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BESMEX

Bering Sea Marine Mammal Experiment

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA 94035

(BESMEX)

BERING SEA MARINE MAMMAL EXPERIMENT

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This document was prepared by

Dr. G. Carleton Ray and Dr. Douglas Wartzok

of

NASA
Ames Research Center
Biotechnology Division 239-1
Moffett Field, CA 94035

and

The Johns Hopkins University
615 North Wolfe Street
Baltimore, Md. 21205

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PREFACE

BESMEX is a collaborative research program involving cooperation among scientists of different disciplines and the services, manpower, and equipment of several agencies. The federal user agencies are: the Office of Naval Research (Oceanic Biology); the Department of the Interior (Fish and Wildlife Service); and the Department of Commerce (National Oceanographic and Atmospheric Administration/National Marine Fisheries Service). The budget allocations of these agencies for work related to and partially supportive of BESMEX are: ONR, \$50K for FY 74 and \$50K for FY 75 for continuing support of radio-tracking; NOAA, \$21K in FY 74 and \$45K planned for FY 75 for whale censuses; FWS, \$5K in FY 74 and \$75K planned for FY 75 for walrus research. The ONR, in particular, has supported work leading to this project in the form of instrumentation development toward marine mammal radio tracking and telemetry, involving both the Aquatic Facility at The Johns Hopkins University and field testing. The other agencies are contributing manpower for ground truth observations along with their own considerable field support which includes aircraft, boats, laboratory space, and data processing facilities.

The United States Sea Grant Program under NOAA is directly supporting walrus research that is critical in the interpretation of BESMEX data with a grant of \$25K to Dr. Francis Fay of the University of Alaska. The Marine Mammal Commission of the United States supports research on walrus food organisms with a grant to Dr. Fay of \$39K and on walrus systematics with a grant of \$7K to Dr. Fay and John J. Burns of the Alaska Department of Fish and Game.

Logistics support is essential to the continuance of BESMEX. The Research Vessel *Alpha Helix* of the Scripps Institution of Oceanography provided a platform in the summer of 1974 for radio-tracking and behavioral studies of walruses in Bristol Bay, Alaska. Icebreakers of the United States Coast Guard have been essential in Bering Sea investigations, during which they have provided a unique opportunity for gathering ground truth and oceanographic data. These ships continue to be important and their role during BESMEX will be analogous to that during the 1973 Joint US/USSR Bering Sea Experiment (BESEX). The considerable costs of icebreaker cruises are borne by the USCG.

The Alaska Department of Fish and Game and the Fish and Wildlife Service both have contributed considerable manpower and logistic support and their direct collaborative efforts will continue. For example, in September 1974 representatives of both agencies assessed marine mammals from Department of the Interior aircraft, concurrently with NASA/BESMEX flights. This aircraft aided in directing us to concentrations of marine mammals, thereby effecting substantial economy in search hours.

Throughout the BESMEX project, investigators involved in the Arctic Ice Dynamics Experiment (AIDJEX), supported by the National Science Foundation, will be sharing and cross-referencing data collected by NASA satellites and aircraft and from ships and ground truth stations. Data interpretation of ice dynamics by AIDJEX investigators is also a valuable asset to BESMEX. This sharing results in cost benefits for both projects as the same imagery aboard the same aerospace vehicles is often used by both projects.

The user agencies and collaborators are specifically identified on pages 39 and 40.

SUMMARY

The Bering Sea Marine Mammal Experiment (BESMEX) is a four-year program having as its major goal the development and quantification of predictive ecological models for management and conservation of Bering Sea marine mammals. The total target area includes the continental shelf portions of the Bering and Chukchi seas. This program concentrates on two target species of marine mammals: the walrus, *Odobenus rosmarus*, and the bowhead whale, *Balaena mysticetus*. These species have been chosen because of their ecological importance and because the maintenance of their populations is a matter of national and international concern and obligation. The walrus is the primary target species because of the background information available and the relative ease of remote sensing and radio tracking.

Sea ice is a major component of the ecosystem of both target species and is an integral part of the two target questions addressed by this program. These questions are related to the distribution and movements of the target species relative to sea ice, and the role of sea ice in determining the carrying capacity of the target area for them. A heuristic model has been formulated as a framework within which the first question can be approached for walruses. A model for the second question has not yet been developed. It is expected that quantitative, predictive models for both of these important ecological questions will be forthcoming from this program.

Two major techniques will be employed in answering the target questions. These are remote sensing and radio tracking. Both of these techniques are appropriate for the target species. Hauled-out walruses present a strong visual and thermal contrast with the background sea ice. Furthermore, they can be approached closely to attach tracking devices. Bowheads are among the largest of whales and there is a strong possibility that the heat of their respiration can be sensed against the cold background of their environment. Both species must surface periodically, and the attached radio-tracking gear can then transmit to aircraft, ships, or satellites. Both remote sensing and radio tracking are required since they complement each other by providing both synoptic and specific data on numbers, distribution, social behavior, and activity patterns of animals, and on the influence of environmental variables.

The models of distribution and abundance developed in this program are needed by user groups for management; these groups are the United States Fish and Wildlife Service (USF&W), Department of the Interior, and the National Marine Fisheries Service (NMFS), Department of Commerce. The Bering Sea ecosystem can be modeled on a synoptic basis only through the use of NASA technology and support including aircraft, remote-sensing instruments and satellites.

MAJOR GOALS

for the Bering Sea Marine Mammal Experiment (BESMEX)

1. To develop, quantify, and validate predictive ecological models for management and conservation of Bering Sea marine mammals.

2. To assess populations of target species critical to model formulation.

3. To assess meteorological and ecological parameters that influence the distribution of target species within the model framework.

4. To develop better methods for assessment essential for model development and validation, principally by remote sensing and radio tracking.

5. To transfer information derived from models and methods to user agencies and to cooperative international environmental programs.

SPECIFIC OBJECTIVES

for the Bering Sea Marine Mammal Experiment (BESMEX)

1. To specify the walrus, *Odobenus rosmarus*, and the bowhead whale, *Balaena mysticetus*, as target species because they are of critical importance and because they exemplify many marine mammal ecological and management problems.

2. To demonstrate the utility of the following technologies in the data-gathering process: (a) high-resolution aerial photography, (b) infrared imagery, (c) satellite imagery, (d) radio tracking and telemetry, (e) differential radiometry, and (f) microwave imagery.

3. To gather specific distributional data for both target species at all times of year and to quantify a model that relates sea-ice dynamics and meteorology to mid-winter walrus distribution.

4. To construct further ecological models, derived from remote sensing and radio tracking, addressed to: (a) behavioral thermoregulation and energetics, (b) behavioral and distributional relationships of subpopulations of the target species and (c) distributional relationships between the target species and other marine mammal species.

5. To begin the process of quantifying a model describing the role of sea ice on the carrying capacity of the Bering and Chukchi seas for walrus, also taking behavioral and trophic relationships into account.

INTRODUCTION

The Bering Sea Marine Mammal Experiment (BESMEX) responds to the urgent need to assess marine mammals within an environmental context in order better to be able to predict natural fluctuations of populations and man's perturbations upon them. It also responds to public opinion, which resulted in the passage of the Marine Mammal Protection Act of 1972 (PL 92-522). This Act requires a basic and major effort towards assessment, monitoring, and prediction of the status of marine mammal populations. It states:

Sec. 2. The Congress finds that –

(1) Certain species and population stocks of marine mammals are, or may be, in danger of extinction or depletion as a result of man's activities.

(2) Such species and population stocks should not be permitted to diminish beyond the point at which they cease to be a significant functioning element of the ecosystem of which they are a part, and, consistent with this major objective, they should not be permitted to diminish below their optimum sustainable population.

This legislation is a radical departure from past practices of marine mammal protection or harvest; indeed, we do not know nearly enough about how marine mammals relate to their ecosystems to be able to estimate what their "optimum sustainable population" might be or to predict how natural or man-made perturbations are reflected in marine mammal abundance.

BESMEX thus responds to the mandate to describe marine mammal ecological relationships with a program and provides techniques and models for the assessment, monitoring, and managing of populations of important target species, the walrus and bowhead whale, in a target area of critical national and international importance, the Bering and Chukchi seas. BESMEX initially addresses itself to two major target questions involving the interface between both species and the dominant ecological component of the study area, namely, sea ice:

1. How does sea ice influence the distribution of the target species?

2. How does sea ice influence the carrying capacity of the target area for these species?

The answers to these questions will provide a basis for constructing predictive ecological models for assessment and management. Burns (1970) emphasized the importance of sea ice in the ecology of ice-inhabiting marine mammals, and Fay (1974) states: "The study of ice as a major factor in the ecology of marine mammals is still in a rudimentary stage . . . it has become increasingly apparent that ice plays many roles in the ecology of marine mammals and that its full importance to them has been greatly underestimated in the past."

The history of exploitation of marine mammals of the Beringean (Bering-Chukchi) region – whales, fur seals, walrus, sea otter, Steller's sea cow, and others – is well known. Obviously, these animals have been important to man the exploiter and they remain so to this day. However, they have also become important to man the conserver, especially as we have come to recognize that they exemplify many ecological and exploitive processes and are important components of their ecosystems. For example, we now realize that it is no longer possible to maintain healthy marine mammal populations without also assessing man's impact on their food supply and on the health of their habitat. Most important, we need to know how these animals contribute to the health and stability of the ecosystem of which they are a part. Further, we are now aware that man has so perturbed ocean environments and the populations they contain (Hood, 1971) that it is incumbent on us to manage our activities so that greater stresses will not be imposed.

To understand these matters, we must look at a broad range of parameters such as weather, productivity, oceanography, pollution, and fishery exploitation, as well as at the behavior, physiology, reproduction, and distribution of marine mammal populations themselves. BESMEX represents an effort toward the integrated research required. However, it cannot look at all these parameters at once; rather, it concentrates on specific features and depends on collaboration with other workers and programs for the emergence of models reflecting the total Beringean ecosystem and man's impact on it.

Ecosystem research in the United States has just begun. The International Biological Program has recently developed rigorous research procedures for integration of effort, for rapid transfer of results and exchange of ideas, and for development of ecological models for validation. The integrated research approach has emphasized that first efforts are to provide a functional array of data from a number of years, if necessary, in order to experience the full range of variation and to discern the interaction of variables. Then a model for testing can be built.

The necessity for an ecological approach to marine mammal research and management has been clearly recognized in several international quarters, in addition to the International Biological Program, Marine Productivity Section (Theme D. Marine Mammals). These include: The United Nations Food and Agriculture Organization, Acting Committee on Marine Resources Research, Marine Mammal Working Party; The United States-Soviet Joint Committee on Cooperation in the Field of Environmental Protection (of which BESMEX is a proposed part); the International Conference on the Biology of Whales, Skylands, Va., June 1971 (Schevill, Ray, and Norris, 1974); and the International Whaling Commission recommendation for an International Decade of Cetacean Research at its June 1972 meeting. For these reasons and because marine mammals of Beringea are creatures of the high seas, we have visualized BESMEX as developing into an international research effort, after an initial period for proving out our technology.

The succeeding sections of this Program Plan present the justification for BESMEX, provide a summary of the relevant scientific studies on both the target species and their environment, and review the technical background covering the two major tools we will employ, radio tracking and remote sensing. Next, we give our rationale for selecting target areas, target species, and target questions. This is followed by the four-year implementation plan for BESMEX covering 1974-1977. The Plan concludes with an outline of management organization, a bibliography, and supporting documents, and an appendix.

JUSTIFICATION

Integrated environmental research on marine mammals is exemplary of ocean management problems in general, the solution of which is essential for the wise management of the marine resource base on which mankind increasingly depends. Wagner (1969) states: "A considerable part of the world's food supply comes from largely wild, undomesticated systems. Most notable, of course, is the ocean which undoubtedly will be exploited to an increasing degree in the future." The implications of this statement rest in the historical overexploitation of ocean resources, the continuing degradation of the ocean environment by man, and the increasing human population. The imperative of maintaining these oceanic resources is clear. However, it is essential to realize at the outset that we are not yet at a sophisticated stage that allows the construction of models expressing optimum populations. Research on marine mammals has rarely involved technology capable of a synoptic view of their habitat or populations, nor has such research often been ecologically oriented. Thus, we still are faced with the fundamentals of gathering a data base on population numbers and environmental relationships for model construction. BESMEX is largely dedicated to that end.

Population studies of marine mammals have been severely limited by a lack of both technology and logistics. Peterson (1968) states: "... until the ecological niches of the various species can be better documented, all explanations will lack a firm foundation. Very much like icebergs, the lives of ... [marine mammals] cannot be understood adequately without more information about the unseen portions beneath the surface of the sea" – to which we might add "at sea" as well.

There are at least four aspects to understanding the rest of the iceberg: (1) environmental interactions such as between weather and sea ice movements; (2) population ecology, relating the species to its habitat and niche; (3) behavior as it affects group structure, thermoregulation, and reproduction; and (4) relationships between food supply and the cycling of nutrients, as these affect carrying capacity of the habitat for the population. An attack on these problems must involve new methods and new questions. Ray (1970a) has asked some of these questions regarding the relationship between marine mammals and the pack ice:

1. What is the relationship between the pack ice and food, hydrology, and the benthos?

2. What are the limiting factors that determine carrying capacity for each species?

3. Are "pagophilic" (ice-inhabiting) seals obligate or facultative in their relationship with the ice?

4. To what extent is the pack ice an "ecosystem"?

These questions represent ultimate goals. Our proximate goals are more circumscribed.

Lately new tools have become available that facilitate the realization of our objectives. Radio tagging has become a tool of great value for describing movements and trophic relationships of marine mammals, as Evans (1974) has shown for dolphins. This technique may also tell us about migrations, group relationships, and social behavior of individuals at sea. It has long been thought that remote sensing, such as photography and infrared imagery, could be useful for population assessment and habitat evaluation. It is now clear that the time is ripe for a coordination of radio tagging and remote sensing to provide significant breakthroughs in data acquisition.

NASA technology, as exemplified on the Joint US/USSR Bering Sea Experiment (BESEX) during which we participated in the CV-990 portion, could be critical in developing a better understanding of marine mammals within their ecosystems. Although BESEX was directed toward climatology and ice dynamics and not toward marine mammal research, some important new approaches emerged, particularly in the remote infrared sensing of walrus (fig. 8) and the potential of integrated geophysical-biological studies of walrus distribution relative to sea ice.

In fact, it is difficult to imagine how sufficient understanding for management of living resources on the high seas can be achieved without such technology as NASA has within its purview. It is also abundantly clear that research on living resources must be at least as intensive and as well supported as that on climate and atmospheric physics.

