PROCEEDINGS OF A WORKSHOP CONCERNING WALRUS SURVEY METHODS

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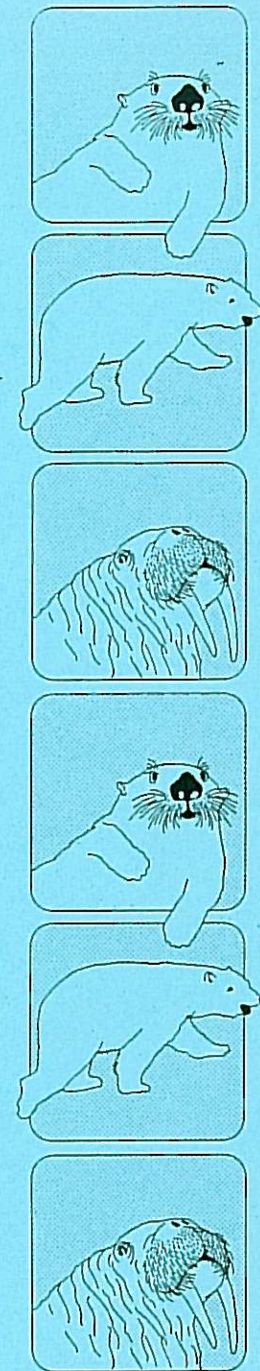
MARCH 27-28, 2000



Joel Garlich-Miller and Chadwick V. Jay
Editors

September 2000

Technical
Report
MMM 00-2

MARINE MAMMALS MANAGEMENT
Fish and Wildlife Service
Region 7, Alaska
U.S. Department of the Interior

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EXECUTIVE SUMMARY

In March 2000, the U.S. Fish and Wildlife Service and U.S. Geological Survey hosted a workshop to evaluate various techniques and approaches to estimate the size and trend of the Pacific walrus population. Workshop participants included American and Russian experts in walrus biology and survey design, subsistence hunters, and resource managers. Workshop participants reviewed previous efforts to survey the Pacific walrus population and identified problems that were encountered in designing and conducting those surveys. The group also summarized survey conditions by season and evaluated potential tools and techniques for surveying walrus populations.

Workshop participants identified and discussed several approaches to evaluate and monitor the status and trend of the Pacific walrus population. Three different survey objectives were considered: 1) Population counts that would serve as minimum population estimates (Nmin) for meeting stock assessment requirements, 2) Index counts which could be used to track population trends, and 3) Estimates of total population size with a measure of precision. There was general agreement that estimates of total population size would be more useful for stock management than would estimates of Nmin or index counts.

The workshop also considered three alternatives to conducting population surveys to evaluate population status and trends: 1) Monitoring trends in walrus life history variables, 2) Monitoring trends in the age-sex composition of the population, and 3) Monitoring trends in harvest statistics. There was a general consensus that while these techniques would provide valuable qualitative measures of population health, they would not provide quantitative information on the status and trend of the Pacific walrus population.

It is expected that the amount of survey effort required to achieve a population estimate with an acceptably small variance will be large, and therefore expensive. The overall cost of surveying the Pacific walrus population could likely be reduced through the development of new survey techniques and by focusing survey effort. Workshop participants recommended investing in research on walrus distribution and haulout patterns, and testing new survey techniques prior to conducting another survey.

Future surveys need to address the precision of derived estimates. Estimates of walrus numbers at coastal haulouts should be derived from replicate counts spanning from one haulout peak to another. Replicate sampling could also help reduce variance associated with counts of walruses in pack ice. Replicate counts over ice habitat could potentially be accomplished from an icebreaker platform located in areas where concentrations of walruses occur.

Survey effort can be maximized by flying more transects, increasing survey swath width to sample a wider area, or both. Remote sensing techniques may allow for survey aircraft to fly at higher altitudes, thereby sampling a wider survey swath.

Stratification could help focus survey area and reduce the amount of survey effort required, but will require additional research on the relationship between walrus distribution and environmental variables.

Estimating the fraction of walruses that are available to be counted during the survey period will require the development of correction factors. The most promising technique for investigating haulout periodicity is satellite telemetry. Workshop participants recommended that efforts should continue to improve immobilization techniques and transmitter design to accomplish long-term tracking and to investigate haulout behavior. Transmitters are usually attached to the tusk, but efforts should be made to investigate alternative attachment methods, including implanted transmitters.

Improving the accuracy of counts of walruses in large groups should be a goal of future surveys. High resolution aerial photography is a useful technique for counts at terrestrial haulouts, but is not practical for sampling ice habitat. The application of remote sensing technologies should be explored.

INTRODUCTION

The Pacific walrus (*Odobenus rosmarus divergens*) is represented by a single stock of animals which inhabits the continental shelf waters of the Bering and Chukchi seas. The population ranges across the international boundaries of the United States and Russia, and both nations share common interests with respect to the conservation and management of this species. Walruses are also a valuable resource to the coastal natives of Alaska and Chukotka. For thousands of years, walrus hunting has been an important source of food and raw materials for traditional equipment and handicrafts. Today, walrus hunting remains an important part of the culture and economy of many coastal villages. The need to develop international conservation efforts such as monitoring population status and trend and assessing human impacts are recognized priorities by wildlife managers and subsistence walrus hunters in both countries.

The current size and trend of the Pacific walrus population are unknown. Over the past 150 years, the size of the Pacific walrus population has fluctuated markedly in response to varying levels of human exploitation. While recent harvest levels are lower than historical highs, the lack of modern data on population status and trend precludes a meaningful assessment of the impact of the harvest. Efforts to survey the Pacific walrus population were suspended after 1990 due to unresolved problems with survey methods and budgetary constraints in the United States and Russia. Recent observations, including age-sex composition studies and reports from walrus hunters, suggest that the rate of recruitment of calves into the population has been low for the past several years. It is unknown whether the walrus population has been affected by ecosystem changes that have contributed to declines in other species of marine mammals and sea birds in the Bering Sea. Conservation organizations and the scientific community have identified the lack of information on population status and trend as a continuing threat to the Pacific walrus population.

In March 2000, the U.S. Fish and Wildlife Service (USFWS) and U.S. Geological Survey (USGS) hosted a workshop concerning walrus survey methods (Appendix 1, Workshop agenda). Workshop participants included American and Russian experts in walrus biology and survey design, subsistence hunters, and resource managers. The goal of the workshop was to identify and evaluate various survey techniques and approaches to estimate the size and trend of the Pacific walrus population.

This document summarizes the proceedings of the Pacific walrus census workshop. The report is based on the oral and written contributions of workshop participants (Appendix II and Appendix III). Supplemental information concerning previous efforts to survey the Pacific walrus population was obtained through literature review. Prior to the workshop, participants were provided with a primer on the potential application of remote sensing techniques to Pacific walrus surveys (Appendix IV). Participants also received a package of information on the seasonal distribution of walruses on sea ice, the seasonal use of terrestrial haulouts in Alaska, subsistence walrus hunting patterns, seasonal variations in sea ice coverage and weather patterns, and the capabilities of potential survey aircraft (Appendix V). Additional information on walrus haulouts in Russia was presented at the workshop, and has been included with the data summaries in Appendix V.

The workshop proceedings have been organized into eight sections, each addressing one of the following workshop objectives:

- Review previous efforts to survey the Pacific walrus population and identify the difficulties associated with designing walrus surveys.
- Summarize survey conditions (walrus distribution, weather, and ice conditions) by season.
- Evaluate various tools and techniques for surveying walrus populations.
- Identify survey approaches to obtain a population count that would serve as a minimum population estimate for meeting stock assessment requirements.
- Identify survey approaches to index the size and trend of the Pacific walrus population.
- Identify survey approaches to estimate the total size of the Pacific walrus population with an acceptable level of precision.
- Identify alternative ideas and approaches for assessing the status and trends.
- Identify research priorities to develop walrus survey methods.

SECTION 1. BACKGROUND INFORMATION

The size of the Pacific walrus population has never been known with certainty. Early efforts to survey the population were limited to abundance estimates in either U.S. or Russian waters. Surveys on the U.S. side generally occurred in the spring when animals were accessible on the sea ice in U.S. waters. Surveys on the Russian side generally occurred in the fall when counts of walruses utilizing terrestrial haulouts along the Russian coasts were maximal. Cooperative aerial surveys by the U.S. and Soviet Union (now Russia) were initiated in 1975 under the auspices of the *Agreement on Cooperation in the Field of Environmental Protection.* The 1975 survey estimated the population size at 221,360 (Estes and Gilbert 1978, Estes and Gol'tsev 1984). A second joint census, conducted in 1980, estimated population size at 246,360 (Fedoseev 1984, Johnson *et al.* 1982). A third survey, conducted in 1985, produced a population estimate of 234,020 (Fedoseev and Razlivalov 1986, Gilbert 1986, 1989). The most recent aerial survey, flown in 1990, produced an estimate of 201,039 (Gilbert *et al.* 1992), however a considerable portion of the eastern Chukchi Sea usually inhabited by walrus in more typical ice years was not surveyed because sea ice was not present. The estimates generated from these surveys should be viewed as conservative population estimates that are not useful for detecting population trends (Gilbert *et al.* 1992, Hills and Gilbert 1994). Cooperative aerial surveys were suspended after 1990 due to unresolved problems with survey methods.

The precision of previous aerial survey results were limited by biases associated with survey methods and variability in walrus haulout behavior (Estes and Gilbert 1978, Gilbert *et al.* 1992, Hills and Gilbert 1994). Differences in sampling methods between surveys have also made comparisons of previous survey results difficult (Gilbert 1999). Estimates of the number of walruses utilizing terrestrial haulout sites were typically presented as a single value without a measure of variance. Estimates of the number of walruses hauled out on ice have variously been presented with or without a variance estimate. When presented, variance estimates for the number of walruses in the pack ice were typically large with confidence limits approaching the size of the estimate. Survey effort over ice habitat has been inadequate to achieve an acceptable level of precision. The inadequate sample size of previous surveys was primarily a function of the difficulties and expense of flying aerial surveys over large remote habitats, and a poor understanding of walrus distributions and haulout behavior.

Workshop participants identified the following problems that have been encountered in designing and conducting walrus surveys:

Patchy distribution
Walruses are not randomly or evenly distributed over their potential habitat. Walruses typically haul out in groups ranging in size from two to several thousand animals. This clumped distribution contributes significant variance to abundance estimates based on strip or line transects.

Walrus haulout behavior is poorly understood
An unknown proportion of animals are in water and not available for counting during surveys. Counts of walruses at terrestrial haulouts can range from zero to thousands within a few days. Haulout behavior appears to have some degree of synchrony, however the factors influencing haulout behavior are poorly understood. This synchrony is also apparent in walruses hauling out on ice. Even during maximal haulout periods on ice and on land, some proportion of animals is likely to be in water and unavailable for counting.

Counting walruses in large groups
The contagious (clumped) haulout behavior of walruses on land and ice haulouts, results in large groups (up to several thousand animals) that are difficult to count visually with any degree of accuracy. During previous aerial-visual surveys of walruses over ice, group size was typically estimated for all groups larger than twenty animals. Estimates of group size vary between observers. Visual survey techniques provide no data record for verification of group size.

Walrus distribution and movement patterns are poorly understood
Problems associated with the capture and handling of walruses have constrained research regarding walrus distribution and behavior. Questions regarding the location of seasonal aggregations, site fidelity, diving behavior, and correlations between distribution and various habitat types remain unanswered.

Pacific walruses inhabit a dynamic and unpredictable environment
Ice conditions, weather, and concomitantly, walrus distributions, are highly variable annually and seasonally. The dynamic ice environments of the Bering and Chukchi Seas results in inter-annual variation in walrus distribution which make it difficult to predict where to focus survey effort. The Bering and Chukchi Seas also have unstable weather patterns. Fog, wind, and number of daylight hours will limit the number of days of survey effort.

Walruses are distributed over a large remote area
The vast area over which Pacific walruses are distributed presents financial, logistic, and safety concerns.

Financial considerations
The amount of survey effort required to obtain a population estimate with an acceptable degree of precision will be large, and therefore expensive. The most recent cost estimates for conducting a survey of the Pacific walrus population range from one to three million U.S. dollars. Although expensive, workshop participants pointed out that these estimates are comparable to what the

National Marine Fisheries Service (NMFS) allocated to carry out dolphin surveys in the eastern tropical Pacific. The overall cost of surveying the Pacific walrus population could likely be reduced through the development of new survey techniques and by focusing survey effort. Unfortunately, new survey techniques for walruses have yet to be developed and seasonal distribution patterns are poorly understood.

Political considerations

Pacific walruses range across the international border of the United States and Russia. A comprehensive population survey will require close international coordination. Given the current economic crisis in Russia, Russian managers are unlikely to be able to direct significant resources toward an assessment of the Pacific walrus population. Another consequence of the economic crisis in Russia is that fuel is no longer available at many of the airstrips in the Russian Far East.

SECTION 2. SURVEY CONDITIONS BY SEASON

Workshop participants identified and evaluated four potential survey periods:

- Spring (March/April)
- Summer (July/August)
- Fall (September/October)
- Transitional periods which coincide with the movement of the ice edge through Bering Strait; either early Summer (May/June), or late fall (October/November)

Challenges common to all seasons include:

- Walruses will be distributed over a large area.
- Walrus distribution over potential habitat will be non-uniform (patchy aggregations).
- Walruses will occur in large groups.
- Some proportion of animals is expected to be in the water and unavailable for counting.
- Haulout dynamics are poorly understood, but appear to be synchronous and non-random.
- It will be difficult to predict walrus distribution in pack ice, because its extent is highly variable from year to year.
- There will be a high probability of inclement weather.

Workshop participants summarized information on walrus distributions, weather, and ice conditions by season. There was insufficient information available on walrus distributions to make recommendations about the "best" season to survey. Each potential survey season has its strengths and weaknesses. There was a general consensus that the "best" season depends on the objectives of the survey.

Spring (March/April) survey conditions

Walrus distribution on ice

In early spring, most walruses are found in the pack ice of the Bering Sea. Concentrations of walruses are most likely to be found in areas where, open leads, polynyas, or thin ice occurs. The specific location of these groups will vary annually and seasonally depending upon the extent of the sea ice. Previous spring survey efforts have located walruses in open leads and polynyas in the Gulf of Anadyr, southwest of St. Lawrence Island, southeast of St. Matthew Island, and in the southeastern Bering Sea from south of Nunivak Island into northwestern Bristol Bay.

Walrus distribution on land

Walruses are not known to haulout on land in March and April.

Weather/light conditions

Early spring weather is characterized by stable clear days (relative to other seasons) with rapidly increasing daylight hours. The wind chill is often high. As the season progresses, there is a greater chance of fog and storms.

Ice conditions

In late winter/early spring, the pack ice is at its maximum extent and the ice edge is at its southernmost limit.

Benefits of the spring season

- Most walruses are expected to be associated with pack ice in the Bering Sea. This would reduce the complications of having to survey multiple habitats within a short time frame.
- The ice environment, and concomitantly walrus distribution, is thought to be relatively stable at this time. Walruses may be aggregated through the winter-spring breeding season.
- There will be good thermal contrast between walruses and ice if thermal sensors are used as a survey method.
- There will be good visual contrast between walruses and clean (snow covered) ice.
- There are increasing numbers of daylight hours for flying and a relatively good chance of having favorable weather/survey conditions.

Challenges of the spring season

- It will be difficult to predict where spring concentrations of walruses will occur.
- Walrus concentrations are likely to be distributed over a very large area.
- If the weather is extremely cold, walruses are likely to remain in the water and unavailable for viewing.
- The periodicity of walrus haulout behavior on ice is unknown and will be difficult to assess.
- A spring aerial survey over walrus concentrations has the potential to conflict with subsistence users conducting their spring walrus hunt.

Summer (July/August) survey conditions

Walrus distribution on ice

During the summer months, walruses that have migrated through Bering Strait continue moving northward with the receding ice pack. By late August, large concentrations of walruses occur near the coasts between 70° N and Pt. Barrow in the east and between Bering Strait and Wrangel Island to the west. The distribution of walrus herds in the pack ice will vary annually and seasonally depending upon the extent of sea ice.

Walrus distribution on land

During the summer season, concentrations of walruses, primarily adult males, can be found on and near terrestrial haulouts in the Bering Sea in Bristol Bay and in the northern Gulf of Anadyr. The proportion of females and dependent young utilizing summer haulouts in the Gulf of Anadyr have been increasing over the past decade. In minimal ice years, when the ice has rapidly retreated north, walruses may also use haulout sites along the north coastline of Chukotka in late summer. The peak number of walruses utilizing land haulouts in the U.S. and Russia occurs during July and August.

Weather/light conditions

Air temperatures are warm and the days are long. The Chukchi Sea is subject to extensive fog during the summer months.

Ice conditions

The extent of ice coverage during the summer season is less than in the spring, although highly variable from year to year. The ice edge is rapidly retreating north.

Benefits of the summer season

- Walruses can predictably be found in large numbers at terrestrial haulout sites in the Bering Sea. The periodicity of haulout behavior at terrestrial haulout sites could be assessed with ground-based observations.
- When the ice edge has retreated just north of Bering Strait, the potential ice habitat occupied by walruses may be at its minimum extent.
- There may be a tendency for walruses to form larger group sizes at this time (although there are few data to evaluate this assumption).
- There are many daylight hours for surveying.

Challenges of the summer season

- The proportion of animals utilizing land and ice haulouts in the Chukchi sea at this time of year are highly variable. The survey design will have to account for walruses associated with both land and ice haulouts.
- The extent and structure of pack ice will be highly variable year to year. Therefore, it will be difficult to predict walrus distribution in the Chukchi Sea.
- During summer months, walruses are actively feeding and migrating, and will be difficult to track. This movement raises the issue of double counting.
- The periodicity of haulout behavior on ice is unknown and will be difficult to measure.
- Unstable weather patterns and fog are typical for this time of year.

Fall (September/October) survey conditions

Walrus distribution on ice
In previous fall surveys, the greatest concentrations of walruses were found in the vicinity of Wrangel Island and along the northwestern coast of Alaska. Walruses were generally distributed within 150 km of the southern edge of the ice pack. By late September, walruses in the Chukchi Sea begin moving south. Based on observations at Russian haulouts in the Gulf of Anadyr and limited telemetry data from Bristol Bay, some walruses summering in the Bering Sea swim north to the Bering Strait region in the fall.

Walrus distribution on land
In minimum ice years, large concentrations of walruses can be found at terrestrial haulout sites on Wrangel Island and along the north coast of the Chukotka Peninsula. Haulout attendance appears to be a function of ice availability and weather. Walruses appear to prefer to haul out on ice whenever suitable ice flows are available. During stormy weather, walruses frequently leave terrestrial haulouts. In September, haulout attendance may be declining at Bering Sea haulouts, while peaking at haulouts along the north coastline of Chukotka and at Wrangel Island.

Weather/light conditions
Weather patterns are highly variable in the fall. Some workshop participants felt that flying conditions might be better along the Russian coastline than along the Alaskan coast. There is generally less chance of fog than in the summer season, however storms and snow squalls occur frequently. There are rapidly decreasing hours of daylight for surveying.

Ice conditions
In September, the ice edge is at its northernmost limit, and pack ice is at its minimal extent. In October, pack ice develops rapidly in the Chukchi Sea. The ice begins advancing through Bering Strait by November.

Benefits of the fall season
- Large numbers of walruses can be predictably found at terrestrial haulout sites.
- Walruses associated with pack ice are expected to occur within a narrow band along the southern ice edge.

Challenges of the fall season
- The proportion of animals utilizing land and ice haulouts in the Chukchi Sea at this time of year are highly variable. A comprehensive survey must be designed to account for animals on both ice and land.
- Haulout attendance will be affected by storms.
- There will be a lot of walruses in the water and unavailable for detection.
- It will be difficult to predict walrus distribution in the pack ice because its extent is highly variable from year to year.
- The periodicity of haulout behavior on ice is unknown and will be difficult to measure.
- There are rapidly decreasing hours of daylight for surveying.
- It will be difficult to delay a survey at this time of year due to decreasing daylight.

Survey conditions during transitional seasons

Two potential survey periods which coincide with the ice edge moving through Bering Strait were considered. The spring migration occurs primarily in May and June, while the fall migration occurs in late October and November.

Walrus distribution on ice
During the spring migration, walruses frequently haul out to rest on ice flows. During the fall migration, most of the animals are in water.

Walrus distribution on land
Many walruses remain south of Bering Strait throughout the summer utilizing haulout complexes in Bristol Bay and the Gulf of Anadyr. Based on observations at Russian haulouts in the Gulf of Anadyr and limited telemetry data from Bristol Bay, some walruses summering in the Bering Sea swim north to the Bering Strait region in the fall. During the fall migration, large mixed herds of walruses occasionally come ashore at terrestrial haulout sites in the Bering Strait region.

Weather/light
During the spring migration, the weather in the Bering Strait region is characterized by frequent storms and extensive fog. There are a maximum number of daylight hours for surveying. During the fall migration, the Bering Strait region frequently experiences storms and the number of daylight hours is rapidly decreasing.

Benefits of transitional seasons
A large number of walruses predictably move through Bering Strait (a relatively small area) over a relatively short time frame (6-8 weeks). Transitional seasons offer a potential window of opportunity for trend (index) counts.

Challenges of transitional seasons
- The Bering Strait region frequently experiences unstable weather during the spring and fall walrus migrations. There is a high probability that inclement weather will interfere with survey efforts.
- The proportion of the Pacific walrus population passing through Bering Strait each year is unknown. Many walruses will be utilizing terrestrial haulouts south of Bering Strait. The fraction passing through Bering Strait each year may be variable. The survey design must account for animals on both land and ice haulouts.
- Walruses may pass back and forth through the Strait more than once, presenting problems with double counting.
- Walruses will be actively migrating. A large proportion of animals are expected to be in water and unavailable for viewing.

SECTION 3. SURVEY TOOLS AND TECHNIQUES

Workshop participants identified and discussed potential survey tools and techniques.

Survey platforms

Fixed winged aircraft

All previous survey efforts for Pacific walruses have been conducted from fixed winged aircraft. Past visual surveys were generally flown at an altitude of 100-300 meters. Today, fixed winged aircraft remains the most versatile and useful platform for conducting walrus surveys. Fixed winged aircraft are commercially available and can be configured for a variety of survey techniques. Potential applications of fixed winged aircraft include vertical aerial photography at terrestrial haulouts and visual, photographic, or digital techniques over sea ice (see sensors). Workshop participants recommended that a survey aircraft should be a high winged, twin engine, long range aircraft.

The entire range of the Pacific walrus population can theoretically be reached by fixed winged aircraft (figure F1). The amount of survey effort possible over sea ice will be inversely related to the distance between the survey area and airstrip. During the 1990 fall survey, the sea ice was extremely far offshore, and the survey crew could only fly a few transects before they had to return to base.

Potential survey aircraft in the U.S. include Twin Otters and Aero Commanders. Potential survey aircraft in Russia include an AN-26 based in Magadan, and two AN-28s based in Kamchatka. Logistical considerations include the availability of fuel at potential airfields. It will be difficult to arrange fuel drops at remote locations, particularly in Russia. Walruses will be distributed over large and remote areas, therefore, the cost and safety of flying aerial surveys needs to be considered.

Ship (Icebreaker) with shipboard helicopters

An icebreaker with shipboard helicopters would be a useful research platform for investigating walrus haulout dynamics to develop correction factors for walruses not available for counting in ice habitat. An icebreaker could also be used in combination with a fixed winged aircraft to survey walrus concentrations in pack ice. Fixed winged aircraft could survey large areas and direct ship/helicopters to areas of walrus concentration for more intensive surveys. Shipboard helicopters could also be used to survey walrus concentrations in pack ice with replication to address cyclic haulout patterns. Participants familiar with conducting marine mammal research from helicopters cautioned that helicopters have a limited flying range over ice and are noisy. Disturbance can be minimized by flying straight past walrus groups; pilots should minimize turning or changing speeds.

The U.S. Coast Guard presently has three icebreakers available for Arctic research. In 1998 and 1999, GreenPeace contributed an icebreaker for walrus and seabird research in pack ice of the Chukchi Sea. The availability of Russian icebreakers is unknown. Russian participants suggested that Russian icebreakers might be available if outside funding were available.

Satellite systems capable of detecting walruses

Commercially available satellite imagery is not at sufficient resolution to distinguish individual animals. The new IKONOS system has 1-meter panchromatic and 4-meter multi-spectral capability which could theoretically be used to detect large groups of walruses. Potential applications of higher resolution military satellite imagery for detecting walruses at terrestrial haulouts are currently being evaluated by the USFWS. The application of military satellites for surveying walrus concentrations will be limited by the amount of imagery that can be obtained for non-military purposes. All satellite sensors capable of detecting walruses will be constrained by cloud cover and light availability.

Satellite imagery capable of detecting walruses would be a useful tool for survey stratification. The IKONOS system is potentially capable of determining the presence or absence of large walrus herds on land or ice, while military satellites could potentially be used to document the presence/absence and relative abundance of walruses at terrestrial haulouts.

Ground-based observers

Stationing observers at terrestrial haulouts is a relatively inexpensive method of monitoring haulout use and dynamics. Ground-based observers could also report weather (flying) conditions and walrus distribution in a potential survey area. At some locations, a low angle of observation limits the ability of observers to count large densely packed herds of walruses.

Natural promontories or man-made towers

As with ground-based counts, counting walruses from elevated platforms is a relatively simple and inexpensive technique. The improved viewing angle offered by natural promontories or man-made towers will help improve counts of walruses at terrestrial haulout sites. Natural promontories or man-made towers could potentially be used to monitor animal movement patterns (e.g., through Bering Strait during spring or the fall migrations).

Remotely controlled aircraft

A remotely controlled aircraft could potentially be used to obtain vertical photographs of walruses on flat terrestrial haulouts. The potential application of this technique will require further research and development.

Sensors

Visual observations/counts

Human observers are able to detect and enumerate walruses in real time with high resolution. There are problems however, associated with visual counts of walruses when group size is greater than twenty. Problems associated with observer biases can be improved by having two or more independent observers. Counts of larger walrus groups might be better done using other techniques. Visual counts are also hampered by the lack of a data record for count verification. This problem could potentially be resolved by using visual counts in combination with video or photography.

High resolution aerial photography

Vertical aerial photographs have been used successfully to count walruses on terrestrial haulouts. Aerial photographs need to be of fairly high-resolution in order to identify and count individuals, particularly calves. Previous survey efforts suggest that resolution of sufficient detail can be obtained from a large format camera flown at an altitude of up to 2,000 ft. Participants familiar with photographic survey techniques recommended having a dedicated photographer during survey effort. High resolution photography has a relatively small footprint, and is not a practical technique for surveying large expanses of ice habitat. Several participants suggested using high resolution photography in combination with other coarser sensors (see infrared/multi-spectral scanners).

