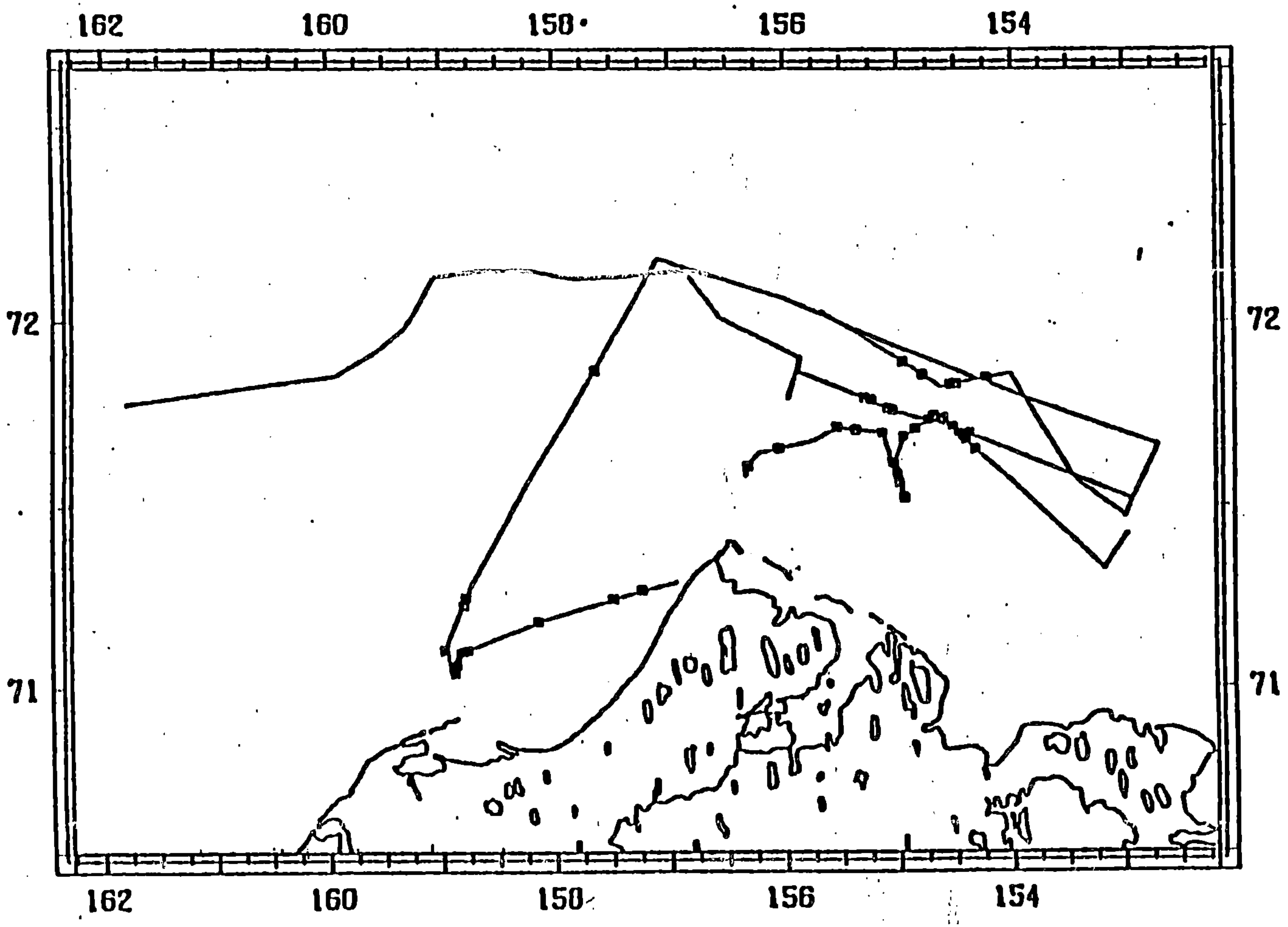


FIGURE 7. TRANSECTS FLOWN AND AREAS WHERE WALRUSES WERE SIGHTED EAST OF PT. BARROW 10 SEPTEMBER 1980.