The Importance of Marine Mammals

It is perfectly reasonable to inquire: "But why should a major research effort be directed toward maine mammals; what if all marine mammals disappeared; would this represent a loss to man or alter their ecosystems?" There are at least seven answers to these questions:

1. Marine mammals have been and continue to be important sources of food, oils, and other products on a world basis. The magnitude of this is only partly contained in such summaries as the UN/FAO provides. FAO data exclude, for example: native uses of the northern seals; the catches of many nations that do not report data; the important function of "tuna-finding" porpoises used by (and accidentally killed by!) tuna fleets; and the real or potential value of such small species as Antarctic seals and small tropical and temperate Cetacea, which remain under-utilized or virtually untapped. Nevertheless, the FAO estimated that whale oils alone were worth $25 million in 1971 (expressed as exports from producing countries).

   The attractiveness of marine mammals to the exploiter lies partly in their extreme efficiency as harvesters of ocean productivity. For example, Antarctic whales are effective "packagers" of krill. A single shot of a harpoon may secure 20 or more tons of oil and protein equivalent to a quarter million servings of beef. Though the preparations for this shot are costly, the truth is that the whale has done most of the work of energy conversion (Mackintosh, 1965). Man's attempts to harvest krill prove to be much less efficient.

2. The importance of marine mammals to the way of life of native Alaskans, Siberians, and Canadians, among others, cannot be overestimated (Hickok, 1968). For example, the 1971 harvest of walrus provided the Alaskan natives with a realized value of $400,000 to $500,000 (Burns, 1972). However, there is a long and unfortunate history of Western man's impact on whales and pinnipeds, which has deleteriously affected Aleuts and Eskimos particularly.

3. Esthetically, marine mammals have become symbolic of man's "rape of nature." This is a complex issue, but there is no question that the esthetic consideration alone makes the continued existence of healthy populations a national requirement of the very first magnitude.

4. Marine mammals are important animal models for human respiratory, circulatory, anatomical, and other biomedical research (Ridgway, 1972; Harrison, 1972). Physiological systems can often be understood best by studying those animals in which they are most elaborated. For example, the inhibition of the trigeminal nerve on the carotid nerve in the

"diving reflex" of seals is being studied as a possible model for the sudden infant death syndrome.

5. Marine mammals may be sensitive indicators of environmental pollution. For example, will pesticides affect women in the same way the apparently affect sea lions by causing abortion (Delong, Gilmartin, and Simpson, 1973), and if so what are the physiological and ecological pathways involved?

6. Ecosystem considerations are perhaps the most important matter of all in their implications. The loss or depletion of a species represents a loss in benefits to man directly, but such loss can also lead to great difficulties indirectly. For instance, should ecological displacement occur, wherein the overutilization of one species leads to the increase in another, what then is the effect on the total system? There exists some evidence that seals or penguins or fish - or all three - may have occupied the niche left mostly vacant by the decline of the Antarctic whales. How then does man utilize such an altered system, as inevitably he will, to support his growing biomass? To take another example, how would the removal of walruses affect Bering Sea productivity? Would the nutrients that probably are released by the walrus' benthic feeding activity no longer be recycled so efficiently? And further, how does man's competition for marine mammal food species affect marine mammal numbers? Are we reducing total Bering Sea production by overfishing there? There is a strong suspicion that fur seal recruitment may be adversely affected by overharvest of herring and pollack (Ray and Norris, 1972).

7. It is important to understand that marine mammals are tools by which we may come to understand oceanic biological relationships. Marine mammals are large, and they must breathe at the air-water interface where they may be sensed and observed and where attached instrumentation may send signals to receivers, including satellites. Thus, they are relatively easy to study, as compared with large oceanic fish such as tuna. This factor of observability makes them very useful in the study of marine ecology.

Thus, marine mammals represent many important scientific, esthetic, and ecological considerations that we must understand for management of the living resources of the sea. We hope BESMEX will illustrate the integrated approach we are convinced is necessary and in so doing will clarify some important marine ecosystem relationships.

Several potential spinoffs of this program have been alluded to already. Intellectually, BESMEX could provide an example of an integrated, multidisciplinary approach to marine ecosystem monitoring and management. The marine radio-tracking technology developed during this experiment should be applicable to other oceanic wildlife tracking studies. For example, the requirements for a walrus transmitter are essentially the same as those for sea turtles, crocodiles, dugongs, manatees, seals and sea lions, and certain whales. Remote-sensing techniques developed in the Bering Sea, where visual and infrared contrast of marine mammals with sea ice is high, would be immediately applicable to the Antarctic and would provide a basis for similar use over temperate and tropical seas where such contrast is not so great.

THEORETICAL BACKGROUND

Here we summarize relevant information in four areas:

1. Population dynamics and wildlife management.
2. Population assessment and distribution.
3. Food webs and their relationship with the ecosystem.
4. Conflicts in resource use.

Population Dynamics and Wildlife Management

Almost all wildlife management models are based on the well-known logistic growth curve which can be expressed as:

$$dN/dt = r_n N(K - N)/K$$

in which the rate of change in the numbers of a population is a function of the natural rate of increase (r_n), the number of individuals in the population (N), and the carrying capacity of the habitat (K). This equation has three major implications. First, the growth rate per individual $(1/N)(dN/dt)$ decreases with increasing population. Second, the maximum recruitment rate to the population $(dN/dt)_{max}$ occurs at N = 0.5K. Third, when N is greater than K, (dN/dt) is negative and the population will decline to K due to natural causes.

This basic equation is really too simple to use predictively although it is often used in that way. For example, it does not account for the fact that N is a function of the age and sex structure of the population; it does not consider that r_n is a function of age, sex and environment; and it considers the carrying capacity to be a constant when in fact it is highly dependent on time, on changes in the environment, and on N itself. One has only to review the annual reports of the International Whaling Commission to see these variables at work and the length to which population dynamicists must go to estimate these variables. In truth, we possess no adequate way to assess accurately the numbers of marine mammals at sea, to predict how environmental variation will result in population fluctuation, or to know how undercrowding or overcrowding of a population of marine mammals may affect the environment itself.

Historically, there have been two general approaches to wildlife resources management. These approaches can be termed the fisheries approach and the terrestrial game approach (Wagner, 1969). The fisheries approach has been to maximize the recruitment rate into the population by consistently holding the population levels at about half of the estimated carrying capacity. There are three major problems with this approach. The first is the uncertainty in the determination of the carrying capacity K at a given time and the lack of a predictive model for estimating it at later times. Second, population numbers depend on interactions between events that can only be described by probability functions. The attempt to maximize recruitment rate by holding N at about 0.5K may result in natural variation reducing N below a minimum threshold value for any growth, and the population ceases, at least temporarily, to be a functioning part of its ecosystem. Small populations are particularly vulnerable to this type of effect, called r extinction. Third, maintaining N at values well below K can result in "ecological displacement" whereby other species can invade the now incompletely occupied niche, perhaps altering K for the species of interest. For example, Slobodkin (1961) has described the following interaction between two species:

$$dN_1/dt = r_1N_1(K_1 - N_1 - \beta N_2)/K_1$$

$$dN_2/dt = r_2N_2(K_2 - N_2 - \alpha N_1)/K_2$$

in which $\beta(\alpha)$ is the depressive effect of the individuals of a second (first) species on a first (second). Partial removal of either species leads to ecological displacement. The overexploitation of California sardines, which led to displacement by anchovies, is a classic example (Murphy, 1966, 1967). The succession of species of deepwater fish in Lake Michigan brought about by exploitation is another spectacular example (Smith, 1966, 1968). The likelihood that man's exploitation of marine mammals has had similar effects is real, but we will not be able to ascertain its extent until the niches of sympatric marine mammals are better described.

The theory used in game management is quite different. It assumes that K is determined by the season or by conditions when the fewest numbers may be supported. This is the "winter threshold" for deer and upland game. Each year these animals reproduce in excess of K and the exploiter (man or predator) takes a portion of this excess. The primary difficulty with this approach is again the difficulty in determining K both at a given time and at later times, although there are much better estimates of K for game than for marine species. Also, game management makes little attempt to maximize recruitment rate under given environmental conditions. Thus, the game management approach is ecologically more conservative than the fisheries management approach.

Marine mammals, and in particular cetaceans and fur seals, have traditionally been managed in line with single-species, population dynamics models as used in fisheries. One of the primary reasons marine mammals have been managed by this means is the paucity of ecological data from which carrying capacity can be determined. We believe that a significant step can be made toward determining K for our target species through the methods proposed here.

Population Assessment and Distribution

Historically, population studies of marine mammals have involved: recovery of implanted tags from harvested animals; ship and aerial surveys; largely intuitive or laboratory-derived environmental relationships; behavioral study of certain seals that breed on land rookeries; strandings of moribund or dead animals; food studies; and certain other derivative information. Only for a few populations has information on numbers, distributions, and fluctuations been sufficient to allow estimates of N or K to be made. Even in those few cases, the ranges of variations are often very great and environmental correlates have not been clearly established such that reliable prediction is possible. Clearly, new tools must be developed for data gathering. Here we are concerned mostly with the walrus, as data on bowhead whale numbers and distribution are at present very scarce.

Assessment and management-oriented studies on walrus by Soviet and U.S. biologists since the early 1950s (Brooks, 1953, 1954; Fay, 1957; Buckley, 1958; Fedoseev, 1963; Krylov, 1962 *et seq.*; Burns, 1965) have contributed a substantial body of information on distribution, biology, and utilization. Although the walrus is one of the easiest marine animals to assess from the air, our knowledge of its numbers and the distribution of subpopulations is but rudimentary. Kenyon (1972) gives the population size as 136,000 (range of 85,000 to 162,000) as a result of visual aerial counts, which covered 4,280 nmi^2 and during which 9,300 walrus were seen on the ice. This number includes an assumption of about 10% in the water, a figure without a data base. It is not generally realized that this population estimate is rather good, as estimates of marine animals usually go. In contrast, Erickson, Gilbert, and Otis (1973) made a population count of the Antarctic crabeater seal, *Lobodon carcinophagus*. They covered only 1.33% of the outer pack ice (0.68% of total pack) between 145° and 170° E, comprising but 605 nmi², and from this small sample have extrapolated 181,000 seals for the area!

Kenyon pointed out the difficulties encountered in making his counts, including observer fatigue, lack of precision aerial photography, and the lack of ice dynamics and microclimatic data. He states: "The recorded observations of walruses are intended to reflect the order of magnitude of the numbers of animals seen." Nevertheless, his figures appear to be the best we have to date. Demographic analyses by the Alaska Department of Fish and Game and a recent aerial photographic survey conducted by Soviet scientists seem to support Kenyon's estimate. In sum, these studies indicate that the walrus population may be increasing slowly, but statistical variability is such that no trends can be demonstrated. Methods of assessment utilizing visual counts and unsupportable estimates of animals in the water must be replaced by more sophisticated sensing by means of visual and other wavelengths. Fay (1973) states: "More and better high-resolution photographs will be needed to provide the data base necessary for detailed analysis of the distribution and of the overall population structure."

Fay and Ray (1968) found a circadian rhythm in the walrus' hauling-out behavior. They found that at "effective temperatures" of greater than about −20° C, walruses in air were vasodilated with skin temperature plateauing between 20 and 32° C. Thus when hauled out, their thermal contrast with the ice might be as much as 50° C and was rarely less than 5° C. These studies are summarized in figure 1. Data were acquired largely on captives and on wild animals during the spring migration,

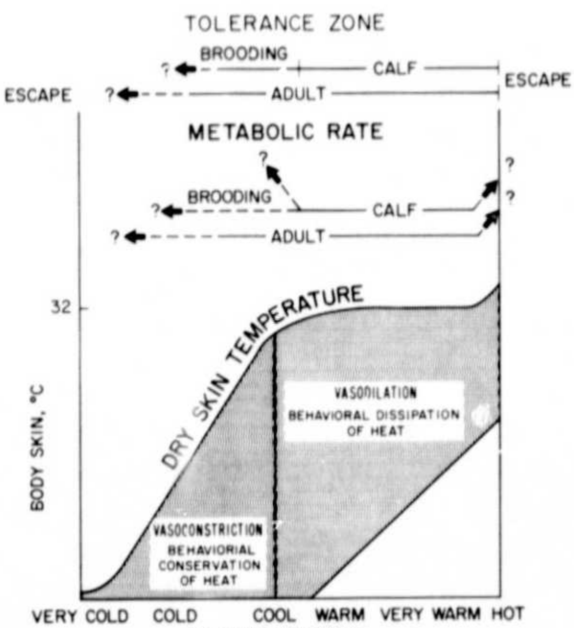


Fig. 1.– Schematic representation of dry skin temperature and its relation to the tolerance zone and metabolic rate of walruses at rest in air. Thermal neutrality, i.e., the "comfort zone," is predicted within the entire tolerance zone.

so the results need to be expanded to include other seasons. A knowledge of behavioral thermoregulation is essential for any assessment program since the animals can only be sensed when environmental conditions are favorable for hauling out.

