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PROJECT TITLE: Development of a method for monitoring the productivity, survivorship, and recruitment of the Pacific walrus population

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TABLE OF CONTENTS

ABSTRACT

In response to the need for a more sensitive method than those currently in use for monitoring the status of walrus populations, we developed a scheme for classifying the individual animals to morphological categories that are representative of sex/age classes. As is the case with other wildlife populations for which age/sex classes are morphologically distinct, this scheme will allow composition sampling, useful for estimating calf production, juvenile survival, and recruitment rate of adolescents into the adult population. We and several co-workers field-tested various aspects of the scheme a number of times between 1960 and 1980, and we performed six full tests of it in 1981-84. This is a report on the analysis of the data from those six tests. The results indicate that (1) classification of animals in the water was highly biased in favor of inflated juvenile/cow ratios, apparently because dependent/cow pairs were easiest to identify, (2) our ability to classify groups on the ice declined as group size increased, and (3) the ability to classify groups fully and accurately was a function of observer experience; inexperienced observers had some difficulty in identifying sexes and tended to misidentify dependent young more often than did experienced observers. The bias from in-water groups can be controlled by excluding the in-water sample from the analysis. The potential bias from uneven sampling of group sizes can be minimized by sampling as wide a range of group sizes as possible and extrapolating to the overall group size frequency. Observer bias can be overcome only by training and experience. Dependent/cow ratios apparently were independent of group size, east-west geographical location, depth of water, and time of day. The tests of influence of distance into the pack and weather were inconclusive. The optimal time and place for sampling appear to be in July in the outer part of the Chukchi Sea pack ice. The optimal sample size is about 2,500 animals.

INTRODUCTION

The Pacific walrus (Odobenus rosmarus divergens) population is a natural resource of major importance to the native people of western Alaska and eastern Siberia, who depend on it for much of their food, raw materials, and cash income. Thus, for economic reasons alone, there are concerns in both the USA and the USSR about maintaining the Pacific walrus population at a high, productive level. There are concerns also for ecological reasons, for the walrus appears to be a "keystone" species in the Bering-Chukchi marine system, not only because of its structuring influence on the benthic biota through selective predation, but also through its massive perturbation of the benthic sediments and release of bound nutrients to organisms on the bottom and in the water column (Ray 1973; Fay et al. 1977; Oliver et al. 1983). The walrus is, furthermore, one of the most conspicuous mammalian inhabitants of the Bering-Chukchi system, and it is therefore very much in the public eye. Its population appears to be in good condition at present, but its status may be precarious, due to increasing harvests, decreased productivity, and the inability of present management programs on both sides of the international boundary to measure population changes and respond to them in timely fashion (Fay et al. in press).

The status of the Pacific walrus population is monitored by American and Soviet governmental agencies. Those agencies periodically conduct joint aerial censuses and collect biological samples from the harvested animals. Those methods for monitoring are expensive, time-consuming, and tend to be poor indicators of the current status of the population. The data from the aerial censuses, at best, can be expected to show only broad, general trends of population size, because they potentially contain large sampling errors (Estes and Gilbert 1978). A change in population size cannot be recognized from those censuses with certainty, unless it is very large or until a new trend has been established from the results of several censuses, over a decade or more. Furthermore, the inferences from both the censuses and the harvest samples about changes in composition of the population are so crude that even the loss of a whole series of cohorts of young could not be detected for at least 8 to 10 years after the fact (Fay et al. in press).

Walruses have the lowest reproductive rate of all pinnipeds, and like other large mammals, are long-lived and slow to mature. Presumably, they also have very high survival and recruitment rates, which compensate for the low fecundity, but that hypothesis has been difficult to test. Estimates of survival rates of other wild pinnipeds ordinarily have been based on the strength of successive age classes in catch samples (e.g., Laws 1960; Sergeant 1975; Shustov 1969). The biological samples from the Pacific walrus catch, however, tend to be strongly biased by hunter-selection, as well as by the animals unequal vulnerability and differential availability in different years and in different localities (Sease 1986). As a whole, the catches are made up principally of adults, with extreme under-representation of the immature age classes (Burns 1965; Krylov 1965; Fedoseev and Gol'tsev 1969; Fay 1982), hence neither the survival rates of the young cohorts nor the recruitment rate of adolescents into the adult population can be derived from them (Fay 1982). The adult survival rates indicated by those biased catch samples also are highly questionable, because they probably are influenced not only by hunter selection but by the growth mode of the population (DeMaster 1984; Sease 1986). That is, the slope of the catch curve from a growing population is steeper than that from a stationary or declining population, though the actual survival rate can be the same in all of them.

In the interest of developing a sensitive method for monitoring the status of walrus populations and for obtaining information that would be of use in both prospective and retrospective modelling, the P.I. began 30 years ago to develop a scheme for visual sampling of Pacific walruses that would provide an estimate of the age/sex composition of that population. If such a method could be developed and truly representative samples could be obtained, these would allow timely assessment of productivity, juvenile survival, and recruitment, as well as a rounded estimate of the age composition of the adult segment of the population. This kind of sampling already was well underway in studies of large terrestrial mammals, for example, mountain sheep (Couey 1950; McCann 1956), muskoxen (Tener 1965), and caribou (Kelsall 1968), and it was in use also in population studies of a few pinnipeds, notably fur seals (Kenyon et al. 1954; Rand 1956)and southern elephant seals (Laws 1953; Carrick et al. 1962).

Walruses appeared to lend themselves especially well to visual sampling, because in all seasons they spend a high proportion of their time out of the water, where they can be seen and counted. Furthermore, they are large and characteristically colored, easily sighted from long distances, comparatively fearless when lying on the ice, and highly gregarious, hauling out on the ice in groups of mostly less than 30 individuals. The groups appeared to congregate seasonally in certain predictable areas, and there was some indication that the adults segregated geographically in some seasons (Brooks 1954; Fedoseev 1962; Burns 1965).

The first step toward development of an age/sex sampling method for walruses was to define a set of criteria for classifying the animals. Ultimately, the optimal time and place for the sampling also would need to be identified, and it would be necessary to determine how large the samples should be. Definition of the criteria for visual sampling appeared to be feasible, for it was already known that walruses are sexually dimorphic (Chapskii 1936; Brooks 1954; Fay 1955; Mansfield 1958), and that, from the relative size of their tusks, individuals can be placed into clearly definable morphological classes that correspond closely to age classes. Although individuals in the youngest age classes were not easy to identify to sex, that seemed unimportant, since their sex ratio was likely to be near unity anyway, as was later confirmed by Burns (1965) and Krylov (1968). Acquisition of the necessary experience and expertise for rapid, accurate identification of the morphological classes, however, turned out to be rather a prolonged process, and the development of age class criteria that could be applied by inexperenced observers was not sufficiently advanced until very recently.

From the beginning, it was clear that determination of the optimal size for the samples would depend not only on best estimates of population size but on knowledge of the seasonal movements of its different parts and their approximate age/sex composition. The first significant contributions on those points were made by Brooks (1954), Kenyon (1960), and Fedoseev (1962), and many others followed. Estimates of the sex ratio and probable age structure of the population, however, were not available until Fay (1982) compiled and synthesized data from all sources. Identification of the best location(s) and time(s) for the sampling was not feasible until the 1980s, because there simply was not enough known about the population and its movements before that time.

It has become clear also, in the meantime, that the sampling method needs to be focused mainly on the ratios of the juvenile age classes to the adult females. From those ratios, one could expect to derive estimates of net production of young and survival rates of the juvenile cohorts. There needs to be focus also on the independent adolescents, for assessment of their numbers will allow estimation of their recruitment rate into the breeding population. If the sampling method can be sufficiently refined, it might also offer the prospect of determining the approximate age composition of the adult part of the population.

The P.I. began to develop and field-test the classification method as early as 1958 (Fay 1960) and continued that effort with help from a few colleagues and co-workers on several research cruises from 1971 to 1980. By 1981, we felt that it was ready for a full-scale test. Accordingly, we and our colleagues conducted the first two tests of it in the Chukchi Sea that summer and four more tests in 1982-1984, working from several different ice-strengthened American and Soviet ships. Our preliminary analyses of the resulting data (Fay et al. 1986) indicated that the method probably would be capable of detecting small changes in net production and recruitment, but it was clear that there were numerous possibilities for error and bias, such as from the differing ability of observers, group size and location, time of day, weather, depth of water, and geographical location. Hence, further development of the method would require, first, that we analyze those data for any signs of influence from those potential factors and, if necessary, devise sampling and analytical strategies that could deal effectively with them.

The primary objective of the project reported here, therefore, was to conduct those analyses of the data from the six tests. The following were our findings.

METHODS

To develop a set of criteria that could be used by experienced and inexperienced observers alike for classifying Pacific walruses to sex and age, we based our definitions on measurements and photographs of the snout and tusks of specimens harvested by Alaskan Eskimos (e.g., see Fay 1982, fig. 71) and by Soviet sealers. From those data (Table 1) and measurements summarized earlier by Fay (1982, fig. 81), we prepared a set of outline drawings to scale, showing front and side views of the head of the average juveniles at 0, 1, 2, 3, and 4-5 years and of the average subadult and adult at 6-9, 10-15, and more than 15 years of age (Fig. 1). These were traced from photographs that were selected to match the relative dimensions of snout and tusks for the age class means. Ages of those measured specimens had been determined from counts of annual layers in the cementum of the cheek teeth, as described by Mansfield (1958), Burns (1965), Krylov (1965), and Fay (1982). For animals in the first five classes, 0 to 4-5 years old, identification to sex was regarded as unimportant, since practically all of those are sexually immature, and the sex ratio at those ages is about 1:1 (Burns 1965; Krylov 1968; Fay 1982). Only the animals 6 years old and older

Table 1. Dimensions (mean and S.D. in cm) of the snout[1] and tusks[2] in relation to sex and age of Pacific walruses taken by Soviet sealers in the Chukchi Sea, during July to September.

Age class (yrs)	Males							Females						
	n	Snout width M	S.D.	Snout depth M	S.D.	Tusk length M	S.D.	n	Snout width M	S.D.	Snout depth M	S.D.	Tusk length M	S.D.
0	3	16.5	2.18	10.2	0.76	0.0	0.00	5	16.9	1.34	10.1	1.24	0.0	0.00
1	4	19.2	1.89	11.4	1.25	3.0	0.71	1	19.0	---	11.0	---	3.0	---
2	3	22.0	1.53	13.3	1.53	5.8	1.04	4	21.5	0.58	12.0	2.00	5.6	1.17
3	2	22.0	3.00	14.2	0.75	9.5	---	5	21.4	1.08	13.2	0.84	10.6	1.19
4-5	12	24.8	1.03	14.2	1.14	15.7	1.51	15	23.6	1.04	13.7	0.92	14.3	4.49
6-9	5	28.6	2.33	15.8	1.92	26.4	6.55	21	26.3	2.61	15.0	1.23	23.1	3.53
10-15	4	31.8	1.50	17.8	1.50	35.9	6.86	18	26.8	2.31	15.0	1.60	31.6	5.40
>15	12	35.6	2.64	18.7	2.20	51.8	6.03	20	27.1	3.16	15.8	1.85	41.2	6.95

[1]Measured on relaxed, dead specimens with the head upright.

[2]Length along anterior surface from edge of gingiva to distal tip, as described by Fay (1982). In anterior view, about 2 to 2.5 cm of the tusks are hidden from view by the overhanging upper lip; in lateral view, 3 to 4 cm are hidden by the lip.

