HARBOR SEAL INVESTIGATIONS IN ALASKA
ANNUAL REPORT
NOAA GRANT NA57FX0367

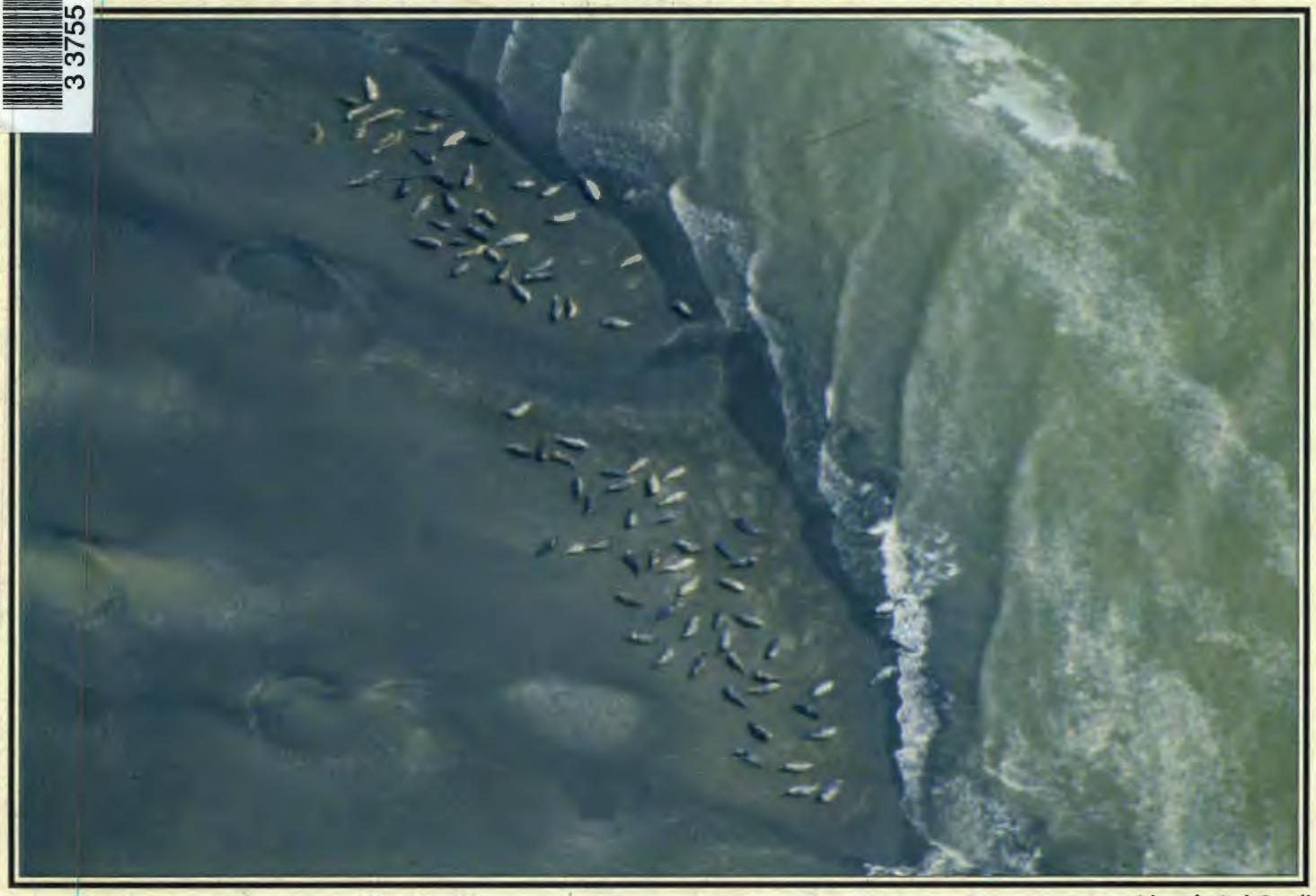

Photo by Bob Small

CONTRIBUTORS

er, P. Boveng, M. Castellini, S. Crowley, R. Daniel, L. Jemison,
B. Kelly, K. Laidre, G. O'Corry-Crowe, R. Papa, G. Pendleton,
R. Small, J. Thomason, S. Trumble, K. Wynne

Division of Wildlife Conservation
Alaska Department of Fish and Game
333 Raspberry Road, Anchorage, Alaska 99518

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P. Becker, P. Boveng, M. Castellini, S. Crowley, R. Daniel, L. Jemison, B. Kelly, K. Laidre, G. O'Corry-Crowe, R. Papa, G. Pendleton, R. Small, J. Thomason, S. Trumble, K. Wynne

Principal Investigator

Robert J. Small
Division of Wildlife Conservation
Alaska Department of Fish and Game
333 Raspberry Road, Anchorage, Alaska 99518

State of Alaska
Tony Knowles
Governor

Department of Fish and Game
Frank Rue
Commissioner

Division of Wildlife Conservation
Wayne Regelin
Director

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EXECUTIVE SUMMARY

In response to a severe decline in the numbers of harbor seals in the Gulf of Alaska, the National Marine Fisheries Service (NMFS) has provided annual grants to the Alaska Department of Fish and Game to investigate causes of the decline and to monitor population trends. The conceptual approach to this research has been to compare various population parameters between the declining Gulf of Alaska population (experimental population) and the increasing or stable Southeast Alaska (SE) population (control population).

The first overall objective of this research project is to monitoring harbor seal population trends in selected areas of Alaska. Population trend routes in the Sitka area of Southeast Alaska (SE) and in the Kodiak Island area were surveyed again in 1997, whereas the Ketchikan route was not flown as it is monitored on a biennial basis because of the high precision of the current increasing trend estimate. For Sitka, the current (1983-1997) significantly increasing annual trend estimate of 2.0% indicates seal numbers are increasing in SE, although the estimate is 1.0% lower than reported last year. The current Sitka trend estimate is based on five counts, two from the early 1980s, and the influence of *time of day* and *time from low tide* has not been determined because the time of surveys conducted in the 1980s is not available. Once the 1998 count is included in the trend analysis, the influence of time dependent covariates will be determined, and a recent trend from four consecutive counts (i.e., 1995-1998) will be estimated. For Kodiak, the current (1993-1997) trend estimate of +0.3% was not significant, contrasting sharply with the significantly increasing trend of 7.2% reported last year. The statistical model used in the trend analysis was modified slightly from last year to more effectively assess the influence of tide (both height and time). The result of this modification appeared minimal, as the Ketchikan trend estimate increased 0.1% from that reported last year using the same set of counts; however, the Kodiak trend estimate decreased 2.9% with the same set of counts using the revised methods. Thus, the model revision accounts for a portion of the decrease in the Kodiak trend estimate, and also demonstrates how the effect of covariates may differ among survey routes. The other cause of a decreased trend estimate is the significant influence of survey *date*, which suggests counts are higher early in the survey window compared to late in the window, and the confounding of *date* and *year*. The mean annual date of the Kodiak trend surveys has not been consistent; rather, the date has been earlier in recent survey years. These factors complicate the distinction between a population increase and changes in counts due to survey date, especially with only five annual counts. The 1998 Kodiak trend counts, completed in August, were collected during two separate survey windows (mid-August and early September) to help resolve the confounding between *date* and *year*. Until the 1998 counts are included in a new trend analysis, the number of harbor seals in the Kodiak Archipelago should be considered stable and remaining at levels much lower than reported in the 1970s. Numbers of harbor seals on southwest Tugidak Island during the molting period have increased 8.9% per year from 1992-1997 after a 6.5% per year decline from 1982-1990. These land-based counts have not yet been adjusted for the possible influences of *date*, *time of day,* and *time from low tide*, and are thus not directly comparable to the other trend estimates.

The number of harbor seals counted during a survey of the northeast Gulf of Alaska in 1997 was 52% larger than the 1996 count (3,079) and 93% larger than the 1993 count (2,422). However, the counts from these three surveys are difficult to compare because the potential influence of environmental covariates has not been determined and the surveys were not performed with the objective of estimating population trend. The greatest variation in counts, both within and among years, was at the glacial sites in Icy and Disenchantment bays where large numbers of seals are

dispersed over large areas. The current survey technique (visual counts combined with oblique 35 mm photography) is inefficient with potential for considerable error for such glacial sites, and an alternative method of obtaining an accurate estimate of the number of harbor seals, along with the variation of such estimates, is needed. Until such a method is developed, combining terrestrial and glacial sites within the same trend survey route should be discouraged.

The investigation of factors that affect harbor seal populations is the second overall objective of this project. Such factors may include reduced prey availability, either by environmental changes or through commercial exploitation, human caused mortality through harvest or incidental take in fisheries, diseases, pollutants, and predation. In 1993, available data indicated a stable or increasing population in SE compared to declining seal numbers in Prince William Sound (PWS) and Tugidak Island. Similar geographic differences in Steller sea lion populations had been recorded, adding support to the hypothesis that some factor(s) influences the two pinniped species differently in SE as opposed to the Gulf of Alaska. Comparative research studies were thus initiated, with the goal of determining whether certain factors differed between the two geographic regions.

The current status of harbor seals in the Gulf of Alaska varies geographically. The number of seals on Tugidak Island appears to be increasing since 1992, whereas numbers for the overall Kodiak region appear stable yet depressed, and a population decline continues in PWS (Frost *et al.* 1998). Thus, a comparison between the Kodiak region and SE may not currently represent a direct comparison between declining and increasing seal populations. Regardless, determining what factors affect seal populations in different regions of Alaska must continue to be a research priority for this project. Due to the dramatic decline in the Kodiak region, it remains a key area for such research. SE presents the opportunity to study an increasing population. In PWS, the long-term research investigation of a decreasing population continues (Frost *et al.* 1998). Research efforts should expand to include the relatively large number of seals along the north side of the Alaska Peninsula in the Bering Sea. Overall, these investigations will provide a greater understanding of the proximate and ultimate factors that regulate harbor seal populations throughout their range in Alaska, which is required to develop effective management and conservation strategies. The results of the various research projects presented in this report, and summarized below, represent progress towards such an understanding.

Tugidak Island studies expanded considerably in 1997, with documentation of pupping and molting phenology conducted throughout the May-September period. The date of peak pupping was 11 June, nearly identical to the previous three years, and the timing of three distinct molt stages (pre-molt, active molt, and post-molt) was documented for yearlings, subadults, adult females, and adult males. The molt patterns for these sex/age classes indicate that yearlings begin the molt sequence first, followed by subadults, adult females, and adult males. Peak counts for each sex/age class corresponded to the early stages of the active molt, and 90% or more of the yearlings, subadults, and adult females completed the molt by the beginning of September, compared to only about 30% of adult males. Understanding the timing and magnitude of differences in the molting period among sex/age classes should be considered in determining optimal population survey periods.

Twenty harbor seal pups were captured on Tugidak Island in June 1997, and 10 were tagged with satellite-linked depth-recorders (SDRs) to describe pup movements and development of diving behavior during their first year of life (Objective 3 of the research proposal). Five SDRs continued to collect data through May 1998, and two through June. The complete data set from the 1997 SDRs is now available and data processing and analysis have begun. All 20 pups captured in 1997 were also fit with VHF transmitters to provide additional information on their movement patterns. Ten

previously tagged pups were observed on Tugidak during May-September 1998; each of the five pups tagged with SDRs the previous summer was initially seen with the satellite units still attached.

Blood was drawn from pups captured on Tugidak Island in 1997 as part of the first field season of a study to establish reference ranges of blood chemistry and hematology in harbor seal pups. Additional pups were captured within PWS, and captures were made in both areas during June 1998, and are scheduled for 1999. This study is the first effort to gain information on assessing the health of harbor seal pups in Alaska, with the potential to relate changes in blood chemical and hematological parameters to specific environmental or nutritional factors. Preliminary results indicate significant differences between males and females, as well as differences between the two geographic areas. Screening of blood panels based on calculated reference ranges did not indicate population-level chronic diseases.

Preliminary results from disease testing of more than 300 harbor seals sampled in Alaska during 1978-1995 were reported in last year's report (Sheffield *et al.* 1997), and did not support the hypothesis that disease has been an important factor in the decline of seal numbers in some regions of Alaska. Additional blood serum samples are being collected and archived for future disease analyses, and results from the analysis of an additional set of samples are nearly complete (Objective 4 of the research proposal). These results will be integrated with the existing database, followed by a thorough review by a marine mammal disease specialist and manuscript preparation.

A preliminary statistical analysis and descriptive summary of the data collected from a 4-year study using SDRs deployed on harbor seals in SE and the Kodiak Archipelago was presented in the last two annual reports (Swain et al. 1996, Swain and Small 1997). These chapters have provided information on the general dive behavior and movement patterns of seals tagged with SDRs during one or two years; data from seals tagged in 1993 & 1994 were reported in 1996, and data from the 1995 SDRs were reported in 1997. In 1996, SDRs were deployed on 8 harbor seals (3 female, 4 male; 4 adult, 4 subadult) in SE during late September, and 8 (all males; 5 adults, 2 subadults, 1 yearling) in Kodiak in mid October. The data from the SDRs deployed in 1996 are not presented in this report (Objective 2 of the research proposal); rather, data from all 4 years is being combined for a more comprehensive statistical analysis, for both diving behavior and haulout patterns. This new analysis will include an index to foraging effort derived from an integration of the frequency, duration, and depth of dives. The foraging index will then be examined for differences on several temporal scales (i.e., daily, monthly, and seasonally), and the sex and age of the seals. The foraging index will also be examined in a spatial context, first between SE and Kodiak, and then at finer scales by incorporating estimates of bathymetry, if available. These tests will permit a more general understanding of the overall foraging ecology of harbor seals in SE and Kodiak than has been presented previously. Completion of analyses is scheduled for early summer 1999 followed by manuscript preparation.

The development of methods to estimate vital life history parameters of harbor seals continued in 1997 through two studies. First, the analysis of tooth fine structures to obtain data on individual reproductive histories and growth for harbor seals continued with upgraded sectioning and imaging equipment. Preliminary results indicate that growth layers in the cementum may not be substantially clearer than specimens prepared previously by decalcification and staining techniques. Second, photographic images were obtained of harbor seals on Tugidak Island in June 1998, with image quality and resolution sufficient for a computerized photo-identification technique that has been used successfully with grey seals (*Halichoerus grypus*) (Hiby and Lovell 1990). Images are currently being digitized and the technique modified specifically for harbor seals. Once modifications are

completed, the application of photo-identification can potentially be used as a mark-recapture technique for population dynamics studies.

The primary objective of the Alaskan harbor seal genetic research conducted by the Southwest Fisheries Science Center of the NMFS is to identify distinct population units for which conservation and management strategies can be designed and implemented. Initial results indicate substantial variation in mtDNA, suggesting at least two genetically distinct stocks in Alaska (Westlake 1997). Current research includes examining the variation in microsatellite nuclear markers to elucidate genetic and behavioral differences in more detail; specifically, the level of interbreeding among geographically, and possibly demographically, distinct subpopulations. Preliminary analysis of patterns of variability at eight microsatellite loci revealed significant genetic differentiation among seals sampled from PWS and Kodiak suggesting limited interbreeding between these two areas. In contrast, no consistent genetic differentiation was found between PWS and Kodiak using mtDNA. The reasons for these apparent inconsistencies between markers remain, as yet, unclear. A more extensive investigation, using both mtDNA and microsatellites, involving larger numbers of samples from a greater number of locations within both areas as well as other areas, including SE, has begun.

The investigation of the diet of Alaskan harbor seals expanded considerably in 1997. A thorough inventory of scats and stomachs collected during the 1990s was conducted, followed by the processing of those samples to identify prey species. The biosampling program was reestablished in SE, and additional samples were collected in Kodiak and Bristol Bay. Twenty blubber samples collected during 1997 are currently being analyzed in the ongoing fatty acid research program, and primary prey species from different regions are being collected such that their fatty acid signatures can be related to the patterns found in seals. Blubber samples from the 1970s will be analyzed for fatty acids and results compared with recently collected samples. Ultimately, the results of these various food habit studies will be integrated, in cooperation with PWS researchers, to provide a more complete understanding of the harbor seal diet in Alaska.

Existing data and information on levels of contaminants in harbor seals of Alaska, the contiguous U.S., and other areas of the world were reviewed. The main finding was a paucity of published data on contaminant levels in Alaska harbor seals, particularly for heavy metals, as well as persistent organic contaminants (e.g., chlorinated hydrocarbons). Available data are 10 to 25 years old and regionally spotty, suggesting that some data may be useful for historical comparisons, but not appropriate for extrapolating to contemporary conditions. Little information is available to establish baseline levels of contaminants in harbor seals throughout this species' distribution in Alaska waters, much less to evaluate likely impacts. Recommendations for a minimum approach to gathering information to evaluate the health of harbor seals relative to contaminant concentrations were provided.

Providing the National Marine Fisheries Service with information that can be used in the management and conservation of Alaskan harbor seals is the final overall objective of this research project. The results and discussion from the various subprojects presented herein can be used to further develop a management strategy. Trends in population abundance may be used in conjunction with NMFS statewide population size estimates to evaluate stock status. Detailed information on the pupping and molting phenology of seals has been collected in one geographic area, providing additional insights on how to determine optimal population surveys in other areas. The scientific basis for stock delineation has expanded with the use of microsatellite nuclear markers. Collection of data on the movement patterns and diving behavior of pups has begun, which when combined with information on the foraging ecology of older cohorts and results from diet studies will provide a better understanding of habitat use patterns.

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INTRODUCTION

Dramatic declines in the number of harbor seals (*Phoca vitulina richardsi*) have been documented near Kodiak Island and in Prince William Sound (PWS), Alaska. Specifically, the number of seals decreased by approximately 90% between 1976 and 1995 on Tugidak Island (Pitcher 1990, Lewis *et al.* 1996), located southwest of Kodiak Island, and in PWS numbers decreased by 62% between 1984 and 1996 (Frost *et al.* 1997). A research program to investigate the possible cause(s) of the population decline in Alaska was initiated in 1993 by the Alaska Department of Fish and Game (ADF&G) through funds allocated by the U.S. Congress. This research program has continued with annual grants awarded to ADF&G and administered by the National Marine Fisheries Service (NMFS), Alaska Region, of the National Oceanic and Atmospheric Administration (NOAA). This report presents the progress of the investigation of harbor seals in Alaska achieved during the 1997 performance period (1 July 1997–30 June 1998), fulfilling the reporting requirements under NOAA grant number NA57FX0367.

Overall, the status and trend of harbor seals in Alaska was poorly understood when ADF&G began their research investigations in 1993. Trend routes had been established in PWS, and the Sitka and Ketchikan areas of Southeast Alaska (SE) in 1983 as a means to collect population data in a standardized, repetitive manner. These trend routes were surveyed again in 1984, but none were flown again until 1988 when the PWS and Ketchikan routes were surveyed. Annual surveys of the PWS route have been conducted since the *Exxon Valdez* oil spill in 1989. With the start of the NOAA-funded harbor seal research program in 1993, trend route surveys were re-initiated in SE and an additional route was established in the Kodiak Island area. A reliable estimate of the total number of harbor seals in Alaska was not available until NMFS conducted the first statewide population survey beginning in 1991. Aerial surveys were conducted in Bristol Bay, along the north side of the Alaska Peninsula, and in PWS in 1991; the remaining areas of the Gulf of Alaska, including the Copper River Delta, were completed in 1992. NMFS then surveyed SE in 1993 and the Aleutian Islands in 1994. NMFS also conducted research projects during 1994 in SE and during 1996 near Cordova to estimate 'correction factors' that can be used to extrapolate counts of the number of seals hauled out during aerial surveys to an estimate of the total population size. The second statewide population survey began in 1995, with accompanying correction factor studies. ADF&G researchers funded by this NOAA contract have assisted NMFS in their research projects on harbor seals in Alaska.

An understanding of harbor seal population dynamics, ecology, and behavior is necessary to determine what proximate and ultimate factors may cause their populations to decrease. In addition, an understanding of the genetic structure of Alaskan harbor seals is required to properly delineate distinct population stocks for which conservation and management strategies can be effectively implemented. Such knowledge was also limited or did not exist in 1993. Recognizing this lack of necessary information, a diverse research program was initiated to increase our general understanding of harbor seal biology, and to address specific hypotheses related to the population decline.

The decline of harbor seal populations must be considered within the context of the Gulf of Alaska and Bering Sea ecosystems. Declines in other marine mammal populations have occurred, most notably the western stock of the Steller sea lion (*Eumetopias jubatus*) which was classified as endangered in May 1997. The northern fur seal (*Callorhinus ursinus*), whose numbers decreased by over a million animals (>50%) between 1950 and 1983, was given depleted status by NMFS in 1988.

1993). Changes in fish species composition have been recorded, with substantial increases in some species, such as walleye pollock (*Theragra chalcogramma*), and decreases in others (Alton *et al.* 1987, Piatt and Anderson 1996). Whether such population fluctuations are inherent to the dynamic nature of the ecosystems or are the result of specific perturbations, perhaps anthropogenic, is unknown. Regardless, because harbor seals are predators near the top of the trophic structure, knowledge of population status and trends of species interacting with seals, particularly prey species, should be integrated into hypotheses aimed to determine the cause of seal declines.

Work undertaken during 1997 marks the completion of five years for the NOAA-funded harbor seal research program. Considerable progress has been made since 1993. The number of years annual trend counts were conducted in the Ketchikan, Sitka, and Kodiak areas continues to increase, allowing a better understanding of population status in different geographic regions of the state. The northeast Gulf of Alaska was surveyed again in 1997, resulting in additional recommendations for future population trend surveys in that area. Demographic studies on Tugidak Island were conducted throughout the May-September period, providing additional insight on the changes that have occurred there since the 1970s. Sixty-four adult and subadult seals have been monitored with satellite-linked depth recorders to describe foraging behavior, seal movements, and haulout patterns. A study to examine the foraging behavior and movement of pups was initiated in 1997 with satellite-linked depth recorders attached to 10 pups captured on Tugidak Island. Blood chemistry and hematology data were also collected from the Tugidak pups. An extensive review of environmental contaminants was completed, along with an annotated bibliography. Genetic research focused on delineating management stocks of Alaskan harbor seals continues. Studies examining seal diet through scat, stomach contents, and fatty acids have expanded. Lastly, the investigation of Alaskan harbor seal life history characteristics using patterns in the deposition of material in seals' teeth continues.

However, much work remains. Results and progress made in each of the first five years must be synthesized and integrated for a more thorough understanding of the results, which can then be used to determine the most effective and efficient means to provide further knowledge of Alaskan harbor seals.

As stated in the project proposal, the focus of the 1997 research program was fourfold:

1. Monitor the trend in harbor seal numbers in selected areas.

2. Investigate factors that may be affecting harbor seals in those areas.

3. Complete statistical analysis and reporting of existing data.

4. Provide information to NMFS that can be used for designing a conservation and management program for harbor seals.

The specific objectives to meet these overall research goals were as follows:

Objective 1: Determine and monitor the number and trend in number of harbor seals at selected sites in the Ketchikan, Sitka, Kodiak, and the northeastern Gulf of Alaska areas.

Objective 2: Determine the movements and habitat use of harbor seals in Southeast Alaska and the Kodiak Archipelago, including temporal and spatial patterns of haulout use.

Objective 3: Describe the areas and depths used for feeding by harbor seal pups in Southeast Alaska and the Kodiak Archipelago.

Objective 4: Compare indices of health status and the prevalence of some infectious diseases of harbor seals in Southeast Alaska and the Kodiak Archipelago.

Objective 5: Determine genetic structure of harbor seals in Alaska.

Objective 6: Develop methods for estimating vital life history parameters of harbor seals, such as growth rates, age at sexual maturity, reproductive interval, and pregnancy rate.

Objective 7: Determine prey utilization by harbor seals in various locations throughout Alaska.

Objective 8: Tugidak demographic studies.

Objective 9: Provide support to studies by other investigators that will examine the nutritional status, energetic requirements, and food habits of harbor seals.

Objective 10: Compile information on contaminants in Alaskan harbor seals, evaluate adequacy of current information and make recommendations for future contaminant work. (Objective 9 of the 1996 reporting period)

These ten objectives were addressed by a diverse group of research scientists from several state and federal agencies and universities working cooperatively with ADF&G. In this annual report, the results of these research efforts are presented in separate chapters prepared by the individual scientists, and in the summary.

ACKNOWLEDGEMENTS

Financial support for this project was provided by the annual Congressional appropriations in the Department of Commerce budget that were passed on to the Alaska Department of Fish and Game (ADF&G) through the National Oceanic and Atmospheric Administration.

The 1997 Alaskan harbor seal research project was a joint effort by many individuals associated with several agencies and academic institutions. Contributions from the following individuals were instrumental to the success of the project. From ADF&G: Rob Delong for development of software to manage and analyze satellite tag data; Kathy Frost for assistance in the analysis of satellite tag data and fatty acid research; Lauri Jemison for leading the food habitats studies, Tugidak Island field research, and reestablishing the biosampling program in Southeast Alaska; Matt Kookesh for assistance with the biosampling program in Southeast; Lloyd Lowry for oversight of the project, satellite data analysis, and assistance with the northeast Gulf of Alaska population survey; Dennis McAllister for technical assistance; Grey Pendleton for statistical analysis and conducting trend counts in the Sitka area; Ken Pitcher for discussions of historic data; Gay Sheffield for database preparation and maintenance; Una Swain for analysis of dive data; Dave Van Den Bosch for logistical support and equipment preparation; Vicki Vanek for the collection of specimens from Alaska Native subsistence hunters, and Randy Zarnke for disease analysis. Administrative support within ADF&G was provided by Jean Fults, Diana Ground, and Lauri Ritter.

From the National Marine Fisheries Service: Alaska Regional Office, Kaja Brix as the project's technical monitor and Peter Jones as program officer; National Marine Mammal Laboratory, Peter Boveng for tooth structure research and Thomas Loughlin for project oversight; Southwest Fisheries Science Center, Greg O'Corry-Crowe for genetic research. From the University of Alaska, Brendan Kelly for continued interest, ideas, and supervision in Tugidak Island research, Steve Trumble for pup captures on Tugidak Island, and the subsequent collection of physiological samples; Shannon Crowley and Raychelle Daniel for maintaining the Tugidak Island summer field camp and collection of pupping and molting phenology data; and Kate Wynne for field research assistance, collection of specimens from Alaska Native subsistence hunters, and conducting trend counts in the Kodiak region. From the National Institute of Standards and Technology, Paul Becker and Rebecca Papa for completing the contaminant review.

Thanks are also due to Monica Riedel and Harold Martin of the Alaska Native Harbor Seal Commission for their efforts to help organize the collection of specimens from Alaska Native subsistence hunters, and for insight on how traditional knowledge can be incorporated into the management of harbor seals in Alaska.

A special thanks go to John and Midge Garber for all their help in making the work on Tugidak Island more enjoyable and productive. Finally, thanks to the numerous pilots who often flew in adverse conditions for extended periods.

CHAPTER 1

DEMOGRAPHY

OBJECTIVE 1

Determine and monitor the number and trend in number of harbor seals at selected sites in the Ketchikan, Sitka, Kodiak, and the northeastern Gulf of Alaska areas

OBJECTIVE 6

Develop methods for estimating vital life history parameters of harbor seals, such as growth rates, age at sexual maturity, reproductive interval, and pregnancy rate

OBJECTIVE 8

Tugidak demographic studies: pupping and molting phenology of harbor seals

HARBOR SEAL POPULATION TRENDS IN THE KETCHIKAN, SITKA, AND KODIAK ISLAND AREAS OF ALASKA

Robert J. Small[1], Grey W. Pendleton[2], and Kate M. Wynne[3]

[1] Division of Wildlife Conservation, Alaska Department of Fish and Game
333 Raspberry Road, Anchorage, Alaska 99518

[2] Division of Wildlife Conservation, Alaska Department of Fish and Game
P.O. Box 240020, Douglas, Alaska 99824

[3]Alaska Sea Grant College Program, Fishery Industrial Technical Center,
900 Trident Way, Kodiak, Alaska 99615

INTRODUCTION

In the Gulf of Alaska and Prince William Sound (PWS) regions of Alaska, harbor seal (*Phoca vitulina richardsi*) numbers declined substantially from the late 1970s through the early 1990s (Pitcher 1990, Hoover-Miller 1994, Frost *et al.* 1998). A sympatric species of pinniped, the Steller sea lion (*Eumetopias jubatus*), also declined greatly in the Gulf of Alaska and Aleutian Islands during this period and was classified as "endangered" in the western portion of its range under the Endangered Species Act in May 1997. In Southeast Alaska (SE), harbor seal numbers appeared to be increasing or stable in recent years and seals are thought to be relatively abundant (Small *et al.* 1997). Likewise, Steller sea lion numbers appear stable in SE (Calkins *et al.* 1997).

The Alaska Department of Fish and Game (ADF&G) established harbor seal population trend routes in the Ketchikan and Sitka areas of SE (Figures 1 & 2) and in Prince William Sound (PWS) in 1983 (Calkins and Pitcher 1984). ADF&G surveyed the three aerial trend routes in 1984 (Pitcher 1986), but then routes were not surveyed again until the Ketchikan and PWS routes were flown in 1988 (Pitcher 1989). Although the PWS route was flown annually after 1988 through Exxon Valdez oil spill funding, the Ketchikan and Sitka routes were not surveyed again until 1993 when the National Marine Fisheries Service (NMFS) surveyed the entire SE region as part of their first statewide survey (Loughlin 1994), including the areas where both the Ketchikan and Sitka trend routes are located. Beginning in 1993, ADF&G received funding from NOAA to investigate declining harbor seal populations, and ADF&G subsequently surveyed the Ketchikan route in 1994 (Lewis 1995), and both the Ketchikan and Sitka routes in 1995 (Lewis *et al.* 1996) and 1996 (Small *et al.* 1997). NMFS surveyed the Kodiak Archipelago in 1992, also as part of their first statewide survey (Loughlin 1993), and a Kodiak trend route was established by ADF&G in 1993 that used some of the sites counted by NMFS (Figure 3). The Kodiak trend route was subsequently surveyed annually by ADF&G from 1994-1996. In 1997, the Ketchikan route was not surveyed because the low variation associated with the annual increasing trend of 9.3% permitted a biennial survey schedule; the route will be surveyed in 1998. The Sitka and Kodiak trend routes were surveyed in 1997, and will be again in 1998.

The first major decline of harbor seals in Alaska was documented with land-based population counts collected from Tugidak Island, southwest of Kodiak Island (Figure 3, site # 23) (Pitcher 1990). Counts on Tugidak were conducted again in 1997, as they were during 1976-1979, biennially from 1982-1994, and in 1995 and 1996 (Lewis *et al.* 1996, Small *et al.* 1997).

METHODS

Survey Methods

Trend routes were surveyed with single engine, float equipped aircraft during the molting period in late August and early September. Surveys were flown between two hours before and two hours after low tide, at an altitude of 800 feet unless weather conditions required slightly lower altitudes. After locating hauled out harbor seals, the aircraft circled and the observer counted all seals (including those in the water near haulouts), using 7 or 8 power binoculars when necessary, and then took 35mm color slide photographs (ASA 400) with an 80-200mm zoom lens for groups of more than 10-15 seals. Weather conditions (e.g., wind speed, air temperature, cloud conditions) were recorded at each haulout. We attempted to obtain at least five replicate surveys for each route. Seal numbers were later counted from projected slide images. Counts from each trend site within the Sitka and Kodiak survey routes for 1997 are summarized in Appendices I-II; counts from previous years were presented by Lewis *et al.* (1996) and Small *et al.* (1997).

At the southwestern Tugidak Island haulout site counts of seals were conducted within one hour of daytime low tide from atop 30 m bluffs during the molting period in August and early September. The 1997 count data are summarized in Appendix III, and were analyzed separately from aerial trend route counts.

Model Selection

An estimate of population trend based on trend counts must account for the variation in those counts that results from both real changes in population abundance and factors that affect the proportion of the population visible during surveys. Rather than assume that a constant proportion of seals were visible, and thus observed during each survey, we modeled counts as a function of environmental covariates; e.g., tide height and time of day. We then estimated the population trend for a series of annual counts using overdispersed multinomial models (Link and Sauer 1997). With this type of model, counts (Y_{ij} , i indicates site and j indicates replicate) are assumed to be overdispersed Poisson random variables (i.e., negative binomial) with expected values (m_i) that have the relationship $\ln(m_i) = h(i) * g_i(\underline{x}) * f_i(t)$. In this equation, h(i) represents site effects, which are treated as a multiplicative nuisance parameter, $g_i(\underline{x})$ is a loglinear function of the environmental covariates ($\underline{x}$) that are unrelated to population change, and $f_i(t)$ is the population trajectory with t indicating year.

The population trajectory can be thought of as a smoothed curve proportional to the actual population sizes across years. Because trajectories were not always linear (i.e., the rate of change varies through time) on the log scale, we defined trend as the geometric mean rate of change over the interval of interest. Trend is therefore a single-number summary of the average change in the trajectory.

The environmental covariates used in our analysis included *date, time of day, tide height* at the survey time of each site, and *time from low tide (tide time)*. These main effect covariates were the same as those investigated by Frost *et al.* (1998) who used categorical versions of these variables rather than the continuous forms we used. We investigated 4 category versions of *time of day* (within 1 hr of midday, between 2 and 1 hr before midday, between 1 and 2 hr after midday, times not in these categories) and *tide time* (same pattern as time of day but in 0.5 hr blocks). We found that these formulations provide poorer model fits (based on AICc; Hurvich and Tsai 1989, Burnham *et al.* 1995) than the models with their continuous counterparts. In addition to the linear form of covariates, we also included *date, time*, and *tide time* as quadratic covariates (e.g., $date^2$) and allowed the effect of *tide height* to vary by site (*site*tide height* interaction). The quadratic and interaction covariates were chosen because of known or suspected patterns in seal haulout behavior. Models with both linear and quadratic population trajectories (i.e., change in population size across years on the log scale) were tested.

The combination of covariates and degree of polynomial used to produce the trajectory, and subsequent trend estimate, were determined by first starting with a model containing all covariates and a quadratic trajectory. Covariates were then eliminated one at a time based on the likelihood ratio tests until all remaining covariates were significant ($P<0.05$) or were a component of a higher order term (i.e., quadratic or interaction) that was significant. The final model was then used to estimate a single composite trajectory, and subsequently an associated trend estimate, for all sites within a route; this process assumes that the covariate functions (except tide) were the same for all sites.

We calculated an adjusted index of population size by fitting a year-effects model. In this model, year was fit as a categorical variable after adjusting for the covariates retained in the polynomial trajectory model. This results in an estimate of abundance for each year relative to a fixed year. Because actual abundance is not known, the trend and adjusted indices are scaled to an arbitrary level. We used the observed mean count in 1997 as the fixed point; thus, in 1997 the adjusted index is equal to the observed mean count and the trend line passes through this value. All other indices and the trend line are relative to this value.

The population trend for the southwest beach site on Tugidak Island was estimated by linear regression of the natural logs of mean annual land-based counts during two separate periods: 1982-90 and 1992-1997.

RESULTS

The mean count for the Sitka route increased 36.3% from the 1996 count of 1,602 to 2,183 in 1997 (Table 1). A similar increase of 33.3% was observed along the Kodiak trend route, with a 1997 mean count of 3,387 compared to 2,540 in 1996. Although mean uncorrected counts in 1997 for both the Sitka and Kodiak routes increased, trend estimates based on modeling these counts and environmental covariates resulted in annual trends lower than what had been reported through 1996. For Sitka, the annual trend estimate from 1983-1997 was 2.0% ($P=0.007$; Table 2, Figure 4) compared to the trend estimate through 1996 of 3.0%. For Kodiak, the 1993-1997 annual trend estimate of 0.3% was not significantly different from zero ($P=0.814$), and contrasted sharply with the significant increasing trend of 7.2% reported through 1996 (Table 2, Figure 5). As the model selection process used for the current trend analysis was slightly different than reported last year

(Small *et al.* 1997), a new analysis for the same set of annual counts from the Ketchikan trend route was conducted. The trend remained essentially the same, increasing only slightly from 9.3% to 9.4% ($P<0.001$; Table 2, Figure 6).

Based on final model selections, environmental covariates significantly influenced the number of seals hauled out along all three trend routes (Table 3). For Sitka, time of day for surveys conducted in 1983 and 1984 was not available, thus *date* was the only covariate available for all years. *Date* had a negative effect in Sitka, Ketchikan, and Kodiak, indicating that counts decreased during the survey period. $Date^2$ had a negative effect in Ketchikan, but a positive effect in Sitka, suggesting counts decreased more rapidly near the end of the survey window in Ketchikan, but not as rapidly in Sitka. *Time of day* had a positive influence in Ketchikan and Kodiak, and $Time^2$ had a negative influence in Ketchikan, suggesting counts initially increased during the day for both routes, but then stabilized or decreased later in the day for the Ketchikan route. *Time from low tide* had a negative influence in Ketchikan and Kodiak, indicating counts decreased as time from peak low tide increased. Counts decreased with increasing *Tide height* in Kodiak, but tide height did not influence counts in Ketchikan.

The mean number of seals counted on the southwest beach site of Tugidak Island during the molting period of August and early September 1997 was 960, up 30.8% from the 1996 count of 734. Linear regression on the natural log of the mean annual counts found a significant ($P=0.002$) decreasing trend of –6.5% per year from 1982-1990, followed by an increasing trend of 8.9% per year ($P=0.07$) for the 1992-1997 period (Figure 7). The affect of environmental covariates has not yet been determined for the Tugidak Island count data.

DISCUSSION

The inclusion of the 1997 Sitka trend count into our analysis supports the conclusion that harbor seal numbers are increasing in SE, whereas the addition of the 1997 Kodiak count leaves the interpretation of population trend in that area equivocal. The model selection process to determine which covariates influenced the number of seals counted was basically the same likelihood ratio test as reported last year (Small *et al.* 1997), although the covariate structure was revised. The most substantial revision was a restructuring of *tide height* as a covariate, from height at peak low tide nearest the survey time, to tide height at the time a site was surveyed. The result of this model revision was minimal for the Ketchikan route, where *tide height* was not a significant covariate, and the change in trend estimates was 0.1% from that reported last year compared to the current analysis using the same set of counts (i.e., 1983-1996). In contrast, the trend estimate reported last year for the Kodiak counts of 1993-1996 was +7.2%, compared to +4.3% with the same set of counts using the revised methods. Thus, the model revision accounts for a portion of the decrease in the Kodiak trend estimate, and also demonstrates how the effect of covariates may vary among survey routes.

Another possible cause of the decrease in the Kodiak trend estimate from +7.2% (1993-1996) to +0.3% (1993-1997) is the significant influence of survey *date*, which suggests counts are higher early in the survey window compared to late in the window, and the confounding of *date* and *year*. The mean annual date of the Kodiak trend surveys has not been consistent; rather, the date has been earlier in recent survey years (Figure 8). The lowest annual mean count was recorded in 1993 when the survey was performed later (2-8 September) than any other year, whereas the highest annual mean count was recorded in 1997 during the earliest survey (20-27 August). These factors

complicate our ability to distinguish between a population increase and changes in counts due to survey date, especially with only five annual counts.

Conducting trend counts both early and late in the survey window, in the same year, should help distinguish between the effect of *date* and survey *year*. Accordingly, the 1998 survey will be performed in two separate time periods, the first in mid August and the second in late August-early September.

The continued increase in numbers on Tugidak Island (Figure 7) suggests a growing population for the southern area of the Kodiak Archipelago; however, these land-based counts have not yet been adjusted for the possible influences of *date*, *time of day,* and *time from low tide*, and are thus not directly comparable to the other trend estimates. Therefore, until the 1998 trend count survey has been conducted, the population trend of harbor seals in the Kodiak Archipelago should be considered stable, rather than increasing; but, seal abundance remains at levels much lower than reported in the 1970s.

The results of our current analysis confirms the importance, and potential pitfalls, of integrating the effect of environmental covariates on the number of harbor seals hauled out during aerial surveys. The influence of *date*, *time of day*, and *time before low tide* on counts from both the Kodiak and Ketchikan trend routes was significant. The harbor seal population in PWS is also monitored using aerial trend counts, and although the analysis to estimate population trend is slightly different, the same three environmental covariates consistently have had a significant influence on population trend counts (Frost *et al.* 1998, Frost *et al. in press*). Overall, the effect of *tide height* appears to have less influence, except for the Kodiak route as discussed above. The timing of surveys during the 1983 and 1984 Sitka counts is not available, and thus *date* was the only covariate tested, which had a significant negative influence as observed in the other routes. Once the 1998 Sitka trend count is completed, four consecutive annual counts (1995-98) will be available for which the effect of time dependent covariates (i.e., *time of day*, *time before low tide, tide height*) will be determined. The assumption that peak numbers of harbor seals ashore during molting occurs during the same relative period among different geographic areas, and remains relatively constant from year to year, should also be examined as a potential influence on both abundance and trend survey counts (Jemison *et al.* 1998). Additional discussion on the use of modeling with covariates and their significance to population monitoring studies has been presented elsewhere (Small *et al.* 1997, and Frost *et al. in press*).

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Table 1. Annual mean total counts of harbor seals from population trend routes in the Ketchikan, Sitka, and Kodiak areas of Alaska, 1983-1997. An adjusted index of population size for each year was calculated after adjusting for the covariates present in the final model, and then scaled to the observed 1997 count (see text).

	Ketchikan		Sitka		Kodiak	
Year	Mean Count	Adjusted Index	Mean Count	Adjusted Index	Mean Count	Adjusted Index
1983	1059	1133	1168	1588	--	--
1984	1554	1425	1273	1769	--	--
1988	1821	2097	--	--	--	--
1992	--	--	--	--	1563[1]	--
1993	835[1]	--	875[1]	--	2522	3303
1994	2228	2191	--	--	3184	3447
1995	2604	3833	2041	2279	3276	3878
1996	2706	2706	1602	1998	2540	3398
1997	--	--	2183	2183	3387	3387

[1]Reported from the NMFS state-wide survey and not included in the trend analysis.

Table 2. Annual harbor seal population trend (%change/year) estimates, 95% confidence limits (CL), test statistics, and probability that the trend is different from zero for the Ketchikan, Sitka, and Kodiak areas in Alaska, 1983-1997.

Area	Years	N	Trend (se)	95% CL	Chi-square (df)	*P*
Ketchikan	1983-96	6	9.4 (0.78)	7.8 - 11.1	135.35 (1)	<0.001
Sitka	1983-97	5	2.0 (0.75)	0.5 - 3.5	7.34 (1)	0.007
Kodiak	1993-97	5	0.3 (1.47)	-2.5 - 3.3	0.06 (1)	0.814

Table 3. Levels of probability (*P*)[1] for environmental covariates that significantly influenced the number of harbor seals hauled out in the Ketchikan, Sitka, and Kodiak areas of Alaska, for the time periods listed. *P*-values are listed for those covariates that were retained in the final model selection to determine population trend, along with their respective direction of influence (+ = increasing; - = decreasing) on the number of seals hauled out; remaining covariates were either not available for consideration (NA) or not significant (NS).

	Ketchikan 1983-96		Sitka 1983-97		Kodiak 1993-97	
Covariate	P	+/-	P	+/-	P	+/-
Year	<0.001	+	0.007	+	0.814	+
Year*Year	NS		NS		NS	
Date	0.007	-	0.013	-	0.033	-
Time of day (Time)	<0.001	+	NA		0.117	+
Tide height at survey time	NS		NA		0.083	-
Time from low tide (Tide time)	0.001	-	NA		0.043	-
Date*Date	<0.001	-	0.002	+	NS	
Time*Time	<0.001	-	NA		NS	
Tide time*Tide time	0.001	-	NA		NS	
Site*Tide height	NS		NA		NS	

[1]Individual probabilities are based on the Wald statistics from the final model, and likely differ from the probabilities of the likelihood ratio statistics used in testing the significance of each covariate in the model selection process.

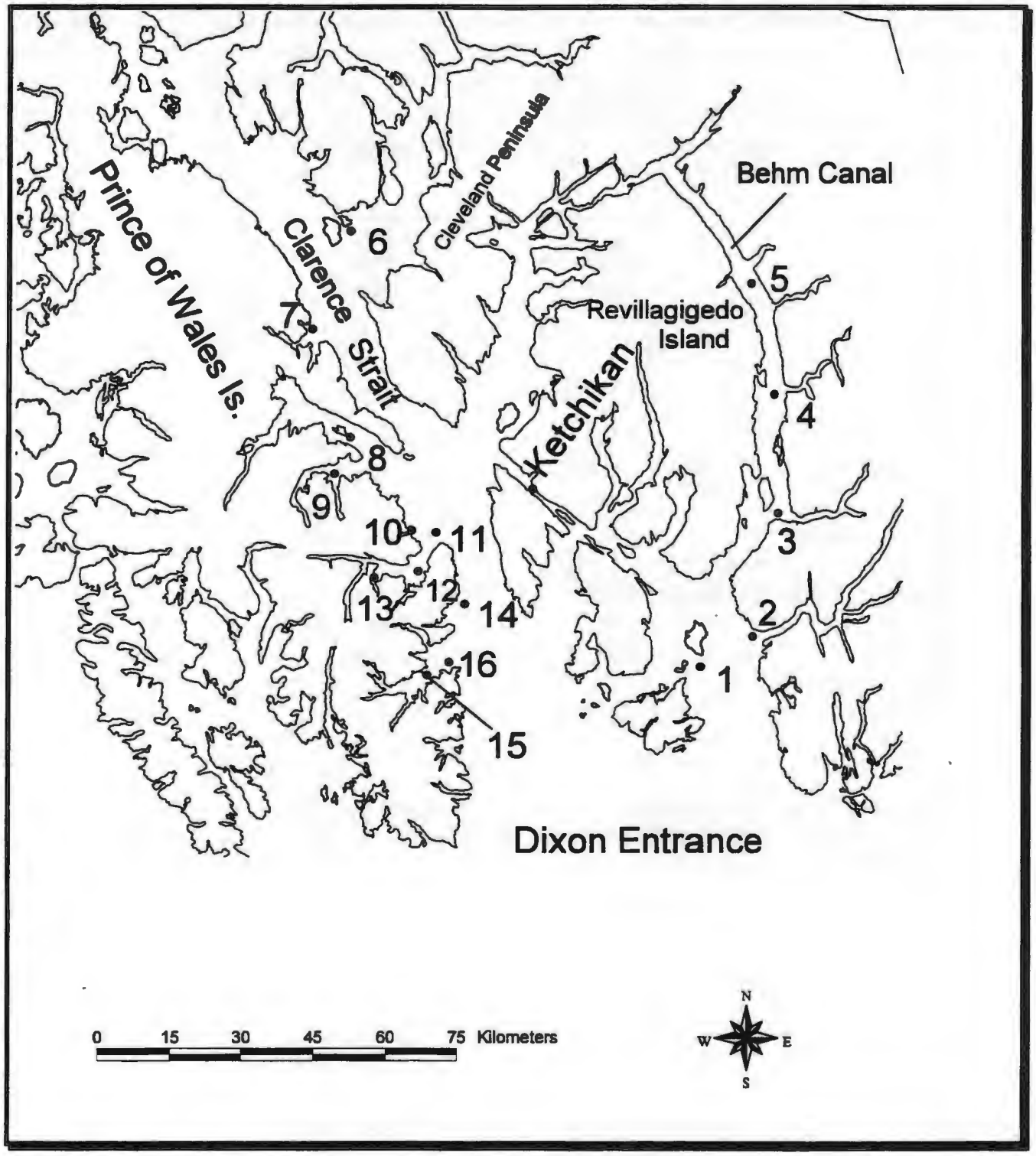

Figure 1. Trend count sites in the Ketchikan area of Southeast Alaska.

1. Whale Rock	2. White Reef	3. Carp Island	4. New Eddystone
5. Channel Island	6. Eagle Island	7. Tolstoi Island	8. Daisy Island
9. McKenzie Island	10. Clover Bay	11. Skin Island	12. Lancaster Cove
13. East Dora Bay	14. Wedge Island	15. Moria Sound	16. Whiterock Island

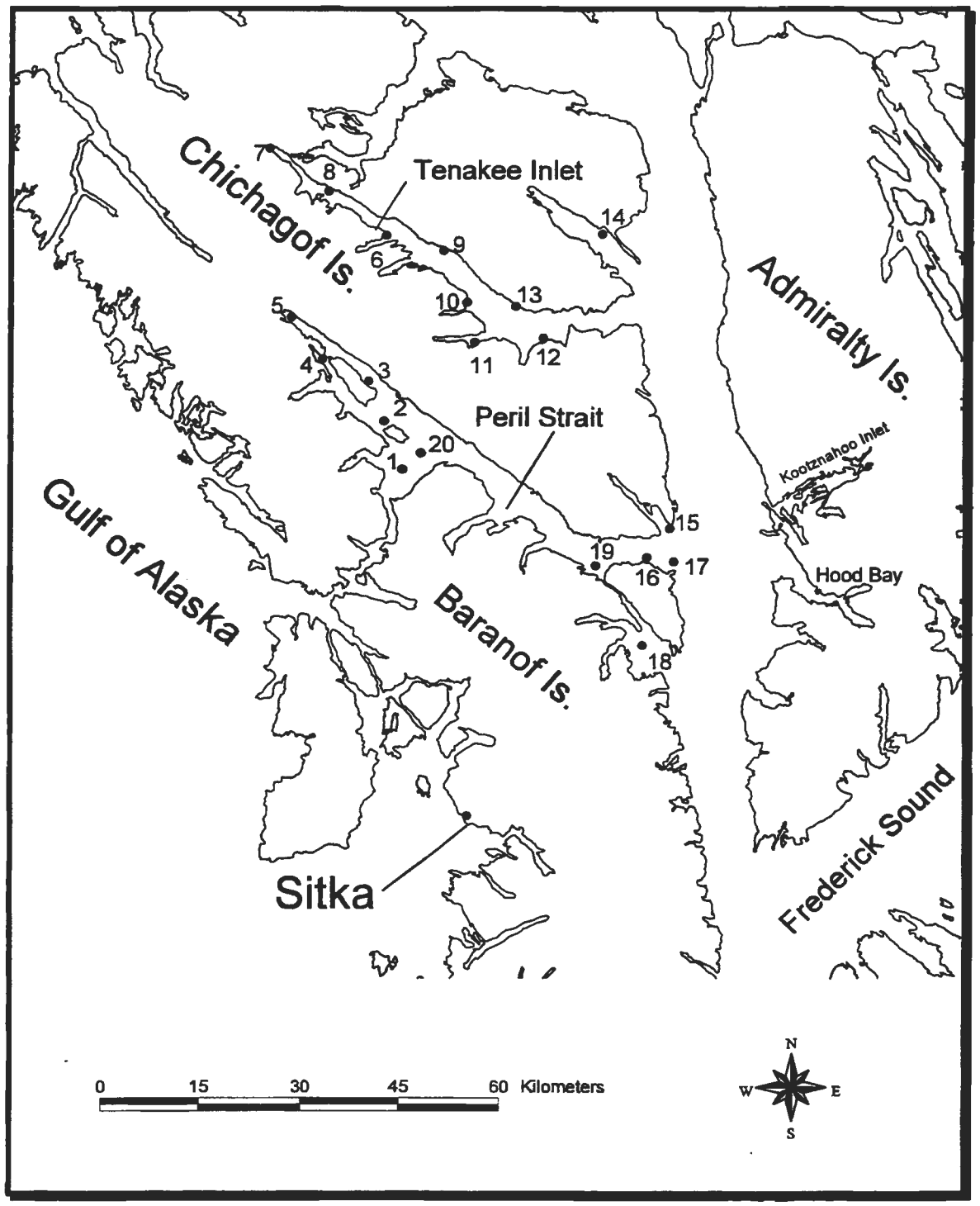

Figure 2. Trend count sites in the Sitka area of Southeast Alaska.