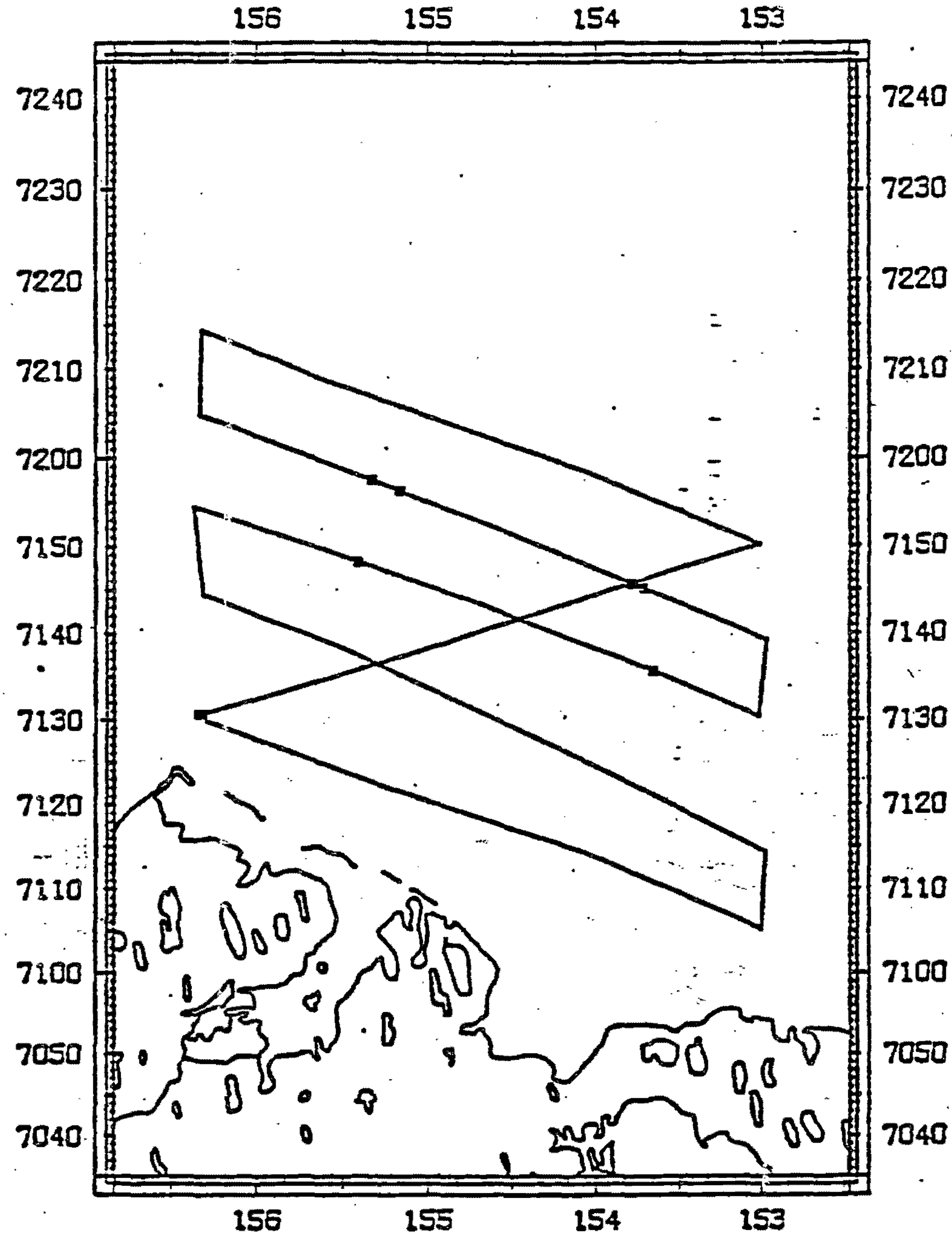


FIGURE 8. TRANSECTS FLOWN AND LOCATIONS OF WALRUS SIGHTINGS
EAST OF PT. BARROW 11 SEPTEMBER 1980