Infrared/multi-spectral scanners

Infrared or multi-spectral scanners could potentially be used to sample walrus habitat at higher altitudes than visual surveys. Increasing platform altitude, and concomitantly sampling swath width, would increase sampling effort per transect. Multi-spectral or thermal scanners could potentially be used to detect walruses from a high altitude to identify high and low density strata. Although resolution may be insufficient to distinguish individual animals, airborne scanners could also potentially be used to sample an area of ice covered by walruses. Workshop participants suggested that these sensors might be used in combination with visual or photographic techniques to count walruses. An advantage of airborne imagery over satellite imagery, is that it could potentially be verified with visual or photographic methods from a single platform. Potential applications of multi-spectral or thermal sensors will require further research and development.

Digital video

Digital video has been successfully used to detect and count individually hauled out ice seals. It is unknown if the resolution of digital video is sufficient to distinguish individual walruses in a group. Potential applications of digital video techniques to count walruses will require further research and development.

Remote video

Remotely controlled video is used to study Steller sea lions hauled out at the Chiswell Islands. The Alaska Sea Life Center uses cameras capable of delivering real time, high resolution photography. A telephone satellite link is currently under development. Remotely controlled video could potentially be used to study walruses at remote haulout sites or to evaluate weather conditions prior flying a survey. Potential applications of remote video techniques will require further investigation.

Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) has the capability to penetrate through clouds. Workshop participant questioned whether the resolution of SAR was sufficient to detect walruses.

Acoustic sensors

The U.S. Navy maintains a network of underwater listening stations in the Bering Strait region. Workshop participants suggested that although it is theoretically possible to detect walruses with acoustic sensors, without information on aquatic call rates it would be difficult to assess the number of walruses passing by the sensor arrays. An acoustic array would not necessarily determine the absence of animals in the region.

Satellite imagery of ice

Real time, or near real time satellite imagery of pack ice is a potentially useful tool for survey design and stratification. Ice imagery is readily available from the National Ice Center. The lag time between the acquisition of satellite imagery and its availability on the web site is improving. Ice imagery is often available a half hour to an hour after the satellite has collected it. The resolution and classification of ice imagery may be insufficient for detailed analysis, as smaller leads and openings where walruses could potentially haulout will not appear. Microwave imagery typically has a 12.5-25 km resolution. In good weather, it is possible to collect images with a resolution of 0.5 km, which is sufficient to show larger leads. Stratification of a potential habitat will still require verification. Some participants expressed concern that satellite imagery could not distinguish between water-covered ice and open water.

Sampling design

Workshop participants found it difficult to discuss sampling design without a specific sampling strategy in mind. A few general principles were discussed.

Sampling effort

One of the biggest problems with previous walrus surveys was that insufficient levels of sampling effort resulted in large confidence intervals. Participants agreed that increasing sampling effort should be a goal of future surveys. The amount of survey effort relative to previous surveys could be increased either by flying more survey transects or by increasing the swath width of transects (by flying at a higher altitude).

Haulout dynamics

Future survey efforts will need to address synchronous haulout patterns of walruses, either through real time correction factors developed from tracking instrumented animals, or by conducting replicate counts over the same area to estimate what proportion was hauled out. One problem with sampling a location across time is the potential for animal migration. The application of replicate counts might be better suited to coastal haulouts or surveys over ice in the spring when animals are (presumably) not migrating.

Line transect surveys

Line transect survey methods have advanced significantly since the last walrus survey. One improvement, which has been used successfully in polar bear studies, is the use of two independent observers on each side of the aircraft. Cetacean surveys also use this technique with two independent observers on different decks of a ship. This double counting technique relaxes one primary assumption of line transect survey theory, namely that all animals available to be seen on the inside edge of the survey strip are detected. The analysis method used by Manly *et al.* (1996) permits the variables to be used in a logistic regression.

Adaptive sampling

Participants suggested that in-season adaptive sampling (adding survey effort in areas where high densities of walruses occur) might be one method to reduce biases associated with the contagious (clumped) distribution of walruses on sea ice. Researchers attempted to incorporate adaptive sampling into the 1990 walrus survey (Gilbert *et al.* 1992) with disappointing results. Adaptive sampling requires extra fuel and survey time which will come at the expense of standard flight lines. If adaptive sampling is incorporated into future survey efforts, additional observer and pilot training will be required. The costs and benefits of adaptive sampling over more classic search procedures will need to be explored.

Stratification

The ability to stratify census areas could help focus survey effort, and would likely reduce the variance of the estimate. Unfortunately, the relationship between walrus distribution and ice habitats is poorly understood. Stratification of a dynamic ice habitat will be difficult. It may be more practical to plan the most intensive uniform sampling regime possible, and then post-stratify during data analysis.

Correction factors

Telemetry

Researchers from USGS are currently using satellite transmitters and time-depth-recorders (TDR's) to investigate movement patterns and dive behavior of male walruses in Bristol Bay. Immobilization of walruses is still problematic. The mortality rate of drugged animals is approximately 10-15%. USGS will continue efforts to reduce the mortality of captured animals by searching for better immobilizing agents.

Satellite transmitters have successfully been attached to walrus tusks. Over the past five years, the USGS deployed approximately 50 transmitters. The longevity of the transmitters was typically less than three months. The primary causes of transmitter failures were unknown because tagged walruses were seldom re-sighted, however antenna damage was observed on several occasions.

TDR's have been deployed and retrieved from five male walruses at terrestrial haulouts in Bristol Bay. Over a one-month period, approximately 80% of their time was spent at sea, during which about 60% of the time was spent diving. Haulout attendance and dive behavior in animals using ice haulouts is likely to be different from animals hauling out on land, and will have to be quantified in order to apply corrections to survey counts over ice habitats. One participant reported reasonable success drugging walrus on ice from Russian hunting boats based off a mother-ship. The Russian delegation to the workshop suggested tagging female walruses at terrestrial haulouts along the north coast of Chukotka with long term transmitters might be easier than conducting tagging operations in pack ice. There was a general consensus that developing a reliable method of tagging walruses, either through immobilization or remotely (e.g., barbed tags) is critical to studying walrus movement and haulout patterns.

Participants pointed out that applying a correction factor to adjust for animals unavailable for sighting during a survey will add variance to the abundance estimate. The synchronous nature of walrus haulout patterns will contribute to variance associated with the correction factor, which could potentially be as large as the variance associated with the survey. The most efficient sampling design for estimating correction factors from instrumented walruses would depend on the overall survey design, but might include replicate counts over a period of time to reduce variance.

SECTION 4. APPROACHES TO OBTAIN A MINIMUM POPULATION ESTIMATE

Workshop participants identified and discussed three potential approaches to obtain a minimum population estimate (Nmin) for the Pacific walrus population. The common theme of all approaches was to maximize counts of the observable portion of the Pacific walrus population. Variations on this theme included utilizing replicate counts and correction factors to improve the precision of the estimates.

Approach 1: Maximize counts of walruses on terrestrial haulouts

Season

The optimal survey season would be sometime during the summer or fall. Information on seasonal peaks is available for most significant terrestrial haulout sites in Alaska and Russia. This information should be used to select an optimal survey period.

Approach

Conduct synchronous or near synchronous counts of walruses at all significant terrestrial haulout sites in the U.S. and Russia, using high resolution aerial photographs, remote sensing techniques, and/or ground-based observers. Maximum counts of walruses would likely be obtained during years of minimal ice coverage in the Chukchi Sea.

Benefits of the Approach

- The approach is economically and logistically feasible.
- The location of most significant terrestrial haulouts is known (Appendix V).

Limitations of the Approach

- The fraction of the population associated with the ice pack is unknown and will vary from year to year.
- An unknown fraction of walruses utilizing monitored haulout complexes will be at sea (feeding) and unavailable for counting.
- Unless all haulouts are monitored, there is the potential to miss a significant fraction of the population.
- Interpreting population trends from counts of male dominated haulouts will be difficult.
- The summer/fall survey season is characterized by unstable weather patterns. Inclement weather will influence survey conditions and walrus haulout patterns.

Recommendations to improve estimates

- Synchronize haulout counts as much as possible to reduce the chance of double counting animals that move among haulouts.
- To reduce the likelihood of missing significant concentrations of hauled out animals, maximize the number of haulouts surveyed and survey the coastline between haulouts.
- Use ground observers stationed at selected haulout sites to help determine optimal survey times (peak haulout numbers) and report on weather/flying conditions.
- Conduct replicate counts to improve the likelihood of obtaining peak numbers at haulouts.
- Develop correction factors to estimate the proportion of walruses unavailable for counting.

Approach 2: Maximize counts of walruses at terrestrial haulouts in combination with survey effort over ice habitat

Season

The optimal survey season would be similar to Approach 1 (Summer or Fall). The strategy would be to time survey effort to coincide with maximal haulout use. Existing information on seasonal peaks in haulout attendance should be analyzed to help define the optimum survey period.

Approach

Surveying walruses at terrestrial haulout sites would be similar to Approach 1. Additional aerial survey effort over ice habitat would be conducted using visual or remote sensing techniques.

Benefits of the Approach

- The location of major terrestrial walrus haulouts is known (Appendix V).
- Counting walruses at terrestrial haulout sites is economically and logistically feasible.
- The addition of aerial survey effort over ice habitat would result in a larger estimate of abundance (will reduce the negative bias of the estimate).
- Adding survey effort over ice habitat would also capture a more representative sample (across age and sex classes) than would counts from terrestrial haulouts alone.

Limitations of the Approach

Several problems encountered with counting walruses at terrestrial haulout sites are listed under Approach 1. The additional challenge of this approach would be to locate and survey concentrations of walruses in the pack ice.

Recommendations to improve estimates

Recommendations to improve (increase) the estimate of the number of walruses utilizing terrestrial haulouts are identified under Approach 1. To improve the estimate of walruses associated with pack ice, workshop participants recommended:

- Focus survey effort as much as possible into areas with large concentrations of walruses. Satellite telemetry would be a useful for locating aggregations of walruses in the pack ice.
- Survey effort can be maximized by flying more transects, increasing survey swath width to sample a wider area, or both.

- The development of correction factors for walruses hauled out on ice would help estimate the fraction of walruses in the survey area which were unavailable for counting.
- The use of an icebreaker with ship-based helicopters may prove to be a useful platform for surveying concentrations of walruses in pack ice.
- Replicate counts over ice habitat are likely to improve the accuracy of the estimate.

Approach 3: Maximize counts of walruses hauled out on ice

Season

A March/April survey period was recommended as the best time to survey concentrations in pack ice of the Bering Sea. Walruses are not known to haulout on land at this time.

Approach

Conduct an aerial survey of walrus concentrations in pack ice using visual or remote sensing techniques. The strategy would be to locate major concentration areas and maximize counts of walruses hauled out on ice.

Benefits of the Approach

- Most of the Pacific walrus population will be associated with pack ice in the Bering Sea at this time of year. This would reduce the complications of having to survey multiple habitats over a short time frame.
- There are relatively good survey conditions in the spring (abundant daylight and good visual contrast between walruses and snow-covered ice). In addition, there is considerable thermal contrast between walruses and the background environment, which makes the use of airborne infrared sensors a possibility.
- Although movement patterns are poorly understood, walrus distribution may be fairly static at this time (ice conditions are relatively stable, and animals have not yet begun migrating).
- Walruses may also be aggregated by their breeding behavior (walruses breed in late winter/early spring).

Limitations of the Approach

- Spring walrus concentrations will likely occur over a large area. Some participants felt that the potential ice habitat occupied by walruses was significantly greater in the spring than during the fall survey period.
- Extensive aerial survey effort over pack ice will present financial and safety considerations.
- The location and extent of spring concentrations of walruses are poorly known. Although walruses are most likely to be found in major concentrations in areas where leads, polynyas, or thin ice occur, specific locations of these groups are likely to vary from year to year.
- An unknown fraction of walruses will be in the water and unavailable for counting.
- Wind chill factors remain a consideration throughout March-April; walruses tend to remain in the water during periods of intense cold.

Recommendations to improve the estimate

Recommendations to improve the estimate of the number of walruses utilizing ice haulouts are identified under Approach 2.

SECTION 5. APPROACHES TO OBTAIN A POPULATION INDEX

Workshop participants identified and discussed five potential survey approaches to index the size of the Pacific walrus population. A common theme of all approaches was to conduct periodic counts of a subset of the Pacific walrus population to look for trends which might be affecting the population as a whole. Workshop participants agreed that survey approaches similar to past spring or fall survey efforts were more likely to provide a reliable population index than would counts at terrestrial trend sites, but could not reach a consensus on the best season to survey. The precision of index counts could be improved by utilizing replicate counts and correction factors.

Approach 1: Conduct annual trend counts of walruses at select coastal haulouts (index sites)

Season

The optimal survey season will be site specific. Information on haulout attendance is available for most significant terrestrial haulout sites in Alaska and Russia. This information should be used to select an optimal survey period.

Approach

Conduct annual counts of walruses at terrestrial index sites using high resolution aerial photographs and/or ground-based observers.

Benefits of Approach

- The locations of all significant terrestrial haulouts are known.
- The approach is economically and logistically feasible.

Limitations of the Approach

- Haulout monitoring studies have shown considerable annual variability in the number of walruses attending specific haulouts. Factors affecting haulout attendance are poorly understood but likely include weather and ice conditions, learned behavior, disturbance levels and proximity to prey-base.
- An unknown fraction of walruses utilizing the index sites will be feeding (at sea) and unavailable for counting.
- Interpreting population trends from counts at male dominated haulouts will be difficult.
- Changes in animal behavior (e.g., the amount of time spent away from the haulout) will be a confounding variable in interpreting trend counts.
- Although there is anecdotal evidence of individual walruses returning to the same haulout, the degree of site fidelity unknown. Walruses using one trend site in a given year may use different haulouts in subsequent years.
- Only certain segments of the population will be monitored. The relationship between walruses at index sites and the population as a whole is unknown.
- The summer/fall survey season is characterized by unstable weather patterns. Inclement weather will influence walrus haulout patterns and survey conditions.

Recommendations to improve the estimate

- Maximize the number of monitored haulouts (See Approach 2).
- Walruses are believed to use regional haulouts complexes. Synchronizing counts of walruses at index sites would reduce the chance of double counting animals that are moving among haulouts.
- Conduct replicate counts at haulouts to minimize biases associated with haulout behavior.
- Develop correction factors to estimate the fraction of walruses that are at sea and unavailable for counting.

Approach 2: Conduct annual trend counts of walruses at all coastal haulout sites

Season

The optimal survey season would be sometime during the summer or fall. The strategy would be to conduct the survey when maximal numbers of walruses are using terrestrial haulouts. Existing information on haulout attendance could help define the optimum survey period.

Approach

The primary difference between this approach and Approach 1, is the number of haulouts monitored. The strategy would be to conduct synchronous, or near synchronous, counts of walruses on all significant terrestrial haulout sites in the U.S. and Russia using high resolution aerial photographs and/or ground-based observers.

Benefits of the Approach

- The locations of all significant terrestrial haulouts are known.
- The approach is economically and logistically feasible (although more expensive than Approach 1).
- This approach would provide a more representative sample of the population than simply looking for trends at one or more index sites.

Limitations of the Approach

Many of the problems associated with using haulout counts to track trends in the Pacific walrus population listed under Approach 1, apply here as well. An additional consideration is that the fraction of population associated with ice pack tends to vary from year to year in response to ice availability. This will present a problem with interpreting information from some of the coastal haulouts in northern Chukotka which are only used during minimum ice years. Finally, coastal haulouts tend to be male dominated. It is unclear how to interpret these data.

Recommendations to improve estimates

Recommendations to improve estimates of the number of walruses utilizing terrestrial haulouts are listed under Approach 1. Workshop participants reached a general consensus that adding survey effort over ice habitat would improve the estimate (see Approach 3).

Approach 3: Conduct periodic counts of walruses at all terrestrial haulouts in combination with survey effort over ice habitat

Season

The optimal survey season would be similar to Approach 2 (Summer or Fall). The strategy would be to time survey effort with the peak use of terrestrial haulouts. Existing information on haulout attendance could help define optimum survey period.

Approach

This approach is similar to previous fall survey efforts (e.g., Gilbert *et al.* 1992). Survey techniques for coastal haulouts would be similar to Approach 2. Additional aerial survey effort over ice habitat could be conducted using visual or remote sensing techniques.

Benefits of approach

- The locations of all significant terrestrial haulouts are known (Appendix V).
- The addition of aerial survey effort over ice should provide a more representative sample of the population than looking for trends at coastal haulouts alone (more females and juveniles will be represented).
- Survey results would be comparable with previous fall survey efforts.

Limitations of Approach

Some problems associated with using haulout counts to track trends in the Pacific walrus population are listed under Approach 1.

Gilbert (1999), summarized problems associated with conducting aerial surveys for walruses over ice habitat. These include:

- The contagious distribution patterns of walruses result in estimates with a high variance.
- The synchronous haulout behavior of walruses make it difficult to estimate the fraction of walruses available for counting.
- Walruses tend to form large groups that are difficult to count visually.
- Walrus distribution and movement patterns are poorly understood.
- Ice habitat is highly dynamic and unpredictable, which make survey design difficult.
- The vast area over which the population is distributed presents logistic, financial, and safety considerations.
- Walruses will be distributed in U.S. and Russian waters. The survey will require close international coordination.

Recommendations to improve estimates

Recommendations to improve the estimate of the number of walruses utilizing terrestrial haulouts are identified under Approach 1.

To improve estimates of the number of walruses associated with pack ice:

- Focus survey efforts as much as possible. Telemetry would be a useful tool for identifying concentrations of walruses in pack ice.

- Survey effort can be maximized by flying more transects, increasing survey swath width to sample a wider area, or both. Remote sensing techniques may allow for survey aircraft to fly at higher altitudes, thereby sampling a wider survey swath.
- The development of correction factors for walruses hauled out on ice could help estimate the fraction of walruses in the survey area which were unavailable for counting.
- The use of an icebreaker with helicopters may prove to be a useful tool for surveying concentrations of walruses in the pack ice.
- Replicate counts over ice habitat are likely to improve the precision of abundance estimates.

Approach 4: Conduct periodic counts of walruses on ice in area of winter/spring concentrations

Season

A March/April survey period was recommended as the best time to survey walrus concentrations in the Bering Sea pack ice. Walruses are not known to haulout on land at this time.

Approach

This approach is similar to previous spring survey efforts (e.g., Fedoseev *et al.* 1988). The approach would be to conduct a periodic aerial survey of walrus concentrations in the Bering Sea pack ice using visual or remote sensing techniques.

Benefits of Approach

- Most of the Pacific walrus population will be located in the Bering Sea pack ice. There is only one substrate to survey, therefore, a single survey method could be applied.
- There are relatively good survey conditions in the spring (abundant daylight, good visual contrast between walruses and snow-covered ice). In addition, there is considerable thermal contrast between walruses and their background environment, which makes the use of airborne infrared sensors a possibility.
- Although movement patterns are poorly understood, walrus distribution may be fairly static at this time (ice conditions are relatively stable, and animals have not yet begun migrating).
- Walruses may also be aggregated by their breeding behavior. This approach is likely to index the breeding component of the population.

Limitations of Approach

Many of the problems associated with conducting aerial surveys for walruses over ice habitat identified by Gilbert (1999) would apply to this approach as well. Specific concerns related to conducting surveys in the spring include:

- Spring walrus concentrations will be distributed over a large area. Some participants felt that the potential ice habitat occupied by walruses was significantly greater in the spring than during the fall survey period. Extensive aerial survey effort over pack ice will present financial and safety considerations.
- The location and extent of spring concentrations of walruses are poorly known. Although walruses are most likely to be found in major concentrations in areas where leads, polynyas,

or thin ice occur, specific locations of these groups are likely to vary from year to year.
- Wind chill factors remain a consideration throughout March and April; walruses tend to stay in the water during cold weather.

Recommendations to improve estimates
Recommendations to improve estimates of the number of walruses utilizing terrestrial haulouts are identified under Approach 1. Recommendations to improve estimates of walruses associated with pack ice are listed under Approach 3.

Approach 5: Monitor walrus migration through Bering Strait

Season
The survey season would be selected to coincide with the seasonal migration of walruses through Bering Strait in either the spring or the fall. The spring migration occurs primarily in May and June. The fall migration typically occurs in October and November.

Approach
The approach would be to conduct index counts of walruses migrating through Bering Strait using some combination of aerial survey techniques (visual or remote sensing); satellite imagery; sonic tags/acoustic sensors, and/or ground-based observers east and west of the Diomedes.

Benefits of Approach
- A large number of walruses migrate through Bering Strait twice a year.
- This approach could prove to be inexpensive relative to range-wide surveys, particularly if ground observations were feasible.
- Counts of adult females and calves could be used to index productivity.

Limitations of Approach
- An unknown subset of the population would be sampled.
- Migration patterns through Bering Strait are poorly understood. It is unknown whether the same number of animals move through Bering Strait each year. Movement patterns are not necessarily unidirectional (presenting problems with double counting).
- Weather and ice conditions in the Bering Strait region during spring and fall migrations are not conducive to collecting visual, photographic, or satellite observations.
- Walruses are actively migrating during the proposed survey season. Many animals will be in water and unavailable for viewing; the likelihood of detecting animals in the water is low.

Recommendations to improve estimates
Participants recommended quantifying potential survey biases and evaluating whether or not this approach is feasible.

SECTION 6. APPROACHES TO ESTIMATE TOTAL POPULATION SIZE WITH AN ACCEPTABLE LEVEL OF PRECISION

Workshop participants identified and discussed four different approaches to obtain a population estimate with an acceptable level of precision. Three of the proposed approaches involved surveying walrus concentrations on land and/or ice haulouts and using correction factors to account for the fraction of animals unavailable for counting. The primary difference between these proposed survey approaches was the choice of a survey season. The group was unable to achieve a consensus on the "best" season to conduct the survey. More information on the seasonal distribution patterns of walruses is necessary to resolve this issue. Workshop participants also discussed the possibility of using mark-recapture techniques to estimate the size of the Pacific walrus population.

The group discussed what level of precision would be necessary for a useful population estimate. The National Marine Fisheries Service has a marine mammal task force that prioritizes marine mammal survey proposals on an annual basis. Their guidelines recommend an abundance estimate with a coefficient of variation (CV) between 0.2 and 0.3 for target species. This standard is set to avoid Potential Biological Removal (PBR) levels which are too conservative (abundance estimates with high CV's produce more conservative estimates of Nmin and concomitantly PBR). The likelihood of classifying a stock as strategic (when in fact it is not) becomes problematic when abundance estimates have CV's greater than 0.3 (Wade and DeMaster, 1999).

Approach 1: Survey walrus concentrations on land and ice haulouts in the fall corrected for the fraction not available to be counted

Season

Previous fall survey efforts have been flown in September/October when the pack ice in the Chukchi Sea is at its minimum extent.

Approach

The strategy would be to conduct synchronous, or near synchronous, counts of walruses on all significant terrestrial haulout sites in the U.S. and Russia, using high resolution aerial photographs and/or ground-based observers. Intensive survey effort would also be flown over pack ice in the Chukchi Sea in areas of known or expected concentrations of walruses using visual or remote sensing techniques. Abundance estimates would be adjusted using correction factors developed for terrestrial haulouts and ice habitat.

Benefits of approach

The primary advantage of a fall survey season is that many walruses will be associated with terrestrial haulout sites. The potential ice habitat for walruses is at its seasonal minimum.

Limitations of Approach

Problems associated with previous efforts to survey walrus populations are covered in detail by Estes and Gilbert 1978; Gilbert 1999; Gilbert *et al.* 1992; Hills and Gilbert 1994. Some of the problems encountered in previous aerial surveys include:

- Sample sizes over ice habitat were inadequate to achieve an acceptable level of precision. The inadequate sample size was primarily a function the expense of flying aerial transects over large remote habitats.
- Walrus groups were not randomly or uniformly distributed throughout potential ice habitat. The patchy distribution of walrus herds contributed a significant variance to the estimates.
- The unpredictable haulout behavior of walruses has hampered efforts to estimate the fraction of animals available to be counted. The application of satellite telemetry techniques to develop correction factors is still under development.
- The contagious haulout behavior of walruses results in large groups (up to several thousand animals) which are difficult to count.

Problems specific to the fall survey period include:

- The survey design must address both land and ice haulouts.
- The relationship between land and ice haulouts are poorly understood. A significant exchange between the two habitats could result to double counting or under counting animals.
- Fall weather patterns in the Chukchi Sea are highly unstable; storms and snow squalls occur frequently during this period.
- The number of daylight hours available for surveying is decreasing rapidly.

Recommendations to improve estimates

- Future surveys should address the precision of derived estimates. Estimates of walrus numbers at coastal haulouts should be derived from replicate counts spanning from one haulout peak to another. Replicate sampling would also help reduce variance associated with counts of walruses in pack ice. Replicate counts over ice habitat could potentially be accomplished from an icebreaker platform located in areas where concentrations of walruses occur.
- Increasing survey effort over ice habitat would potentially reduce the bias associated with the patchy distribution of walrus herds. Survey effort can be maximized by flying more transects, increasing survey swath width to sample a wider area, or both. Remote sensing techniques may allow for survey aircraft to fly at higher altitudes, thereby sampling a wider survey swath.
- Stratification could help focus survey area and reduce the amount of survey effort required, but will require additional research on the relationship between walrus distribution and environmental variables.
- Estimating the fraction of walruses that are available to be counted during the survey period will require the development of correction factors. The most promising technique for developing correction factors is satellite telemetry. Haulout patterns are likely to vary between sites. Therefore, many transmitters will need to be deployed.
- Improving the accuracy of counts of walruses in large groups should be a goal of future surveys. High resolution aerial photography is a useful technique for counts at terrestrial haulouts, but is not practical for sampling ice habitat. The application of remote sensing technologies should be explored.

Approach 2: Survey walrus concentrations on ice haulouts in the spring corrected for the fraction not available to be counted

Season

A March/April survey period was recommended as the best time to survey concentrations of walruses in the Bering Sea pack ice. Walruses are not known to haul out on land at this time.

Approach

The approach would be to conduct intensive survey effort over the Bering Sea pack ice in areas of known or expected concentrations of walruses using visual or remote sensing techniques. The fraction of walruses in the water and unavailable for counting could be estimated using correction factors developed for ice habitat.

Benefits of approach

- The primary advantage of a spring survey over a fall or summer survey period is that only one habitat type (ice) needs to be considered. A spring survey over the pack ice would be less complicated than surveying multiple habitats over a short time period and would have fewer sources of additive variance.
- There are relatively good survey conditions in the spring (abundant daylight and good visual contrast between walruses and snow-covered ice). In addition, there is considerable thermal contrast between walruses and the background environment which makes the use of airborne infrared sensors a possibility.
- Although movement patterns are poorly understood, walrus distribution may be fairly static at this time (ice conditions are relatively stable, animals have not yet begun migrating into the Chukchi Sea).
- Walruses may also be aggregated by their breeding behavior (walruses breed in late winter/early spring).

Limitations of Approach

Many of the problems identified under Approach 1 would apply to this approach as well.