1. Hogatt Reef	2. Vixen Island	3. Moser Island N.	4. Southarm
5. Northarm	6. Long Bay	7. Head of Tenakee	8. Grassy Island
9. Mid Island Shoal	10. Saltry Bay	11. Crab Bay	12. Strawberry Rock
13. Tenakee Rock	14. Heidi Rock	15. Point Hayes	16. Traders
17. Midway Reef	18. Plover	19. Point Moses	20. Krugloi Island

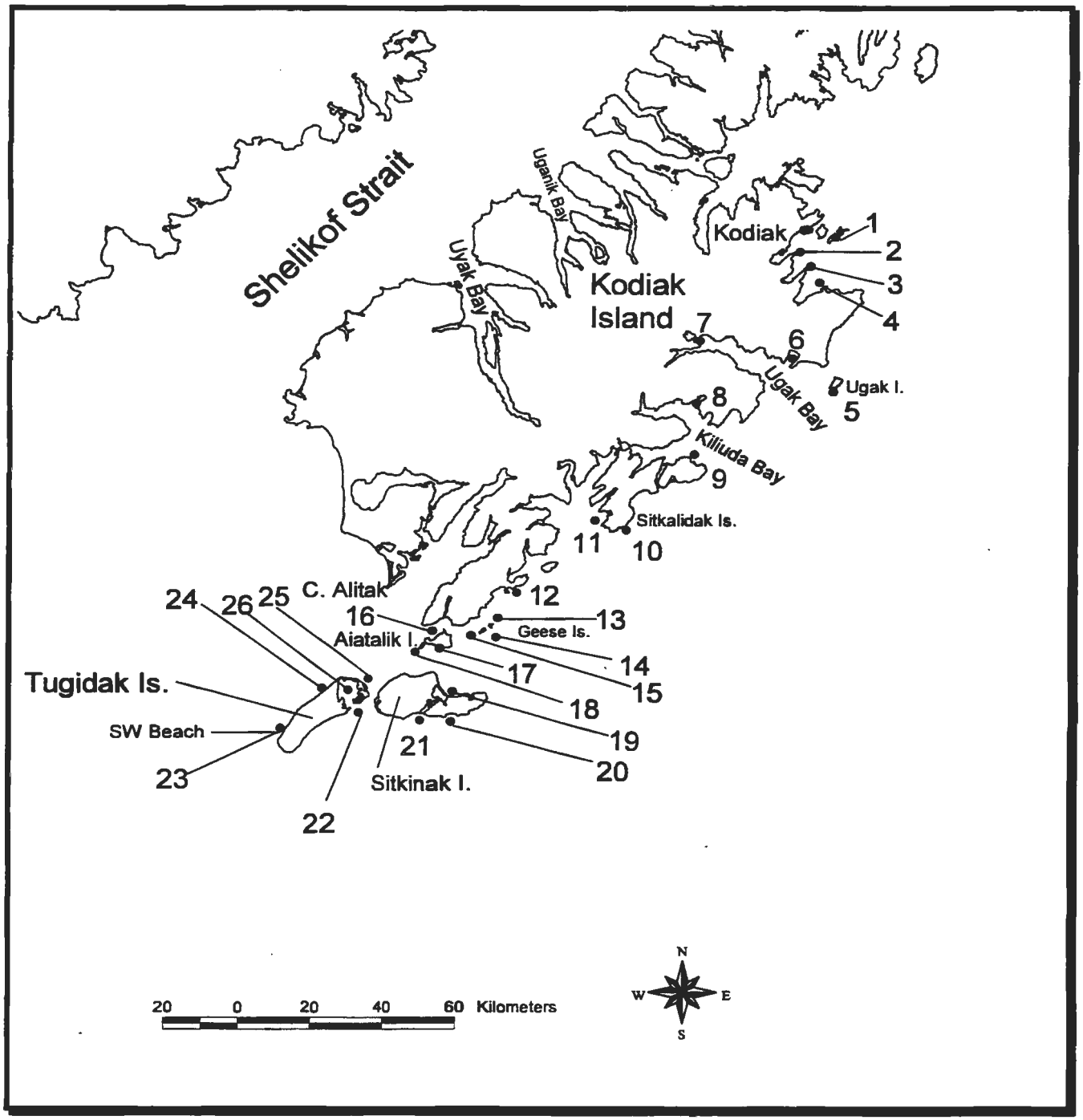

Figure 3. Trend Count Sites in the Kodiak Island area of Alaska

1. Long Island	2. Cliff Point	3. Broad Point	4. Kalsin Bay
5. Ugak Island	6. West Pasagshak	7. Upper Ugak Bay	8. Shearwater Bay
9. Barnabas Rocks	10. Black Point	11. Rolling Bay	12. Outer Kaguyak
13. Geese Island N	14. Geese Island SE	15. Geese Island SW	16. Aiaktalik Ledges
17. Aiaktalik Island	18. Sunstrom Island	19. Sitkinak Lag. N	20. Sitkinak SE
21. Sitkinak Lag. S	22. Tugidak Bars	23. SW Tugidak	24. Tugidak N
25. Tugidak NNE	26. Tugidak Lagoon (Inside)		

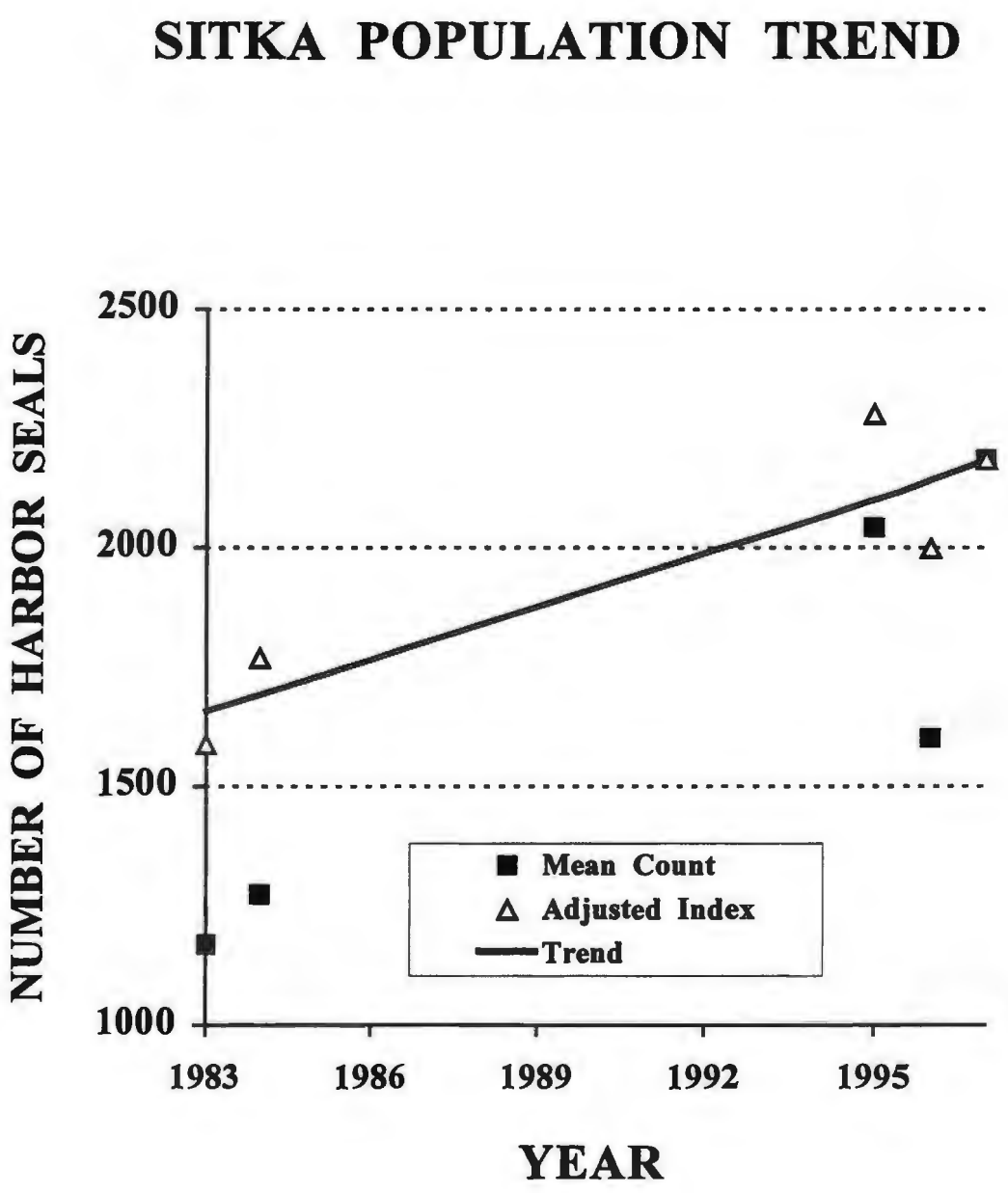

Figure 4. Estimated annual population trend of 2.0% for harbor seals in the Sitka area of Alaska, 1983-1997. See text for description of adjusted index.

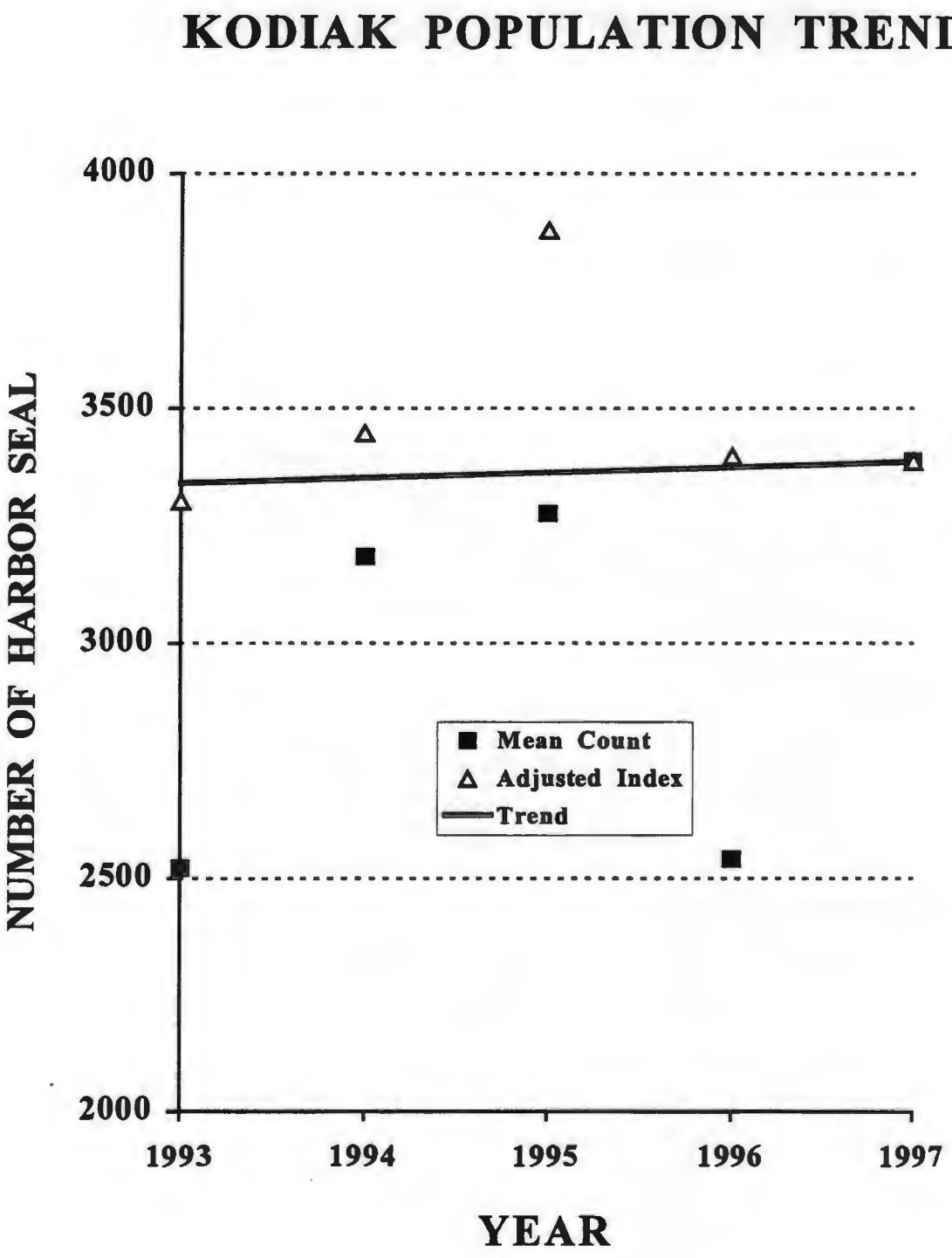

Figure 5. Estimated annual population trend of 0.3% for harbor seals in the Kodiak Island area of Alaska, 1993-1997. See text for description of adjusted index.

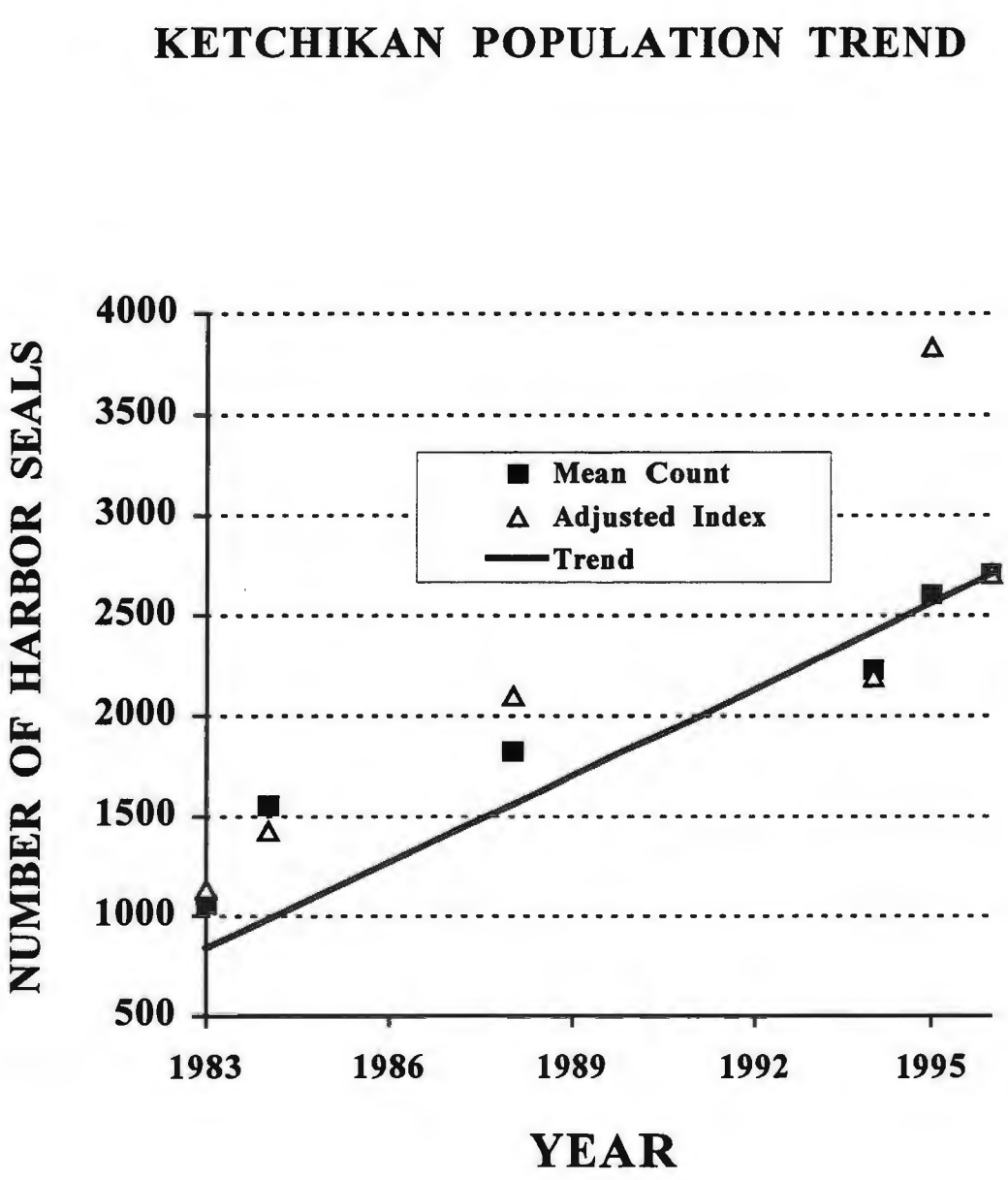

Figure 6. Estimated annual population trend of 9.4% for harbor seals in the Ketchikan area of Alaska, 1983-1996. See text for description of adjusted index.

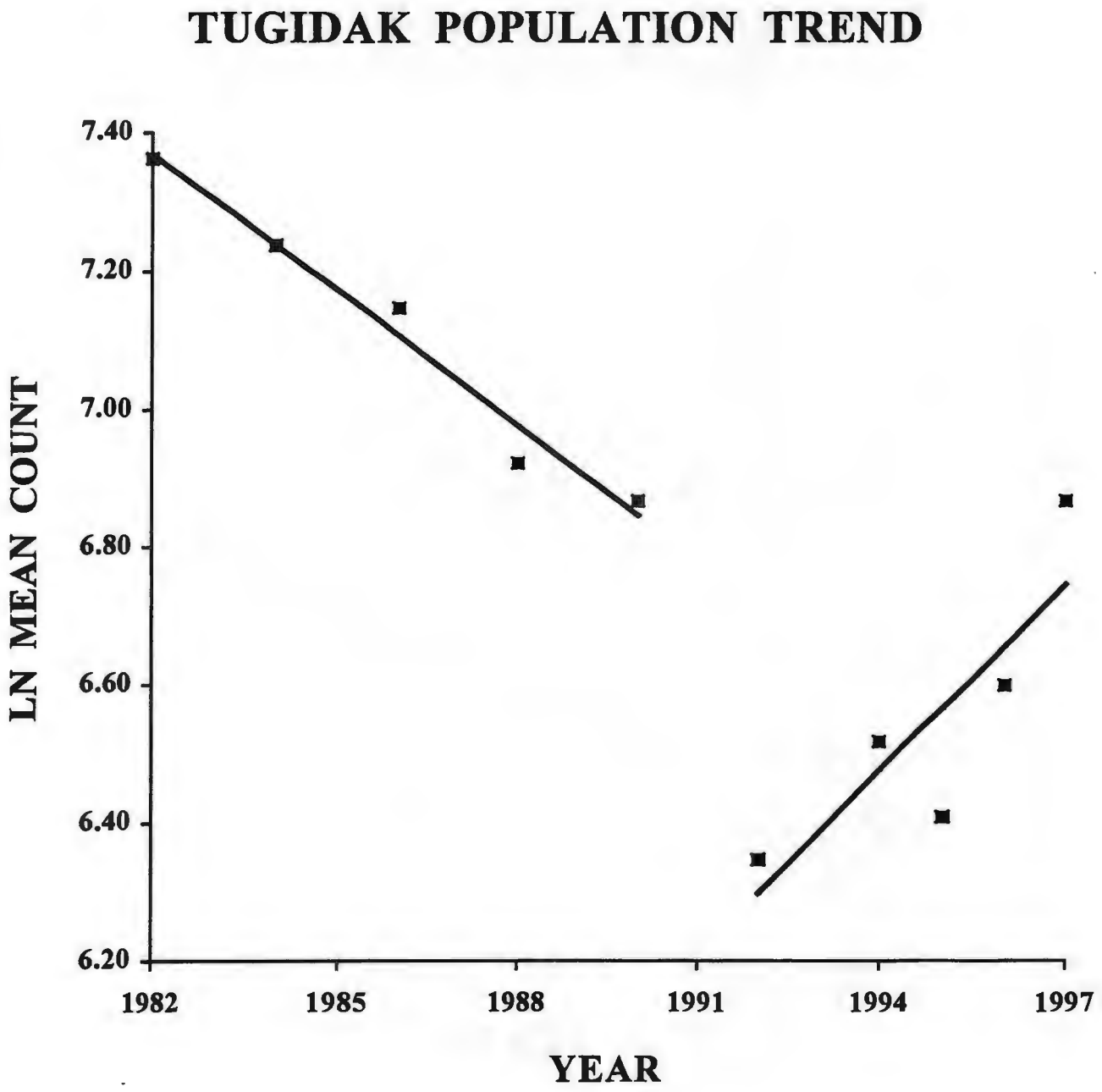

Figure 7. Linear regression of annual mean counts of harbor seals from 1982-1997 during the molting period on southwest beach of Tugidak Island, Gulf of Alaska.

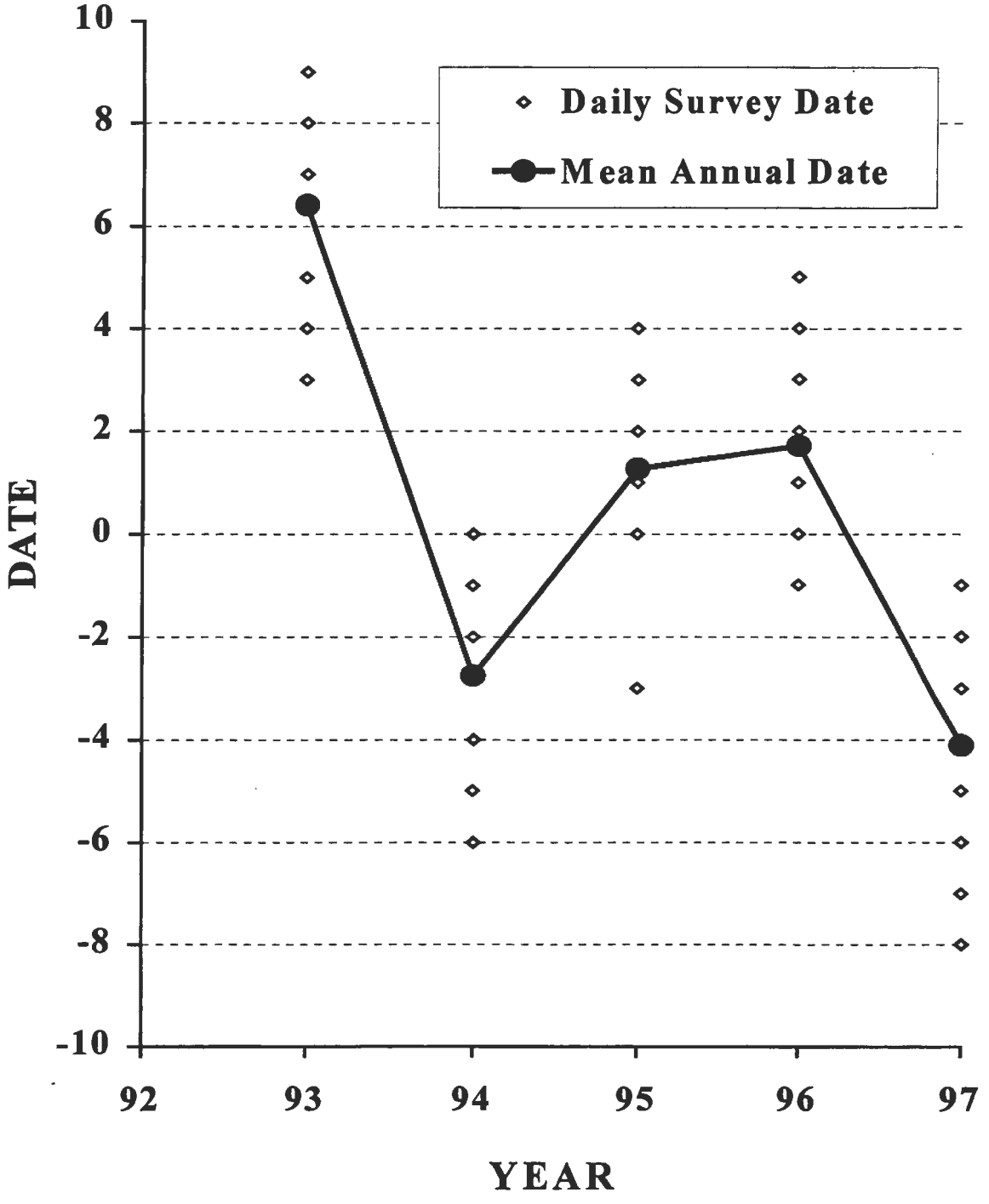

Figure 8. Mean annual survey dates for the Kodiak trend route during 1993-1997, based on daily trend survey dates relative to the overall mean date for the entire survey period.

Appendix I. 1997 harbor seal aerial survey counts from the Sitka area trend route.

Site#	Site Name	8/18	8/20	8/21	8/22	8/24	8/25	8/26
1	Hoggatt	238	173	114	121	96	105	49
2	Vixen	321	537	500	443	516	557	481
3	Moser Island N	77	26	29	12	10	19	29
4	Southarm	0	0	14	10	0	0	4
5	Northarm				48	71	88	
6	Long Bay	250	304		196	187	216	161
7	Head of Tenakee	185	169	108	57	126		122
8	Grassy	0	0	0	142	0	0	0
9	Mid Island S	34	42	17	15	15	19	40
10	Saltry Bay	0	0	0	0	0	0	0
11	Crab Bay	331	326	304	327	296	251	206
12	Strawberry Rock	6	8	36	34	40	26	29
13	Tenakee Rock	285	132	238	253	227	276	323
14	Heidi Rock[1]	238	328		388	25	215	149
15	Point Hayes		74	0	15	31	72	
16	Traders	28	39	45	30	37		13
17	Midway	101	125	51	28	14	63	56
18	Plover	168	191	107	120	62	166	196
19	Point Moses	27	0	0	0	0	0	1
20	Krugloi	61	0		58	0	0	0
21	East Cathrine Island		16		36	37	12	9

[1]Site #14 was previously named "Appletree" but changed to "Heidi Rock" in 1997 to conform with USGS maps and NOAA charts.

Appendix II. 1997 harbor seal aerial survey counts from the Kodiak area trend route.

Site#	Site Name	8/20	8/21	8/22	8/23	8/24	8/25	8/26	8/27
1	Long Island	68	72	36	20	26	40	57	33
2	Cliff Point	0		0	0	9	19	23	27
3	Broad Point	0		1	0	0	0	0	0
4	Kalsin Bay	110	57	123	106	129	127	99	101
5	Ugak Island	364	369	423			336	275	344
6	West Pasagshak	184	273	192	218	105	166	187	175
7	Upper Ugak Bay	20	71	52	89	88	0	48	0
8	Shearwater Bay	126	154	119	121	131	103	90	63
10	Black Point	136	139	173	122	123		142	105
11	Rolling Bay	25		9	21	15	61	56	49
12	Outer Kaguyak	16	14	5	6	8	5	3	4
13	Geese Island North		212	210	205	246	330	297	318
14	Geese Island Southeast		27	14	9	12	10	11	10
15	Geese Island Southwest		28	9	10	8	8	17	16
16	Aiaktalik L		23		22	10	18	18	0
17	Aiaktalik Island		138	78	71	110	127	131	78
18	Sunstrom Island		20	13	10	11	15	8	15
19	North Sitkinak Lagoon	102	87	88	102	135	102	113	111
20	Sitkinak Island SE			241	230	208	150	144	156
21	South Sitkinak Lagoon			169	167	182	187	140	188
22	Southeast Tugidak Lagoon			239	187	161	196	129	168
23	Southwest Tugdiak			601	566	546	495	498	826
24	North Tugidak (out)			0	0	0	0	0	0
25	NE Tugidak (out)			506	430	475	361	371	399
26	Tugidak Lagoon (in)			324	301	333	241	242	201
27	NNE Tugidak (out)			279	395	353	303	265	299
28	Upper Kiliuda		69	86	96	99	100	99	94
29	Womens Bay	65		59	31	52	52	30	
30	Chiniak Marker	0							
31	Gull Point Lagoon	0	0	24	51	39	17	0	63
32	I Kaguyak	15	13	8	9	6	19	17	15

Appendix III. 1997 land based counts of harbor seals on southwestern Tugidak Island.

Date	# Seals
1-Aug	968
3-Aug	1222
4-Aug	1135
6-Aug	1316
7-Aug	1312
9-Aug	1296
10-Aug	1283
12-Aug	1271
13-Aug	1275
15-Aug	1266
16-Aug	1202
17-Aug	930
18-Aug	531
19-Aug	485
20-Aug	781
22-Aug	627
23-Aug	543
24-Aug	595
25-Aug	695
26-Aug	825
27-Aug	890
28-Aug	871
29-Aug	1054
30-Aug	1050
31-Aug	1096
1-Sep	759
2-Sep	761
3-Sep	844

AERIAL SURVEYS OF HARBOR SEALS IN THE NORTHEAST GULF OF ALASKA, AUGUST 1997

Robert J. Small

Division of Wildlife Conservation
Alaska Department of Fish and Game
333 Raspberry Road, Anchorage, Alaska 99518

INTRODUCTION

Formal efforts to count harbor seals (*Phoca vitulina richardsi*) in Alaska began in the 1970s. Pitcher and Calkins (1979) compiled count information from a variety of sources and reported the maximum number of seals at numerous haulouts in the Gulf of Alaska. The most intensive study was begun by the Alaska Department of Fish and Game (ADF&G) on the southwestern beach of Tugidak Island (Pitcher 1990), with systematic counts made from atop 30m bluffs during the molting period during 1976-79, followed by biennially counts through 1992, and currently with annual counts that began in 1994. During the June pupping period of 1975-77, aerial surveys of the major haulout sites along the north side of the Alaska Peninsula were conducted by the National Marine Fisheries Service (NMFS) (Everitt and Braham 1980), and again in 1985 by ADF&G (Pitcher 1986). In 1983 ADF&G began monitoring harbor seal population trends using aerial surveys in the Ketchikan, Sitka, and Prince William Sound areas. These trend monitoring efforts expanded in 1993 when ADF&G received funding from NOAA to investigate why harbor seal numbers were declining in some areas of Alaska. In addition to continuing the surveys near Ketchikan and Sitka (PWS surveys were being conducted with Exxon Valdez oil spill funding), ADF&G established two new trend routes, one in the Kodiak Archipelago in 1993 and the second along a portion of the south side of the Alaska Peninsula, including the Semidi Islands and Chirikof Island, in 1995 (Lewis *et al.* 1996). In a separate effort that has been coordinated with ADF&G trend surveys, NMFS began census surveys in 1991 that are intended to produce estimates of the minimum size of the Alaska harbor seal population statewide (see Loughlin 1992, Loughlin 1993, Loughlin 1994).

One geographic area within the range of harbor seals in Alaska that has not been surveyed on a regular basis is the northeast Gulf of Alaska. This area may represent a transition zone between increasing or stable seal populations in Southeast Alaska and the Gulf of Alaska (including Prince William Sound and the Kodiak archipelago) where dramatic population declines have been observed since the mid 1980s (Pitcher 1990, Hoover-Miller 1994, Frost *et al.* 1998). One of the recommendations from a workshop on population assessment of Alaskan harbor seals held in November 1995 was to establish additional trend routes, with the area of highest priority the northeast Gulf of Alaska (Small 1995). Thus, in 1996 ADF&G contracted Beth Mathews of the National Park Service to conduct a population survey in the northeast Gulf, in the region from Icy Bay to Cross Sound and Icy Strait (Figure 1), and provide recommendations on a new trend route that would be surveyed in subsequent years. The results of the 1996 survey indicated approximately 36 haulout sites present in the survey area, which included both terrestrial and glacial ice sites

(Mathews and Womble 1997). A survey of the entire area could not be performed in one day with a single engine aircraft in 1996, so the recommendation was made to exclude sites south of Dry Bay, which represented approximately 24% of the seals counted; those sites could be surveyed with an additional survey crew based in Gustavus. Another survey recommendation was to use a twin engine aircraft that could potentially reach all terrestrial sites within the 4-hour period around the daily low-tide, and the glacial ice sites in Icy and Disenchantment bays (Mathews and Womble 1997).

The decision was made to use a twin engine aircraft in 1997 to (1) determine if the entire survey area from Icy Bay to Icy Strait could be flown in one day; (2) estimate seal numbers at sites within that area; and (3) make a revised recommendation for a population trend route for the northeast Gulf of Alaska.

METHODS

Although Mathews and Womble (1997) reported all haulout sites observed in 1996 within the northeast Gulf survey area, the entire coastline was searched the first two days of the 1997 ADF&G trend survey to look for additional haulouts, and to concur with NMFS rangewide survey protocol (see Loughlin 1994). The NMFS population census survey for 1997 took place in the northern portion of Southeast Alaska, and data from the 1997 ADF&G trend survey in the northeast Gulf were to be used in the NMFS population census for that region.

Surveys were conducted from 18 to26 August 1997, timed such that terrestrial sites were counted from 2 hours before to 2 hours after low tide; timing of counts of glacial ice sites varied from 1030 to 2000 hrs. On 18 August, the aircraft left Anchorage such that a survey from the Martin Islands south to Yakutat (Figure 1) could begin 2 hours before low tide. The area from the Martin Islands to Icy Bay was surveyed to provide NMFS with additional information about seal abundance and distribution, particularly between Cape Suckling and Icy Bay. On 19-20 August, the coastline from Yakutat south to Cross Sound was searched during the morning low tide to locate haulout sites. An ADF&G biologist acting as an observer on the NMFS population survey (U. Swain) searched the Cross Sound and Icy Strait area to locate haulouts during 16-18 August, and therefore the flightline during this survey was relatively direct from haulout to haulout in that area. In the afternoon of 19 August, the glacial ice sites in Disenchantment and Icy bays were surveyed, and the coastline from Yakutat northwest to the Martin Islands was searched for haulout sites. Thus, the entire area from the Martin Islands south to Icy Strait was searched entirely on at least two days. The glacial sites were flown in the afternoon after the terrestrial sites, except for the last day (26 August) when the sites in Disenchantment Bay were surveyed at about 1030 hrs, prior to the terrestrial sites. For the last five surveys (21-26 August), the flight route was direct from haulout to haulout, yet the area along the flightline was searched.

Surveys were flown in a twin engine AeroCommander Shrike, which has high-wings providing a safe and stable platform with excellent downward and lateral visibility. The typical flight plan was to leave Yakutat 2 hours before low tide, survey the sites near Yakutat, then survey the sites south along the coast and into Cross Sound and Icy Strait; average time for this segment of the survey was about 3 hours. The aircraft was refueled at Gustavus, and then flown north to survey Nunatak fiord, Disenchantment Bay, and then Icy Bay before returning to Yakutat. This second segment took an average of about 4 hours, for a total daily flight time of about 7 hours. Aircraft

speed could be maintained near 135 km/hr when tight circles were required to count and photograph seals, yet when traveling over extensive areas without haulout sites a higher cruising speed of 240 km/hr could be obtained. An altitude of ≥800 feet was maintained during surveys, with counts and photographs made from the front right seat; an additional observer (L. Lowry) counted seals from the back seat during the first four days and assisted the main observer (R. Small). When hauled out harbor seals were located the aircraft circled and the observer(s) counted all seals (including those in the water near haulouts), sometimes using 7 or 8 power binoculars, and then took 35mm color slide photographs (ASA 400) with a 80-200mm zoom lens; focusing was done manually. Seal numbers were later counted from slide images projected on a white surface. The location of each haulout site was recorded using the Global Positioning System (GPS) aboard the aircraft.

RESULTS

Harbor seals were observed at 43 individual haulout sites (Table 1). Nine sites were located between the Martin Islands and Cape Suckling, 5 sites were in Icy and Disenchantment bays, 15 sites were along the coast from Yakutat south to Cape Spencer (including 2 sites in Russell and Nunatak fiords), and 14 were in Cross Sound and Icy Strait (Figures 1 & 2). The coastline between Cape Suckling and Icy Bay was searched intensively, under ideal weather conditions, on 18-19 August but no seals were located. Haulout substrates used included sand beaches, rocky spits, tidal rocks, and glacial ice.

The main survey area from Icy Bay to Cross Sound was surveyed on 7 days (Table 2), with relatively complete coverage each day resulting in 6-7 replicate counts for most sites. Some additional sites were located in Cross Sound as the survey progressed, and thus only 2-5 replicate counts were conducted for those sites. The largest concentrations of seals (>500) were observed on the glacial ice of Icy (sites 10-12) and Disenchantment bays (sites 13 & 14), and the sandbars in Dry Bay (site 24) (Table 2). The mean count at all other sites was less than 100, except at Russell Fiord (site 16, count=108) and the NW side of Lemesurier Island (site 41, count=190). Based on the sum of mean counts, an average of 193 seals was counted between the Martin Islands and Cape Suckling, 2,378 in Icy and Disenchantment bays, 1,480 from Yakutat to Cape Spencer (including Russell and Nunatak fiords), and 589 in Cross Sound and Icy Strait. The total mean count for the route was 4,680 seals.

DISCUSSION

The 1997 mean count of harbor seals for the northeast Gulf of Alaska population survey was 52% larger than the 1996 count (3,079) and 93% larger than the 1993 count (2,422). However, the counts from these three surveys were not collected with the objective of estimating population trend, and are thus difficult to compare due to differences in sites surveyed and the number of replicate counts per site. In addition, factors such as date, time of day, and time from low tide which are known to significantly affect the number of seals hauled out (Frost *et al.* 1998, Small *et al.* 1998) have not been accounted for. Acknowledging these concerns, Mathews and Womble (1997) made a thorough comparison between their mid August 1996 survey and the mid September 1993 survey conducted by the NMFS, and suggested the 21% increase was perhaps due to the nearly 4 week

difference in survey date. The 52% increase in counts from 1996 to 1997 is less easily understood, as the survey dates were nearly identical and the number and location of haulout sites very similar. Population growth can not account for such an increase without substantial immigration, and there is no evidence for such movement in the survey area. The lack of any seals between Icy Bay and Cape Suckling further decreases the likelihood of a large number of immigrants.

The substantial variation in counts at the glacial sites in Icy and Disenchantment bays, during both 1996 and 1997, presents alternative explanations for the large increase in the 1997 count. Three of five replicate counts in 1996 for Icy Bay were > 1,000, with two remaining counts of 125 and 219 (Mathews and Womble 1997). In 1997, the first count for Icy Bay was 423 and all remaining counts were > 1,100; two counts were above 2,000. Another example of variation in counts from Icy Bay is the estimate of 1,864 seals obtained using strip transect methods on 14 August 1994 (Kozie and Route 1995), followed by a mean estimate of 3,253 from 3 surveys between 16and 21 August 1995 (Kozie *et al.* 1996). As these glacial sites represented 45-50% of the total mean count in 1996 and 1997, and 85% of the increase was at these sites, understanding what may influence the counts from glacial sites is critical.

The variation in counts from Icy Bay may represent actual differences in the number of seals hauled out due to either changes in the amount of ice suitable as a haulout substrate or the time of day surveys were conducted. Two-fold changes in counts at Johns Hopkins Inlet in Glacier Bay during mid-August surveys have been reported (Mathews 1995), and Mathews and Womble (1997) suggested the 5-fold variation in their 1996 Icy Bay counts was due to greater changes in substrate availability from storms and drifting ice production. Significant changes in the location and concentration of ice was observed in 1997 in both Icy and Disenchantment bays, yet the relationship between such changes and counts of harbor seals is unknown. On a smaller scale, however, the number of seals hauled out in Lituya Bay appeared directly related to the availability of ice in 1997. All seals observed in Lituya Bay were on small (3-10 m diameter) pieces of ice, and a maximal count of 127 was recorded on 21 August when numerous pieces of ice where in the bay. On 22 August strong winds and rain precluded a survey, and then on 23 August only eight seals were counted, all on the only small piece of ice in the bay. As for the time of day surveys are conducted, during both 1996 and 1997 survey time of the glacial sites varied considerably (~0900-1800 hrs), which was thought to be appropriate based on the finding of Calambokidis *et al.* (1983) who reported that the number of seals hauled out remained relatively stable from 0900 to 2100 hrs in Muir Inlet, Glacier Bay. There was no apparent relationship between time of day and the number of seals hauled at the glacial sites during either 1996 or 1997.

Regardless of whether the number of seals hauled at glacial sites is independent of tide and time of day, estimating the number of seals at glacial haulouts is problematic due to the large number of animals dispersed over a large area. Whereas counting smaller numbers of seals on terrestrial sites by photographing haulouts from a small airplane has been successful, this technique does not work well when much larger numbers of seals are spread out over a larger area. In contrast to terrestrial sites where all the seals can usually be included in 1-5 photographs, the larger glacial haulouts (e.g., Icy Bay, Hubbard Glacier) may require >50 photographs. There are two substantial problems in accurately estimating the number of seals hauled at glacial sites: (1) determining which seals remain to be photographed after censusing has begun; and (2) assessing the amount of overlap between the large number of photographs such that a photographic 'mosaic' can be constructed which includes all of the seals present.

Based on research in Icy Bay, Kern and McDonald (1994) and Kern (1996) recommended stratifying glacial sites into high and low density strata during a pre-survey stratification flight, followed by either census or sample surveys using strip transects. Their recommendation was to estimate the total number of seals per unit area of the different strata, and then obtain an estimate of the variance of the combined estimate. Alternatively, Mathews *et al.* (in preparation) used high-resolution, medium format aerial photography to estimate the abundance of harbor seals at glacial haulouts in Glacier Bay National Park in 1997. Four parallel transect lines were flown, with approximately 60% overlap between sequential images. This approach is an improvement over the standard method of taking photographs with a 35mm camera and zoom lens through a side window; still, creating the mosaic of photos such that an accurate count is obtained remains a substantial task. Another alternative is to use medium format aerial photography linked to a GPS such that a geographic benchmark is available with each image. The geo-spatial difficulty of creating the photographic mosaic becomes much less with such a system, which has been used successfully in censusing caribou populations (P. Valkenburg, *personal communication*). The relationship between ice cover and seal abundance should be examined such that ice cover could possibly be used as a covariate in explaining variation in counts.

The current technique of visual counts combined with 35 mm photography is an efficient and accurate means to estimate the number of harbor seals at terrestrial sites. The technique is inefficient with potential for considerable error for glacial sites with large numbers of seals. An alternative method of obtaining an accurate estimate of the number of harbor seals at such glacial sites, along with the variation of such estimates, is needed. Until such a method is developed, combining terrestrial and glacial sites within the same survey route should be discouraged. Thus, based on the abundance and distribution of seals observed in 1996 and 1997, two separate survey routes are proposed for the northeast Gulf of Alaska. The first would include the terrestrial sites from Yakutat south into Cross Sound, the second would include the glacial sites in Icy and Disenchantment bays that would be censused using alternative survey methodology. Surveys of glacial sites in a larger geographic area could be conducted if an alternative technique permits enough time for counts of additional sites in a single day. Surveying several glacial sites from mid morning to early evening assumes seals haul out independent of time of day or tide, an assumption that requires more thorough examination.

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Table 1. Locations and descriptions of harbor seal haulout sites surveyed in 1997 in the northeast Gulf of Alaska, from the Martin Islands southeast to Icy Strait.

Site	Location	GPS Coordinates		Site Description
1	Martin Islands	60°10.68′ N	144°33.44′ W	small rocks near shore E of Martin Islands
2	Wingham Island	60°04.68′ N	144°19.15′ W	sand spit N of Wingham Island
3	Kayak Island 1	59°54.91′ N	144°28.34′ W	small nearshore rocks SW of Kayak Island
4	Kayak Island 2	59°52.34′ N	144°33.53′ W	straight nearshore reef, SW of Kayak Island
5	Kayak Island 3	59°47.31′ N	144°34.01′ W	large reef attached to S tip of Kayak Island
6	Kayak Island 4	59°53.85′ N	144°24.51′ W	large rock offshore SE side of Kayak Island
7	Kayak Island 5	59°57.52′ N	144°14.64′ W	N end rocky reef offshore NE side of Kayak Island
8	Cape Suckling 1	59°59.27′ N	144°01.15′ W	rocks offshore S of Cape Suckling
9	Cape Suckling 2	59°59.07′ N	143°54.57′ W	reef nearshore at Cape Suckling
10	Tsaa Fiord (Icy Bay)	60°05.69′ N	141°31.76′ W	drift ice center of Tsaa fiord (Icy Bay)
11	Icy Bay NW	60°07.11′ N	141°28.27′ W	drift ice NW arm of bay
12	Icy Bay NE	60°08.07′ N	141°23.79′ W	drift ice NE arm of bay
13	Turner Glacier	59°59.30′ N	139°37.06′ W	drift ice near shore South of Turner face
14	Hubbard Glacier	60°01.48′ N	139°33.18′ W	drift ice W of main Hubbard Glacier face
15	Nunatak Fiord	59°48.16′ N	138°55.14′ W	S end of sand flats of glacial fan, E end of Nunatak Fiord
16	Russell Fiord	59°35.02′ N	139°18.96′ W	sandy beach on SW end of islet, S end of Russell Fiord
17	Kriwoi Isl.	59°37.63′ N	139°40.52′ W	rocks offshore NW side of Kriwoi Island
18	Otmeloi Island	59°38.75′ N	139°39.21′ W	small nearshore rocks W & NW of Otmeloi Island
19	Foxy Reef	59°39.91′ N	139°37.80′ W	N end of long low reef, E and SE of Krutoi Island
20	Krutoi Island	59°40.15′ N	139°38.88′ W	small nearshore rocks N of Krutoi Island
21	Knight Island Reef	59°42.84′ N	139°37.68′ W	SE section of large low reef, SW of Knight Island
22	Blacksand Spit	59°24.41′ N	139°28.49′ W	small sandbar in mid-channel SE of Blacksand spit

Table 1. Continued.

Site	Location	GPS Coordinates		Site Description
23	Dangerous River	59°22.62′ N	139°18.93′ W	sand flat in NW section of main bay draining Dangerous River
24	Dry Bay	59°09.40′ N	138°35.66′ W	sand bars in western side of middle Dry Bay
25	Lituya Bay	58°39.46′ N	137°29.86′ W	small pieces of drift ice near head of Lituya Bay
26	Astrolabe Rocks	58°20.40′ N	136°53.45′ W	large rocks off S tip of the Astolabe Peninsula
27	Venisa Point	58°17.83′ N	136°49.90′ W	offshore reefs south of Venisa Pt, NW of Libby Island
28	Graves Rocks	58°14.98′ N	136°44.70′ W	medium sized rock in SE area of Graves Rocks
29	Cape Spencer (South)	58°12.44′ N	136°40.07′ W	small nearshore rocks, S of Cape Spencer
30	Cape Spencer (E)	58°12.74′ N	136°36.74′ W	small nearshore rocks, E of Cape Spencer
31	Althorp Peninsula	58°08.15′ N	136°25.07′ W	N side of large rock, offshore (N) of Althorp Peninsula
32	Three Hill Island	58°10.38′ N	136°24.51′ W	rocky beach on NW side of cove between N & middle hill of 3 Hill Isl
33	Port Althorp Reef	58°10.06′ N	136°21.58′ W	small reef W of 3 Hill Island
34	Gaaf Rock	58°11.57′ N	136°25.51′ W	large offshore rock (Gaff Rock)
35	Inian Islands SW	58°14.83′ N	136°23.16′ W	nearshore rocks NW of Island NW of Pt. Lavinia
36	Inian Islands NW	58°15.28′ N	136°22.71′ W	rocks along SE edge of and S of western most Inian Island
37	Shaw Island	58°12.08′ N	136°13.98′ W	small rock on SE side of smaller Shaw Island
38	Quartz Point	58°13.32′ N	136°02.92′ W	2 low offshore reefs N & NW of Goose Island
39	Lemesurier Isl SE	58°16.11′ N	136°02.08′ W	reef at SE point of Lemesurier Island
40	Lemesurier Isl NE	58°18.64′ N	136°02.16′ W	long low reef S of NE point of Lemesurier Island
41	Lemesurier Isl NW	58°18.50′ N	136°07.11′ W	rocks on N side of small island, midway on NW Lemesurier Island
42	Dundas Bay N	58°23.98′ N	136°27.22′ W	rocks W of southern island near head of main Dundas Bay
43	Dundas Bay SW	58°21.16′ N	136°29.71′ W	SW Arm of Dundas Bay, rocks S of Island in middle

Table 2. Daily and mean counts of harbor seals at haulout sites surveyed from 18-26 August 1997 in the northeast Gulf of Alaska, from the Martin Islands to Icy Strait.