One of the critical new questions being asked regarding certain ice-inhabiting species of marine mammals is that of the influence of sea ice on their distribution, behavior, and assessment (Burns, 1970; Ray, 1970a; Kenyon, 1972; Fay, 1974). Recent surveys and the observations from the CV-990 during BESEX indicated that one cannot adequately assess walrus without reference to sea-ice dynamics. Walrus prefer to haul out on thick annual ice containing pressure ridges interspersed with leads and polynyas, which provide access to the water. Ice cover cannot be complete. Figure 2 shows areas of the Bering Sea that are preferred by walrus; within the general areas

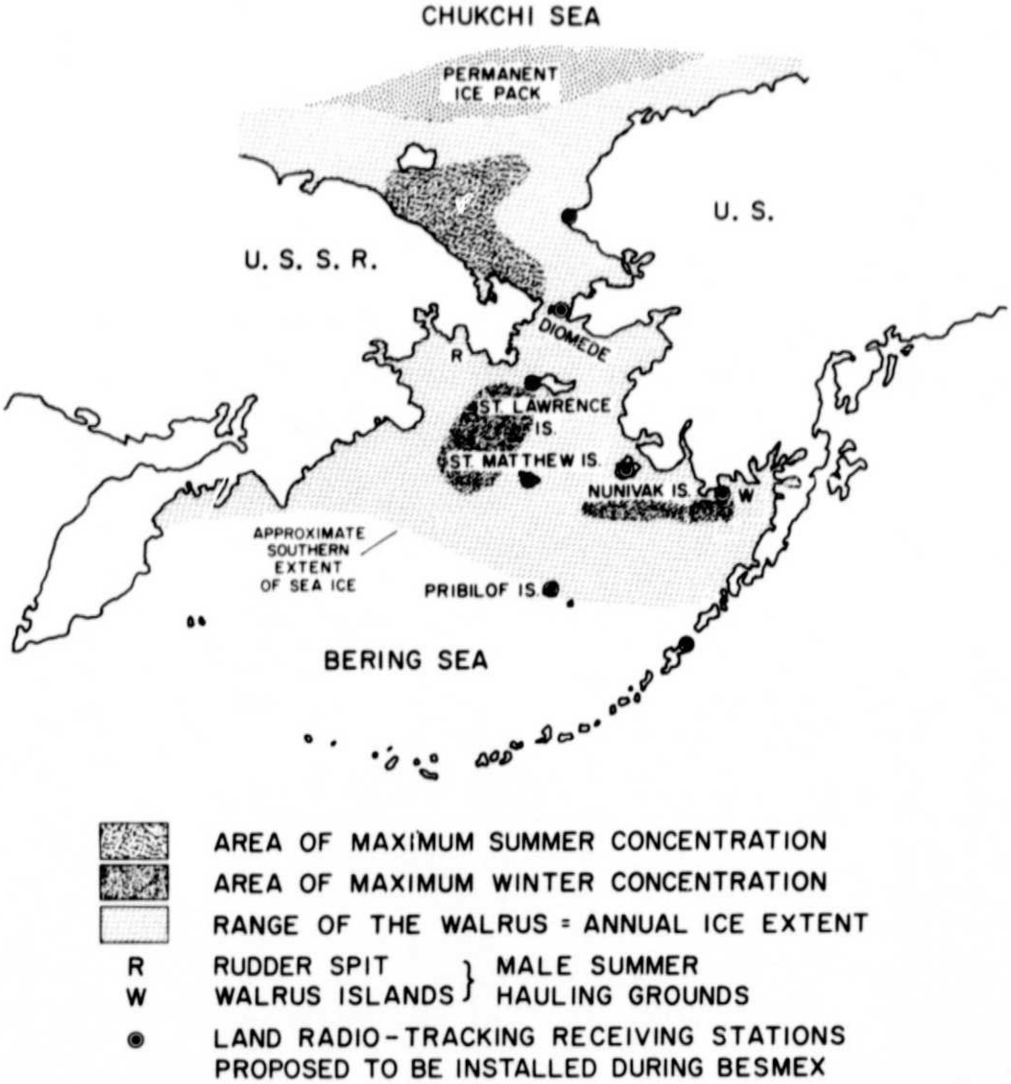
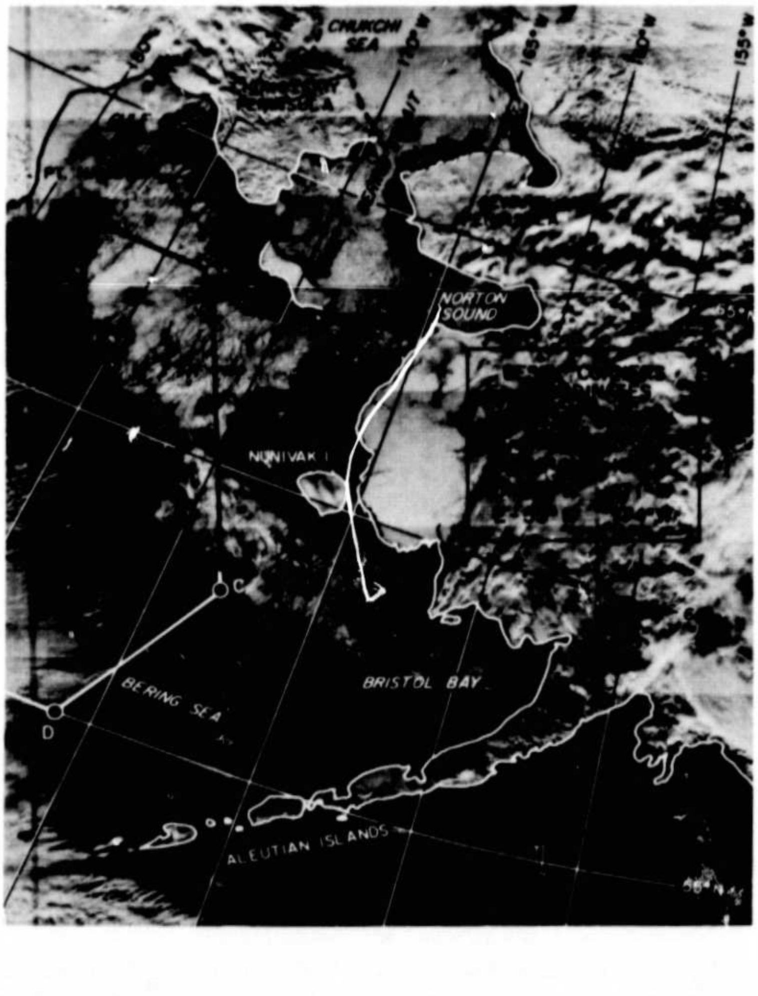


Fig. 2.– Walrus distribution in the Bering and Chukchi seas with proposed locations of land receiving stations.

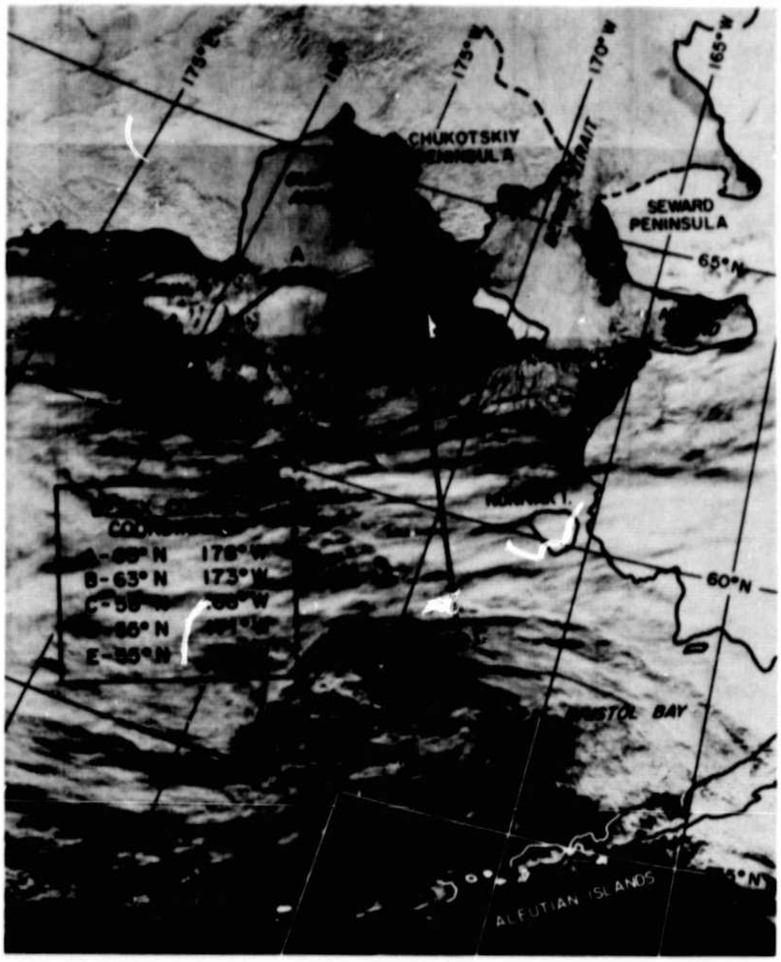
indicated, the actual locations of walruses depend on the ice type and distribution. Obviously, where there is no ice, few or no walruses will be encountered. Nevertheless, there is some indication that in spite of ice movement, females may actively seek to remain in a defined geographical area in the western central Bering Sea during the winter; in contrast, the males may move more in accord with the ice movements throughout the area of their total winter distribution. (F. H. Fay and J. J. Burns, pers. comm.).

Furthermore, the geographical location of groups of walruses changes markedly from day to day due to ice movements. Ice movements can be extensive and rapid, up to 45 km or more a day (W. Campbell, pers. comm.). For example, figure 3 shows two satellite photographs that illustrate the extent of ice movement in response to wind stress fields. The two photographs were taken



(a) 15 February

Fig. 3.– DAPP satellite visual wavelength images of weather and ice conditions during BESEX 1973.



(b) 7 March. Note movement of ice southward in response to northerly winds.

Fig. 3.– (Concluded)

20 days apart. Thus, a potential source of errors in aerial assessment techniques is a lack of consideration of ice movements, the nature of which is illustrated in figure 4. Clearly, it will be difficult to narrow the confidence limits of estimates of walrus numbers, as obtained in previous surveys, unless sea-ice dynamics are considered.

Sea-ice dynamics models are in a state of rapid evolution. The Arctic Ice Dynamics Joint Experiment (AIDJEX) is involved in a series of major drifting station programs in the Beaufort Sea in an effort to create an accurate dynamic-thermodynamic model for the polar pack ice. However, good observations of sea-ice dynamics are costly and rare. Therefore, we will start with a relatively simple ice model and then move on to more complex ones as the study demands.

The movement of pack ice is governed by the interaction of five forces: the wind stress at the ice-air interface ($\vec{T}_a$); the water stress at the ice-water interface ($\vec{T}_w$); the Coriolis force ($\vec{D}$); the pressure gradient force due to the tilting of the sea surface ($\vec{G}$); and the internal ice stress ($\vec{R}$).

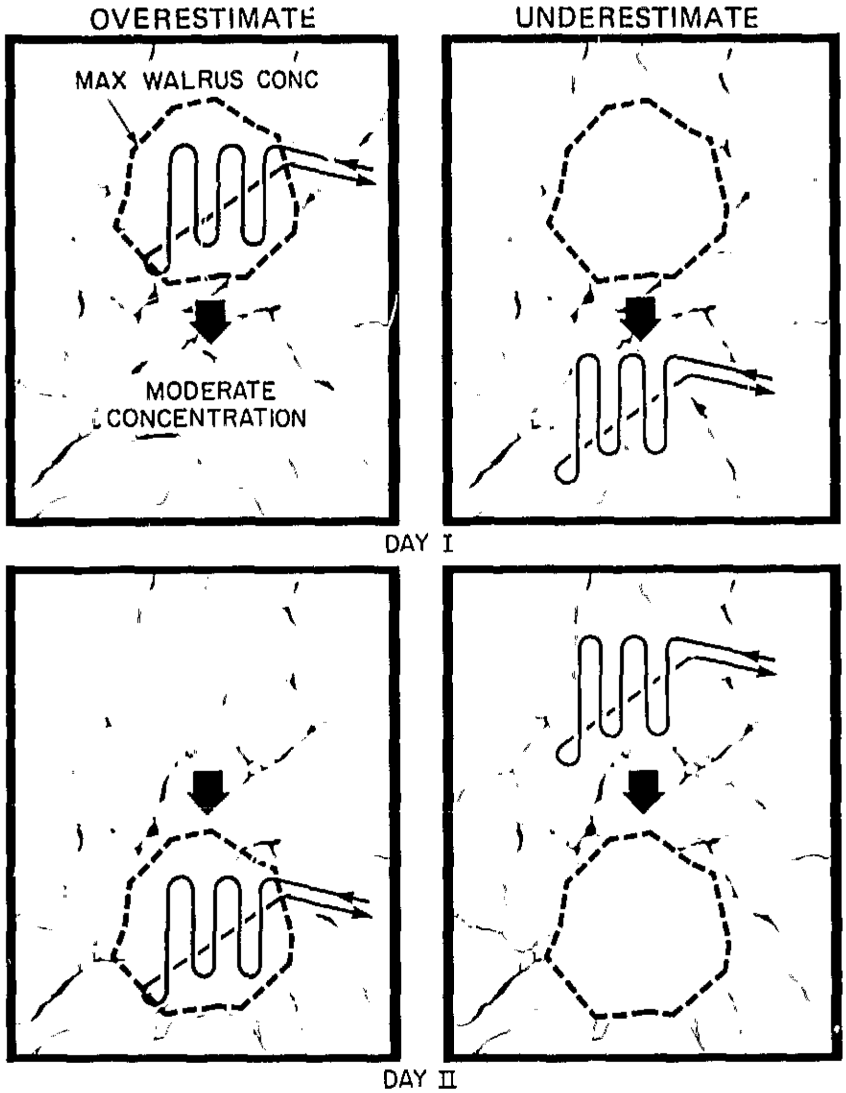


Fig. 4.-- Over- and underestimate of walrus numbers on sea ice may result unless ice dynamics is taken into account. The area enclosed by dashes is that of maximum concentration which is moving southward with the ice. Grids coordinated with this movement will result in an overestimate (left side); grids in opposition to this movement will result in an underestimate (right side). This is particularly true when walrus distribution is nonuniform.

The general equation for sea ice motion is then:

$$\rho_i h \frac{\partial h}{\partial t} = \vec{T}_a + \vec{T}_w + \vec{D} + \vec{G} + \vec{R} \qquad (1)$$

where ρ_i is the ice density and h is ice thickness.

Reed and Campbell (1960) have shown that with a change in wind stress, sea ice 3 m thick will approach a steady-state flow in about 3 hours, providing that $\vec{G}$ and $\vec{R}$ are small compared to $\vec{T}_a$. Knowledge of the field of $\vec{G}$ in the Bering Sea is essentially nonexistent, especially where the sea ice lies, and the scant observations available indicate that normally $\vec{G}$ is small compared to $\vec{T}_a$; hence, we neglect $\vec{G}$. Also, since the ice of the Bering Sea is thin and unbounded along its southern edge, $\vec{R}$ is bound to be small compared to $\vec{T}_a$ and we neglect it. Finally since the average ice thickness in the

Bering Sea is about 1 to 1.5 m, it would reach steady-state flow in about 2 hours with a change in wind stress. Therefore, since forecasts for BESMEX will be for periods of one to several days and detailed knowledge of the $\vec{T}_a$ field will be unavailable anyway, we assume that accelerations of sea ice are negligible. Thus, equation (1) reduces to:

$$\vec{T}_a + \vec{T}_w + \vec{D} = 0 \tag{2}$$

This equation would be simple to solve were it not for the fact that logarithmic Prandtl-type boundary layers exist at both ice interfaces. This equation with such boundary layers was solved analytically by Reed and Campbell (1960). A full derivation of their solution is not needed here, but the final equation is:

$$V_i^2 = r^2 + \sqrt{2}Br^{5/2} + B^2r^3$$

$$\sin\beta = \left[\frac{B^2 r}{2(B^2 r + \sqrt{2B^2 r} + 1)}\right]^{1/2}$$

$$\gamma_W{}^2 r^4 + 2\rho_i hf\gamma_W \sin\beta V_i r^2 + (\rho_i hfV_i)^2 = T_a{}^2 \tag{3}$$

where V_i is the ice velocity; r is the velocity of relative motion between the ice and the bottom of the water boundary layer; B is a constant involving the water boundary layer thickness, H; γ_W is the water drag coefficient, which can also be parameterized in terms of H; f is the Coriolis parameter; and β is the variable angle between V_i and r.