Specific concerns related to conducting surveys in the spring include:

- Walruses are likely to be distributed over a larger area in the spring than in the fall.
- Extensive aerial survey effort over pack ice will present financial and safety considerations.
- The location and extent of spring concentrations of walruses are poorly known. Although walruses are most likely to be found in major concentrations in areas where open leads, polynyas, or thin ice occur, the specific locations of these groups is likely to vary from year to year.
- Wind chill factors remain a consideration throughout March-April; walruses tend to stay in water during cold weather.

Recommendations to improve estimates

Recommendations to improve the precision of abundance estimates in ice habitat are listed under Approach 1.

Approach 3: Survey walrus concentrations on land and ice haulouts in the summer corrected for the fraction not available to be counted

Season
The optimal survey season would be in June or July when the relatively intact ice edge has moved just north of Bering Strait.

Approach
Conduct synchronous, or near synchronous, counts of walruses on terrestrial haulout sites in the Bering Sea in combination with intensive survey effort along the ice edge north of Bering Strait. The survey design might include a vessel strategically stationed near walrus concentrations in pack ice and ground observers at haulouts in Bering Strait, the Gulf of Anadyr, Karaginskii Bay and Bristol Bay. Abundance estimates could be adjusted using correction factors developed for terrestrial haulouts and ice habitat.

Benefits of approach
- The summer weather is characterized by long daylight hours, warm temperatures, and low average wind velocities. There is ample time to wait for favorable weather, the potential survey day is long and general aircraft operations are easier.
- Walruses will be found along the margin of a still intact, relatively closed, ice pack just north of Bering Strait, reducing the amount of flying time required over ice.
- Large concentration of walruses will be found on coastal haulouts that are ice free.

Limitations of Approach
Many of the problems identified under Approach 1 would apply to this approach as well.

Specific concerns related to conducting surveys in the summer include:
- Frequent fog over the pack ice during summer months will make it difficult to sample the ice component of the population.
- An unknown fraction of the population may have already moved north of Bering Strait. These animals would be unavailable for counting.

Recommendations to improve estimates
Recommendations to improve the precision of abundance estimates for the number of walruses utilizing land and ice haulouts are listed under Approach 1. Satellite telemetry will also be required to verify walrus distribution during summer months.

Approach 4: Develop a mark-recapture population estimate

Approach
Workshop participants discussed using a mark-recapture approach to estimate the size of the Pacific walrus population. Biopsy darts could potentially be used to collect a large sample of tissue samples from the population and DNA fingerprinting techniques could be used to identify (mark) individual animals. Biopsy sampling of a large number of walrus could potentially be accomplished at

terrestrial haulout sites (Wiig *et al.* 2000). The population could then be re-sampled with biopsy darts or by collecting tissue samples from subsistence-harvested animals. This idea was based on the success of a genetic mark-recapture study of the north Atlantic Humpback whale (*Megaptera novaeangliae*) (see Smith *et al.* (1999) for further details).

Benefits of Approach

This approach would avoid many of the sampling biases associated aerial surveys. The approach might also prove to be cost effective relative to a range wide survey.

Limitations of Approach

This approach is untested for walruses. It will first be necessary to determine whether an adequate survey design can be developed.

Recommendations to improve the estimate

- Determine if it is possible to use DNA fingerprinting techniques on walrus skin biopsies to identify individuals.
- Determine how many "marks" and "recaptures" would be required to estimate population size with a reasonable level of precision.
- Develop a sampling strategy which meets the assumptions of mark-recapture theory. The sampling design should consider obtaining a representative sample across all age/sex categories.

SECTION 7. ALTERNATIVE APPROACHES TO ASSESSING POPULATION STATUS AND TRENDS

Workshop participants considered three alternatives to population surveys to evaluate population trends. There was a general consensus that while these techniques may provide valuable qualitative measures of population health, they would not provide quantitative information on the status and trend of the Pacific walrus population.

Approach 1: Monitor trends in life history variables

An alternative approach to monitoring the size of the Pacific walrus population would be to monitor changes in life history variables over time to infer changes in population status relative to the carrying capacity of the environment. In other pinniped species, shifts in population density have been correlated with changes in maturation and fertility rates. For example, the population of northwest Atlantic harp seals declined by more than 50% between 1950 and 1975 as a result of intense commercial harvesting. During this time, the mean age of sexual maturity dropped by approximately two years and pregnancy rates increased by approximately 10% (Bowen *et al.* 1981). These shifts in life history parameters were likely mediated by density dependent mechanisms.

Approach

Examine changes in the age of first reproduction from aging structures and reproductive organs collected from harvested animals.

Benefits of Approach

- The analytical techniques are established, and a biological sampling program is in place.
- Biological samples are relatively easy and inexpensive to collect.
- There is a large historic data set available for comparative studies.

Limitations of Approach

- The status of the Pacific walrus population relative to the carrying capacity of the environment (current and historic) is unknown. As a result, it will be difficult to interpret changes in life history variables.
- There are inherent sampling biases in collecting biological samples from harvested animals. Observed trends in sampled animals may not reflect population changes.
- The age classes over which maturation occurs are poorly represented in the harvest. As a result it will be difficult to generate a meaningful estimate of variance for comparisons between sample years.
- The carrying capacity of the environment may have changed over time.
- Observed changes in life history parameters will not provide quantitative data on population status or trend. A biological index will only be useful for monitoring the population if it can positively be correlated with population size.

Approach 2: Monitor trends in the age-sex composition of the population

Approach

Researchers at the University of Alaska have developed a field method for estimating walrus productivity, juvenile survival, and recruitment based on visual observations of skull and tusk morphology. During research cruises in 1998 and 1999, they found that the ratios of calves, 1-year-old, 2-year-old and 3-year-old animals to adult females were lower than expected, and postulated that the Pacific walrus population might be in decline.

Benefits of Approach

- A non-invasive field method of classifying the age class and sex of free ranging walrus herds has been established.
- The method provides valuable information on productivity and recruitment. Estimates of these parameters are essential for population modeling efforts.
- Future results could be compared with past efforts to look for trends in these parameters.

Limitations of Approach

- The technique requires an icebreaker platform. The cost has been offset by conducting surveys on "ships of opportunity" offered by the U.S. Coast Guard and GreenPeace.
- Sources of sampling biases are still being investigated. Observed trends in sampled animals may not reflect changes occurring at the population level.
- The method assumes adult survivorship remains constant between surveys.
- This index cannot be used to directly determine population size, although it may be useful in models that can be verified by periodic survey data.

Approach 3: Monitor trends in hunting success

Approach

Trends in hunting success may reflect changes in walrus abundance, similar to a catch-per-unit-effort index.

Benefits of Approach

- A harvest monitoring program is already in place.
- The data are relatively easy and inexpensive to collect.
- There is an historic data set available for comparative studies.

Limitations of Approach

- Trends in hunting success may also be affected by conservation education and law enforcement efforts. Hunting patterns may also be affected by changing social, political, and economic conditions as well as advancements in hunting technology.
- There is large annual variation in hunting success presumably related to prevailing weather and ice conditions (animals might be present but inaccessible to hunters).
- Most significant walrus hunting villages in Alaska and Chukotka are strategically located in core areas of abundance (seasonal). Population changes are more likely to become apparent at the periphery of the range.
- Walruses may move to other areas if food resources are limited or hunting causes too much disturbance. It will be difficult to interpret changes.
- This approach will not provide quantitative data on population status or trend.

SECTION 8. WORKSHOP RECOMMENDATIONS

Survey objectives

Workshop participants agreed that, although required by section 117 of the Marine Mammal Protection Act, a minimum population estimate (Nmin) by itself has little value as a management tool. Without knowledge of what fraction of the population is being sampled, estimates of Nmin will be negatively biased. This could lead to an inaccurate assessment of population status. If pursued, the strategy should be to attempt to count sufficient numbers of walruses to establish whether current harvest levels are sustainable.

There was general agreement that large seasonal and inter-annual variations in walrus distribution will make interpretation of index counts difficult. Social factors, learned behavior and proximity to prey probably influence locations of seasonal walrus concentrations, however, little is known about these factors. Variability associated with animal behavior also needs to be quantified; observed changes at trend sites could potentially reflect changes in animal behavior rather than relative abundance. Due to inherent sampling biases of index counts, there is a low probability of success in detecting anything short of a catastrophic decline in population size (Gerrodette 1987). The International Whaling Commission agrees with this opinion and warns managing marine mammal populations by index counts is unlikely to achieve management goals (Cooke 1995).

There was general agreement that a population estimate with a reasonable level of precision would be a more useful management tool than would estimates of Nmin or index counts. This information would meet the primary needs of resource managers: evaluating population status, monitoring population trends, and determining sustainable removal levels. Unfortunately, the survey tools and techniques necessary to obtain population estimates with an acceptable level of precision are not presently available. It is also expected that a large amount of survey effort will be required to achieve an acceptably small variance.

Survey seasons

Workshop participants were unable to reach a consensus on the best season to survey the Pacific walrus population. Each potential survey season has its strengths and weaknesses (See Section 2, Survey conditions by season). Workshop participants recommended that potential survey periods should be evaluated by comparing the relative amount of survey effort required to produce a satisfactory abundance estimate. A modeling exercise to evaluate the cost/benefit ratios of conducting population surveys during different seasons should be undertaken. Workshop participants also recommended quantifying potential sampling biases and evaluating the feasibility of conducting index counts of walruses migrating through Bering Strait in June/July.

Survey tools and techniques

Improve methods of tracking walruses

There was a general consensus by workshop participants that a survey can be designed most effectively with a better understanding of walrus movement patterns, seasonal fidelity to haulout sites and regions, and haulout periodicity in terrestrial and ice habitats. Methods for addressing these questions, much of which requires the use of telemetry, will require further development.

Current methods for the chemical immobilization and capturing of walruses provide only short handling periods and result in an undesirable number of mortalities. Researchers need to be able to reliably capture and handle animals from various age and sex classes, both on land and ice.

Movements by individual animals have been tracked from satellite transmitters, conventional VHF transmitters, and TDR's. The use of satellite telemetry has been limited by transmitter failures resulting from the rigors of attachment to the animal's tusk. Workshop participants recommended that efforts should continue to improve transmitter design to accomplish long-term tracking. Transmitters are usually attached to the tusk, but efforts should be made to investigate alternative attachment methods, including implanted transmitters.

The ability to remotely deploy either visual tags or radio transmitters using barbed tags would also be useful for the study of short-term movement patterns. Applying numerous short-lived transmitters over a brief period of time would be useful for developing correction factors during a survey. Correction factors might also be developed by using TDR's. Retrieving data from deployed TDR's is problematic and requires further investigation.

Investigate the application of remote sensing techniques

One of the major shortcomings of previous efforts to survey the Pacific walrus population has been an insufficient level of survey effort. Remote sensing techniques may allow for survey aircraft to fly at higher altitudes thereby sampling a wider survey swath. A remote sensing system capable of detecting walruses would also be a potentially useful tool for survey stratification.

Participants recommended investigating the application of airborne infrared and/or multi-spectral sensors for walrus surveys over ice. While these sensors are unlikely to distinguish individual animals from higher altitudes, they could potentially be used to sample the footprint of walrus herds. Remote sensing and photographic techniques could potentially be combined. Research is necessary to determine the optimum combination of swath width and ground sample distance that maximizes sample area and minimizes the number of animals that would go undetected.

Participants also recommended evaluating potential applications of satellite imagery for walrus surveys. Imagery from the IKONOS satellite should be examined to see if that system is capable of detecting and enumerating large walrus herds.

Investigate the application of digital video

One limitation of visual-aerial surveys of walrus herds on ice is the lack of a data record for verification of group size estimates. This problem could potentially be addressed by videotaping walrus herds. Workshop participants recommended evaluating whether or not digital video would have the resolution necessary to distinguish individual walruses in a group.

Evaluate the feasibility of using mark- recapture techniques to estimate population size

Participants recommended considering DNA fingerprinting techniques in a mark-recapture study for walruses. If a mark-recapture study is determined to be unfeasible for walruses, the DNA fingerprinting might still be a useful for studying long-range movement patterns and distribution of individuals from hypothesized stocks.

Walrus distribution and behavior

There was a general consensus that more information on walrus distribution and behavior would improve the precision of survey efforts.

Investigate seasonal distributions of walruses

As telemetry techniques are developed further, satellite transmitters should be used to track seasonal movement patterns of walruses. Workshop participants recommended deploying satellite transmitters across various age and sex classes to monitor seasonal distributions of the population. Reconnaissance surveys flown over ice habitat would also provide useful information on seasonal distributions of walrus herds.

Investigate habitat selection

The relationship between walrus distribution and sea ice characteristics could be investigated using location data collected from satellite transmitters overlain with sea ice imagery. Reconnaissance surveys or satellite imaging over ice habitat could also provide useful information on habitat selection.

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APPENDIX I: WORKSHOP AGENDA

PACIFIC WALRUS SURVEY WORKSHOP

Gordon Watson Conference Room
U.S. Fish and Wildlife Service Regional Office
1011 East Tudor Road, Anchorage, AK
March 27-28, 2000

Monday, March 27

9:00 a.m.	**1. INTRODUCTION**	
	Greetings	*Gary Edwards*
	Workshop Goals and Expectations	*Rosa Meehan*
	Review Agenda	*Joel Garlich-Miller*
9:30 a.m.	**2. BACKGROUND**	
	Review previous surveys and problems with counting walruses	*Jim Gilbert*
	Review data summaries	*Chad Jay*
		John Burns/Anatoly Kochnev
10: 00 a.m.	**BREAK**	
10:15 a.m.	**3. OUTLINE WORKSHOP STRUCTURE/OBJECTIVES**	*Robyn Angliss*
10:30 a.m.	**4. SURVEY CONDITIONS** Summarize information on walrus distribution, weather, and ice conditions by season	
12:30 p.m.	**LUNCH**	
1:30 p.m.	**5. SURVEY TECHNIQUES** Identify potential survey platforms, sensors, sampling designs, and approaches for developing correction factors, etc.	
2:15 p.m.	**BREAK**	
2:30 p.m.	**6. SURVEY APPROACHES** *Develop one or more survey approaches to obtain a population count that would serve as a minimum population estimate for meeting stock assessment requirements*	
5:00 p.m.	**END OF DAY 1**	

PACIFIC WALRUS SURVEY WORKSHOP

Gordon Watson Conference Room
U.S. Fish and Wildlife Service Regional Office
1011 East Tudor Road, Anchorage, AK
March 27-28, 2000

Tuesday, March 28

8:00 a.m.	**7. SURVEY APPROACHES** *Develop one or more survey approaches to estimate an index of population size*
10:00 a.m.	**BREAK**
10:15 a.m.	**8. SURVEY APPROACHES** *Develop one or more survey approaches to estimate total population size with an acceptable level of precision*
12:30 p.m.	**LUNCH**
1:30 p.m.	**9. WORKSHOP RECOMMENDATIONS** Evaluate the various approaches developed for each objective, review assumptions, and prioritize research recommendations
2:30 p.m.	**BREAK**
2:45 p.m.	**10. ALTERNATIVE APPROACHES TO ASSESSING POPULATION STATUS AND TRENDS** Brainstorm ideas/approaches other than enumeration for assessing status and trend of the Pacific walrus population
4:30 p.m.	**11. WORKSHOP WRAP UP** Review/clarify workshop accomplishments, group recommendations
5:00 p.m.	**ADJOURN**

APPENDIX II: WORKSHOP PARTICIPANTS

PACIFIC WALRUS SURVEY WORKSHOP

Gordon Watson Conference Room
U.S. Fish and Wildlife Service Regional Office
1011 East Tudor Road, Anchorage, AK
March 27-28, 2000

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21 March 2000

Mr. Chad Jay & Mr. Joel Garlich-Miller
U.S. Geological Survey & U.S. Fish and Wildlife Service
1011 East Tudor Road
Anchorage, AK 99503

Dear Chad and Joel:

Many thanks for the materials you sent recently about the Pacific Walrus Survey Workshop. I regret not being able to attend due to conflicts. However, I do have a few comments that I hope will prove useful. These will be brief, as you are both aware of the work with Bud Fay, Doug Wartzok, Gary Hufford and others, and you have copies of our papers. I am taking the liberty of sending copies to Jim Estes and Tom Loughlin, who I understand were invited but could not attend, and also to Gary Hufford and Doug Wartzok, to whose work I also refer herein.

First, I agree with Estes and Gilbert (1978): "Estimates of total abundance based on limited survey efforts will provide information of little reliability." Knowledge of this problem led NASA, in the mid-1970s, to initiate its "Wildlife Monitoring Program Plan," which was developed with the cooperation of management agencies and wildlife scientists. I was fortunate to be asked to attend, along with Ken Norris and others. The walrus was one of the animals chosen for initial investigation, due largely to its presumed susceptibility to advanced technology (e.g., remote sensing, radio-tracking, etc.). The Plan reflected a truism in wildlife management, that the minimal requirement for assessment is description of life history in the context of environmental relationships. This inference reaches into environmental policy in the Marine Mammal Protection Act and was stated more poetically by George Bartholomew (*BioScience*, vol. 6, No. 5: p. 324); "Indifference to a phenomenon's natural context can result in a paralyzing mismatch between the problem and the questions put to it."

The walrus falls into a difficult category because: (1) some individuals are missed in counting, leading to underestimation, and (2) an index of abundance is not known to be constant, nor are the environmental variables determined (see *Measuring and Monitoring Biological Diversity: Standard Methods for Mammals*, Don E. Wilson *et al*, Smithsonian Institution Press).

Resolution of these difficulties will not be possible absent understanding the dynamics of walrus behavior and the dynamics of habitat, principally sea ice, together and at least in principle, and quantitatively if at all possible. The information packet you have provided indicates that you may follow this logic, as it contains normalized information on sea-ice and walrus distributions together. However, as useful as this is for general purposes, it is out of scale with the problem of assessment. For example, walruses evidently choose specific sea ice types and structures for hauling out, as has long been suspected, but rarely measured. Our NASA/ONR Bering Sea Marine Mammal Experiment (BESMEX) and Ray and Hufford (1989) resulted preliminary data on distribution within the "broken pack", which need to be repeated due to possible type I and II errors. But the essential point is that means should be employed that can result in real-time, concurrent, quantitative assessment of the animals and their sea-ice habitat, in order to get a handle on hauling-out behavior, observability, and determinants of patchy distribution patterns.

Other factors needing consideration are that walruses seem to:

- exhibit fidelity to specific areas of sea ice: that is, they appear to haul out on the same or adjacent patches to rest and drift with the ice between feeding bouts, both winter and summer (but probably not during migrations);
- favor specific sea ice types, both winter and summer (but probably not during migration);
- have considerable diving synchrony: that is most are either "in" or "out" of the water, casting doubt on the utility of Fay's 1/3 : 2/3 observability index; and
- show considerable sensitivity to weather, but specific times of hauling out are not necessarily predictable on this basis alone, except perhaps for consecutive days of good weather following consecutive days of lousy weather.

All of these conclusions need a lot more work, but some principles arise out of them. One is the need for a large "window of opportunity" to await the "best" conditions. Ideally, the target should be at least three days of consecutive flying under improving weather conditions. The second is the need for repeated surveys of the same areas; for example, we estimated ~400, 1500, and 4,000 walruses on successive days in the same sea-ice area in winter (BESMEX) and also observed the same sort of thing during a summer cruise in the Chukchi Sea. I am sure that others may have similar results. What sort of statistic can be used to extrapolate the phenomenon of synchronous behavior, or of habitat choice, to the entire population, I cannot imagine (having asked several statisticians). This is all to suggest that your principle objective should be to record habitat and behavior, while doing the counting.

In this regard, there seem to be two related problems that are too often not distinctly segregated, and which require differing assessment methods. They are detectability and countability. I am convinced that detectability is best accomplished during winter by passive IR. There appears to be no other method with such high signal to background ratio. It is also pretty cheap. This does not mean there are no pitfalls; e.g., recent haulouts may give pretty good thermal signatures. There is controversy about whether counts are possible by this means (I am certain that with a bit more effort, IR would surpass visual means by a wide margin!). Therefore, for counts you might consider aircraft-borne, multi-spectral imagery, which is also pretty cheap (much less than aerial photography, all things considered). The application of these two methods may require that you beg, borrow, or steal the equipment, which is pricy, or hire it, which may not be. Also, you might have to make separate flights, possibly at different altitudes, to accomplish these two tasks. For example, you could first detect major groupings; subsequent flights could do the counting. However, I am sure that your workshop could resolve these issues in the session on "alternative approaches."

Clearly, in view of past results of low numbers of animals detected and high uncertainty in counts, alternatives are what you seek. This was the conclusion of Estes and Gilbert way back in 1978, and, I take it, the conclusion following the 1990 survey. However, Gilbert (1999) seems to follow the past, not to reflect upon it, and it contains some dubious assumptions. One is that area coverage of walruses is lesser in summer than winter, which may be so for range, but is probably not for distribution. That is, walrus distribution on sea ice is highly variable among seasons depending on sea-ice dynamics, which we do not yet sufficiently understand to make any definitive statements. This is obviously a subject for further investigation, but in my view, it simply makes sense that walruses would be most concentrated during the winter breeding season; the problem lies in detection of where that is, or those are, somewhere in the broken pack, and different from year to year. Thus, total possible range should not bias your choice of when to fly. I would also argue that the clearest weather occurs in winter, when walruses are on winter ice and where they are easier to see. Length of day should not be a problem, as "winter" in Beringia extends to the post-equinox world, not a problem for any aircraft worthy of flying there.

Whatever you decide, I wish you luck. There's obviously no simple "solution" to the problem of counting any animal and whatever solution there may be for walruses will not be cheap. I only presume that you will be reminded of the old saw: "If history teaches us one thing, it is that we don't easily learn from history," and that low-flying, visual surveys will be rejected.

Very best wishes,

G. Carleton Ray
Research Professor of Environmental Sciences

Cc: Jim Estes, Gary Hufford, Tom Loughlin, Doug Wartzok

APPENDIX IV: APPLICATION OF REMOTE SENSING TO PACIFIC WALRUS SURVEYS

Prepared by: Douglas Burn, USFWS

Introduction

Remote sensing involves obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the subject of the investigation. In that sense, visual observations constitute a form of remote sensing. However, remote sensing is more often thought of as involving a collection device such a film camera or electronic sensor.

Recent advances in remote sensing technologies offer new tools that may be useful for conducting marine mammal abundance surveys. Airborne sensors are currently available, while satellite systems with increasingly finer spatial and spectral resolutions are awaiting successful deployment. In addition to collection systems, the computer hardware and software necessary to analyze remotely-sensed data has become affordable to most scientists. The purpose of this white paper is to briefly summarize these remote sensing tools, and their potential application in surveying the Pacific walrus population.

Remote sensing concepts

In simple terms, remote sensing involves the collection of electromagnetic radiation from a portion or portions of the electromagnetic spectrum. Although the electromagnetic spectrum represents a continuum from shorter to longer wavelengths, it is generally classified into "regions" such as ultraviolet, visible, infrared, and microwave. For example, visible light covers the wavelengths from 400-700nm. In addition, the infrared portion of the spectrum is often further subdivided into near-infrared, mid-infrared, and thermal infrared regions.

Sensors can be broadly classified as passive or active, depending on the origin of the radiation they measure. An active sensor, such as synthetic aperture radar (SAR) provides its own source of radiation. Passive sensors typically record radiation that is reflected or emitted by the object of interest.

Another important concept of remote sensing is resolution. Spatial resolution refers to the size of the smallest object that can be recognized in an image. In digital imagery, spatial resolution is referred to as pixel size or ground sample distance (GSD). Spatial resolution is primarily a function of the sensor and the collection altitude. For example, a linear detector consists of an array of charge-coupled devices (CCDs). At a given altitude, this sensor may produce an image with 1-meter GSD; at higher altitudes the resulting image would have a larger GSD and correspondingly wider swath width.

Spectral resolution refers to the number and width of regions within the electromagnetic spectrum that a sensor can detect. Panchromatic sensors incorporate all visible light into one measurement, similar to black and white film. The ability to detect information beyond what the human eye can see is what sets modern remote sensing apart from traditional aerial photography. These regions are typically referred to as "bands." Depending on the number of bands a sensor has, the data are classified as single band, multispectral, and hyperspectral imagery.

Radiometric resolution refers to the number of levels available within each band, and is measured as an exponent of the number 2. A panchromatic image with 4-bit data would have 16 gray levels, while a similar image with 8-bit data would have 256 gray levels. An 8-bit image with red, green, and blue bands would have 256 levels of each color, which can be combined to produce over 16.7 million colors.

Spectral and radiometric resolution are typically fixed for a given sensor, as are the dimensions of the detector array. Therefore, while spatial resolution may be controlled by varying the collection altitude, there is a direct relationship between GSD and image "footprint." Imagery with better spatial resolution (smaller GSDs) generally samples a smaller portion of the earth.

The three types of resolution directly impact the storage requirements for digital data. Smaller GSDs, more bands, and greater radiometric resolution all increase the size of the resulting image files. Depending on these resolutions, single images can range from tens of megabytes to several gigabytes of information. Remotely-sensed data adhere to the Steven Wright maxim: you can't have everything; where would you put it?

Habitat assessment

The focus of this paper is the use of remote sensing techniques to detect walrus. However, remotely-sensed data from existing sources may also be used in survey design and to determine survey strata. A brief discussion of this subject is included below.

A number of satellite collection systems exist that can provide information about sea ice. The Advanced Very High Resolution Radiometer (AVHRR), Sea Viewing Wide Field of View Sensor (SeaWiFS), and RadarSat systems all collect oceanographic information. These systems collect information over large areas with pixel sizes in excess of 1km.

The NOAA National Ice Center interprets remotely sensed data from a variety of sources and classifies sea ice in the Bering and Chukchi seas twice per week. Given the spatial resolution of the raw data, the resulting ice classification is fairly course, and considerable variability exists within the classifications. For example, polygons with high total ice concentrations may contain leads and polynyas that may be important for walrus, but are to small to be detected and mapped. An alternative to using National Ice Center ice maps is to obtain the raw data and perform algorithms to produce classifications that are more meaningful for walrus.

Detection systems

Aerial photography has been used successfully to detect and count walrus on terrestrial haulouts in both the U.S. and Russia. However, photography is only an appropriate tool when walrus are at a known location. It would not be feasible to use aerial photography as a sampling tool, as the expense and analysis requirements would be prohibitive.

Digital cameras and video systems are a relatively new development in remote sensing. Spatial resolution of digital cameras is approaching that of photographic film. Accurately geo-referenced images and mosaics can be created by interfacing these systems with a Global Positioning System (GPS) receiver. These systems have been successfully used to map wildfires, water resources, and utility structures such as pipelines.

Airborne digital imagery has been used to a small degree. In 1989, Canadian researchers successfully detected walrus groups on ice using a Forward-Looking Infrared (FLIR) system in the thermal band. Walrus have considerable thermal contrast from their background environment of sea water, sea ice, and snow. This contrast allows walrus groups to be easily discriminated by computer analysis. Some drawbacks of this method are that individual walrus within a group are not discernable. In order to determine the number of walrus in a group, a conversion factor based on walrus size and spacing must also be used. In addition, the nature of FLIR imagery requires complicated processing and analysis. A thermal sensor that images directly below the aircraft and produce geo-referenced images would be a better collection system for walrus.