Site	Location	8/18	8/19	8/20	8/21	8/23	8/24	8/25	8/26	Mean
1	Martin Islands	5								5
2	Wingham Island	38	25							32
3	Kayak Island 1	3	6							5
4	Kayak Island 2	16	11							14
5	Kayak Island 3	18	20							19
6	Kayak Island 4	5	5							5
7	Kayak Island 5	93	67							80
8	Cape Suckling 1	35	27							31
9	Cape Suckling 2	4	0							2
10	Icy Bay (Tsaa Fiord)					15	16	86		39
11	Icy Bay NW	310	1225	2210	2501	1680	1140	1390		1494
12	Icy Bay NE	113	220	151	253	120	120	185		166
13	Turner Glacier		24	262	63	312	34	140	25	123
14	Hubbard Glacier		350	740	946	440	642	420	356	556
15	Nunatak Fiord			75	67	30	81	55	73	64
16	Russell Fiord		101	106	130	195	10	130	82	108
17	Kriwoi Isl.							12	2	7
18	Otmeloi Island		8	17	20	0	10	7	8	10
19	Foxy Reef		40	50	31	35	38	28	28	36
20	Krutoi Island		1	2	3	1	6	5	0	3
21	Knight Island Reef		9	6	30	14	16	19	18	16
22	Blacksand Spit		9	0	0	0	0	0		2

Table 2. Continued.

Site	Location	8/18	8/19	8/20	8/21	8/23	8/24	8/25	8/26	Mean
23	Dangerous River			64	60	23	109	104	70	72
24	Dry Bay		1008	724	1039	1122	1306	1082	1024	1044
25	Lituya Bay		27	35	127	8	31	42	38	44
26	Astrolabe Rocks		29	30	47	52	61	69	26	45
27	Venisa Point		2	0	1	0	0	0	0	0
28	Graves Rocks			31	44	22	37	38	20	32
29	Cape Spencer (South)		20	11	14	0	6	17	0	10
30	Cape Spencer (East)		12	23	4	21	37	38	0	19
31	Althorp Peninsula				33	18	41	22	8	24
32	Three Hill Island			18	38	33	33	11	13	24
33	Port Althorp Reef		5	43	36	45	34	40	47	36
34	Gaaf Rock		21	22	24	18	24	23	0	19
35	Inian Islands SW		26	91	100	50	100	75	76	74
36	Inian Islands NW		9	6	28	2	7	11	4	10
37	Shaw Island			11	20	0	0	0	0	5
38	Quartz Point			43	84	0	24	35	18	34
39	Lemesurier Isl SE		0	20	17	16	18	41	46	23
40	Lemesurier Isl NE		25	22	82	65	96	99	73	66
41	Lemesurier Isl NW		58	231	251	238	201	170	179	190
42	Dundas Bay N							25	23	24
43	Dundas Bay SW					35	27	26	24	28

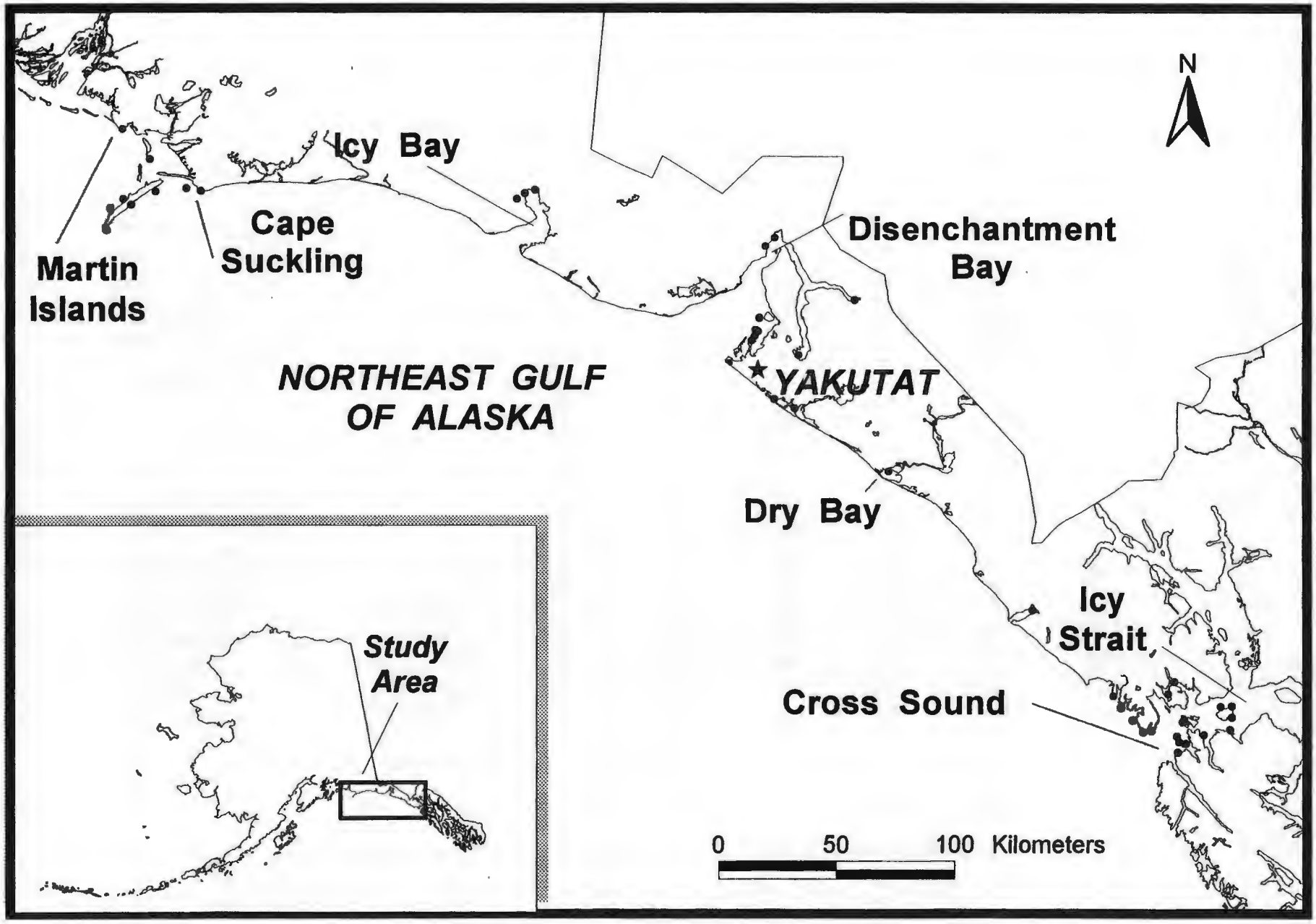
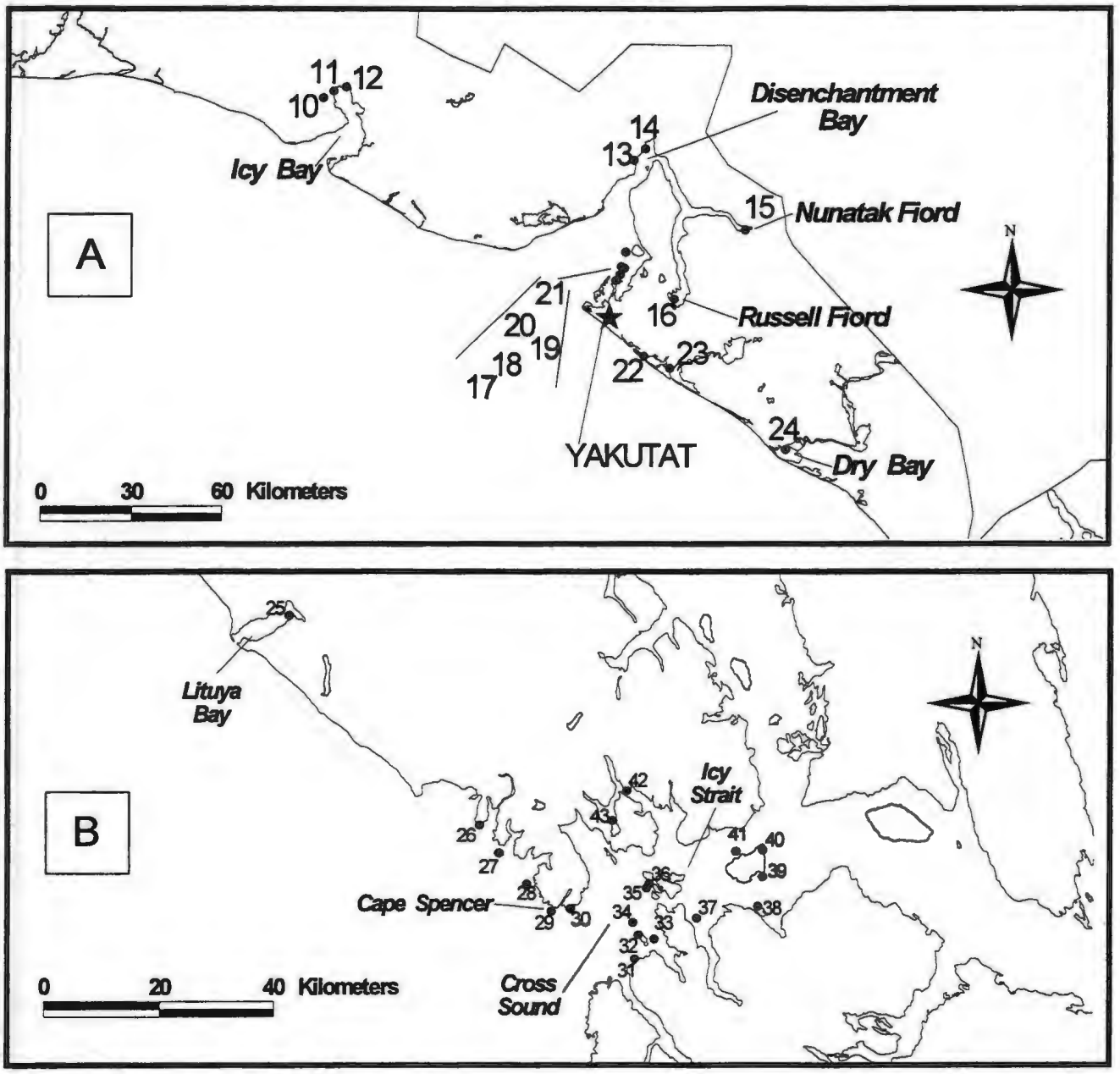


Figure 1. Harbor seal haulout sites from the 1997 harbor seal population survey conducted in the northeast Gulf of Alaska from the Martin Islands to Icy Strait.



10 Icy Bay NW
11 Icy Bay NE
12 Otmeloi Island
13 Krutoi Island
14 Foxy Reef
15 Knight Island Reef
16 Russell Fiord
17 Blacksand Spit
18 Dry Bay
19 Lituya Bay
20 Astrolabe Rocks
21 Venisa Point
22 Cape Spencer (East)
23 Port Althorp Reef
24 Gaaf Rock
25 Inian Islands SW
26 Lemesurier Isl NW
27 Hubbard Glacier
28 Turner Glacier
29 Dangerous River
30 Graves Rocks
31 Three Hill Island
32 Shaw Island
33 Quartz Point
34 Nunatak Fiord
35 Althorp Peninsula
36 Tsaa Fiord (Icy Bay)
37 Dundas Bay SW
38 Kriwoi Isl.
39 Dundas Bay N
40 Cape Spencer (South)
41 Inian Islands NW
42 Lemesurier Isl NE
43 Lemesurier Isl SE

Figure 2. Harbor seal haulout site locations and names for the northern (A: Icy Bay to Dry Bay) and southern (B: Lituya Bay to Icy Strait) areas of the northeast gulf of Alaska surveyed in August 1997. Sites 1-9 from Martin Island to Cape Suckling are not shown but listed in Table 1.

PUPPING AND MOLTING PHENOLOGY OF HARBOR SEALS ON TUGIDAK ISLAND, ALASKA

Lauri Jemison[1], Raychelle Daniel[2], Shannon Crowley[2], Grey Pendleton[1], and Brendan Kelly[2]

[1] Division of Wildlife Conservation
Alaska Department of Fish and Game
P.O. Box 240020, Douglas, Alaska 99824

[2]School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
11120 Glacier Highway, Juneau, Alaska 99801

INTRODUCTION

Tugidak Island, located 40 kilometers southwest of Kodiak Island in the western Gulf of Alaska (Figure 1), was a haulout site for an estimated 15,000-20,000 harbor seals (*Phoca vitulina richardsi*) during the late 1950s through the mid 1960s (Mathisen and Lopp 1963, Pitcher 1990). Counts of seals on the southwestern shores of the island, which have been used as an index of the Tugidak Island population, document a 72% - 85% decline in the number of seals between 1976 and 1988 (Pitcher 1990). Since 1992, numbers appear to be increasing at an annual rate of 8.9% (Small *et al.* 1998). Whereas counts of overall numbers of harbor seals have been essential in identifying the population decline, an increased understanding of the decline may be gained by examining pupping phenology and demography of the seals on shore (Jemison and Kelly 1997). Changes in the demographic structure of the population or the timing of pupping may change the timing of molting. During molting, the period when old, worn hair is shed as new hair emerges, seals haul out more frequently and for longer periods (Stewart and Yochem 1984, Calambokidis *et al.* 1987, Thompson *et al.* 1989, Watts 1996). Changes in the molting period should also be considered in the timing of aerial surveys that are used to track population trends and estimate abundance.

In 1997, we continued to collect pupping phenology, demographic, and count data which have been collected every year since 1994 and sporadically since the mid 1970s (Pitcher 1990, Jemison and Kelly 1997). A primary focus of this year's work was to collect data on stages of the molt progression for each sex/age class, and examine how molting phenology relates to changes in the number of seals on shore. We report our findings on pupping and molting phenology, how the timing of molting relates to the number of seals on shore, and discuss management implications.

METHODS

Harbor seals on Southwest and Middle beaches along the southern and western shores of Tugidak Island (56°30'N, 154°40'W) were surveyed from 12 May – 3 September. We used spotting scopes (15 - 60x) and binoculars (10 x 25) from atop 30 meter bluffs to observe seals.

We categorized seals according to sex and age class throughout the summer. Sex was determined by the location of genitalia when the ventrum was visible or by association of a mother and pup. When sex could not be ascertained, the sex was recorded as unknown. We classified seals as either pups, yearlings, subadults, or adults. Pups were easily identified by their small size, new pelage, and association with their mother. Unattended pups that were either starvelings or appeared too young to be weaned were recorded as lone pups. Yearlings were defined as the smallest size class excluding pups, which during the pupping and weaning periods typically had a muddy or bleached pelage and lacked obvious spots and rings. By the time most yearlings had molted (early to mid August), we were able to distinguish between pups and yearlings by the increasingly worn and faded appearance of the pups' pelage. When pups or yearlings were wet, however, we had difficulty distinguishing between these age classes and recorded these seals as unknown (pup or yearling). The division of subadults and adults was somewhat subjective; we used a combination of relative size of the seal, presence of fresh wounds or scarring in the neck region, and comparison with seals of known age as criteria to separate the two age classes. For example, we classified a female as a subadult if she was smaller than the smallest females attending pups yet larger than yearlings. Smaller males with little or no scarring or bloody wounds in the neck region were also classified as subadults (Thompson and Rothery 1987). Several seals known to be young adults based on sightings in previous years were used to compare relative sizes. While there was likely some overlap in sizes between subadults and adults, data were collected consistently by the same observers throughout the summer. The subadult and adult categories can be lumped into an "older" category for comparisons with data collected in previous years (Jemison and Kelly 1997).

We collected data on the progression of the molt in 22 sessions from 8 July through 1 September. The molting period was broadly divided into three categories: (1) pre-molt, old hair is still present with no visible hair loss or new hair growth; (2) active molt, old hair is being shed and new hair is visible; and (3) post-molt, all old hair has been shed and the seal has a completely new pelage. Pre-molt is divided into three stages (a – c), based on the amount of bleaching that has occurred. Bleaching presumably occurs when the sebaceous glands cease to produce protective oils (Ling 1970), resulting in the hairs becoming faded and dull in appearance. Only stages b and c were used in analyses of the pre-molt data. Active molt, also divided into three stages (d - f), is based on the amount of shedding hair and new hair that is visible. It is important to note that the erupting (new) hair pushes the old hair out of the shared follicle and the new hair is immediately visible.

Molt categories

Pre-molt

Stage a: No / very slight bleaching of hair

Stage b: Hair bleaching – spots and rings become indistinct; pelage beginning to take on a uniform color, typically either tan/beige or muddy brown

Stage c: Hair completely bleached with few spots and rings visible; pelage a uniform, dull color

Active molt

Stage d: Includes any signs of new hair growth up to about 25% new hair; hair loss primarily on and under flippers, urogenital area, head, and scarred areas; hair loss beginning on the mid ventral and ventral neck region; new hair occurs in isolated patches

Stage e: About 50% new hair growth; hair loss begins on dorsal neck region; flippers usually molted; primarily new hair on ventral anterior half; large areas of new hair growth begin to connect

Stage f: Approximately 75% new hair growth, but includes any seals with the presence of small patches of old hair; old hair is primarily present in isolated patches on the dorsum and sides of body

Post-molt

Stage g: Seal completely molted; no old hair visible, new pelage is bright and shiny; spots and rings very distinct

Statistical Analyses

Comparison of molt timing among sex/age classes:

We compared the timing of the molt among yearlings, subadults, adult females, and adult males using randomization (Manly 1991). For each of the 22 days sampled, we calculated the proportion of seals in each sex/age class in the categories pre-molt (stages b and c), active molt (stages d, e, and f), and post-molt (stage g). For example, the proportion of yearlings in the active molt would equal the total number of yearlings in molt stage d+e+f divided by the total number of yearlings for that day. The statistic, C, for comparing similarity between any 2 molt curves was

$$C = \sum_i | p_{1i} - p_{2i} |$$

where i represents the sample day, p_1 is the proportion in a molt category for group 1 (e.g., yearlings) and p_2 is the proportion in the same molt category for group 2 (e.g., subadults). To determine whether an observed C for any comparison was larger than expected by chance, we compared the result to a randomization distribution; i.e., we randomly assigned the seals to the 2 groups being compared, maintaining the group totals for each day. We then computed the proportion in the molt category of interest and computed C. This procedure was repeated 9999 times. The probability of getting C larger than the observed C was calculated by placing the observed C in its rank order among the C's from the randomized samples. We rejected the hypothesis of no difference in molt curves for large values of C relative to the randomization distribution (i.e., observed C in upper 5% of the randomization distribution).

We computed similarity values for all pairs of curves within a molt category as the observed C divided by the average of the minimum and maximum C's based on randomization. The pairwise similarities were then used in a complete linkage cluster analysis (Romesburg 1984) to produce dendrograms of similarity in molt sequence.

Prediction of abundance based on molt:

We used linear regression to investigate the relationship between the proportion of seals within the various molt stages and sex/age class abundance. For each sex/age class, the proportion in each molt stage (b-g) was computed. These proportions were used as explanatory variables in predicting the abundance of seals. Abundance was the total number of seals counted in a sex/age class on each day including those not assigned to a molt stage. In using the total we assumed that the unclassified seals had the same distribution among the molt stages as those that were classified. Variables (i.e., proportions) were added to the regression one at a time based on the p-value. The variable with the smallest p-value was added first, followed by the variable that had the greatest

contribution to the regression given that the first variable was already in the model. This continued until no additional variables improved the model ($p<0.05$). The proportions used as predictor variables are correlated among themselves so there could be other combinations of variables that produce models that fit almost as well as our final models. This does not invalidate the usefulness of our models for prediction; however, caution should be used in interpreting the models.

We also investigated molt diversity as a predictor of seal abundance. We used Shannon's diversity index as a measure of the variability in the molt sequence within a sex/age class. The index increases when more molt stages are observed and when seals are more evenly distributed among the molt stages; diversity is 0 when only 1 stage is observed. Shannon's index is computed as

$$H = \sum_{i=1}^{n} p_i * \ln(p_i)$$

where n is the number of molt stages and p_i is the proportion of individuals in the i^{th} stage.

We used linear regression in a similar way to predict the total number of seals (all sex/age classes combined) hauled out. However in this combined analysis, we used proportions calculated by grouping molt stages into larger categories (i.e., premolt [b,c], molt [d,e,f], post molt [g]) as explanatory variables.

RESULTS

Population Counts

Surveys were conducted simultaneously at Southwest and Middle beaches on 67 days throughout the summer; the Middle Beach haulout was abandoned on 20 August. In general, the number of seals on shore increased from mid May until the maximal count during the pupping period of 1,124. The number of seals then decreased to a low during the first week of July when pups were being weaned and mating was likely occurring. In mid July the population began increasing; the maximal count during the molting period was 1,316 on 6 August (Figure 2).

Pupping Phenology and Demographics

The first pups were seen on 13 May, the number increasing until the maximal count of 280 on 13 June. On 11 June we counted 276 pups on shore and at least 20 mother-pup pairs in the water. We consider 11 June to be the date of the maximal pup count since a low-flying aircraft disturbed seals just prior to our count and some of the mother-pup pairs in the water had likely been hauled out before the plane disturbance.

During the maximal counts associated with pupping and molting, the proportions of each sex/age class on shore were similar (Figure 3). The largest proportion of adult females (74%) occurred on 9 June whereas the largest proportion of adult males occurred on 27 August and 1 September (53% both days). The two days when the largest proportions of immature seals (yearlings and subadults combined) hauled out were 28 May and 19 July (40% and 30%, respectively) (Figure 4).

Molt

Comparison of molt timing among sex/age classes

All curves for the pre-molt and active molt periods were different from each other ($p<0.0001$; Figures 5 & 6). During the post-molt, the patterns for yearlings and subadults did not differ ($p=0.114$) whereas all other comparisons indicated differences ($p<0.0001$; Figure 7). The molt patterns for the sex/age classes indicate that yearlings begin the molt sequence prior to the other classes, followed by subadults, adult females, and adult males. The post-molt analysis shows that subadults completed the molt at the same time as yearlings indicating that yearlings take longer to molt or are less synchronous than subadults. Alternately, the inability to distinguish some molted yearlings from pups (due to wet pelage) may have resulted in fewer yearlings being included in the post-molt category. The absence of these individuals in the post-molt category may result in delaying the molt completion date for yearlings.

The patterns of yearlings and subadults are more similar to each other than to adults for all molt stages (Figures 8-10). Adult females had patterns most similar to adult males for entering pre-molt but were more similar to yearlings and subadults for later molt stages. Adult males have generally different molt timing than other classes, as they begin the pre-molt later than other classes and also have molts of longer duration, or less synchrony among individuals. Ninety percent or more of the yearlings, subadults, and adult females have completed the molt by the beginning of September, while only about 30% of adult males have completed the molt by this date (Figures 11-14).

Prediction of abundance based on molt

The abundance of seals in each sex/age class was most strongly associated with the proportion of that class in one of the first two stages of the active molt (d, e) (Table 1). The regression equations accounted for the most variation for yearlings and the least for adult females. Molt diversity was positively related to abundance for all sex/age classes (Figure 15), but explained less of the variation in abundance for yearlings and subadults than the molt class proportions (Table 1). Molt diversity followed a pattern similar to abundance, including sex/age class-related characteristics such as adult males maintaining a high diversity into September (Figure 16).

DISCUSSION

Molt progression

The general shedding pattern we observed was similar to patterns described by Stutz (1967), Ashwell-Erickson *et al.* (1986), and Moss (1992). Shedding began on the face, neck, ventral midline, flippers, and body openings (anus, urogenital). Additionally, we noticed that shedding first began in areas of scarred tissue (including the navel). Shedding then progressed over the ventrum and finally onto the dorsum. Molting yearlings and subadults followed this pattern most closely while older seals exhibited greater individual variation in molt patterns.

Seals haul out more frequently and for longer periods during shedding and new hair growth (Stewart and Yochem 1984, Calambokidis *et al.* 1987, Thompson *et al.* 1989, Watts 1996) presumably because warmer temperatures on land allow skin temperatures to be elevated, expediting hair growth (Feltz and Fay 1966). Since the period of hair loss and regeneration may last several (4-

8) weeks (Ashwell-Erickson *et al.* 1986), it would be valuable to know when during that period seals are more likely to increase the amount of time they spend ashore. Our data show that increased seal abundance for each sex/age class is most closely tied to the first two stages of the active molt. Ashwell-Erickson *et al.* (1986) found that resting metabolic rate (RMR) in harbor and spotted seals declined during the beginning stages of shedding and new hair growth. They suggested that the decrease in RMR may help regulate the molt by reducing energy requirements, thus allowing seals to spend more time on shore resting and less time at sea foraging, without a large loss in fat reserves. While Thompson *et al.* (1989) found a marked increase in the amount of time males spent on shore immediately before the molting period, they did not find a similar pattern in females prior to the molt. In a study on molting seals in Scotland, Thompson and Rothery (1987) found that yearlings molted first, followed by females, immature males, and finally adult males. Although this sequence is somewhat different than what we found, it is not directly comparable as subadult and adult females were grouped together in their study while we grouped male and female subadults and kept adults separate.

Pupping and molting phenology

The timing of pupping in 1997 was nearly identical to the previous three years (Table 2). The onset of pupping and the date of the maximal pup count occurred 1–3 weeks earlier in 1964 and the mid 1990s than in the mid to late 1970s (Jemison and Kelly 1997). A shift in the timing of pupping may result in a corresponding shift in the timing of the molting period. Since standardized data collection began on Tugidak in the mid 1970s, only during 1976 and 1997 were data collected from early May through early to mid September; thus, these are the only two years for which we can determine whether there was a shift in both pupping and molting periods. Pupping occurred 11-19 days earlier in 1997 than 1976 (Jemison and Kelly 1997); interestingly, the peak count during the molting period occurred 25 days earlier in 1997 than in 1976 (6 August and 31 August, respectively), suggesting that a shift in the pupping period may be followed by a shift in the molting period. Further support of a shift in the molting period between these decades is evident by comparing our data on the molt with two days when Johnson (1976) recorded the percentage of seals that had completed the molt. On 1 September 1997, a higher percentage of seals on shore had completed the molt than in late September of 1976 (Table 3).

Jemison and Kelly (1997) suggest that differences in the timing of pupping in the 1970s and 1990s may be due to temporal changes in food availability or a reduction in available food. Because timing of the molt varies with sex and age, differences in the sex/age structure of the population could also influence the timing of the molt, although it is unlikely that this caused the observed shift in the pupping period (Jemison and Kelly 1997). Enough data exist to show a shift in the timing of pupping between the 1970s and 1990s (Jemison and Kelly 1997). Our molt data, however, raise questions as to whether the observed shift in the molting period occurred abruptly or gradually over a number of years. These data highlight the need to collect data of this nature over several field seasons to determine whether the timing of molt among the sex/age classes remains constant or varies considerably from year to year.

Differences between the 1970s and 1990s can also be seen when comparing the maximal counts during the pupping and molting period. The molting peaks in both 1976 and 1997 were higher than the corresponding peaks in numbers during the pupping period. The 1997 molting peak, however, was only slightly larger than its corresponding pupping peak, while the molting peak in 1976 was nearly three times as large as the pupping peak in that year. These differences may be

related to changes in haulout behavior and/or the sex/age structure of the population (Jemison and Kelly 1997). We were surprised to find that the proportion of each sex/age class on shore during the maximal counts associated with pupping and molting were very similar; composition data of this sort were not collected in 1976.

Relevance to population monitoring

In Alaska, population trends and abundance are estimated through aerial surveys; these surveys are conducted during mid to late August, when the largest numbers of seals are assumed to be hauled out during a peak in the molting period. The precise timing of molting, however, is not well known throughout Alaska and may vary among regions. Abundance surveys not conducted at a similar stage of the molt among regions may not be directly comparable. Similarly, a shift in the molting period over time would confound comparisons of abundance estimates, and increase the variation associated with trend estimates.

We found that the timing of the molt varies by sex and age class and that the peak count for each sex/age class corresponds to the early stages of the active molt. Differences in the molting period among sex/age classes should be considered in determining optimal survey periods. For example, if the number of yearling or subadults hauled out decreases substantially when the maximal number of adults are hauled out in mid to late August, an aerial survey during that period may not fully detect decreased survival in the younger cohorts. Population growth is most sensitive to changes in survival of the youngest cohorts (pups to 5 year olds) (Frost *et al.* 1996).

Trend analyses of aerial counts of seals have found that certain environmental variables significantly affect counts (e.g., date, time of day, time relative to low tide) (Frost *et al.* 1998, Small *et al.* 1998). Incorporating these covariates in the analysis reduces the variation in the trend estimate. Inclusion of variables, such as date, will indirectly take into account fluctuations in seal numbers related to differential timing of the molt. Land-based studies conducted during the molt period at trend sites in different regions of the state, combined with trend analyses which account for the impacts of various covariates should help better define our survey window and interpret any observed changes in seal abundance.

ACKNOWLEDGMENTS

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Table 1. Molt stage proportions retained in linear regression that were positively related to the abundance of harbor seals in different sex and age classes on Tugidak Island, Alaska, 1997.

Age/Sex Class	Molt Stage Proportions[a]	Coefficient (p)	R^2 - proportions	R^2 – diversity
Yearling	c	46.7 (<0.001)	0.805	0.513
	d	105.8 (<0.001)		
	f	68.2 (0.012)		
Subadult	d	122.4 (0.026)	0.695	0.458
	e	610.8 (<0.001)		
Adult Female	d	915.9 (0.002)	0.357	0.393
Adult Male	e	1180.5 (0.001)	0.457	0.440
Combined	cM[b]	2442.2 (0.026)	0.908	
	fY	1577.4 (<0.001)		
	gM	1399.3 (<0.001)		
	dY	555.7 (0.006)		

[a]Molt stages in the pre-molt (a,b,c), active molt (d,e,f), and post-molt (g) are defined in text.
[b]cM denotes the proportion of adult males in molt stage c; proportions ending in Y are proportions of yearlings.

Table 2. Harbor seal pupping phenology on Tugidak Island, Alaska.

Year	Onset (> 1 attended pup)	Date of maximal pup count	Source
1976	1 June	22 June	Johnson 1976
1994		11 June	Jemison and Kelly 1997
1995		11 June	Jemison and Kelly 1997
1996	13 May	12 June	Jemison and Kelly 1997
1997	13 May	11 June [a]	This study

[a] Disturbance prior to count; estimated to be date of maximal pup count based on ground count plus pups counted in water just off shore.

Table 3. Percentage of harbor seals that completed the molt, Tugidak Island, Alaska.

Date	% total molted seals	% molted adults	% molted immature [c]
10 August 1976 [a]	9	1	30
10 August 1997	15	7	45
Late September 1976 [a]	49	44	63
1 September 1997 [b]	64	60	96

[a] Source: Johnson 1976
[b] Last day that molt data were collected in 1997
[c] Includes both subadults and yearlings

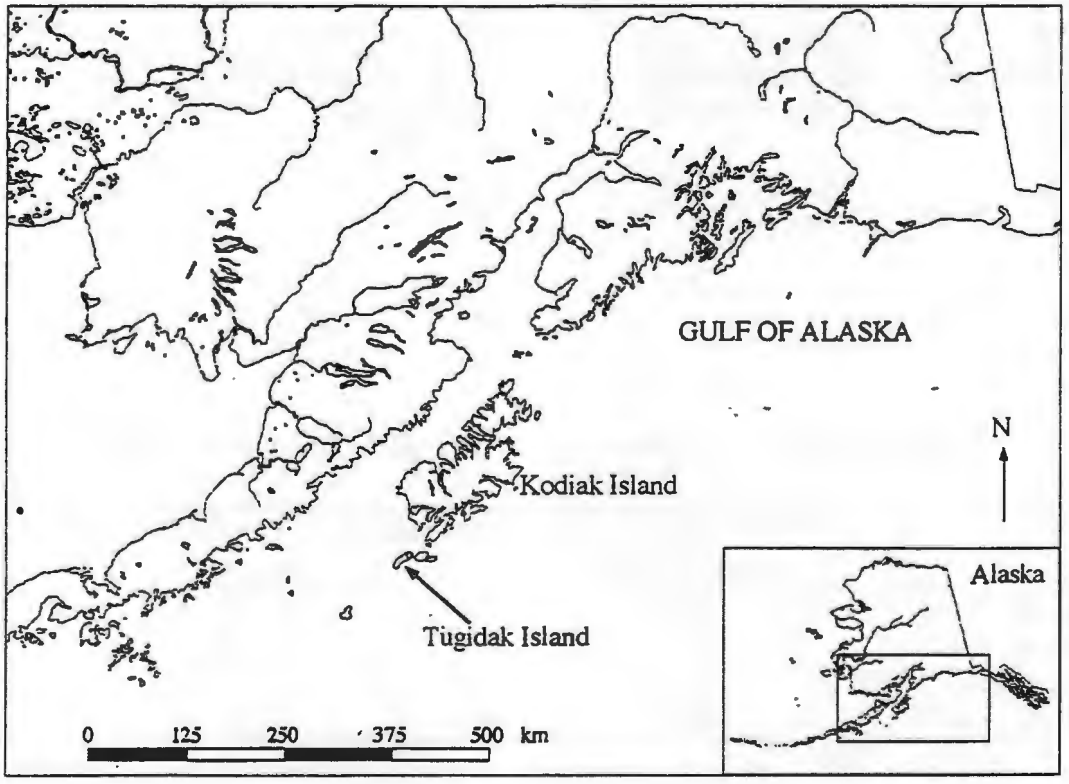


Figure 1. Location of Tugidak Island, Alaska.

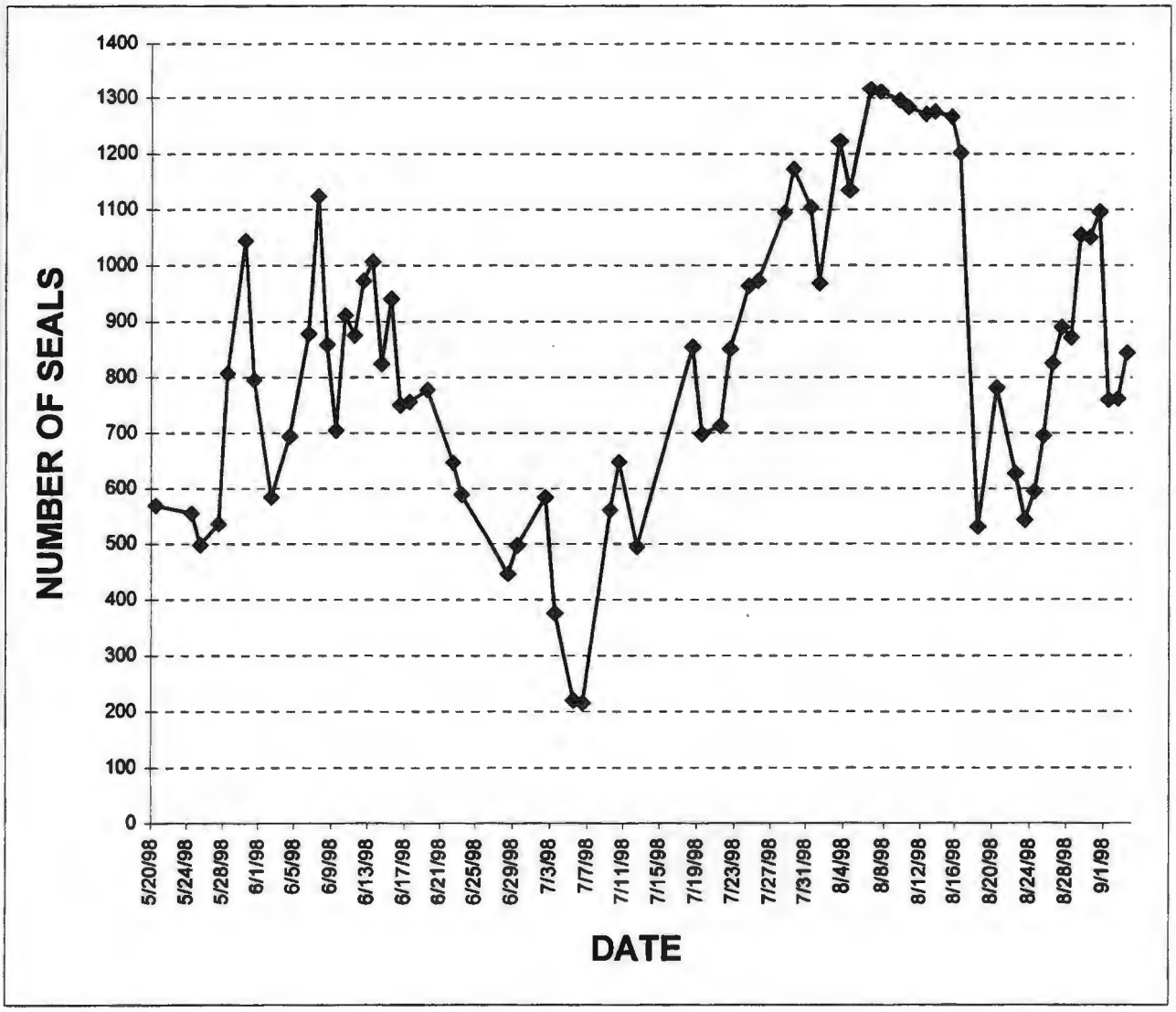
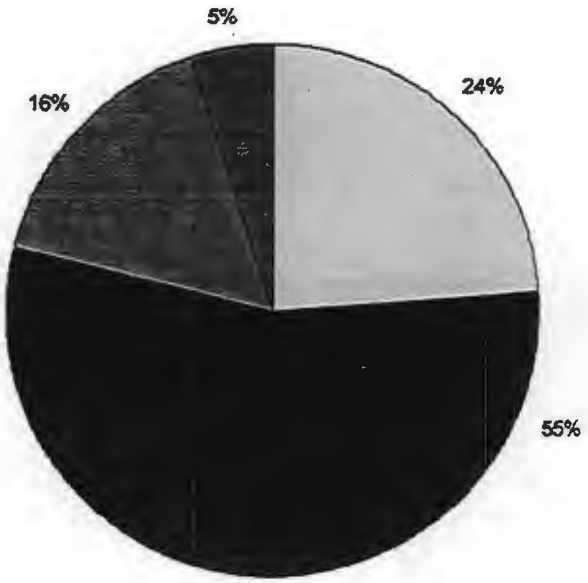


Figure 2. Harbor seal counts on the southern and western shores of Tugidak Island, Alaska, May-September 1997.

PUPPING



MOLTING

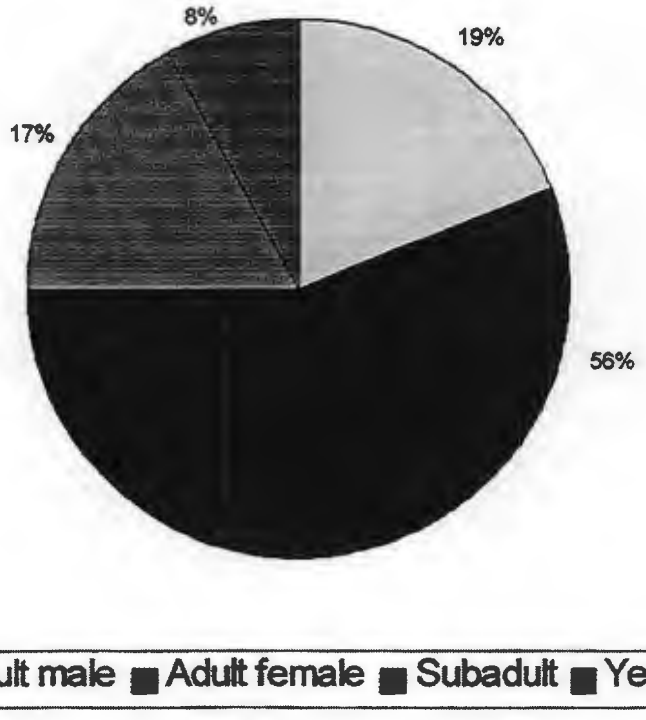


Figure 3. Proportion of harbor seals in each sex/age class on the date of maximal counts during pupping and molting, Tugidak Island, Alaska.

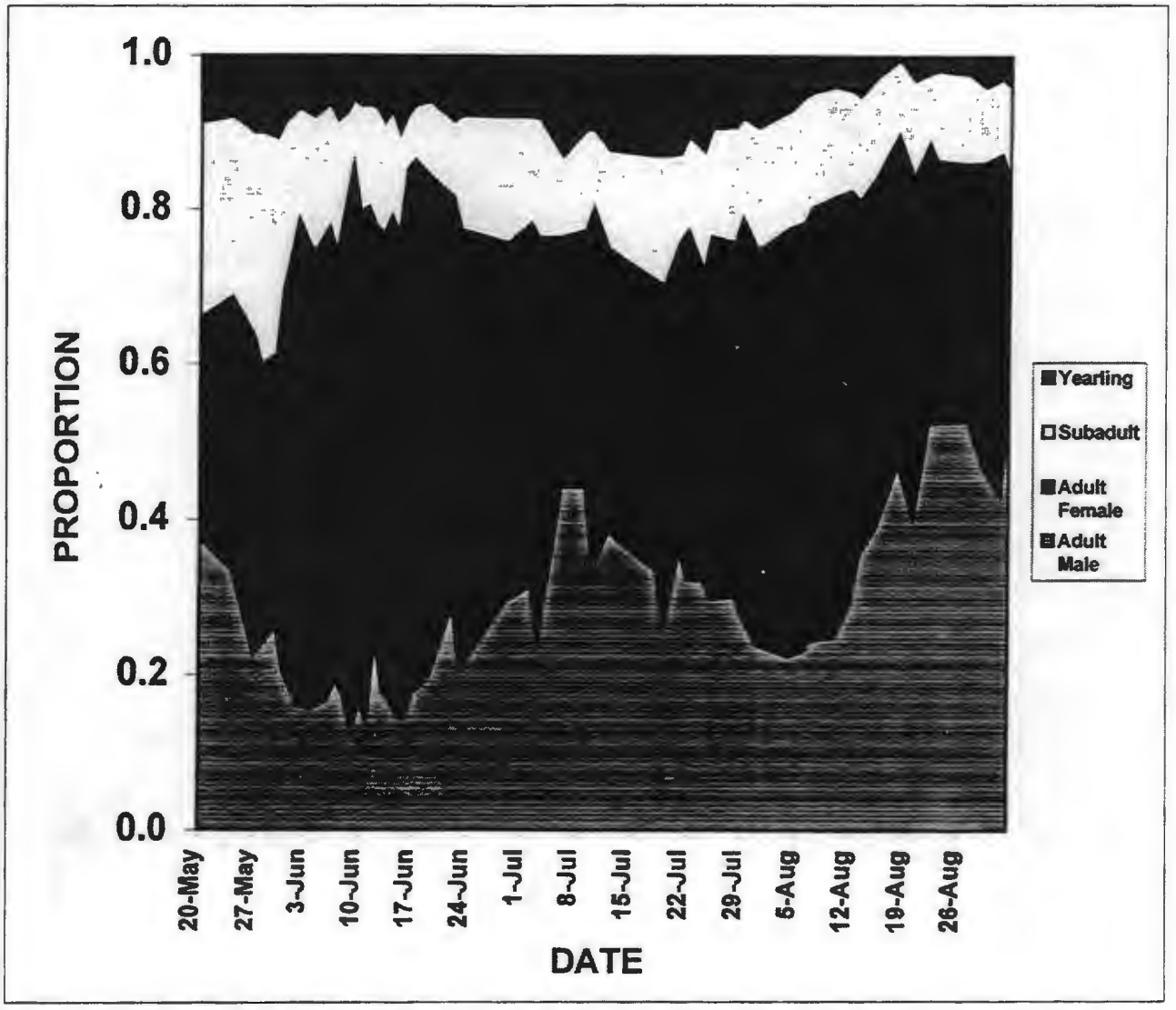


Figure 4. Proportion of harbor seals in each sex and age class on the southern and western shores of Tugidak Island, Alaska, May-September 1997.

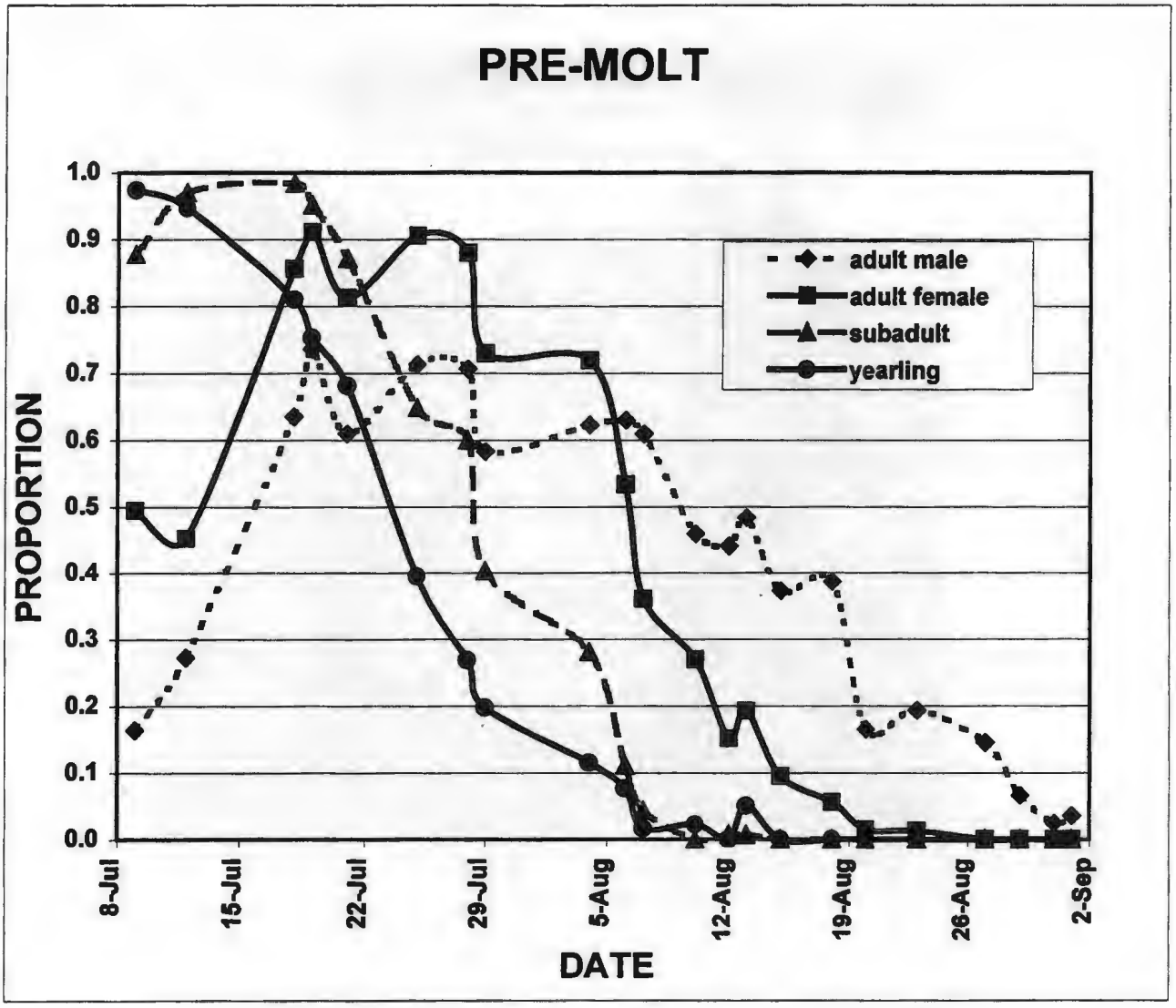


Figure 5. The proportion of harbor seals in pre-molt stages (b + c) for each sex /age class on Tugidak Island, Alaska, July-September 1997.

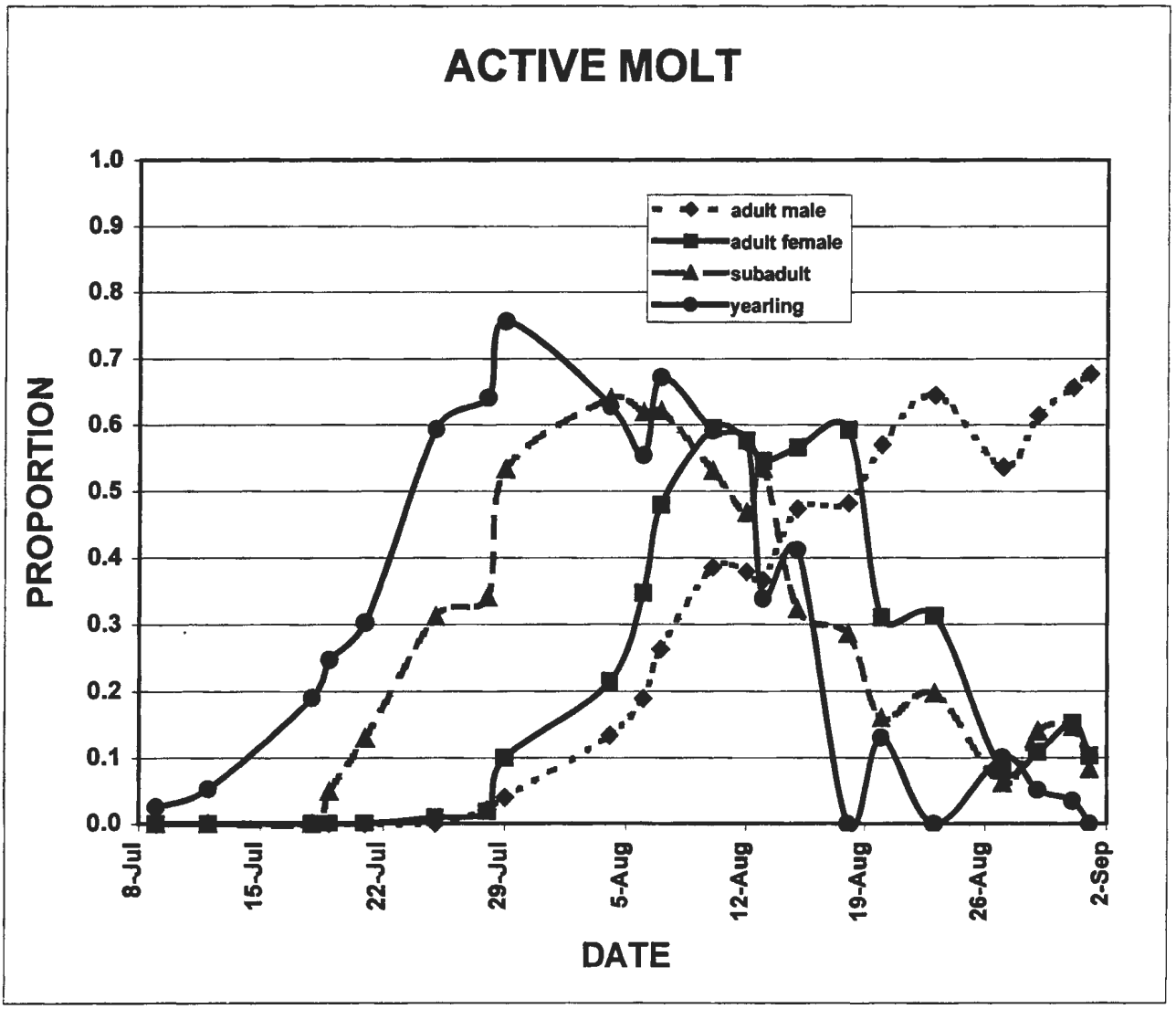


Figure 6. The proportion of harbor seals in active molt stages (d, e, + f) for each sex/age class on Tugidak Island, Alaska, July-September 1997.