For a field of known h, the system of equations (3) can be solved in terms of the two key parameters: H, the water boundary layer thickness, and Z_O, the aerodynamic roughness of the ice-air interface. Reasonable guesses of these parameters can be made. The solution will provide a short-term predictive capability for estimating the subsequent location of moving sea ice with which marine mammals are associated.

Food Webs and Their Relationship with the Ecosystem

In addition to its role as a moving substrate that transports marine mammals, sea ice is also an important factor in the productivity of the Bering Sea. For instance, subice diatoms contribute a large portion, perhaps a third or more of the total primary production (C. P. McRoy, pers. comm.). The flow of nutrients from primary productivity to marine mammal consumption and other pathways in the Bering Sea food web are summarized in figure 5 (adapted from McRoy, Goering, and Shiels, 1973; Irving, McRoy, and Burns, 1970; Burns, 1970). Our present knowledge is such that we are unable to quantify the various pathways and interrelationships. Fisher and Lockley (1954) proposed that population sizes of marine mammals are generally dependent on the size of their food supply. But we do not know the effect of primary or secondary productivity on marine mammal diversity and distribution, although secondary productivity is probably the more critical of the two.

Furthermore, we do not know the extent to which marine mammals affect total Beringean productivity. They certainly influence it, for example, through nutrient "short circuiting," that is, the transport of nutrients at rates not in accord with current movement or structure (Walsh, 1972) but probably related to movements of consumer organisms. There is some suggestion that marine

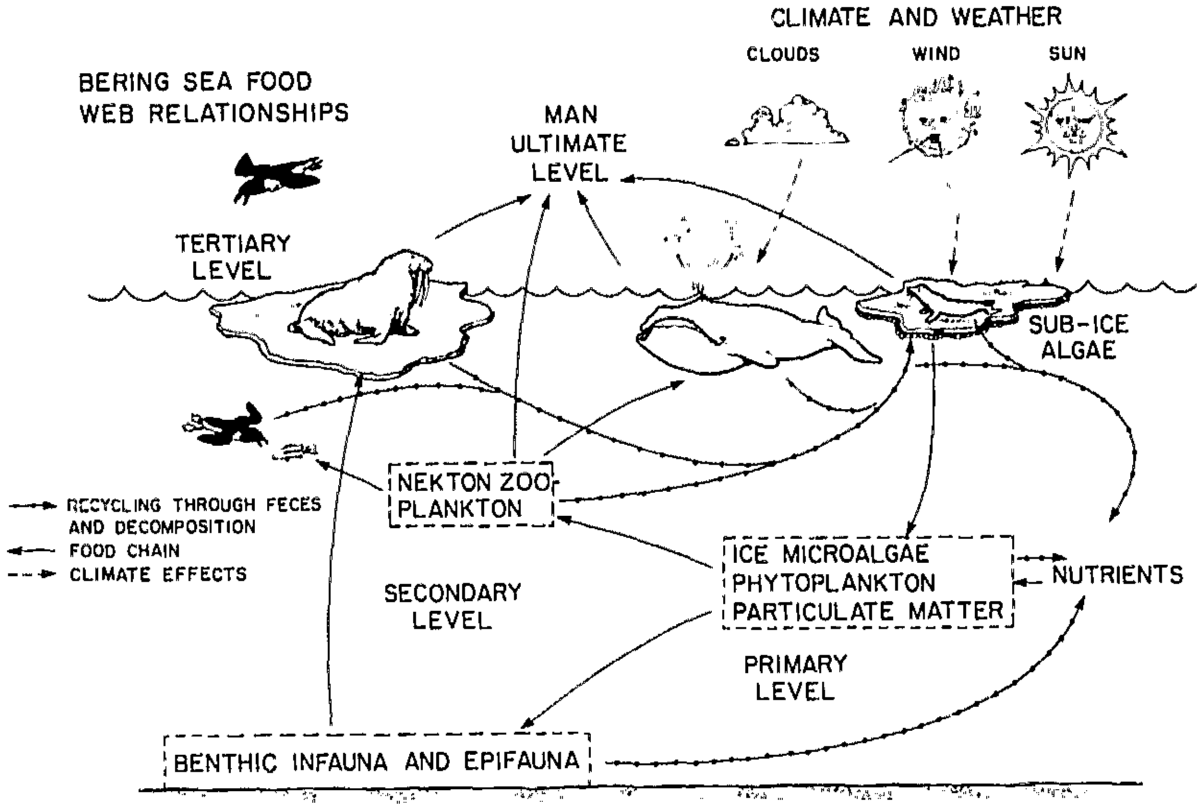


Fig. 5.– Food web and climatic relationships of ice-inhabiting marine mammals of Beringea.

mammals influence the primary productivity of subice algae. Some marine mammals are dependent on sea ice as a platform on which to rest and bear young. These species eliminate waste products near the surface where the water thus becomes enriched and presents a source of nutrients to the algae. The simultaneous assessment of chlorophyll concentration, marine mammal distribution, and sea ice should provide data essential to understanding some of these interrelationships.

Probably marine mammals also affect productivity by alterations in the physical environment. For example, benthic feeding by walrus may leave deep furrows in the unconsolidated benthos (Ray, 1973). To what extent this activity provides increased nutrient turnover within the sediments and superjacent water column we cannot say, but the chances are good that walrus digging is analogous to that of earthworms in providing positive feedback to production.

There are about 1 million metric tons of marine mammals of 15 major species in the Bering Sea, and they are estimated to consume 50,000 to 70,000 tons of food daily. The walrus population of about 136,000 animals (Kenyon, 1972) may consume 3 million tons of food during the nine months it spends in the Bering Sea (F. H. Fay and S. Stoker, pers. comm.). The Bering Sea has been estimated to contain 160 million tons of benthic standing crop, of which about 64 million tons comprise walrus food species (S. Stoker, pers. comm.). We do not know the rates of production of these food species, so it is hazardous to guess the total impact of walrus feeding on benthic organisms. Nevertheless, the impact of the walrus on the benthic community is no doubt significant, that is, almost 2% of total standing crop or almost 5% of walrus food species.

Furthermore, it is important to realize that walrus do not feed everywhere at once; that is, they "pulse fish." Their *local* influence on food species and nutrient transfer can be huge, even involving *total* utilization of some local populations of food species. Quite obviously, the local impact of pulse-fishing must be understood so that habitat effects can be understood and so that conflicts with man's potential utilization of the same resource do not lead to deleterious effects on walrus populations or their food species.

Conflicts in Resource Use

There are presently at least two conflicts between man and marine mammals in the Bering Sea. The first is a direct conflict between fishermen and several species of seals; for instance, the Steller's sea lion, *Eumetopias jubata*, and the common harbor seal, *Phoca vitulina*, either interfere with fishing operations or compete with fishermen for netted fish. The second is the indirect conflict between man and the Northern fur seal, *Callorhinus ursinus*, for the same food species (herring, pollock, etc.) which might be the cause of a reduced recruitment rate for the seals (Ray and Norris, 1972). This could lead to difficulties in carrying out international treaty obligations that call for achievement of maximum sustainable yield in the seal population. A potential source of conflict between mineral and fisheries exploitation and the stability of the walrus' support system is given in figure 6. The salient point is that man requires both renewable and nonrenewable resources and he also wishes to protect some of these renewable resources, e.g., marine mammals. Only by taking an ecosystem view can he meet these twin objectives.

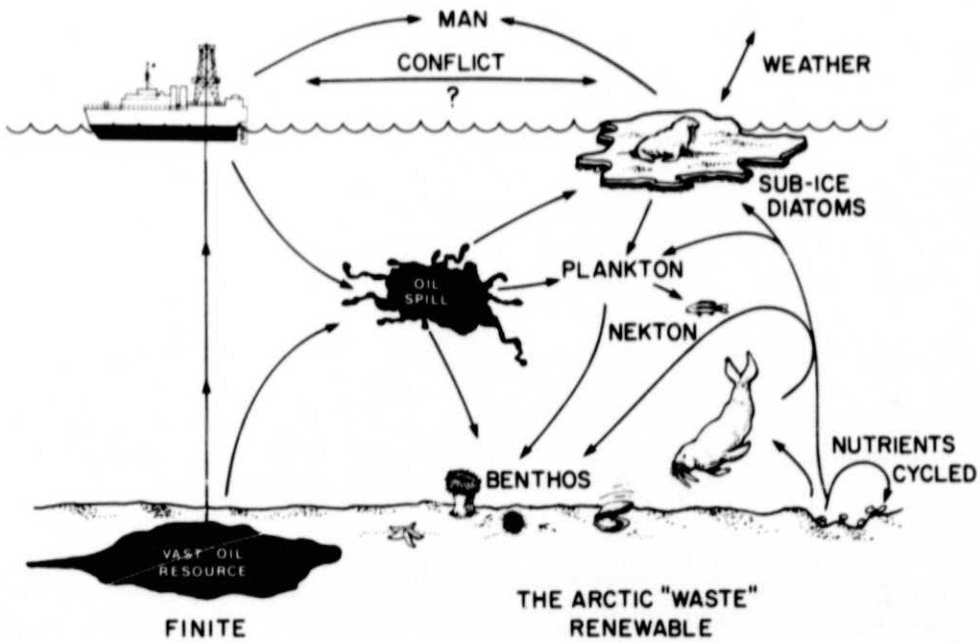


Fig. 6.– Potential conflicts which may arise from man's requirements for the living and nonliving resources of Beringea. The popular conception of an Arctic "wasteland" ignores the huge living resource of the region and the fact that it is renewable. Oil threatens benthic fauna, subice diatoms, plankton, and the integrity of sea ice and its role as a determinant of northern climate.

Thus, broad ecosystem knowledge is required to maximize long-term human benefits and to resolve the conflicts in both renewable and nonrenewable resource utilization. The "regional management" concept has been suggested for marine systems (Ray, 1970b; Ray and Norris, 1972) but it is not yet effective for any area of the world's oceans. BESMEX constitutes a first step in research toward that end.

TECHNOLOGICAL BACKGROUND

Radio tracking

Evans (1974) has demonstrated that radio tracking provides a tool of great value for describing movements and trophic relationships of small cetaceans. This technique may also be used to tell us of migrations, group relationships, and other behavior at sea. The transmitter and automatic direction finder used on these successful experiments were developed by Ocean Applied Research Corporation (OAR) and have been described by Martin, Evans, and Bowers (1971). The walrus beacon transmitter to be used in the initial phases of this program is a modification of the OAR transmitter and we expect similar success. However, it is important to consider a number of variables and to emphasize that though the promise of radio tracking is great, the biological factors are often more difficult to solve than technological ones. That is, success with one species does not necessarily ensure success with another because attachment, behavior, and other variables are species-specific.

Under contracts from the Office of Naval Research to The Johns Hopkins University, we began in 1972 with Ocean Applied Research Corporation to modify their small cetacean transmitter for use on walrus. The major modification has been the replacement of the whip antenna with a low-profile antenna more appropriate to the environment of the ice-inhabiting walrus. Electronically the two transmitters are the same; they both have an unmodulated carrier at about 27 MHz, which is turned on for 50 msec about once a second when in air and shut off under water. Identification codes for different animals are provided either by crystal-controlled frequencies or by means of varied repetition rates for transmitters of the same frequency.

In order to determine the optimum transmission frequency and transmitter-receiver design, we have conducted a number of tests over the past year on the east and west coasts of the U.S. and at the Naval Arctic Research Laboratory, Barrow, Alaska. The results follow. The small cetacean transmitter with the whip antenna and 500 mW radiated power has a maximum range of 60 km over open temperate sea water to a receiving antenna 330 m high (W. E. Evans, pers. comm.). The walrus transmitter with the low-profile antenna and a radiated output of 1 W has a maximum range of 3 km over sea ice to an antenna 3 m above the ground at temperatures as low as −40° C. The same unit has a range of 35 km to an aircraft at 500 m, again with the transmission path over sea ice. The signal-to-noise ratio at 27 MHz is poor.

Under a contract with NASA in 1974, Ocean Applied Research Corporation modified their 150 MHz moose beacon transmitter for use on the walrus, and we have tested this frequency against 27 MHz. The 85 mW moose unit also has a low-profile antenna, and when attached to the neck of a moose, it has a maximum range of 100 km to a Yagi antenna with a 12 dB gain mounted on an aircraft flying at 300 m. Our modified unit feeds 500 mW into a low-profile antenna. Over sea ice, it has a maximum range of 35 km to an omnidirectional receiving antenna with no gain mounted on an aircraft flying at 500 m and at −40° C. It has a range of 7 km over sea ice to an Adcock antenna 3 m above the surface. At 150 MHz, the signal to noise ratio is high compared to that at 27 MHz.

A comparison of the ranges of the 27 and 150 MHz walrus beacon transmitters clearly indicates that 150 MHz is the frequency of preference with transmission surface-to-surface over sea ice. Over open water, however, the surface-to-surface range is better at 27 MHz (H. Martin, pers. comm.). These results encourage us to utilize both frequencies in our initial attempts to track walrus and to expect 20 to 35 km ranges when receiving antennas are 300 to 500 m high. But here an important biological effect may become a problem. In the 150 MHz vs. 27 MHz tests conducted over sea ice, the transmitters were resting on a 2-m^2 ground plane on snow. When the transmitters are on the animals and the animals are hauled out, the radiated power will be reduced because of coupling to the body, which acts as a dissipative radiating element. This reduction can be up to 97% at 27 MHz, but decreases with increasing frequency (Krupka, 1968).

Ideally, radio tracking could provide information on group constancy, activity patterns (i.e., proportion of time hauled out), feeding and breeding locations, migrations, and energy budgets. Certainly some of this information will be forthcoming from any successful tracking attempt. However, it is again important to realize that these data will be representative of walrus behavior only within broad limits. This is true because only a limited number of animals can be tagged and because the data from each animal will be influenced by individual variations and reaction to the tracking package. Nevertheless, radio tracking certainly provides an unparalleled tool for gaining information that cannot be acquired through other means.

Remote Sensing

Remote sensing is not subject to the vagaries of individual behavior. As it is able to detect many animals at once, it describes average conditions on a synoptic level; if carried out from a sufficiently great distance, it will not alter the animals' normal behavior. However, it is limited in the number of questions for which it can provide data. Depending on the resolution available, location, orientation, age and sex of the animals, surface temperature, substrate temperature, and other components of the environment could be determined.