Airborne multispectral and hyperspectral systems have the potential to detect walrus, but to date have not been used for this purpose. Examples of these sensors include the Compact Airborne Spectrographic Imager (CASI) and Airborne Visible and Infrared Imaging Spectrometer (AVIRIS). These systems would be more expensive to operate than a thermal sensor. One possible advantage of a multi- or hyperspectral sensor is the use of subpixel classification algorithms. Digital sensors average the received radiation over the entire pixel size. As the GSD increases, a given pixel may include several different materials that contribute to the averaged pixel value. However, if the individual spectral reflectance of the different materials is known, it is possible to determine the proportions of these materials within a given pixel. Subpixel classification has been used with hyperspectral imagery in geological applications to detect and map various minerals. Theoretically, this technique could allow detection of walrus in imagery with large GSDs.

Until recently, commercial satellite systems (such as Landsat and SPOT) did not have sufficient spatial resolution to be useful in detecting walrus. The Landsat Thematic Mapper (TM) collects seven-band data with 28.5m resolution for bands 1-5 and 7, and 120m resolution in band 6, which is a thermal band. SPOT imagery has 10m panchromatic resolution, and 20m multispectral (3-band). The recently-deployed IKONOS satellite has 1m panchromatic resolution, and 4m multispectral (4-band). At this time, IKONOS is the only commercial satellite system that may have applicability to walrus surveys. Newer satellite systems with better spatial and spectral resolution are under development or awaiting deployment.

In addition to commercial satellite systems, classified military satellites, referred to as National Technical Means (NTM), have been made available to other Federal agencies. The spatial resolution of the panchromatic sensor is classified. However, over the past three years, the U.S. Fish & Wildlife Service has tasked these satellites and obtained imagery of walrus haulouts in Bristol Bay, Alaska. Preliminary analysis indicates that NTM data can be a useful where walrus locations are known, such as remote haulouts. However, similar to aerial photography, it is not a practical tool for sampling large areas.

Potential application

Recent work with high resolution color aerial photography indicates that a very high degree of spatial resolution is necessary to discriminate individual walrus. Counts of walrus groups in an image with a GSD of 51mm were 23% lower than an image of the same groups with a GSD of 34mm. Imagery with spatial resolution sufficient to actually count walrus would have a prohibitively small footprint. The application of remote sensing to walrus surveys will therefore require a combination of systems.

As detailed above, an airborne sensor can sample a swath of variable width dependent upon altitude. The resulting imagery can be used to determine the area sampled and detect any walrus groups present. Regardless of the sensor (thermal, multispectral, hyperspectral) or platform (airborne, spaceborne), it will not be possible to actually count individual walrus in the imagery. However, it is possible to determine the area covered by each group. A conversion factor based on the number of walrus per unit area can be used to estimate the number of walrus within each group. High resolution color aerial photography is suitable for estimating the density of walrus within a group.

A potential remote sensing system would require two components: a sensor to sample a swath of walrus habitat, and a high resolution aerial camera to photograph individual groups. Ideally, both systems would fly on the same aircraft. A portion of the walrus groups detected by the sensor could be photographed to produce the density conversion factor. The optimum combination of swath width and GSD that maximizes sample area and minimizes the number of walrus missed remains to be determined.

A remote sensing system has several advantages over a visual aerial survey. First and foremost, it may be possible to sample with a larger swath width, with uniform detection probability. Observer bias and fatigue would also be eliminated. In addition, the imagery and photography would comprise a permanent data record that could be analyzed at any time in the future. Feasibility studies are needed to determine the actual survey protocols.

APPENDIX V: DATA SUMMARIES

The distribution of walruses on ice

Figure A1. Walrus distribution by month
Copied from: Fay (1982).
Purpose: To illustrate the approximate monthly range-wide distribution of Pacific walruses.
Method: Compiled by F.H. Fay from published and unpublished sighting records collected between 1930 and 1979.

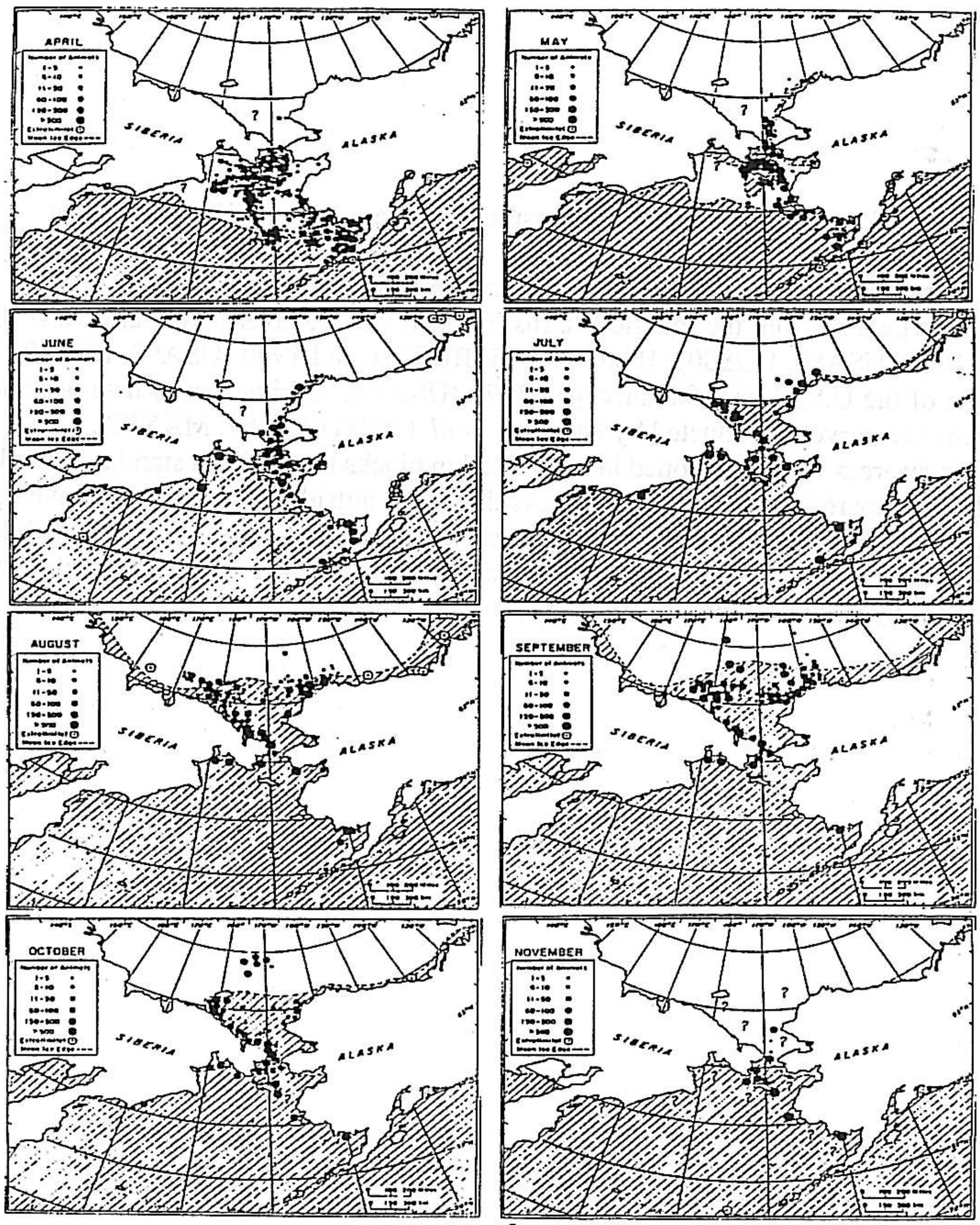
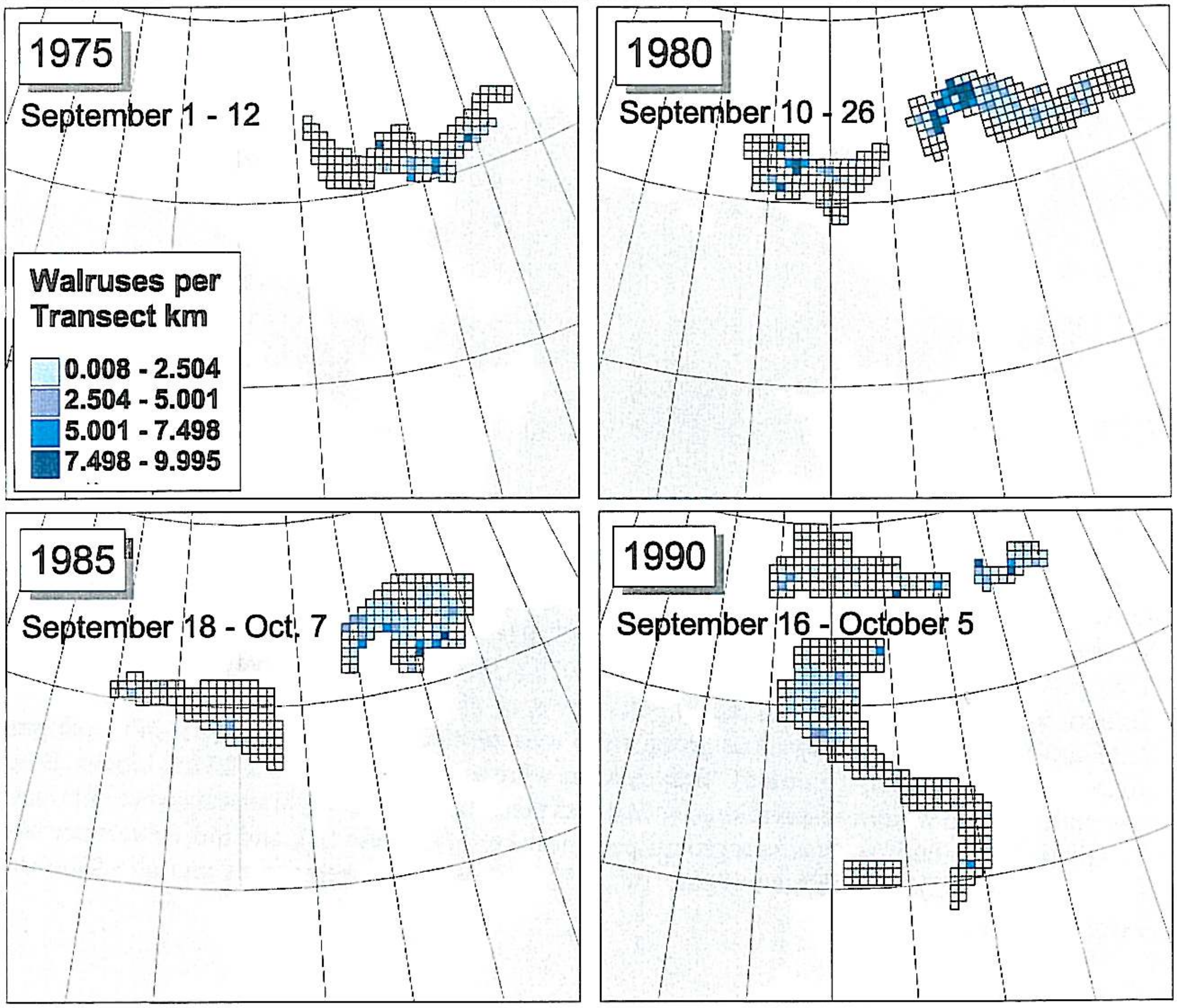


Figure A2. Spatial distributions of walrus densities in aerial surveys of Pacific sea ice
Prepared by: USGS
Purpose: To compare walrus distributions observed in spring and fall surveys.
Data: Fall survey data from the Pacific Walrus International Database: Cooperative U.S.-Soviet surveys in 1980 (USA80, RUS80), 1985 (USA85, RUS85), and 1990 (USA90, RUS90), and the U.S. portion of the U.S.-Soviet fall survey of 1975 (USA75). Spring survey data provided by J. Gilbert, from two surveys conducted by Fedoseev *et al.* (1988) (APR87, MAY87).
Method: Survey areas were partitioned into 25 x 25 km blocks to provide a standard sampling unit that could be compared across surveys. Blocks that were outside the minimum convex polygon containing all blocks in which walruses were observed were eliminated. Blocks that had less than 25 km of survey transects were also eliminated. Density was estimated within each remaining block as walruses per linear km of transect.

Fall Surveys



Spring Surveys

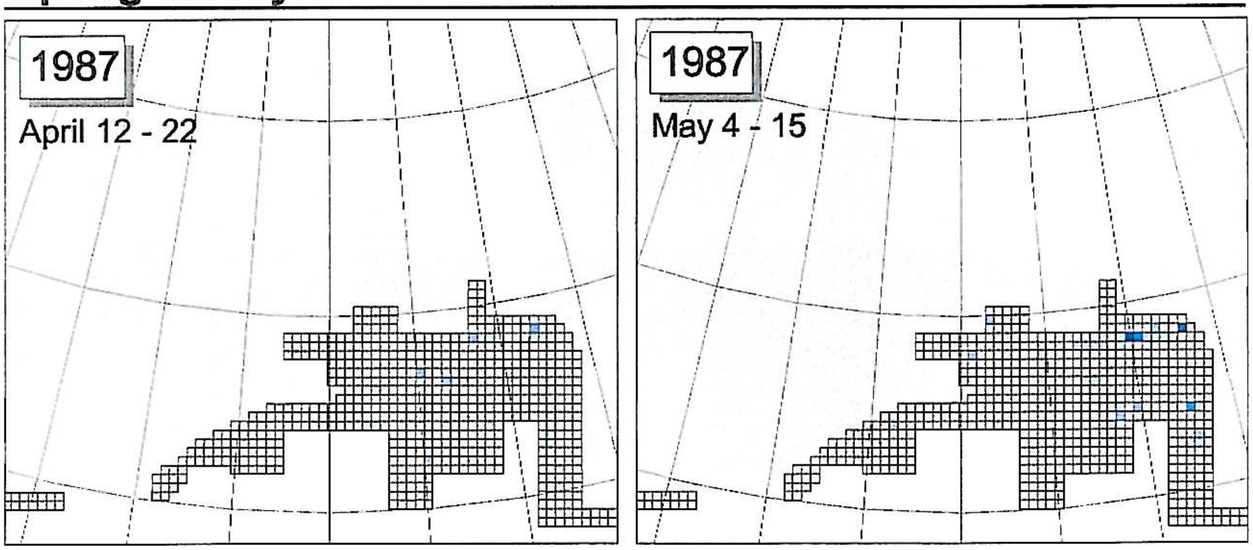


Figure A3. Walrus group sizes and densities in aerial surveys of Pacific sea ice

Prepared by: USGS

Purpose: To compare walrus distributions observed in spring and fall surveys.

Data: Fall survey data from the Pacific Walrus International Database: Cooperative U.S.-Soviet surveys in 1980 (USA80, RUS80), 1985 (USA85, RUS85), and 1990 (USA90, RUS90), and the U.S. portion of the U.S.-Soviet fall survey of 1975 (USA75). Spring survey data provided by J. Gilbert, from two surveys conducted by Fedoseev *et al.* (1988) (APR87, MAY87).

Method:(A) Distributions of walrus group sizes were plotted (except for RUS85, in which group sizes were not separately recorded). Survey areas were partitioned into 25 x 25 km blocks. Blocks that either had no walrus observations, or had less than 25 km of survey transects were eliminated. The plotted distributions represent groups per linear km of transect (B), and individuals per linear km of transect (C). Box plots indicate 10th, 25th, 50th, 75th, 90th percentiles and all of the more extreme observations.

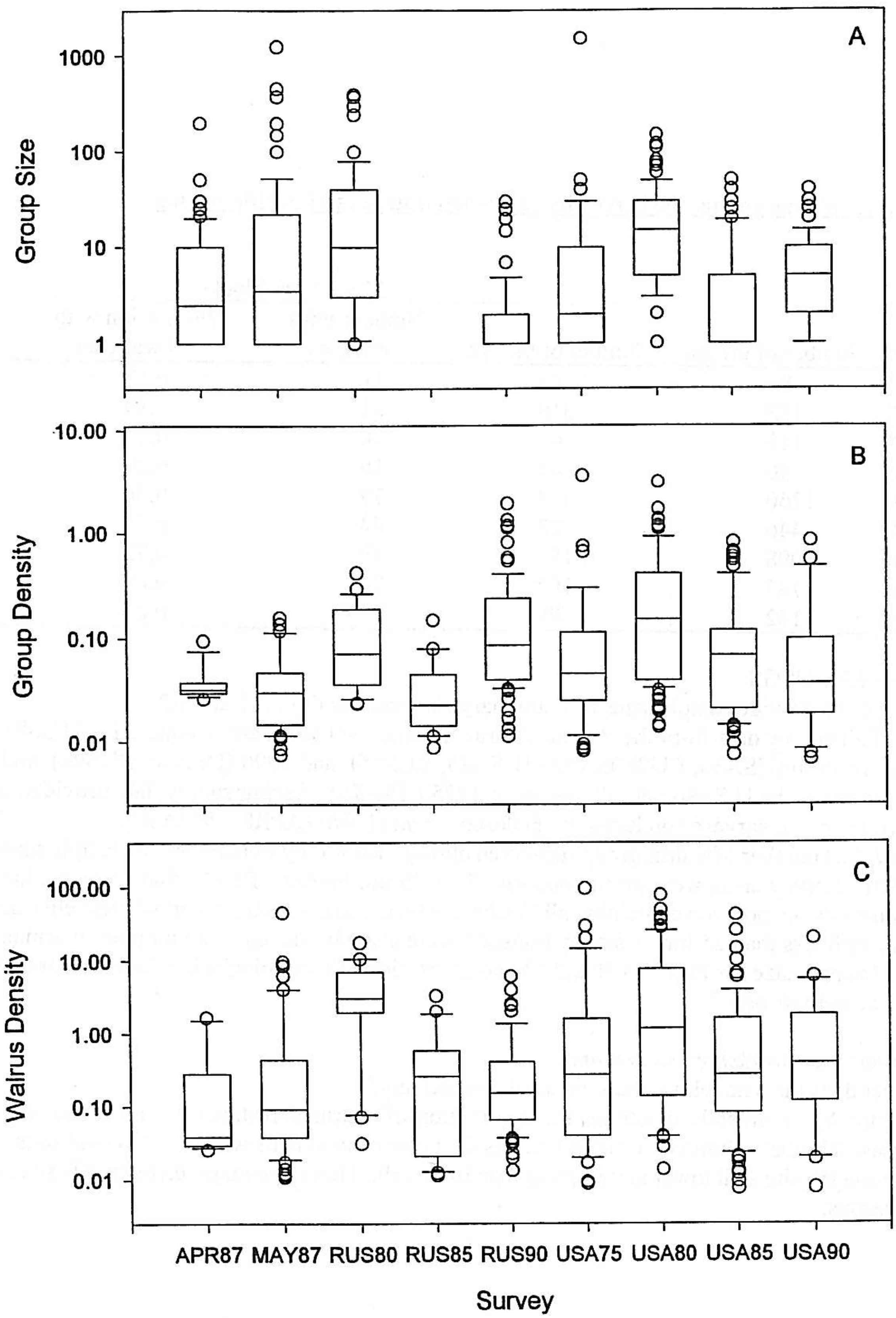

A
B
C
Group Size
Group Density
Walrus Density
1000
100
10
1
10.00
1.00
0.10
0.01
100.00
10.00
1.00
0.10
0.01
APR87 MAY87 RUS80 RUS85 RUS90 USA75 USA80 USA85 USA90
Survey

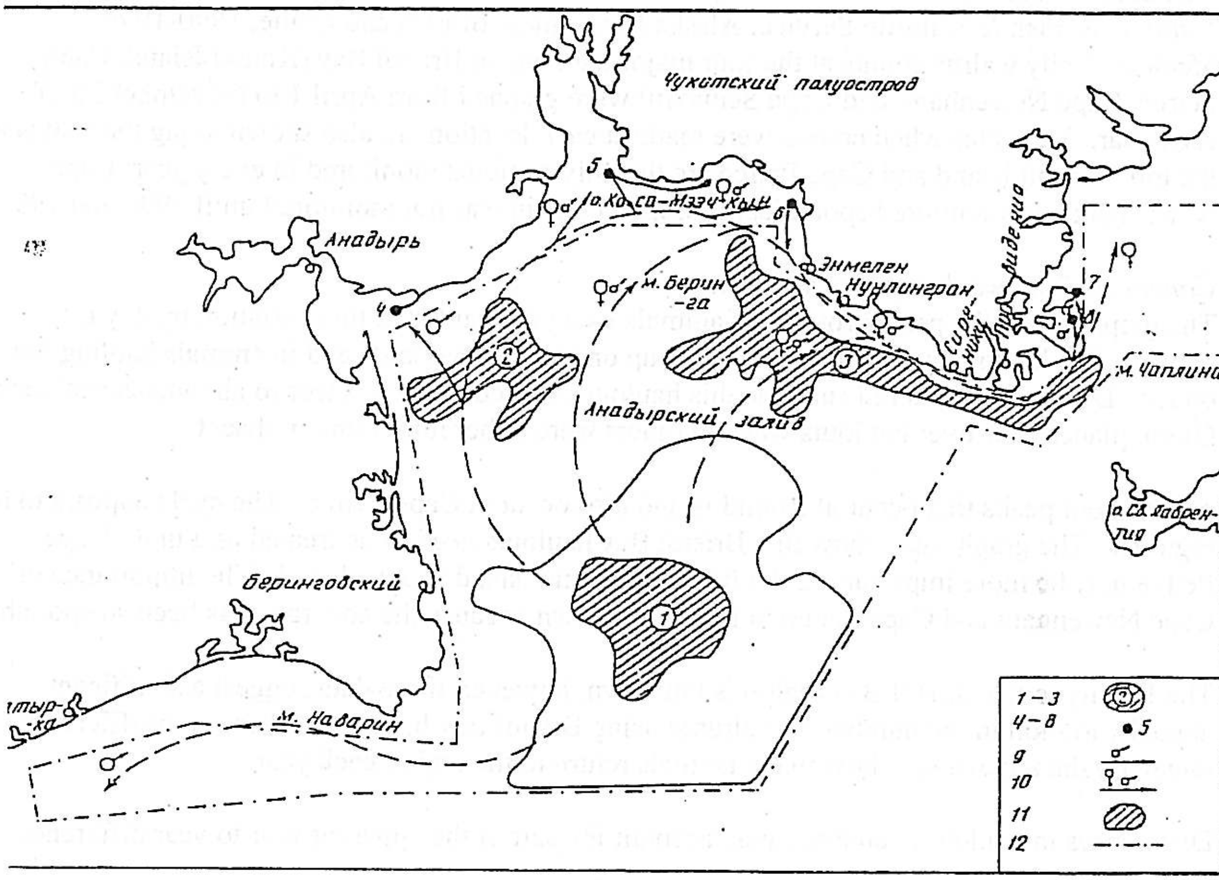
Table A1. Walrus groups and survey blocks in aerial surveys of Pacific sea ice

Survey	Number of groups	25 x 25 km blocks Number of blocks	Number with >0walruses	Proportion with >0 walruses
APR87	86	64	11	0.17
MAY87	123	319	61	0.19
RUS80	113	49	18	0.37
RUS85	46	81	16	0.20
RUS90	1260	123	79	0.64
USA75	446	83	44	0.53
USA80	1098	109	78	0.72
USA85	787	107	70	0.65
USA90	162	20	17	0.85

Prepared by: USGS
Purpose: To provide sample sizes and summary statistics for Figs. A2 and A3.
Data: Fall survey data from the Pacific Walrus International Database: Cooperative U.S.-Soviet surveys in 1980 (USA80, RUS80), 1985 (USA85, RUS85), and 1990 (USA90, RUS90), and the U.S. portion of the U.S.-Soviet fall survey of 1975 (USA75). Spring survey data provided by J. Gilbert, from two surveys conducted by Fedoseev *et al.* (1988) (APR87, MAY87).
Method: The number of walrus groups observed during each survey were recorded (sample sizes for Fig. A2). Survey areas were partitioned into 25 x 25 km blocks. Blocks that were outside the minimum convex polygon containing all blocks in which walruses were observed were eliminated. Blocks with less than 25 km of survey transects were also eliminated. The number of remaining blocks (sample size for Figs. A3-B and C) and proportion of these blocks in which walruses were observed were recorded.

Questions from workshop participants:
Q: What does the data tell us about areas of zero density?
A: Figure A2 graphically illustrates the distribution of walrus densities for those areas that had walruses. The last column of Table A1 shows the proportion of cells which had >0 walruses. The proportion is quite a bit lower in the spring than in the fall. That is the major difference between the two seasons.

Figure A4. Results of an aerial survey of walrus herds in the Gulf of Anadyr in March 1987
Copied from: Mimrin *et al.* 1990.
Purpose: To provide information on the distribution and abundance of walruses in the Gulf of Anadyr in March.
Method: Aerial survey (March 15-20, 1987) counts of walruses on ice (uncorrected).



1. Central concentration (shaded) and border (solid line). Approximately 45,000-49,000 animals.
2. Walrus concentration in the Cape Geck area. Approximately 410-480 animals.
3. Walrus concentration in the Seriniki Polyna area. Approximately 1,290-1,380 animals.

The occurrence of walruses on land haulouts

Figure B1. Bristol Bay haulout counts
Prepared by: USFWS
Purpose: To summarize the use of terrestrial haulouts in Bristol Bay, Alaska.
Data: U.S. Fish & Wildlife Service, Alaska Department of Fish and Game, 1990-1999.
Method: Daily walrus counts at the four major haulouts in Bristol Bay (Round Island, Cape Peirce, Cape Newenham, and Cape Seniavin) were graphed from April 1 to November 30 of each year. The dates when counts were made at each location are also shown along the x-axis at the top. Round Island and Cape Peirce are the only haulouts monitored in every year; Cape Newenham was monitored sporadically; Cape Seniavin was not monitored until 1998 and 1999.