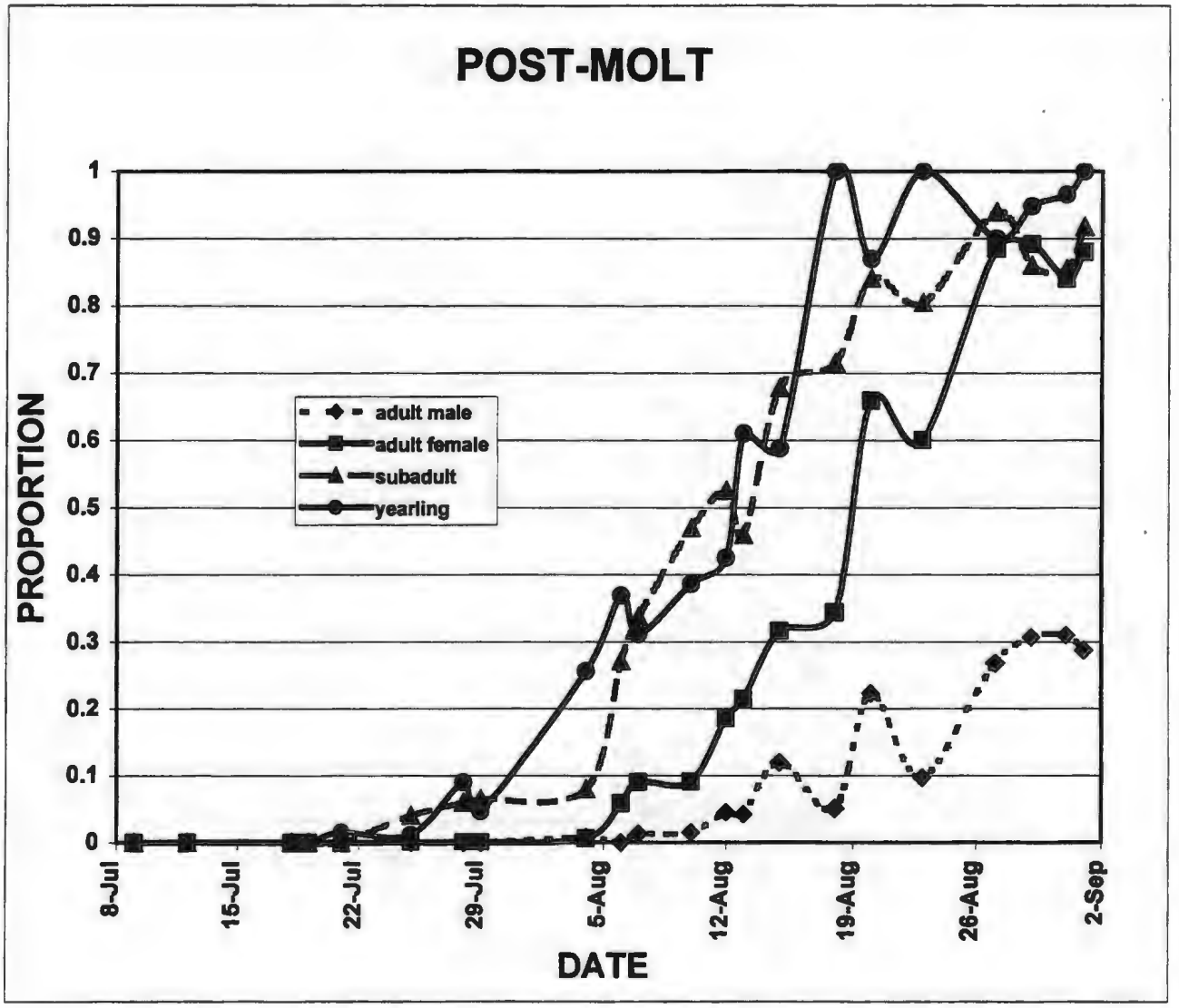


Figure 7. The proportion of harbor seals in the post-molt stage (g) for each sex/age class on Tugidak Island, Alaska, July-September 1997.

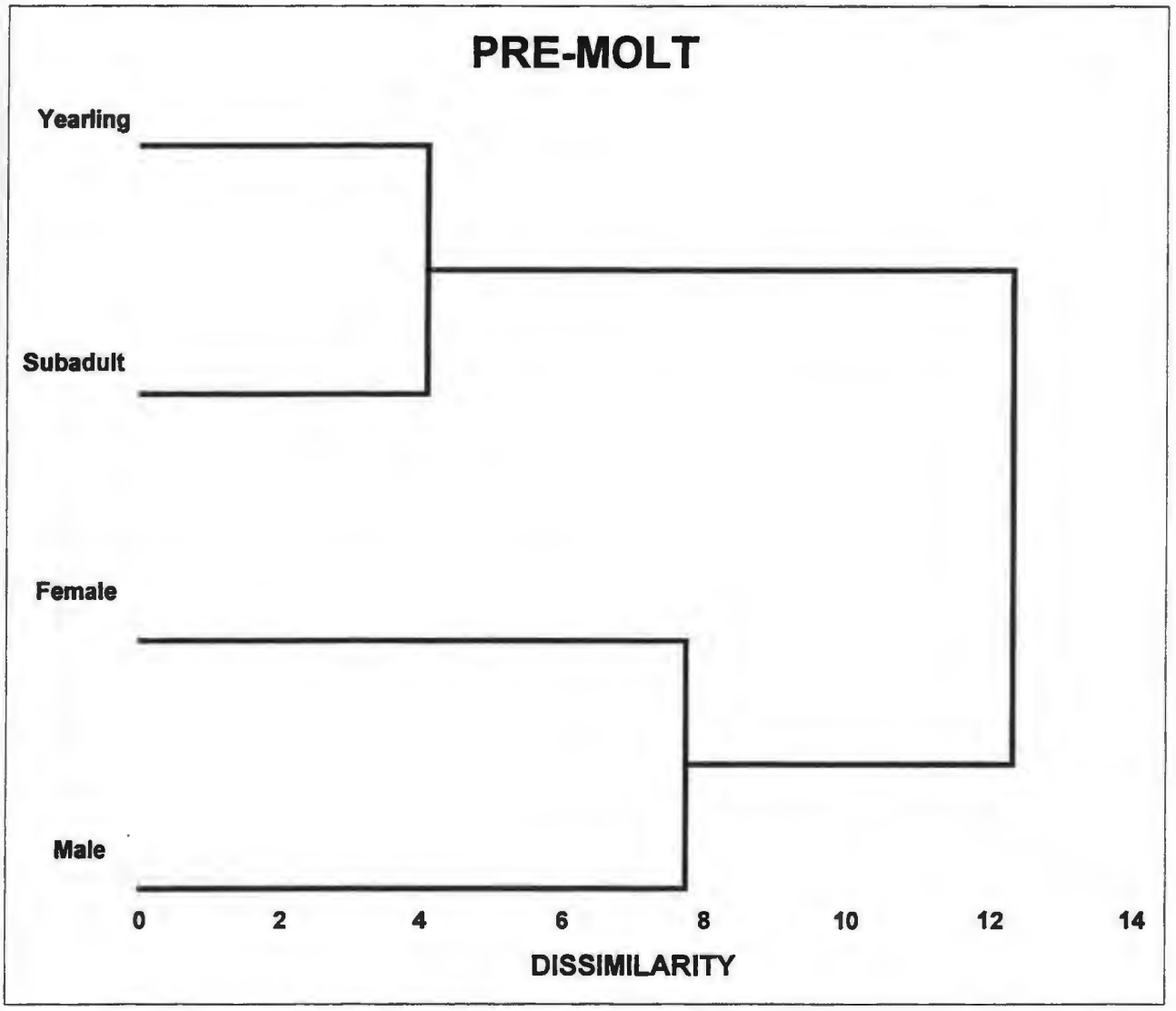


Figure 8. Similarity in the pre-molt (stages b + c) curves (see Figure 5) among yearlings, subadults, adult females, and adult males on Tugidak Island, Alaska, 1997.

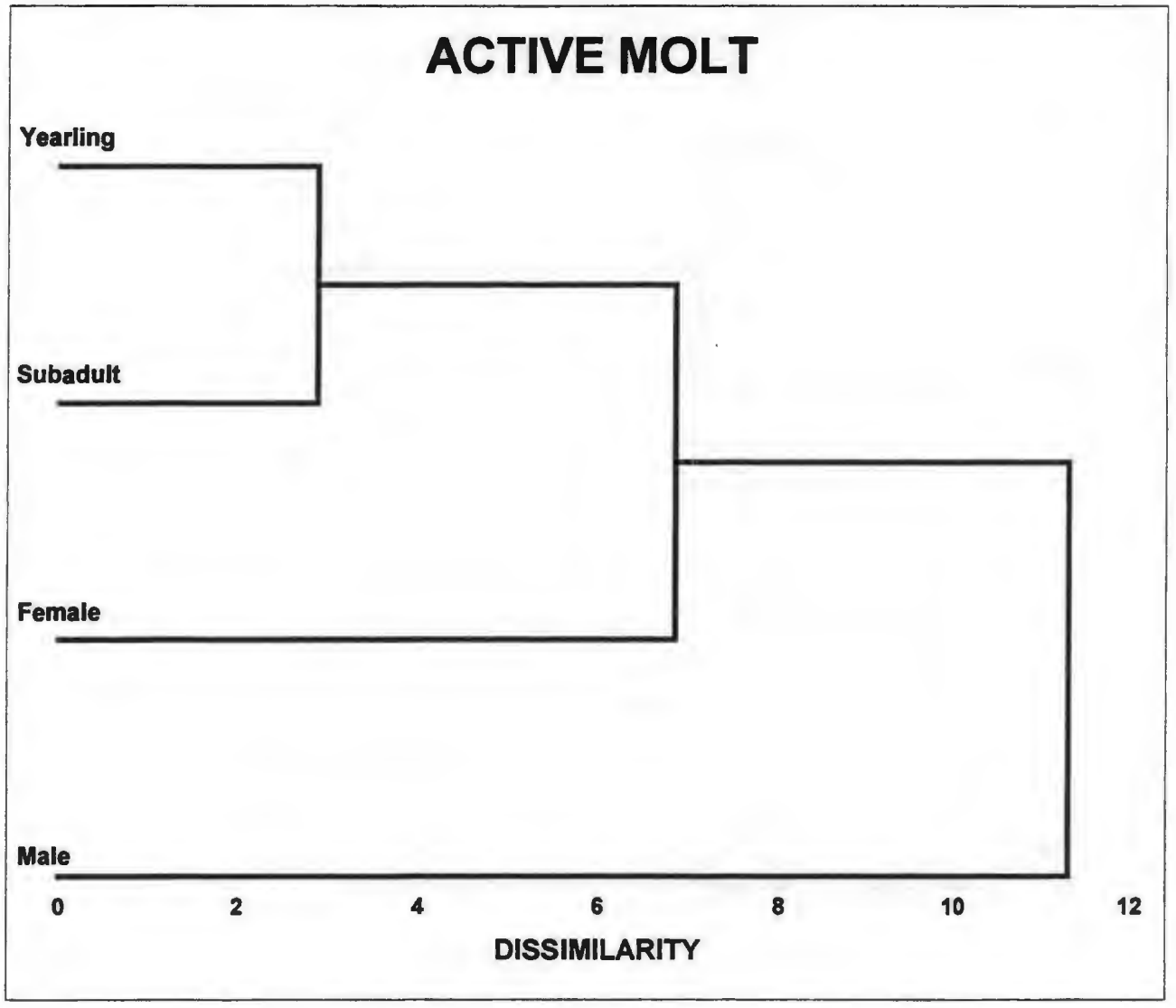


Figure 9. Similarity in the active molt (stages d, e, + f) curves (see Figure 6) among yearlings, subadults, adult females, and adult males on Tugidak Island, Alaska, 1997.

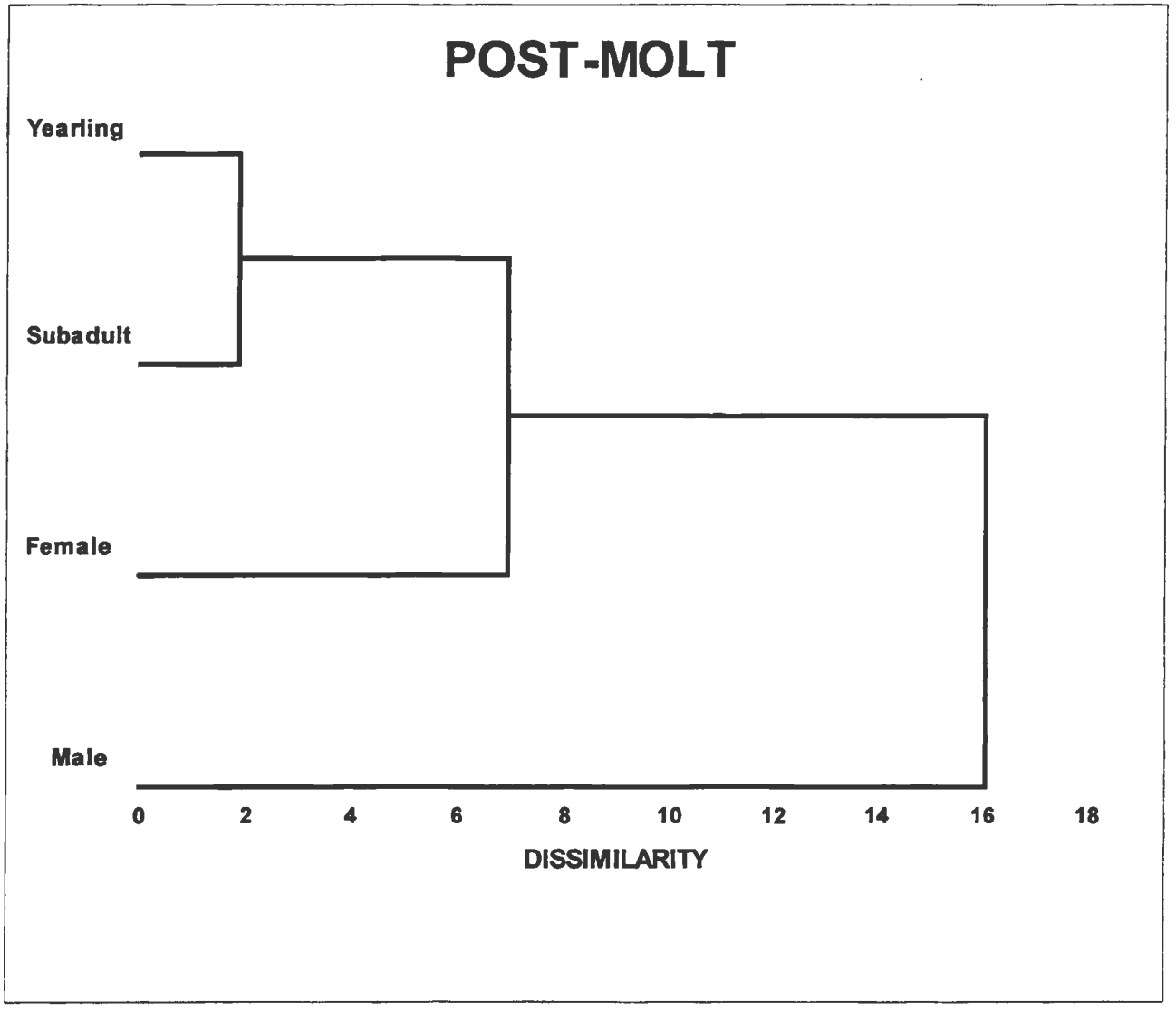


Figure 10. Similarity in the post-molt (stage g) curves (see Figure 7) among yearlings, subadults, adult females, and adult males on Tugidak Island, Alaska, 1997.

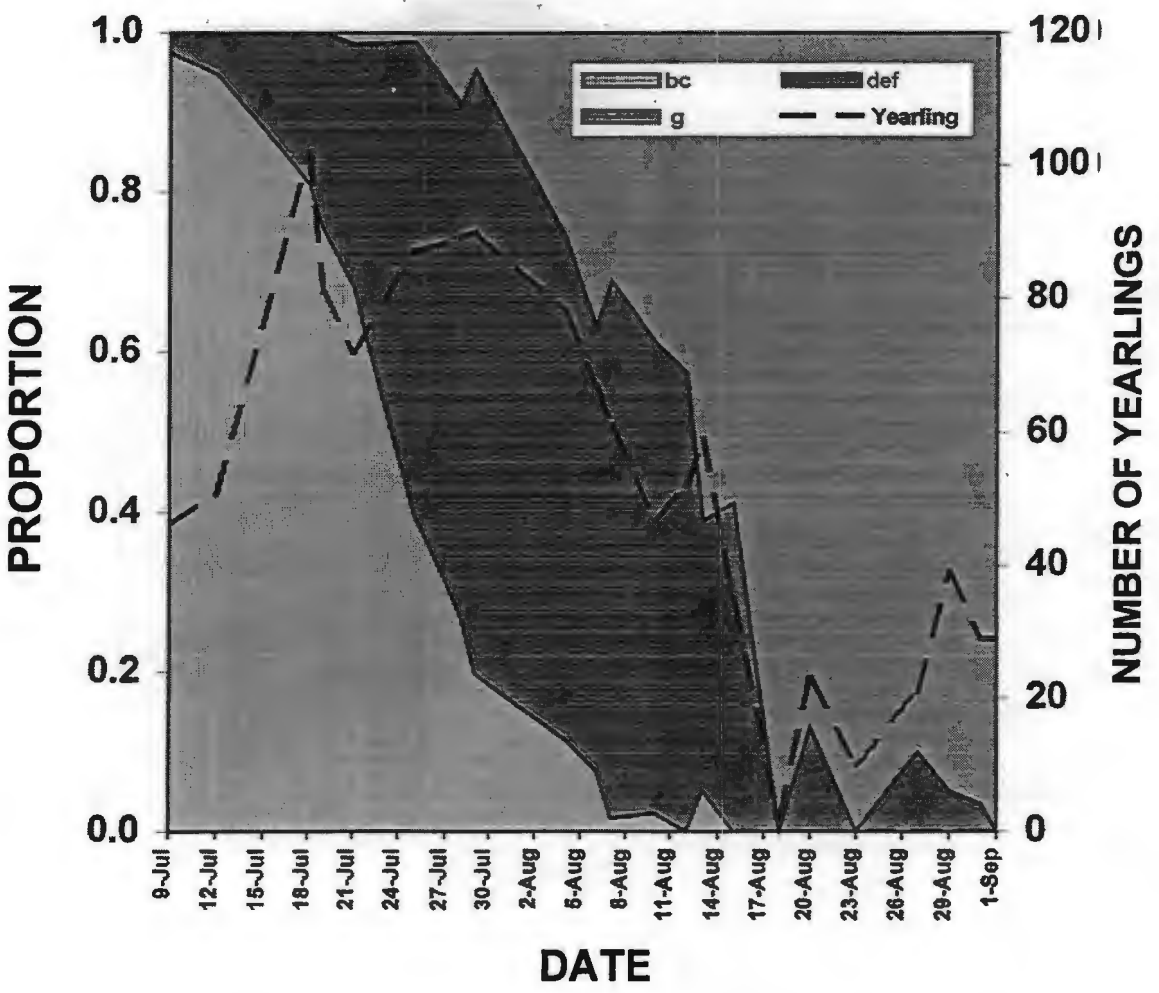


Figure 11. Proportion of yearlings (dotted line) in pre-molt (stages b +c), active molt (stages d, e, + f), and post-molt (stage g) categories on Tugidak Island, Alaska, July-September 1997.

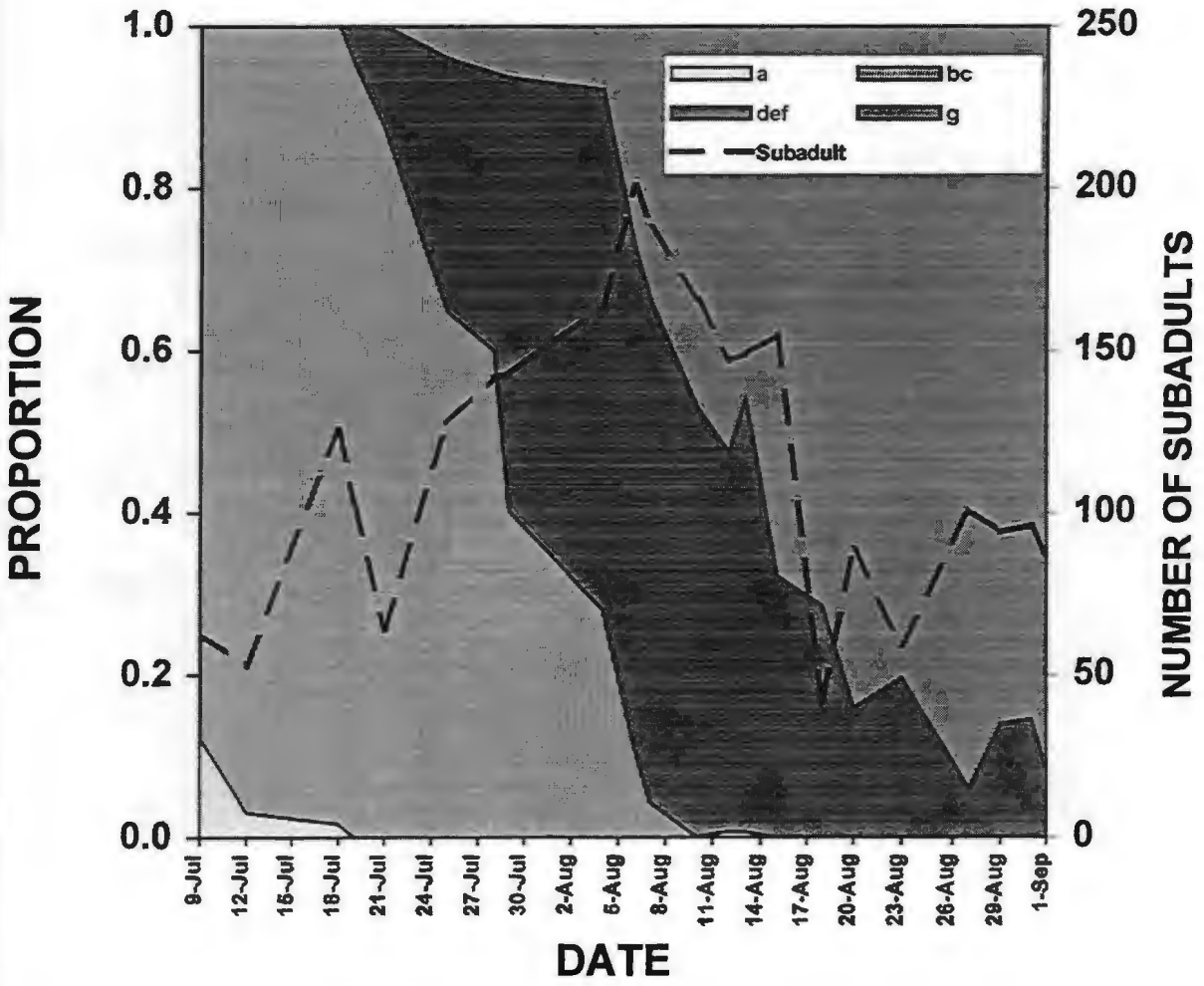


Figure 12. Proportion of subadults (dotted line) in pre-molt (stage a, stages b + c), active molt (stages d, e, + f), and post-molt (stage g) categories on Tugidak Island, Alaska, July-September 1997.

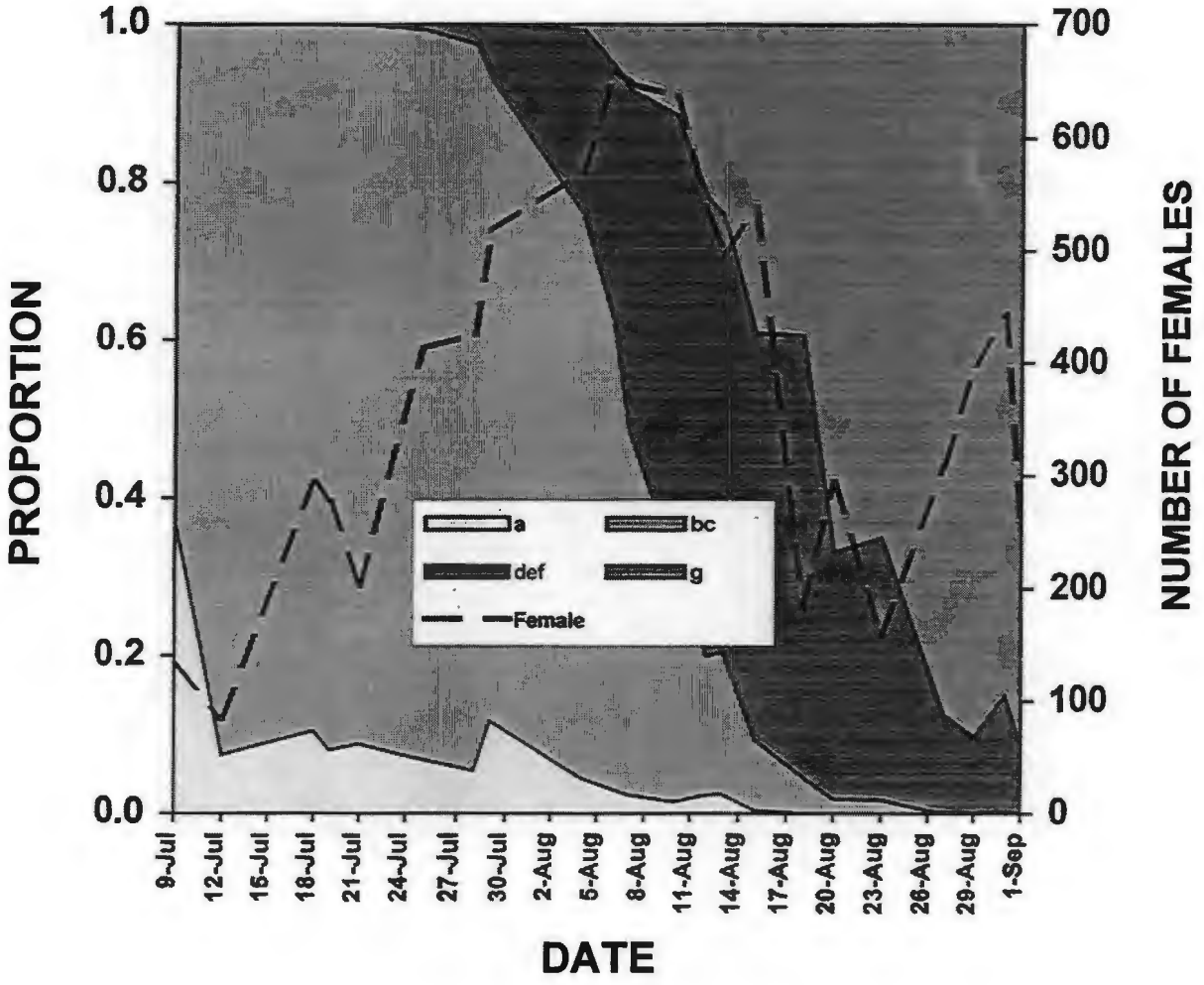


Figure 13. Proportion of adult females (dotted line) in pre-molt (stage a, stages b + c), active molt (stages d, e, + f), and post-molt (stage g) categories on Tugidak Is, Alaska, July-September 1997. The dotted line on the secondary y-axis represents the number of females.

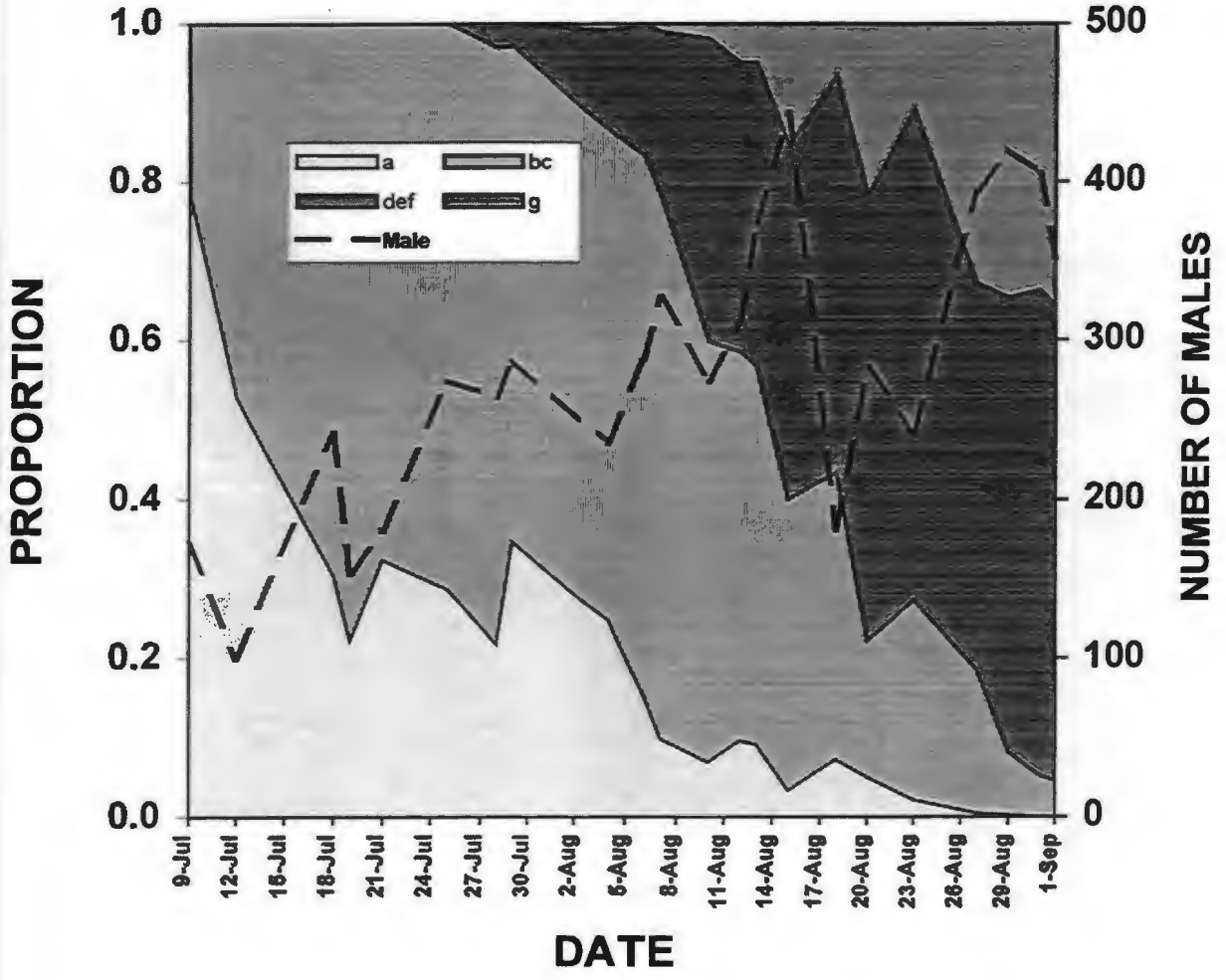


Figure 14. Proportion of adult males (dotted line) in pre-molt (stage a, stages b +c), active molt (stages d, e, + f), and post-molt (stage g) categories on Tugidak Island, Alaska, July-September 1997.

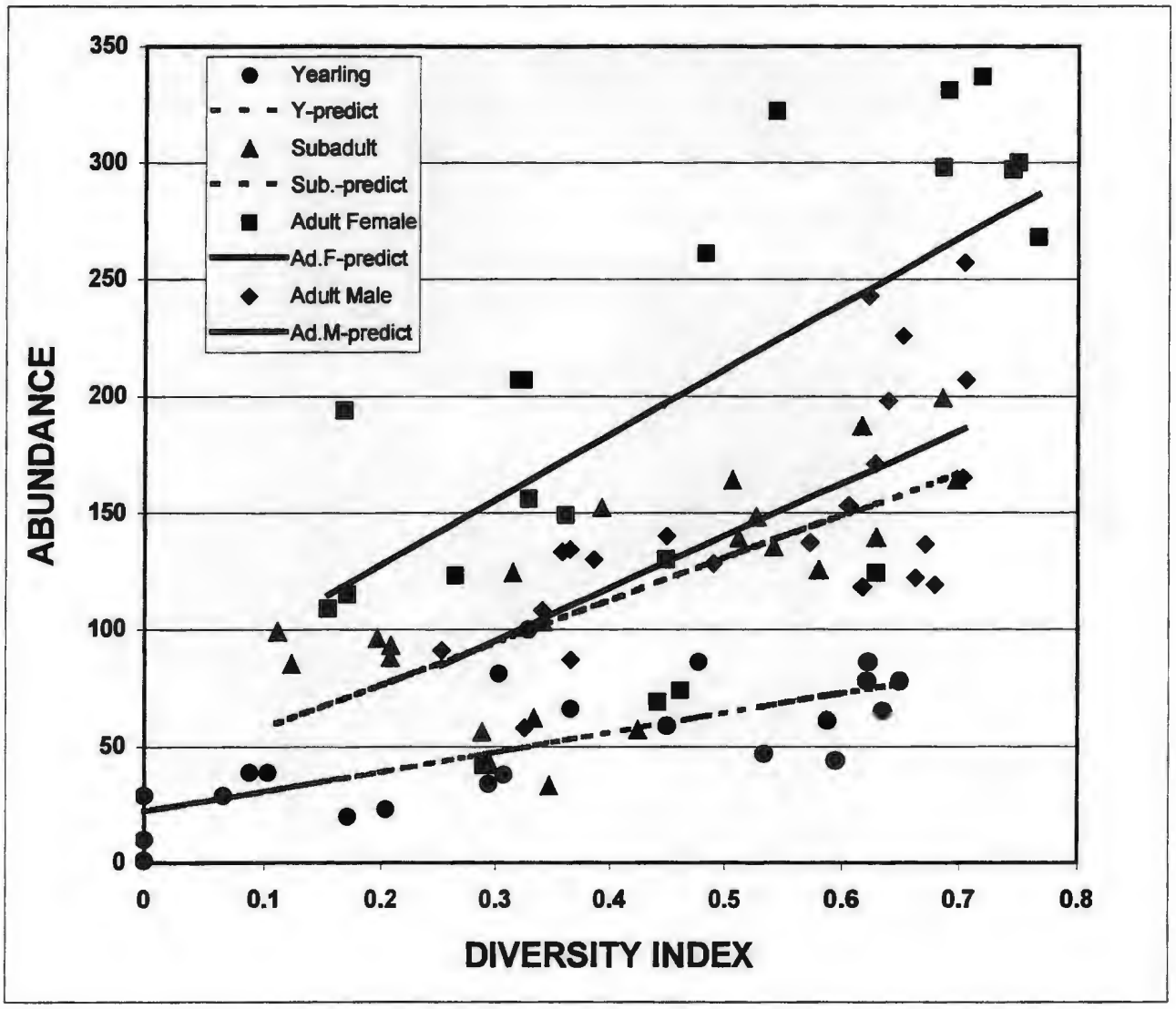


Figure 15. Molt diversity in relation to abundance for each sex/age class on Tugidak Island, Alaska, 1997.

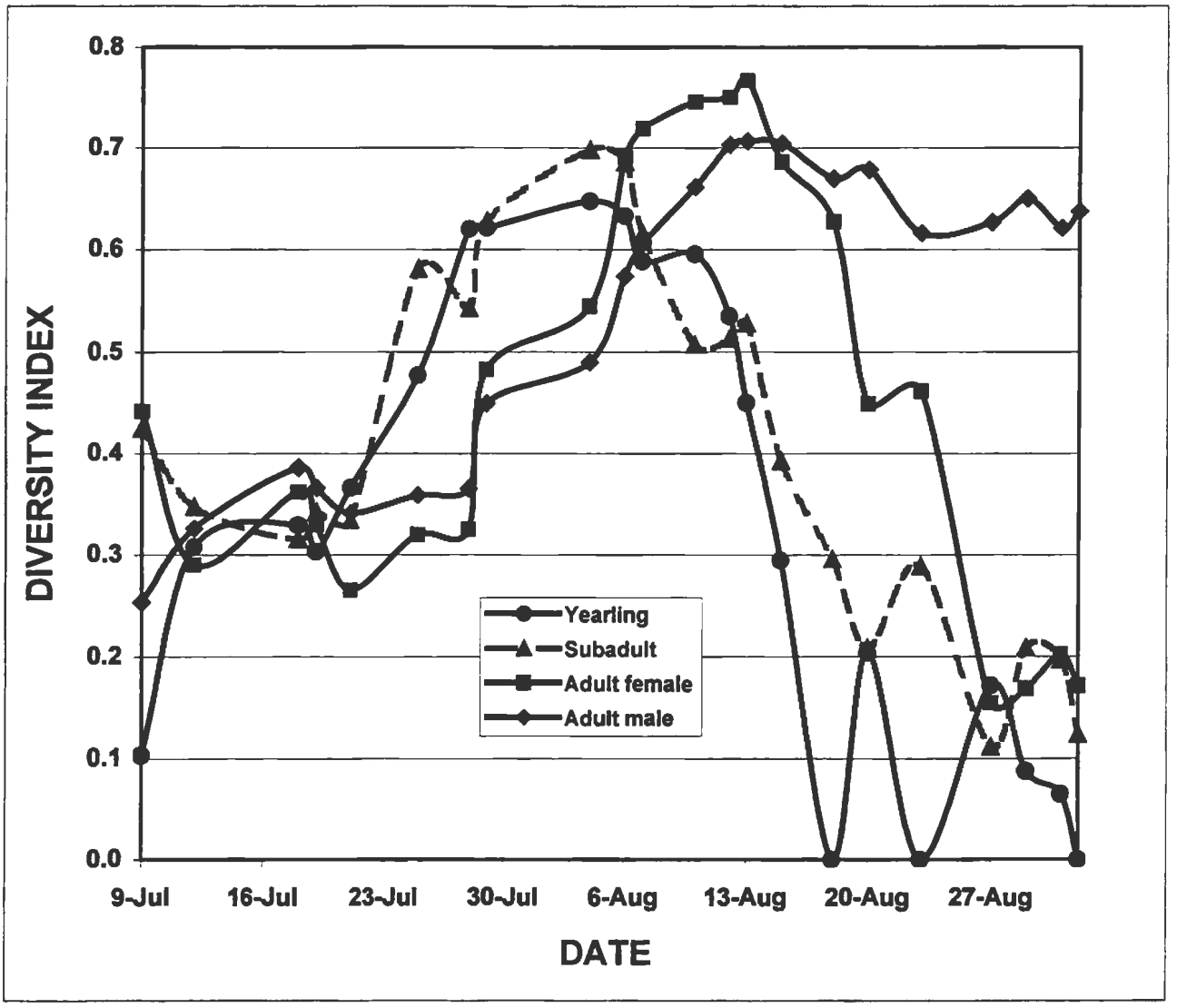


Figure 16. Molt category diversity among harbor seal sex/age classes on Tugidak Island, Alaska, from July-September 1997.

HISTORIES OF GROWTH AND CONDITION FROM TEETH OF HARBOR SEALS

Peter L. Boveng[1], Kristin Laidre[2], and James R. Thomason[3]

[1]National Marine Mammal Laboratory, Alaska Fisheries Science Center,
7600 Sand Point Way N.E., Seattle, WA 98115

[2]7717 15th Ave. N.E., Seattle, WA 98115

[3]3614 N.E. 117th St., Seattle, WA 98125

PROJECT DESCRIPTION

A collaborative study by the Alaska Department of Fish and Game (ADF&G) and the National Marine Fisheries Service (NMFS) to investigate the life history and growth of harbor seals in Alaska using patterns in the deposition of material in the seals' teeth continued in 1997. The first phase of the project was a study of the feasibility of estimating age at sexual maturation from transition zones in the cementum of harbor seal teeth (Baker and Boveng 1997). This report describes our initial efforts in the second phase of the project, a study of whether teeth can be used to derive cohort- or year-specific histories of growth and condition.

METHODS

The ADF&G provided 52 canine teeth from harbor seals collected in Southeast Alaska and Prince William Sound, 1995-1996. Prior to processing the harbor seal teeth, approximately 30 canine and postcanine teeth from various species of pinnipeds were obtained from the National Marine Mammal Laboratory (NMML). These teeth, for which no supporting data (date of collection, sex, location, etc.) were available, were used to refine a method for cutting and mounting thin sections.

Cutting and mounting thin sections

A Hillquist® thin-section machine was acquired to supplement the tooth-preparation equipment already on hand at the NMML (petrographic trim saws and grinders). Each tooth was either coated with or cast in a block of optical-grade epoxy resin (Epotek 401®). The tooth was cut longitudinally (medial-distal) with a petrographic trim saw, just off center so that the saw kerf was taken entirely from one half of the tooth. The cut face of the more complete half of the tooth was then polished on a Buehler Ecomet III® grinder with 600 grit abrasive paper. The polished face was glued to a glass slide using the optical epoxy. The portion of the tooth that was glued to the slide was cut and ground to a thickness of 0.12 mm using the thin-section machine. A glass coverslip was affixed over the tooth section using Permount® mounting medium.

Image capture and analysis

A system for capturing digital images from a dissecting microscope and recording measurements from the images was acquired and installed. The system includes a Polaroid® digital camera, a stereo dissecting microscope (provided by the NMML), a desktop computer, and Media Cybernetics Optimas® image analysis software. We are in the initial stages of developing macros and tools within the image analysis package to facilitate measurements and recording of data.

RESULTS AND CONCLUSIONS

Forty-five of the 52 harbor seal teeth were cut into thin sections and mounted on glass slides. The remaining 7 teeth were cracked or broken from desiccation; these are being reassembled with epoxy or cast in epoxy blocks before preparation of thin sections.

An initial inspection of the prepared slides indicates that certain features, such as the neonatal line in the dentine can be seen clearly in most specimens. The appearance of growth layers in the cementum, however, may not be substantially clearer than specimens prepared previously by decalcification and staining techniques (i.e., the specimens analyzed by Baker and Boveng(1997)). We will undertake additional tests using the same sample of teeth to determine whether the clarity and definition of the cementum layers can be improved by cutting in a different plane (e.g., buccal-lingual rather than medial-distal) or by staining the tooth section (without decalcification). In any case, each of the prepared specimens will be measured to provide a data set that includes estimates of total age and age at sexual maturation, thickness of the neonatal and first-year dentine, and thickness of each cementum layer at one or more standardized locations on the tooth.

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CHAPTER 2

GENETICS

OBJECTIVE 5

Determine genetic structure of harbor seals in Alaska

ANALYSIS OF GENETIC AND BEHAVIOURAL DIFFERENCES AMONG HARBOUR SEAL POPULATIONS IN ALASKA USING MICROSATELLITE DNA VARIATION

Gregory O'Corry Crowe

National Marine Fisheries Service, Southwest Fisheries Science Center
8604 La Jolla Shores Dr., La Jolla, CA 92038

INTRODUCTION

Over the past two decades harbour seals (*Phoca vitulina richardsi*) have declined dramatically in Prince William Sound (PWS) and at a number of locations throughout the Gulf of Alaska, most notably on Tugidak Island within the Kodiak Archipelago (KOD) (Pitcher, 1990; Lewis *et al.*, 1996; Small *et al.*, 1998; Frost *et al.*, 1997). In contrast, seal numbers in other regions of Alaska remained stable or increased during this same period (Lewis *et al.*, 1996; Small *et al.*, 1998). Although the causes of the decline remain unclear, differences in trends and abundance of harbour seals among areas suggests population structure and highlights the need to identify separate management stocks.

An understanding of the amount of dispersal between areas is critical to the definition of biologically meaningful management units. Recent telemetry studies of harbour seals in PWS found that few tagged seals left the Sound during the period they were tracked (Frost *et al.*, 1995). The majority of movements were within 20km of the point of capture, and seals exhibited a high degree of fidelity to haulout site. Similar studies of harbour seal movements in KOD and Southeast Alaska (SE) showed a similar pattern of strong fidelity to one or two haulout sites, usually within 50km of each other (Pitcher & McAllister, 1981; Swain & Small, 1997). Seals made occasional long distance movements, sometimes in excess of 100km, but tended to return to their main area in a matter of days or weeks. Such studies add to the perception of harbour seals as relatively sedentary animals but tell us little about the rate and mode of dispersal. Genetic analyses offers the most viable approach to estimating levels of dispersal and thus defining management units in this species. Identifying stock boundaries in this way will help in estimating population size and interpreting trend counts. Genetic investigation can provide insights into differences in breeding and movement behaviour among areas and elucidate the relationship between gene flow and dispersal.

As well as revealing population genetic structure, molecular techniques can be used to investigate the consequences of population decline on spatial and temporal patterns of genetic variation. Rapid population declines can result in the loss of important genetic heterozygosity which may affect individual and population 'fitness' and compromise a population's ability to respond to environmental change (Franklin, 1980; O'Brien and Evermann, 1988). Many other factors, including spatial organization, mating systems and founder effects, can influence genetic variability, and comparisons of levels of heterozygosity among several genetic loci across different populations may reveal much about the behavioural ecology, evolutionary history and potential of a species and how these relate to population viability.

The Southwest Fisheries Science Center (SWFSC) of the National Marine Fisheries Service thus undertook a long-term molecular genetic study of harbour seals to investigate the evolutionary history,

breeding behaviour and movement patterns of this species in Alaska. The primary objective was to identify distinct population units upon which conservation and management strategies can be designed and implemented. Secondarily, we wanted to gain insights into how the movement and breeding behaviour of harbour seals influence population dynamics within the different units. Specifically, what aspects of harbour seal behavioural ecology might act to aid or confound population recovery. A third objective was to assess the utility of indices of genetic variability in determining the evolutionary history and potential of populations. Mitochondrial DNA was chosen as the primary marker in the stock structure study (Westlake, 1997). This rather unique genetic marker can potentially provide an evolutionary as well as a contemporary perspective to population subdivision in terms of historical biogeography and current levels of dispersal. Final results from this study will be reported on in 1999. Microsatellites, a class of highly variable nuclear markers similar to the minisatellites used in DNA fingerprinting, were chosen to elucidate in more detail the genetic and behavioural differences among harbour seal populations. We examined variation in these markers to determine the level of interbreeding among geographically, and possibly demographically (mtDNA), distinct subpopulations. Levels of variability within these loci as well as within mtDNA were compared with similar measurements from other harbour seal populations in an initial assessment of the utility of indices of genetic variation in assessing population viability. The most recent results from the microsatellite study are reported here.

MATERIALS AND METHODS

Choice of Sampling Locations

The initial microsatellite research has focused on seals in (PWS) (Fig. 1) and around KOD (Fig. 2) for a number of reasons:

1. PWS and KOD are two of the areas of highest conservation concern within Alaska because of the documented declines in harbour seal numbers.

2. Much research has been done on the seals in both areas including abundance estimation, trend analysis and investigations on animal movements.

3. We possess a large number of tissue samples from both areas in our archive.

4. A potential confounding effect in discerning large-scale population structure across regions is the existence of extensive substructure within the strata (regions) being compared. For example, if there is extensive genetic subdivision among areas within the Gulf of Alaska (including PWS) and SE regions, respectively, the majority of genetic variation in the overall system may reside within regions. It thus may be difficult to detect any real differences that may exist between regions. Thus our first objective is to determine if there are significant genetic differences in PWS and KOD.

Sample Collection and Molecular Analysis

Harbour seal samples have been collected throughout the period of the most recent population declines from a number of discrete locations throughout PWS and KOD (Table 1, Fig.1 & 2). Tissue

samples (typically flipper plugs) were preserved by freezing or placing in 20% (v/v) dimethyl sulfoxide (DMSO) saturated with sodium chloride. Total cellular DNA was isolated by conventional phenol-chloroform extraction and ethanol precipitation methods (Sambrook *et al.*, 1989). Primer sequences for harbour and grey seal (*Halichoerus grypus*) microsatellite loci were accessed from Genbank and the oligonucleotide primers synthesized and labeled. Microsatellite DNAs were amplified using the polymerase chain reaction (PCR) and allele length polymorphism analyzed on an ABI 377 Automated Sequencer and data analyzed with ABI's GENESCAN software.