Photography: High-resolution photography is currently the most reliable remote-sensing tool to identify animals from a distance. Most photographs taken during BESEX from the CV-990 using the KS-87 camera with a 3-in. (wide-angle) lens lacked the definition required to identify animals unambiguously, although some were adequate for both positive identification of walrus and for reasonable estimates of their numbers (fig. 7). In many cases, the relative angular speed was apparently too great at low altitudes so that image blurring occurred, and the altitude of 300 m was not sufficient to prevent the animals from being frightened by the plane. Color film was not often used, but appeared to be the only film on which any defensible designation of animals could be made at altitudes greater than about 300 m. For example, only on color film could the brown patches on the ice left by the excrement of a walrus herd at a previously used uglek (haulout) be distinguished from the darker brown animal groups. Because of the inconclusive results of the BESEX flights, we do not presently have high-resolution, high-altitude photographs on which to base precise plans for ensuing years. However, our experience indicates that the high subject-to-background contrast and large image size of walrus herds will allow photographic detection at altitudes up to 5,000 m and counts of individuals from 1,000 m or less if color film is used.

Infrared Imagery: Walker (1965) conducted the first apparently successful attempt at infrared imagery of a marine mammal. His subjects were gray whales, *Eschrichtius robustus*, and the results were only marginally satisfactory. This was probably due to a lack of thermal contrast between the subject and the background, and inadequate resolution in the equipment used. However, the walrus presents an excellent thermal contrast when hauled out on ice. Figure 8 presents an infrared image obtained during BESEX of thermal characteristics of a walrus herd. The scanner sensed the 10-12 μ band where the atmosphere is relatively transparent. Also, at these wavelengths the emissivity of the animals' hides is almost 1. Thus, according to Wein's law, the true surface temperature can be obtained from a measurement of the radiation; for example, the wavelength of maximum amplitude is 10 μ for a temperature of about 17° C. The resolution of the scanner is 1 mrad in spatial extent and less than 1° C thermally.

Figure 8 shows not only the high thermal contrast of the walrus with sea ice, but also the thermal gradient within the group, with the hotter animals in the group's center. This technique also provides information on environmental temperatures during which animals may be hauled out, a vital datum for walrus assessment; that is, animals with high surface temperatures (over about 20° C) are within their environmental "comfort zone," and we may assume the proportion of animals on the ice to be relatively high. Under adverse conditions, the proportion of animals in the water where they cannot be counted increases. Simultaneous infrared measurements of animal surface temperature and substrate temperature can be combined with local climatic variables such as wind and radiation to provide a "chill factor." These data provide much essential information necessary to calculate the total heat budget of the animal (Porter and Gates, 1969).

Passive microwave imagery: Nordberg (1971) reported on the results of passive microwave imagery of sea ice obtained on the CV-990 flights in the Arctic in 1970. At frequencies on the order of 30 GHz, the apparent brightness temperature difference between sea ice and open water was as much as 150° C. Also, large-scale variations in the ice surface texture were detectable by contrasts in microwave emissivities. Brightness temperatures over ice covered with dry snow were 5% lower than over melted and recrystallized snow or bare ice surfaces. Passive microwave imagery is thus a valuable tool for the survey of general surface characteristics of sea ice.

Differential radiometry: NASA/Ames has developed a differential radiometer for detecting chlorophyll content of waters to a depth of one-third that of a black Secchi disc (Averson, Millard, and Weaver, 1971). This unit compares the light intensity at a wavelength outside the region of

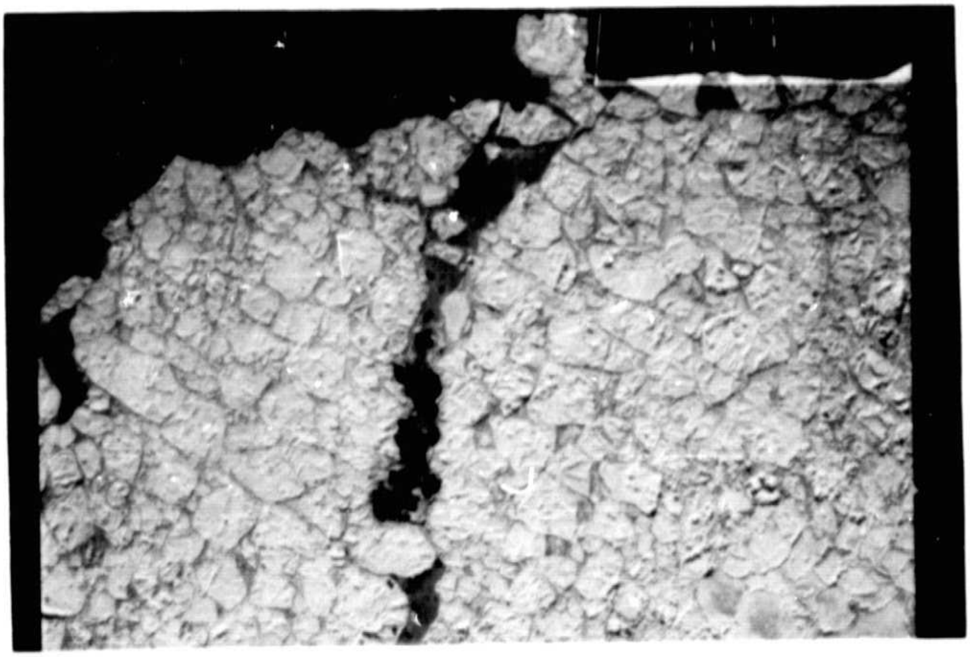


Fig. 7.– Photographs of walrus on sea ice from about 300 m altitude.

Fig. 8.– Infrared false color representations of the walrus herd shown in figure 7. Sea ice is about $-12°$ C and the warmest walrus range from $8°$ to $12°$ C.

chlorophyll absorption with the intensity at a sample wavelength at the chlorophyll absorption maximum. Changes in light intensity, variations in water surface roughness, or scattering within the water body have similar effects on the intensity at both wavelengths. The output signal is a voltage proportional to the difference in intensity at the two wavelengths. Hence, the output is proportional to the logarithm of the chlorophyll concentration. The instrument is capable of continuous readings of chlorophyll concentrations from 0.03 mg/m^3 to 10 mg/m^3 along the flight path, but it is limited to elevations of less than 330 m due to Raleigh scattering in the atmosphere.

These remote-sensing technologies – high-resolution photography, infrared imagery, passive microwave imagery, and differential radiometry – are tools which in themselves yield valuable information. However, when used together, they are potentially of great power in providing information on the animals and on environmental correlates to animal distribution or behavior. Use of these technologies will advance knowledge greatly, but their application in marine mammal research will require rigorous assessment before their true value will emerge.

PROGRAM RATIONALE

Target Area

Our emphasis is upon one of the richest seas on earth, the Bering-Chukchi system or Beringea. This area is currently receiving a great deal of attention. It is the site of the world's largest fishery and contains perhaps the highest density and variety of marine mammals anywhere on Spaceship Earth. However, its advantage as a study area resides not only in the intense interest in resources that has developed there, but also in its relatively small size and simplicity (as marine ecosystems go) and the great advantage that only two nations (essentially) contain it – two nations that have also agreed to study some of its features on a collaborative basis (US/USSR Joint Committee on Cooperation in the Field of Environmental Protection, BESEX, and other agreements).

In an analysis of ecosystem dynamics, the ecological dominance of seasonal sea ice in Beringea is important for three reasons: (1) sea ice is relatively easy to sense and is subject to predictive modeling on a fairly sophisticated basis; (2) animals hauled out on sea ice stand out in sharp contrast both visually and thermally; and (3) sea ice is an easily quantifiable feature of the environment and may be related to carrying capacity for certain marine mammals.

The Bering Sea contains both deep water and shelf regions. The deep basins lie south and west of the shelf. The shelf, mostly less than 40 m deep and over which seasonal ice forms, covers about 1 million km^2 (44% of the total surface area). Communication with the Chukchi Sea is through the narrow (82 km) Bering Strait. Thus, there are two operant systems in the Bering Sea: a deep water, ice-free one, and the shallow Beringean Shelf, which is seasonally ice-covered. It is the latter area that concerns us here.

The Chukchi Sea is similar to the Bering Sea except that it is entirely a shallow sea and is delimited by the deep Arctic Ocean to the north. Much less is known of the Chukchi Sea than the Bering Sea. It is the summer home (June-September) of many Beringean marine mammals. Recent studies have shown it to be as productive in summer as the Bering Sea.

So far, the natural equilibria of this Beringean ecosystem have not been seriously altered by human activity. Thus, it is particularly attractive to study this well-defined area where reliable baseline data can be obtained prior to extensive perturbation. If we are able to construct predictive ecological models of at least certain aspects of the marine mammal populations in this area, then we will have an indicator for assessing man's accelerating impact on the area in the future.

Alterations of the Beringean ecosystem can be expected on at least two fronts (see fig. 6). First, fisheries may soon be intensified northward, impinging further on the food sources of marine mammals, notably those of the benthic-feeding walrus, bearded seal *(Erignathus barbatus)*, and gray whales. Second, mineral, gas, and oil exploitation could lead to major pollution problems. Oil spills in that ice-dominated system may have dire consequences on both weather and productivity. Oil, for instance, changes the albedo of sea ice and resulting large-scale melting could have dramatic impact on Arctic thermal flux (Campbell and Martin, 1973). Oil also presents a lethal hazard to sub-ice algae, which contribute so much to the Bering Sea's primary productivity.

Target Species

The walrus, *Odobenus rosmarus*, and the bowhead whale, *Balaena mysticetus*, have been chosen for initial emphasis. The migrations and associations of both species appear to be determined to a large degree by the nature and extent of sea ice. Figure 2 shows our present knowledge of the correlation between walrus distribution and the seasonal excursions of sea ice. We have few comparable data for the bowhead, unfortunately, although its migrations are similar in extent to those of the walrus.

The walrus appears ideally suited for utilization of both remote-sensing and radio-tracking techniques. As noted earlier, walruses are large and gregarious, providing large target size. This species presents perhaps the strongest thermal and visual contrast to background of any marine mammal when hauled out on ice, and it spends more time hauled out than any other ice-inhabiting pinniped. Further, the walrus is relatively docile and may be approached closely on foot for the attachment of radio tags. The walrus is a subject of intense interest to natives, conservationists, and scientists, and is specifically mentioned as a species of concern by the US/Soviet Joint Committee on Cooperation in the Field of Environmental Protection. Research on walruses is relatively advanced, and a cadre of workers exists for a broad program of work. Thus, because of the extent of our knowledge and for reasons of ease of work, we believe the walrus is a particularly appropriate species of initial choice.

Much less is known of the bowhead whale, but this is no less important a species. It is one of the rarest and largest of mammals, and its recovery to previous abundance and subsequent conservation are the subject of a major U.S. commitment to the international community. Our knowledge of its seasonal distribution is derived mostly from whaling records. Bowheads migrate as walrus do, from the ice-dominated Bering Sea in winter to the Chukchi and Beaufort Seas in the summer, but the routes of migration are not known. Distribution and enumeration are data to be derived from BESMEX for this species.

Bowheads may infrequently expose themselves when at the surface, often blowing at small fissures in the ice cover. We have calculated, from scanty information gathered on two ice-breaker voyages in 1971 and 1972 and during BESEX in 1973, that about one whale may be visually observed at the surface per 500 km^2, but we do not take this figure as a true indication of density. In fact, we doubt that the density of bowheads in large areas can be attained visually. Assessment is best approached through other techniques, possibly through infrared detection of the heat of exhalation. A bowhead expells the contents of its lungs in a double plume several meters high and several meters wide. As discussed earlier, heat sensing of whales has been accomplished only once and that marginally. However, thermal contrast is much greater in the northern seas than elsewhere, and the technique of thermal detection of exhalation is perhaps better attempted there than in more southern climes. Other possibilities for gathering distributional and numerical data rest largely on a trial-and-error basis, for instance, on counts made during relatively ice-free seasons and during the migration through Bering Strait where the area to be searched is small.

Target Questions

So little is known about the ecology and behavior of marine mammals that many questions come to mind that could be attacked using remote sensing and radio tracking. We have already mentioned some of the most important of these. Further questions regarding migration, nutrient flow, and group behavior on which data will be obtained during BESMEX are discussed later. The questions of prime importance, and those for which predictive models are required for the purpose of environmental management, are related to the maintenance of marine mammals at optimum population levels. This difficult matter cannot be addressed without consideration of two initial matters: (1) the number of animals presently occupying the area, and (2) the carrying capacity of the area.

Returning to our earlier discussion of population dynamics models, these questions require the determination of N, the number of animals, and K, the carrying capacity, both within given times. The association of the walrus and bowhead whale with sea ice provides the handle by which these questions can be grasped.

The first question requires that the animals be assessed. We first need to know where they are and what proportion of them are hauled out so that they may be counted. These two variables are broadly dependent on ice, weather, food availability, behavior, and season. The interrelationships between the dependent and independent variables and some of the feedback loops involved are diagrammed in the model for walrus assessment presented in figure 9. How these interrelationships will be quantified is described in the next section. Clearly, both remote sensing and radio tracking will be required. Remote sensing can assess the animals hauled out on the ice and perhaps identify sex and age components of groups of animals. However, it cannot provide information on the percentage of animals in the water at any given time under any given conditions, nor can it tell us of subpopulation interrelationships and cohesion of groups. Radio tracking is required to determine the relationship between environmental, seasonal and behavioral conditions, the proportion of the time the animals are hauled out and accessible to remote sensing, and whether males, females and subadults move through their environments independently or together.

The second question is intimately associated with the same model. By looking at a broad range of weather, productivity, and oceanographic parameters, an estimate of the factors influencing the environmental carrying capacity for the walrus can be made. Some initial attempts have been made along this line for other marine mammals. For instance, knowledge of currents, ice distribution, and food has aided research on whales (Mackintosh, 1965) and we also are able to correlate ice type, in a rough way, with the distribution of Bering Sea ice-inhabiting pinnipeds (Burns, 1970; Fay, 1974). However, as far as we know, no study has yet been made in which results have emerged to correlate the population dynamics of oceanic vertebrates with environmental carrying capacity so that management on this basis is possible (D. G. Chapman, pers. comm.).