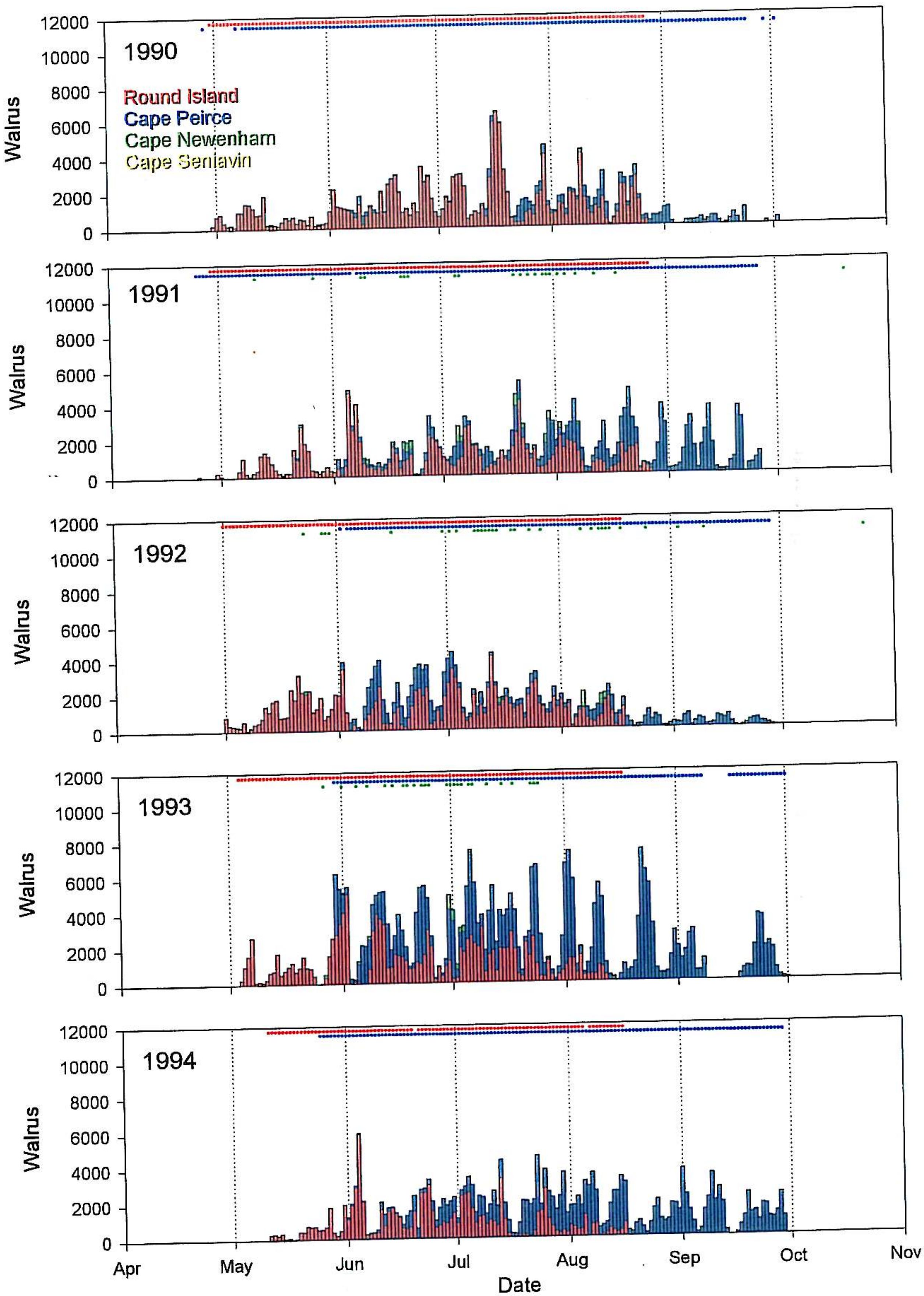
Comments from workshop participants:
The graph shows the peaks/troughs of animals using the haulouts; this variation by day is typical. The haulout synchrony also shows up on Russian haulouts and in animals hauling out on ice. During previous fall surveys, this haulout cycle contributed error to abundance estimates. Often, planes flew over haulouts when numbers were either minimum or absent.

The haulout peaks that occur at Round Island also occur at Cape Peirce. The cycle appears to be regional. The graphs also show that Bristol Bay haulouts need to be treated as a unit. Cape Peirce may be more important in the fall after Round Island is abandoned. The importance of Cape Newenham and Cape Seniavin is still unknown because the coverage has been so sporadic.

The fidelity to the Bristol Bay region is unknown, however, these data suggest a significant annual variation in the number of walruses using Bristol Bay haulouts. There is insufficient telemetry data to evaluate how many animals return to the region each year.

Differences in haulout attendance may account for part of the apparent year to year differences.

The scale of the annual variability is probably too great to be accounted for by differences in haulout attendance. There are probably different numbers coming into the system each year.


1990
Round Island
Cape Peirce
Cape Newenham
Cape Seniavin
1991
1992
1993
1994
Walrus
12000
10000
8000
6000
4000
2000
0
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Date

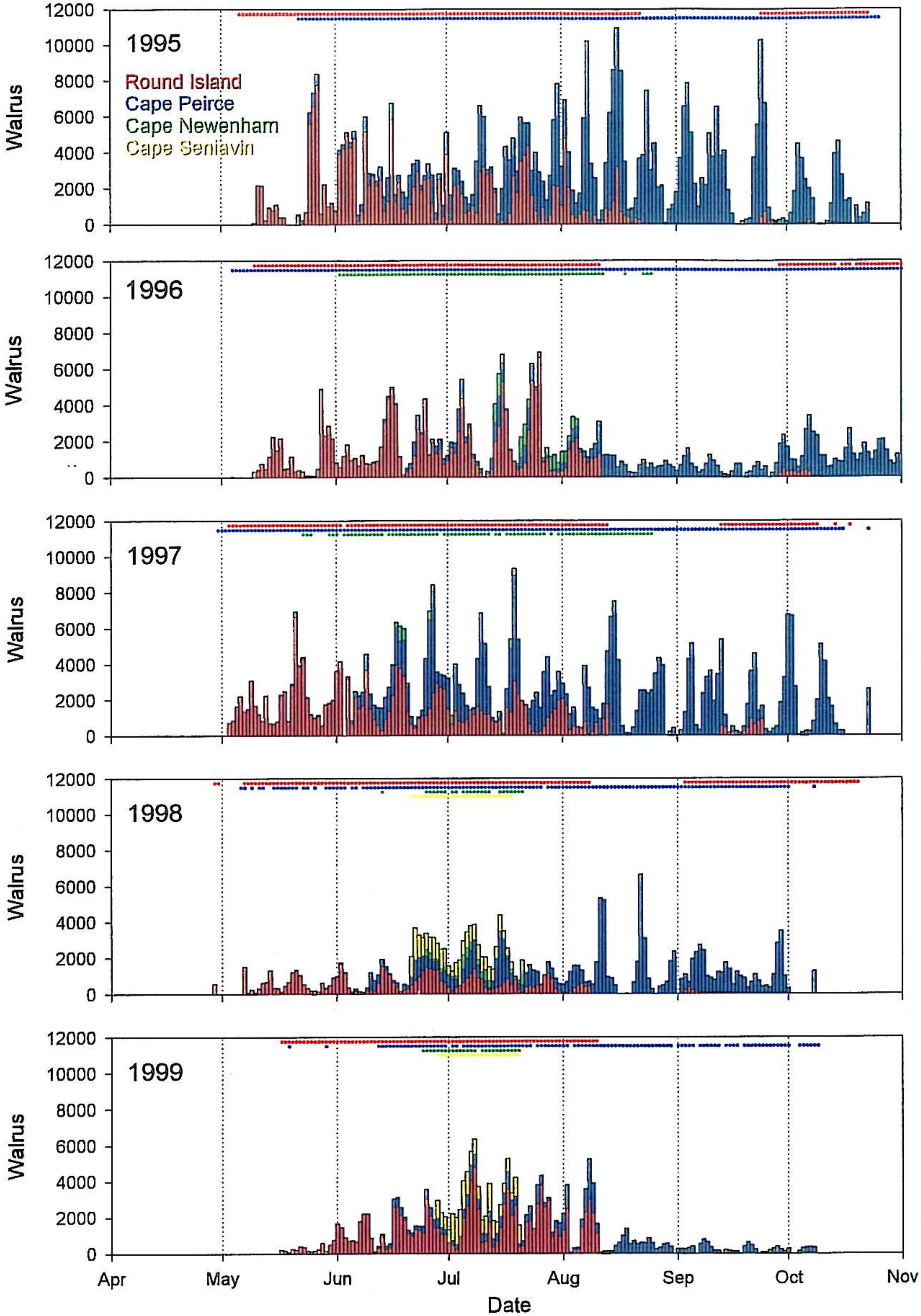

12000
10000
8000
6000
4000
2000
0
1995
1996
1997
1998
1999
Walrus
Round Island
Cape Peirce
Cape Newenham
Cape Seniavin
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Date

Figure B2. An overview of the historical use of walrus haulouts on the Russian coast

Prepared by: John Burns, Living Resources Inc.

Walrus haulouts are/were located along the Russian coastline between the southeastern Kamchatka Peninsula and the central part of the East Siberian Sea. There are seven regions that have multiple active haulouts, and two regions with haulouts which are infrequently active. The former category includes: 1) offshore islands in the eastern Chukchi Sea (Wrangel and Herald); 2) northern Chukotka/Chukchi Peninsula; 3) eastern Chukchi Peninsula/Bering Strait; 4) Gulf of Anadyr; 5) Koryak coastal region; 6) Olyutorski Bay region; and 7) Karaginskii Bay. The areas used infrequently and by relatively few walruses are the East Siberian Sea and the Kamchatka Peninsula south of Karaginskii Bay (Region 8). Maps of the major haulouts in these regions, except for the East Siberian Sea, were made available to workshop participants (Figure B2).

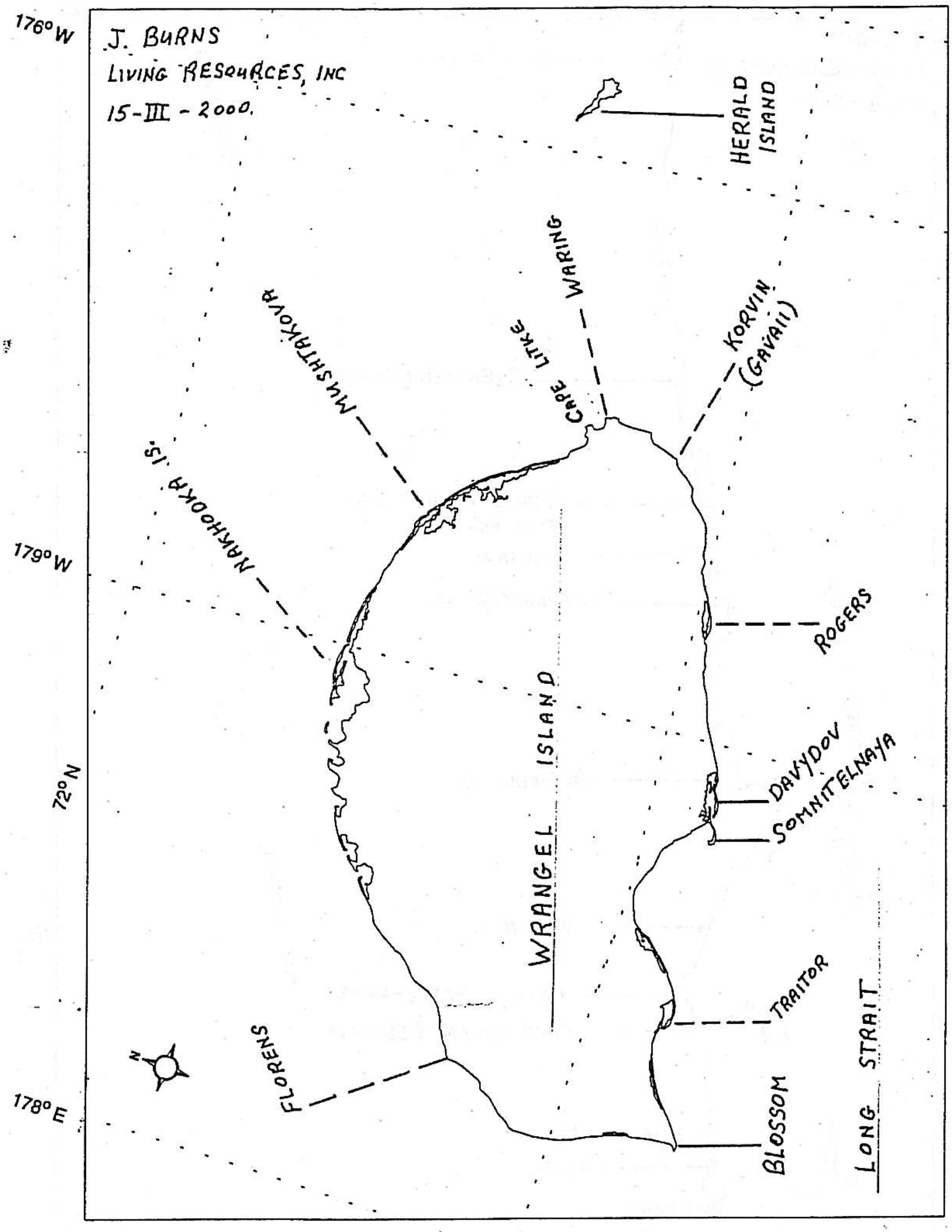
The Pacific walrus population has fluctuated in size in response to varying levels of exploitation. In the mid 1930s, all haulouts south of the northern Gulf of Anadyr became virtually extinct, although there was infrequent use by individual walruses, and occasionally by small groups. The southern margin of the summer range of the much reduced population had shifted northward to the vicinity of the southern Chukchi Peninsula. In 1938, it was reported that only five active haulouts remained in Chukotka (Zenkovich 1938), not including those on Wrangel and Herald islands. According to Kleinenberg (1957) there were only three by 1954.

In the 1950's and 60's, various protective measures were implemented by the U.S. and Russia (the former Soviet Union) and the population is believed to have increased rapidly. Many of the former haulouts south of the Gulf of Anadyr became active in the mid to late 1970s, and many more animals used the more traditional haulouts of Chukotka, Bering Strait, Herald and Wrangel Islands. Peak haulout use, on a regular basis, apparently occurred during the late 1970s and early 1980s. By the late 1980s, more than 45 haulouts on the Russian coast were being used with some regularity, though the number of walruses hauling out on some of them was already declining. By the mid-1990s, some of those in the southern part of the summer range were again not in use, or were used by small numbers of walruses on an intermittent basis.

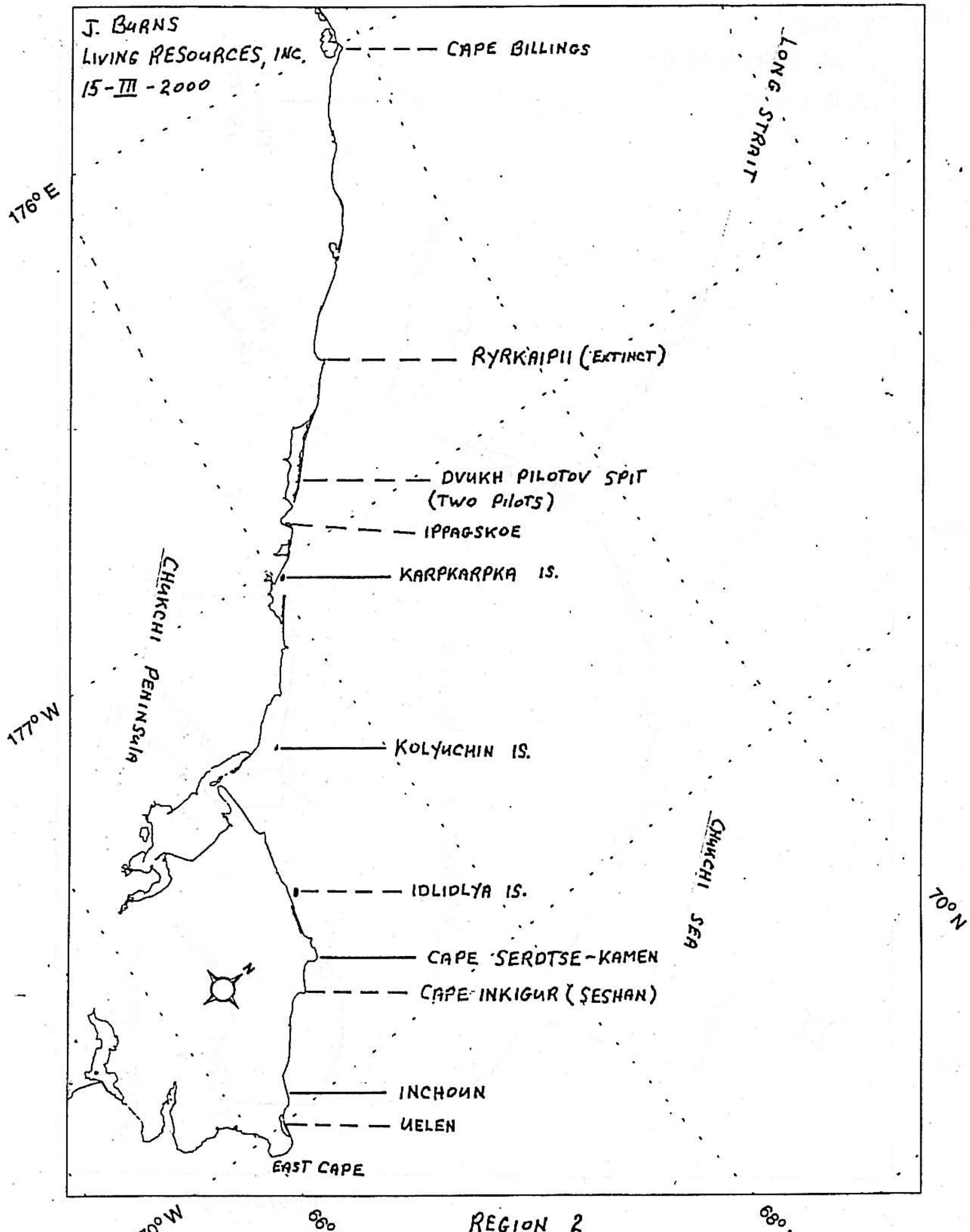
Questions from workshop participants: Q: Could a survey be designed in such a way to say in these months at these haulouts 80% of the walruses were on land? A: By September or October most of the haulouts are reaching their low numbers. To determine an optimum time for surveying haulouts (maximum use), observers would need to be on key haulouts. The periodicity from Bristol Bay is evident at other haulouts also. It is not synchronous over all of the walrus world but it is within a region. The Russians have published information that correlates walruses leaving the haulout with falling barometric pressure. Q: Can the Russian haulouts be parsed into complexes? A: That is in essence what they are. According to the Russian scientists, after the walruses go into the Gulf of Anadyr, there is a general movement to the east- they begin to use Arakamchechen. Q: Are there a manageable number of haulouts on the Russian side? It seems that on both sides of Bering Sea that it would be very helpful to get an idea of the magnitude of yearly variation. A: There is tremendous variability in haulout use. Every one of the major regular haulouts shows this variability. Tracking haulout use - yes it is trackable.

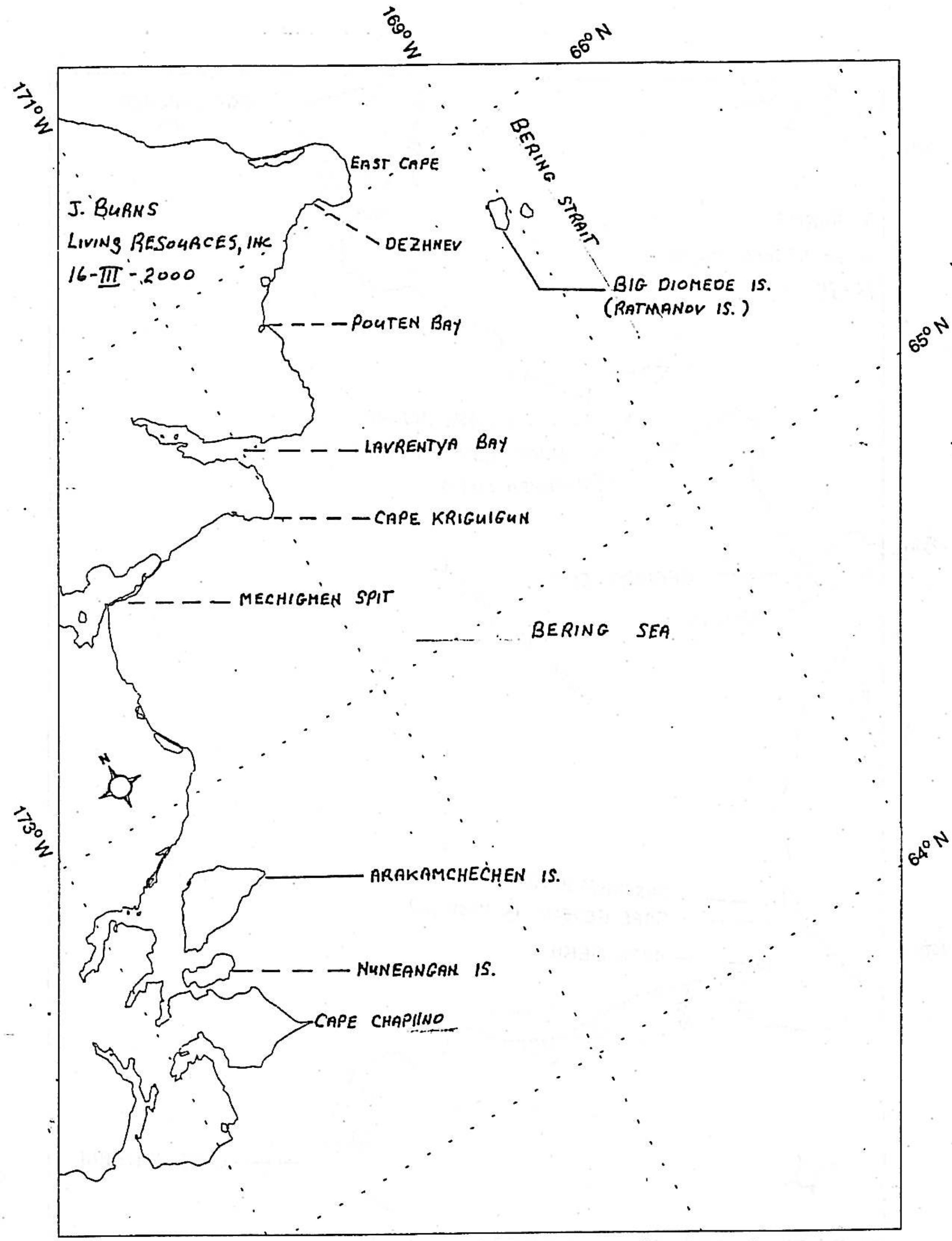
Comments from Russian workshop participants:
Every hunting community close to a haulout says when the ice comes, the walruses leave the haulouts.

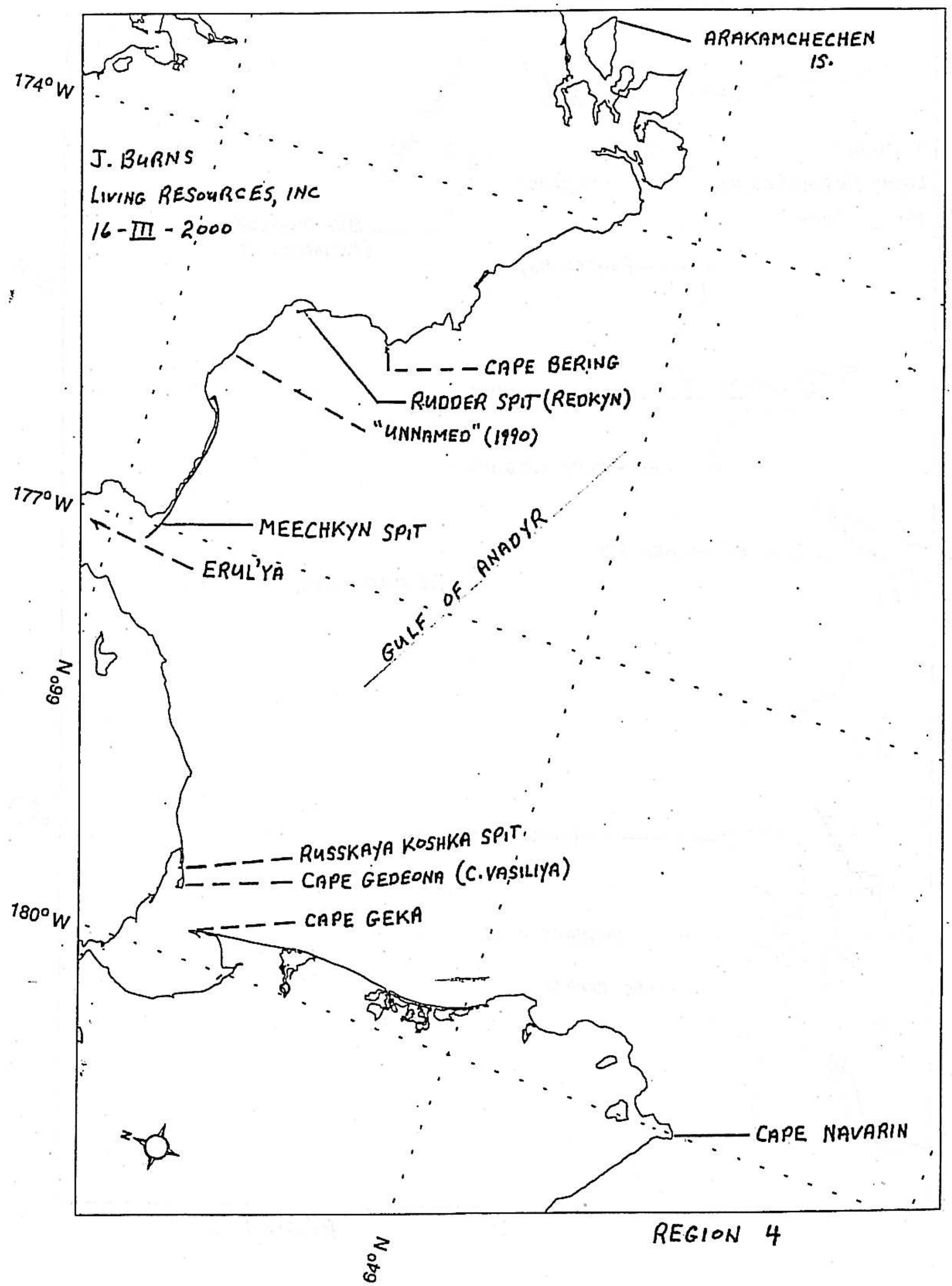
Many of the haulouts identified here were used only once in 100 years. The historic increase of haulouts and number of walruses on them may not be as closely linked to harvest as presented. Regular changes over many years of ice and climate may be more important factors in haulout use. The absence of haulouts in Kamchatka may not be as closely linked to extermination as to the fact that ice has allowed them to haul out in other areas. The absence of haulouts in those areas in historically distant times may be due to the fact that there wasn't as much research done then. As to the question of complexes of haulouts, yes you can single out several complexes along the coast of Chukotka. But to be able to draw the boundaries between the complexes, one has to do more work along the boundary haulouts.