Data Analysis

An exact test that uses a modified version of the Markov-chain random walk algorithm (Guo and Thompson, 1992) was used to test for deviations from Hardy-Weinberg equilibria at each locus and linkage disequilibria among pairs of loci. Both the GENEPOP program (version 1.2) of Raymond and Rousset (1995) and the ARLEQUIN program (version 1.1) of Schneider *et al.* (1997) were used. Heterozygosity (H) at each locus within each area was estimated using microsat version 1.5b (Minch *et al.*, 1997). Genetic differentiation was first investigated by comparing genotypic and allelic frequencies among areas. Fisher exact tests were used instead of traditional Chi-square tests and significance was determined by multiple permutation (1000 x 50) using the Markov chain method. Wright's *F* statistics were also used to investigate genetic structure. *F*st was estimated both by a standard analysis of variance (Weir and Cockerham, 1984) and the analysis of molecular variance method of Excoffier *et al.* (1992), and its significance tested by multiple permutation. A number of distance-based statistics analogous to *F*st, designated Rst, standardized Rst, and Φst, were also used to assess genetic subdivision. All analyses of genetic differentiation were executed on a number of computer packages including Goodman's (1997) RSTCALC version 2.2 and the three previously mentioned programs.

RESULTS

A total of 73 samples from PWS (n=38) and KOD (n=35) were screened for variability at 8 polymorphic microsatellite loci (Table 1; Figs 1 & 2). Three samples from KOD had to be excluded from the analysis due to poor quality results or limited DNA. Our initial examination into the potential utility of microsatellites in studies of harbour seals in Alaska revealed a range of variability among loci that suggested that these markers may prove highly informative in investigating the population structure and behaviour of this species (O'Corry-Crowe, 1997). One locus, originally typed on grey seals Hg6.1 (Allen *et al.*, 1995), did not amplify in this earlier work. Subsequent re-synthesizing of primers and adjustment of PCR conditions, however, has resulted in the consistent amplification of this locus.

Test for Linkage Disequilibrium and Deviations from Hardy-Weinberg Expectations

In 56 pairwise comparisons across all eight loci in both subpopulations, no two loci were found to be in linkage disequilibrium ($0.075 \geq P \leq 0.99$). Significant deviation from Hardy-Weinberg proportions was observed for only 2 out of 16 locus by population comparisons. This involved the locus Pvc63 for both the PWS and KOD subpopulations and was due to a heterozygote deficiency in both cases. Such a deviation could be due to selection acting on this locus or a linked locus, nonrandom mating, further structure within both subpopulations or null or nonamplifying alleles (Workman and

Niswander, 1970; Pemberton *et al.*, 1995). Initial indications are that there may indeed be a problem with nonamplifying alleles at this locus and future work will involve varying PCR conditions and sequencing alleles.

Genetic Variability

All loci scored to date are polymorphic. The number of alleles at each locus ranged from 4 in Locus Hg8.10 to 9 in locus Hg6.1. Average heterozygosity was 0.617 and ranged from 0.342 at locus Hg 8.9 to 0.822 at locus Hg6.1.

Genetic Structure

Genotypic frequencies differed significantly between PWS and KOD (overall exact test χ^2= 36.867, P=0.0022) indicating that there are significant differences in the pattern of genetic variation among areas. This could be due to a number of factors including variation in the mating system and selection. Allele frequencies, however, also differed significantly among areas (overall exact test χ^2=37.06, P=0.0021) suggesting that the genetic differences among the two areas are due to differences in the gene pools.

An analysis of molecular variance based on allele frequencies yielded a significant *F*st value between PWS and KOD (ARLEQUIN *F*st= 0.0117, P=0.0373). This compares well with the *F*st estimate by GENEPOP of 0.0122. Both, however, are somewhat lower than the value estimated with microsat (Fst= 0.023). Thus, although the vast majority of microsatellite variation (~98%) resides within the two areas, the distribution of this variation is significantly non-random. Genetic structure was also assessed using Rst and its analogues (standardized Rst, Φst) to determine if there was an evolutionary component to the genetic subdivision among these two areas. The proportion of total variance that is due to variance among subpopulations was found to be similar to the values for Fst (1.6 - 2%). The distance-based values (i.e., Rst, etc.) however, are only significant at the 10% level.

DISCUSSION

Genetic Variability

There is much debate over what can in fact be learned about a population's history and viability from estimates of genetic variation as there are a wide variety of factors that can influence the level of variability at individual loci (Pimm *et al.*, 1989; Caro and Laurensen, 1994). To date a number of studies have examined variability in both nuclear (isozymes, blood proteins, RAPDs, minisatellites) and cytoplasmic (mtDNA) markers in harbour seals. Swart *et al.* (1996) attributed the lack of variability recorded in 21 isozyme and blood protein systems in harbour seals from the Dutch Wadden Sea and British Wash to genetic bottlenecks during the Pleistocene. They suggested that the lack of heterozygosity may have compromised the immune response of seals in the Wadden Sea where an epidemic caused by the Phocine Distemper Virus (PDV) in 1988 reduced the population by 80%. A study of variation in the DNA itself also revealed low levels of variation in the Wadden Sea population, as well as a much larger population in the North Sea (Kappe *et al.*, 1995). The authors suggested that harbour seals in the North Sea have experienced one or more bottlenecks and reached similar conclusions as

Swart and colleagues about the relationship between genetic variation and susceptibility to PDV (Kappe *et al.*, in press).

The limited data available on genetic variation in Pacific harbour seals presents a somewhat more complex picture. An electrophoretic study of three Alaskan 'populations' found no variation at 9 loci (Shaughnessy, 1975). By contrast, high levels of heterozygosity have been recorded at multiple minisatellite loci in Alaskan (Kappe *et al.*, in press), as well as Californian and Washington harbour seal populations (Lehman *et al.*, 1993). Similarly, substantial levels of variation have been recorded within the mtDNA genome in Alaskan populations (Westlake & O'Corry-Crowe, 1996; Westlake, 1997). To this we can now add our recent findings of moderate to high levels of variability at eight microsatellite loci, one of which (Hg 6.1) was found to possess much lower levels of heterozygosity in harbour seals at twelve separate geographic areas throughout Europe (H= 0.053 - 0.750: Goodman, 1997). Although harbour seals in some areas of Alaska have declined by over 60% in the past 15 years, they still number in the thousands. Thus, it is not surprising that levels of variability within a diverse range of loci are quite high. The extensive variation within mtDNA particularly suggests that North Pacific harbour seals have not gone through prolonged bottlenecks in recent evolutionary history (probably in the order of tens of thousands of years).

Genetic Subdivision

Preliminary analysis of patterns of variability at eight microsatellite loci revealed significant genetic differentiation among seals sampled from PWS and KOD suggesting limited interbreeding between these two areas. Microsatellite analysis has been successful in revealing extensive genetic differentiation among geographic 'populations' of harbour seals in Europe (Goodman, 1998) and the current study demonstrates the utility of microsatellites in addressing questions of population structure and gene flow in this species in Alaska. In a concurrent study of population structure using mtDNA no consistent genetic differentiation has been found between PWS and KOD at this locus (R. Westlake, pers com.). The reasons for these apparent inconsistencies between markers remain, as yet, unclear. Caution, however, is required when interpreting these initial findings. Sample size is low and thus the power to characterize true patterns of genetic variation, and thus behaviour, may be limited. A more extensive investigation involving larger numbers of samples from a greater number of locations within both areas as well as other areas, including SE is required. Work in this direction has already begun.

Future Directions Of Genetic Research

It is essential now to further investigate the relationship between dispersal and movements by combining more detailed molecular genetic analysis with a reappraisal of behavioral and ecological data. We have learned much about harbor seal movements in Alaska from satellite-linked telemetry, but to date these studies have been restricted to particular age or sex classes, although this is changing (L. Lowry and K. Frost, pers. comm.). Moreover, the chances of recording dispersal by this approach are low as current instrumentation technology cannot last the lifespan of the animal. Another uncertainty that must be addressed, is at what geographic scales dispersal may be a factor in preventing or promoting population structure.

Recent telemetry studies have shown that despite apparent strong site fidelity, seals make occasional long-distance trips that can last periods of days or weeks. Although such excursions beyond the typical home range do not represent actual dispersal (i.e., emigration), do they represent effective

dispersal (i.e., gene flow)? Furthermore, if a substantial proportion of seals spend a significant proportion of their time on such trips, these movements may confound genetic investigations of stock structure if they occur across areas where no dispersal (actual or effective) typically occurs. For example, if 50% of seals make long-range movements 20% of the time then approximately 10% of seals will be sampled in the 'wrong' place. This is certainly enough to conceal any genetic structure that may exist in terms of limited emigration or interbreeding.

One approach to addressing these and other questions relating to the relationship between movements, interbreeding and dispersal is an extensive analysis of variation within mtDNA and several microsatellite loci within large sample sizes of seals of different sex and age classes from a number of areas. Tissue samples have been systematically collected from large numbers of seals from PWS and KOD. Information on age, size, body condition and reproductive status is available for most of these samples. A substantial number of these samples are from seals (including pups) for which extensive movement and dive data is available. PWS and KOD are also the areas of the most dramatic declines in harbor seal numbers and are thus of greatest conservation concern. Tissue samples are available from throughout the period of most recent decline (mid 1970s to present) and many samples have already been analyzed from both areas for mtDNA and microsatellite variation (Westlake, 1997).

ACKNOWLEDGMENTS

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LOCALITY	# Mst. Samples	# mtDNA Samples
KODIAK AREA		
ZACHER BAY	1	2
SEAL BAY, AFOGNAK IS	1	2
SHUYAK ISLAND	1	1
BIG BAY, SHUYAK IS	4	4
FOUL BAY, AFOGNAK IS	1	2
AFOGNAK BAY	1	1
KITOI BAY, AFOGNAK IS	1	1
S. SITKINAK ISLAND	2	4
UGAK BAY	5	5
TUGIDAK ISLAND	8	12
UGANIK BAY / PASS	4	8
UGANIK PASSAGE	2	8
BLUE FOX, SHUYAK IS	1	1
KAGUYAK BAY	0	2
UPPER UGAK BAY	0	4
TOTAL	32	57
PRINCE WILLIAM SOUND		
GULL ISLAND	1	1
HERRING BAY	1	1
JOHNS(T)ON BAY	1	1
DRIER BAY	1	11
ERLINGTON ISLAND	1	1
PR OF WHALES PT.	1	1
NASSAU FIORD	1	1
LONG BAY, AK	1	1
FAIRMONT ISLAND	1	1
EASLIK (EAGLEK?) BAY	1	2
SEAL ISLAND	10	11
CHANNEL ISLAND	3	3
MAKARKA PT. HAWKINS IS	4	4
SIMPSON BAY	2	5
NELSON BAY	1	1
LITTLE GREEN ISLAND	3	0
APPLEGATE ROCKS	2	2
STOCKDALE HARBOR	2	0
PORT CHALMERS	1	0
BALD HEAD	0	1
OLSEN ISLAND	0	1
HORSESHOE BAY, LATOUCHE	0	2
OLSEN BAY	0	5
GRAVINA BAY	0	3
TOTAL	38	49

Table 1. Collection sites and number of harbor seal genetic samples analyzed for mtDNA and eight microsatellite (Msat) loci from the Kodiak Archipelago and Prince William Sound areas of Alaska.

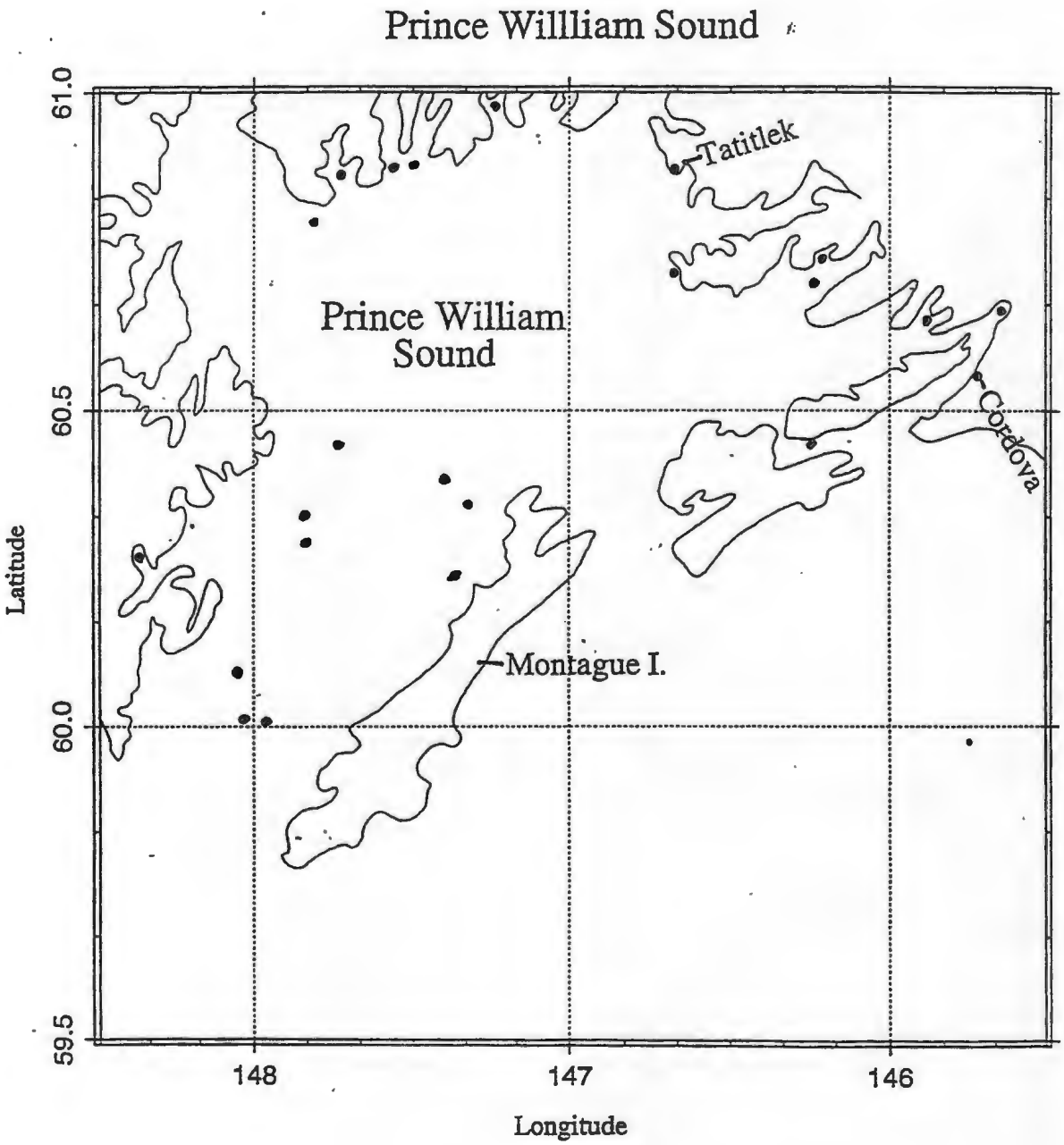

Figure 1. Locations within Prince William Sound, Alaska, where harbor seal genetic samples were collected for microsatellite analysis.

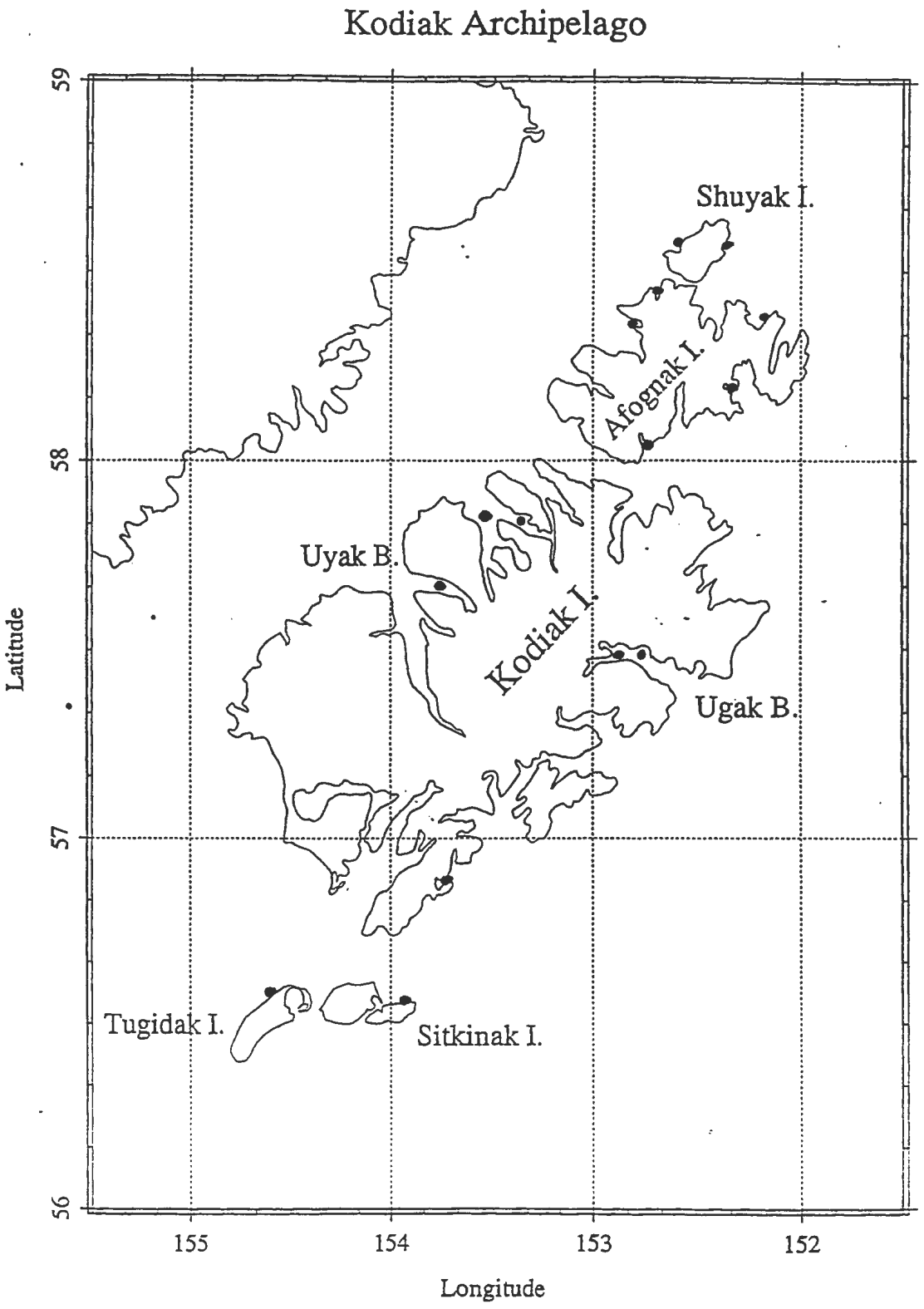

Figure 2. Locations in the Kodiak archipelago, Alaska, where harbor seal genetic samples were collected for microsatellite analysis.

CHAPTER 3

FOOD HABITS

OBJECTIVE 7

Determine prey utilization by harbor seals in various locations throughout Alaska

SUMMARY OF HARBOR SEAL DIET DATA COLLECTED IN ALASKA FROM 1990–1997

Lauri Jemison

Division of Wildlife Conservation
Alaska Department of Fish and Game
P.O. Box 240020, Douglas, Alaska 99824-0020

INTRODUCTION

During the past 20 years, harbor seal (*Phoca vitulina richardsi*) numbers have declined in several regions of Alaska including the western Gulf of Alaska (Pitcher 1990, Lewis *et al.* 1996), Prince William Sound (PWS) (Frost *et al.* in press), Aialik Bay (Hoover 1983, Hoover-Miller 1994), the north side of the Alaska Peninsula (Withrow and Loughlin 1996), Otter Island (Johnson 1976, Kelly 1978, Jemison 1996), and northern Bristol Bay (Johnson 1976, Wilson and Jemison 1994, Wilson 1995, Moran and Wilson 1996). The harbor seal decline was not an isolated event, as Steller sea lions (*Eumetopias jubatus*), northern fur seals (*Callorhinus ursinus*), and several species of piscivorous seabirds have also declined in the Gulf of Alaska and the Bering Sea during this same time period (Braham *et al.* 1980, Fowler 1982, Merrick *et al.* 1987, York and Kozloff 1987, Loughlin *et al.* 1992, Springer 1993). Harbor seal numbers in Southeast Alaska (SE) have remained stable or increased during the past 15 years (Small *et al.* 1998).

A change in prey abundance and/or availability is one of the leading hypotheses for the cause of the decline in marine mammals and seabirds in the Gulf of Alaska and the Bering Sea (e.g., Merrick *et al.* 1987, Trites 1992, Springer 1993, Jemison and Kelly 1997). Harbor seals eat a wide variety of fish and invertebrate prey, their diet varying seasonally, regionally, and probably annually (Imler and Sarber 1947, Fisher 1952, Wilke 1957, Pitcher and Calkins 1979, Pitcher 1980), but data on these variations are largely incomplete (Hoover-Miller 1994). The most recent and comprehensive food habits study in Alaska was conducted from 1973 through 1978 in the central and western Gulf of Alaska where 548 seals were collected, 269 of which had food remains in the stomach (Pitcher 1980). Few historical diet data are available from the Bering Sea and Aleutian Islands regions, and limited information is available from SE. It is important to establish baseline information on the diet of harbor seals throughout their range in Alaska and to compare current diet with historical data.

A renewed interest in food habits of harbor seals developed in the 1990s, with studies of their primary prey through the examination of feces (scat) and stomach contents, and through fatty acid blubber analyses. Initially, scats were opportunistically collected from haulouts in conjunction with other marine mammal fieldwork, followed by standardized collections of scats and stomachs beginning in 1997. A biological sampling (biosampling) program began in October 1995 through which a suite of measurements and biological samples (including stomachs and blubber) were collected from harbor seals taken by Alaska Native subsistence hunters. The biosampling program was a cooperative effort between subsistence hunters, the Alaska Native Harbor Seal Commission (ANHSC), the National Marine Fisheries Service (NMFS), the Alaska Department of Fish and Game (ADF&G) Subsistence and Wildlife Conservation divisions, and the University of Alaska Museum.

Since 1994, the diet of harbor seals in PWS has been evaluated through fatty acid analyses of seal blubber (Frost *et al.* 1997). This report describes the date and location of samples collected and summarizes the number of scats and stomachs that have been processed (cleaned and diagnostic parts identified) during the 1990s.

METHODS

Scat collections

From 1990 through 1996, scats were collected opportunistically in conjunction with other harbor seal and sea lion field studies in SE, the Kodiak archipelago, and northern Bristol Bay. In 1997, standardized collections were initiated in these same regions, with defined seasonal collection periods: winter (November through March), spring (April through mid May), and late summer/autumn (August through October). A special effort was made to obtain stomachs and blubber samples from SE hunters to increase sample sizes from that region of the state. Scats were not collected during the pupping and weaning period from mid May through July. In order to have adequate statistical power to detect seasonal, annual, and regional differences in diet, attempts were made to collect 75 scats seasonally from each region.

Individual scats were collected in ziplock bags, labelled, and frozen as soon as possible. Frozen scats were sent to the University of British Columbia where they were put through an elutrification process which separated the skeletal parts from the rest of the feces. Skeletal remains were identified by Pacific Identifications in Victoria, British Columbia.

Stomach collections

Beginning in 1995, harbor seal stomachs were obtained from Alaska Native subsistence hunters through a biosampling program funded by the *Exxon Valdez* Oil Spill Trustees Council and the NMFS. Samples primarily were collected in PWS and SE, although small numbers of samples were collected from other regions of the state. In autumn of 1997, funding for the biosampling program in SE was no longer available. To obtain samples from SE, the ANHSC and the ADF&G Wildlife Conservation and Subsistence divisions worked cooperatively to fund and implement a scaled back biosampling program where harbor seal heads and stomachs were collected from hunters. In January 1998, ADF&G and the ANHSC met with subsistence hunters, local tribes, and community associations in Sitka, Ketchikan, Craig, and Klawock. In these meetings, information was provided on previous samples collected, a network of hunters interested in biosampling was developed, and hunters were trained in sample collection.

Stomach collections were made primarily during the winter months to obtain large enough sample sizes for annual comparisons of winter diet. Stomachs were frozen as soon as possible after collection and then shipped to Juneau where they were thawed and the contents rinsed through a series of progressively smaller sieves, retaining all hard parts. The prey remains were thoroughly dried and then shipped to Pacific Identifications for identification.

Fatty acids

We collected blubber samples through the biosampling program and during capture operations, following the methods of Frost *et al.* (1997). Samples were sent to Sara Iverson at Dalhousie University, Nova Scotia.

RESULTS & DISCUSSION

Seven hundred and thirty-three scats were collected from 1990 through June 1998 in SE, the Kodiak archipelago, and the Bering Sea (Table 1); prey remains have been identified from 687, and 46 are unprocessed. Identified prey include a minimum of 32 genera of fish from 14 families, polychaete worms (Polychaeta), and cephalopods (Cephalopoda). Two hundred and seventeen stomachs were collected throughout the state during 1995-98, of which 140 contained prey (Table 3). The majority of stomachs were collected from seals harvested during the winter months in SE and PWS (Table 4).

Stomachs were collected over a larger geographic area than scats and thus will provide a broader spatial examination of the annual winter diet among regions. Comparison of prey remains in stomachs will also be made between 1990 collections and historical data from the 1970s. During the next reporting year, we will continue to work cooperatively with the ANHSC, ADF&G Subsistence Division, and subsistence hunters to obtain stomachs from seals harvested during winter months in SE; additionally, we hope to obtain an adequate number of stomachs from the Kodiak area. Seasonal scat collections will continue in SE, Kodiak, and northern Bristol Bay. Analyses of the diet data will begin in winter of 1998.

During the current reporting year, 10 blubber samples were collected from both the Kodiak Archipelago and SE; Sara Iverson is currently analyzing these 20 samples. Previous analyses of blubber samples collected from seals in Kodiak, Yakutat, and SE show different fatty acid patterns, suggesting differences in diet among these regions (Iverson and Frost 1997). Additional blubber samples will be collected for fatty acid analyses. At present, information on the variability of fatty acids in seal prey species across regions is not available. Thus, primary prey species from different regions are being collected such that their fatty acid signatures can be related to the patterns found in seals. Blubber samples from the 1970s will be analyzed for fatty acids and results compared with recently collected samples. Our interest in fatty acid research is designed to enhance and expand the work in PWS, and will be performed cooperatively with PWS researchers.

ACKNOWLEDGEMENTS

A number of people and various agencies were involved in scat, stomach, and blubber collections. A special thanks to the Alaska Native hunters who provided stomach and blubber samples, and the ANHSC, NMFS, and ADFG Subsistence Division for help in coordinating these efforts. Staff at Togiak National Wildlife Refuge (USFWS) continue to generously provide time and logistics for the collection, storage, and transportation of scat from northern Bristol Bay. Thanks to the seal and sea lion tagging crews in the Kodiak area and SE for their time spent collecting scats and blubber samples, and to Pamela Rosenbaum (University of British Columbia) for processing

scats. Gay Sheffield compiled the taxonomic key and assisted with database management. I am grateful to Susan Crockford (Pacific Identifications) for identification of prey remains and for assistance with sample tracking. A draft of this chapter was improved by comments from Bob Small.

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Table 1. Year, region, month, sample size, and location of harbor seal scat collected between August 1990 and June 1998.

Year	Region	Months	N	Location
1990	Bering Sea	Aug - Oct	39	Nanvak Bay
1991	Bering Sea	Apr - Jul	35	Nanvak Bay
1991	Bering Sea	Aug - Oct	40	Nanvak Bay
1992	Bering Sea	Apr - Jul	48	Nanvak Bay
1992	Bering Sea	Aug - Oct	81	Nanvak Bay
1997	Bering Sea	Aug - Oct	52	Nanvak Bay
TOTAL	**Bering Sea**		**295**	
1995	Kodiak	Aug - Oct	29	East side of Kodiak Is.
1995/1996	Kodiak	Nov - Mar	3	West side of Kodiak Is.
1997	Kodiak	Aug - Oct	45	East & south side of Kodiak Is.
1997/1998	Kodiak	Nov - Mar	16	East & south side of Kodiak Is.
TOTAL	**Kodiak**		**93**	
1995	Southeast	Apr - Jul	7	Stephens Passage / Frederick Sound
1995	Southeast	Aug - Oct	71	Stephens Passage / Frederick Sound
1995/1996	Southeast	Nov - Mar	94	Stephens Passage / Frederick Sound
1996	Southeast	Apr - Jul	4	Stephens Passage / Frederick Sound
1997	Southeast	Aug - Oct	69	Stephens Passage / Frederick Sound
1997/1998	Southeast	Nov - Mar	65	Stephens Passage / Frederick Sound
1998	Southeast	Apr - Jul	35	Stephens Passage / Frederick Sound
TOTAL	**Southeast**		**345**	

Table 2. A taxonomic key to harbor seal prey identified from scats collected in Southeast Alaska, the Bering Sea, and the Kodiak Island region between 1990 - 1997.

	JAWLESS FISH	Order	Gadiformes	Order	Pleuronectiformes
Class	Agnatha		**codfishes**		**righteye flounders**
Order	Petromyzontiformes	Family	Gadidae	Family	Pleuronectidae
Family	Petromyzontidae	Genus	*Gadus*	Genus	*Atheresthes*
Genus	*Lampetra*	Genus	*Microgadus*	Genus	*Lepidopsetta*
		Genus	*Theragra*	Genus	*Limanda*
	CARTILAGINOUS FISH	Genus	*Merluccius*	Genus	*Microstomus*
Class	Chondrichthyes		**eelpouts**	Genus	*Platichthys*
Order	Rajiformes	Family	Zoarchidae	Genus	*Pleuronectes*
	cat sharks				
Family	Scyliorhinidae	Order	Perciformes		**INVERTEBRATES**
	skates		**sand fishes**		**worms**
Family	Rajidae	Genus	*Trichodon*	Class	Polychaeta
Genus	*Raja*		**ronquils**		
		Family	Bathymasteridae		**squid/octopus**
	BONY FISH		**pricklebacks**	Class	Cephalopoda
Class	Osteichthyes	Family	Stichaeidae		
Order	Anguilliformes		**gunnels**		
	wolffish	Family	Pholidae		
Family	Xenocongridae		**sand lances**		
Genus	*Anarchias*	Family	Ammodytidae		
		Genus	*Ammodytes*		
Order	Clupeiformes		**scorpionfishes**		
	herring	Family	Scorpaenidae		
Family	Clupeidae	Genus	*Sebastes*		
Genus	*Clupea*	Genus	*Sebastolobus*		
			sablefishes		
Order	Salmoniformes	Family	Anoplopomatidae		
	trouts	Genus	*Anoplopoma*		
Family	Salmonidae		**greenlings**		
Genus	*Oncorhynchus*		Hexagrammidae		
	deep sea smelts	Genus	*Hexagrammos*		
Family	Bathylagidae	Genus	*Pleurogrammus*		
Genus	*Bathylagus*		**sculpin**		
	smelts		Cottidae		
Family	Osmeridae	Genus	*Artedius*		
Genus	*Mallotus*	Genus	*Enophrys*		
Genus	*Osmerus*	Genus	*Hemilepidotus*		
Genus	*Thaleichthys*	Genus	*Myoxocephalus*		
		Genus	*Mallacottus*		
Order	Myctophiformes	Genus	*Oligocottus*		
	lanternfishes	Genus	*Triglops*		
Family	Myctophidae		**poachers**		
		Family	Agonidae		
			snailfishes		
		Family	Cyclopteridae		

Table 3. Summary of the number and status of harbor seal stomachs collected by subsistence hunters from October 1995 through June 1998.

	Southeast Alaska	Prince William Sound	Kodiak &Kenai	Aleutian Islands	Bristol Bay	Total all regions
Total no. collected	107	85	11	3	11[a]	217
Stomachs containing prey	68	54	9	2	7	140
Stomachs empty	39	31	2	1	4	77
Stomach contents identified	67	17	3	0	6	93
Stomach contents currently at lab for identification	1	37	6	2	1	47

[a] Includes 4 stomachs from either harbor or spotted seal

Table 4. Summary of harbor seal stomachs collected by region, season, and sex, October 1995 through
June 1998.

	Southeast Alaska	Prince William Sound	Kodiak & Kenai	Aleutian Islands	Bristol Bay	Total all regions
November – March	55	39	3	2	2	101
April – July	7	10	5	0	3	25
August - October	5	5	1	0	2	13
Date unknown	1	0	0	0	0	1
Male	31	24	5	1	0	61
Female	33	23	4	1	5	66
Sex unknown	4	7	0	0	2	13

CHAPTER 4

BLOOD CHEMISTRY AND HEMATOLOGY

OBJECTIVE 9

Provide support to studies by other investigators that will examine the nutritional status, energetic requirements, and food habits of harbor seals.

A COMPARISON OF BLOOD CHEMISTRY AND HEMATOLOGY VALUES FOR HARBOR SEAL PUPS CAPTURED ON TUGIDAK ISLAND AND WITHIN PRINCE WILLIAM SOUND, ALASKA, 1997

Stephen J. Trumble and Michael A. Castellini

University of Alaska Fairbanks
School of Fisheries and Ocean Sciences, 200 O'Neill Building
University of Alaska, Fairbanks, Fairbanks, AK 99775

INTRODUCTION

Populations of marine mammals and seabirds in the Gulf of Alaska and Bering Sea have experienced significant declines over the past two decades. The population declines observed in pinniped species such as the harbor seal (*Phoca vitulina*), Steller sea lion (*Eumetopias jubatus*), and northern fur seal (*Callorhinus ursinus*) are especially notable (Pitcher 1990, Loughlin *et al.* 1992). For example, prior to the *Exxon Valdez* Oil Spill harbor seal population declines of up to 85% had been reported from Tugidak Island (Pitcher 1990), and declines also have occurred in the eastern Bering Sea and Aleutian Islands (Hoover-Miller 1994). A similar reduction in Steller sea lions numbers in the Gulf of Alaska has forced the National Marine Fisheries Service (NMFS) to list this species as endangered under the Endangered Species Act.

In attempts to explain the observed declines, many hypotheses dealing with environmental and anthropogenic factors that may affect pinniped populations have been tested. The human based factors that could play a role in marine mammal biology include subsistence harvesting, fishery interactions, exposure to pollutants, and human disturbance (Sease 1992, Lowry *et al.* 1996), while environmental factors include long-term environmental changes in the Bering Sea and Gulf of Alaska (Hoover-Miller 1994). At this time, anthropogenic factors do not appear to be the primary cause for the widespread decline in pinniped populations (Lowry *et al.* 1996). However, in an attempt to determine if animal condition can be correlated with changes in prey availability, studies compared physiological and pathological parameters between stable and decreasing adult harbor seal populations in Alaska (Fadely and Castellini 1996). There is some evidence that suggests that the declining harbor seal population in Prince William Sound are possibly exposed to some physical, physiological, or environmental stress (Zenteno-Savin *et al.* 1997).

Changes in prey availability due to natural or anthropogenic causes can be reflected in the body condition or nutritional status of top trophic-level consumers, such as harbor seals. Historically, primary prey items of harbor seals in Alaska have been large pollock (*Theragra chalcogramma*), octopus (*Octopus* sp.), capelin (*Mallotus villosus*), eulachon (*Thaleichthys pacificus*), and herring (*Clupea pallasii)* (Pitcher 1980). Recent studies using fatty acid signatures to determine the diet of harbor seals in the Gulf of Alaska have indicated that large pollock remain a primary prey item (Iverson *et al.* 1997), but these studies have been unable to quantify the relative importance of forage species in the diet. Shifts in prey abundance or prey quality, may cause stress to individual animals, which can be detected by morphological or physiological measurements. However, indices used to

assess body condition may also vary with season, age, or gender (Pitcher 1986, Trites and Bigg 1992, Renouf *et al.* 1993, Fadely *et al.* 1997) independent of foraging ability or prey availability. Therefore, normal ranges of body size, shape and blubber distribution must be quantified for all age classes before useful interannual comparisons can be performed. Blood chemical and hematological parameters have also been shown to change significantly in response to environmental or nutritional effects (Seal *et al.* 1975, Geraci *et al.* 1979, McConnell and Vaughan 1983, Kuiken 1985, Roletto 1993, Thompson *et al.* 1997). Chemical profiles and complete blood counts can identify potential homeostatic imbalances in organ systems or metabolic pathways if the effects of non-health related variation can be quantified (Payne and Payne 1987, Kerr 1989, Castellini *et al.* 1993).

The study by Fadely *et al.* (1997) in the Gulf of Alaska suggested although variability exists among adults (location, age, gender, handling), some blood chemistry parameters differed among the regions and seasons. However, the vast majority of adults sampled appeared healthy. These health data coincide with recent trend count data which suggests that harbor seals in SE Alaska appear to be stabilizing or increasing (Small *et al.* 1998). Population counts on Tugidak Island appear to be increasing after several years of decline (Small *et al.* 1998). Trend count data in PWS indicate a continued decline of about 6% per year (Frost *et al.* 1997).

While few studies have suggested that the nutritional status of the mother may impact her pup (Ross *et al.* 1995), few studies have attempted to collect pup blood during the lactation period in order to correlate blood chemistry and hematology profiles with the health of the pup population. While Fadely *et al.* (1997) suggests that blood values were sensitive to environmental changes, many blood factors differed between adults and juveniles, and also state that these trends are consistent with dietary differences.

Construction of plasma chemistry and hematological reference ranges from 245 free-ranging adult and sub-adult harbor seals collected between 1989-95 in the Gulf of Alaska has been an invaluable tool for assessing the health of harbor seals in Alaska (Fadely *et al.* 1997). Although a small number of harbor seal pups have been captured during past studies, this is the first study to focus on the health of the pup population in Alaska waters.

The short-term objective of our project was to collect hematological data to establish reference ranges of blood chemistries and hematologies in harbor seal pups captured within PWS and Tugidak Island and determine variation attributable to gender and location. The second, long-term, objective was to compare blood and morphological indices of health and condition to examine interannual changes, potential spill-related impacts, and to help interpret changes in population status.

METHODS

Seal Capture Locations

Within Prince William Sound, 1997 field work was conducted from 25 June through 7 July using chartered vessel, the *Pacific Star*. Within PWS, harbor seals were live-captured by net entanglement using methods previously described by Frost *et al.* (1995). After removal from the net, seals were transported to ship or shore, and were restrained manually (pups) or chemically by intramuscular injection with a ketamine/diazepam mixture (adults). Weights were measured (±0.1 kg) with a hanging electronic load cell balance (Ohaus Model I-20W), and blood samples were

collected prior to any other invasive procedures. Morphometric measurements were then completed and other procedures performed as detailed in Frost *et al.* (1995) and Lewis (1995). Seals were categorized into age classes of pup, yearling, subadult or adult on the basis of size and time of year. Seals were held for variable periods to recover from drugging effects before being allowed to return to water.

On Tugidak Island, harbor seal pups were captured from 25 June to 3 July 1997. Researchers captured hauled out harbor seal pups opportunistically usually at low tide using large salmon nets or hoop nets. Once captured, the pups were manually restrained, weighed with an electronic hanging scale, morphometric measurements gathered and blood samples drawn for laboratory analysis.

In conjunction with this study, the Alaska Department of Fish and Game fitted harbor seals captured at Tugidak Island with Satellite Linked Time Depth Recorders to determine dive behavior and movements.

Blood Collection, Processing and Analyses

Blood was sampled from the intervertebral extradural vein using 1.5 or 3.5 inch 18 ga. spinal needles (Monoject) into various blood collection tubes (Vacutainer). Typically up to 40 mL of blood were collected for serum and plasma for complete blood counts (CBC) and hormone analyses. In the field, blood hematocrit (% red blood cells by volume) was measured using a portable centrifuge (Compur M1100). Samples of whole blood were pipetted into Drabkin's reagent for hemoglobin analysis. Blood was then centrifuged and plasma, serum, and whole blood samples were frozen in liquid nitrogen for later laboratory analyses. Blood smear slides were made for determination of differential leukocyte counts.

Blood Chemistries

Blood samples from PWS and Tugidak Island were prepared in the field for shipment and ultimately transferred to the University of Alaska for further analysis. Plasma samples were sent to Fairbanks Memorial Hospital (FMH) for assessment of "standard" health indices and analyzed at our laboratory for indicators of dehydration, nutritional status, and hormonal imbalance.

Standard panels that assay plasma sodium, potassium, chloride, phosphorus, blood urea nitrogen (BUN) creatinine, cholesterol, direct and total bilirubin, total protein, albumin, globulin, alkaline phosphatase, glucose, lactate dehydrogenase (LDH), gammaglobulin transferase (GGT), creatinine phosphokinase (CPK), aspartate aminotransferase (AST) and alanine aminotransferase (ALT) were performed by automated machine analysis at the Fairbanks Memorial Hospital (FMH) using an Ektachem Analyzer. Additionally, concentrations of hemoglobin were determined using standard kits from Sigma Chemical Co. and performed in our laboratory. Plasma hormone levels, nutritional status and dehydration indices from samples collected during 1997 are ongoing. Complete blood counts of white and red blood cells, platelet and differential white blood cell counts were performed by technicians at FMH from blood collected in EDTA collection tubes using a Coulter Model S-Plus-4 Counter, and from blood smears produced in the field.

Morphometric Measurements and Analyses

In addition to mass, lengths and girths were measured. Standard length (SL; straight-line distance between tip of nose and tip of tail) and total curvilinear length (CL; distance between tip of nose and tip of tail with measuring tape laying on animal) were measured (± 1 cm) with the seal positioned dorsal side up. Blubber thickness was measured in pups captured within PWS (dorsal, lateral, ventral) at each girth measurement location (except at ear girth ring) using a portable ultrasonic unit (Scanoprobe II, Model 7310, Scanco, Inc.), similar to Gales and Burton (1987).

Statistics

Blood chemistry, hematological, and morphological parameters were analyzed to determine if statistical differences were evident, for transformed data, among region and sex for all harbor seal pups. No adults were captured at Tugidak Island, therefore comparisons to PWS adults were not performed. Reference ranges for blood chemistries and hematologies were calculated as being within two standard deviations of the mean (Kerr 1989). Non-normally distributed data were first arcsin or square-root transformed (Zar 1984). Values presented in the text are means with standard deviations.

Plasma chemistry and hematology panel data from all pups sampled during 1997 were screened for outliers based in calculated reference range criteria (Fadely *et al.* 1997). Expected frequencies of numbers of outliers per seal were calculated from a binomial expansion of $(p+q)^k$, where p is the probability of an outlier (0.05) and q was the probability of no outlier (0.95), and k is the number of variables (31).

RESULTS

Data Collection

Blood chemistry and hematological values measured from harbor seals from two geographic sampling regions within the Gulf of Alaska were combined to calculate reference ranges (Tables 1 and 2). A large proportion of blood samples taken from pups at Tugidak Island and PWS were lipemic (40%), thus at the time of this report all samples were used in the analysis of reference ranges. At the time of this report haptobglobin data (health/stress indicator) and whole blood water were not completed.

Fifty harbor seals (18 pups and 32 adults) were captured within PWS between 27 June and 1 July 1997, while 20 pups (blood taken from 18 pups) were captured at Tugidak Island between 25 June and 2 July 1997. Data collected from 18 pups from each region were used in statistical comparisons. Samples were homogeneous among males and females (Tugidak Island 10 males, 8 females: PWS 8 males and 10 females). Normality was determined for each parameter by Kolmolgorov-Smirnoff Probability Test ($P<0.05$) along with a Q-Q plot. Data were transformed to correct for non-normality. Alpha (α) levels were placed at 0.05 for all statistical tests.

Morphology

Although no gender-specific difference was detected in mass, there was a significant difference in pup mass among regions, with PWS pups significantly heavier at time of capture (PWS, 29.9 Kg; Tugidak, 26.6 Kg, P = 0.007). There was no statistical difference in standard length among gender or regions (Tugidak Island mean = 93.73 cm, PWS mean = 94.0 cm; P = 0.62).

Hematology

Hematology values for pups from Tugidak Island and PWS revealed significantly greater hemoglobin levels for pups captured at Tugidak Is (P = 0.014, Table 1). Also, there was a gender-specific difference in Hb levels for pups captured on Tugidak Island with greater levels found in females (27.4 g/dL, males 25.4g/dL). Monocyte levels were significantly greater in male pups when compared to female pups on Tugidak Is (males 5.50%, females 2.71%, Table 1). Monocyte levels were also higher, though not significantly, in PWS pups.

Blood chemistry

Five of 22 blood chemistry values were statistically higher for harbor seal pups on Tugidak Island, while only creatinine was statistically higher for pups captured within PWS (Table 2). Blood chemistry variables that were significantly elevated in Tugidak island pups included sodium, phosphorus, blood urea nitrogen, creatinine, albumin, and the enzyme gammaglutamyl transferase (GGT). Of the 22 variables studied, 8 (36%) exhibited non-normal distributions.

Statistical Outliers

Reference ranges were calculated as $\pm$ 2 SD from the pooled mean of blood and hematology parameters (Tables 1 and 2). Out of the harbor pups seals captured, forty-four percent (44%) of harbor seal pups on Tugidak Island had at least one statistical outlier in blood chemistry or hematological variables, whereas PWS pups revealed a greater percentage (65%; Figs. 1 and 2). The percentage of pups with at least four outliers (33% PWS, all female; 11% Tugidak Island) was greater than that predicted by a binomial expansion model.

DISCUSSION

Blood Chemistry and Hematology

Of the studies presenting plasma chemical and hematological reference ranges for harbor seals, this is the first study to compare harbor seal pups from various geographic locations. Preliminary screening of blood panels based on calculated reference ranges did not present indications of population-level chronic diseases, consistent with findings from serological survey data for common phocid diseases (Frost *et al.* 1995, Lewis 1995). Without histological determinations of disease state, diseased seals may have been included in our reference ranges. The assumption in setting a normal reference range within two standard deviations is that outliers will be

mostly comprised of potentially physiologically compromised animals, although this may not hold true (Kerr 1989).

Development of reference ranges appropriate for free-ranging Gulf of Alaska harbor seal pups permits examination of veterinary blood panels with more confidence than would have been possible utilizing ranges published with adult values, small sample sizes, or from captive or free-ranging seals of other geographic regions.

Harbor seal pups captured from Tugidak Island and PWS revealed gender-specific differences in hemoglobin and monocyte values. Female pups on Tugidak Island had greater Hb levels than their male cohorts. While low Hb concentration may indicate anemia, elevated levels may suggest dehydration. However, it is important to acknowledge that these levels may be a function of sample size and/or development of the pup. Monocyte levels were significantly greater in males versus females on Tugidak Is (Table 1). These data may suggest some inflammatory response or impaired immune function, although at this time it would be difficult to ascertain without further tests. It is immediately important to note that none of these differences indicate diseased seals, as these activities were all within the normal reference ranges we established.

Although not statistically significant, trend differences among PWS and Tugidak Island harbor seal pups are apparent in several blood chemistry variables (Fig.1b, 1d, 1I, 1j). Although too early to link with nutrition, declining herring stocks in the western-southwestern region of PWS have been documented (Brown *et al.* 1996). Whether these diet shifts for the pre-lactating female represent subtle levels of food limitation is not clear since the condition indices for nursing harbor seal pups infer relatively good condition during this period. Thompson *et al.* (1997) suggested that some hematology parameters (e.g MCV and Hb) did not differ between seals in good or poor condition, only between seals sampled during 'good' and 'poor' clupeid abundance years. Since seals in this area tend to be very localized in their foraging patterns (Frost *et al.* 1995), further analyses should focus on updating differences in prey abundance among regions.

Of the blood chemistry variables, sodium, phosphorus, BUN, albumin, and GGT were significantly different among regions. Tugidak Island pups had significantly greater sodium levels than pups captured within PWS. It has been revealed that sodium levels fluctuate with hydration state of mammals. This may be linked to the nutritional state of the mother. However, at this time we have no evidence to make this connection. Further test are being done on the hydration state of the pups.

Phosphorus levels were also significantly greater in Tugidak Island pups. Phosphorus concentrations in the plasma may be indicative of early development and bone growth (Kerr 1989). Pups captured within PWS were on average larger and possibly older, which may explain the decline in phosphorus levels in Tugidak Island pups. Phosphorus levels in harbor seal adults appear to be much lower than when compared to pups captured in PWS and Tugidak Island (Fadley 1997).

BUN levels, which reflect protein intake and renal excretory capacity, were greater in pups captured at Tugidak Island. Interestingly, elevated BUN levels appear also to be a function of hydration state, as is sodium. Bossart and Dierauf (1990) stated that BUN ranges for captive harbor seal adults is 25-97 mg/dL, whereas Fadley *et al.* (1997) established a mean of 43 mg/dL in adults captured with PWS. The BUN levels for all pups captured fall with these values and until further tests can confirm any nutritional stress, they should be viewed as normal.

Albumin, a serum protein, was also significantly greater in pups from Tugidak Island. Bossart and Dierauf (1990) suggest that increased albumin levels may indicate dehydration in marine mammals, whereas Kerr (1989) states that a single protein fraction alone is rarely clinically

significant by itself. Although decreased levels of albumin may suggest malnutrition, there are no data to support this hypothesis in pups captured within PWS.

GGT, which was also elevated when compared to PWS pups, participates in the transfer of amino acids across cellular membranes and in glutathione metabolism. The enzyme level is usually an indicator of liver or muscle disease. Because of the non-specificity of enzymes, it is clinically more significant when suites of enzyme levels change, which was not the case in this study thus far.

Outliers

The binomial expansion model was used as a method to determine expected frequencies of individual outliers and thus population level diagnosis of health status for harbor seal pups in the Gulf of Alaska. It appears that the PWS pups had a higher incidence of "clinically significant" outliers ($\geq$4, 33%). Interestingly, all pups captured within PWS with four of more outliers were female. These data, along with data collected during the 1998 season, may prove valuable as Frost *et al.* (1997) suggests that the population of PWS harbor seals is still declining.