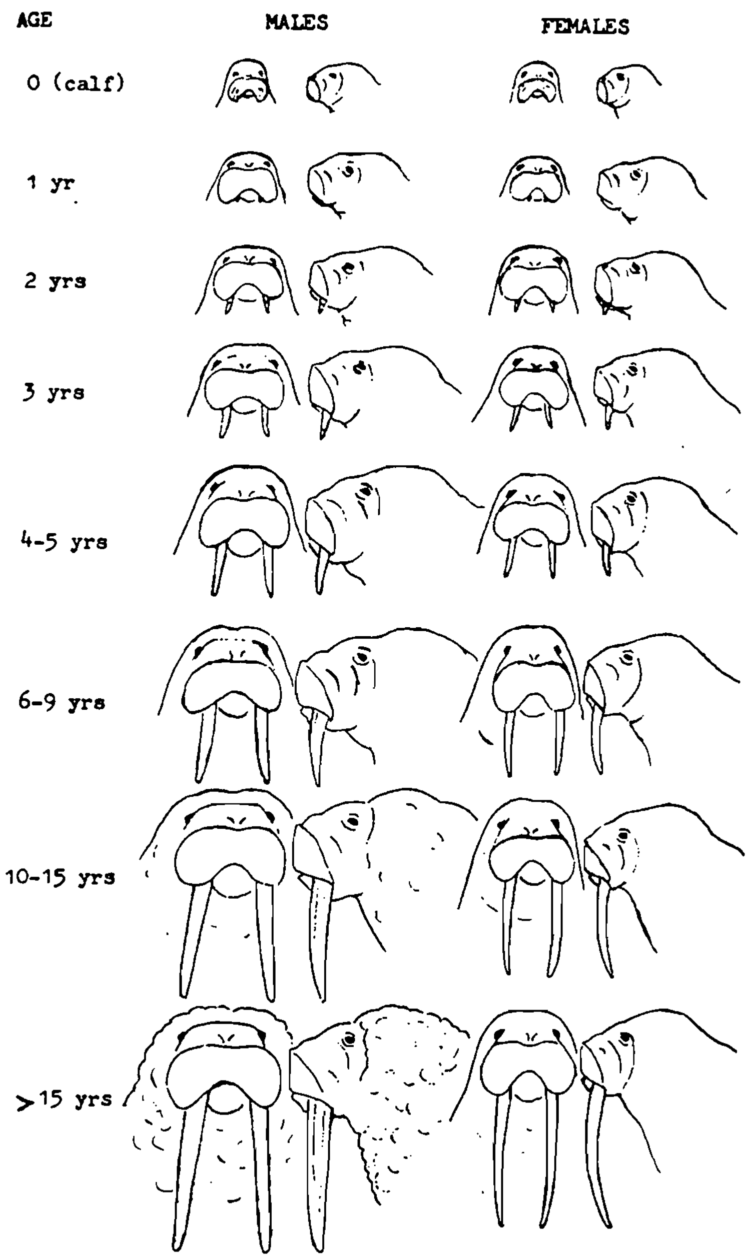

Figure 1. Anterior and lateral views of average facial characters of walruses in the age/sex classes identified in the field samples. Age classification was based primarily on tusk size, in relation to breadth and depth of the snout.

were identified to sex. The majority of females become capable of breeding by age 6 or 7 (Burns 1965; Krylov 1966; Fay 1982); males become capable of breeding at 9 to 10 years but do not reach full maturity until they are 15 or more years old (Fay 1982).

Identification to sex was based primarily on the dimorphism of adults in size, shape, and coloration of the body, head, and tusks, as described by Fay (1982). In general, Pacific walrus males are much larger and paler than females and have a relatively larger, blockier neck and head. The skin on the neck and shoulders of males frequently is "lumpy," whereas that of females appears smooth. The tusks of males are mostly straighter and more often divergent than those of females, as well as being whiter, very oblong in cross-section, and having deeper longitudinal grooves (usually two) on the lateral surface. The tusks of females usually appear more slender and curved to convergent, slightly yellowish to brownish overall, rounded to oval in cross-section, and lacking grooves in the lateral surface.

We felt that the outline drawings were the key to standardization of field identification of those classes by all observers, whether experienced or not. Each observer was instructed to classify each animal on the basis of the relative dimensions of the snout and tusks in those outlines, rather than to rely on personal knowledge or intuition about an animal's age. That is, all animals were to be classified by all observers in precisely the same way to morphological classes, rather than to age classes *per se*. Hence, the inexperienced observer would not be required to have any prior knowledge of age and growth of walruses, and the experienced observer would have no advantage in making judgements about age.

The objective in the field was to classify to age and sex every member of every group that was encountered. Frequently, this was not possible, because one or more individuals in the group were hidden from view or left the floe before there was time to observe them; in some cases, the observer simply was uncertain about the classification. We recorded the data from those incompletely classified groups, anyway, but because the data from them usually were not random subsamples of the group, they were excluded from most of the analyses (except as indicated). For the most part, we used only the data from the groups for which all members were classified. A "group" was defined as one or more animals in a cluster that was separated from other individuals and clusters by at least one adult body length (Estes and Gilbert 1978). The data from each group were recorded separately, and the location of the group "on-ice" or "in-water" also was noted, as was the time of day when the group was under observation. The time notations later were correlated with geographic position, determined from the ship's log.

Our first full test of the method was conducted in July 1981 from the U.S. Coast Guard icebreaker POLAR STAR in the eastern Chukchi Sea. For this test we had nine observers with a wide range of experience and expertise. Eight of the observers were paired up as "observer-teams" that were on regularly scheduled 2-hour watches while the ship was underway. The ninth observer (Fay) worked independently, as well as with each team as needed, providing instruction and backup support. Instruction was intentionally kept to a minimum, so that the observers would rely mainly on the outline drawings for guidance in age/sex identification.

The most experienced team (Team A) consisted of one observer with many years as a walrus hunter and another with experience as a marine mammal observer on two previous marine mammal research cruises and two other walrus research expeditions. The next most experienced team (Team B) was made up of one person with several months of field time in studies of walrus behavior on shore haulouts and one having some familiarity with male walruses in Bristol Bay and in aerial censusing of walruses in the Chukchi Sea. The third team (Team C) consisted of one person who had done research on marine mammals for a dozen years and had been a walrus observer during one previous summer cruise in the Chukchi Sea, paired with another who was experienced in classifying other pinnipeds to sex/age classes but had no previous experience with walruses. The least experienced team (Team D) included one person who had been a marine mammal observer on two previous cruises and one who was acquainted with the procedure but was observing walruses for the first time.

In that first test, we surveyed groups in the area between the Alaskan coast near Barrow and the central Chukchi pack ice at 169°W longitude (Fig. 2). We penetrated up to 70 km inside the ice edge, into areas with up to 8/10 coverage by heavy, multi-year ice. The area surveyed was comparable to about 90 percent of the walrus habitat in the eastern Chukchi Sea identified by Estes and Gilbert (1978), Johnson et al. (1982), and Gilbert (in press) from aerial surveys in September 1975, 1980, and 1985. For the first half of our 2-week trip, we cruised through the ice from northeast to southwest, surveying as much of the area within the pack as we could, to determine the distribution of the walruses and any geographical pattern of sex-age segregation. The POLAR STAR's two helicopters were used to explore the areas away from the ship's track whenever weather permitted. On our return northeastward in the second half of the cruise, we allocated most of our time to compositional sampling and behavioral observations in the areas where the main concentrations had been identified earlier. There, we approached and classified as many walruses as possible, without duplication of groups.

Most of the groups were observed from the bridge of the ship, at a height of about 10-12 m above the ice; a few were observed from the ship's Arctic Survey Boat (ASB) and from an inflatable boat (Zodiac), during intermittent sessions of behavioral study. The ASB and the Zodiac allowed viewing from approximately 2.5 and 0.5 m above the ice, respectively. As a rule, each group was approached by the ship and other craft upwind at speeds of 2 to 3 kt, to a minimal distance of about 100 to 200 m from the ship or 40 to 60 m from the small boats. Usually, as the vessels closed to those distances, each animal in the group raised its head, exposing the tusks and snout to the observers' view. One member of the observer-team, using a 16-36X "zoom" spotting scope on a sturdy tripod, identified the sex and age of each of the animals in the group, while the second observer obtained an accurate count of the total number of animals in the group and recorded the data. Generally, for each observation team, the most experienced member did the classifying, and the other member did the counting and recording. The most experienced observer's (Fay) priority in classification was, first, to scan the group for a general overview of its composition, then to count the five classes of juvenile animals, followed by the three classes of subadult and adult males, and finally, often by exclusion, the adult females. The latter usually were too numerous to classify further in the short time spent with each group. During periods of behavioral observation, when the observers worked from small boats, they also operated principally in pairs,

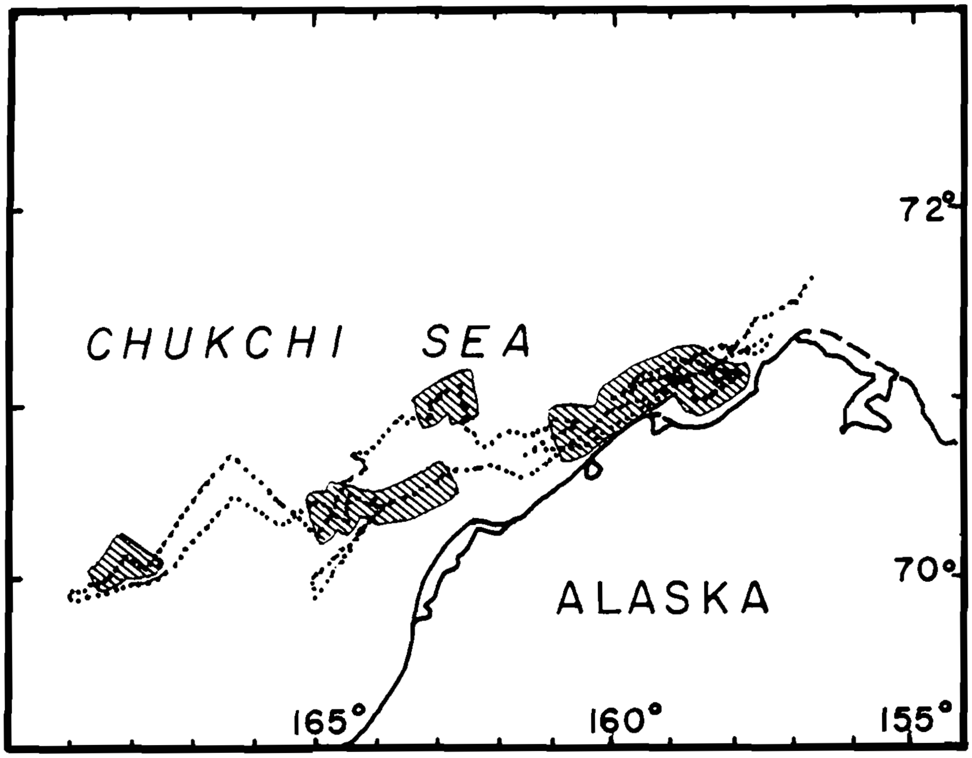

Figure 2. Cruise track (dotted line) of the CGC POLAR STAR in the eastern Chukchi Sea, 17-28 July 1981. The locations of the walrus groups surveyed are indicated by cross-hatching.

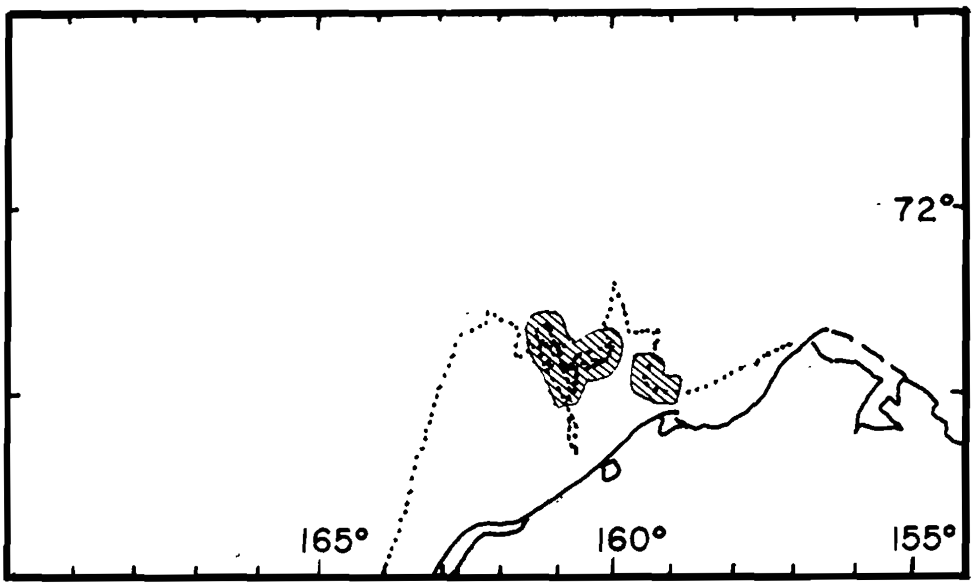

Figure 3. Cruise track (dotted line) of the N/S OCEANOGRAPHER in the eastern Chukchi Sea, 12-16 September 1981. The locations the surveyed groups of walruses are indicated by the cross-hatching.

but used 7 x 35 binoculars for observation.

Following the first test, all observers who were to take part in subsequent tests were given further instruction and training by Fay. The objective was to improve their skill and speed in identifying sexes and age classes, until their results were equal to his. On that basis, the subsequent samples were judged to be at least equal in quality to Fay's sample from the POLAR STAR.