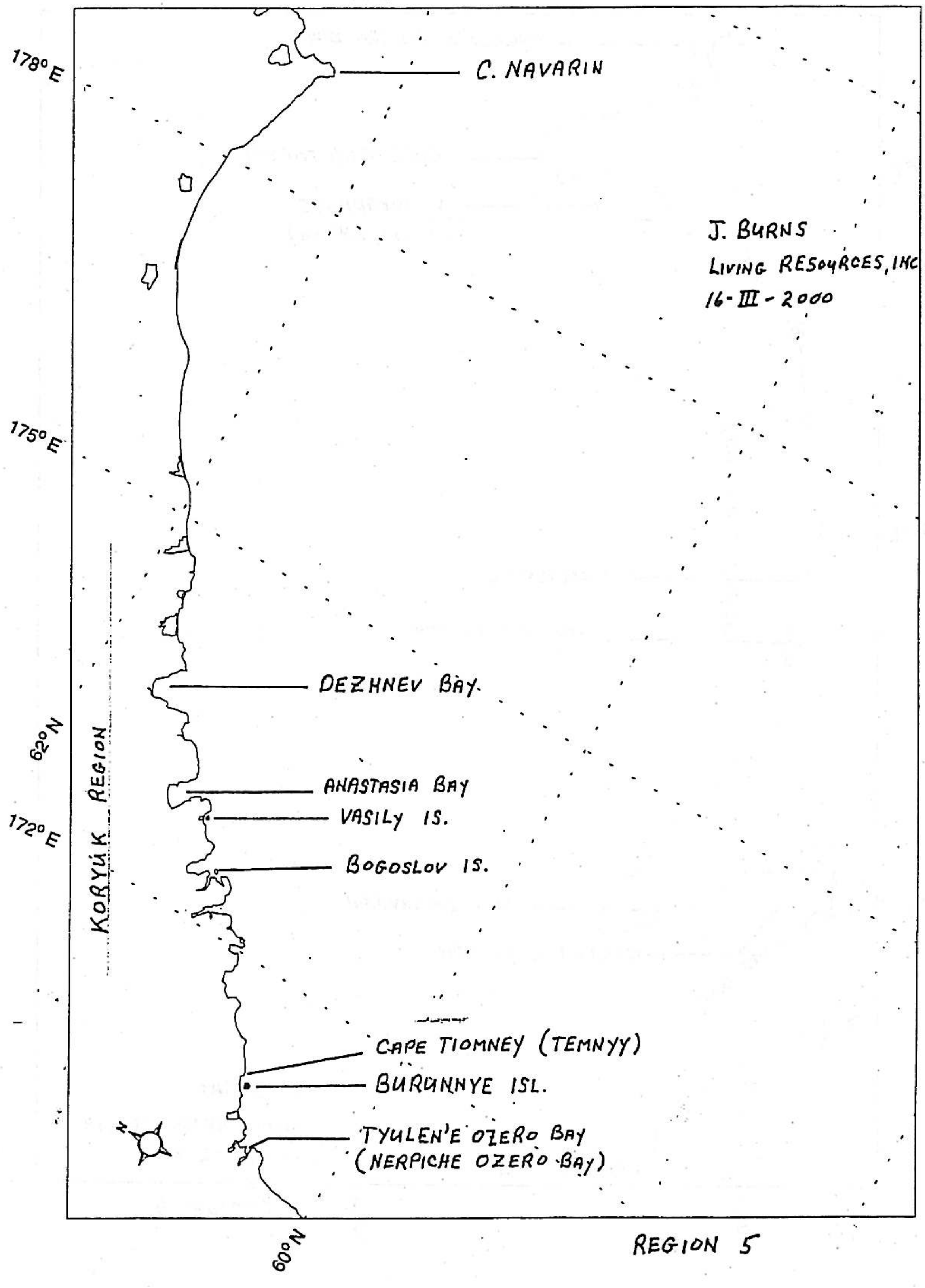

176° W
J. BURNS
LIVING RESOURCES, INC
15-III-2000.
HERALD ISLAND
WARING
CAPE LITKE
KORVIN (GAVAII)
MUSHTAKOVA
NAKHOOKA IS.
179° W
ROGERS
WRANGEL ISLAND
DAVYDOV
SOMNITELNAYA
72° N
TRAITOR
LONG STRAIT
FLORENS
BLOSSOM
178° E
71° N

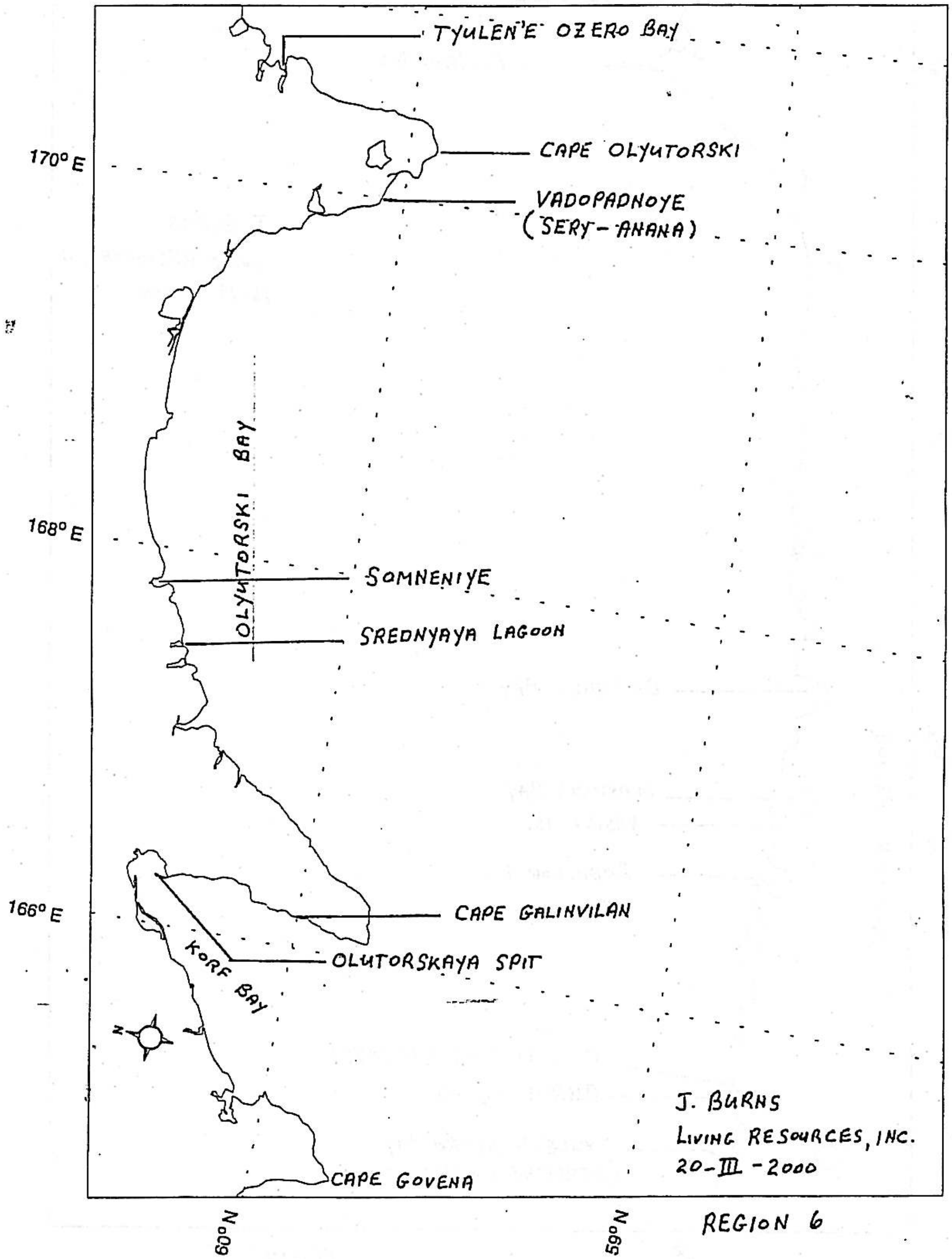
REGION 1


J. BURNS
LIVING RESOURCES, INC.
15-III-2000
CAPE BILLINGS
LONG STRAIT
176° E
RYRKAIPII (EXTINCT)
DVUKH PILOTOV SPIT
(TWO PILOTS)
IPPAGSKOE
KARPKARPKA IS.
CHUKCHI PENINSULA
177° W
KOLYUCHIN IS.
CHUKCHI SEA
IDLIDLYA IS.
70° N
CAPE SERDTSE-KAMEN
CAPE INKIGUR (SESHAN)
N
INCHOUN
UELEN
EAST CAPE
170° W
66° N
REGION 2
68° N

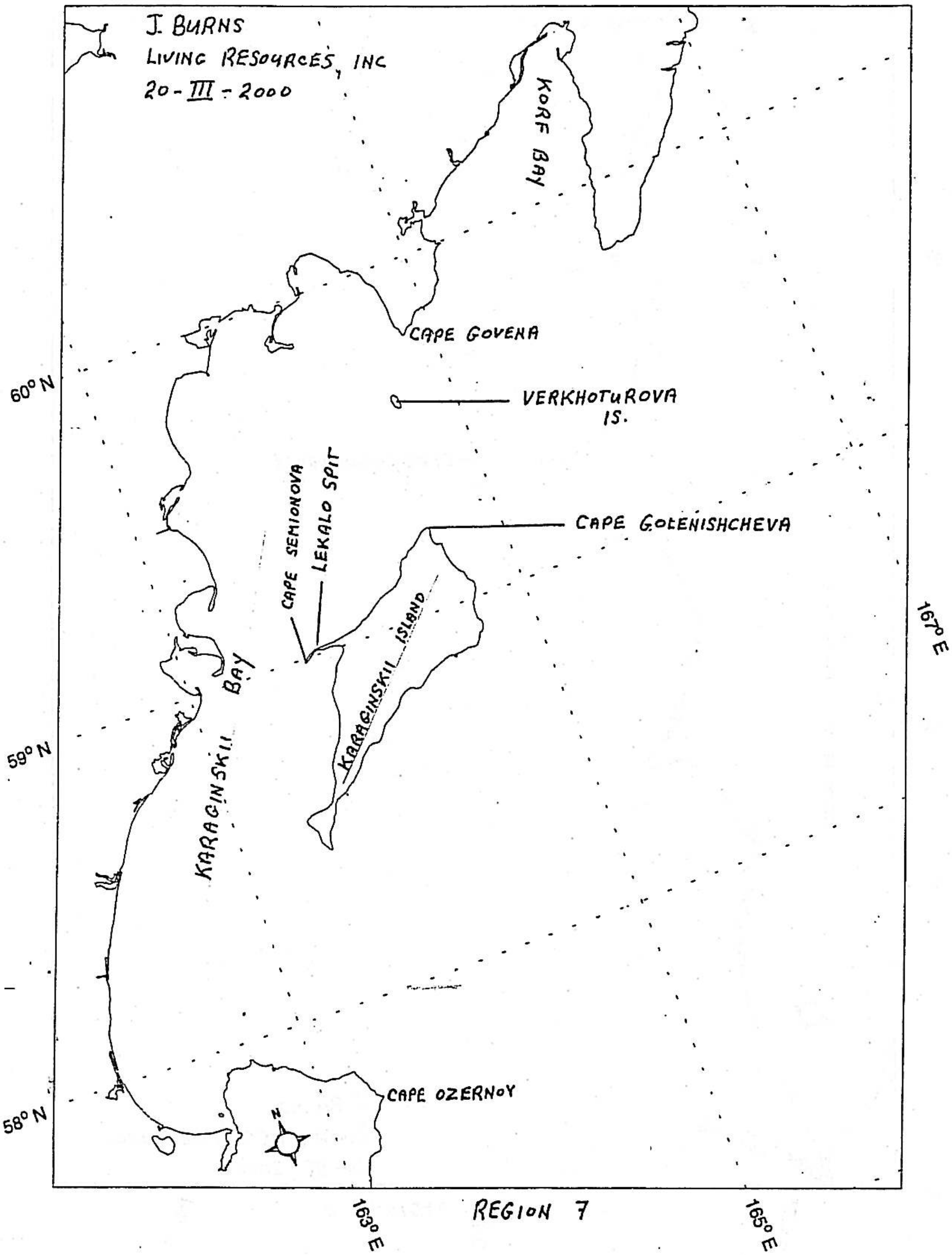

169° W
66° N
171° W
BERING STRAIT
EAST CAPE
J. BURNS
LIVING RESOURCES, INC
16-III-2000
DEZHNEV
BIG DIOMEDE IS.
(RATMANOV IS.)
POUTEN BAY
65° N
LAVRENTYA BAY
CAPE KRIGUIGUN
MECHIGMEN SPIT
BERING SEA
N
173° W
ARAKAMCHECHEN IS.
64° N
NUNEANGAN IS.
CAPE CHAPLINO
REGION 3


174° W
177° W
180° W
66° N
64° N
J. BURNS
LIVING RESOURCES, INC
16 - III - 2000
ARAKAMCHECHEN IS.
CAPE BERING
RUDDER SPIT (REDKYN)
"UNNAMED" (1990)
MEECHKYN SPIT
ERUL'YA
GULF OF ANADYR
RUSSKAYA KOSHKA SPIT
CAPE GEDEONA (C. VASILIYA)
CAPE GEKA
CAPE NAVARIN
N
REGION 4

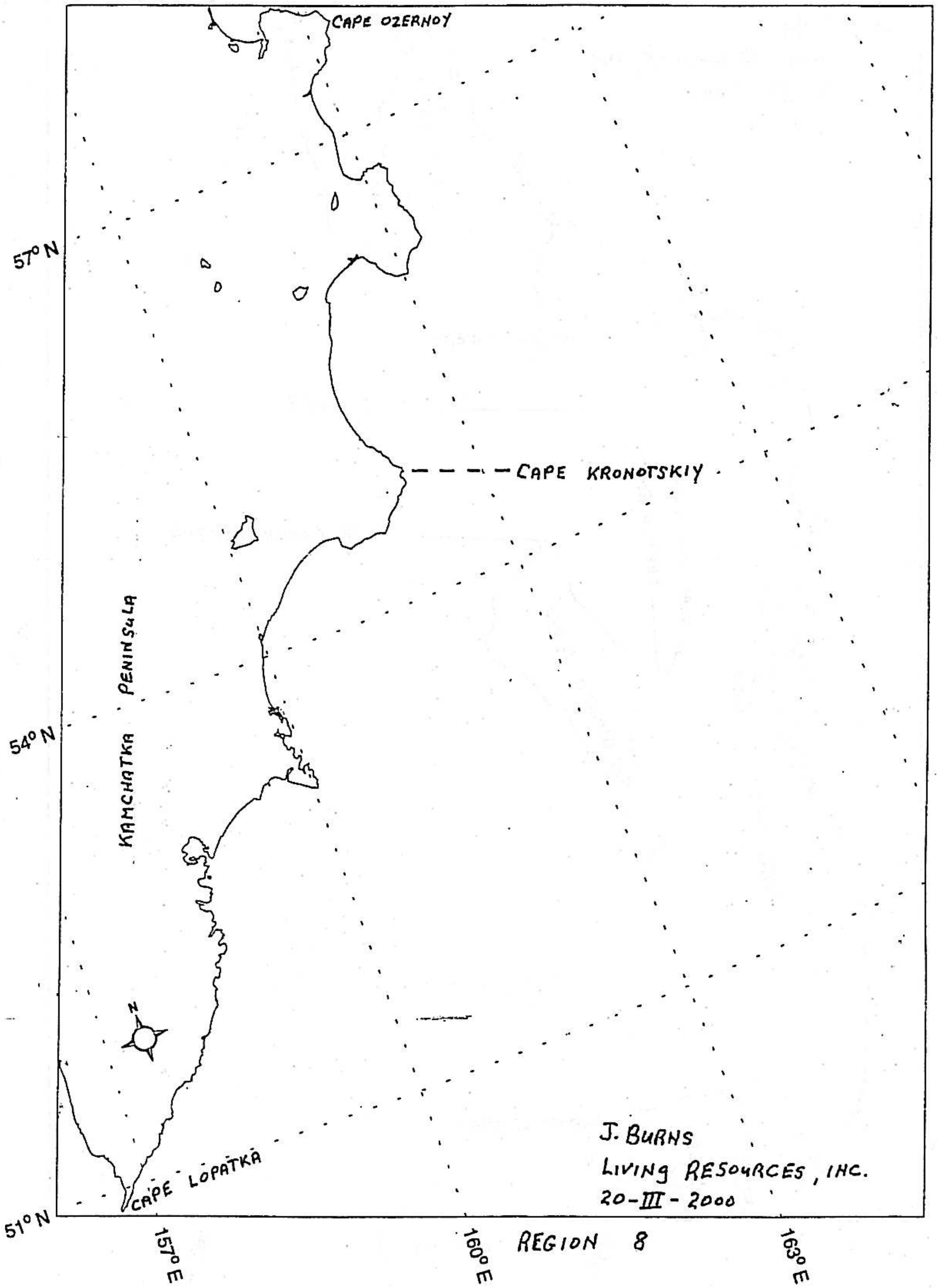

178° E
C. NAVARIN
J. BURNS
LIVING RESOURCES, INC
16-III-2000
175° E
DEZHNEV BAY
62° N
ANASTASIA BAY
172° E
VASILY IS.
BOGOSLOV IS.
KORYUK REGION
CAPE TIOMNEY (TEMNYY)
BURUNNYE ISL.
TYULEN'E OZERO BAY
(NERPICHE OZERO BAY)
60° N
REGION 5


TYULEN'E OZERO BAY
CAPE OLYUTORSKI
170° E
VADOPADNOYE
(SERY-ANANA)
OLYUTORSKI BAY
168° E
SOMNENIYE
SREDNYAYA LAGOON
166° E
CAPE GALINVILAN
OLUTORSKAYA SPIT
KORF BAY
N
J. BURNS
LIVING RESOURCES, INC.
20-III-2000
CAPE GOVENA
60° N
59° N

REGION 6


J. BURNS
LIVING RESOURCES, INC
20-III-2000
KORF BAY
CAPE GOVENA
VERKHOTUROVA IS.
60° N
CAPE SEMIONOVA
LEKALO SPIT
CAPE GOLENISHCHEVA
KARAGINSKII ISLAND
KARAGINSKII BAY
59° N
167° E
CAPE OZERNOY
58° N
N
163° E
165° E

REGION 7


CAPE OZERNOY
57° N
CAPE KRONOTSKIY
KAMCHATKA PENINSULA
54° N
N
J. BURNS
LIVING RESOURCES, INC.
20-III-2000
CAPE LOPATKA
51° N
157° E
160° E
163° E

REGION 8

Figure B3. The most important mixed coastal haulouts of Chukotka

Prepared by: Anatoly Kochnev, Chukotka TINRO

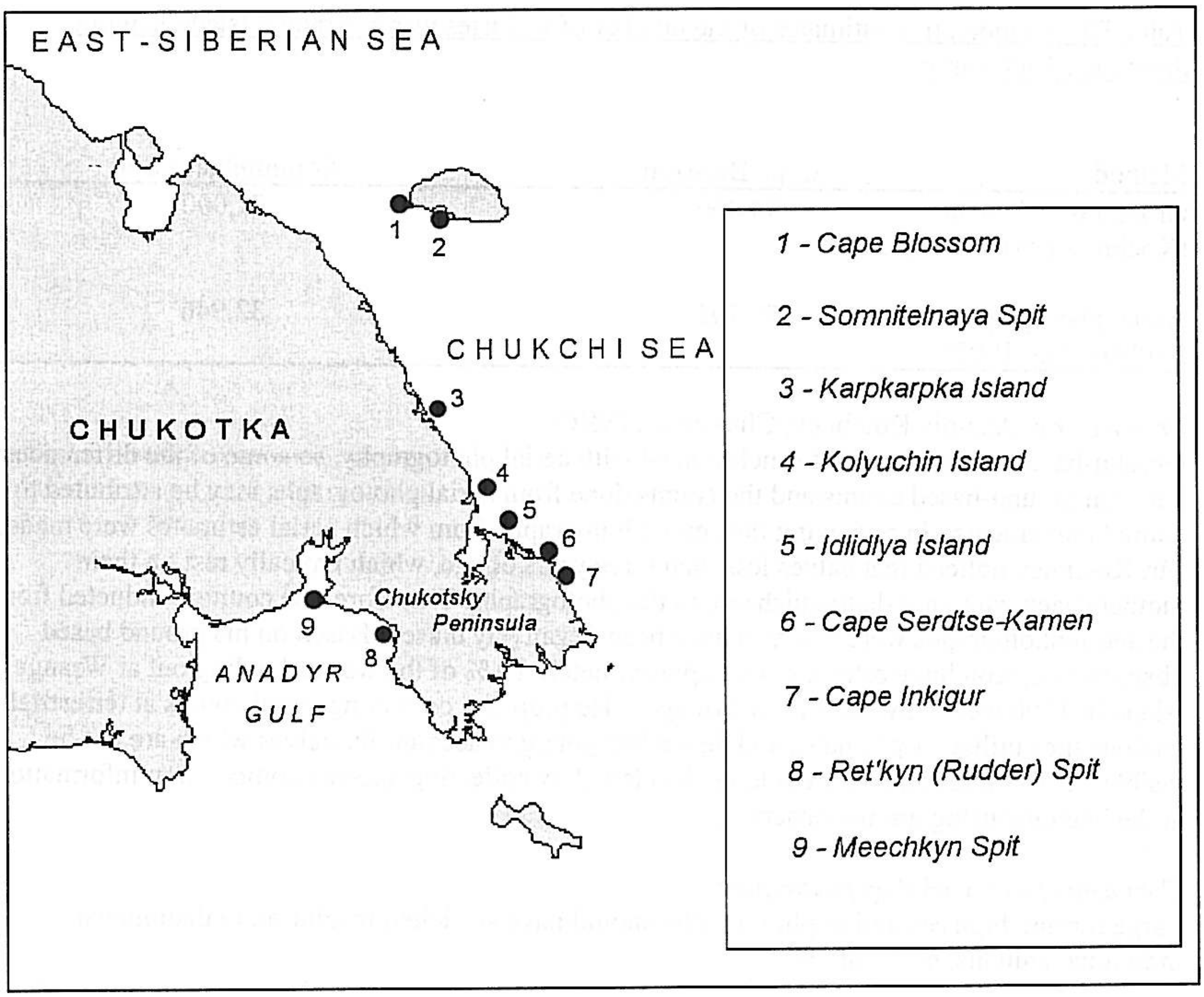


Table B1. Comparative estimates of the number of walruses using Wrangel Island haulouts during the 1990 survey

Method	Cape Blossom	Somnitelnaya Spit
Ground based counts (Kochnev,1991-Unpublished)	50,000	71,000
Aerial photographs (Gilbert et al. 1992)	76,702	32,946

Prepared by: Anatoly Kotchnev, Chukotka TINRO
Ground-based counts were not synchronized with aerial photography, so some of the differences between ground-based counts and the counts done from aerial photographs may be attributed to animal movements. In reviewing the aerial photographs from which aerial estimates were made, Mr. Kotchnev noticed that calves less than three years of age, which typically rest on their mothers back, were not distinguishable in the photographs. Therefore, the counts conducted from the aerial photographs were likely to have been negatively biased. Based on his ground based observations, Kotchnev estimates that approximately 19 % of the walrus hauling out at Wrangel Island in 1990 were calves (0-2 years of age). He proposes correcting aerial counts at terrestrial haulout sites utilized by females and dependent young to account for calves which are not be visible. The correction factor could be developed by collecting age-sex composition information at the haulouts using ground observers.

Comments from workshop participants:
Large format, high resolution photography should have sufficient resolution to distinguish individual animals, even calves.

The subsistence walrus harvest

Figure C1. Walrus Harvest Monitor Project (WHMP) data
Prepared by: USFWS
Purpose: To summarize the timing of walrus hunting in the three major walrus hunting villages of Gambell, Savoonga, and Diomede.
Data: U.S. Fish & Wildlife Service, WHMP data from 1992-1999.
Method: WHMP data were summarized by day for the three villages. The timing of the spring hunt is similar for Gambell and Savoonga. Hunting in Diomede usually begins about two weeks later than the other villages. Harvest levels are assumed to coincide with walrus availability.