CONCLUSION

Currently, we can not infer any environmental link to the regional differences found among harbor seal pups in this study because of temporal biases associated with these data, and we did not have the sample size to omit lipemic blood samples. However, it is interesting that the blood variables which were statistically significant may be linked to a possible nutritional source. Also, while difficult to interpret at this time, outliers pointed to PWS as the region with possible "clinically significant" harbor seal pups. Blood chemistry and hematological data have been collected for the 1998 season at Tugidak Island and within PWS, and will be incorporated. Also, comparison of data collected from rehabilitated harbor seal pups at the Alaska SeaLife Center with free-ranging pups from Tugidak Island and PWS will also elucidate developmental or nutritional status.

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Table 1. Harbor seal pup reference ranges for hematology values and differential leukocyte counts collected at Tugidak Island (n = 18) and Prince William Sound (n = 18) during summer 1997.

Variable	Tugidak Isla Means	PWS Means	P value	Reference Mean	SD	Reference Range
Hematocrit[a]	0.53	0.55	ns	0.54	0.036	0.47 - 0.61
Hemoglobin (g/dL)[b]	26.1	23.1	0.014	24.7	3.3	18.1 - 31.3
MCHC (g/L)[a]	0.43	0.42	ns	42	4.7	32.6 - 51.4
PMN (%)[a]	63.2	61.3	ns	61.8	13.8	74.1 - 89.4
Lymphocytes (%)[a]	29.1	27.5	ns	29.0	11.4	6.3 - 51.8
Monocytes (%)[ac]	3.7	6.4	ns*	5.4	4	0 - 13.5
Eosinophils (%)[ad]	2.3	2.2	ns	2.1	1.4	0 - 4.8

[a] Tugidak Island and PWS pup data were analyzed among regions and sexes and pooled if not statistically different

[b] Significant lower values among males than female pups on Tugidak Island ($p<0.05$)

[c] Statistics calculated from square root transformed data.* Significant higher monocyte values for males versus female pups on Tugidak Island ($P=0.027$)

[d] Non-normal distribution (Q-Q plot, Kolmolgorov-Smimoff Probability Test: $p<0.05$), statistics calculated using non-parametric tests

Table 2. Harbor seal pup blood chemistry (N=35) parameters collected at Tugidak Is (n=18) and Prince William Sound (n=17) during the summer of 1997. Reference ranges are ± 2sd.

Variable	Tugidak Mean	PWS Mean	P	Reference Mean	SD	Reference Range
Sodium (mmol/L)[a]	144.6	143.6	0.026	144.1	1.3	141.4 - 146.8
Potassium (mmol/L)	3.9	3.7	ns	3.8	0.3	3.2 - 4.3
Chloride (mmol/L)	102.6	103.4	ns	103.0	2.0	99.1 - 107
Glucose (mg/dL)	148.3	155.6	ns	151.8	15.9	120.1 - 183.6
Phosphorus (mg/dL) [c g]	7.4	6.2	0.008	6.8	1.2	4.3 - 9.3
Calcium (mmol/L)	10.7	10.6	ns	10.6	0.5	9.5 - 11.7
Blood Urea Nitrogen (mg/dL) [c e]	40.8	30.7	0.001	35.9	9.1	17.6 - 54.2
Creatinine (mg/dL)	0.70	0.75	0.001	0.72	0.1	0.5 - 1.0
BUN:Creatine [f]	60.9	41.5	ns	51.5	15.9	19.6 - 83.4
Cholesterol (mg/dL)	341.2	356.2	ns	348.4	93	162.6 - 534.3
Total Bilirubin (mg/dL) [c]	0.39	0.51	ns	0.45	0.2	0 - 0.85
Direct Bilirubin (mg/dL) [c]	0.42	0.43	ns	0.425	0.1	0.23 - 0.63
Total Protein (g/L)	70.2	68.0	ns	69.0	5	59.0 - 79.0
Globulin (g/L)	35.0	34.3	ns	23.0	1.3	0 - 47.8
Albumin (g/L)	36.0	33.7	0.01	35.0	2.4	29.9 - 39.5
Albumin:Globulin	1.04	1.0	ns	1.02	0.1	0.8 - 1.2
Alkaline Phosphatase (iu/L) [c]	448.8	339.3	ns	395.6	181.5	32.5 - 758.7
Asparatate Aminotransferase (iu/L) [c]	98	95.6	ns	96.8	47.8	1.2 - 192.4
Alanine Aminotransferase (iu/L)	24.6	34.2	ns	29.2	13.8	1.6 - 56.9
Creatine Phosphokinase (iu/L) [c]	1406	1043	ns	1230	1798	0 - 4827
Gammaglutamyl Transferase (iu/L)[b]	21.7	20.5	0.025	21.1	8.6	3.7 - 38.4
Lactate Dehydrogenase (iu/L) [c]	3873.3	3783	ns	3829	1127	1576 - 6083

[a] Log-transformed data reveal significantly higher sodium levels in female pups than male pups at Tugidak Island (n = 8, p = 0.045)
[b] n = 7
[c] Non-normal distribution (Q-Q plots, Kolmolgorov-Smimoff Probability Test (p <0.05), statistics calculated using two sample non-parametric tests
[d] Data were log transformed.
[e] Data were square root transformed
[f] Data were arcsine transformed
[g] Data were square root transformed.
*ns = not statistically significantly

Figure 1. Reference ranges and outliers shown for selected blood parameters for harbor seal pups captured during 1997 within PWS and on Tugidak Island.URR = upper refernce range, LRR = lower reference range.

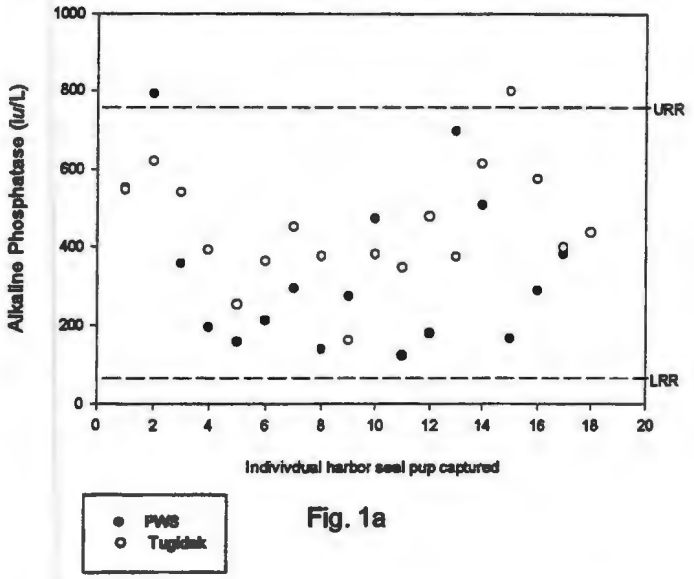


Fig. 1a

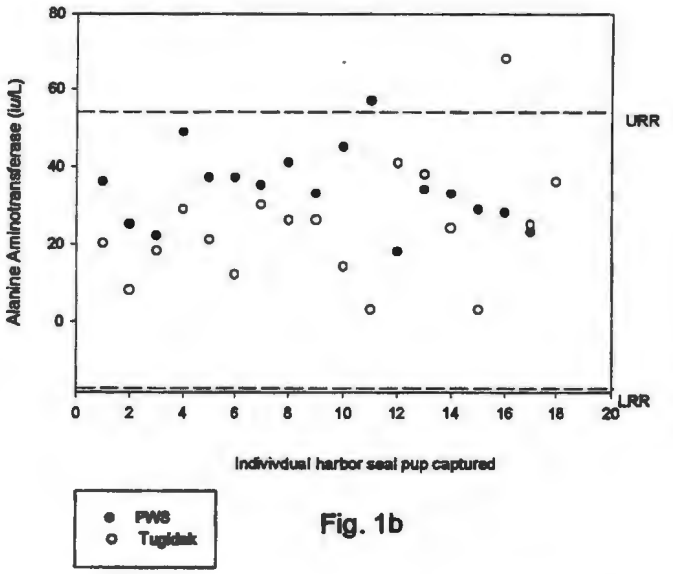


Fig. 1b

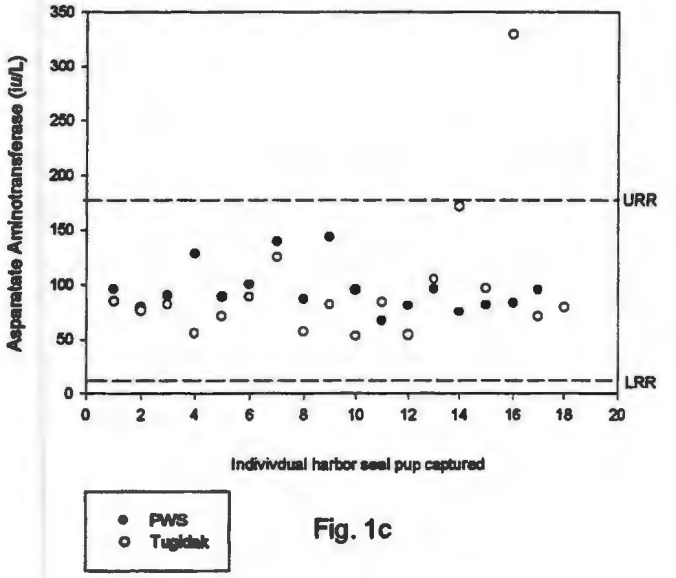


Fig. 1c

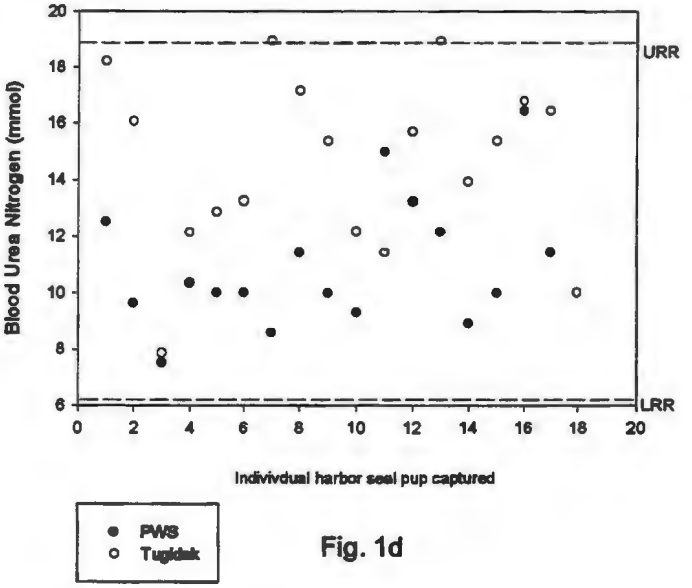


Fig. 1d

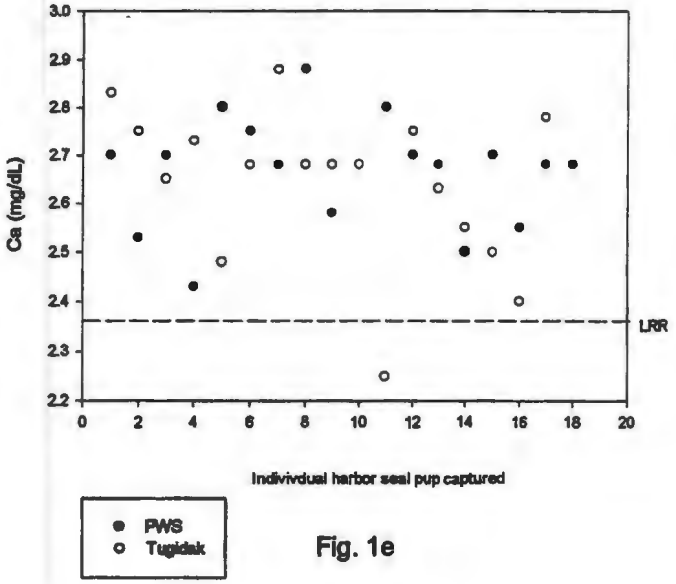


Fig. 1e

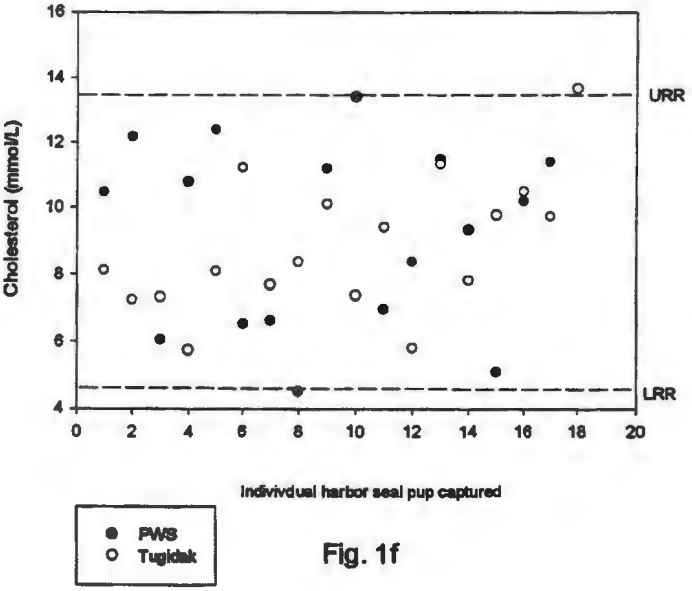


Fig. 1f

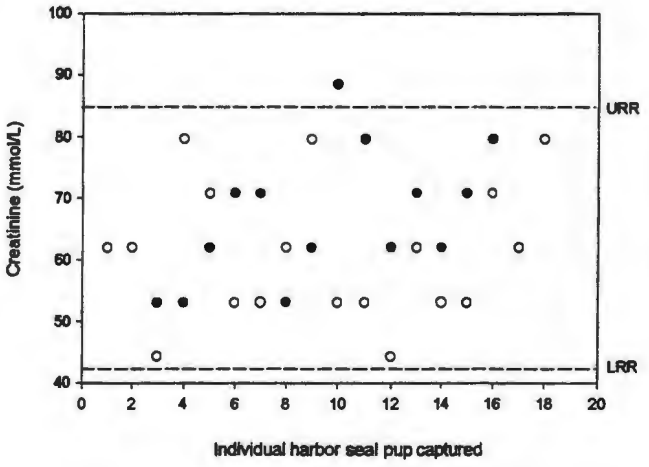


Fig. 1g

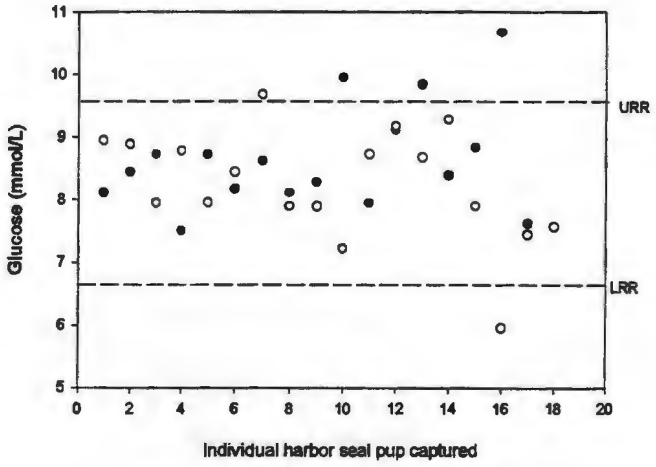


Fig. 1h

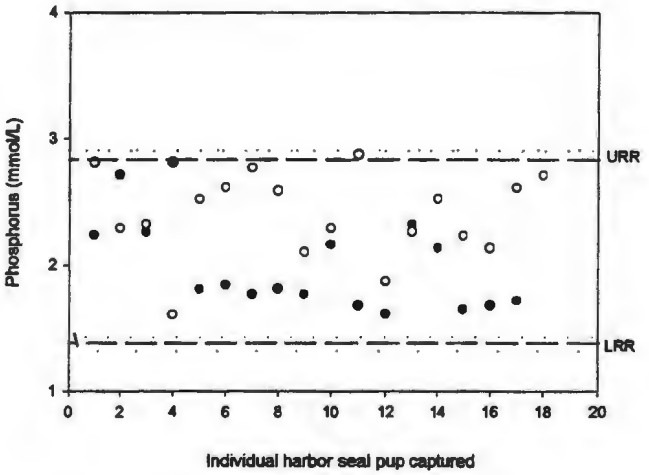


Fig. 1i

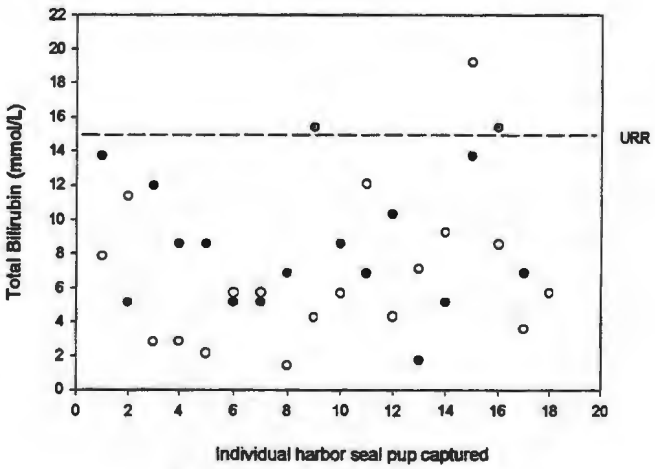


Fig. 1j

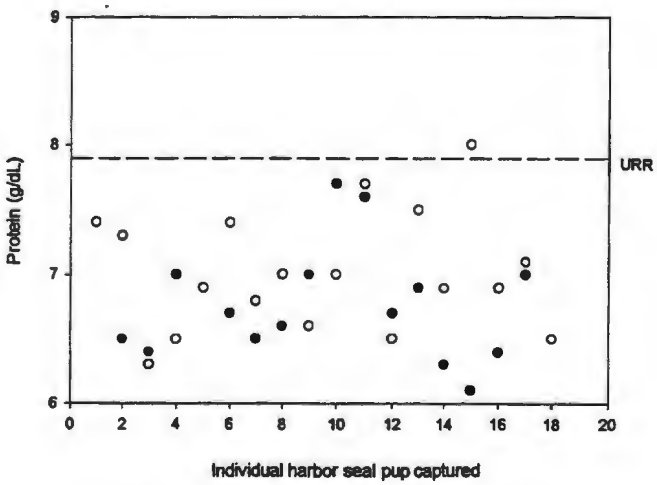


Fig. 1k

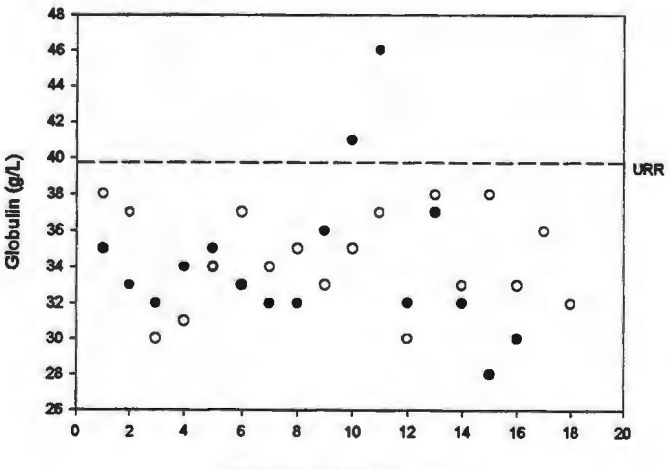


Fig. 1l

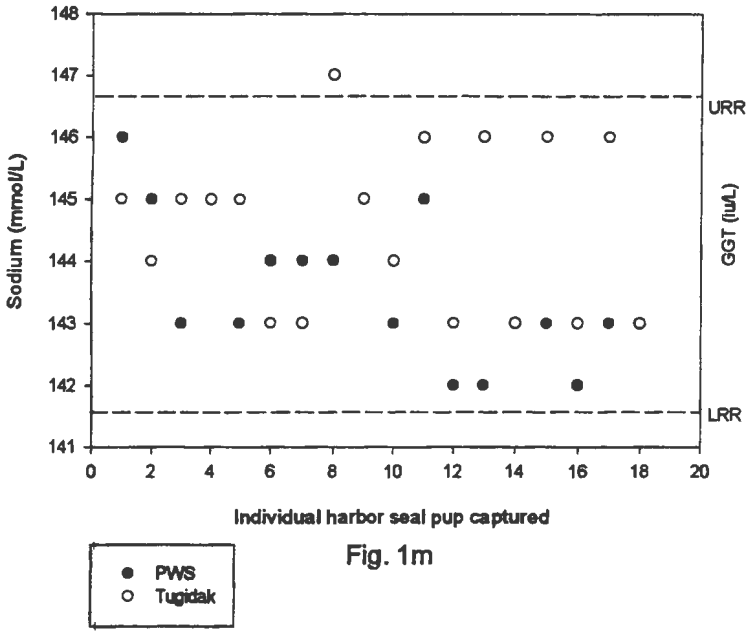


Fig. 1m

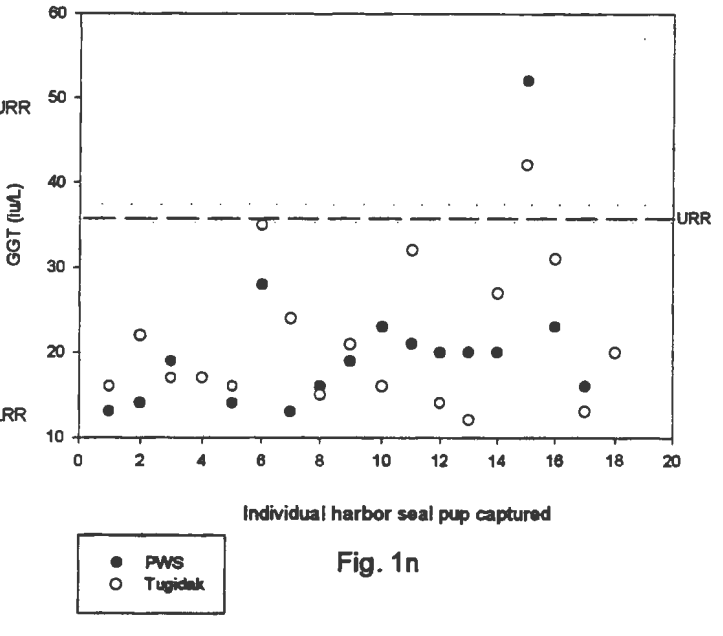


Fig. 1n

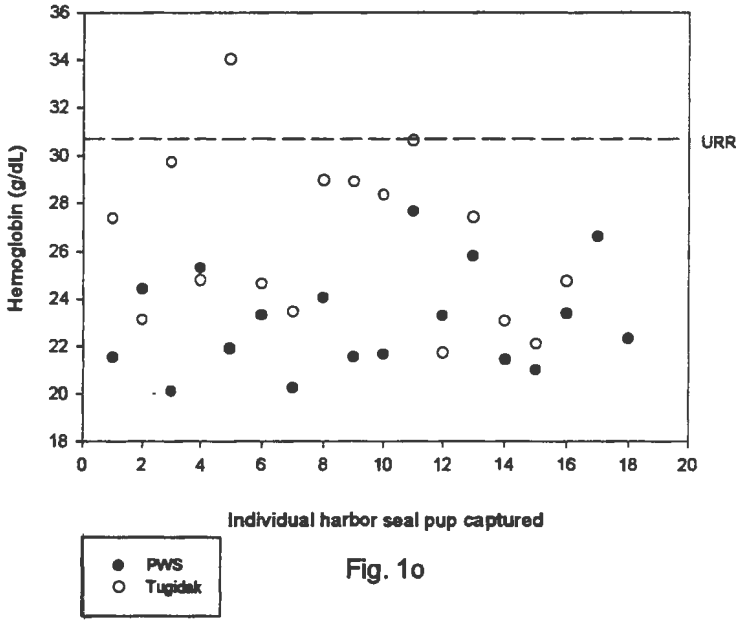
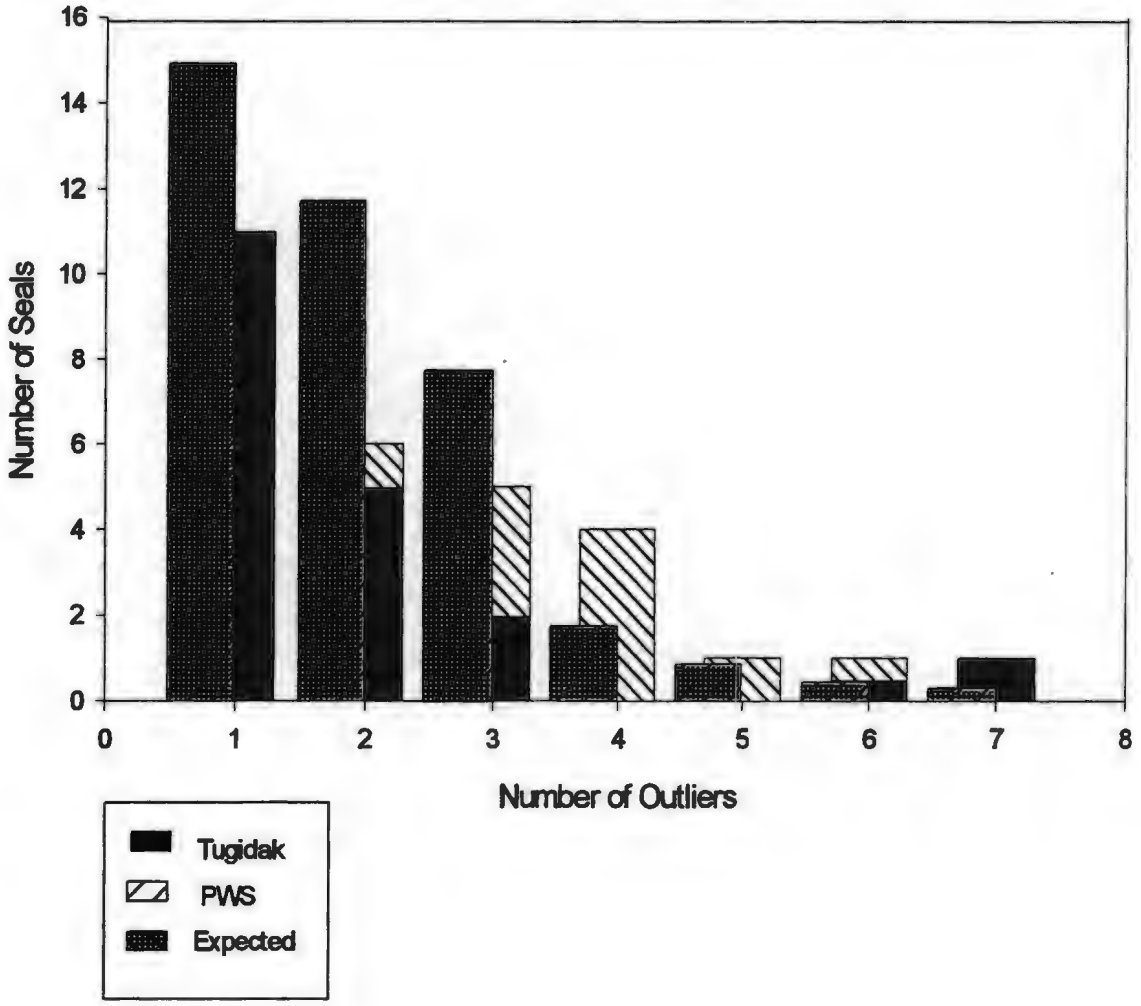


Fig. 1o

Figure 2. Expected outlier frequency versus observed outlier frequency for all blood chemistry data for pups captured during the 1997 season in PWS and Tugidak Island.



CHAPTER 5

CONTAMINANTS

OBJECTIVE 10

Compile information on contaminants in Alaskan harbor seals, evaluate adequacy of current information and make recommendations for future contaminant work

ALASKA HARBOR SEAL CONTAMINANTS: A REVIEW

Rebecca S. Papa and Paul R. Becker

National Institute of Standards and Technology
U.S. Department of Commerce, NIST Charleston Laboratory
219 Fort Johnson Road, Charleston, SC 29412

PREFACE

The numbers of harbor seals (*Phoca vitulina*) have declined steadily and substantially over the last two decades in the Central and Western Gulf of Alaska, including Prince William Sound. Although the reasons for this decline have not been identified, hypotheses have included fishery interactions, changes in availability of food resources, human harvests, disease, increase in predation, increase in disturbance, and pollution. The decline of the harbor seals in this region of Alaska has coincided with the decline in the numbers of the Steller sea lion (*Eumatopias jubatus*), suggesting common reasons for the decrease in numbers of both pinniped species.

Although the presence of contaminants has been suggested as one possible causative factor in the decline of both the harbor seal and Steller sea lion, very little information is readily available on contaminant concentrations in these animals. As an initial step in the development of a database that can be used to define the types of studies needed to address the possible role of anthropogenic contaminants in the decline of harbor seals, existing data and information on levels of contaminants in the harbor seals of Alaska, the contiguous U.S., and other areas of the world were reviewed. This report provides references and current scientific literature, as well as "gray" literature and unpublished databases.

Although the results of past research and monitoring in Alaska were emphasized, comparative information was available from Canada, other areas of the North Pacific, Northern Europe (particularly the Baltic Sea region), and the North Atlantic and is included in this report. Information on other marine mammal species is also included only as it lends to the interpretation of the harbor seal data.

This report is divided into two sections: (1) a synthesis of information based on the review, and (2) tables that summarize the published data. An annotated bibliography has also been completed, which is divided into two parts, a database for references containing vital information on harbor seals, both in Alaska and other parts of the world, and a second database that includes other supplemental information, such as research relating to contaminants and other marine mammals, including other pinniped species and cetaceans. Currently, 432 references are entered, each including an abstract and a keyword index. Many of the "gray literature" reports have no abstracts; therefore, abstracts have been written for inclusion in this bibliography. The great majority of the information on contaminants and their potential health effects on harbor seals in this volume (47%) is derived from European studies. Additional information is derived from studies of other pinniped species and, in some cases, small cetaceans. The bibliography will be published in the National Institute of Standards and Technology (NIST) report series, and diskettes containing the current bibliographies can be obtained by contacting the second author.

DISCLAIMER

Certain commercial equipment or instruments are identified in this paper to specify adequately the experimental procedures. Such identification does not imply recommendations or endorsement by the NIST nor does it imply that the equipment or instruments are the best available for the purpose.

SECTION I: SUMMARY OF THE AVAILABLE DATA

BACKGROUND

Harbor seal (*Phoca vitulina*) distribution includes temperate and subarctic coastal waters of the North Pacific, North Atlantic, and contiguous seas. In Alaska, harbor seals inhabit the coastal areas and offshore islands from Dixon Entrance to Kuskokwim Bay and Nunivak Island (Figure 1). They are distributed in small groups (25-250 animals) along the shorelines of southeast Alaska, the south side of the Alaska Peninsula, the Aleutian Islands, and northern Bristol Bay; and in larger groups (>500 animals) in fjords with tidewater glaciers in southeast and southcentral Alaska, and in major estuaries (Hoover-Miller, 1994). These animals occur primarily in coastal waters within 20 km of shore, often aggregate in estuaries and protected waters, and are thought to have strong affinity to specific haulout areas. Haulout sites include sand beaches, tidal mud flats, offshore rocks and reefs, and man-made objects. Harbor seals are sedentary animals that feed, reproduce, and rest near or on shore and are top-level trophic consumers. Because harbor seals feed at high trophic levels (fish, octopi, etc.), they have the potential for relatively high organochlorine contaminant concentrations in their tissues and are good indicators of bioaccumulation.

Anthropogenic contaminants and their impacts on marine mammals have become a widespread concern among biologists over the last several decades. Organochlorine pollutants (e.g., dichlorodiphenyltirchloroethane (DDT), polychlorinated biphenyls (PCBs), chlordane, and toxaphene, dieldrin, etc.) constitute a multitude of compounds that were not present in the natural environment before the first quarter of the 20th century. It wasn't until the 1960s that these contaminants were first detected in tissues of marine mammals (Holden and Marsden, 1967). Because organochlorine compounds are lipophilic, toxic, and easily stored in body fats of animals, most marine mammals, which feed at or near the top of the food web, are excellent monitoring tools for determining bioaccumulation of contaminants and long-term effects concerning global pollution associated with industrialization.

The presence of contaminants has been suggested as one possible cause for the decline of several marine mammals species, including the harbor seal (*Phoca vitulina*). The number of harbor seals has declined steadily and substantially over the last two decades in the Central and Western Gulf of Alaska, including Prince William Sound and the Aleutian Islands. The concern with the decline in this region of Alaska has been magnified because it has coincided with the decline in the Stellar sea lion (*Eumatopias jubatus*) population, suggesting common reasons for the decrease in numbers of both pinniped species. With the insufficient amount of information currently available on contaminant concentration loads in harbor seals in Alaska and the extensive increase in human industrial activities that this region has been experiencing, it is imperative that a database be established. This database can be used to define what studies need to be conducted to evaluate what role anthropogenic contaminants have on the decline of harbor seals. As an initial step in the development of this database, existing data and literature on contaminants in the harbor seals of Alaska, as well as other regions, have been compiled and reviewed.

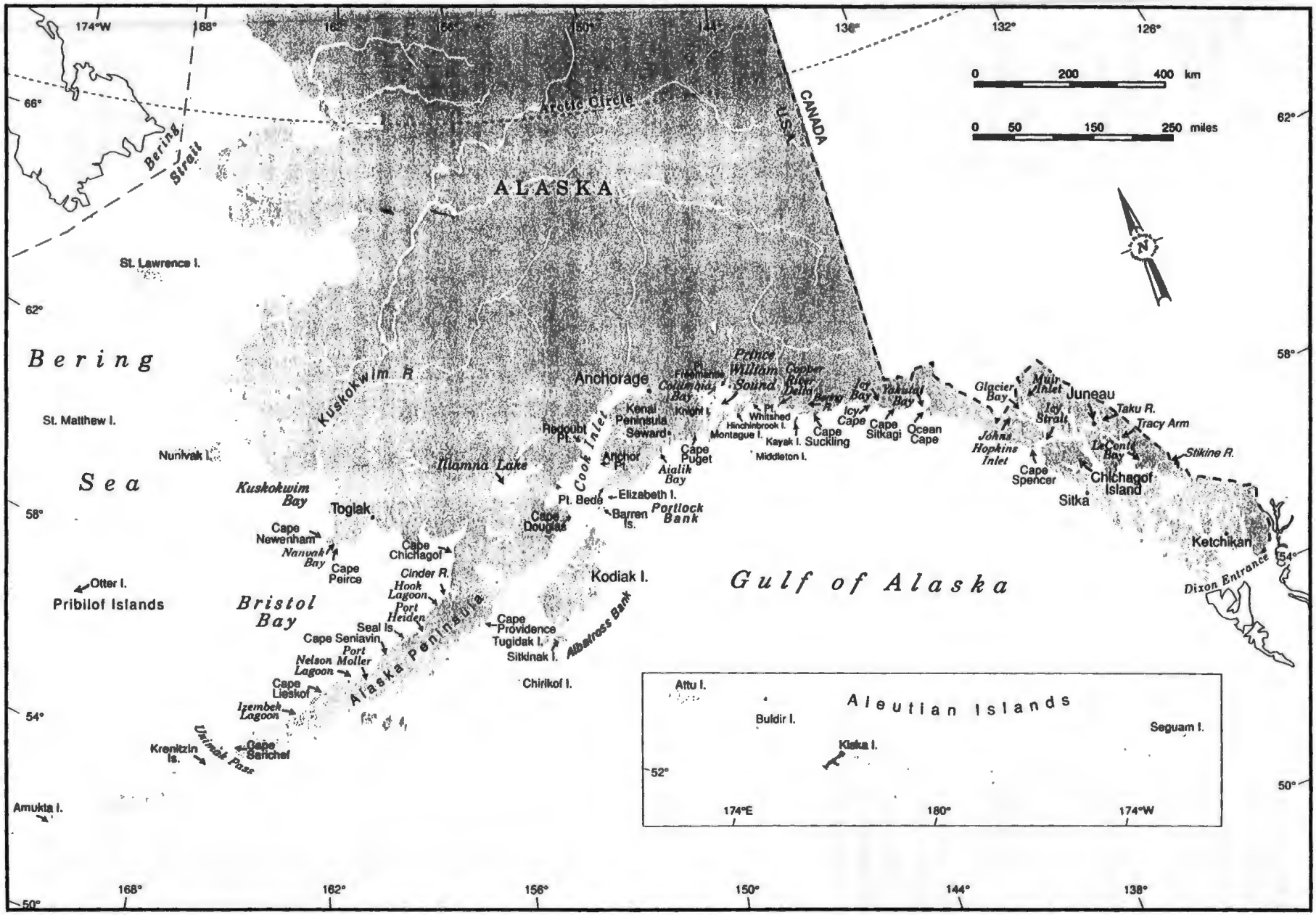


Figure 1. Harbor seal (*Phoca vitulina*) distribution in Alaska (taken from Hoover-Miller, 1994).

The amount of literature available on harbor seals is concentrated in areas of Northern Europe, particularly the Baltic Sea region, as well as Canada and the North Atlantic. From this, scientists can only suggest that organochlorines and other contaminants may play a role in toxicological and physiological effects, such as reproductive dysfunctions and immunosuppression, and could be a causative factor in the decline of these animals in Alaska.

Currently, 152 references have been entered into the bibliography that pertain to vital information on harbor seals worldwide and approximately 20% of those include data for Alaskan harbor seals. The literature that is available from Alaska is limited and almost all previous research has concentrated on harbor seals from Prince William Sound, Southeast Alaska, and Kodiak Island. Earlier reports focused primarily on persistent organic pollutants, such as DDT and PCBs, but more recently heavy metals, particularly mercury, and radionuclides have also become a concern as well as recent oil spills, including the 1989 *Exxon Valdez* spill. Because of the natural occurrence of heavy metals and some petroleum hydrocarbons, specifically those compounds found in crude oil, it is even more difficult to assess the effects they have on harbor seals. With the insufficient amount of data available, the contaminant concentration loads in Alaska harbor seals are not well understood, which makes it essential that a database be compiled that can help scientists to evaluate the information that is available to determine the impact these compounds do have on the health of harbor seals in Alaska.

HEAVY METALS

Heavy metal concentrations in marine mammals are usually reported for liver and kidney, with some data published for muscle, blood, skin, and hair. For many of the trace elements in marine mammal tissues (including heavy metals), little is known of what concentrations are within the normal ranges for a particular species. Concentrations of essential trace elements, such as copper and zinc, are generally characterized by relatively narrow ranges of values within a species and, for many elements, the ranges are similar from one species to another. The concentrations of selenium in marine mammals vary much more widely than most other essential elements; however, this is probably due to its relationship to the accumulation of mercury and the positive correlation between the two metals in the livers of animals that accumulate mercury. The nonessential, potentially toxic elements, such as arsenic, cadmium, mercury, and lead, show the greatest variability with concentration ranges often spanning several orders of magnitude.

A summary of data published on heavy metal concentrations in the tissues of harbor seals, worldwide, are presented in Section II, Tables II.1 - II.3. Only two papers were found that report the concentrations of heavy metals (i.e., cadmium, lead, arsenic, mercury, and selenium) in Alaska harbor seals (Anas, 1974; Miles, *et al.*, 1992) but these data were for animals that were sampled 20 to 30 years ago in Kodiak Island (Gulf of Alaska) and the Pribilof Islands in the southern Bering Sea. The geometric means and value ranges for these data are presented in Table II.1 (Note that one paper was published in 1992, but the data were based on samples collected in 1976 through 1978).

The available information for the contiguous U.S. is not much better (Table II.2). The most recent data are for cadmium, copper, lead, nickel, mercury, and selenium concentrations in blood collected seven to nine years ago from harbor seals from southern Puget Sound, San Nicolas Island, San Francisco Bay, and on the Monterey, California coast (Kopec and Harvey, 1995). The liver concentration values for these heavy meals have been published for harbor seals from Puget Sound (Calambokidis *et al.*, 1984), but these animals were sampled 16 to 26 years ago. Although it appears that European studies have

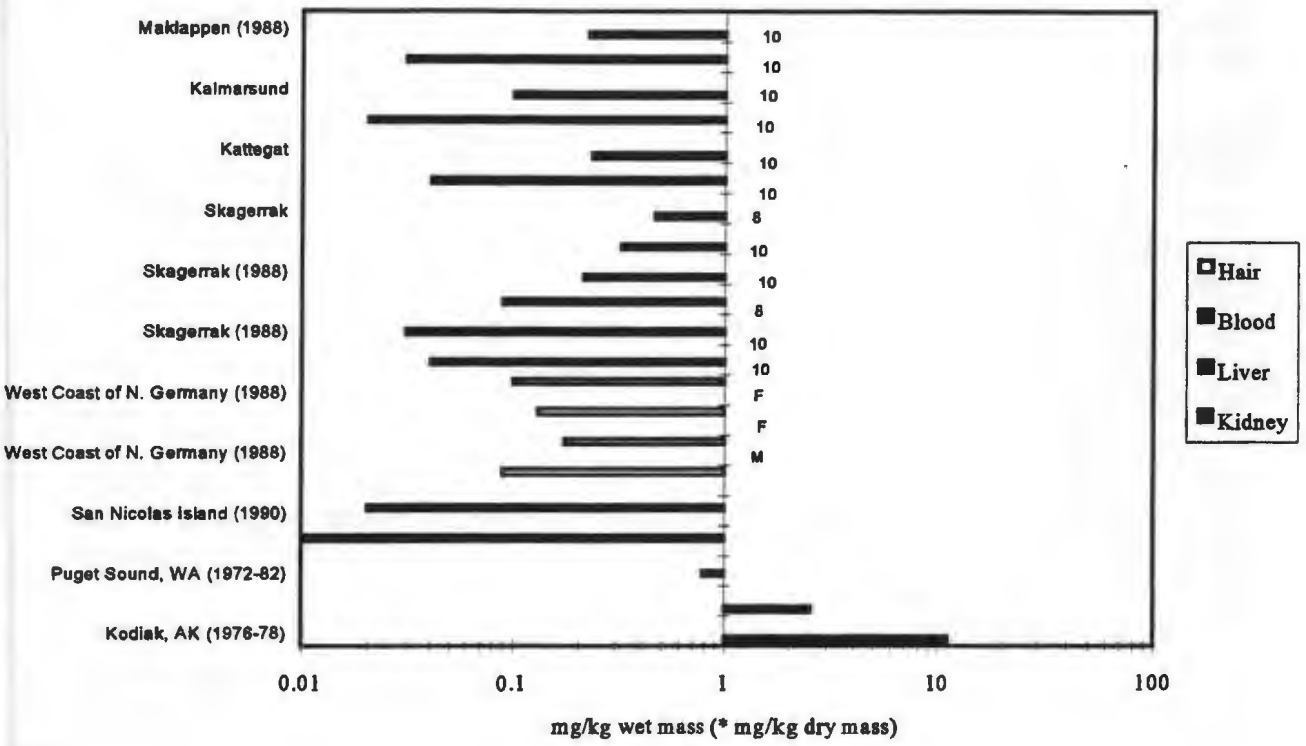


Figure 2. Concentration values of cadmium in tissues of harbor seals.

concentrated on chlorinated hydrocarbon contaminants in harbor seals, some relatively recent (10 years old) heavy metal data (i.e., mercury, selenium, cadmium, and lead) are available for this species from Norway (Skaare *et al.*, 1994), the coast of Germany (Wenzel *et al.*, 1993), and the coast of Sweden (Frank *et al.*, 1992) (Table II.3). The best comparative data for Alaska harbor seals are the mercury and selenium concentrations reported in liver and kidney from this species sampled in the Sea of Okhotsk in 1989 (Himeno *et al.*, 1989).

Cadmium: Cadmium is a nonessential element, with limited metabolic regulation by mammals. Highest concentrations occur in kidney and liver of mammals and birds, with most of the body burden occurring in the kidney. Cadmium has an extremely long half-life (30 years in humans) and unlike other metals, including mercury, little or no cadmium is transferred from female to newborn via lactation. As in the case of mercury, cadmium is incorporated in a metallothionein complex in the liver and kidney and may combine with selenium to form an insoluble cadmium selenide complex, thereby reducing the toxicity of the metal (Martoja and Viale, 1977). Cadmium concentration levels reported for harbor seal tissues are shown in Figure 2.

Miles *et al.* (1992) reported kidney concentrations of this metal in harbor seals sampled near Kodiak Island in 1976 to 1978 ranging from 0.3 mg/kg to 44 mg/kg wet mass for both male and female animals (Table II.1) which lies within the range reported for northern fur seals (Zeisler *et al.*, 1993) and bowhead whales (Bratton *et al.*, 1997). This range was substantially narrower than has been found for walrus (Taylor *et al.*, 1989; Warburton and Seagars, 1993). No cadmium data were found for harbor seal kidney tissue from the contiguous U.S. or for areas outside the U.S.

Mercury: Mercury is a non-essential, toxic trace element that tends to concentrate to its highest level in liver tissue. The relatively high concentration values for this element in marine mammal tissues are well known. The database on mercury in marine mammals is probably the largest of all the heavy metals. Concentration values of mercury among species, within species, and among geographical areas vary widely. Since it is not easily regulated internally by vertebrates, this element tends to bioaccumulate. The organic form, methylmercury, has a relatively long half-life and is relatively toxic. There is evidence to support the idea that both seabirds and marine mammals have the metabolic ability to de-methylate the methyl mercury, converting it to inorganic mercury, which is less toxic, can be stored in relatively high levels within a metallothionein complex or selenium complex, and is eventually excreted. This ability to de-methylate organic mercury appears to be an adaptive means of maintaining high body burdens derived from fish prey high in mercury content. The de-methylation ability may not be present in newborn and young animals; at least this appears to be the case for some pinnipeds. Mercury concentration levels reported for harbor seal tissues are shown in Figure 3.

Anas (1974) reported total mercury concentrations in livers collected in 1971 from Pribilof Island harbor seals to range from 0.6 to 8.9 mg/kg wet mass. These values are comparable with concentrations reported recently by Mackey *et al.* (1996) of ringed seals from Norton Sound (0.45 mg/kg to 5.2 mg/kg wet mass), and for northern fur seals from the Pribilof Islands (Zeisler *et al.*, 1993), and are substantially less than those reported by Miles *et al.* (1992) for the harbor seals sampled in the Kodiak Island area in the late 1970's (0.4 mg/kg to 72 mg/kg wet mass). As a comparison, ranges of total mercury reported for this species in the contiguous U.S. have been 3.3 to 78 mg/kg wet mass for Puget Sound (Calambokidis *et al.*, 1984), and 16 to 138 mg/kg wet mass for the Northeast U.S. (Lake *et al.*, 1995). No methylmercury values have been reported for harbor seals in the U.S.

Selenium: Selenium is an essential element believed to have an antidotal action on the toxic effects of mercury, cadmium, arsenic, copper, and thallium. Although the mechanism for this action is not clear, two possibilities are that the selenium stimulates the formation of metallothioneins or that heavy metals are incorporated in insoluble selenide compounds. Concentrations of silver and selenium may also be related. The case of silver differs from other selenium-metal interactions in that silver can cause the symptoms of selenium deficiency in vitamin E-deficient animals by the formation of a silver-selenium complex that may reduce the available selenium required for normal cellular processes (Ridlington and Whanger, 1981).

Within physiologic limits, mammals appear to have a homeostatic mechanism for retaining trace amounts of selenium and excreting the excess material. Toxic effects can occur when the rate of intake exceeds the excretory capacity. The most consistent positive correlation of selenium with any other element in liver tissue has been with mercury; therefore, animals with relatively high mercury levels will also have high selenium levels. The selenium concentrations in harbor seal livers reported by Miles *et al.* (1992) for animals from Kodiak Island tend to support this assumption (Table II.1). Selenium concentration levels reported for harbor seal tissues are shown in Figure 4.

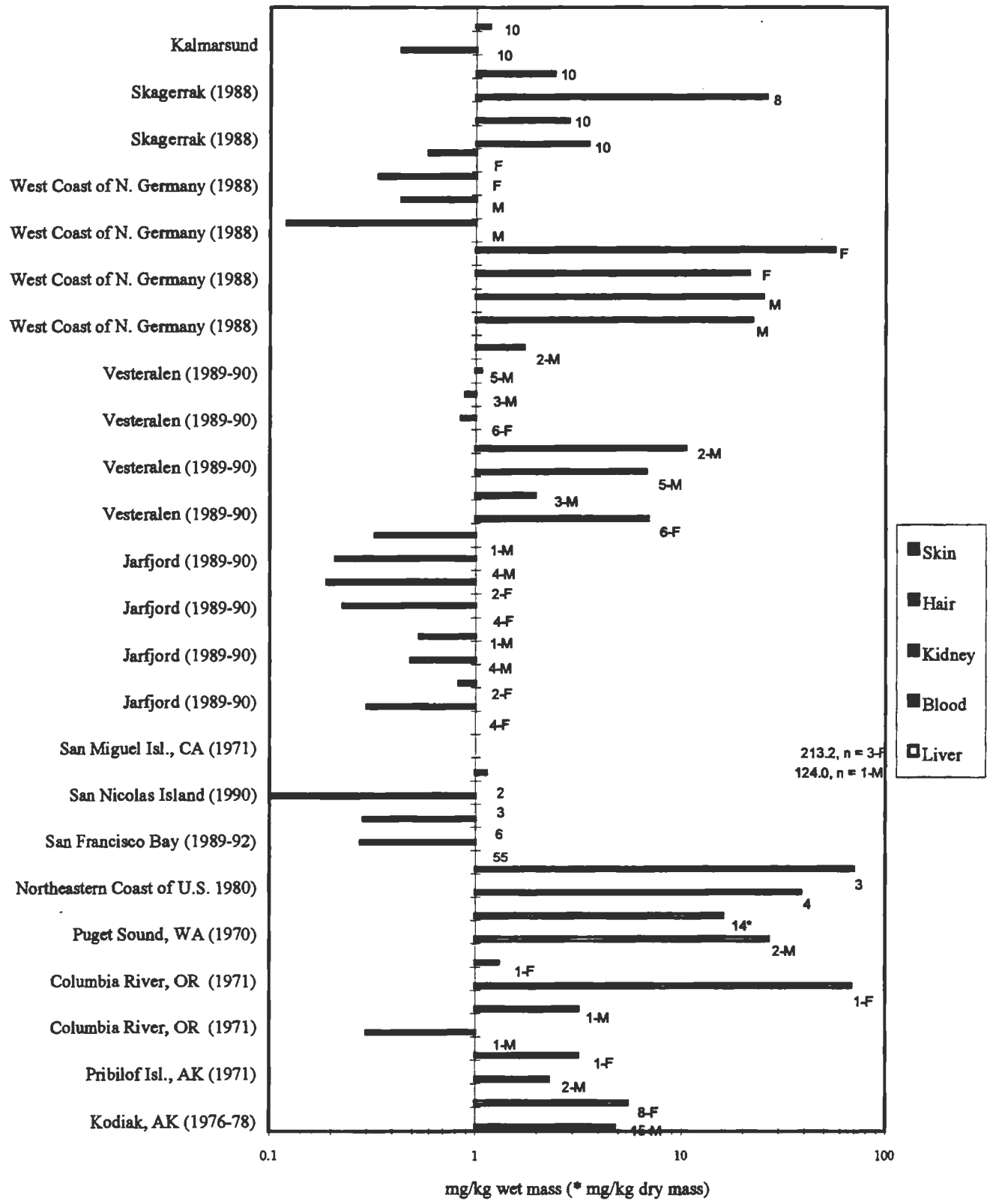


Figure 3. Concentration values (mean, n to the right of mean) of mercury in tissues of harbor seals (M = male, F = female).