The second test of the method was conducted in mid-September 1981 from the N/S OCEANOGRAPHER, primarily by A. A. Hoover, who had been one of the participants in the first test. The area surveyed was comparable to the eastern half of the area covered two months earlier from the POLAR STAR (Fig. 3). Because of very limited time and the ship's limitations on penetration into the ice, the cruise track intercepted only the herds in the ice edge.

The third and fourth tests were conducted by the authors, with assistance from R. V. Miller, R. R. Nelson, G. C. Ray, and D. J. Rugh in July and August 1982. Both tests were conducted in the Chukchi Sea from the flying-bridhge of the K/S ENTUZIAST, a decommissioned Soviet whale-catcher. Since the vessel was not strengthened for breaking ice, we were obliged to deal only with the groups in the southern edge of the pack. In each test, we covered the entire Chukchi ice edge, from the vicinity of Koliuchin Bay, Chukotka to Point Franklin, Alaska (Fig. 4).

The fifth test was conducted by Fay and J. L. Sease in the western Chukchi Sea, during a cruise of the ZRS ZYKOVO, a Soviet icebreaking sealer/trawler. On 16 and 18 August 1983, we surveyed herds from the flying-bridge in two small areas of the pack ice off Cape Schmidt, Chukotka (Fig. 5).

The last test was conducted by R. R. Nelson and L. F. Lowry from the flying-bridge of the R/V ALPHA HELIX, between 20 and 24 July 1984. They surveyed herds in the ice edge of the eastern Chukchi Sea between 160° and 167°W longitude (Fig. 5).

For each test of the sampling method, we classified as many animals as the circumstances allowed. The actual number classified was determined more by opportunity than by design, for we were limited occasionally by unfavorable weather and more often by the other functions of the ships of opportunity from which we conducted the work. All observers used the same equipment and all were exposed to the same instruction, as well as the same group discussions each evening. Observations during each of the tests were conducted throughout the daylight hours, except that they were discontinued whenever the ship was not in motion and when the visibility was poor due to fog and/or snow squalls.

For analysis of the data, we assumed foremost that the data from the completely classified, on-ice groups were the most reliable, repeatable, and representative, hence the standard against which all other samples could be compared. Although the on-ice groups tended to be larger than those in the water, the assumption was that they were composites of the in-water groups. There was no rationale for any other interpretation; walruses spend part of their time in the water, dispersed and feeding, and the rest of the time on

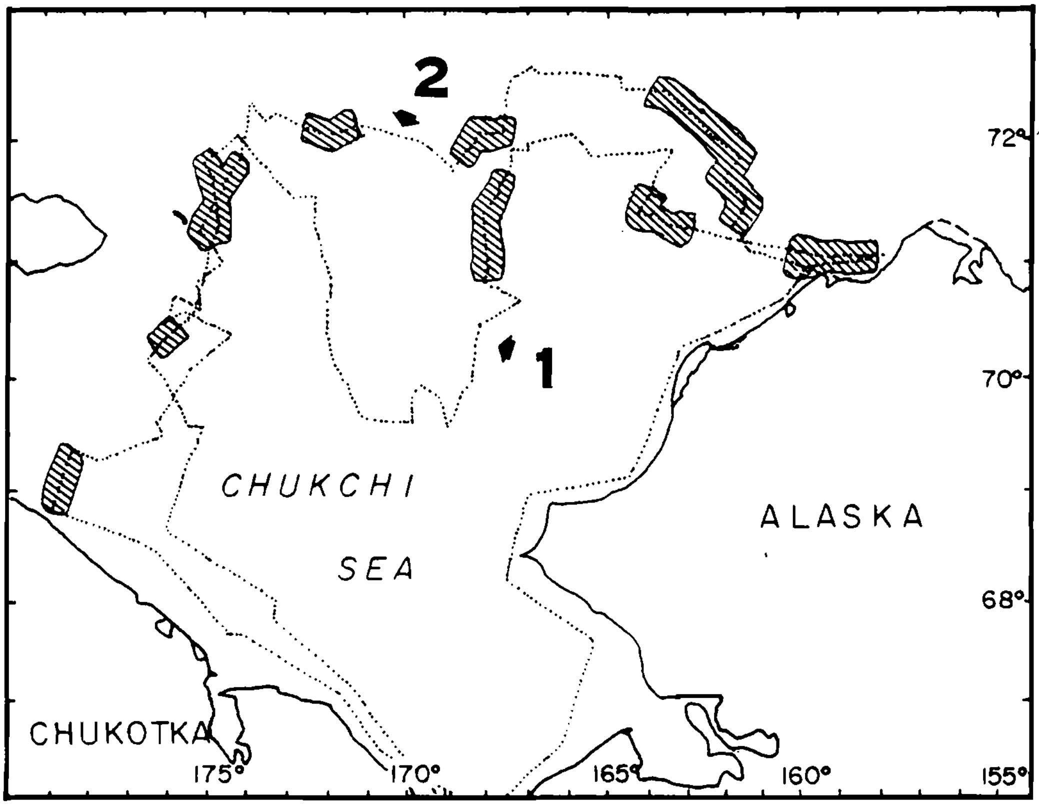

Figure 4. Cruise tracks of legs 1 and 2 of the K/S ENTUZIAST along the edge of the pack ice in the Chukchi Sea, 26 July to 17 August 1982. The locations of the main aggregations of walrus groups surveyed are indicated by the cross-hatching.

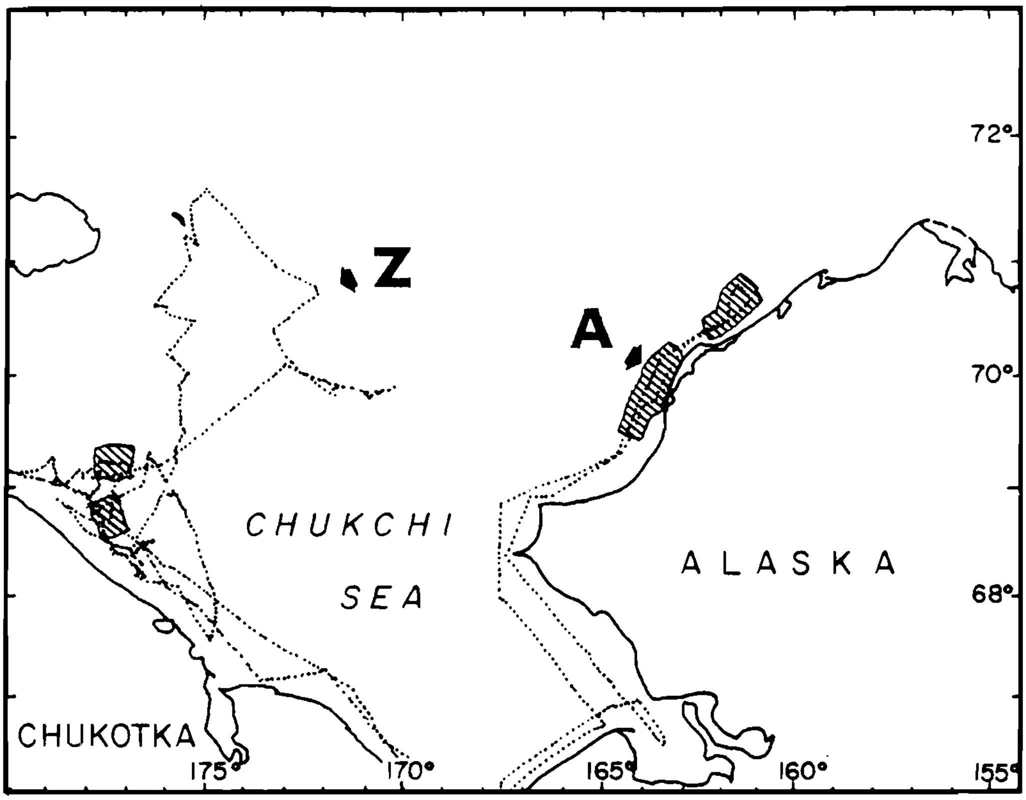

Figure 5. Cruise track of the ZRS ZYKOVO in the open pack ice of the western Chukchi Sea, 24 July to 22 August 1983 (**Z**) and of the R/V ALPHA HELIX in the eastern Chukchi Sea, 20-24 September 1984 (**A**). The locations of the aggregations of walrus groups surveyed are indicated by the cross-hatching.

ice floes or on shore, aggregated and sleeping. We also assumed that the samples from ships were the best and most representative. Because the observers have a more oblique, 3-dimensional view of each group from the height of the bridge, they have equal possibilities for accurate sampling of groups of all sizes, whereas the low angle of incidence from the small boats generally allows only a 2-dimensional view, hence accurate assessment only of very small groups.

We did not expect any observer bias, but we were prepared to test for it, using the data set from the POLAR STAR cruise. We used Fay's classifications on that cruise as the control against which the data from each of the other observer teams were compared. The accuracy of Fay's classifications of the sex and age of walruses was assured by his 30 years of experience as a walrus observer, including examination of over 3,000 specimens, whose age was determined from tooth sections. After the POLAR STAR cruise, all primary observers in subsequent tests received further training. Their data from those tests were judged to be comparable in quality with Fay's.

Since the object of the method is to measure the relative strength of the juvenile cohorts by matching them against the adult females, we used only the data for the juvenile age classes and the adult females for most of the analyses. We knew that we had not sampled groups of all sizes equally in any of the tests, so we were aware that our samples might have been biased thereby, if the age/sex composition varied with group size. We did not know that there was any such variation, but dependent-cow pairs obviously could not occur in groups of one, and the concern was that the young-of-the-year might be most common in large groups, as they are in spring (Burns 1970).

We also expected that the age/sex composition of the herds might vary from east to west in the Chukchi Sea, based mainly on earlier observations by Brooks (1954) and Fedoseev (1962, 1966), whose data suggested non-uniform distribution of adult males. We did not know whether the distribution of the adult females and the various juvenile age classes also varied from east to west or whether the groups found deep in the pack might be different in composition from those at the southern edge, so we made some effort to test those possibilities. We thought also that the composition might vary with time of day, depth of water, and perhaps, weather, but those kinds of potential relationships had not been investigated before. Although Pacific walruses in general show no diel rhythm of activity (Wartzok and Ray 1980; Fay 1982), and there are no known differences between sexes in feeding effort during the summer, there may well be differences among age classes and between pregnant, lactating, and nonpregnant or nonlactating females (Fay 1982; Gehnrich 1984). We also supposed that females with calves might remain in shallower waters than would the other females, because the calves have the least diving ability (Loughrey 1959; Gehnrich 1984).

To examine those potential sources of sampling error, our primary analyses were tests for within-sample homogeneity of the ratios of juveniles to the adult females. For those tests, the data were classified according to the following conditions, each of which can be expressed as a working hypothesis:

Location - Hypothesis: Animals in groups on the ice have the same overall age/sex composition as those in the water.

Observer - Hypothesis: Given the outline drawings for age/sex classification of walruses, all observers (whether experienced or not) will classify them equally well.

Group Size - Hypothesis: The dependent/cow ratios do not vary with group size.

Geographic Location - Hypothesis: The dependent/cow ratios of walrus herds are the same from east to west in the Chukchi Sea pack ice in summer.

Distance from Ice Edge - Hypothesis: The dependent/cow ratios of walrus groups in the edge of the pack ice are the same as those of groups that penetrate far into the pack.

Time of Day - Hypothesis: The dependent/cow ratios of walrus herds on the ice do not vary with time of day.

Water Depth - Hypothesis: The dependent/cow ratios of walrus herds do not vary with depth of water.

Weather - Hypothesis: The dependent/cow ratios of walruses on ice floes are not influenced by weather.

As an adjunct to the analysis, we summarized by months all of the data available to us on group size of Pacific walruses. These were in 21 sets that had been recorded by us and by several colleagues, during aerial and shipboard surveys of marine mammals in both the Bering and the Chukchi seas. Those surveys had been conducted during all months except January, since 1960.

Each set consisted of a tabulation of the number of animals in each group for which a full count or estimate was obtained, together with a notation of the time when the group was sighted, its location on ice or in the water, and frequently, its principal components in terms of sex and age. For the present purpose, we compiled only the data from the on-ice groups.