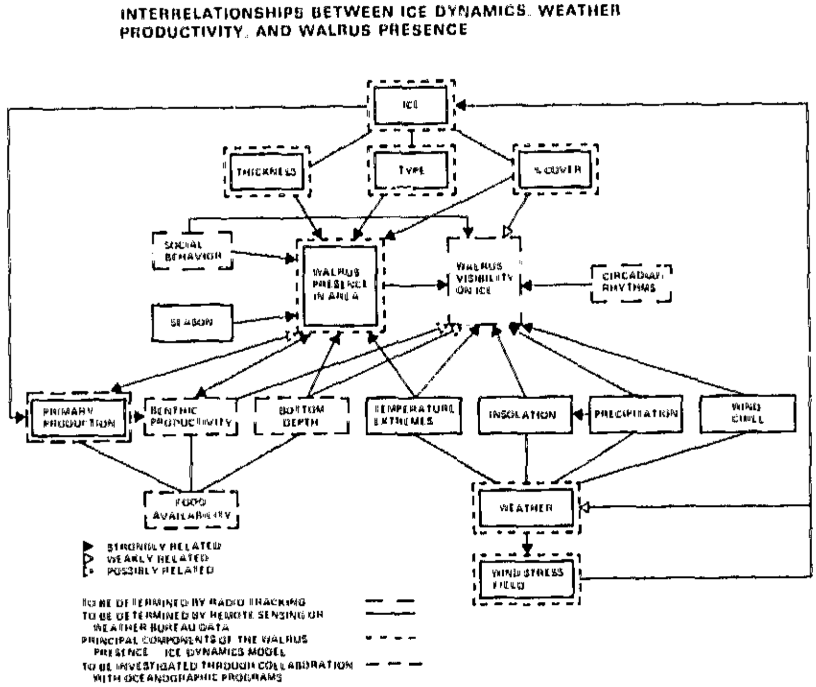


Fig. 9.– Heuristic model of walrus ecodynamics.

Of these two major considerations, assessment of population is far the simpler. Estimation of carrying capacity is difficult, but the attempt must be made, for only in this way will the definition of optimum population be attained. Though we will concentrate on the walrus in this regard, we shall not ignore other Bering Sea species in the formulation of models.

These two central questions incorporate a subset of questions which we shall attempt to address specifically. Some of these are:

1. Migration: What routes do the animals follow? What is the speed of migration? Does the population move as a unit? If not, what is the average migratory group size and what is its sex/age structure?

2. Group behavior: Is there an exchange of individuals between different groups? What is the effect of breeding condition on group stability or size? How do environmental conditions influence group size or stability? What is the spacing between individuals in a group? How does the spacing correlate with type of group, thermal characteristics, environmental conditions, and season of the year?

3. Primary productivity and food supply: What correlations are there between walrus presence and primary productivity on ice and in the water column? How do chlorophyll

concentrations and walrus food supply correlate with distribution and activity patterns of walrus? Does chlorophyll concentration correlate with benthic productivity of walrus food species?

These questions will be approached through a study of target species under BESMEX, but answers will not emerge through this program alone. Collaboration with other workers and agencies is one of the objectives of our program. Indeed, certain essential matters cannot be settled by any one program alone; for instance, the elucidation of productivity and nutrient and energy transfer will depend on a widespread integration of effort.

IMPLEMENTATION PLAN

Several sophisticated data-gathering and data-analyzing techniques will be required to quantify the transfer functions in our assessment model, to answer our target questions, and to gather data on the supplemental questions for future modeling. Essentially our techniques are a combination of aerial remote sensing and surface-to-surface and surface-to-air radio tracking, all of which depend heavily on logistics: long-range aircraft (CV-990), short-range aircraft, icebreakers, research ships (R/V *Alpha Helix*), and various means of land transport. Remote sensing includes high-resolution photography, infrared imagery, passive microwave imagery, temperature radiometry, and differential radiometry. Data-analysis techniques include digitization systems to translate visual and other imagery into computer compatible formats; computer programs to process digitized imagery; and computer programs to predict ice dynamics in response to wind stress fields. Of course, techniques will certainly change as time passes, as experience is gained, or as new instrumentation and techniques become available.

Table 1 presents the four-year schedule proposed for BESMEX and lists logistics, sensors and equipment required, and the purpose of each mission. The schedule includes the initial year, now under way, for planning and testing of procedures, an initial aerial survey, and first attempts to radio tag walrus. The latter involves cooperative work aboard the R/V *Alpha Helix* during which behavioral and feeding studies on walruses will be conducted. The "formal" BESMEX program will begin in calendar 1975 with the first flights of the CV-990 Galileo II. The Galileo II is speedy and capable of flying more territory on a single mission than was covered during the entire 10-day flight program of the 1972 walrus survey (Kenyon, 1972); the range and speed of the CV-990 exceeds any other NASA aircraft and makes possible the accumulation of the large quantities of data necessary for assessment and model construction. It is a relatively vibration-free platform for high-resolution imagery because it is jet-powered, it carries a real-time computer for flight data and observational data, and it is the only NASA aircraft now equipped with the high-resolution infrared scanner needed for this program. It is a flying laboratory whose equipment and crew are admirably suited for our purposes. Also, it will probably continue to be the aircraft of choice for the arctic Ice Dynamics Joint Experiment (AIDJEX) with which we hope to cooperate.

Flight Plans

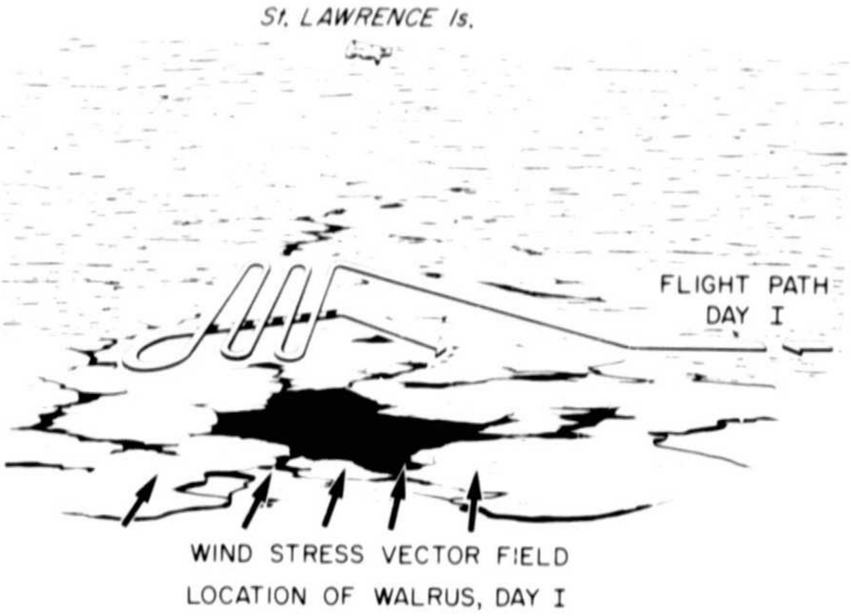
Three sets of flights are proposed for each of the succeeding three full years of BESMEX with a preliminary flight for testing and data gathering in 1974. Three years are necessary to experience a range of conditions for model testing and expansion. During these flight periods, as well as at other times of the year, satellite information on sea ice (see fig. 3) will be correlated with ice dynamics and marine mammal assessment data obtained on the flights. The CV-990 provides an essential link between ground studies and satellite sensing, because only aircraft can be used to sense movements of both animals and ice simultaneously.

The first flights under BESMEX will be in September 1974, using the NASA/NP-3 aircraft out of Barrow, Alaska. The area to be covered by these flights will be from the eastern Beaufort Sea at about 127° W longitude to the central Chukchi Sea at about 174° W longitude, north from Alaska possibly 200 nmi (to about 74° N latitude) to the permanent polar pack ice. The area to be covered is highly dependent on the extent of the pack ice. The total area is about 400,000 km^2 of which about a third or 133,000 km^2 might be classed "walrus territory." These flights will be compatible with the UFS&W walrus survey flights. USF&W will be using their Grumman Super Goose and covering the same area at the same time, but at a much lower altitude and without the benefit of high-resolution aerial photography and infrared imagery.

The NP-3 flights will be conducted at both low (0.3 to 1 km) and medium (3 km) altitudes. The lower flights will be used to obtain detailed thermal and visual information on walrus groups. Walrus assessment only will be attempted on the higher altitude flights. At least one flight should combine both altitudes: After assessing and photographing walrus herds from 3 km, the plane will spiral down to 300 m to determine the optimum elevation for determining exact numbers and the best altitude for remotely sensing physiological and behavioral data. A flight at 3-km altitude covering a 4.5-km path width (the field of view of a 6-in. lens on a KA62 camera) and at a cruising speed of about 250 knots will result in 2250 km^2/hr coverage. If the total flight time over the target area is 4 hours, a single flight results in 9000 km^2 or about 6% of the total "walrus territory." We believe four flights, covering 25% of the walrus territory, should be sufficient for thoroughly testing all procedures and sensors and for adequate data gathering. As about half the days are flyable from Barrow during September, the duration of this program should be from about 17-27 September.

We have planned these flights with the USF&W, which is anxious to have NASA assistance in helping determine the distribution of walruses, the total population numbers, and the variance in estimated numbers for areas of differing animal densities. We are anxious to grasp the opportunity to conduct concurrent missions. The information gained will be used during a November/December meeting with Soviet scientists in order to determine where and when joint US/USSR surveys should be undertaken.

The results of the NP-3 flights will be used in refining our planning for the CV-990 flights. The most essential CV-990 flights will be conducted in midwinter 1975, at the time when the correlation of walrus distribution with ice movements is best known from available data. Approximate location and procedures are given in figure 10. This flight plan involves three steps: (1) flying over a track of sea ice during which walrus and possibly whales will be assessed and marking of ice with a dye for later visual recognition; (2) calculation of the movements of ice in response to wind stress fields (see below); and (3) flights over the same ice as flown over the previous day, during which walrus and other mammals will again be assessed to determine what changes can be observed. Flights must be in clear weather and would best be conducted daily for three to five days, after which biweekly flights are sufficient for the duration of the flight period. The areas of greatest interest will be, in order of priority: (1) an area south and west of St. Lawrence Island and roughly the focus of BESEX Option C; (2) Bristol Bay; and (3) the ice edge that runs in a northwest-southeast direction from about 62° N and 180° W to 55° N and 163° W.



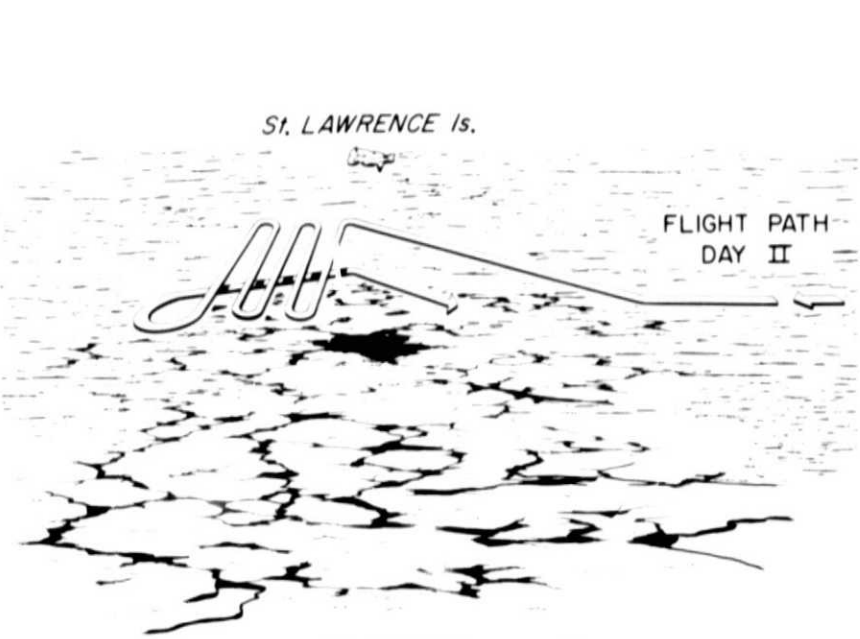


Fig. 10.– Assessment flights designed to show numbers of walrus related to ice dynamics. The same sea ice, but not the same geographic area, is flown on subsequent days.

Daily surface isobaric charts of the Bering Sea will be obtained from the U.S. Weather Bureau. Surface wind stress vectors will be estimated from these charts using standard meteorological procedures. For select areas of the Bering Sea ice cover, initial guesses of the parameters H and Z_0 will be made by applying the Reed-Campbell model to floes of known motion (see Theoretical Background). Then the model will be used to forecast motion of certain areas of interest, that is, where mammals are observed. The model can be set up in such a way that it can be solved for given parameter choices with a portable field computer.

The areas for the August/September and November/December flights cannot be specified at this time in any greater detail than that outlined in table 1. The joint BESMEX/BSFW survey of September 1974 will aid in delineating the areas for maximum effort in succeeding years.

Remote Sensing

Visual observation and flight data record: The CV-990 will carry sophisticated equipment for visual, infrared, and passive microwave imaging; possibly it will carry sensors for other spectra as well. However, to integrate all of these data and to place them in their proper context, the real-time, synchronized comments by experienced marine mammal and sea-ice observers on the aircraft must be included. The techniques for remote sensing of ice have been more fully developed and tested than those for remote sensing of marine mammals. For example, it is not known whether any of the equipment onboard the CV-990 will be able to detect the presence of bowhead whales. In all cases, the integrative and interpretive aspects of data collection and analysis can best be accomplished by the human observer.

During BESEX flight operations, a complete record was kept of observer notes, together with such parameters as altitude, air temperature, air water vapor content, and wind speed, which were automatically recorded by the aircraft's sensors and inertial navigation system. Thus, visual observations, times of flights over marine mammals, and various conditions over the entire flight path become a permanent record (see Programming Methods, 1973).

Satellite: As figure 3 shows, satellite imagery is extremely useful in obtaining a synoptic view of sea ice type and dynamics. Two systems are available to us, the military DAPP satellites and NOAA 2 or NOAA 3. Data from the former are available in the form of both visual and IR working pictures in Alaska. The NOAA satellites also provide visual and IR data, and working prints are available in Alaska. Both are high resolution, but IR from the NOAA satellites is a bit cleaner, that is, free of ozone contamination. These photographs provide essential information for validation of the ice-dynamics model.

Photography: High-resolution photographs are required to determine not only the presence of animals but also group size and structure. Photographs must be taken from a high enough elevation so as not to disturb the animals. The results obtained on the 1973 BESEX flights (described in the Technological Background section) indicated that the flights should not be conducted at altitudes of less than 1000 m while engines are under full cruising power.

The camera should be capable of resolutions on the order of 10^{-4} rad. Resolution, even when expressed in radians, depends on the altitude for which the camera is tuned. Past experience dictates that the camera should be tuned for maximum resolution at an altitude of about 2000 to 3000 m.

For reasons enumerated earlier, color films should be used exclusively and the best available resolution film must be used.

The flight plan and location of the grid to be flown will be determined according to the ice-dynamics model discussed above. Along the route to and from the grid and within the grid itself, the location of walruses and other marine mammals encountered will be determined primarily by aerial photography. The navigation system on the CV-990 will allow precise determination of the location of all animals photographed. Subsequent flights will give a comparison of animal abundance from time to time. For example, we should be able to derive a record of walrus movements with respect to the ice by recording the locations of uglek, provided these hauling-out places maintain their relative positions with the grid. Even if the uglek shift and even if there are several walrus herds in the same area, the locations of old uglek will at least give us an indication of the total geographic area occupied by the walrus herd during the flight period and will also give some hints as to the role of ice dynamics in determining that total area.