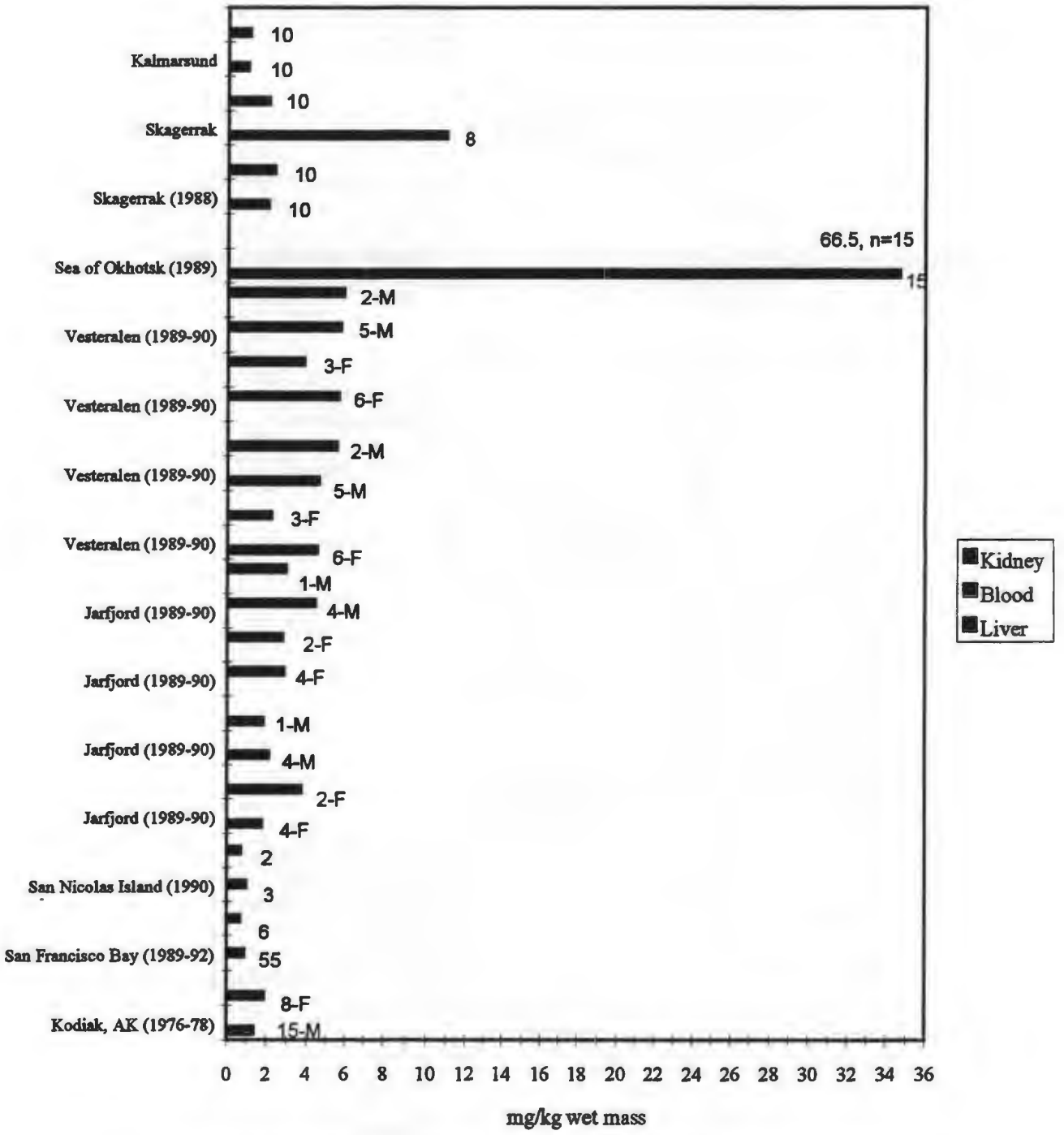


Figure 4. Concentration values (mean, n to the right of mean) of selenium in tissues of harbor seals (M = male, F = female).

Lead: Lead is a non-essential element that has increased markedly in the environment over the last century due to anthropogenic sources. Although most of the environmental exposure is probably of lead in its inorganic form, the organic alkyl lead, which is lipid soluble, results in a more severe toxic response. Although tetraethyl- and tetramethyllead degrade rapidly, triethyllead is relatively stable and once absorbed by mammals, it becomes rapidly distributed among brain, liver, kidney, and blood. Lead particles are readily absorbed in mammals via the respiratory system. Gastrointestinal absorption is age dependent in humans and is probably age dependent for most mammals: 5 to 10% in adults and 30 to 40% in young. The principal route of excretion is urinary.

Few lead values have been reported for harbor seals in general (Figure 5). Miles *et al.* (1992) reported Kodiak Island animals having liver concentrations ranging 0.2 mg/kg to 2.1 mg/kg wet mass. This is higher than levels reported by Calambokidis *et al.* (1984) for Puget Sound harbor seals (0.23 mg/kg to 0.85 mg/kg wet mass). Caution is required when using reported lead values (particularly older data) since this trace element is easily introduced into a sample during sample collections, handling, and analytical determinations.

Copper: Copper is an essential element and is regulated metabolically in vertebrates. As has been reported for other mammals, the highest values occur in the liver, followed by kidney and muscle. Most marine mammal liver values reported are below 20 mg/kg. No copper concentrations have been reported for Alaska harbor seals. Calambokidis *et al.* (1984) reported copper levels in the livers and blood of harbor seals from Puget Sound ranging 14 mg/kg to 63 mg/kg wet mass. Reported liver concentrations for other pinnipeds in Alaska range 6.47 mg/kg to 45.17 mg/kg wet mass for ringed seal to 9.64 mg/kg to 33.3 mg/kg wet mass for bearded seal (Becker *et al.*, 1997). Copper concentrations tend to vary among and within species and attempts to correlate copper concentration in marine mammal tissues with areas of pollution have not been successful (Thompson, 1990). Diet appears to be important in determining copper levels.

Arsenic: Marine organisms generally have higher concentrations of arsenic than terrestrial or freshwater organisms. Miles *et al.* (1992) reported the geometric mean arsenic concentrations in the livers of 15 harbor seals from Kodiak as being 0.08 mg/kg wet weight. Although no arsenic concentration values in liver have been reported for this species in the contiguous U.S., Becker *et al.* (1997) reported arsenic levels in bearded seals and ringed seals from Norton Sound ranging 0.17 mg/kg to 0.56 mg/kg wet mass and 0.165 mg/kg to 2.42 mg/kg wet mass, respectively.

In marine fish, crustaceans, and molluscs arsenic occurs mainly as the non-toxic pentavalent organic compound, arsenobetaine. A recent study by Goessler *et al.* (1998) identified arsenobetaine as the predominant arsenic compound in Alaska ringed seal, bearded seal, and beluga whale liver tissue. Additional organoarsenic compounds identified in this study were arsenocholine, tetramethylarsonium cation, dimethylarsinic acid, and an unknown arsenic compound. The physiological significance of these compounds in marine mammals is unknown.

Tin: Organotin compounds can be toxic and can bioaccumulate. Butyltin compounds have been used worldwide since the 1960s as antifouling agents (tributyltin) for boats and aquaculture nets, as stabilizers for chlorinated polymers, and as catalysts for silicones and polyurethane foams (monobutyltin and dibutyltin). Degradation products of tributyltin (TBT) are dibutyltin (DBT) and monobutyltin (MBT). Both TBT and DBT can cause immunosuppression in mammals (Kannan *et al.*, 1997; 1998). Because

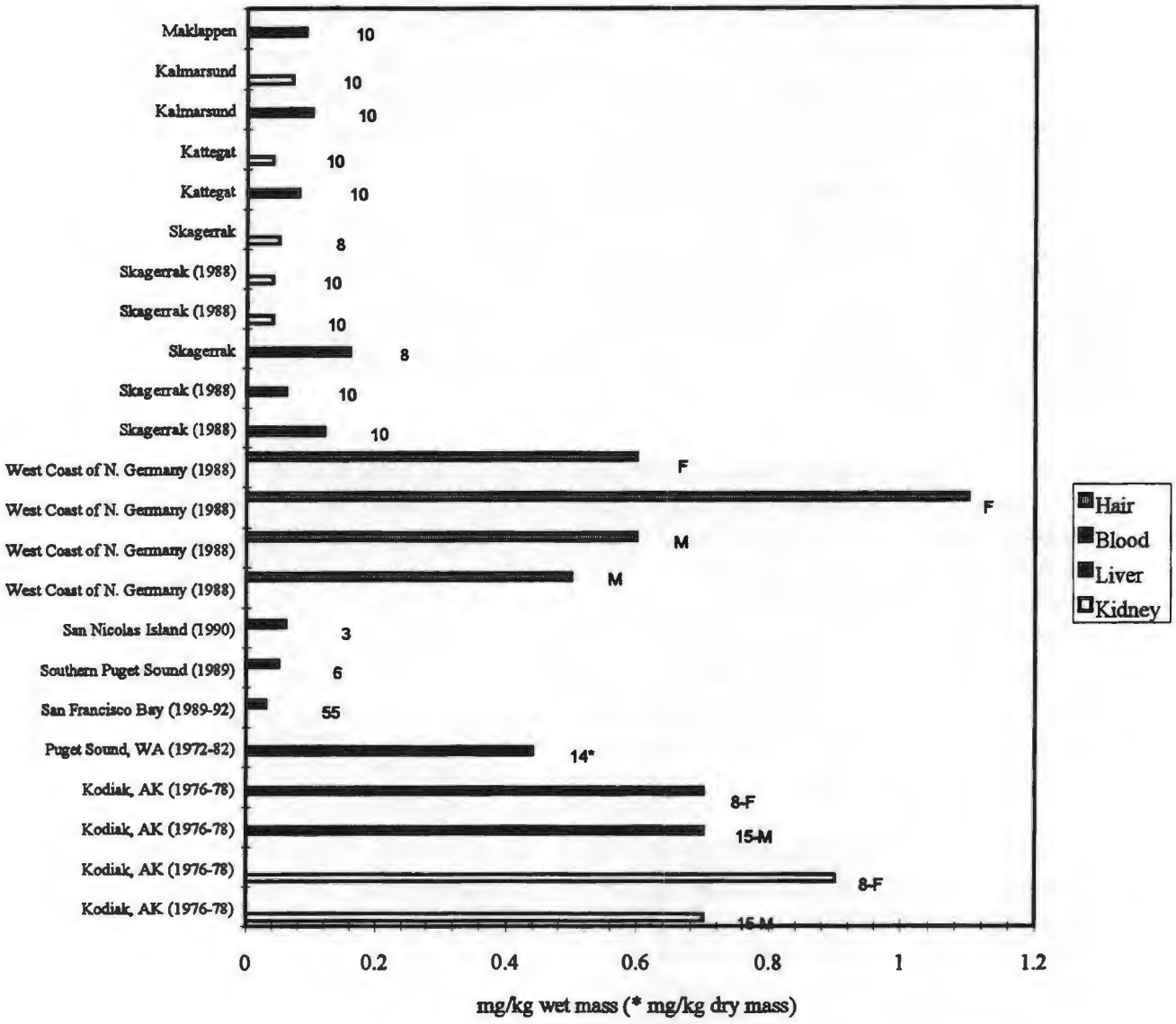


Figure 5. Concentration values (mean, n to the right of mean) of lead in tissues of

of their use, one would expect butyltin (BT) compounds to occur in higher concentrations in coastal waters than in offshore waters.

Because of their tendency to occur in nearshore coastal waters and congregate in discrete haulout areas, one would expect harbor seals to be a prime candidate marine mammal species for the investigation of BT compounds in Alaska waters. No data have been published on these compounds in this species. However, studies by Tanabe *et al.* (1998) also suggest that pinnipeds may have greater capacity for metabolizing BT compounds than cetaceans. Spotted seals (*Phoca largha*) and ribbon seals (*Histriophoca faciata*) from the coast of Japan had mean liver concentrations of total BT of 50 ng/g and 75 ng/g wet mass, respectively. Mean levels in cetaceans from the Japanese coast were one and two orders of magnitude higher. Northern fur seals from the Sanriku Coast had mean BT concentrations of

320 ng/g wet mass, while Dall's porpoise (*Phocaenoides dalli*) from the same area had mean levels of 760 ng/g wet mass.

PERSISTENT ORGANIC POLLUTANTS (POPs)

Persistent organic pollutants include organic compounds, such as PCBs, dioxins, furans, chlorinated pesticides (i.e., DDT, dieldrin, chlordane, endrin, toxaphene, mirex, kepone, etc.), and polycyclic aromatic hydrocarbons (PAHs). Although technically PAHs are considered to be persistent in the environment, they are readily metabolized in mammals and, therefore, do not accumulate in the mammal tissues. Rather than looking for these compounds in marine mammal tissues, a relative measure of recent exposure to PAHs can be derived by the measurement of PAH metabolites in excretory fluid (e.g., bile) (Krahn *et al.*, 1993).

The following persistent organic pollutants have been measured in the blubber and livers of harbor seals from Alaska (Table II.4): PCBs (expressed as total, or sum of congeners, and as congener-specific values), DDT (expressed as total and as isomers of DDT, DDD, and DDE), chlordane compounds, hexachlorobenzene (HCB), endrin, dieldrin, and isomers of hexachlorocylohexane (α-, β-, and γ-HCH). These have been commonly reported in tissues of harbor seals from Prince William Sound, Kodiak, and Southeast Alaska (Krahn *et al.*, 1997; Lewis 1995; Varanasi *et al.*, 1993). In addition, endosulfan, a current use pesticide that is considered to be non-persistent, has been reported by Lewis (1995) at very low levels in the blubber of harbor seals from Southeast Alaska (Figure 6). Data on the concentrations of persistent organic pollutants in tissues (i.e., blubber, liver, kidney, muscle, and brain) of harbor seals from Alaska, the contiguous U.S., and northern Europe are presented in Tables II.4 - II.6.

Polychlorinated biphenyls (PCBs): Much of the past data on PCBs in environmental samples are presented as "total" PCBs or represented as the amount of technical mixtures (Arochlors, Clophens, etc.). Expressing the data in terms of technical mixtures has come about through the use of commercial technical mixtures as reference materials. With the development of high resolution gas chromatography with electron capture detection (GC-ECD), the individual PCBs congeners are now routinely separated, identified, and quantified. Rather than using technical mixtures as reference materials, the individual congeners of interest can then be used for comparison.

The value of congener-specific analysis is apparent when one considers that, although technical mixtures are the original source of PCBs in the environment, the composition of various commercial mixtures with different overall chlorine contents differs from those of environmental mixtures (Duinker, *et al.* 1988). Although the sum of PCBs may be appropriate for identifying hot spots and trend monitoring, a real understanding of the "trends" and the ability to interpret the meaning of the data requires identification and quantification of individual congeners. This requirement is emphasized by the fact that, although PCBs are metabolized by a wide variety of organisms, not all congeners are metabolized at the same rate, nor are all congeners labile (Kannan, *et al.* 1989). In addition, some congeners are apparently more toxic than others. For example, based on toxicity that is similar to that of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD), the PCBs with the molecules in planar configuration (i.e., PCB-77, -126, and -169) and mono-ortho substituted derivatives of the planar compounds (i.e., PCB-105 and -118) have higher toxicities than other PCB congeners. The few data on planar PCBs in marine mammals suggest that they contribute a minor fraction to the total PCB congener

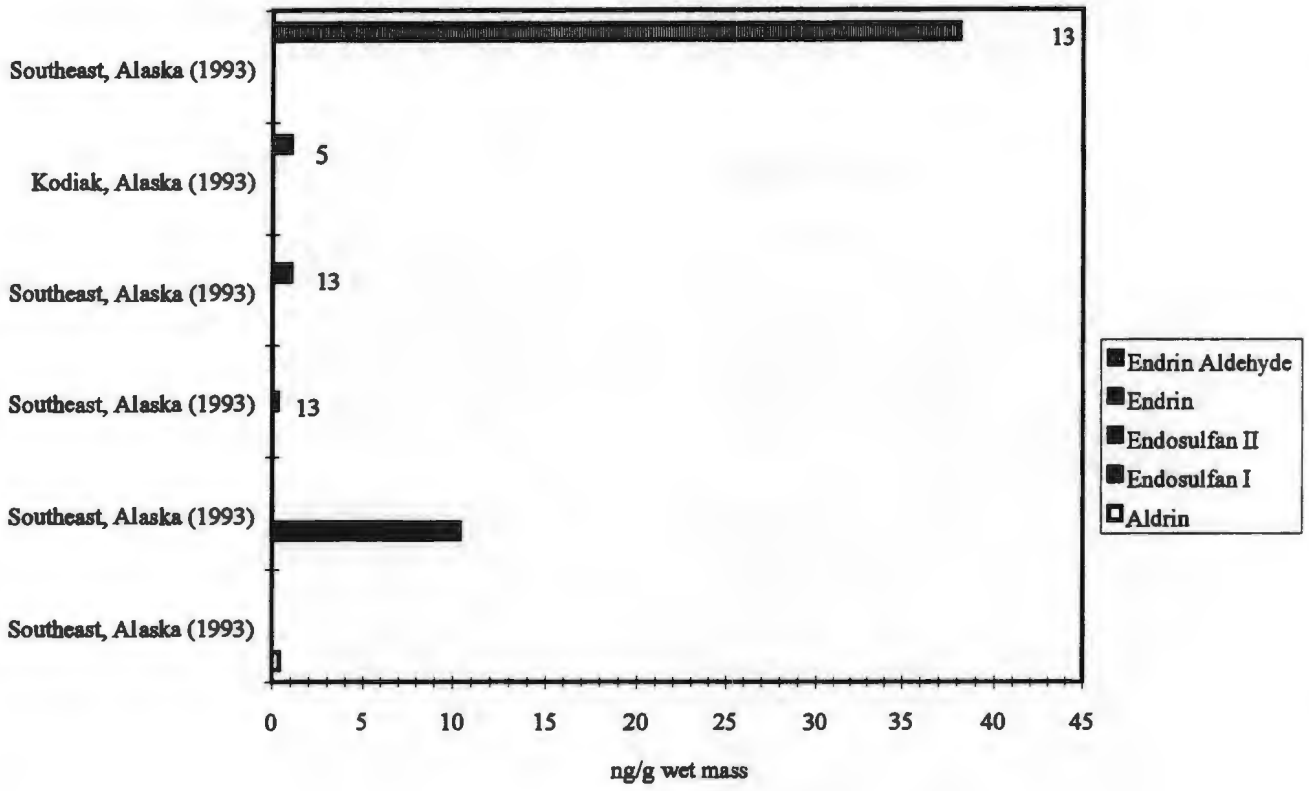


Figure 6. Concentration values of organochlorine compounds in tissues of harbor seals in Alaska.

concentrations in marine mammal tissues. The ortho substituted PCB congeners that have lower toxicities compared to the planar compounds have much higher concentrations in marine mammal tissues and may actually contribute more to the toxicity of these compounds (Tanabe *et al.* 1989; 1997).

The more recent congener specific data is not directly comparable with older PCB data reported on the basis of Aroclors or Clophens. The majority of early PCB data was reported as equivalents of commercial Aroclors, particularly Aroclor 1254, which has been found to be an overestimate of as much as a factor of 2 when compared to more recent reporting of the sum of PCB congeners (Norstrom *et al.*, 1988). In addition, if all the congeners present in a sample were analyzed, their sum would be equal to the total PCBs. However, not all congeners can be completely separated nor are there reference compounds available for all congeners. In most cases this sum does not equal the total, but something less; how much less is usually unknown.

PCB congeners commonly reported in marine mammal tissues include: PCB-18, -28, -44, -49, -52, -95/66, -87, -99, -101, -105, -132, -110, -118, -128, -146, -149, -151, -153, -138, -163, -156, -183, -187, -170, 201/157, -180, -187, -194, -195, -206, and -209. Because of different extraction and analytical techniques used in measuring PCBs in marine mammal tissues, the number and kinds of congeners reported are not consistent between laboratories. PCB-153, however, is routinely reported by all laboratories. This relatively non-toxic congener is highly resistant to metabolic breakdown and almost always dominates the concentration of PCBs in marine mammal tissues. PCB-153 is, therefore, a good congener for comparing relative differences in PCB concentrations among different populations

of animals and among different laboratories and data sets. Figure 7 presents PCB-153 concentration data for the blubber of harbor seals from Prince William Sound Alaska, the northeast and northwest coasts of the U.S., northern Europe, and the British Isles. The Prince William Sound harbor seals had PCB-153 concentrations an order of magnitude lower than were reported for this species from the northwest and northeast coasts of the U.S. and from northern Europe.

Concentrations of the sum of PCB congeners (a total of 17 congeners) in the blubber of Prince William Sound harbor seals are compared with those measured in four other species of pinnipeds in Table I.1. Concentration levels in the animals from Prince William Sound (452 ng/g ± 236 ng/g wet mass) were of the same order of magnitude as measured in ringed seals (*Phoca hispida*) from arctic Alaska, but less than levels found in northern fur seals (*Callorhinus ursinus*) from the Pribilof Islands (1,343 ng/g ± 522 ng/g wet mass) and harbor seals from the coasts of Washington and Oregon (3,116 ng/g ± 1,517 ng/g wet mass), and substantially less than Steller sea lions (*Eumatopias jubatus*) from the Gulf of Alaska (23,000 ng/g ± 37,000 ng/g wet mass).

DDT and Metabolites: Although many different compounds have been identified in various organisms as metabolic products of DDT, the predominant ones in mammals are DDD (dichlorodiphenyldichloroethane), DDE (dichlorodiphenyldichloroethylene), and DDA (dichlorodiphenyl acetic acid). DDD is rarely stored as a metabolite. It is unstable and readily degrades through a series of intermediates to DDA, which is water soluble and excreted in urine. DDE is a degradation product of DDT through the loss of one molecule of HCL (dehydrohalogenation). Metabolism of DDT to either DDE or DDD is considered to be quite fast on the order of years. Although DDE further degrades to DDA by the loss of two more molecules of HCL, this reaction is very slow. DDE is relatively stable and tends to persist. This persistence of DDE results in a portion of the parent compound (DDT) accumulating in the tissues as DDE.

The individual isomers of DDT and its metabolites also vary in the rates of degradation depending on the molecular arrangement of chlorine atoms. The ratio of 2,4'-DDT to 4,4'-DDT in the technical mixture is 1:4. The missing 1,4- disubstitution in one of the phenyl rings of 2,4'-DDT facilitates its degradation. The metabolites 2,4'-DDD and 2,4'-DDE are rarely found to be enhanced to the same extent as are the 4,4'-derivatives.

The degradation of DDT begins in the soil through the activity of microorganisms. DDE has a greater volatility than DDT; therefore, it is probably more easily transported through the atmosphere into areas where application has not taken place, such as the Arctic. Also one would expect the ratio, DDE/DDT, to be generally higher in the open-ocean environment and the organisms inhabiting this environment than in the coastal environment. As the DDT is metabolized and passed along the food chain, one would also expect the ratio to be higher at the upper trophic levels. This pattern appears to be consistent among tissue types, which is illustrated by the comparison of p,p'DDE to total DDT shown in Figures 8-12 for liver, blubber, brain, and muscle tissue from harbor seals sampled in the U.S., Canada, and Europe. Concentrations of the sum of DDT (DDE + DDD + DDT) in the blubber of Prince William Sound harbor seals are compared with those measured in four other species of pinnipeds in Table I.1. Concentration levels in the animals from Prince William Sound (314 ng\g ± 170 ng\g wet mass) were of the same order of magnitude as measured in ringed seals from the Alaska Arctic, but an order of magnitude less than levels found in northern fur seals from the Pribilof Islands and harbor seals from the coasts of Washington and Oregon and two orders of magnitude less than reported for Steller sea lions from the Gulf of Alaska.

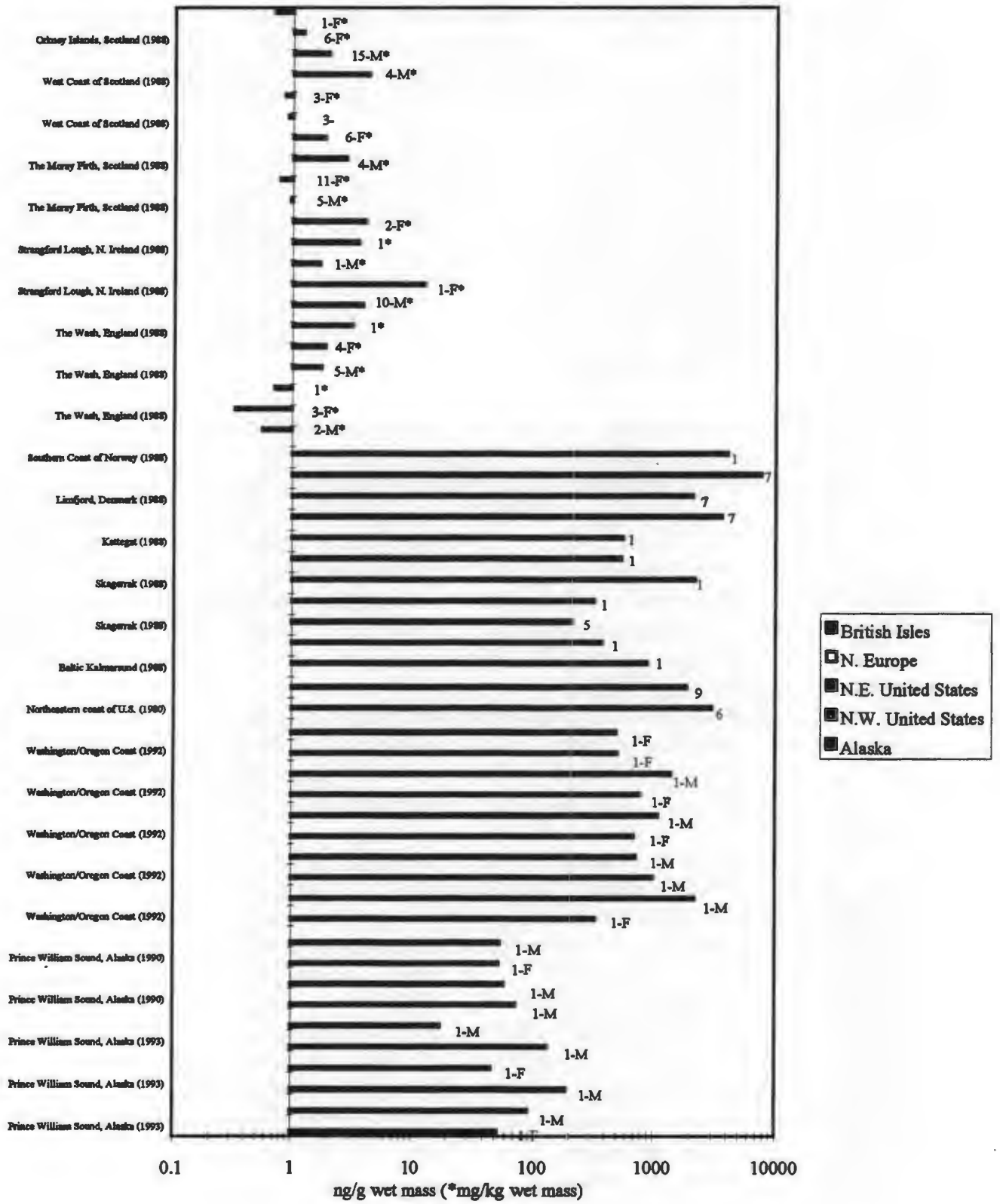


Figure 7. Concentration values (mean, n to the right of mean) of PCB 153 in blubber samples of harbor seals (M = male, F = female).

Table. I.1. Comparison of concentration ranges and means ± 1 standard deviation (ng/g wet mass) of chlorinated hydrocarbons measured in the blubber of harbor seals from Alaska with other Alaska pinnipeds and with harbor seals from the Washington and Oregon coast.

Location	s-PCBs	s-DDT	s-Chlordane	HCB	Dieldrin	Source
Harbor Seal:						
Prince William S.	225 - 798	130 - 523	80 - 331	8 - 16	3 - 9	1
n = 5	452 ± 236	314 ± 170	205 ± 110	12 ± 4	5 ± 2	
WA/OR coast	2,204 - 6,846	961 - 8,545	211 - 1,250	7 - 20	5 - 24	1
n = 10	3,116 ± 1,517	3,756 ± 2,139	657 ± 310	13 ± 4	12 ± 6	
Northern Fur Seal:						
Pribilof Is.	550 - 2,054	946 - 5,602	298 - 1,230	nd - 2	4 - 260	1
n = 7	1,343 ± 522	2,711 ± 1,470	792 ± 361	0.6 ± 0.7	52 ± 85	
Pribilof Is.	275 - 590	1,090 - 1,480	79 - 342	nd	1.2 - 26	2
n = 2	432	1,285	210	-	14	
Steller Sea Lion:						3
n = 8	23,000 ± 37,000		20,000 ± 35,000			
Ringed Seal:						
Norton Sound	89 - 363	69 - 255	90 - 295	7 - 50	4 - 31	1
n = 8	273 ± 83	190 ± 60	182 ± 80	22 ± 13	18 ± 8	
Norton Sound	334 - 1,425	372 - 1,922	124 - 154	24 - 122		2
n = 2	420	590	1,147	139	73	
Barrow, AK		35 - 378	77 - 164	2 - 56	0.6 - 24	2
n = 2	640	225	120	29	12	
Bearded Seal:						
Norton Sound	66 - 356	8 - 366	12 - 451	0.76 - 7	nd - 8.5	1
n = 6	162 ± 112	103 ± 133	155 ± 159	4 ± 3	4 ± 3	

1 - Krahn *et al.* (1997); 2 - Schantz *et al.* (1993); 3 - Varanasi *et al.* (1993)

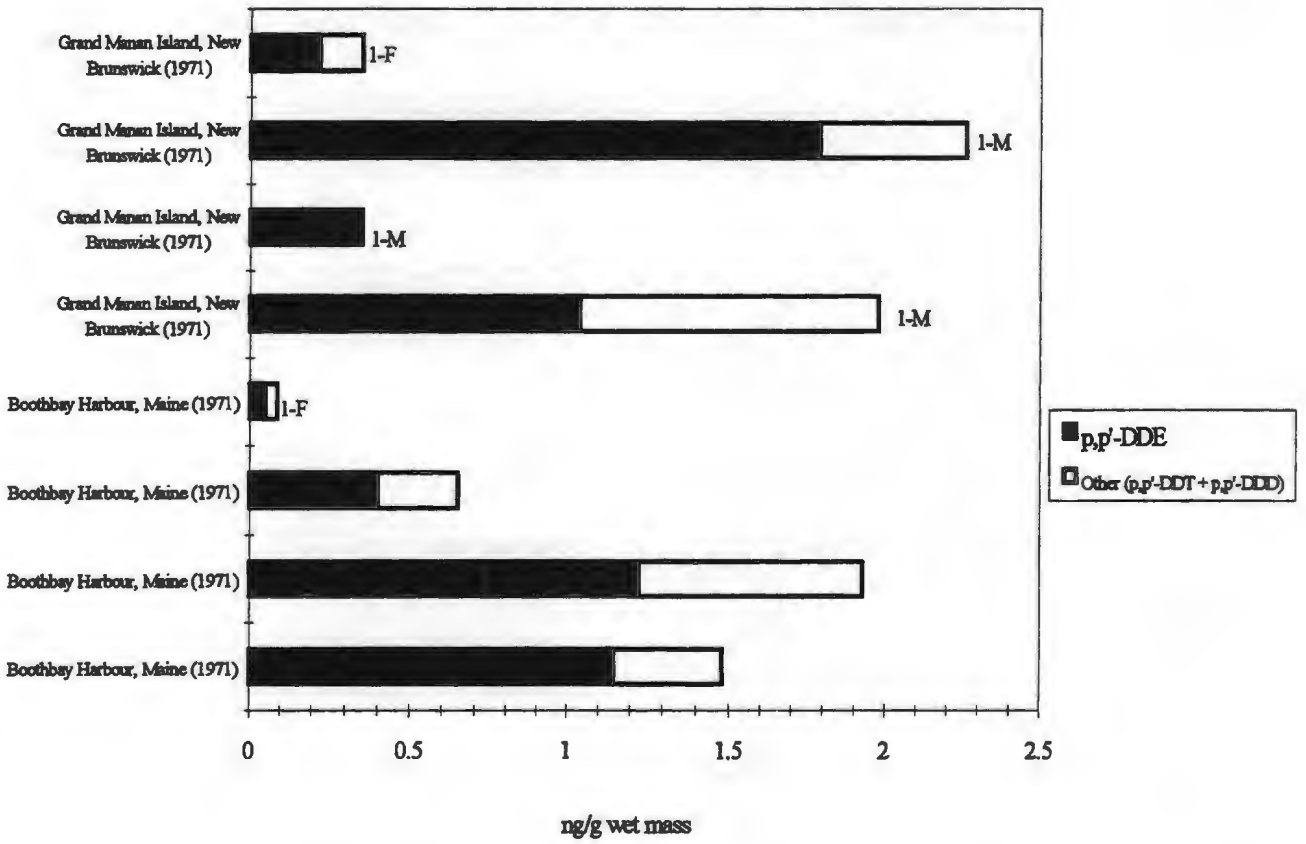


Figure 8. Concentration values of total DDT in liver samples of harbor seals in the United States.

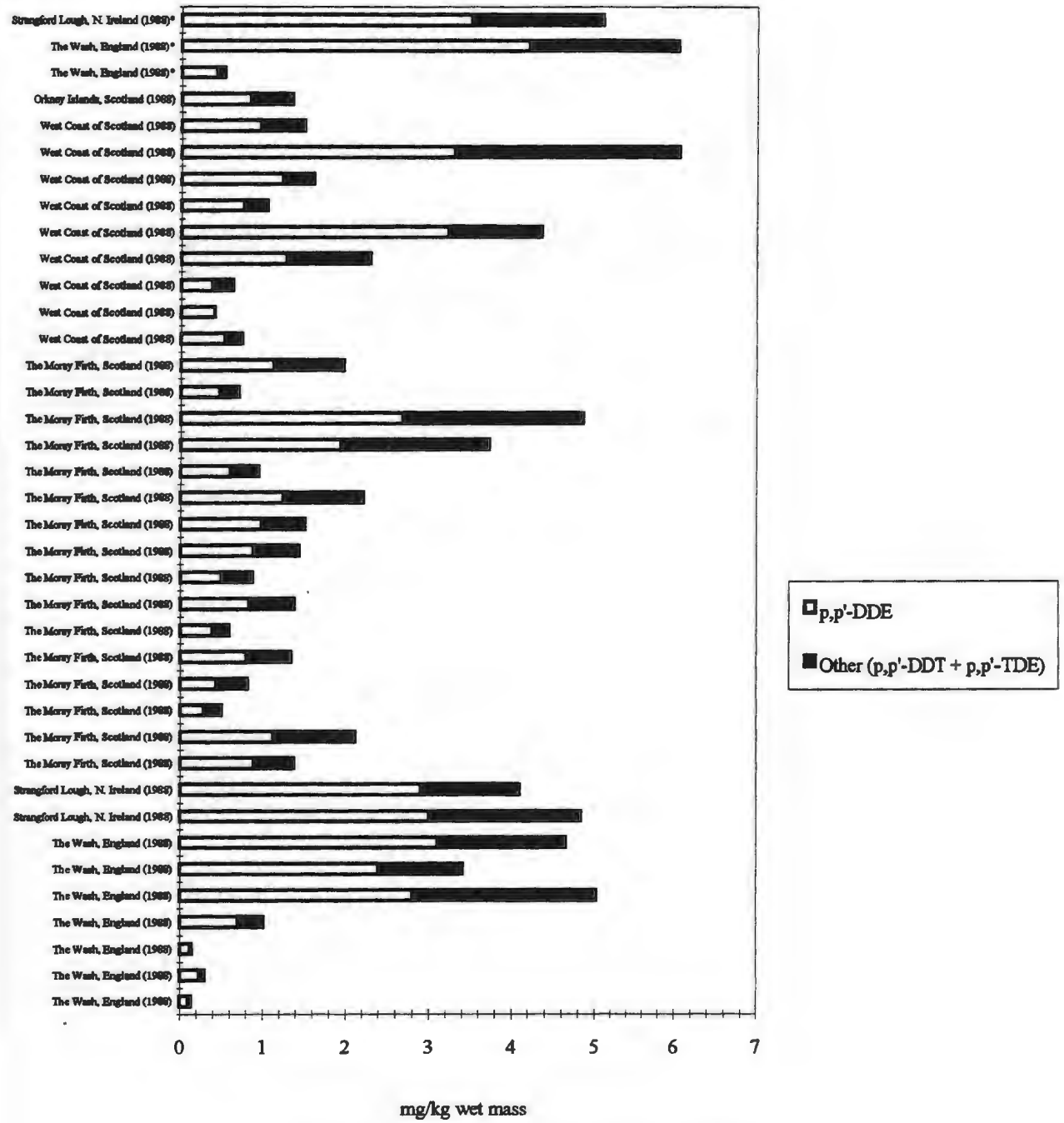


Figure 9. Concentration values of total DDT in blubber samples of female (*unknown sex) harbor seals in Europe.

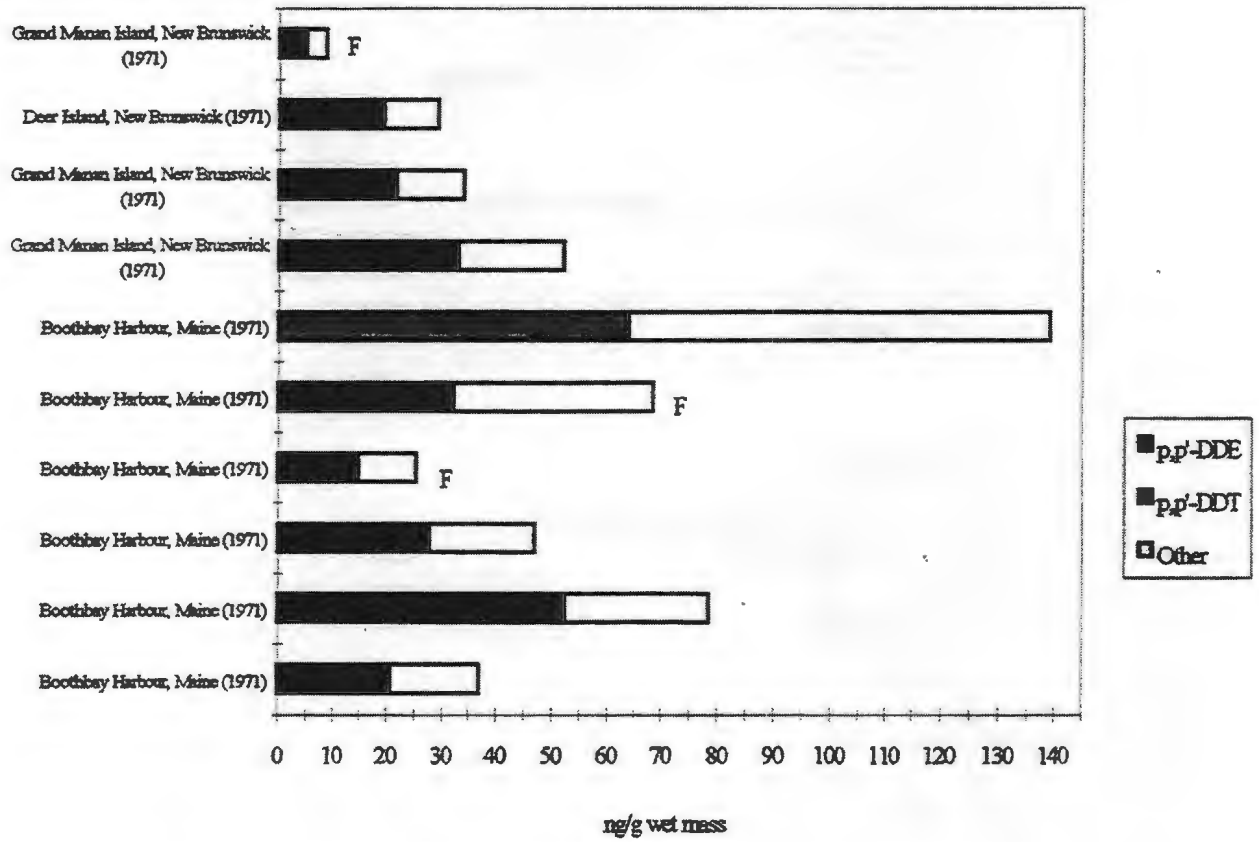


Figure 10. Concentration values of total DDT measured in blubber of harbor seals in the N.E.

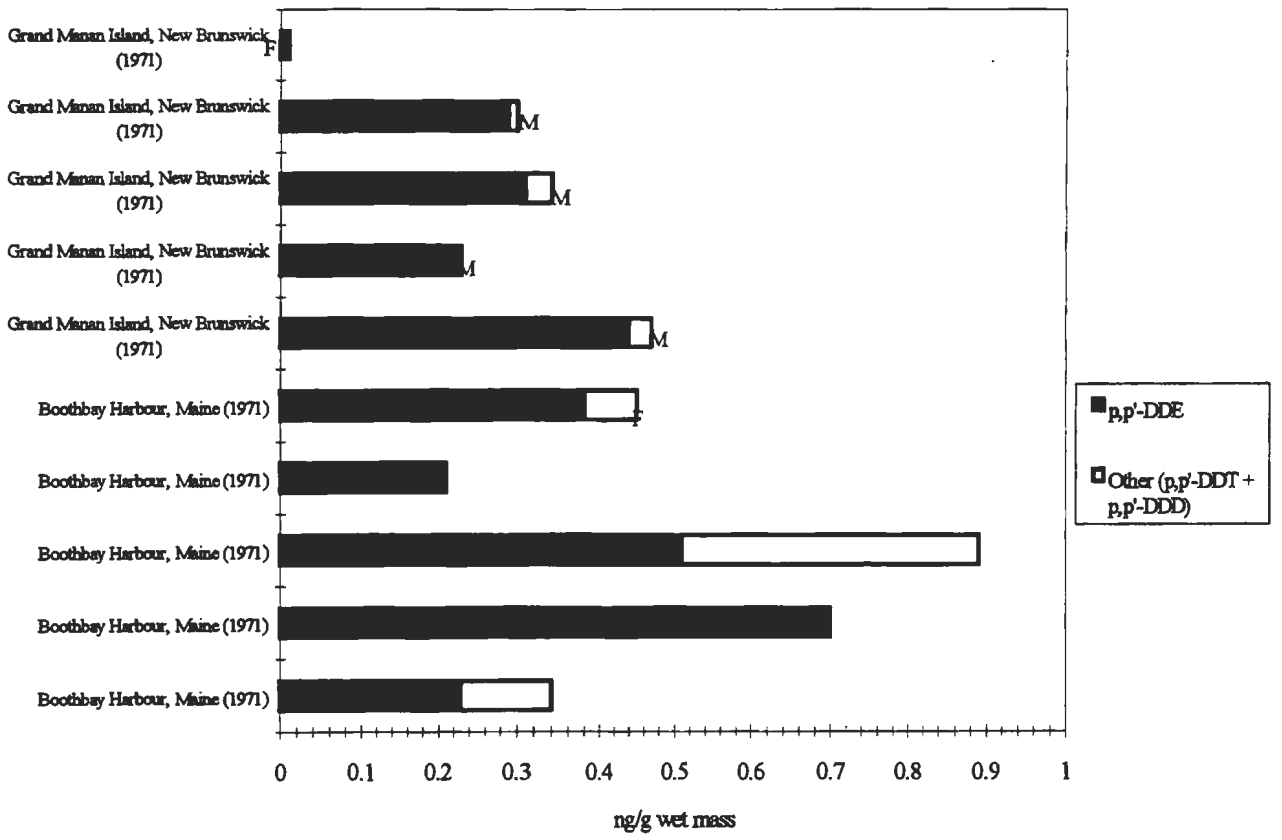


Figure 11. Concentration values of total DDT in cerebrum samples of harbor seals in the N.E.

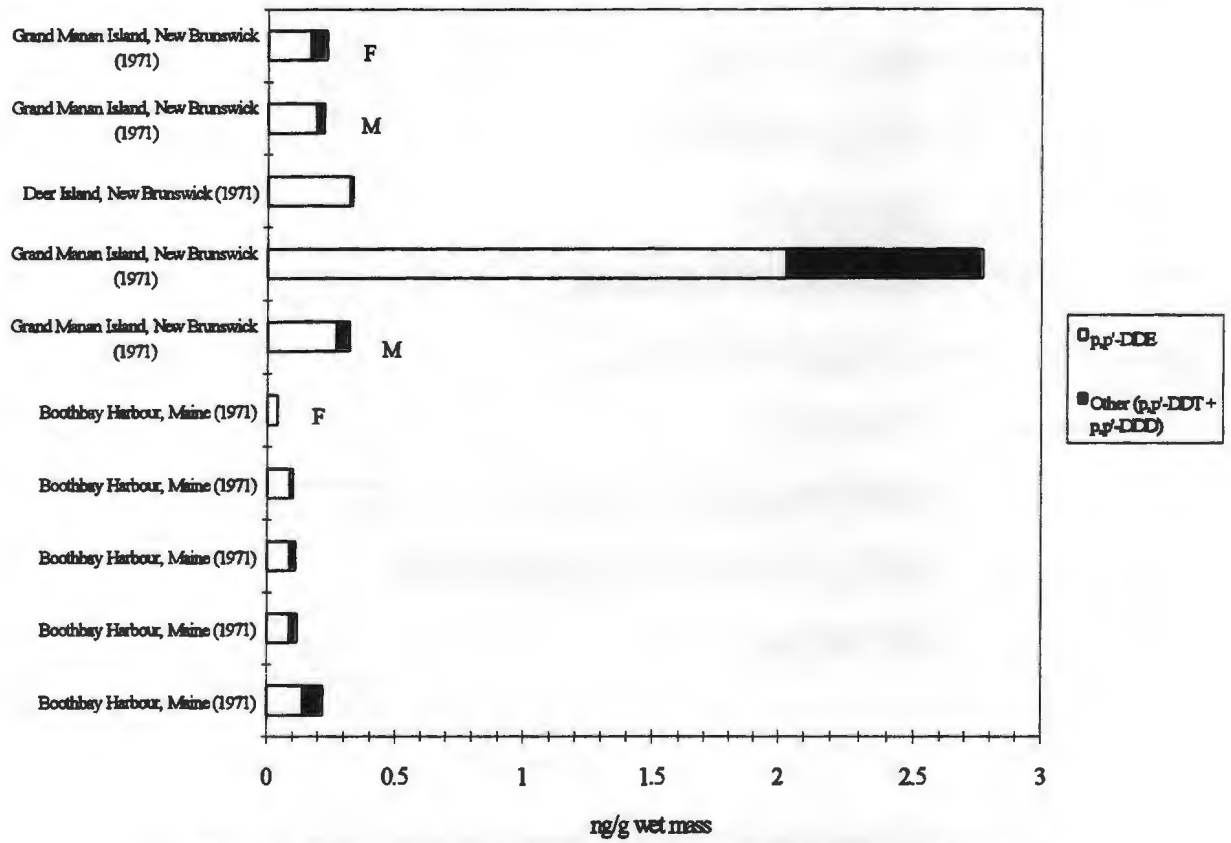


Figure 12. Concentration values of total DDT in muscle of harbor seals in the United States

Hexachlorobenzene (HCB): Of the various chlorobenzene compounds, hexachlorobenzene (HCB) is the most toxic and most persistent. This is a very volatile compound that has the potential for long distance atmospheric transport to northern latitudes. Although persistent in lipids of mammals, HCB is gradually metabolized to a wide variety of metabolites that appear in the feces and urine. Levels of HCB in fat and blubber are usually much higher than those of liver.

In Table I.1 and Figure 13, HCB concentration levels in blubber tissue of harbor seals from Prince William Sound (12 ng/g ± 4 ng/g wet mass) are compared with levels reported for this species in the contiguous U.S. and with other pinnipeds from Alaska. Except for bearded seals from Norton Sound, which have somewhat lower levels, the HCB concentrations reported for Alaska pinnipeds are all very similar. These levels are also similar to those reported for harbor seals from the northwest U.S.