Finally, we calculated the sample size that would be required to estimate the ratio of each juvenile age class to the adult females, with a precision of 0.03 juveniles/100 females at 95 percent confidence. To accomplish this, we used the method described by Czaplewski et al. (1983), relying on the juvenile/cow ratios indicated by our five largest samples and the population size estimates derived by Johnson et al. (1982) and Fedoseev (1984) in the autumn of 1980 and by Fedoseev and Razlivalov (1986) and Gilbert (in press) in 1985.

RESULTS

Description of Samples

First Test, CGC POLAR STAR

The Chukchi ice edge in July 1981 was somewhat farther south than average. Along the Alaskan coast from Barrow to Icy Cape it was less than 15 km offshore; from there, it lay southwestward, toward the Siberian coast. Most of the walruses were within 10 km of the edge; only a few individuals were seen deeper in the pack. The maximal distance from the ice edge at which any groups were encountered was 28 km.

In the area from the Alaskan coast to 169°W, we sighted a total of 533 groups of walruses, mainly in two aggregations. The total number of individuals in those groups was 6,044 animals, which amounted to about 8 and 28 percent of the estimated populations summering in the Chukchi Sea east of 169°W in 1980 and 1985, respectively (Johnson et al. 1982; Gilbert in press). We were able to classify 2,500 of those animals to age/sex in 460 of the groups. This sample included 1,844 individuals in 220 groups for which every member was classified ("complete groups"), and 656 animals in 240 groups for which only partial classification was feasible ("incomplete groups").

Second Test, N/S OCEANOGRAPHER

The ice edge in mid-September 1981 was about 110 km farther north than it had been two months earlier, during the POLAR STAR cruise. The animals in it were congregated mainly to the north and northeast of Point Franklin, in the vicinity of the easternmost aggregation encountered from the POLAR STAR.

A total of 925 walruses were counted in 55 groups. Sex and age class were determined for 709 of those walruses in 39 groups on the ice and for 16 walruses in 13 groups in the water. An additional 200 walruses in 3 groups were counted but not classified to age/sex.

Third Test, K/S ENTUZIAST, Leg 1

The latitude of the ice edge in the Chukchi Sea was about the same in July 1982 as it had been in July 1981. Although we were not able to penetrate it to as great a depth from the ENTUZIAST as we had from the POLAR STAR, we worked well inside the edge in several areas where the pack was dispersed, and we surveyed both sides of the Chukchi Sea, from the coast of northern Chukotka to the coast of northern Alaska.

We counted 1,396 walruses in 245 groups and classified 789 in 149 groups to age and sex. Classification of the other 96 groups was incomplete.

Fourth Test, K/S ENTUZIAST, Leg 2

By the time of the second leg of the ENTUZIAST cruise, the edge of the Chukchi pack ice had retreated markedly to the north. Along it, we again surveyed the herds on both sides of the Chukchi Sea. At that time, we counted 6,493 walruses in 616 groups and classified 1,049 of those in 153 groups. For the other 266 groups, classification was incomplete. An additional 197 groups containing 4,786 walruses were sighted but not classified.

Fifth Test, ZRS ZYKOVO

On this cruise into the western Chukchi Sea in August 1983, our primary mission was harvest sampling, but we had the opportunity to survey herds in two areas near the ice edge between 177°49'W and 178°10'W. There, we sighted 65 small groups on the ice, in which we were able to classify all of the 481 animals to sex and age.

Sixth Test, R/V ALPHA HELIX

The eastern Chukchi ice edge in July 1984 was in a location comparable to that in July 1982, and the walruses encountered during this cruise were aggregated in essentially the same three areas along the ice edge, i.e. at 166°52'-166°55'W, 163°54'W, and 160°20'-160°29'W.

This sample contained 1,612 walruses in 138 groups. Only groups on the ice were counted, and all but one were classified completely.

Tests of Hypotheses

Location

In four of the six tests, groups in the water as well as those on the ice were classified, with the objective of testing the hypothesis that the overall age/sex composition of the in-water groups was the same as that of the on-ice groups. In each test, the in-water samples were made up of significantly more 1- and 2-animal groups than were the on-ice samples (Table 2). Despite the small group sizes, however, the animals in the water were more difficult to classify than were those on the ice, because they usually showed only their head, their tusks frequently were underwater, and they could be observed for only a short time before they dove. As a result, a much lower proportion of in-water than on-ice groups was completely classified (Figs. 6-9). Furthermore, the completely classified in-water groups were more often of two animals than predicted from the group size frequency. This evidently occurred because walruses swimming with small dependents are more easily classified than are any others; large animals swimming alone or with other large animals are much more difficult to identify with certainty. As a result, the in-water samples were made up predominantly of adult females with calves and yearlings (e.g., Table 3).

Table 2. Comparative percentage frequency of occurrence of walruses in groups of 1 to 2 when in the water versus on the ice.

Sample	In-water		On-ice			
	Total no. of groups	Proportion of those as 1 or 2	Total no. of groups	Proportion of those as 1 or 2	$X^2_{(1)}$	p
POLAR STAR	230	65%	303	23%	94.61	0.001
OCEANOGRAPHER	13	92%	42	10%	32.98	0.001
ENTUZIAST-1	114	76%	131	31%	51.17	0.001
ENTUZIAST-2	355	80%	259	16%	234.81	0.001
ZYKOVO	---	---	65	15%		
ALPHA HELIX	---	---	138	15%		

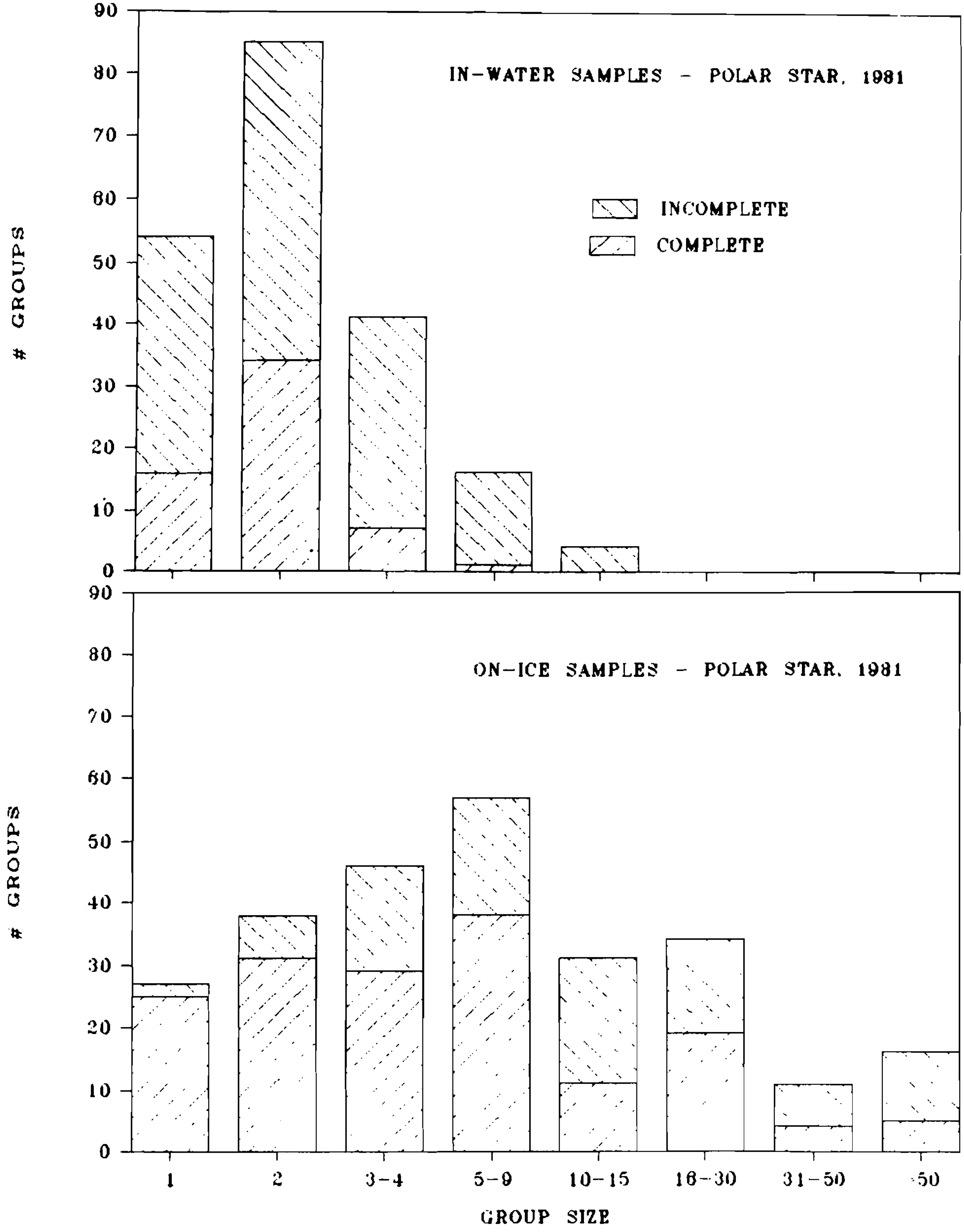

Figure 6. Histograms of frequency of occurrence of group sizes for the in-water (upper) and on-ice (lower) samples obtained from the CGC POLAR STAR in July 1981. The proportions of groups in each category for which all animals were classified to age/sex (complete) or only partly classified (incomplete) are indicated by the differential cross-hatching.

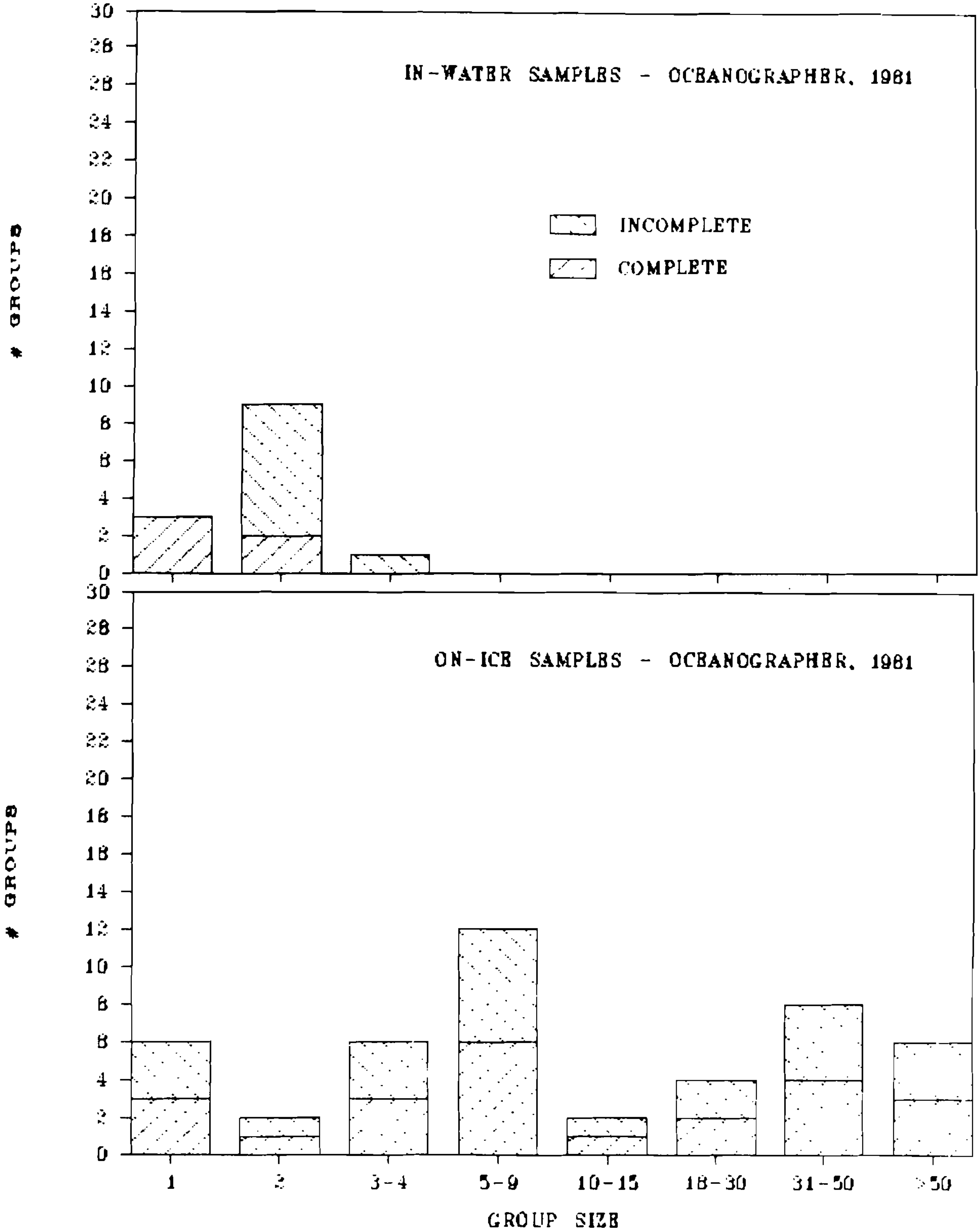

Figure 7. Histograms of frequency of occurrence of group sizes for the in-water (upper) and on-ice (lower) samples obtained from the N/S OCEANOGRAPHER, September 1981. The proportions of groups in each category for which all animals were classified to age/sex (complete) or only partly classified (incomplete) are indicated by the cross-hatching.