Infrared Imagery: As discussed earlier, the walrus has a high thermal contrast with its background when it is out of the water. To obtain significant data from infrared imagery, equipment capable of a resolution of 1 mrad is required to determine the surface temperature of individual walruses within groups and the temperature of their substrate. Temperatures of huddled animals will be correlated with their location within the group to determine the temperature gradient from the center of the group to the edges. Correlations will be attempted between the surface temperature of the animals and their interindividual spacing. All of these thermal data will be useful in formulating the thermoregulatory section of a model to be constructed concerning walrus energetics.

Ultraviolet Sensing: Canadian workers have recently had success sensing marine mammals using near-ultraviolet wavelengths (320 to 400 nm). The animals appear as dark spots highly contrasted with the bright background (D. M. Lavigne, pers. comm.). The high animal-to-background contrast results from the difference in emissivities of the animal's surface and the ice and snow at ultraviolet wavelengths. For example, the white fur of polar bears and pup seals has an emissivity of almost 1 while the emissivity of ice is only 0.3. This technique is extremely valuable for species that present little thermal or visual contrast with the background, for example, polar bears and white-coat seals. It will possibly also be useful for detecting darkly colored whales at the surface. We will attempt to use this technique in the early stage of BESMEX.

Chlorophyll Sensing: A differential radiometer will be used to determine the chlorophyll content of surface water. Chlorophyll content is an indication of the biomass of primary producers. We make no assumption of the correlation between the biomass of primary producers and walrus distribution because the walrus does not feed on the primary producers, but on benthic organisms. There is often a marked downstream effect between the surface location of primary producers and the location where the nutrients derived from them reach the benthos. Nutrients also may be trapped and recycled within the benthos with little introduction of nutrients from the surface. However, it is important to identify areas of a heavy concentration of primary production in the search for correlations with current structure and the short-circuiting of nutrients by marine mammals.

Passive Microwave Sensing: Passive microwave sensing will be used to determine ice type from which ice thickness can also be inferred. We already have some data correlating walrus presence with ice type and thickness, as discussed in the Theoretical Background section. We suspect that surface conditions of the ice may influence walrus behavior. The presence of snow or melted water on the ice can also be sensed by this method.

Data Analysis

Visual and other imagery of the herds will be analyzed to determine certain aspects of group size and structure. The extent of the analysis possible will be determined by the resolution of the imagery. Tentatively, data analysis will be carried out under contract to the Remote Sensing Institute of South Dakota State University, which has a Signal Analysis and Dissemination Equipment (SADE) system for rapid digitization of such images as will comprise much of our data. Animals are distinguished by anomaly recognition within the matrix of digitized values from the image. The computer programs used in anomaly recognition hopefully will be modified to provide data besides merely animal counts.

Ideally, we will be able to quantify and computerize the number of animals, their thermal characteristics, their spacings, their orientations, their size, and possibly their sex. The spacing of the animals and any indication of subgroups within the herd would be of interest in understanding social structure. Spacing will be correlated with group sizes, season of the year, and breeding condition. As discussed earlier, some herds will be breeding herds and some groups will be primarily nonbreeding males and subadults. The spacings within these different groups will be noted. The spacing will also be correlated with such environmental variables as insolation, temperature and wind. Orientation will be observed relative to the angle of the wind and the angle of the incident solar radiation. These data are important for a model of walrus energetics.

Radio Tracking

The minimum requirements for a radio-tracking system are that it works in the environment in which it will be used, that its range and life are sufficient to justify placing it on an animal, and that it can be attached easily and securely. Individual animals of each target species will be radio tracked to monitor their locations, activity, migration, and other aspects of their behavior.

The biological and mechanical problems of attaching a transmitter easily and securely to a marine mammal are greater than the problems associated with the electronics and signal transmission. We do not wish to be forced to capture, anesthetize, or immobilize an animal in order to attach the transmitter. Only as a last resort will the transmitter be attached by immobilization and suturing. Thus, we are developing a "limpet" type of attachment device for the walrus. The preliminary design for the limpet attachment is shown in figure 11. It consists of a baseplate with a set of curved, surgical needles with cutting edges. When triggered, these needles will be driven into the skin of the animal with the force stored in springs. The angle of attack will be such that there will be little tendency for the unit to rise off the surface of the animal. Lateral movement will be minimized by having pairs of needles turn in opposition to each other. The needles will be sterile and will penetrate up to 2 cm into the 2.5 to 7.5 cm thick neck skin of the walrus. It may also prove possible to use topical or local anesthesia in order that the tagged animal will react to the tagging minimally. The transmitter and baseplate will be attached to a 2-m pole for attaching the unit to an animal by hand. With careful stalking, hauled-out animals can be approached to within less than this distance.

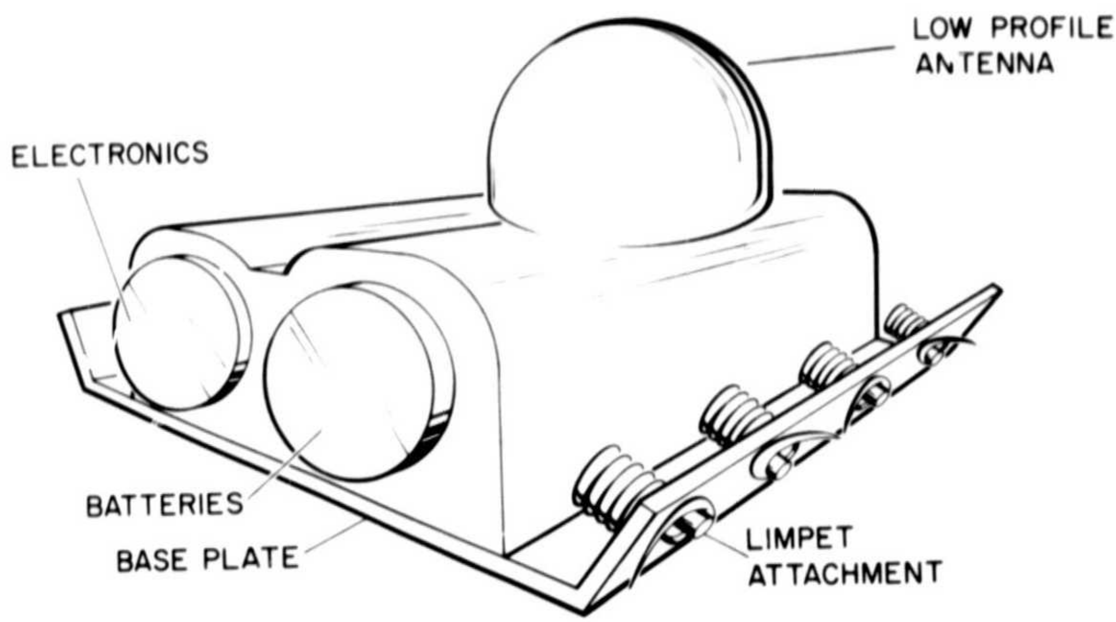


Fig. 11.– Walrus beacon transmitter with limpet attachment device. Electronics and batteries are in the cylinders and a low profile antenna is mounted on top. The overall length is 20 cm and the weight out of water is 3 kg.

Our first attempt to tag and track walrus may occur during July 1974 on Round Island, Alaska, where the conditions are most favorable. Several thousand male walruses spend the summer in this vicinity, and when basking on the beaches, they may be closely approached. The weather is mild, which is an asset for both experimenters and equipment.

Bowhead whales cannot be approached this closely; thus, a bowhead whale transmitter is being designed to be fired from an airplane or boat into the animal using a 12 mm gun. Electronically it is identical to the walrus beacon transmitter. The bowhead transmitter will have a spring-loaded whip antenna instead of the low-profile antenna. Not enough is known about the subice behavior of bowhead whales to know if they will destroy the whip antenna on the under surface of sea ice. However, since the unit will be fired into the whale, it is best to make the first attempts with the whip antenna which is aerodynamically much more satisfactory than the low-profile antenna.

By broadening the back end of the transmitter, penetration into the animal's skin and blubber will be limited. The harpoon end will be designed to penetrate cleanly and to fasten securely so that the transmitter will remain on the animal indefinitely. The transmitter will be coated with antibiotic just prior to firing to reduce the chance of infection.

All transmitters will be color-coded to ensure that they function as visual tags long after their batteries are dead. The transmitters will also function as recovery tags since they will be marked with numbers and a return address.

The transmitters will operate at relatively low frequencies of about 27 and 150 MHz depending on whether the environment is open water or sea ice and whether the transmission path is surface to surface or surface to air. Surface-to-surface tracking will occur primarily during ship-supported work, either in Bristol Bay with the R/V *Alpha Helix* in 1974 or elsewhere in Beringea with icebreaker support during later years. Because of the slim chance of obtaining ship support over long periods of time, we are designing our transmitters for both surface-to-air and surface-to-surface tracking.

The method of tracking will be to use an Ocean Applied Research Corporation automatic direction finder (ADF). This unit operates in conjunction with an antenna system consisting of two loop antennas at 90° to each other plus a whip antenna. After appropriate signal processing, voltages proportional to the strengths of the signals on the two crossed loops are sent to the x and y inputs of a cathode ray tube display, which locates the transmitter along an axis. By adjusting the phase difference between the x and y inputs, a narrow ellipse can be formed on the cathode ray tube. The 180° ambiguity is removed by processing the phase difference between the loop antennas and the whip antenna and using this information to blank half of the display on the cathode ray tube.

Directional information is obtained only with a strong signal. As the signal weakens, the blanking fails and the display indicates only the axis on which the animal is located. At still weaker signal strengths, the display becomes nonfunctional but the beat frequency oscillator still produces a tone when the signal is received. At ranges great enough for the display to cease functioning, the animal can be tracked with a high-gain, directional Yagi antenna since the angular change of direction is small between surfacings of the animal. Even when directional information is absent, a record of the presence and absence of the signal is indicative of the surfacing pattern of the animal, which can be of value in determining whether the animal is feeding, engaged in vigorous activity, or resting.

A continuous record of the activity of a tagged animal can be stored on magnetic tape. The directional information is converted into a voltage (0 to ±1.8 V for directions of 0 to ±180°), which is then transformed into an audio frequency by a voltage-controlled oscillator. The output of this oscillator is multiplexed with the output of another voltage-controlled oscillator, which reflects the voltage of the automatic gain control of the loop-antenna receivers. The first of these multiplexed frequencies records directional information when the signal is strong enough, and the second records the strength of the signal whenever it is received. The multiplexed data are stored on one channel of a two-channel tape recorder. The other channel stores the audio output of the beat frequency oscillator on the ADF. These signals may be weak and are best processed by ear.

The proposed successional approach to radio tracking is illustrated in figure 12. Since Beringea is a fairly small area with scattered islands in the middle, adequate coverage of the entire area could be obtained with a series of automated ground stations. Figure 2 shows the locations of the land-based, automatic tracking stations, which will cover the movements of radio-tagged animals almost anywhere in Beringea provided the transmitters have a range of 160 km, a distance not yet attained. Each station will consist of an antenna, an automatic direction finder, and units to digitize and store the directional information from the ADF. A transceiver will be added to pass the stored data to a polar-orbiting satellite when such a satellite is available for our use.

Whether we set up such a ground station network or proceed directly to the fourth stage of satellite tracking will depend on both the development of a transmitter capable of such a range and the availability of a synchronous satellite covering Beringea for wildlife monitoring. Polar-orbiting satellites are not feasible for direct transmission from the animal. Because marine mammals surface

STAGE 1: SURFACE–TO–SURFACE TRANSMISSION

STAGE 2: SURFACE–TO–AIRPLANE TRANSMISSION

Fig. 12.– Four-stage successional approach to radio tracking of walruses and bowhead whales to be used in BESMEX.

STAGE 3: ANIMAL TO GROUND STATION
TO POLAR ORBITING SATELLITE

STAGE 4: SURFACE–TO–SATELLITE TRANSMISSION

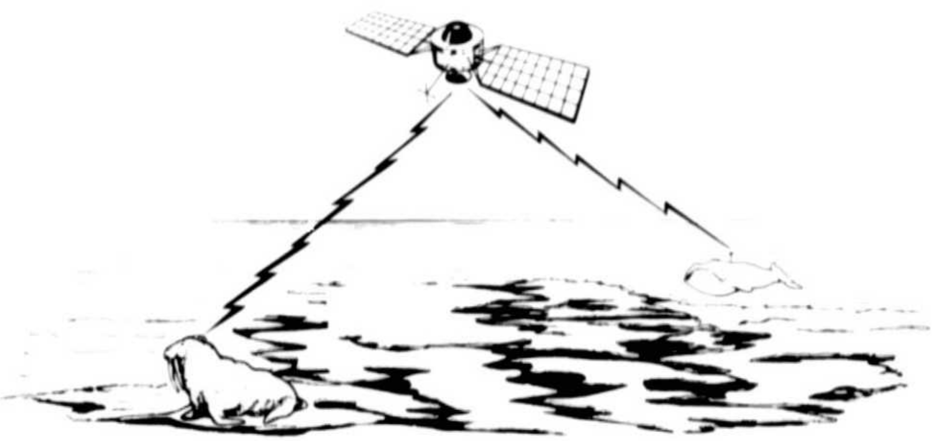


Fig. 12.– Concluded

only briefly at irregular intervals, they might transmit for only brief periods of milliseconds to seconds or maybe not at all during the transmission window on any one orbit. Goodman, Margolin, and Kratzer (1973) presented a thorough review of the subject, and it is clear that much work in application, design, and field testing must be done before one dares ask for the sort of remote-sensing resolution and radio-tracking detail required for a BESMEX type of ecosystem model study. BESMEX presently contemplates use of satellites only for ice remote sensing and as relays for animal-tracking data from isolated, automatic ground stations. Before the termination of our four-year project, we will present a plan for the expansion of satellite use.

Conclusion

The BESMEX program emphasizes remote sensing and radio tracking. Both techniques are required since they complement each other by providing both synoptic and specific data on numbers, distribution, social behavior, and activity patterns of animals and the influences of environmental variables. We believe that this approach is necessary in order to construct models of the ecosystem and to define the transfer functions involved.

MANAGEMENT PLAN

Duration of BESMEX

Table 1 identifies calendar year 1974 as one of planning, equipment design, and testing. We are also engaged in analysis of data acquired during BESEX, which forms the basis for experimental design and management. Calendar years 1975-1977 comprise three full years of the formal BESMEX program, a time period we consider minimal to experience the range of variables necessary for model building. We estimate that an additional two years will be required to complete data analysis, synthesis, and the writing of reports. This represents a minimal duration for accomplishment of our goals.