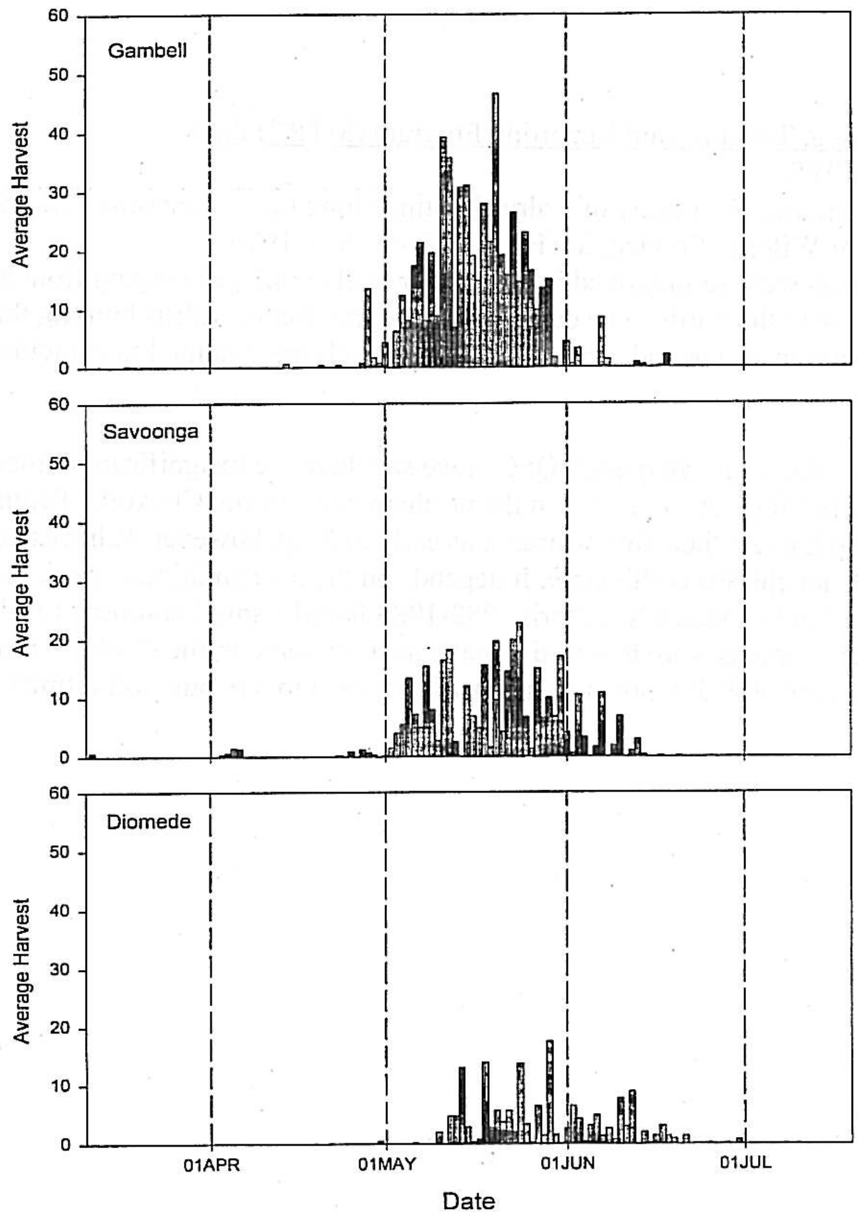
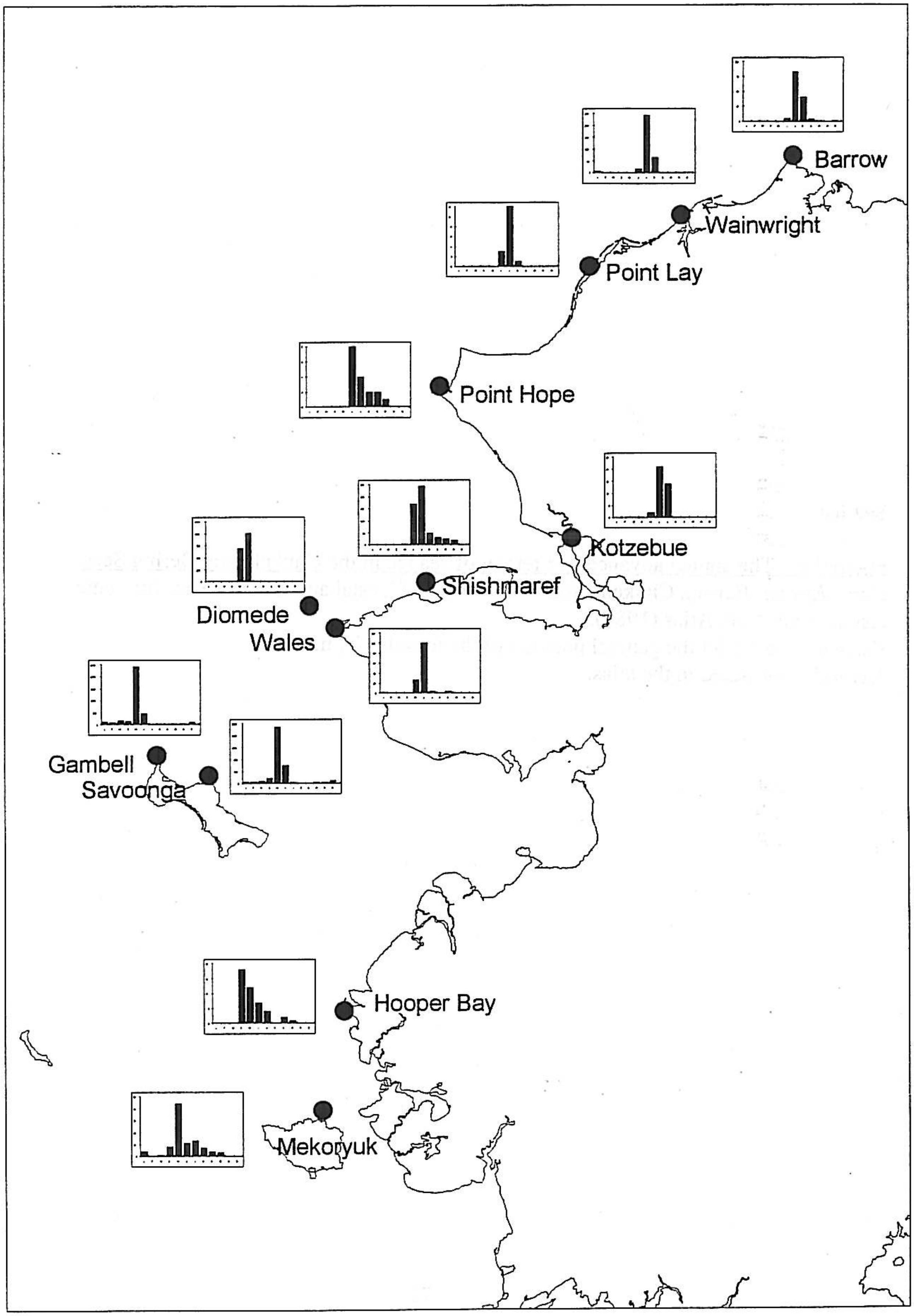


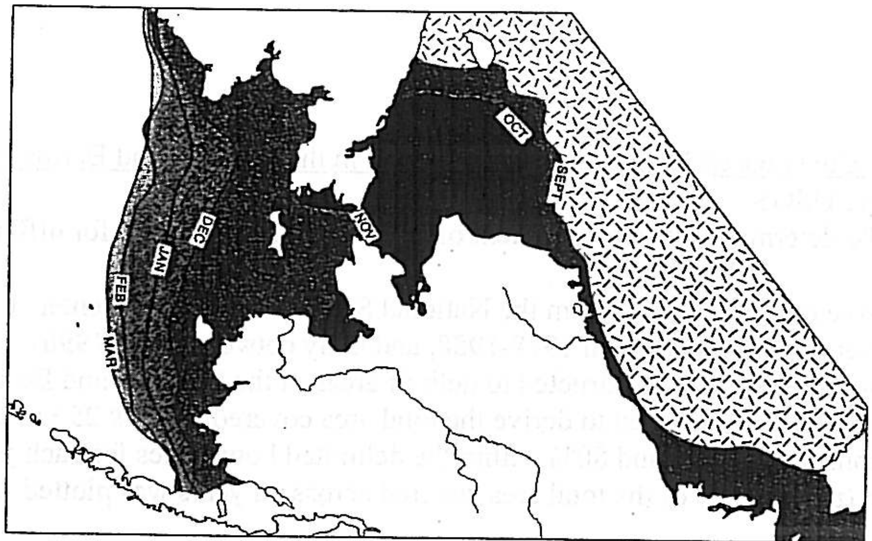
Figure C2. Marking, Tagging, and Reporting Program (MTRP) data
Prepared by: USFWS
Purpose: To summarize the timing of walrus hunting along the western coast of Alaska.
Data: U.S. Fish & Wildlife Service, MTRP data from 1988-1999.
Method: MTRP data were summarized by month for twelve villages ranging from Mekoryuk to the south to Barrow to the north. The data show a progression of walrus hunting that follows the northward migration in spring and summer. Harvest levels are assumed to coincide with walrus availability.

Questions from workshop participants: Q: Can we say there are insignificant numbers north of Bering Strait before May? A: Hunters on the northern coast of the Chukotka Peninsula sometimes (rarely) harvest their first walruses as early as May, however walruses generally do not occur in the Chukchi Sea at this time. It depends on the ice conditions. Aerial surveys around Wrangel Island in March and April 1988-1989 found a small number of walruses in leads in that area. These animals were believed to have over wintered in the Chukchi Sea. These numbers however, are probably not significant with respect to a population estimate.

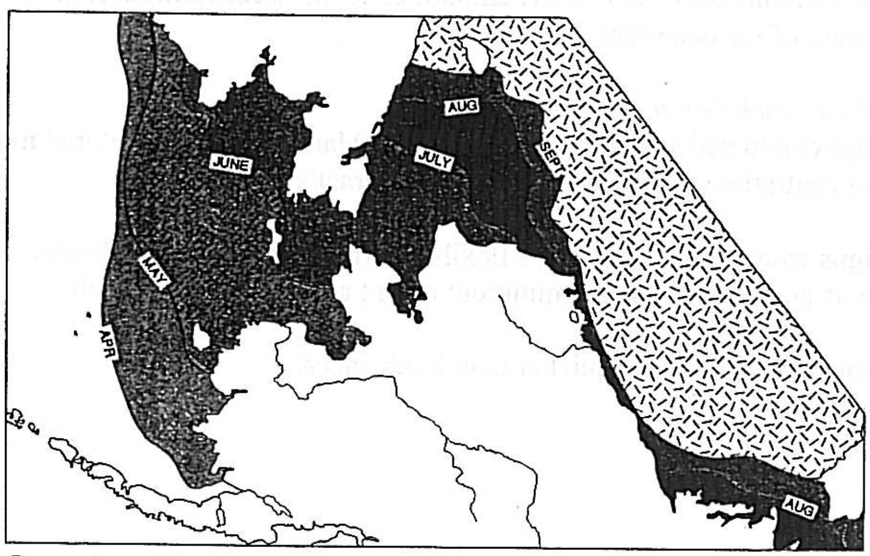

Barrow
Wainwright
Point Lay
Point Hope
Kotzebue
Shishmaref
Diomede
Wales
Gambell
Savoonga
Hooper Bay
Mekoryuk

Sea ice

Figure D1. The annual advance and retreat of sea ice in the Chukchi and Bering Seas
Copied from: Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones Strategic Assessment: Data Atlas (1987).
Purpose: To depict the general position of the ice edge by month.
Method: Not stated in the atlas.



Sea Ice Advance (September 15-March 15)
Average Ice Edge



Sea Ice Retreat (April 15-September 15)
Average Ice Edge

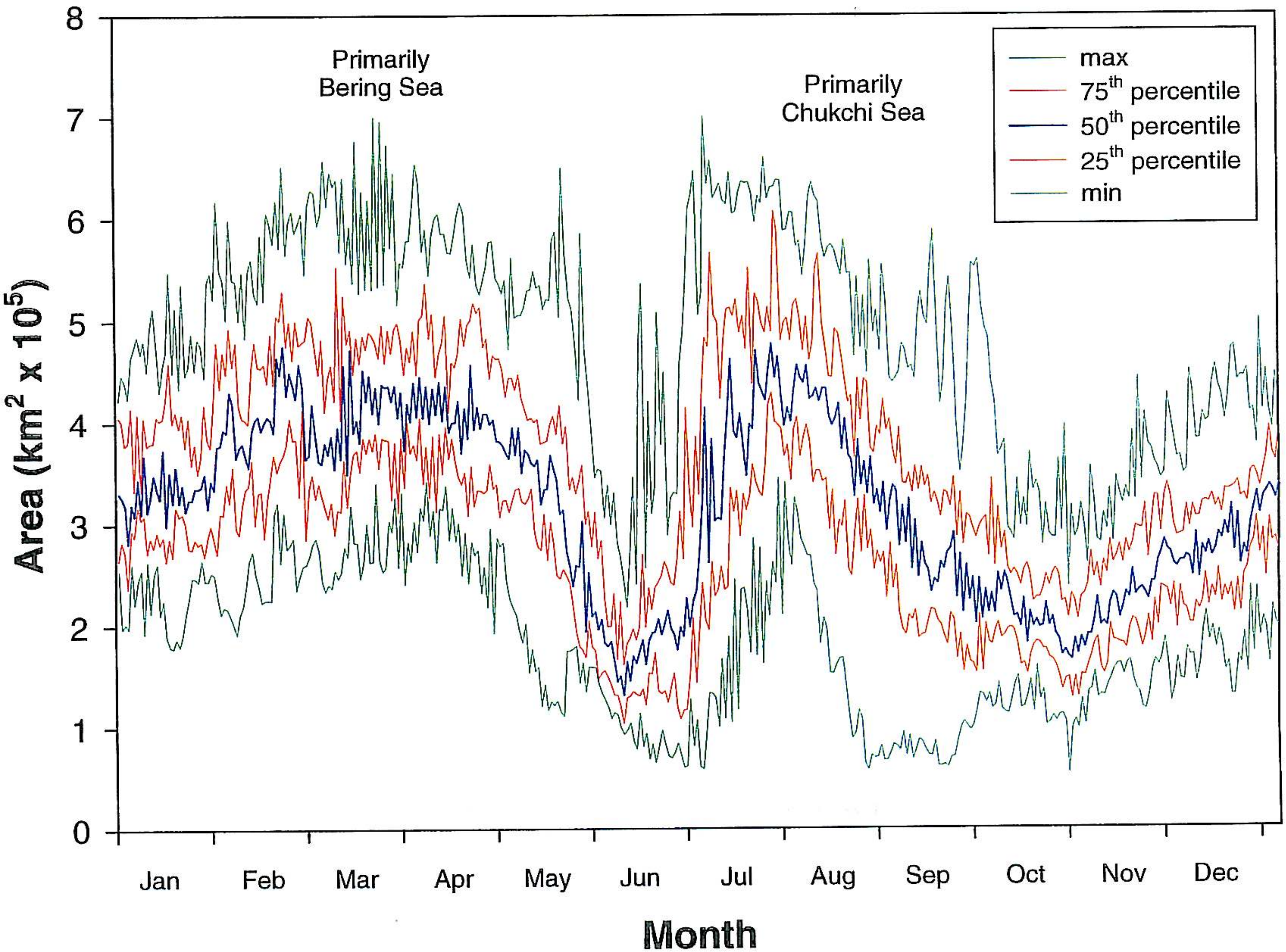
Figure D2. Coverage of 15-80% ice concentration in the Chukchi and Bering Seas, 1978-1996
Prepared by: USGS
Purpose: To determine the relative extent of the potential survey area for different times of the year.
Data: Passive microwave data from the National Snow and Ice Data Center, 1978 to 1996 (data collected every two days between 1978-1988, and daily between 1988-1996).
Method: Boundaries were constructed to delimit areas of the Chukchi and Bering Seas (see Figure D3). Arc/Info was used to derive the total area covered by 25 x 25 km cells that had ice concentrations between 15 and 80% within the delimited boundaries for each year. The distribution (percentiles) of the total area covered across all years was plotted for each day of the year.

Questions from workshop participants:
Q: How can you have as much ice in July as in March?
A: the graph is the coverage of *unconsolidated* ice. The solid ice pack is not counted. As the ice starts to retreat, the amount of 15-80% concentration decreases. Once the ice retreats through Bering Strait and into the Chukchi, the amount of 15-80% concentration increases, even though the total amount of ice decreases.

Comments from workshop participants:
Aerial surveys conducted in the Gulf of Anadyr in March 1987 encountered many walruses in 100% ice concentrations. They were using small cracks and leads.

Survey designs would have to be more flexible during periods of ice advance and retreat than when the ice is at its maximum or minimum extent and not moving much.

Generally, the ice retreats a lot quicker than it advances.



Primarily
Bering Sea
Primarily
Chukchi Sea
max
75th percentile
50th percentile
25th percentile
min
Area (km² x 10⁵)
0
1
2
3
4
5
6
7
8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

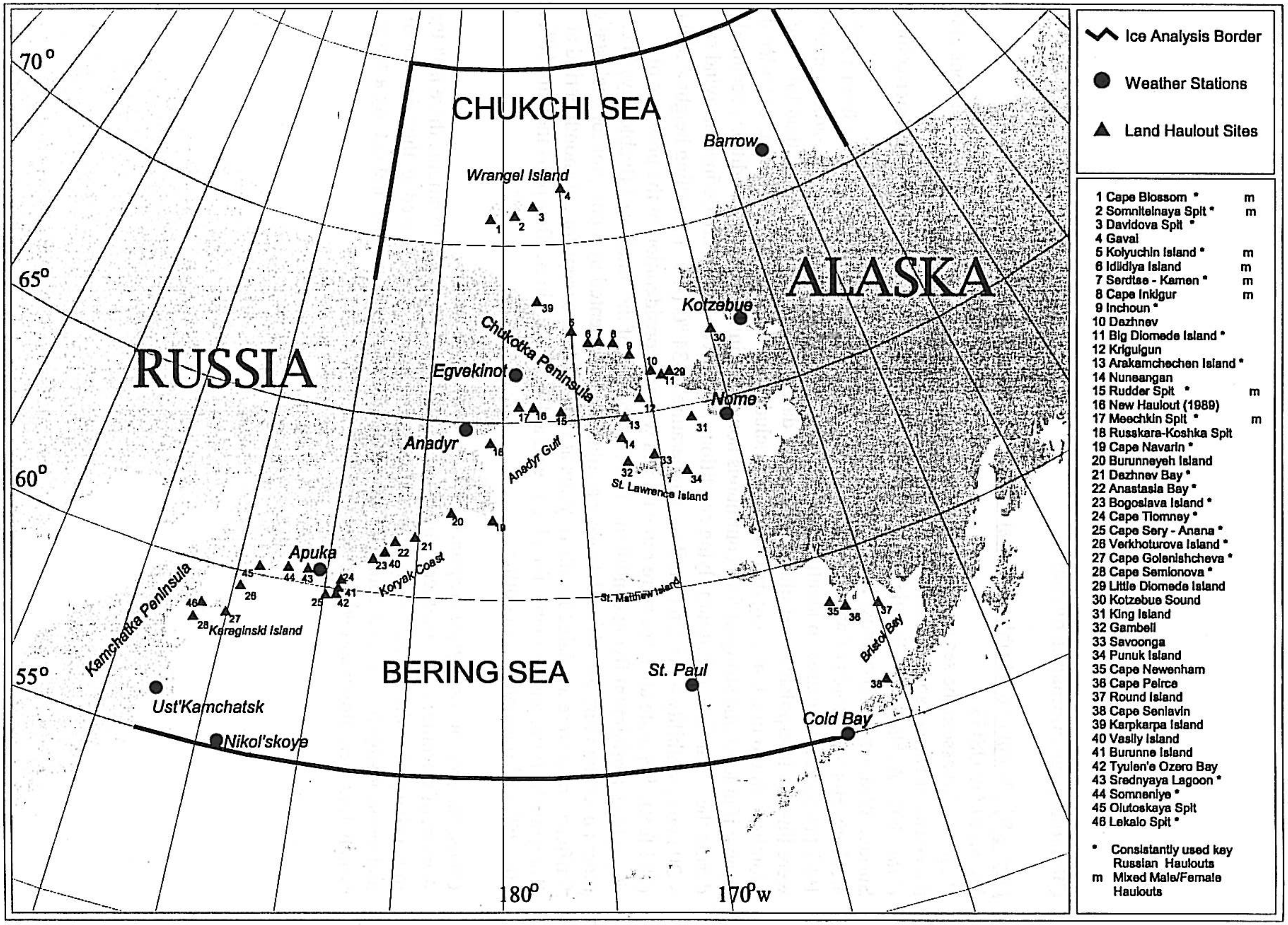
Figure D3. Place names, boundaries used in Figure D2, and location of weather stations used in Figure E1

Prepared by: USGS

Purpose: Map to show place names, and locations pertinent to Figure D2 and E1.

Data: Place names from Fay *et al.* (1997) and Gilbert (1999).

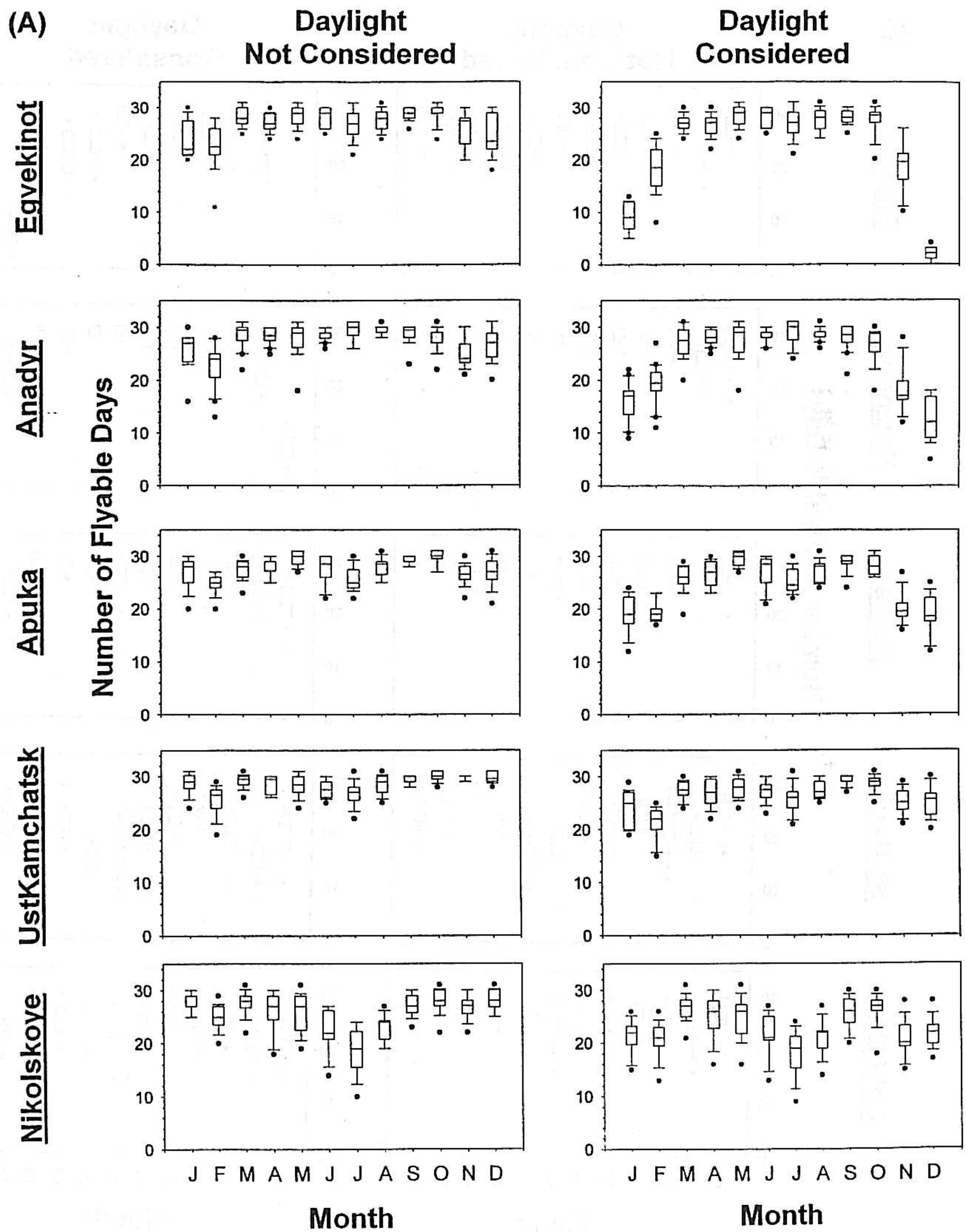
Method: N/A


Ice Analysis Border
Weather Stations
Land Haulout Sites
1 Cape Blossom * m
2 Somnitelnaya Spit * m
3 Davidova Spit *
4 Gavai
5 Kolyuchin Island * m
6 Idlidlya Island m
7 Serdtse - Kamen * m
8 Cape Inkigur m
9 Inchoun *
10 Dezhnev
11 Big Diomede Island *
12 Krigulgun
13 Arakamchechen Island *
14 Nuneangan
15 Rudder Spit * m
16 New Haulout (1989)
17 Meechkin Spit * m
18 Russkara-Koshka Spit
19 Cape Navarin *
20 Burunneyeh Island
21 Dezhnev Bay *
22 Anastasia Bay *
23 Bogoslava Island *
24 Cape Tiomney *
25 Cape Sery - Anana *
26 Verkhoturova Island *
27 Cape Golenishcheva *
28 Cape Semionova *
29 Little Diomede Island
30 Kotzebue Sound
31 King Island
32 Gambell
33 Savoonga
34 Punuk Island
35 Cape Newenham
36 Cape Peirce
37 Round Island
38 Cape Senlavin
39 Karpkarpa Island
40 Vasily Island
41 Burunne Island
42 Tyulen'e Ozero Bay
43 Srednyaya Lagoon *
44 Somneniye *
45 Olutoskaya Spit
46 Lekalo Spit *
* Consistantly used key Russian Haulouts
m Mixed Male/Female Haulouts
70°
65°
60°
55°
180°
170°W
CHUKCHI SEA
BERING SEA
RUSSIA
ALASKA
Barrow
Wrangel Island
Kotzebue
Chukotka Peninsula
Egvekinot
Nome
Anadyr
Anadyr Gulf
St. Lawrence Island
Apuka
Koryak Coast
St. Matthew Island
Kamchatka Peninsula
Karaginski Island
Bristol Bay
St. Paul
Ust'Kamchatsk
Nikol'skoye
Cold Bay

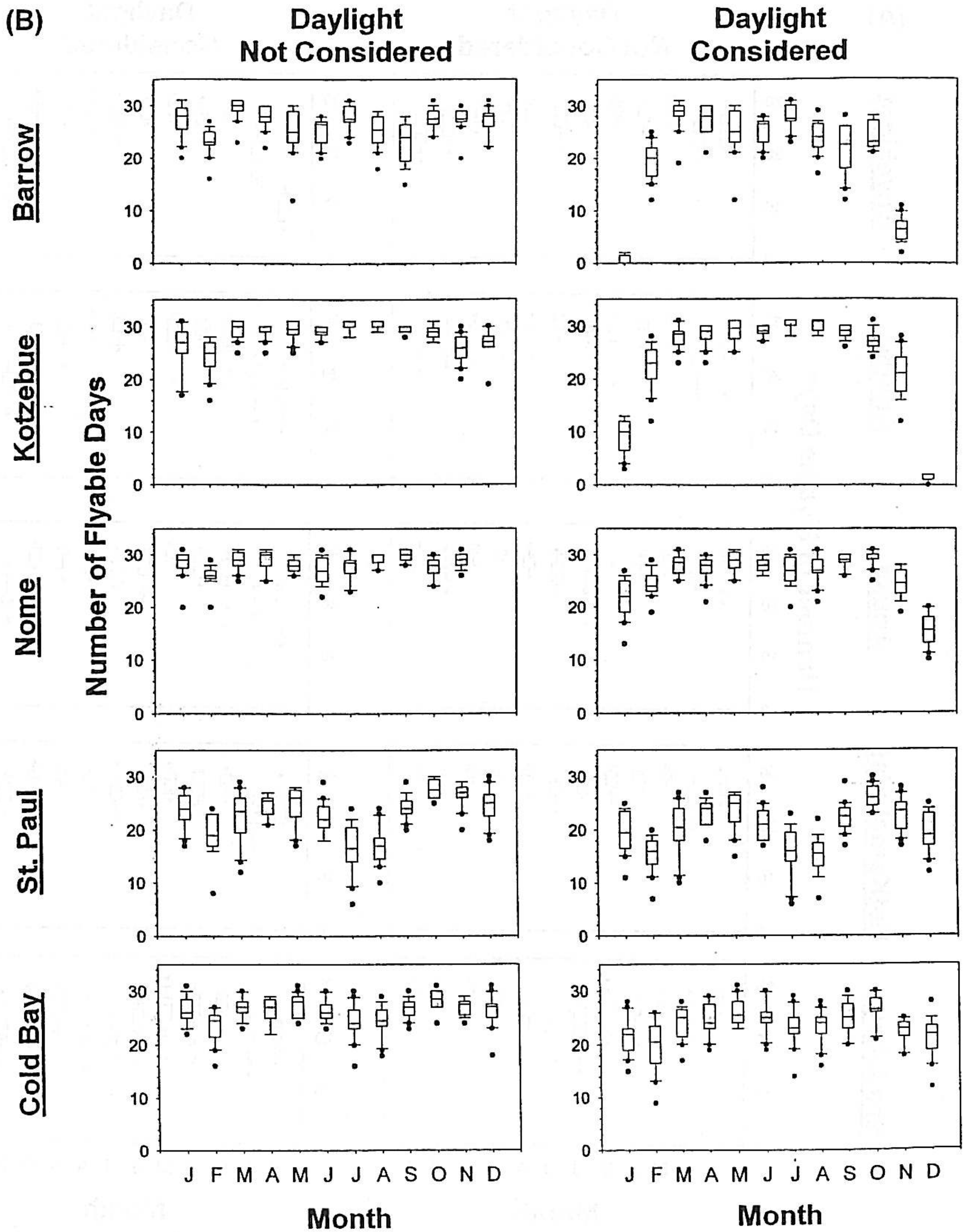
Climatological summaries by season

Figure E1. Number of flyable days at stations along the coasts of Russia and Alaska
Prepared by: USGS
Purpose: To assess the seasonal and inter-annual variability in flyable weather at stations along the coasts of Russia and Alaska.
Data: NOAA, National Climatic Data Center and U.S. Department of Air Force, International Surface Weather Observations, 1998. Station locations shown in Figure D3.
Method: Hourly records of wind speed, visibility, temperature, and ceiling height from 1982 to 1997 (16 years) were used to identify days with flyable weather at each site. Weather variables were linearly interpolated over blocks of missing data for periods of no greater than four hours. Months with too much missing data were not included in the analysis. A day was considered flyable if at least one string of four continuous hours of minimum flying conditions occurred during the 24-hr day. Minimum flying conditions for a given hour were defined as: wind speed < 20 knots, visibility > 4.8 km (3 miles), temperature > -34 °C (-30 °F), ceiling height > 300 m (984 feet). Separate analyses were run with and without consideration of the presence of daylight as a minimum flying condition. The distribution of the number of flyable days in each month over the years for which data were available is represented by a box plot for each station. Sufficient data were available for all 16 years at U.S. stations except for a 4-month period at Kotzebue in 1996, and available for 11-16 years at Russian stations. Box plots indicate 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th} percentiles and outliers.