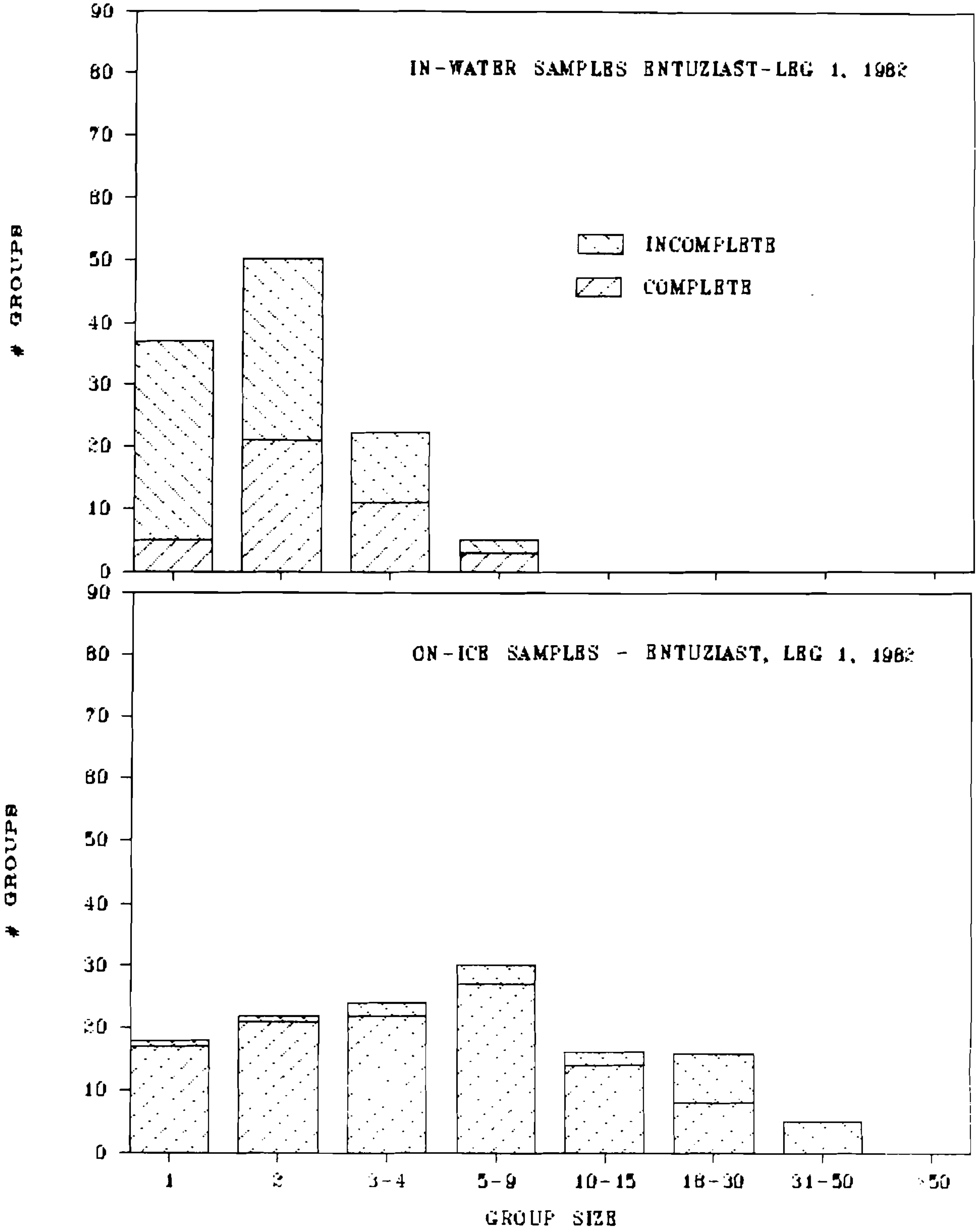

Figure 8. Histograms of frequency of occurrence of group sizes for the in-water (upper) and on-ice (lower) samples obtained from the first leg of the K/S ENTUZIAST cruise in July-August 1982. The proportions of groups for which all animals were classified to age/sex (complete) or partly classified (incomplete) are indicated by the cross-hatching.

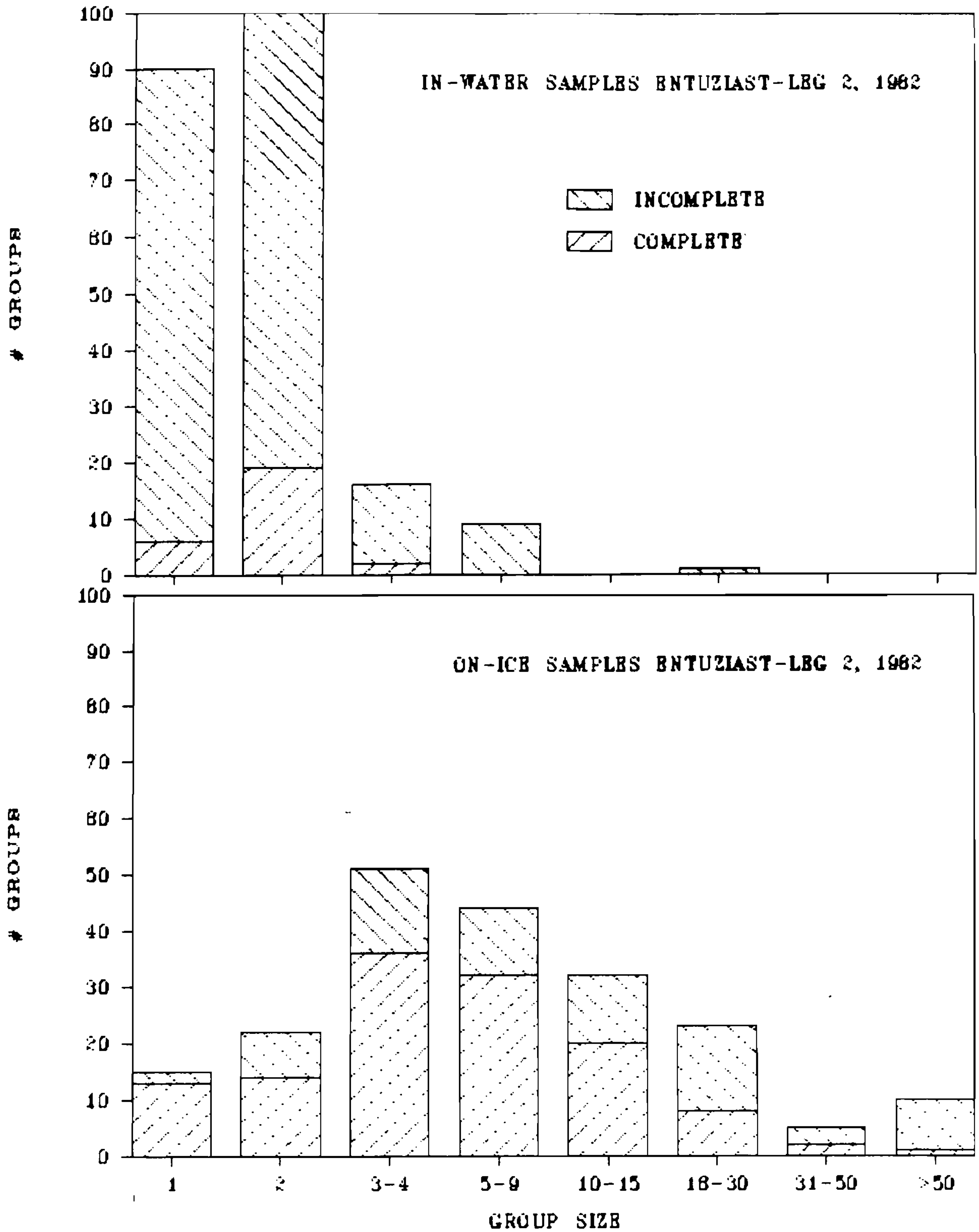

Figure 9. Histograms of frequency of occurrence of group sizes in the in-water (upper) and on-ice (lower) samples obtained from the second leg of the K/S ENTUZIAST cruise in August 1982. The proportions of groups for which all animals were classified to age/sex (complete) or partly classified (incomplete) are indicated by the cross-hatching.

Table 3. Composition of all walrus groups classified by all observers during the CGC POLAR STAR cruise, July 1981.

Class	On-ice groups			In-water groups		
	No. of animals	% of total	Ratio /cow	No. of animals	% of total	Ratio /cow
Calves	121	5.14	0.081	25	17.12	0.325
Yearlings	75	3.19	0.050	12	8.22	0.156
Calf-Yearling	15	0.64	0.010	9	6.16	0.117
2 year olds	82	3.49	0.055	4	2.74	0.052
3 year olds	120	5.10	0.080	5	3.42	0.065
4-5 yr olds	265	11.27	0.177	14	9.59	0.182
6-9 yr males	77	3.27		0	0.00	
10-15 yr males	63	2.68		0	0.00	
15 yr males	36	1.53		0	0.00	
6 yr & older females	1498	63.69		77	52.74	
Total	2352			146		

Observer

The POLAR STAR cruise included composition counts by nine different observers with different levels of experience and minimal training. Eight of those observers were paired up as observer-teams, and the ninth observer (Fay) operated independently. We compared the results among the different teams and Fay only for on-ice groups completely classified from the ship. Fay had classified 89 (71%) of such groups, and the rest were classified by the 2-person teams. These were not concurrent classifications of the same groups of animals by all teams, hence they are not exactly comparable, but all of the sets were from the same concentrations of animals.

The ratio of adult females to the combined immature age classes was homogeneous among the four observer teams and Fay ($X^2_{(4)} = 5.35$, $p = 0.253$), which indicates that all of the teams were differentiating adults from young equally well (Table 4). Relative to Fay, however, the less experienced observers tended to over-estimate the numbers of calves and to under-estimate the numbers of older juveniles, to the extent that the results overall were very significantly heterogeneous among the different observers ($X^2_{(20)} = 59.23$, $p < 0.0001$).

Direct comparisons between Fay's observations and those of the two most experienced teams (A and B) are difficult to assess, due to the low sample sizes. Team C's results differed very significantly from Fay's ($X^2_{(5)} = 16.73$, $p = 0.005$), with 93 percent of the overall chi-square resulting from the disparities in the calf and yearling categories. The D team's results and Fay's observations also were very significantly heterogeneous ($X^2_{(5)} = 32.62$, $p < 0.0001$), with the greatest disparity in the calf category, which accounted for greater than 80 percent of the overall chi-square.

The age/sex composition of all samples subsequent to the POLAR STAR cruise was determined by Fay and by observers trained further by him. All of those samples were judged to be equally accurate and comparable.

Group Size

The overall range of group sizes for animals on the ice was from 1 to 850 individuals. Groups of 5 to 9 individuals were most numerous in each of the samples (Figs. 6-9). In general, all observers found the larger groups to be the most difficult to classify completely, because the animals in them were not synchronous in their activities. Frequently, some of them slipped into the water and swam away before they could be classified, while others slept soundly and were difficult to identify because they did not raise their head. This difficulty was reflected, in every sample. For example, in Fay's classification of on-ice groups from the POLAR STAR, the chi-squared test indicated a lack of independence between group size and complete versus incomplete classification ($X^2_{(7)} = 15.01$, $p = 0.0359$).

The experienced observers in each test succeeded in completely classifying 75-100 percent of the on-ice groups up to about 15 animals, but had decreasing success (down to about 40%) with groups of more than 25 animals (overall success was about 85%). The least experienced observers on the POLAR STAR cruise successfully classified 75-100 percent of groups of 1-2 animals, but their success for larger groups decreased, down to about 30

Table 4. Percentage composition per age class of the juvenile age classes and adult females in groups classified by Fay and each of the four observer teams, during the POLAR STAR cruise, July 1981. Below each percentage is the ratio of that age class to the adult females in the sample (/cow).