It is to be hoped that the experimental program initiated by BESMEX will continue well beyond calendar 1977 for the validation of models and to allow for some of our findings to be put into management practice. We wish to emphasize, however, that BESMEX is an experimental and research-oriented program dedicated to the determination of methods for assessment and the gathering of biological and ecological information for management on an ecosystem basis. BESMEX will not, itself, become involved in monitoring and management.

Personnel and Collaboration

BESMEX is a team effort and depends for its success on the cooperation of several persons not supported directly by this program. All those listed below have committed themselves to the principles and purposes of BESMEX, at least in part. The degree of effort that some individuals may be able to put into BESMEX will to a large extent depend on funding and the support of their various institutions and agencies. Personnel fall into four categories: core, users, collaborators and observers.

Core BESMEX personnel. The following are responsible for management of the program and the integration of data:

1. Scientific Coordinator and Principal Investigator: Dr. G. Carleton Ray, The Johns Hopkins University

2. Assistant Coordinator and Co-Principal Investigator: Dr. Douglas Wartzok, The Johns Hopkins University

3. NASA Coordinator and Co-Principal Investigator: Dr. John Billingham, NASA/Ames Research Center

4. NASA Coordinator and Co-Principal Investigator: Mr. Paul Sebesta, NASA/Ames Research Center

5. Flight Manager (Convair-990): Mr. Earl V. Peterson, NASA/Ames Research Center

6. Flight Manager (NP-3): Mr. Gordon C. Hrabal, NASA/Johnson Space Center

7. Student-Technician: Mr. Thomas J. Eley, Jr., The Johns Hopkins University.

8. Student-Technician: To be identified.

9. Secretary (50% effort): Mrs. Mary A. Mix, The Johns Hopkins University

Users. The user agencies are primarily the Fish and Wildlife Service, Department of the Interior, for walrus; and the National Marine Fisheries Service, Department of Commerce, for bowhead whales. The former agency also has responsibility for polar bears and the latter for all ice-inhabiting seals and other whales that will be encountered during the course of our work. Representatives of these agencies will collaborate fully in our work and all data acquired under BESMEX will be made available to them. The personnel involved are:

USF&W

Dr. Clyde Jones, Director
Bird & Mammal Laboratories
Fish and Wildlife Service
Department of the Interior
National Museum of Natural History
Washington, D.C. 20560

Mr. Ancel M. Johnson, Wildlife Biologist
Bureau of Sport Fisheries & Wildlife
U.S. Department of the Interior
Marine Mammal Laboratory
Naval Support Activity, Bldg. 192
Seattle, Washington 98115

NMFS

Dr. George Y. Harry, Director
Marine Mammal Laboratory
National Marine Fisheries Service
Sand Point Naval Air Station
Seattle, Washington 98115

Mr. Cliff Fiscus, Wildlife Biologist, Task Leader
Marine Mammal Laboratory
National Marine Fisheries Service
Sand Point Naval Air Station
Seattle, Washington 98115

Collaborators. Those who have agreed to collaborate with us or who will be recipients of the results of our work are:

Dr. William Campbell, Ice Dynamics
U.S. Geological Survey, Tacoma

Dr. Douglas G. Chapman, Modeling
University of Washington, Seattle

Mr. Thomas P. Dohl, Imagery, Tracking
University of California, Santa Cruz

Dr. William E. Evans, Radio Tracking
Naval Undersea Center, San Diego

Dr. Francis H. Fay, Marine Mammal Biology
University of Alaska, College

Dr. Roger L. Gentry, Marine Mammal Biology
NMFS, Seattle

Dr. Per Gloersen, Microwave Imagery
NASA/Goddard Space Center

Dr. Peter M. Kuhn, Infrared Imagery
NOAA/Environment Research Laboratory, Boulder

Mr. Paul E. LaViolette, Satellite Imagery
Naval Oceanographic Office, Washington, D.C.

Mr. Jack Lentfer, Marine Mammal Biology
Fish & Wildlife Service, Anchorage

Dr. René O. Ramseier, Ice Physics
Dept. of the Environment, Ottawa, Canada

Mr. Paul N. Sund, Remote Sensing
NMFS/Tiburon

Mr. Hugh B. Martin, III, Radio Tracking
Ocean Applied Research, San Diego

Dr. Kenneth S. Norris, Marine Mammal Biology
University of California, Santa Cruz

Mr. John W. Sherman, III, Satellite Imagery
NOAA/National Environment Satellite Service, Washington, D.C.

Observers. A program such as this one is likely to generate high visibility because of its magnitude, possible application of methods elsewhere, and the public interest in marine mammals. It will be our policy to invite a diversity of persons to observe our work at their expense and on a noninterference basis as space is available. The groups likely to take an interest include: conservation organizations, government environmental agencies (CEQ, EPA, Marine Mammal Commission, etc.), scientific funding agencies, legislators, and the scientific community at large. International organizations are also welcome to observe our work, as appropriate.

Data Handling

As BESMEX is primarily research-oriented, a vital question concerns how data are processed, reported, turned over to user agencies, and published for the benefit of the scientific community and the public. Essentially, each investigator will be responsible for analyzing his own data, and core personnel will be responsible for integration of the different aspects of the work, that is, application of data to the ecological models that are central to our effort.

A typical schedule for planning, data processing, and analysis for a flight series, for instance, is as follows. First, all investigators will take part in the planning of a flight series in detail. Each individual flight will be preceded and followed by briefing sessions. After completion of the flight series of an expedition, each investigator will process his own data. Thence follows a meeting for preliminary analysis and for selection of exemplary data sufficient in quantity or quality for detailed analysis and, if justified, for computerization. The compilation and synthesis stage follows. A final meeting of the investigators will result in a report outline. A full report should follow the flight series by about one year. Archiving of data will be the responsibility of core personnel, except in the case of original notes, film, tapes, and imagery which will remain with the appropriate investigators and agencies.

Thus, we expect data useful to user agencies to emerge within a year of each expedition. Formal publication should follow as appropriate and as arranged between the investigators. In sum, we seek expeditiously to fulfill our role as research investigators through formal publication but also rapidly to transfer results to those responsible for management of the species and systems under investigation by involving user agencies in the planning-analysis-reporting process.

Sponsorship

Aside from NASA support, it is expected that a degree of support will develop from the user agencies, as personnel or services or in the form of cost-sharing. It is important that such a multiple support base develop, as indeed it already has, through time and resources devoted by the personnel identified above as collaborators. A notable example is IR imagery, all costs of which have been borne jointly by NASA and NOAA/Boulder to date.

The other major support for this program has derived over a period of years through contracts to The Johns Hopkins University from the Office of Naval Research (Oceanic Biology). The bulk of the radio-tracking and telemetric gear on hand to date has been developed and purchased through that source. The Navy has a continuing interest in programs such as BESMEX.

Turning from financial to moral support, BESMEX has been tentatively approved as a part of the U.S. program under the US/Soviet Joint Committee in the Field of Environmental Protection. It is expected that data, and perhaps field programs, will be shared with our Soviet colleagues through this means. We also expect collaboration with other international efforts, namely: The Arctic Ice Dynamics Joint Experiment (AIDJEX) and the developing polar experiment (POLEX). The nature of these collaborations remains to be elucidated, but these projects share a common feature with BESMEX, namely a systems-oriented approach, utilizing multidisciplinary, integrated science and remote sensing, in the interest that man learn to predict and monitor the results of his actions with respect to the natural environment on which he depends.

Last, it must be pointed out that all marine mammal work in the United States comes under the purview of the Marine Mammal Commission and its Committee of Scientific Advisors. To that body we look for aid and guidance in all aspects of this program.

TENTATIVE BUDGET
for the Bering Sea Marine Mammal Experiment
(BESMEX)

It is not possible at this time to specify a budget outside the purview of core personnel. Nor are all logistics required for this program assured. Therefore, the following must be considered a bare-bones core requirement during the experimental phase through 1977 only. A budget for the follow-up two-year analysis and reporting period will be prepared at a later date (FY78 provides an estimate).

Note: Indirect costs are not included at this time. Amounts are in thousands.

Personnel		**FY75**	**FY76**	**FY77**	**FY78**
1. Dr. G. C. Ray	(50%)	12.5	13.0	13.6	14.5
2. Dr. D. Wartzok	(50%)	7.5	8.0	8.5	9.0
3. Mr. T. Eley	(100%)	7.5	7.5	8.0	8.0
4. Grad. Student	(100%)	–	6.0	6.5	7.0
5. Secretary	(50%)	4.0	4.2	4.4	5.0
6. Technician	(50%)	5.0	5.5	6.0	6.5
		36.5	44.2	47.0	50.0
Pers. Benefits	(16%)	5.8	7.1	7.5	8.0
Equipment					
1. Tracking		25.0	25.0	20.0	–
2. Telemetry		–	10.0	10.0	–
3. Remote Stations		20.0	40.0	40.0	–
		45.0	75.0	70.0	–
Expendable Equipment					
1. Office Supplies		2.0	2.0	2.5	3.5
2. Film		5.0	5.5	6.0	6.5
3. Tools		1.0	0.5	0.5	–
4. Repair Equipment		2.0	3.0	2.0	–
5. Parts		1.0	1.0	1.0	–
		11.0	12.0	12.0	10.0

Travel-Expeditionary and Travel				
1. Foreign (USSR, etc.)	3.0	3.5	4.0	4.5
2. Domestic (consult, Ames, Expedition)	10.0	11.0	12.0	13.0
	13.0	14.5	16.0	17.5
Other				
1. Processing (Films, etc.)	8.0	9.0	10.0	10.0
2. Computer and Data-Analysis	10.0	20.0	22.0	25.0
3. Ship Time	——— no costs estimated ———			
4. Air Charter	——— no costs estimated ———			
5. NASA/Ames Aircraft	——— no costs estimated ———			
6. Consulting with collaborators (their time and travel expenses)	13.5	14.0	15.5	16.5
7. Feasibility testing and application	5.0	7.0	7.0	-
8. Reports and Publications	2.0	3.0	3.0	5.0
9. Repair	2.0	2.0	3.0	-
	40.5	55.0	60.5	56.5
	FY75	**FY76**	**FY77**	**FY78**
Totals by years	151.8	207.8	213.0	142.0

TABLE 1

1974 -- Year of Planning, Equipment Design and Testing

Date	Location	Equipment	Experiment	Purpose
March	Pt. Barrow	150 MHz and 27 MHz walrus transmitters, small aircraft, ADF.	Comparison tests of range and stability of 27 and 150 MHz transmitters.	Determine best frequency for tracking over sea ice. Determine reliability of transmitters under Arctic conditions.
April	Florida	Boat, 150 and 27 MHz walrus transmitters, ADF.	Same as March 1974 plus tag and track sea turtle.	Determine best frequency for tracking over open water. First open-ocean test of walrus tracking transmitter.
July	Bristol Bay, Alaska	R/V *Alpha Helix* small boats, ADF, walrus trans-mitters.	Tagging and tracking walrus. Behavioral and physiological studies of walruses.	First test of transmitters on walrus. First indication of how attached transmitter affects behavior.
Sept.	Southern Chukchi Sea	Houston aircraft (NP-3*) with high-resolution visual and infrared imaging, USF&W Super Goose.	Comparison assess-ments of walrus populations from the two aircraft.	Determine the relative value of NASA aircraft for population assess-ment particularly relative to efficiency and accuracy.

TABLE 1 (Continued)(?)
1975 – Year of Experiment and Development

Date	Location	Equipment	Experiment	Purpose
Feb.-March	Central Bering Sea	Convair-990* USCG icebreaker	Remote sensing of ice, walrus & weather. Successive flights over the same ice. Radio tagging of walrus.	First test of proposed ice dynamics model. First test of several remote sensing tools for this application. Obtain ground truths.
April	Pt. Barrow/ Wainwright, Alaska	Helicopter small aircraft, snowmobile, whale transmitters and direction finders.	Tag and track bowhead whales.	Follow movements of whales to determine: relationship with ice and bottom topography; and respiration rate and pattern.
July	Bristol Bay, Alaska	Small aircraft, small boats, improved walrus transmitters, and direction finders.	Tag and track walrus.	Same as July 1974 except following tagged walrus for longer periods and at greater distances.
August/ Sept.	Chukchi Sea	Convair-990*	Remote sensing of ice, walrus, bowhead whales, and weather.	Determine walrus and bowhead whale distribution, relationship to ice, and social organization to build a model for this season and location.
Nov./ Dec.	Southern Chukchi/ Northern Bering Seas	Convair-990*	Same as Sept. 1974.	Same as Sept. 1974, noting changes in observed parameters due to changes in season and location with special emphasis on relationship with advancing ice front d' ring migration.

TABLE 1 (Continued)(3)
1976 – Year of Experiment and Model Refinement

Date	Location	Equipment	Experiment	Purpose
Feb./ March	Central Bering Sea	Convair-990* USCG or USSR Icebreaker.	Same as Feb./March 1975.	Testing of refined ice dynamics model based on 1975 results. Obtain ground truth.
April	Pt. Barrow/ Wainwright, Alaska	Same as April 1975 plus automatic land stations.	Tag and track bowhead whales.	Determine migration paths and relationship with moving ice.
July	Bristol Bay, Alaska	Same as July 1975 plus automatic land stations.	Tag and track walrus. Application of long-term radio tags.	Determine what interactions occur between populations.
Aug./ Sept.	Chukchi Sea	Convair-990* USCG or USSR icebreaker.	Same as Aug./Sept. 1975. Tagging and tracking of walrus and bowhead whales.	First test of walrus and bowhead whale movements as predicted by model based on 1975 results. Obtain ground truth.
Nov./ Dec.	Southern Chukchi/ Northern Bering Sea	Convair-990*	Same as Nov./Dec. 1975 plus tracking of walrus and bowhead whales.	First test of a model of walrus and bowhead whale migration based on data obtained in 1975.

.ABLE 1 (Concluded)

1977 – Year of Experiment and Preliminary Synthesis

All expeditions in 1977 will be like those in 1976 except that remote-sensing, radio-tracking and data-telemetry systems will be upgraded as the state of the art advances.

*The Convair-990, Galileo II (and the NP-3, if possible) will carry the following equipment on all flights listed:

1. Passive microwave imagery.
2. Infrared imagery with a resolution of $\leqslant 10^{-3}$ rad.
3. High-resolution photography with a resolution of $\leqslant 10^{-4}$ rad.
4. Temperature radiometry with a thermal resolution of $\leqslant 1°$ C and a spatial resolution of $\leqslant 1$ degree.
5. Differential radiometry for chlorophyll concentration detection to levels of $\leqslant 0.05$ mg/m^3.
6. UV imagery (if equipment is available).

On most occasions when Galileo II flights are listed attempts will be made to secure icebreaker support for ground truth studies. Subject to international agreements, each Galileo II flight will be considered a candidate for US/USSR cooperation.

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