Comments from workshop participants:
A word of warning; these weather stations are on shore. At the shore locations, there isn't that much change but the conditions in the sea are very different. At the ice edge, there is a lot of fog and worse visibility. Another source of data would be from past surveys and getting a sense of which days were flown and which were not.



(A)
Daylight Not Considered
Daylight Considered
Egvekinot
Anadyr
Apuka
UstKamchatsk
Nikolskoye
Number of Flyable Days
0
10
20
30
J F M A M J J A S O N D
Month


(B)
Daylight Not Considered
Daylight Considered
Barrow
Kotzebue
Nome
St. Paul
Cold Bay
Number of Flyable Days
0
10
20
30
J F M A M J J A S O N D
Month

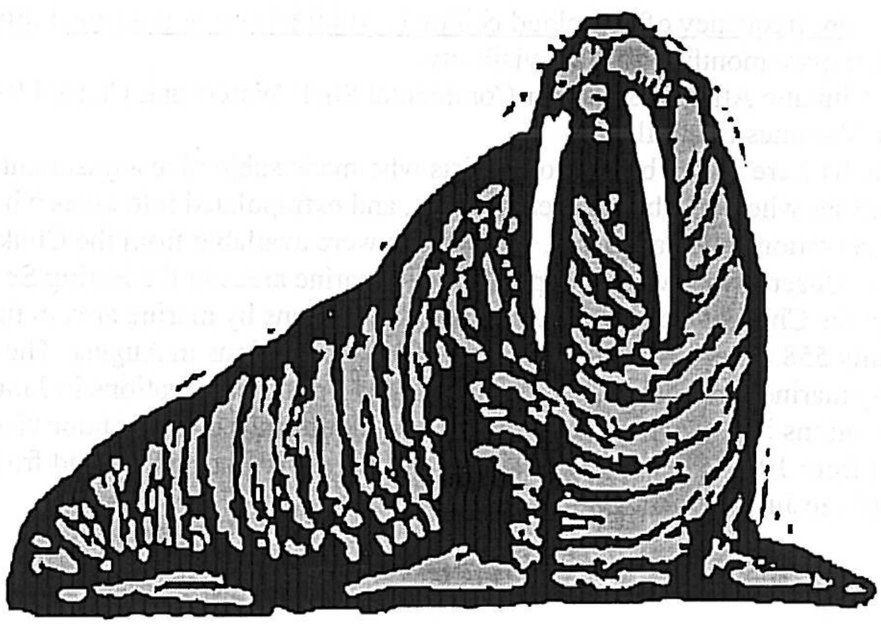


Figure E2. Percent frequency of low cloud ceiling (< 1000 ft) and/or poor visibility (< 5 nmi)
Purpose: To compare monthly offshore visibility.
Copied from: Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska (1988), Volumes II and III.
Method: Isopleths were drawn by meteorologists who made subjective adjustments to the results of weather analyses when data biases were evident, and extrapolated into areas where insufficient observations were available. Fewer data were available from the Chukchi Sea than the Bering Sea. Observations were compiled for six marine areas in the Bering Sea and four marine areas in the Chukchi Sea. The number of observations by marine area in the Bering Sea ranged from only 558 observations in April to 10,232 observations in August. The number of observations by marine area in the Chukchi Sea ranged from 0 observations in January and June to 5,720 observations in August. Frequencies of low cloud ceiling and/or poor visibility over all months ranged from 10% in September to >70% in July in the Bering Sea, and from 15% in October to >60% in July and August in the Chukchi Sea.

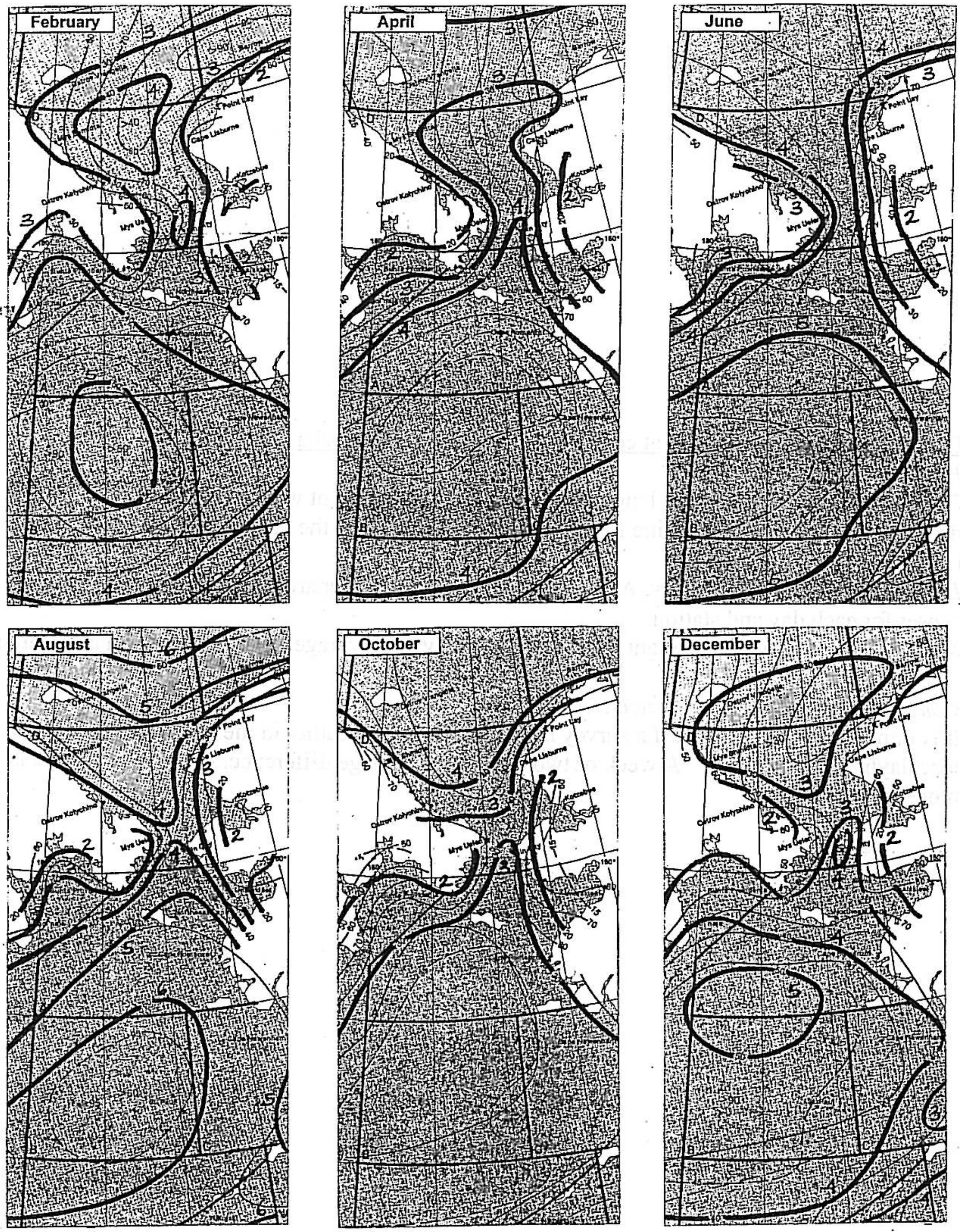

February
April
June
August
October
December

Figure E3. Hours of daylight at coastal sites in Russia and Alaska

Prepared by: USGS

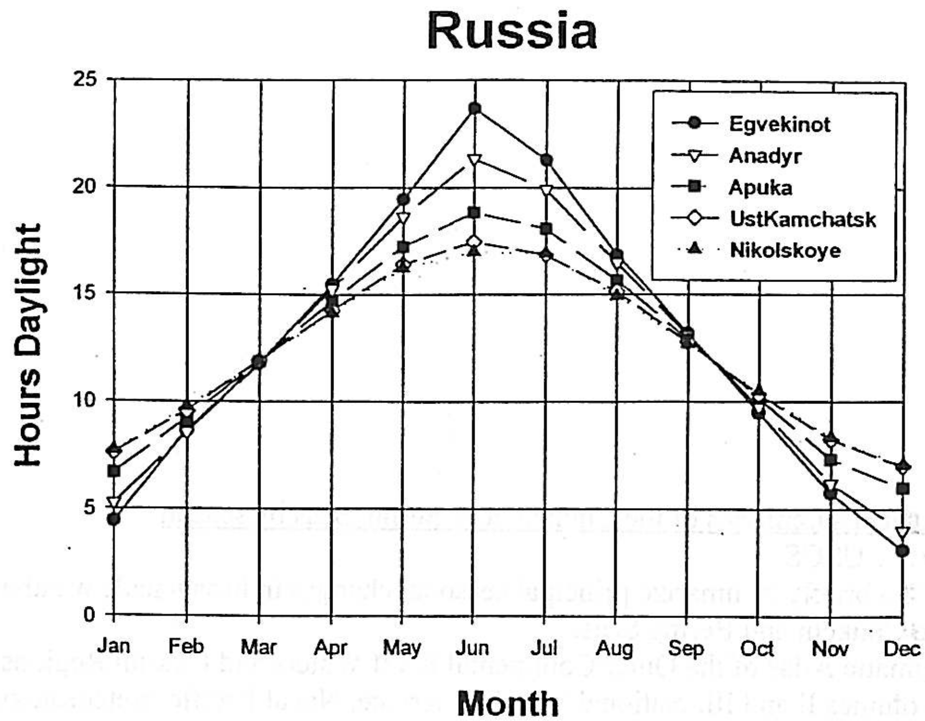
Purpose: To contrast daylight length across a latitudinal gradient within the study area. These data were also used to determine flyable days at stations along the coasts of Russia and Alaska (Figure E1).

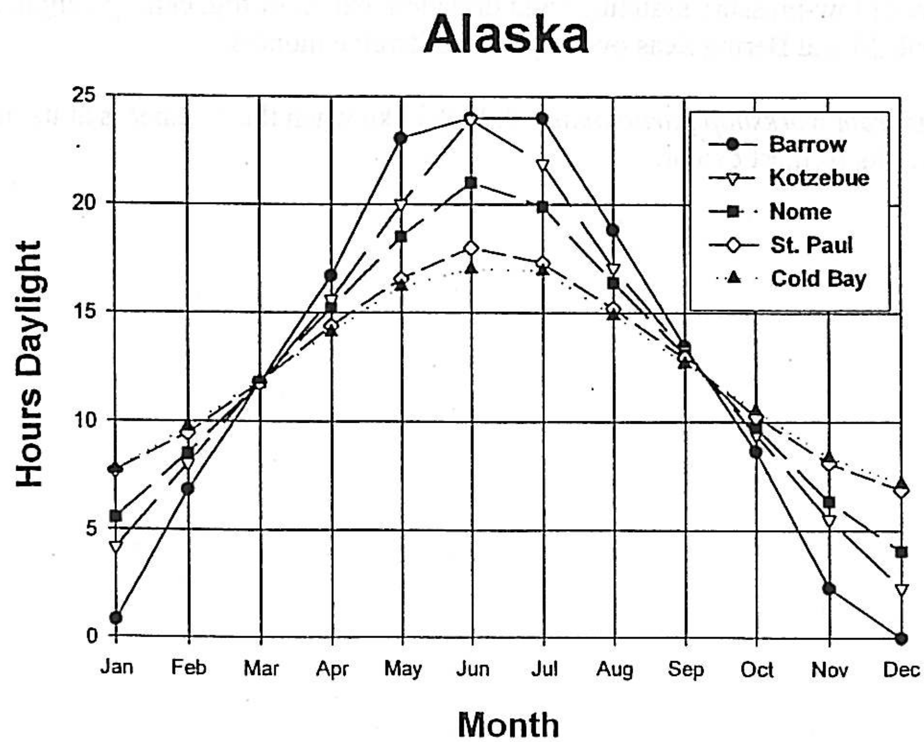
Data: U.S. Naval Observatory, Astronomical Applications Department. Time of sunrise and sunset for each day and station.

Method: The number of daylight hours per 24-hr day was averaged over each month and station.

Comments from workshop participants:

It is important to realize that if a survey is delayed by poor weather in the fall, you will start to lose daylight very quickly. A week or two could make a huge difference. In the spring there is more flexibility.


Russia
Hours Daylight
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
0 5 10 15 20 25
Egvekinot
Anadyr
Apuka
UstKamchatsk
Nikolskoye


Alaska
Hours Daylight
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
0 5 10 15 20 25
Barrow
Kotzebue
Nome
St. Paul
Cold Bay

Climatological summaries of the Chukchi and Bering Seas by season
Prepared by: USGS
Purpose: To briefly summarize principal seasonal changes in broad-scale weather patterns within the Chukchi and Bering Seas.
Data: Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska (1988), Volumes II and III; National Weather Service; Naval Pacific Meteorological and Oceanography Center; Summers (1921).
Method: Synthesized relevant information from climatic atlases, web sites, and weather reports obtained from libraries and local weather offices. Variables assessed included magnitude and movement of low-pressure systems, wind direction, extent of fog, ceiling heights, and visibility in the Chukchi and Bering Seas over a period of twelve months.

Comments from workshop participants: It looks like when the weather is at its most stable when the ice is at its furthest extent.

CHUKCHI SEA

Winter (November – early April)

- Relatively high ice concentrations throughout the Chukchi and Beaufort Seas; little open water.
- Strong winds flowing from the north through the Bering Strait and east over Kotzebue are associated with strong low-pressure systems (~997-1000 mbs) in the Bering Sea. Inclement weather is common, and November is reported to be the windiest month of the year.
- Northerly winds flowing over land and ice pack bring drier air; fog extent and amount is minimal due to the solidity of the ice pack and cold, dry wind. Late March appears to be stable with little fog and relatively good visibility.

Spring (late April – May)

- Percent of open water increasing, particularly in the lower Chukchi Sea.
- Low-pressure systems weaken in the Bering Sea (1008-1009 mbs) and the strength of winds in the Chukchi Sea decreases.
- Wind flows northerly over the Bering Strait, northeast over Barrow, and become westerly over Kotzebue. These west winds may shift the ice pack closer to shore, keeping local Kotzebue conditions clear while fog persists offshore.
- With the increased extent of open water, fog amount and distribution increases notably relative to winter/late winter months.

Summer (June – August)

- Degree of ice coverage decreases through the summer.
- In early summer, weak (~1011 mbs) Aleutian low-pressure systems produce mild winds and conditions stagnate with little movement. In July and August, the low-pressure systems move over into Siberia and create relatively stronger southerly winds through the Bering Straight; westerly winds continue over Kotzebue.
- Warm, moisture-laden southerly winds encounter cooler water temperatures near the Chukchi Sea pack ice, and fog becomes extensive. Visibility becomes much more restricted than in other months of the year.

Fall (September – October)

- Amount of open water in the Chukchi Sea is highest in September; ice begins to build in October.
- Development of moderate low-pressure systems (~1006 mbs) in September in the Bering Sea begins to re-create the winter pattern of northerly winds through the Bering Strait and easterly winds over Kotzebue.
- Fog extent and amount decreases substantially; October tends to reflect the least amount of fog for all months of the year. Although open water still exists throughout much of the area, north winds bring dry, cool air over the ice pack and keep fog from developing.

BERING SEA

Winter (November – March)

- Degree of ice coverage increases from November to March.
- Relatively strong winds from the north over Gambell and St. Paul Island are associated with strong low-pressure systems (~997-1000 mbs) adjacent to the Aleutian Islands.
- Fog extent and amount is minimal due to cold, dry northerly winds; however, inclement weather (cyclonic storms), with low ceilings and limited visibility, is common during winter months. High degree of variability and extreme weather patterns exist (i.e., although really nice days may be frequent, they are difficult to predict). However, late March appears to be more stable with little fog and relatively good visibility.

Spring (April – May)

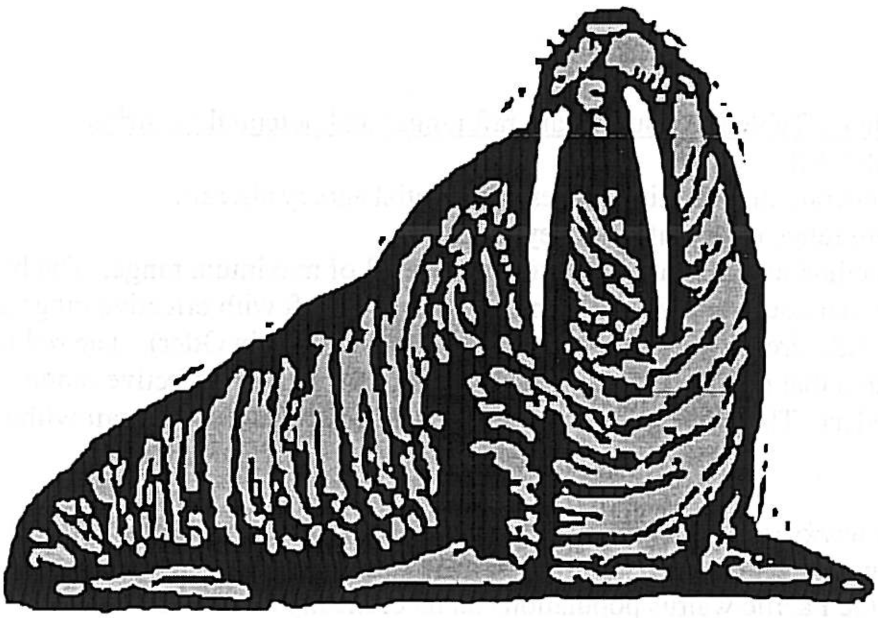
- Extent of ice coverage decreases throughout the spring.
- Winds continue to flow north to south over Gambell and St. Paul, but Aleutian low-pressure systems begin to weaken (~1008-1009 mbs), producing diminished winds.
- Storms occur less frequently, the region 'stagnates' as air movement is reduced, and fog extent/amount increases notably through May.

Summer (June – August)

- The Bering Sea becomes ice-free in late June.
- In early summer, weaker (~1011 mbs) low-pressure systems over the Aleutian chain produce mild winds generally flowing south to north over the region. In July and August, low-pressure systems shift over into Siberia and create more-pronounced southerly winds flowing over Gambell and St. Paul Island.
- Fog becomes widespread as warm, moist winds encounter cooler water temperatures; visibility is at a minimum under these stagnant conditions.

Fall (September – October)

- The Bering Sea remains ice-free until October; ice concentrations begin to develop in Norton Sound in late-October.
- Moderate low-pressure systems (~1006 mbs) emerge in September, once again reflecting the pattern of northerly winds and decreasing fog similar to the mid-winter months.
- Low-pressure systems appear to localize over the Gulf of Alaska in October; at this time, fog is negligible and the percent frequency of poor ceiling/visibility is minimal.



Logistics

Figure F1/ Table F1/Table F2 . Survey aircraft ranges and potential air strips
Prepared by: USFWS
Purpose: To illustrate the effective ranges of potential survey aircraft.
Data: Maximum range of potential survey aircraft.
Method: This method assumes an effective range as 1/3 of maximum range. The blue line depicts the area that could be covered using a Russian aircraft with effective range of 800 km (AN-30) and a U.S. aircraft with effective range of 480 km (Twin Otter). The red line depicts the additional area that could be covered using a U.S. aircraft with effective range of 740 km (Aero Commander). The black lines show the ranges of the two U.S. aircraft within the total area covered.

Questions from workshop participants: Q: Was a safety buffer planned in? A: We used 1/3 of the maximal range to get out there. The graph shows the areas you can theoretically reach. The entire range of the Pacific walrus population can theoretically be reached.

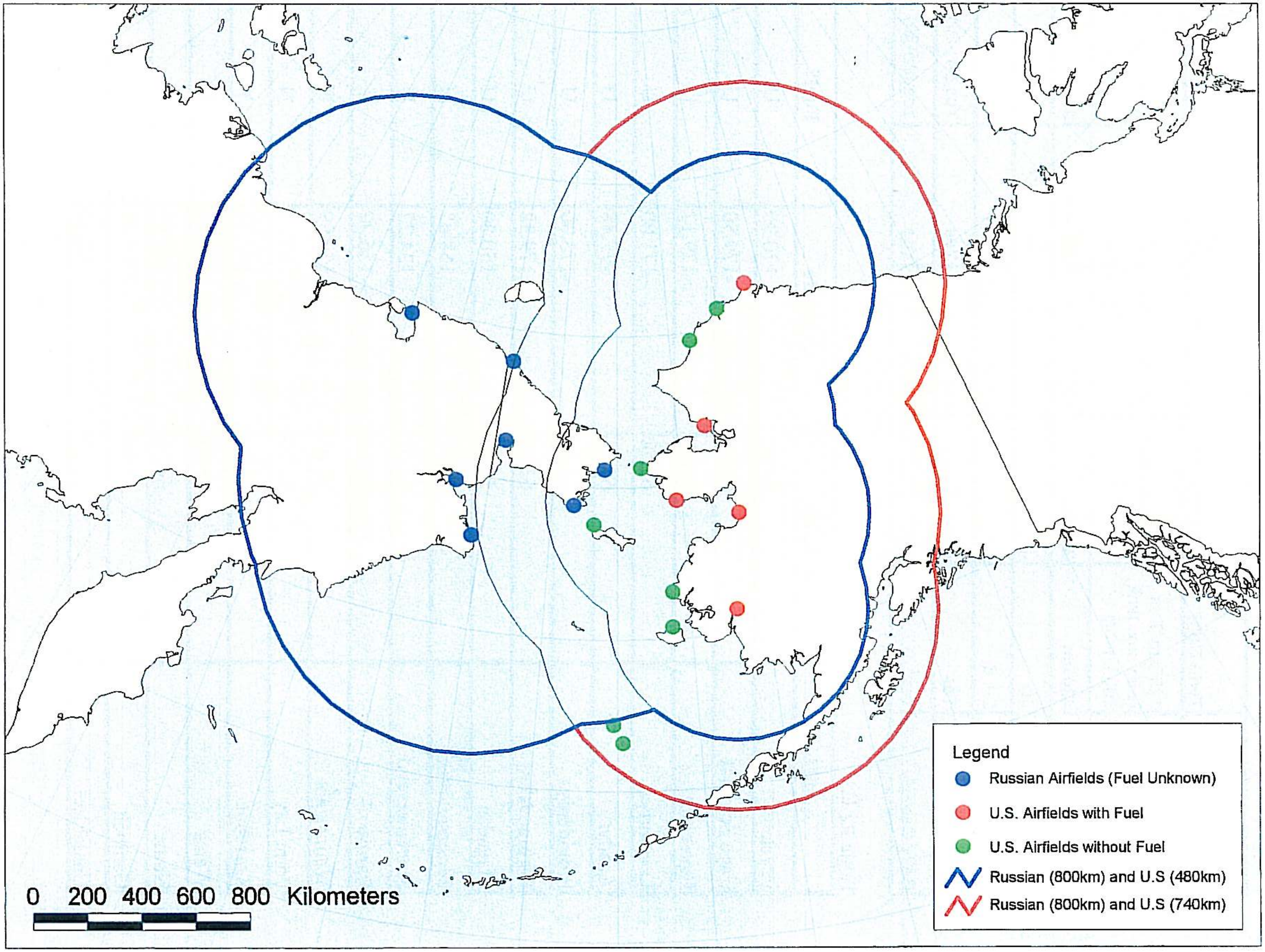

0 200 400 600 800 Kilometers
Legend
Russian Airfields (Fuel Unknown)
U.S. Airfields with Fuel
U.S. Airfields without Fuel
Russian (800km) and U.S (480km)
Russian (800km) and U.S (740km)

Table F1

Survey Aircraft	**Twin Otter**	**Turbine Goose**	**Aero Commander**	**Turbo Commander**	**AN-26/30**
Max Range/Duration	1250km/6hrs (with aux. tank, 200 km/hr)	2400km/10hrs (240 km/hr)	2240km/10hrs (225 km/hr)	*est. 1230km/6hrs (190 km/hr)*	2400km/6hrs (450 km/hr cruise)
Effective Range	480 km	800 km	740 km	*est. 410 km*	800 km
Fuel Type	Jet	Jet	(Aviation Gas)	Jet	Jet
Crew	2 + 6	2 + 8	2 + 5	2 + 5	4 + 30
Bubble Windows?	Yes	No	Yes	Yes	Yes (An-26)
Belly Camera?	Yes	Yes	Yes	Yes	Yes (An-30)

Table F2

Airfields	Latitude	Longitude	Fuel?
Pevek	69.70	170.30	U
Cape Schmidt	68.93	-179.50	U
Egvekinot	66.32	-179.17	U
Lavrentiya	65.58	-171.00	U
Anadyr	64.75	177.48	U
Provideniya	64.38	-173.30	U
Beringovskiy	63.05	179.32	U
Magadan	59.57	150.80	U
Petropavlovsk	53.02	158.65	U
Sheremetyevo	47.37	134.27	U
Barrow	71.28	-156.77	Y
Wainwright	70.64	-159.99	N
Point Lay	69.73	-163.01	N
Kotzebue	66.89	-162.59	Y
Wales	65.62	-168.10	N
Nome	64.51	-165.45	Y
Gambell	63.77	-171.73	N
Unalakleet	63.89	-160.80	Y