Observer team	Total no. of animals	Calves	Yearlings	2-yr olds	3-yr olds	4-5 yr olds	Adult females
Fay	975	2.3	1.3	3.3	4.5	10.8	77.8
/cow		0.029	0.017	0.042	0.058	0.138	
Team A	10	0.0	0.0	0.0	10.0	20.0	70.0
/cow		0.000	0.000	0.000	0.143	0.286	
Team B	15	6.7	13.3	0.0	0.0	13.3	66.7
/cow		0.100	0.200	0.000	0.000	0.200	
Team C	193	4.7	5.2	2.6	4.2	8.8	74.6
/cow		0.062	0.069	0.035	0.056	0.118	
Team D	153	10.5	1.3	1.3	2.0	14.4	70.6
/cow		0.148	0.018	0.018	0.028	0.204	

percent for groups of 25 or more individuals (overall success, about 55%). Hence, for all samples, the proportion of on-ice groups completely classified generally tended to decrease as group size increased (Figs. 6-9). Recognizing that this could influence the overall composition of the sample, if there were any consistent differences in composition between groups of different sizes, we tested for homogeneity of composition with varying group size.

The ratios of each of the juvenile age classes to the adult females in three group-size categories are shown in Table 5. The OCEANOGRAPHER sample was omitted because it was too small for comparable analysis. In each of the five samples, cows with calves were more common in medium-sized groups (15-50) than in smaller or larger groups. That trend was significant, however, only in the ALPHA HELIX sample. In each sample, cows with yearlings were consistently more numerous in groups of 50 or less, but the difference was not significant. The 2 year olds were homogeneous across group-size categories in all samples, but the 3 year olds and 4-5 year olds consistently favored the smaller groups (1-14). The latter was significant only in the POLAR STAR sample.

Geographic Location

During the POLAR STAR cruise in the eastern Chukchi Sea, we found subadult and adult male walruses to be more numerous (99/1235) in the groups near the Alaskan coast (156-159°W) than farther west (17/490)and to be very significantly less numerous than expected in the most western segment (163-169°W) of the study area (2/313, $X^2_{(2)} = 22.629$, $p < 0.001$). The ratios of juveniles to adult females, however, were homogeneous throughout that range.

Each of the ENTUZIAST samples included observations from the entire east-west extent of the Chukchi ice edge. Again, the geographic distribution of males was heterogeneous, but in this case, most of them were far to the west (168-175°W), near Wrangel Island and the coast of Chukotka (Figs. 10,11). The ratios of most of the juvenile age classes to adult females, however, tended to be homogeneous from east to west (Tables 6, 7). The only exception was the calf/cow ratio, which was hetergeneous to a significant degree on Leg 1 and nearly so on Leg 2. There was, however, no distinct pattern to that heterogeneity in either sample and no similarity between them.

Distance from Ice Edge

The POLAR STAR sample was the only one for which distance into the pack could be tested for influence on group composition. Groups ranged from 0 to 28 km (median, 7.4 km) into the ice. Within that range, we found no correlation between group size and distance from the edge ($r = -0.0017$, $p = 0.931$). The ratios of the juvenile age classes to adult females (classified by Fay) were compared for two distance categories: within 11 km (0-6 nautical miles) of the edge and from 11 to 22 km (6-12 nm) of the edge (Table 8). Adult females made up 74.3 percent of all of the groups sampled, and that proportion did not vary significantly with distance from the ice edge ($X^2_{(2)} = 1.609$, $p = 0.447$). The ratios of the juvenile age classes to the adult females, however, tended to be slightly higher near the edge than farther

Table 5. Ratios of the juvenile age classes to the adult female walruses, in relation to group size in summer in the Chukchi Sea.

Sample	Age class	Group size 1 -14	15-50	>50	p
POLAR STAR (Fay)	Calves	0.02	0.04	0.02	0.59
	Yearlings	0.03	0.02	0.005	0.20
	2 yr olds	0.03	0.05	0.03	0.26
	3 yr olds	0.10	0.05	0.04	0.03*
	4-5 yr olds	0.29	0.12	0.04	0.001*
ENTUSIAST-1	Calves	0.21	0.28	--	0.20
	Yearlings	0.07	0.07	--	0.95
	2 yr olds	0.02	0.01	--	0.56
	3 yr olds	0.04	0.02	--	0.23
	4-5 yr olds	0.10	0.06	--	0.21
ENTUZIAST-2	Calves	0.11	0.14	0.05	0.06
	Yearlings	0.08	0.08	0.03	0.19
	2 yr olds	0.01	0.02	0.04	0.07
	3 yr olds	0.04	0.03	0.02	0.50
	4-5 yr olds	0.08	0.005	0.02	0.08
ZYKOVO	Calves	0.09	0.14	--	0.22
	Yearlings	0.08	0.07	--	0.74
	2 yr olds	0.03	0.01	--	0.31
	3 yr olds	0.02	0.03	--	0.73
	4-5 yr olds	0.09	0.04	--	0.05*
ALPHA HELIX	Calves	0.04	0.10	0.07	0.002*
	Yearlings	0.04	0.04	0.02	0.46
	2 yr olds	0.06	0.06	0.03	0.24
	3 yr olds	0.06	0.04	0.03	0.45
	4-5 yr olds	0.10	0.07	0.05	0.07

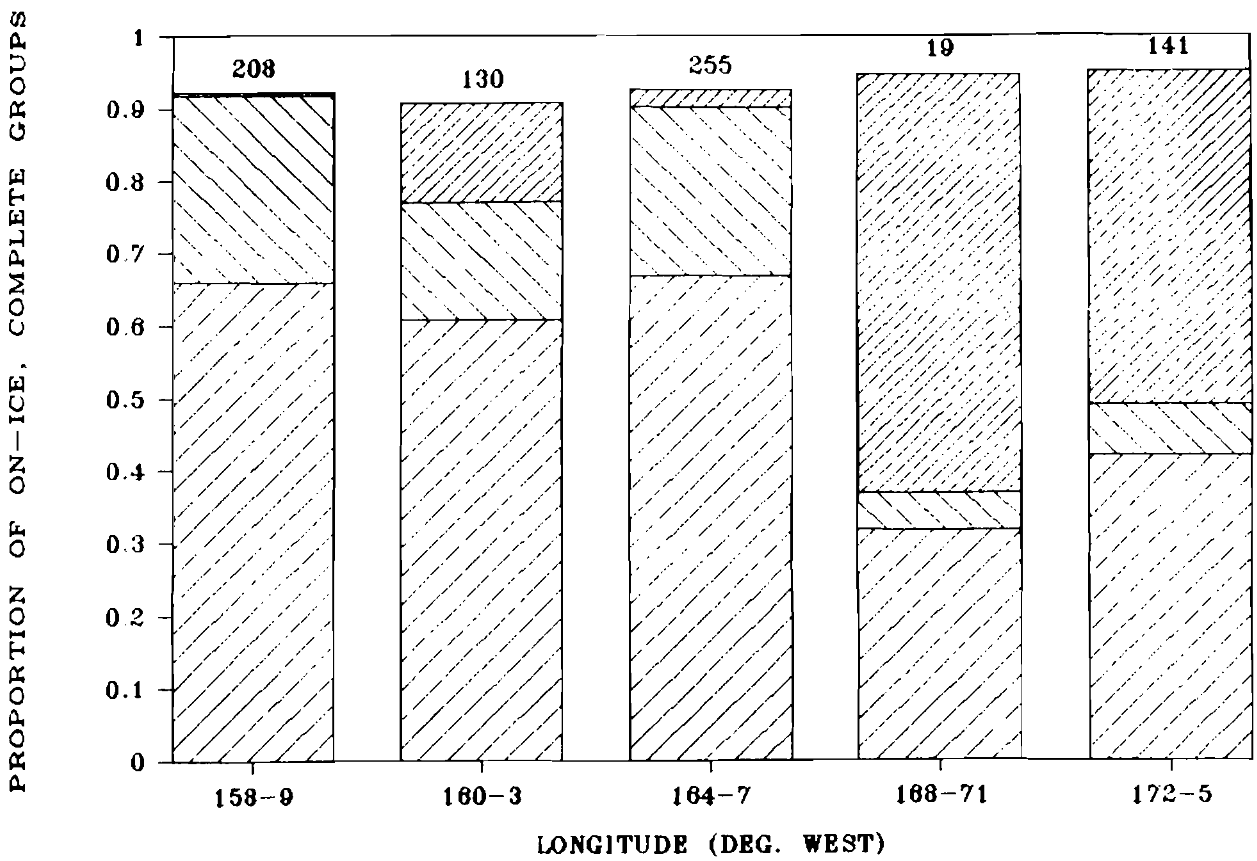

Figure 10. Histograms of the longitudinal shift in proportional composition of completely classified, on-ice groups in the sample from the first leg of the K/S ENTUZIAST cruise in July-August 1982. The three categories represented are indicated by the differential cross-hatching. Uppermost [hatch] are the subadult and adult males; below that [hatch] are the dependent young, 0 to 2 years old; lowermost [hatch] are the females of breeding age, 6 years old and older. The number of groups in each subsample is shown at top.

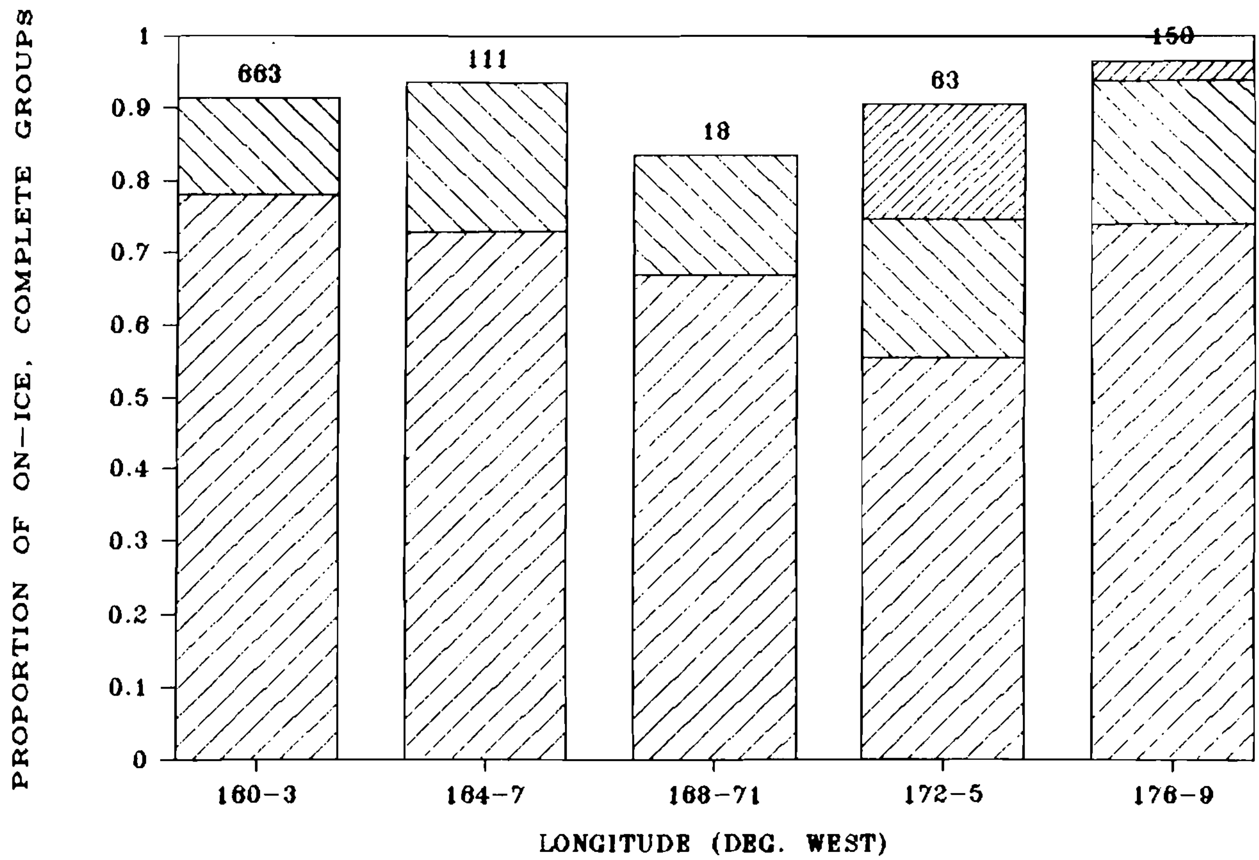

Figure 11. Histograms of the longitudinal shift in proportional composition of completely classified, on-ice groups in the sample from the second leg of the K/S ENTUZIAST cruise in August 1982. The three categories represented are indicated by the differential cross-hatching. Uppermost [dense hatch] are the subadult and adult males; below that [back-slash hatch] are the dependent young, 0 to 2 years old; lowermost [slash hatch] are the females of breeding age, 6 years old and older. The number of groups in each subsample is shown at top.

Table 6. Ratios of the juvenile age classes to adult females for five longitudinal categories from east to west in the ice edge of the Chukchi Sea, during Leg 1 of the ENTUZIAST cruise, July 1982. Data from the two westernmost legs were pooled for the Chi-squared analysis because of small samples.

Age class	Longitude (degrees west) 158-159	160-163	164-167	168-171	172-175	$X^2_{(3)}$	p
Calves	0.336	0.165	0.241	0.167	0.085	11.04	0.012*
Yearlings	0.044	0.051	0.100	0.000	0.085	3.67	0.299
2 yr olds	0.015	0.051	0.012	0.000	0.000	6.15	0.104
3 yr olds	0.029	0.063	0.024	0.000	0.340	2.56	0.464
4-5 yr olds	0.088	0.089	0.088	0.167	0.085	0.01	0.999
(No. of adult females)	(137)	(79)	(170)	(6)	(59)		

Table 7. Ratios of the juvenile age classes to adult females for five longitudinal categories from east to west in the ice edge of the Chukchi Sea, during Leg 2 of the ENTUZIAST cruise, August 1982. Data were pooled from 168 to 175° and from the 2 and 3 year olds for the Chi-squared analysis, due to small samples.

Age class	Longitude (degrees west) 160-163	164-167	168-171	172-175	176-179	$X^2_{(3)}$	p
Calves	0.089	0.185	0.250	0.114	0.144	6.99	0.072
Yearlings	0.070	0.086	0.000	0.114	0.063	0.48	0.924
2 yr olds	0.012	0.012	0.000	0.029	0.036	2.85 (2 and 3 yr olds pooled)	0.415
3 yr olds	0.046	0.012	0.083	0.057	0.000		
4-5 yr olds	0.064	0.074	0.167	0.114	0.045	3.22	0.359
(No. of adult females)	(518)	(81)	(12)	(35)	(111)		

Table 8. Ratios of the juvenile age classes to adult females in relation to distance from the ice edge in the eastern Chukchi Sea, July 1981. Data are from groups classified by Fay during the POLAR STAR cruise.

Age class	Distance from ice edge (km) 0 - 11	12 - 22	$X^2_{(1)}$	p
Calves	0.041	0.014	4.515	0.034*
Yearlings	0.010	0.026	2.872	0.090
2 yr olds	0.046	0.038	0.305	0.581
3 yr olds	0.078	0.035	5.646	0.018*
4-5 yr olds	0.162	0.110	3.298	0.069
(No. of adult females)	(413)	(346)		

into the ice, and those differences were significant in the case of the calves and the 3 year olds.

Time of Day

Two samples were sufficiently large for testing the independence of age composition and time of day for on-ice groups completely classified. The first was the POLAR STAR sample, which included 1,013 walruses in groups completely scored at a known time. We divided that sample into three time intervals, 0800-1300, 1300-1800, and 1800-2200 hours containing samples of 471, 471, and 71 walruses respectively. The overall frequencies of occurrence of the juvenile age classes were independent of the time intervals ($X^2_{(16)} = 24.06$, $p = 0.0883$). Similarly, the ratios of those classes to the adults females also were independent of time of day (Table 9).

The second sample was from the ALPHA HELIX cruise. Counts of walruses by age class and four intervals of time of day for that sample differed significantly from expected values under the hypothesis of independence ($X^2_{(24)} = 45.37$, $p = 0.0053$). The most significant deviation was for 2 year olds, which were observed more frequently than expected between 1000 and 1400 hours and less frequently than expected between 1400 and 1800 hours. The frequency of occurrence of adult females did not vary significantly with time ($X^3_{(3)} = 1.212$, p. $= 0.75$), nor did the ratios of the juveniles to adult females, except for the 2 year olds (Table 10).

Depth of Water

In each sample for which relationship with depth of water could be tested, 75 to 90 percent of the juveniles and adult females were in waters less than 40 m deep. The ratios of juveniles to adult females tended to be highest in depths of less than 50 m, but sample size in deeper waters was too small to be diagnostic.

For the POLAR STAR sample classified by Fay, groups occurred in waters 22 to 75 m deep (median, 27 m). For three depth categories, the adult females were present in the same proportion at all depths ($X^2_{(2)} = 4.153$, $p = 0.125$). The calf/cow ratio, however, was significantly higher in depths of less than 30 m than in greater depths, and the ratios of the other juvenile classes to adult females were greatest in depths exceeding 39 m (Table 11). The differences were significant in the case of the calves, 3 year olds, and 4-5 year olds.

During the first leg of the ENTUZIAST cruise, groups were classified in waters ranging in depth from 20 to 112 m (median, 45 m). Adult females were distributed uniformly over all depths ($X^2_{(2)} = 0.105$, $p = 0.949$). The calf/cow ratio, however, was somewhat higher in waters shallower than 50 m (Table 12). During the second leg of the cruise, water depths ranged from 20 to 71 m (median, 37 m), and adult females again were distributed uniformly over all depths ($X^2_{(2)} = 1.294$, $p = 0.524$). As on the first leg, the ratios of most of the juveniles to adult females also were homogeneous, but the calf/cow ratio was heterogeous to a significant degree. This time, however, the calf-cow pairs occurred more often than expected over the deeper, rather than the shallower depths (Table 13).

Table 9. Ratios of juvenile walruses to adult females per time interval in the Chukchi Sea, July 1981. Data are from groups classified by Fay, during the POLAR STAR cruise. Small sample size in the evening hours required combination of the afternoon and evening intervals for several of the Chi-squared tests, hence reducing the degrees of freedom.

Age class	Time interval (hrs)					
	0800-1300	1300-1800	1800-2200	X^2	d.f.	p
Calves	0.018	0.033	0.080	2.726	1	0.099
Yearlings	0.018	0.011	0.040	0.118	1	0.731
2 yr olds	0.050	0.030	0.080	0.814	1	0.367
3 yr olds	0.077	0.049	0.000	3.316	1	0.069
4-5 yr olds	0.148	0.129	0.120	0.478	2	0.787
(No. of adult females)	(339)	(364)	(50)			

Table 10. Ratios of juvenile walruses to adult females per time interval in the Chukchi Sea, July 1984. Data are from groups classified during the ALPHA HELIX cruise.

Age class	Time interval (hrs) 0600-1000	1000-1400	1400-1800	1800-2200	$X^2_{(3)}$	P
Calves	0.073	0.030	0.051	0.088	5.397	0.145
Yearlings	0.065	0.030	0.038	0.027	6.074	0.108
2 yr olds	0.062	0.164	0.035	0.061	14.333	0.0025*
3 yr olds	0.054	0.060	0.030	0.059	3.918	0.270
4-5 yr olds	0.081	0.104	0.051	0.100	5.993	0.112
(No. of adult females)	(361)	(95)	(468)	(655)		

Table 11. Ratios of the juvenile age classes to adult females in relation to water depth in the eastern Chukchi Sea, July 1981. Data are from groups classified by Fay during the POLAR STAR cruise.

Age class	Water depth (meters) 20-29	30-39	>39	$X^2_{(2)}$	P
Calves	0.045	0.016	0.000	9.488	0.009*
Yearlings	0.018	0.012	0.032	1.529	0.466
2 yr olds	0.041	0.034	0.074	2.558	0.278
3 yr olds	0.070	0.028	0.116	10.530	0.005*
4-5 yr olds	0.152	0.084	0.274	16.550	0.000*
(No. of adult females)	(343)	(321)	(95)		

Table 12. Ratios of the juvenile age classes to adult females in relation to water depth in the Chukchi Sea ice edge, July 1982. Data are from groups classified during Leg 1 of the ENTUZIAST cruise.

Age class	Water depth (meters) 20-39	40-49	>49	$X^2_{(2)}$	P
Calves	0.289	0.252	0.088	5.617	0.060
Yearlings	0.000	0.077	0.088	3.588	0.166
2 yr olds	0.044	0.017	0.000	2.749	0.253
3 yr olds	0.000	0.037	0.035	1.663	0.435
4-5 yr olds	0.133	0.086	0.070	1.125	0.570
(No. of adult females)	(45)	(349)	(57)		

Table 13. Ratios of the juvenile age classes to adult females in relation to water depth in the Chukchi Sea ice edge, August 1982. Data are from groups classified during Leg 2 of the ENTUZIAST cruise.

Age class	Water depth (meters) 20-29	30-39	>39	$X^2_{(2)}$	p
Calves	0.069	0.116	0.172	7.253	0.027*
Yearlings	0.086	0.058	0.086	1.907	0.386
2 yr olds	0.026	0.010	0.016	2.223	0.329
3 yr olds	0.039	0.038	0.031	0.135	0.935
4-5 yr olds	0.064	0.058	0.094	1.729	0.421
(No. of adult females)	(233)	(396)	(128)		

Weather

We did not undertake the analysis of our results in relation to weather, because the only samples with precise meteorological data were those from the POLAR STAR and OCEANOGRAPHER, in which the weather was not variable enough to warrant testing.

Seasonal Variation in Group Size

Our monthly summary of the 21 data sets with information on group size of Pacific walruses on the pack ice showed some strong seasonal trends (Table 14). For example, groups of 1 to 2 animals made up 50 to 75 percent of all on-ice groups in late winter in the Bering Sea but declined to a low of 10 to 20 percent by mid- to late summer in the Chukchi Sea. Conversely, the larger groups were least numerous in winter and most numerous in spring and summer. The majority of groups on the ice in the Chukchi Sea in summer ranged in size from 3 to 15 animals. Groups of more than 30 animals were uncommon in winter, more numerous in spring, and most numerous by late summer.

Estimation of Optimal Sample Size

For calculation of the optimal size of the samples, one must take into account the approximate size of the population being sampled and the expected ratios of each of the juvenile cohorts to the adult females (Czaplewski et al. (1983). Using the census estimates of walruses in the Chukchi Sea by Johnson et al. (1982), Fedoseev (1984), Fedoseev and Razlivalov (1986), and Gilbert (in press), we estimated that the maximal number of walruses (N) summering there in recent years has been about 180,000. The accuracy of that estimate may be open to question, but variation of N between 100,000 and 200,000 had negligible effect on the calculation of sample size, hence the method is not sensitive to errors in populations of that magnitude. Judging from the composition of our test samples, the adult females may make up as much as 75 percent of that number. Calves were less than 30/100 cows; yearlings, 2 year olds, and 3 year olds were less than 10/100 cows each, and the number of 4-5 year olds always was less than 15/100 cows. Those rounded values were used, therefore, in the calculation, since the larger the juvenile/cow ratios, the larger the sample required, and the better the precision of the estimates.

The hypothesized maximal numbers of juveniles per 100 cows and the sample sizes (n) of each age class required to estimate the actual ratios with 95 percent confidence are shown in Table 15. The optimal sample size was derived as the sum of the estimates for the five juvenile age classes (922) plus the maximal number of cows required for any class (1,493). Thus the optimal sample for estimating ratios up to those used in the calculation will be 2,415 cows and juveniles, or about 2,500 animals in all, including any subadult and adult males.

Table 14. Seasonal variation in frequency of occurrence of on-ice walrus groups in four size classes.

Data set	Dates	No. of groups	Group size 1-2	3-15	16-30	> 30
ZVIAGINO '81	25 February-15 March	336	74.7	17.3	4.5	3.6
AERIAL '60	23 February-2 March	512	51.8	42.2	2.7	3.3
BURTON I.'72	27 February-24 March	72	69.4	20.8	4.2	5.5
ZAKHAROVO '85	17-30 March	32	71.9	28.1	0.0	0.0
AERIAL '61	21-30 March	410	52.0	31.5	4.9	11.7
ZAGORIANY '76	17 March-18 April	115	51.3	39.1	7.0	3.5
GLACIER '71	31 March-20 April	88	61.4	35.2	2.3	1.1
AERIAL '72	11-16 April	525	33.3	36.8	12.8	17.3
AERIAL '68	16-23 April	515	41.6	39.4	8.7	10.3
POLAR STAR '80	17-21 May	113	34.5	41.6	13.3	10.6
POLAR STAR '80	5-16 June	52	30.8	59.6	5.8	3.8
POLAR STAR '81	16-28 July	297	23.2	49.5	15.2	12.1
ALPHA HELIX '84	20-24 July	137	14.6	63.5	13.1	8.8
ENTUZIAST-1 '82	26 July- 3 August	131	30.5	53.4	12.2	3.8
ENTUZIAST-2 '82	5-17 August	259	16.2	57.5	14.3	12.0
ZYKOVO '83	16-18 August	65	15.4	73.8	10.8	0.0
ALPHA HELIX '73	21 August-2 September	138	15.2	63.0	13.0	8.7
AERIAL '75	5-12 September	149	14.8	30.2	19.5	35.6
OCEANOGRAPHER'81	13-14 September	42	9.5	45.2	9.5	35.7
ZAKHAROVO '87	26 September-17 October	44	70.4	20.4	6.8	2.3
ZAKHAROVO '84	27 November-12 December	133	40.6	49.6	8.3	1.5

Table 15. Hypothetical composition of the Chukchi Sea summer population of adult females and juveniles and calculated minimal sample sizes needed for estimating actual juvenile/cow ratios, with 95% confidence limits set at ±3/100 cows.

Juvenile age class	Hypothetical no./100 cows	Calculated no. in population (n)	Minimal sample size	
			No. of juveniles	No. of cows
Calves	30	2,133	640	1,493
Yearlings	10	515	52	463
2 yr olds	10	515	52	463
3 yr olds	10	515	52	463
4-5 yr olds	15	842	126	716

DISCUSSION

The method used for obtaining the data reported here has been evolving for many years. Our goal in developing it has been to obtain data that could be used to estimate the net productivity of young, the survival rates of the juvenile year-classes, and the recruitment rate of adolescent females into the the breeding population, hence our emphasis has been on getting the best estimates of each of the juvenile age classes in relation to the adult females. Until our first major test of the method on the POLAR STAR cruise in 1981, however, there were still many essential aspects of the natural history of walruses unknown, so we really did not know whether the method could yield the kind of representative samples desired. Later, as we summed up the results from that first test, we were encouraged to find that the 1980 year class appeared in it as a very small cohort. Since we knew that the calf production in 1980 had been the poorest ever measured up to that time (Fay and Stoker 1982a,b), the data from our first test appeared to be confirmation that the method was sensitive. At least it could detect major differences between cohorts, even with rather small samples. We subsequently derived further encouragement from the finding that the 1980 cohort was the smallest also in four out of the other five samples (Table 16), as well as in a few others that were smaller and collected under less organized circumstances. Very clear, however, was the fact that the samples were not alike in some other respects, possibly as a consequence of sampling error, but perhaps due to unknown sources of bias.

Our analyses have identified the principal source of bias as the comparative ease of classifying dependent (calf or yearling)-cow pairs versus all others. This was particularly strong and uncontrollable in the data from the animals in the water. Sample size of in-water animals often was small, but the disparity in composition relative to on-ice groups was consistently great and highly significant. The difference lay in the much higher proportion of dependent-cow pairs in the in-water samples. Identification of this as a bias, rather than an actual difference in composition, is based on the inordinately high proportion of group size 2 in the completely classified, in-water samples. Whereas individuals or groups of animals unaccompanied by young were most often classified as "unknown," dependent-cow pairs are easily classified, because of their contrasting size, coloration, and behavior. This source of bias is easily dealt with, simply by excluding the in-water sample from the data set used for estimating composition.

The ease of classifying dependents and young also appears to have biased the samples classified by inexperienced observers. On the POLAR STAR cruise they consistently tended to overestimate the ratios of juveniles to adult females, which suggests that they were achieving highest success by classifying groups containing the highest proportions of females and dependents. That is, they inadvertently were exercising selection of those groups in which the most easily classified animals occurred. The inexperienced observers also had difficulty in distinguishing between adult females and juvenile males, which frequently resulted in incompletely classified groups. Where they did succeed in identifying the adults, they frequently misjudged the relative age of the young. Since the goal was to make the inexperienced observers equal to experienced observers in effective sampling, it became clear that they must be trained sufficiently beforehand and tested. Training for recognition of sexes and age classes is not difficult

Table 16. Number of juveniles/100 cows per sample and the 95% confidence limits for those ratios. The 1980 year-class is highlighted.

Sample	n	Age class	No. per 100 cows	95% confidence limits
POLAR STAR	975	Calves	2.90	1.22
		Yearlings	**1.71**	**0.93**
		2 yr olds	4.22	1.48
		3 yr olds	5.80	1.75
		4-5 yr olds	13.83	2.80
OCEANOGRAPHER	396	Calves	2.91	1.92
		Yearlings	**1.62**	**1.42**
		2 yr olds	2.27	1.69
		3 yr olds	4.85	2.51
		4-5 yr olds	7.77	3.21
ENTUZIAST-1	597	Calves	26.77	5.72
		Yearlings	8.08	2.90
		2 yr olds	**2.02**	**1.41**
		3 yr olds	3.79	1.94
		4-5 yr olds	10.10	3.27
ENTUZIAST-2	985	Calves	11.10	2.49
		Yearlings	7.13	1.96
		2 yr olds	**1.59**	**0.90**
		3 yr olds	3.70	1.38
		4-5 yr olds	6.61	1.88
ZYKOVO	478	Calves	11.26	3.63
		Yearlings	7.69	2.95
		2 yr olds	2.47	1.63
		3 yr olds	**2.47**	**1.63**
		4-5 yr olds	7.42	2.89
ALPHA HELIX	1365	Calves	7.16	1.67
		Yearlings	4.10	1.24
		2 yr olds	6.20	1.54
		3 yr olds	4.87	1.35
		4-5 yr olds	**7.92**[1]	**1.75**

[1]The 1980 cohort made up only part of this number.

with an appropriate set of slides and video tapes.

The dependent/cow ratio was consistently higher in groups of up to 50 animals than in the larger groups, and the 4- to 5-year-old adolescents were consistently most numerous in groups of less than 15. Both of these tendencies may have a slight inflating influence on the juvenile/cow ratios of samples obtained only from small groups, but the main effect of group size on the sampling was that the ability of the observers to classify groups completely was negatively correlated with group size. All observers were comparatively unsuccessful in classifying large groups, and the inexperienced observers had the most difficulty. This was mainly a function of speed in making judgements about the sex and age of individual animals. It resulted in infrequent sampling of large groups, which appears likely have a slight influence on composition of the sample. Hence, representative sampling of all group sizes clearly is the ideal condition, but the effect on the ratios from undersampling of large groups appears to be easily mitigated by extrapolation.

Although the distribution of subadult and adult males showed a distinct affinity for the nearshore habitats on both sides of the Chukchi Sea, there was no consistent indication of east-west geographical variation in the juvenile/cow ratios. Also there was no consistent variation in the ratios of dependent young to adult females in relation to either time or water depths, which indicates that the sampling can be done representatively throughout the breadth of the Chukchi Sea, without reference to time of day or bathymetry. The one sample (POLAR STAR) that allowed testing for relationships between juvenile/cow ratios and distance into the pack from the edge implied that the calf/cow and, perhaps, some of the other juvenile/cow ratios were slightly higher near the edge than deeper in the pack. If that is the case, then sampling along the ice edge may result in somewhat inflated juvenile/cow ratios. This was not a very large sample, however, hence the meaning of its heterogeneity is open to question. Certainly, this matter needs to be tested further.

Much of the observed variation within and among our samples probably was due to sampling error, magnified as a consequence of the small size of the samples. Because these tests were done mainly on an opportunistic basis, we had no prospect of obtaining samples of any specific size, but it was clear that the optimal sample size must be taken into account in future testing and practice. Calculation of the optimal sample size is highly dependent on the magnitude of the juvenile/cow ratios and the level of precision desired, whereas the accuracy of the population estimate is comparatively unimportant (Czaplewski et al. 1983). With the Chukchi summering population size about 180,000 individuals (Johnson et al. 1982; Fedoseev 1984; Fedoseev and Razlivalov 1986; Gilbert in press), about 95 percent of which are females and juveniles of both sexes, the sample size required for an estimate with precision of $\pm$ 3 juveniles in each age class/100 cows (95% C.I.) will be about 2,500 animals, which is rather larger than any obtained so far.

Since the ease of sampling is partly a function of group size, the seasonal changes in distribution and in occurrence of groups of different sizes should be taken into account when selecting the time and place for sampling. The location and nature of the ice also will constrain the areas occupied by the walruses and accessible by vessel. Therefore, design of a sampling scheme that involves censusing strips or quadrats is not realistic. The most practical approach is to consider the individual animal as the sampling unit, as described by Czaplewski et al. (1983). That approach has four requirements: (1) that the population is clearly defined in area, (2) that individuals are sampled randomly, (3) that there is a known upper limit to the population size, and (4) that sampling occurs without "replacement." All of those requirements can be met by the method described here.

The occurrence of groups of different sizes appears to be partly due to seasonal changes in social behavior and partly to segregation of the sexes. The smallest groups (1 and 2) in winter are made up mainly of adult males, which mostly haul out singly at that time (breeding season) (Fay et al. 1984). After the breeding season, the males become progressively more gregarious, but by June, most of the adult males have left the ice and returned to their summer haulouts on shore. For the most part, they do not rejoin the females on the ice until autumn.

The so-called "nursery herds" that assemble during the northward migration in spring (Burns 1970) occasionally contain several hundred individuals, mainly adult females with newborn young. Such large herds are uncommon in summer in the Chukchi Sea, perhaps because the females and young occupy much smaller floes in summer than they do in winter (Wartzok and Ray 1980). More than half of the groups in the Chukchi Sea in summer are made up 3 to 15 individuals, which are ideal for sampling. Apparently, there is a shift from small to increasingly larger groups in September. That shift may be related to aggregation on specific food sources or, perhaps, to change in ice quality.

Although the highest frequency of small groups is in winter in the Bering Sea, that is not a practical time or place for sampling, since the wintering areas can be reached only with icebreaking vessels, the daylight period is short, and most of those small groups are only of adult males (Fay et al. 1984). The Chukchi ice edge in July-August appears to be the best choice, because the animals are accessible with only an ice-strengthened vessel, there is 24-hr daylight, the group size is mainly 5 to 15, and the animals are not shy of ships. This timing is indicated also by the fact that virtually all of the females and dependent young from the entire population are in the edge of the Chukchi pack at that time, rather than widely dispersed into the pack, and most of the adult males are still in the Bering Sea (Fay 1982; Fedoseev 1982). The floes on which the walrus herds haul out to rest in summer are mostly about 100 m^2 in area (Wartzok and Ray 1980) and tend to be very oblong. As a result, the animals often lie along the floes in one or two ranks, which makes them easy to count and classify. Also, because most of the animals are far enough away from the subsistence-hunting villages at that time, shipboard surveys can be conducted without conflicting with native subsistence harvests.

The amount of time required for obtaining a sample of 2,500 animals, given ideal conditions, may be 1 or 2 days. Realistically, more time than that probably will be required, for the sampling efficiency will vary with the density and location of the aggregations, weather, and observer fatigue. Fog and snow squalls are can be frequent in the vicinity of the pack ice in summer, reducing visibility nearly to zero much of the time. The sampling, therefore, must make maximal use of the fair weather, preferably by locating the main aggregations beforehand, so that transit time between them is minimal.

CONCLUSIONS AND RECOMMENDATIONS

Ideally, the main aggregations in the sampling area should be located by means of aerial reconnaissance, just before the sampling gets underway. The sampling itself should be done from the "flying-bridge" of an ice-strengthened or icebreaking vessel in the Chukchi Sea in July. An icebreaker would be almost essential for a re-test of the relationship of juvenile/cow ratios with depth into the pack.

The classifications of all groups must be complete and firm, and only those groups lying on the ice should be sampled. For best results, the sampling should be done swiftly (1-2 days, if possible), over a wide area, and groups of all sizes should be sampled as equally as possible. The only significant bias is likely to be from the comparative ease of identifying dependent-cow pairs versus all others, which can be minimized by excluding all in-water groups from the sample and by adequate training of observers.

The resulting calf/cow ratio will provide a nice estimate of the net productivity at the time of the sampling, and comparison among years of the relative strength of the juvenile year-classes will permit estimation of their survival rates. The relative numbers of 4-5 year olds will form the basis for estimates of recruitment of adolescents into the breeding population. Sampling should be conducted annually, if possible, to permit comparisons between years for changes in those parameters.

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