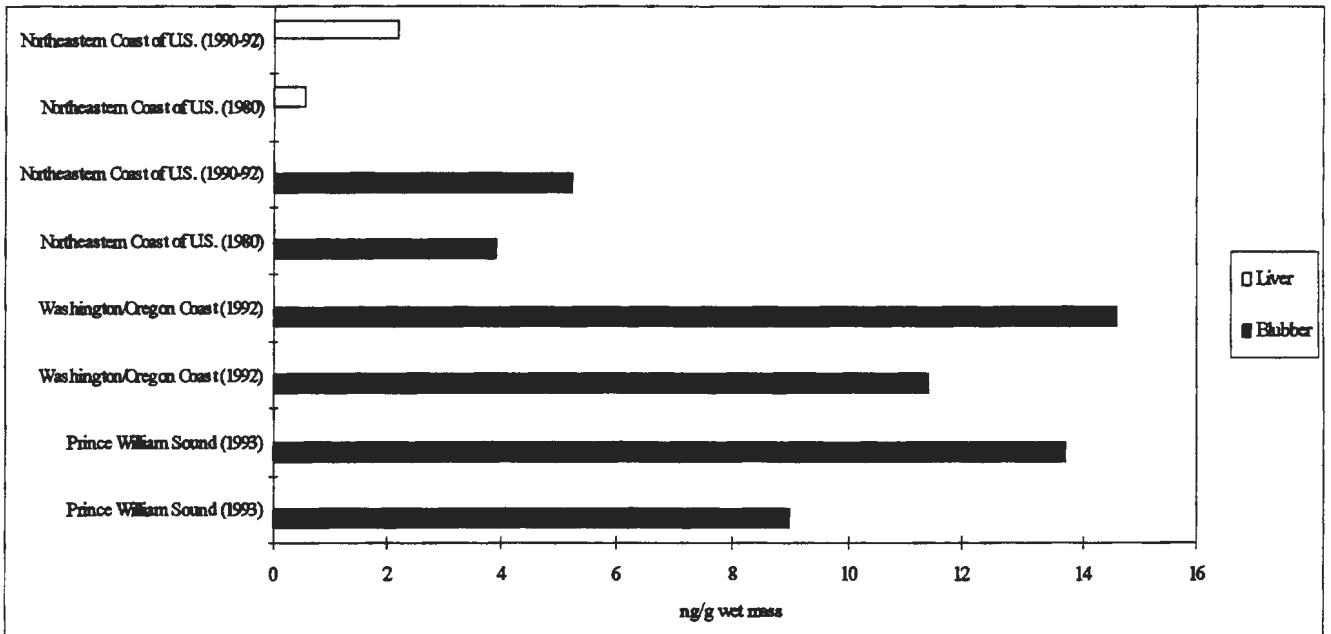


Figure 13. Concentration values (mean, n to the right of mean) of HCB in tissues of harbor seals in

Hexachlorocyclohexane (*gamma*-HCH). Hexachlorocyclohexane (HCH) occurs as several isomers, α-HCH, β-HCH, and γ-HCH (lindane). The levels in fat are an order of magnitude higher than in the liver or other internal organs, i.e., kidney, spleen, heart, and brain (Figures 14 and 15). γ-HCH is less stable than α-HCH and may be transformed to the latter during atmospheric transport. One might, therefore, expect a proportionately smaller amount of the former occurring in Arctic organisms than in animals from lower latitudes. Muir and his associates reported smaller proportion of γ-HCH to α-HCH in the blubber of belugas from the Arctic as compared to those from the Gulf of St. Lawrence which they attributed to continued use of lindane as a pesticide and its possible introduction into the St. Lawrence River (Muir, *et al.* 1990). Data from harbor seals from both southeast Alaska and Kodiak Island suggest that the subarctic marine mammals of Alaska may have proportionately higher levels of γ-HCH to the α-HCH concentrations (Figure 16).

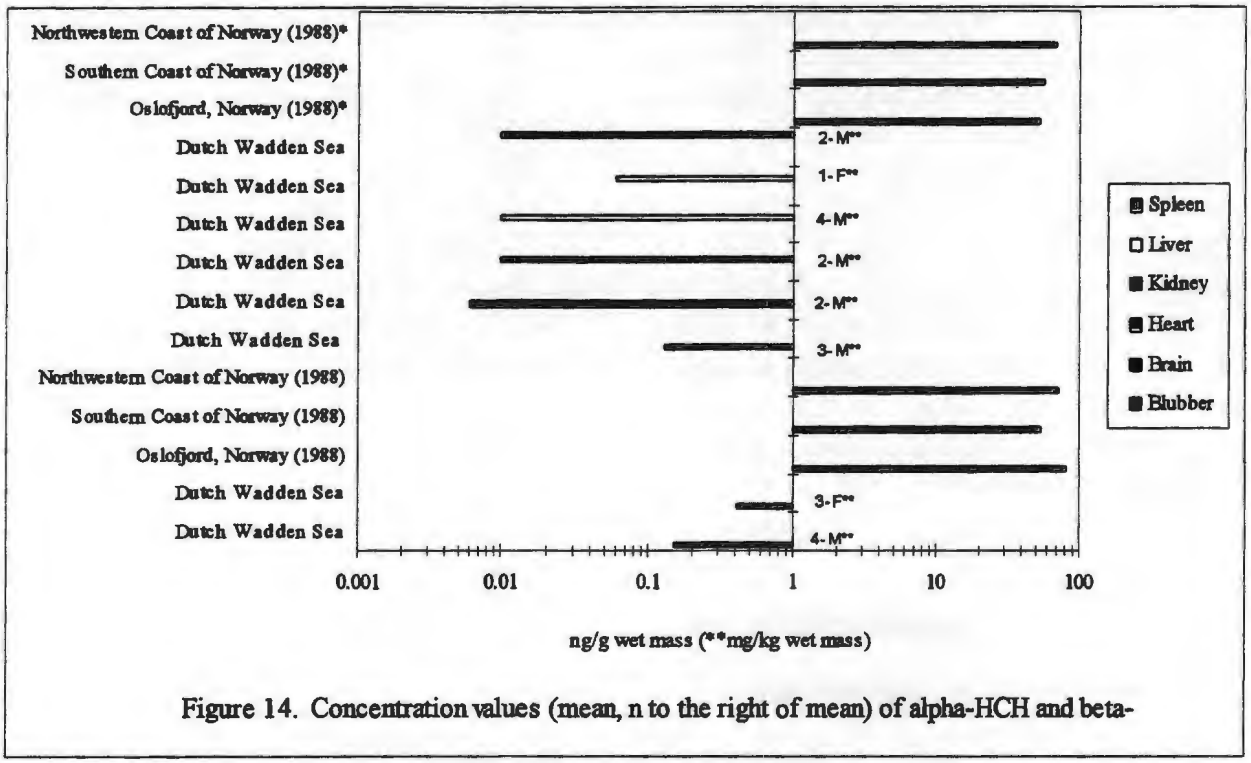


Figure 14. Concentration values (mean, n to the right of mean) of alpha-HCH and beta-

Dieldrin. Dieldrin, which accumulates in animal tissue and is eliminated slowly, is one of the most commonly reported pesticides in marine mammals. Dieldrin concentration in the blubber of harbor seals from Prince William Sound (5 ng/g ± 2 ng/g wet mass) have been reported to be lower than those reported for the same species from the Washington and Oregon coasts (12 ng/g ± 6 ng/g wet mass), but higher than have been reported for this species in the North American Atlantic (Figure 17 and Table I.1). Comparison of levels in the Prince William Sound harbor seals with other Alaska pinnipeds, indicate similar levels, except for the northern fur seals, which have levels ranging an order of magnitude higher (52 ng/g ± 86 ng/g wet mass).

Chlordane-Related Compounds. Technical chlordane is a mixture of as many as 45 isomers and congeners of related cyclopentadienes. Chlordane-type compounds identified in marine mammal tissues include *cis*-chlordane, *trans*-chlordane, *cis*-nonachlor, *trans*-nonachlor, oxychlordane, and heptachlor epoxide. Heptachlor has been used as a pesticide separate from technical chlordane. Not all investigators have measured all of these compounds and some have measured more. In many cases, it is very difficult to assess chlordane trends because it is not always clear from published reports which of the different chlordane group compounds were measured to derive the total chlordane values.

Individual isomers of chlordane differ in their degree of persistence and, therefore, their ability to accumulate in the food web. Based on evidence of relative concentrations in marine vertebrates, their prey, and in sea water (Kawano, *et al.* 1988), and correlations between octanol/water partition coefficients and bioconcentration values (Kawano, *et al.* 1984), it appears that of the two prominent isomers of technical chlordane, *trans*-chlordane is metabolized much more readily than *cis*-chlordane. However, the most prominent chlordane compounds in marine mammal tissues are trans-nonachlor,

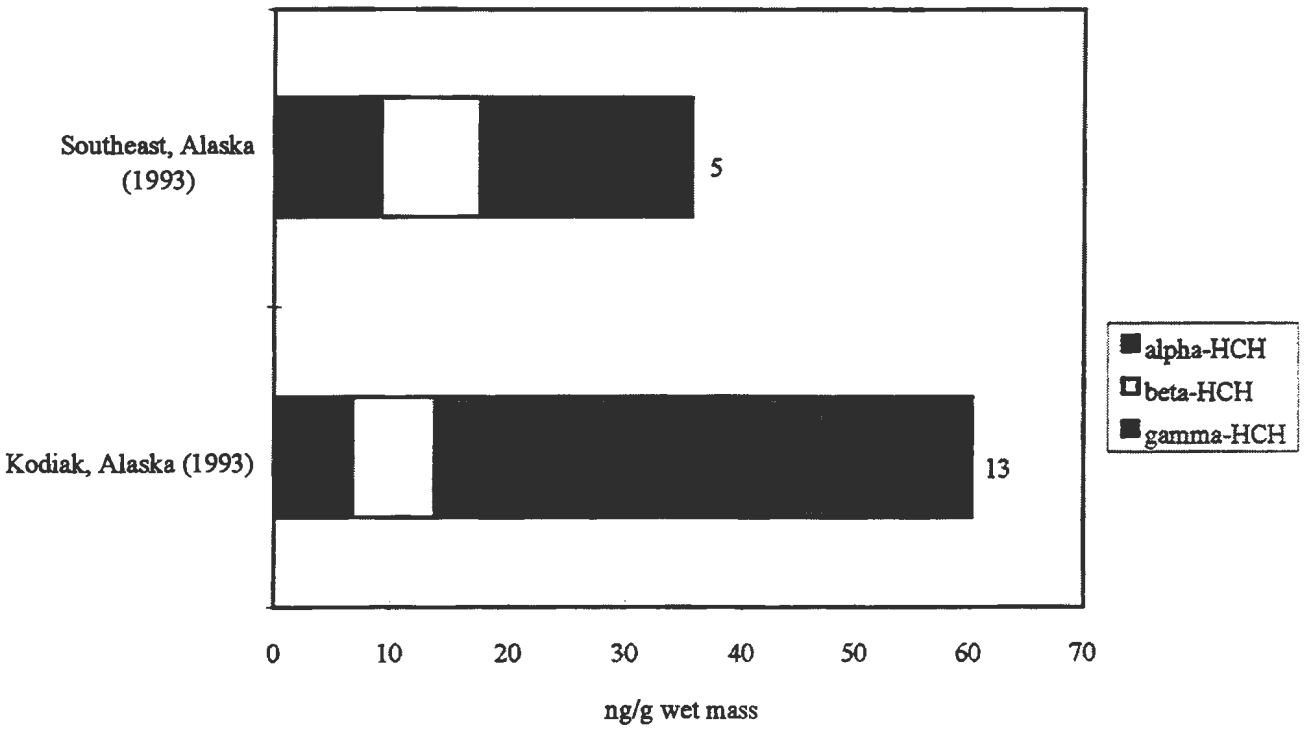


Figure 16. Concentration values of HCH in blubber of harbor seals in Alaska.

oxychlordane, and heptachlor epoxide, the latter two being metabolites.

Chlordane readily volatilizes following soil application. Long-range atmospheric transport appears to be an important mechanism for the global spreading of this compound (Wania and Mackay, 1993). Chlordane was second only to DDT and PCBs in abundance in 1981through 1982 samples of marine life from the Gulf of Alaska and Bering Sea (Kawano, *et al.* 1986).

Figure 18 compares concentration levels of chlordane compounds (*trans*-nonachlor, heptachlor epoxide, heptachlor, *alpha*-chlordane (*cis*-chlordane) and total chlordane) in liver and blubber tissues from harbor seals from Alaska with those from the contiguous U.S. Levels in the Alaska animals are relatively low (205 ng/g ± 110 ng/g wet mass). Chlordane concentrations in Alaska pinnipeds are very similar (Table I.1), except for the northern fur seals, which have higher levels (792 ng/g ± 361 ng\g wet mass) that are the same order of magnitude as reported for harbor seals from the Washington and Oregon coasts (Table I.1).

Toxaphene. Technical toxaphene consists of a mixture of hundreds of polychlorinated camphenes and bornanes produced under the name "toxaphene." This pesticide was commonly used in agricultural areas of the southeastern U.S. before being banned in the early 1980s. Twenty polychlorinated camphenes have been reported in the biota of the Canadian Arctic including marine mammals (Muir *et al.*, 1990; 1992). Toxaphene has also been reported in beluga whales of the Alaska Arctic at levels

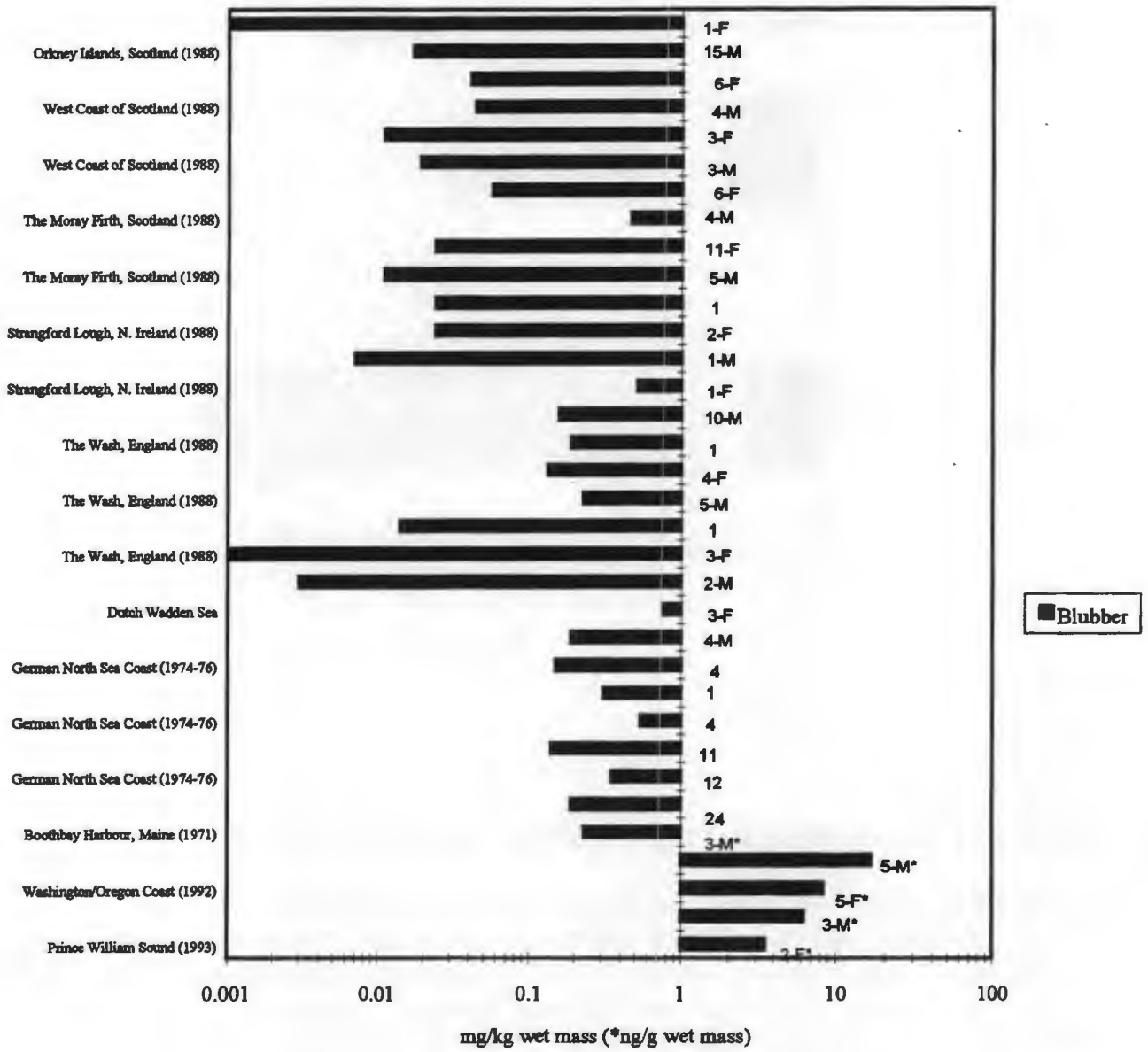


Figure 17. Concentration values (mean, n to the right of mean) of dieldrin in blubber of

approaching those of PCBs and DDT (Becker *et al.*, 1997). Due to the need for additional analytical techniques for toxaphene measurement and the need for the development of toxaphene standards, this group of compounds is not usually measured in marine mammal tissues. No toxaphene data are available for harbor seals in either Alaska or the contiguous U.S.

Other POPs. Dioxins and furans, a group of chlorinated chemicals that are similar in molecular structure to PCBs, are primarily created in high temperature processes, such as waste incineration, metal industries, and pulp and paper mills that use chlorine in the bleaching process. The toxic mechanisms of dioxins and furans are also similar to coplanar PCBs and vary depending on the actual dioxin or furan compound involved. The compound, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD), which is the

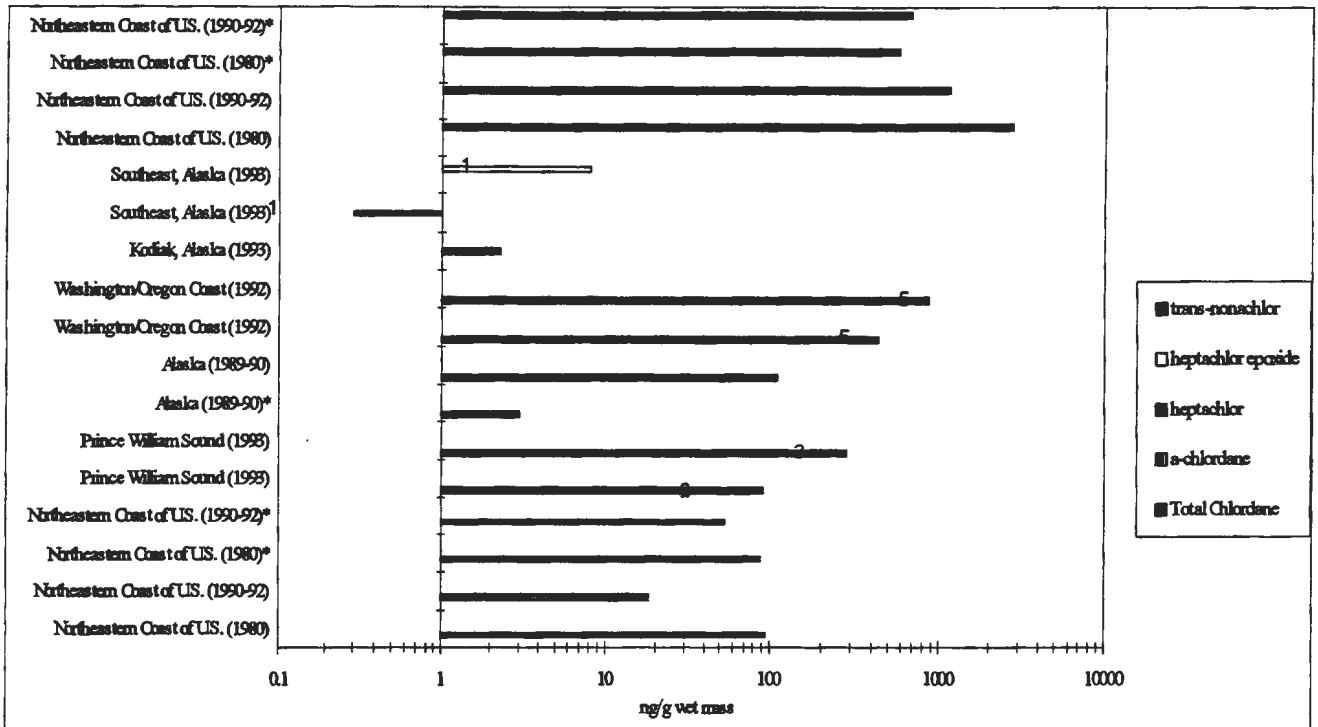


Figure 18. Concentration values (mean, n to the right of mean) of chlordanes in blubber (* liver) samples

most toxic of this group of compounds, is used as the basis for estimating the relative toxicity of other dioxin and furan compounds as well as specific PCB congeners through the calculation of "toxicity equivalents" (TEQs). Refer to Barnes (1991) for a review of TEQs. Although no concentration data have been published for these compounds in Alaska marine mammals, analysis of sea otter livers from Southeast Alaska and the Aleutian Islands have been completed (Doug Dascher, Alaska Department of Environmental Conservation, personal communication) and analysis of polar bear blubber samples from Arctic Alaska (Tom Evans, U.S. Fish and Wildlife, personal communication) has begun. The measurement of 2,3,7,8-substituted tetra- to octachloro dibenzo-*p*-dioxins and dibenzofurans in harbor seals might also be of interest in areas of suspected discharges (i.e., near pulp mills) in Southeast Alaska.

Other POPs that have not been measured in marine mammals, but due to their similarity in toxicity to PCBs, should also be considered for future measurement in harbor seals are polybrominated diphenyl ethers (PBDPEs) and polychlorinated diphenyl ethers (PCDPEs). These compounds have been commonly used as fire retardants and have become quite prevalent in the environment. The future measurement of these chemicals will depend on the development of analytical standards and methods since these are not presently readily available.

CONTAMINANT LEVELS AND HEALTH EFFECTS

Determining the role of contaminants on animal health and on the decline of an animal population requires much more than data on contaminant concentration in tissues or measurement of metabolite residues. Unless animal deaths or health decline can be linked directly to an actual pollution event, the linking of a negative response to a specific contaminant or group of contaminants is very difficult.

Heavy metals occur naturally in the environment and several, such as mercury, lead, arsenic, and cadmium, are highly toxic when in the appropriate valence state. The route of exposure for an animal (i.e., ingestion, inhaling, dermal absorption, etc.) is also critical in determining the toxicity of metals. Whether the metal is incorporated within an organic molecule (e.g., methylmercury and tributyltin) also effects toxicity. One can not equate the "normal" levels of a toxic metal in a terrestrial animal to that of a marine species. Bioaccumulation of trace elements and metals in the marine food web is a worldwide phenomenon. High levels of mercury commonly occur in upper trophic level fish. The same situation occurs for cadmium in some species of crustaceans and molluscs, and arsenic in many marine invertebrates and fish. Thus, marine mammals are commonly exposed to elevated levels of these, as well as other trace elements, via their food source. High liver or kidney levels of mercury or cadmium in a marine mammal does not necessarily mean that the animal is being detrimentally affected. The key to evaluating potential effects is to determine the form of the metal (organic or inorganic, associated with a protein complex [metallothionein] or other binding metal [selenium], valence state, etc.). Unfortunately, most metal concentrations in marine mammal tissues are have been reported as "total" values, only.

Most of the persistent pesticides (chlorinated pesticides, such as DDT, dieldrin, endrin, chlordane, and toxaphene) that are now banned in most developed countries, have relatively low mammalian toxicity as compared to the less persistent current-use pesticides. However, persistent pesticides bioaccumulate and their effects are subtle, being carcinogenic and/or affecting immune functions, hormone levels, embryological development, etc. Persistent industrial chemicals (e.g., PCBs, dioxins, and furans) have also been implicated in such subtle effects in mammals. When considering the potential for such effects to occur, one should remember that sensitivity to such chemicals varies by species, sex, reproductive status, age, and season, and that animals are exposed to not just one chemical, but to thousands of chemicals that may interact to either increase or decrease a specific response. Health of individual animals (and populations) is also affected by physical environmental conditions, the quality and abundance of food resources, disease organisms, hereditary disease, and naturally occurring biotoxins. Thus, animals are usually responding to a myriad of health insults, a potentially toxic compound (contaminant) being only one.

Historically, the most success in linking contaminants to health effects and population declines occurred in studies of ringed, grey (*Halichoerus grypus*), and harbor seal declines in the Baltic Sea during the 1980s (Olsson *et al.*, 1992; 1994). In those cases, the levels of PCBs, DDTs, and other chlorinated pesticides in these animals were very high (two to three orders of magnitude higher than were found reported in the harbor seals from Prince William Sound). The identification of these contaminants as a factor in the decline of the Baltic Sea animals developed out of an intensive effort to describe all factors affecting the health of the animals and the population overall, and to monitor these factors through several years. Key to these studies was the identification of pathologies characteristic of immune disfunction in the animals and reproductive impairment. Symptoms of immune disfunction included bone deterioration (particularly in the area around the teeth), loss of hair, abnormalities of the adrenal glands (observable by gross necropsies as well as histopath samples), emaciation, gastrointestinal lesions and proliferation of gastrointestinal parasites. Reproductive impairment was first noticed by the loss of fecundity in the animals, followed by documentation of abnormalities in the reproductive organs of the females (i.e., uterine stenosis or occlusions) (Olsson 1972; 1978) Monitoring these conditions through the years has resulted in a documentation of the reduction of the frequency of these conditions with decrease in industrial and municipal discharges into the Baltic, improvement in fishery resources, and a general improvement in the overall condition of biotic resources for this region. Although the pathologies documented for the seals in the Baltic Sea are among those characteristic of PCB and other chlorinated

hydrocarbon effects, one should also remember that the Baltic Sea was a mixture of thousands of compounds and the food web supporting the seals had degenerated in diversity and function. Improvement in the condition of the Baltic seals has resulted from an overall improvement in the regional environment, not just the elimination of one or two anthropogenic contaminants.

Research on the health of beluga whales in the St. Lawrence Estuary represents a similar case study (Martineau *et al.*, 1987; 1988; 1994). The St. Lawrence Estuary in Canada has a resident population of beluga whales (450 to 500 animals) that have been exposed chronically to a complex mixture of industrial chemicals for more than 50 years (Martineau *et al.*, 1994). A 10-year study of the health of these animals, that relied to a large extent on stranded dead animals, revealed a low reproductive rate in the population, relatively high incidence of gastrointestinal tract lesions and parasites, lesions of the pulmonary tract and mammary glands; a 40% incidence of various carcinomas, and pathologies characteristic of immune deficiencies (tooth loss, endocrine gland pathologies, and decreased lymphocyte proliferation). The levels of chlorinated hydrocarbons and pathologies for these animals are similar to those that occurred in the Baltic seals. However, in the case of the belugas, additional chemical measurements have been made of metabolites and biomarkers in an attempt to link exposure to effects. These have included benzo[a]pyrene (B[a]P) metabolites, PCB methylsulphones, DDT methylsulphones, B[a]P DNA adducts in the brain, and aromatic DNA adducts in the liver (Béland *et al*, 1993; Martineau *et al.*, 1994).

The health abnormalities shown in the seals from the Baltic Sea and the beluga whales from the St. Lawrence Estuary were reflective of several toxic responses, including increased carcinogenesis, hormonal disruption, and immune deficiencies. Although other factors might be involved, exposure to chlorinated hydrocarbons (as well as some other anthropogenic contaminants) has been shown to also elicit such responses. PCB and DDT methylsulphones are stable metabolites that may be the actual compounds inducing toxic effects (Troisi and Mason, 1997); therefore, they may be appropriate biomarkers for indicating an initial physiological response to exposure to these compounds. The use of DNA adduct measurement also shows promise in linking exposure to effects. One of the responses to exposure to anthropogenic contaminants is modification of DNA (DNA adduct formation) which may be a precursor to toxic response, such as carcinogenesis.

A developing field of research is addressing questions regarding potential endocrine disruption by many of the anthropogenic compounds considered to be persistent toxicants (PCBs, DDT, chlordane, toxaphene, HCB, etc.), others thought to be broken down more readily in the environment (endosulphan, malathion, and parathion) and some heavy metals (tributyltin and mercury) (Harrison *et al.*, 1997). The animal response to such compounds may be reflected in changes in reproductive capacity in adults and disruption of embryonic development. Reduction in productivity may, therefore, be the ultimate biotic response to such compounds. Endocrine disrupters cause adverse effects in an organism by interfering with normal hormonal processes. An early sign of endocrine disruption is the alteration of normal reproductive processes through decrease in blood levels of sex hormones (e.g., testosterone and progesterone) and alteration of steroid metabolism (Subramanian *et al.*, 1987). Such a response ultimately leads to reproductive organ effects and decreased reproduction in the population. In addition, disruption of the endocrine system in animals may affect embryological development leading to non-survival of developing fetus or decreased survival potential of the newborn. Again, the ultimate response of the population is decreased reproduction.

Microsomal cytochrome P-450 enzymes are involved in the biotransformation and metabolism of many chemicals, both endogenous and exogenous. There is some evidence (Colborn and Smolen, 1996) suggesting that reproductive toxicity of PCBs is initiated by interference with P-450 enzyme

function. Induction of P-450 enzymes by PCBs may alter steroid chemistry and cause endocrine imbalance and enzyme inhibition. The toxic potentials of PCB congeners have been classified based on the type of P-450 enzyme systems they induce (bioactivate). The most toxic of PCBs (the coplanar PCB-77, -126, and -169) and 2,3,7,8-TCDD induce the 3-methylcholanthrene-type enzyme system, while the least toxic PCBs induce the phenobarbital-type system. Ortho-substituted derivatives of the coplanar PCBs (PCB-105, -118, -128, -138, -156, and -170) are mixed-type inducers, the ones eliciting the greatest 3-methylcholanthrene response being PCB-105 and -118. Although the non-coplanar PCBs appear to be less toxic, through the use of TEQ calculations, PCBs such as 105 and 118 may contribute more to the total toxicity of PCB levels by being present in much higher concentrations than the coplanar compounds (Tanabe *et al.*, 1997).

The issue of endocrine disrupters is very complicated and not easily addressed since animals are exposed to mixtures of these compounds that may interact in ways that are not easily understood. Although many chemicals have been identified as endocrine disrupters or potential endocrine disrupters through testing of individual compounds, response to mixtures of these compounds is unknown. Critical in evaluating endocrine disrupters in marine mammals will be the development of refined research methods (both analytical and diagnostic) that can be applied to all classes of organisms. Reijnders (1994) has proposed that altered endocrine systems may be the common denominator for both reproductive and immunological disorders. He has also proposed two sets of indicators to evaluate toxicity of organochlorine residues found in marine mammal tissues: (1) interactions of chlorobiphenyls with the cytochrome P-450 enzyme system (enzyme induction studies) and (2) comparative physical and chemical blood parameters directly and indirectly obtained through functional immunoassay. In the case of the latter, this includes mitogen- and antigen-induced proliferative responses of peripheral blood mononuclear cells and natural killer cell activity. Both sets of indicators could provide a basis for multiple response assessment.

CONCLUSIONS AND RECOMMENDATIONS

Based on this review, it is apparent that there is very little published data on contaminant levels in Alaska harbor seals. This is particularly the case for heavy metals. The situation for persistent organic contaminants (e.g., chlorinated hydrocarbons) is little better. For both the heavy metals and persistent organic pollutants, many data are regionally very spotty and are 10 to 25 years old, suggesting that some data are useful for historical comparisons, but not appropriate for extrapolating to contemporary conditions. It therefore follows that little information is available to establish baseline levels of contaminants in harbor seals throughout this species' distribution in Alaska waters, much less evaluate likely impacts.

Status of Contaminants Loads. The amount of available data is presently insufficient to determine the status of contaminant loads in harbor seals throughout this species' range in Alaska. Recently published and other available data on persistent organic pollutants (PCBs and chlorinated pesticides) and heavy metals in Alaska harbor seals are very sparse and are restricted to animals of Prince William Sound, Southeast Alaska, and Kodiak. What little data exist indicate that levels of PCBs and DDT residues are an order of magnitude lower than what has been measured in this species from the Pacific coast of the lower 48 states and two orders of magnitude lower than what has been reported for these animals from the Baltic Sea, the Southern Coast of Norway, and the Dutch Wadden Sea during the late 1980s.

However, no data are available for the animals of the Western Gulf of Alaska, particularly along the Aleutian Chain. It is recommended that levels of persistent organic pollutants be characterized for populations of harbor seals in the major areas of decline (the western Gulf of Alaska, including the Aleutian Chain). Particular contaminants of broad interest are PCBs, DDT compounds, chlordane compounds, toxaphene, and dieldrin. Other compounds of somewhat lesser interest at this time are HCB and HCH (particularly lindane). Dioxin is of interest in areas of suspected discharges (i.e., near pulp mills).

Tissues to be collected for analysis should include: blubber (for establishing body loads), blood (for obtaining some measure of recent exposure and compound mobilization during seasonal periods of blubber reduction), and liver. The collections should include specimens for immediate analysis as well as those to be archived for retrospective analyses for additional compounds, metabolites, etc.

Analyses of samples for PCBs, dioxins, and chlorinated pesticides are very expensive; however, through appropriate use of less expensive analytical screening techniques, some broad-based analysis of selected samples can be conducted, with the idea of identifying trends and "hot-spots." Archived specimens can then be used to more completely characterize populations of particular interest. Screening techniques for initial quantification of the more toxic, coplanar compounds of PCBs, dioxins, and furans are available (Krahn *et al.*, 1994). The quantification of these compounds, in addition to less toxic but related and usually more abundant PCB congeners, such as PCB-118 and -105, would provide a better estimate of the toxic fractions of the dioxin and related compounds present in animal tissues.

Chlordane compounds that are measured should be carefully defined to provide for data comparability. There are many compounds that are classified as chlordane and not all are measured or reported by analytical labs. It is probably not necessary to identify and report all chlordane compounds; however, for marine mammals the dominant fractions are trans-nonachlor and oxychlordane (a metabolite). One should ensure that at least these two compounds are quantified.

Toxaphene is a persistent organic pollutant that appears to be easily transported to the Arctic via the atmosphere. It is often present in relatively high levels in fish, and in the case of Arctic marine mammals, may occur at levels that are higher than those of DDT compounds. Although the toxicity of toxaphene may not be as great as that of some of the other dominant chlorinated hydrocarbons (i.e., coplanar PCBs, dioxin, chlordane) the fact that it does occur at relatively high levels in marine mammals and has been implicated in endocrine system disruption warrants attention. Toxaphene is the commercial name for a complex of many different polychlorinated camphene and bornane compounds. It is not easily measured and there are no commercial analytical standards. Because of this, much of the data on toxaphene reported in animal tissues is not comparable. It is strongly recommended that, if toxaphene is measured, careful consideration be given to selecting the appropriate laboratory.

For all routine analyses, the lipid content of the tissue being analyzed should be determined and the concentration data normalized to lipid concentration in order to reduce the data variation. The methods for lipid determination should be defined and standardized if more than one laboratory is involved in analyses. The lipid data should be available in order to base comparisons on fresh tissue sample weight if that is required.

Measurement of petroleum hydrocarbons in blubber or liver tissue is not recommended, since such compounds are readily metabolized by mammals and excreted. More feasible and less expensive is the collection of bile samples for PAH metabolite screening. Such analysis can be done inexpensively using fluorescence techniques to give some relative measure of exposure to petroleum- derived PAHs. The collection of the bile must be done as quickly as possible after the animal dies since the compounds of interest are heat-labile and light sensitive and quickly breakdown unless frozen right away and maintained

in amber vials. Because of these technical difficulties, it would be most appropriate to limit such screening to animals occurring in areas where petroleum hydrocarbon contamination is of particular concern.

Only two papers were found that report concentrations of heavy metals (i.e., Cd, Pb, As, Hg, and Se) in Alaska harbor seals, but these data were for animals that were sampled 20 to 30 years ago at Kodiak Island and the Pribilofs. Although these data give some historical perspective for these locations, they may not be indicative of the present situation. In order to define the degree of heavy metal contamination in Alaska harbor seals, baseline levels of Hg, Se, and Cd in selected tissues (liver, kidney, blood, hair, etc.) of this species should be established for Alaska regions. Mercury analysis should include methylmercury as well as total Hg, since the former is considered to be the more toxic form. One should not equate high levels of these elements to probable organ disfunction based on information on effects in other species (particularly terrestrial animals). Marine mammals as a group commonly concentrate these heavy metals to relatively high levels. One should also not equate high concentrations of these elements with upper trophic levels as one would see in lipophilic contaminants. For example, the bowhead whale, which occupies a lower level in the food web, has much higher levels of Cd in its kidneys than the beluga whale in Alaska. The factors involved in heavy metal uptake, distribution, and accumulation in marine mammals is very complicated and poorly understood.

Subsamples of tissues collected for Hg, Se, and Cd analyses should be archived for future retrospective analysis for other heavy metals or trace elements, if such elements become a health issue, or for the identification and quantification of metal-binding proteins and organic forms of elements, if such analyses are needed for evaluating the health effects of the elements of interest. The identification of other metals or associated elements for analysis should probably be based on identifying geographical areas where such materials might be of concern. One particular example might be analyses of livers for butyltin in areas where organotin compounds are suspected to be a problem. At a minimum, samples of kidney and liver should be collected for histopathology. Comparing histopathological data with concentrations of Cd and Hg could be a first step in linking any high metal levels with pathological response.

Percent moisture of samples analyzed for elements of interest should be determined and should be part of the database on the sample. This would allow for expressing concentration values on dry mass basis, thus reducing data variability. Having percent moisture as part of the database would also allow for comparisons with other databases that report values on only a wet mass basis.

Role of Contaminants in the Harbor Seal Decline. Based on the previous discussion on "Contaminant Levels and Health Effects," the following are recommended as the minimum approach to gathering information that may be used to evaluate the health of harbor seals relative to contaminant concentrations.

1. For each animal that is sampled for contaminant analysis, samples should be collected from as many tissue types as possible for histopathological analysis. These samples are simple to collect and preserve (in buffered formalin) and relatively inexpensive to analyze. Such samples are very important in identifying abnormalities that might be linked to contaminant exposure and accumulation. At a minimum histopath collections should include liver, kidney, adrenals, testes, ovaries, and any organs that appear to be abnormal.

2. Female reproductive tracts should be collected for evaluation of reproductive history as well as evaluation for abnormalities.

3. Where possible, response measures, such as measurement of DNA adducts, P-450 analysis, and metabolites of contaminants such as methylsulphone forms of chlorinated hydrocarbons should be incorporated into the analytical program.

4. There is a large gap between quantifying contaminant burdens (or exposure) and identifying a definite detrimental response in an animal. Although the measurements listed in item 3 narrow this gap, they do not bridge it. This is a fast developing field of research. It therefore becomes important to archive some of the samples collected for analysis to allow one to apply more refined and specific techniques in the future that will give a better measure of detrimental response to exposure.

5. Whole blood and serum samples should be collected for viral screening and for measurement of metabolites, biomarkers of exposure, and general blood chemistry of the animal. Handled correctly, the samples may be archived for future analysis.

LITERATURE CITED

The literature cited in this report is listed in the NIST report available from the second author.

SECTION II: DATA TABLES

Table II.1. Mean Concentrations of Metals and Metalloids in Harbor Seals, *Phoca vitulina*, from Alaska. [a]

General Location	Date	Sex[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
Kodiak, AK	1976-78	M	Cd	11.2	0.3-44.0	15	kidney	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	M	Pb	0.7	0.3-2.0	15	kidney	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	F	Cd	2.5	0.3-44.0	8	kidney	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	F	Pb	0.9	0.3-2.2	8	kidney	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	M	As	0.09	n.d.[c]	15	liver	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	M	Pb	0.7	0.2-2.1	15	liver	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	M	Hg	4.8	0.4-72.0	15	liver	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	M	Se	1.4	0.2-18.0	15	liver	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	F	As	0.08	n.d.	8	liver	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	F	Pb	0.7	0.2-2.1	8	liver	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	F	Hg	5.5	0.4-72.0	8	liver	Miles, A.K., et al., 1992
Kodiak, AK	1976-78	F	Se	1.9	0.2-18.0	8	liver	Miles, A.K., et al., 1992
Pribilof Isl., AK	1971	M	Hg	2.3	0.6-8.9	2	liver	Anas, R.E., 1974
Pribilof Isl., AK	1971	F	Hg	3.2		1	liver	Anas, R.E., 1974

[a] mg/kg wet mass

[b] M-male; F-female

[c] n.d.- not determined

Table II. 2. Mean Concentrations of Metals and Metalloids in Harbor Seals, *Phoca vitulina*, from the U.S. outside of Alaska.[a]

General Location	Date	Sex[c]	Compound	Geometric Mean	Range	n	Tissue	Citation
San Miguel Isl., CA.	1971	F	Hg	213.24	81.0-700.0	3	liver	Anas, R.E., 1974
San Miguel Isl., CA.	1971	M	Hg	124		1	liver	Anas, R.E., 1974
Columbia River, OR	1971	M	Hg	0.3		1	liver	Anas, R.E., 1974
Columbia River, OR	1971	M	Hg	3.2		1	liver	Anas, R.E., 1974
Columbia River, OR	1971	F	Hg	68		1	liver	Anas, R.E., 1974
Washington Coast	1971	F	Hg	1.3		1	liver	Anas, R.E., 1974
Puget Sound, WA	1970	M	Hg	26.83	12.0-60.0	2	liver	Anas, R.E., 1974
Puget Sound, WA [b]	1972-82	n.d.	Ag	0.16 (0.039-0.63)	n.d.[d]	n.d.	liver	Calambokidis, J., et al., 1984
Puget Sound, WA [b]	1972-82	n.d.	Al	240 (43-1,400)	n.d.	13	liver	Calambokidis, J., et al., 1984
Puget Sound, WA [b]	1972-82	n.d.	Cd	0.78 (0.47-1.3)	n.d.	14	liver	Calambokidis, J., et al., 1984
Puget Sound, WA [b]	1972-82	n.d.	Cu	30 (14-63)	n.d.	11	liver	Calambokidis, J., et al., 1984
Puget Sound, WA [b]	1972-82	n.d.	Cr	0.37 (0.13-0.69)	n.d.	14	liver	Calambokidis, J., et al., 1984
Puget Sound, WA [b]	1972-82	n.d.	Mg	9.6 (5.9-16)	n.d.	12	liver	Calambokidis, J., et al., 1984
Puget Sound, WA [b]	1972-82	n.d.	Pb	0.44 (0.23-0.85)	n.d.	14	liver	Calambokidis, J., et al., 1984
Puget Sound, WA [b]	1972-82	n.d.	Zn	140 (84-240)	n.d.	14	liver	Calambokidis, J., et al., 1984
Puget Sound, WA [b]	1972-82	n.d.	Hg	16 (3.3-78)	n.d.	14	liver	Calambokidis, J., et al., 1984
Northeastern Coast of U.S.	1980	n.d.	Hg	38.5 (7.86)	31.6-49.3	4	liver	Lake, C.A., et al., 1995
Northeastern Coast of U.S.	1991	n.d.	Hg	69.9 (62.1)	16.0-138	3	liver	Lake, C.A., et al., 1995
San Francisco Bay	1989-92	n.d.	Cd	0.02 (0.002)	0-0.1	55	blood	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay	1989-92	n.d.	Cu	0.92 (0.04)	0.4-1.74	55	blood	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay	1989-92	n.d.	Pb	0.03 (0.01)	0-0.54	55	blood	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay	1989-92	n.d.	Ni	0.04 (0.02)	0-0.86	55	blood	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay	1989-92	n.d.	Hg	0.28 (0.02)	0.08-0.73	55	blood	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay	1989-92	n.d.	Se	0.92 (0.04)	0.51-1.80	55	blood	Kopec, A.D. and Harvey, J.T., 1995
Southern Puget Sound	1989	n.d.	Cd	0.01 (0.002)	0.01-0.02	6	blood	Kopec, A.D. and Harvey, J.T., 1995
Southern Puget Sound	1989	n.d.	Cu	0.97 (0.03)	0.87-1.05	6	blood	Kopec, A.D. and Harvey, J.T., 1995

Table II.2. (continued)

General Location	Date	Sex[c]	Compound	Geometric Mean	Range	n	Tissue	Citation
Southern Puget Sound	1989	n.d.	Pb	0.05 (0.03)	0.04-0.14	6	blood	Kopec, A.D. and Harvey, J.T., 1995
Southern Puget Sound	1989	n.d.	Hg	0.29 (0.03)	0.20-0.40	6	blood	Kopec, A.D. and Harvey, J.T., 1995
Southern Puget Sound	1989	n.d.	Se	0.70 (0.02)	0.64-0.79	6	blood	Kopec, A.D. and Harvey, J.T., 1995
San Nicolas Island	1990	n.d.	Cd	0.02 (0.01)	0-0.04	3	blood	Kopec, A.D. and Harvey, J.T., 1995
San Nicolas Island	1990	n.d.	Cu	0.92 (0.05)	0.82-0.97	3	blood	Kopec, A.D. and Harvey, J.T., 1995
San Nicolas Island	1990	n.d.	Pb	0.06 (0.06)	0-0.18	3	blood	Kopec, A.D. and Harvey, J.T., 1995
San Nicolas Island	1990	n.d.	Ni	0.12 (0.06)	0-0.20	3	blood	Kopec, A.D. and Harvey, J.T., 1995
San Nicolas Island	1990	n.d.	Hg	0.10 (0.05)	0.05-0.20	3	blood	Kopec, A.D. and Harvey, J.T., 1995
San Nicolas Island	1990	n.d.	Se	0.98 (0.17)	0.65-1.20	3	blood	Kopec, A.D. and Harvey, J.T., 1995
Monterey Coast	1992	n.d.	Cu	0.81 (0.16)	0.65-0.97	2	blood	Kopec, A.D. and Harvey, J.T., 1995
Monterey Coast	1992	n.d.	Hg	1.13 (0.57)	0.56-1.70	2	blood	Kopec, A.D. and Harvey, J.T., 1995
Monterey Coast	1992	n.d.	Se	0.73 (0.20)	0.53-0.92	2	blood	Kopec, A.D. and Harvey, J.T., 1995

[a] mg/kg wet mass (± 1 SD)

[b] mg/kg dry mass (± 1 SD)

[c] M-male; F-female

[d] n.d.- not determined

Table II.3. Mean Concentrations of Metals and Metalloids in Harbor Seals, *Phoca vitulina*, from Regions Outside of the U.S.[a]

General Location	Date	Sex/Age[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
Jarfjord	1989,'90	F,juv	Hg	0.30 (1.61)	0.15-0.52	4	liver	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	F,a	Hg	0.83	0.40-1.27	2	liver	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	M,juv	Hg	0.49 (0.23)	0.37-0.83	4	liver	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	M,a	Hg	0.54	n.d.[c]	1	liver	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	F,juv	Se	1.76 (1.49)	1.37-2.45	4	liver	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	F,a	Se	3.73	3.03-4.43	2	liver	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	M,juv	Se	2.13 (0.73)	1.59-3.18	4	liver	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	M,a	Se	1.85		1	liver	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	F,juv	Hg	0.23 (0.12)	0.11-0.38	4	kidney	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	F,a	Hg	0.19	0.09-0.28	2	kidney	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	M,juv	Hg	0.21 (0.61)	0.17-0.29	4	kidney	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	M,a	Hg	0.33		1	kidney	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	F,juv	Se	2.86 (1.06)	1.68-4.12	4	kidney	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	F,a	Se	2.8	2.75-2.84	2	kidney	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	M,juv	Se	4.45 (2.33)	2.50-7.68	4	kidney	Skaare, J.U.,et al., 1994
Jarfjord	1989,'90	M,a	Se	2.95		1	kidney	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	F,juv	Hg	6.85 (5.26)	2.47-16.02	6	liver	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	F,a	Hg	1.96 (2.54)	0.21-4.87	3	liver	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	M,juv	Hg	6.68 (4.88)	0.68-13.85	5	liver	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	M,a	Hg	10.48	1.99-18.96	2	liver	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	F,juv	Se	4.54 (2.16)	2.65-7.78	6	liver	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	F,a	Se	2.22 (1.46)	1.08-3.86	3	liver	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	M,juv	Se	4.66 (2.42)	1.99-8.52	5	liver	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	M,a	Se	5.6	2.48-8.73	2	liver	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	F,juv	Hg	0.85 (0.35)	0.57-1.50	6	kidney	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	F,a	Hg	0.89 (0.51)	0.41-1.41	3	kidney	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	M,juv	Hg	1.06 (0.38)	0.41-1.38	5	kidney	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	M,a	Hg	1.72	1.42-2.01	2	kidney	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	F,juv	Se	5.67 (0.88)	4.68-6.68	6	kidney	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	F,a	Se	3.85 (1.10)	2.65-4.79	3	kidney	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	M,juv	Se	5.79 (1.13)	4.49-6.94	5	kidney	Skaare, J.U.,et al., 1994
Vesteralen	1989,'90	M,a	Se	5.94	5.54-6.33	2	kidney	Skaare, J.U.,et al., 1994

TableII.3. (continued)

General Location	Date	Sex/Age[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
West Coast of N. Germany	1988	M,p	Cd	0.09 (0.03)	n.d.[c]	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	M,a	Cd	0.17 (0.12)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	F,p	Cd	0.13 (0.11)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	F,a	Cd	0.1 (0.09)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	M,p	Pb	0.5 (0.1)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	M,a	Pb	0.6 (0.3)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	F,p	Pb	1.1 (0.8)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	F,a	Pb	0.6 (0.3)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	M,p	Hg	22.1 (20.3)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	M,a	Hg	25.0 (16.1)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	F,p	Hg	21.2 (23.4)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	F,a	Hg	55.9 (61.3)	n.d.	n.d.	hair	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	M,p	Hg	0.12 (0.08)	n.d.	n.d.	skin	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	M,a	Hg	0.44 (0.31)	n.d.	n.d.	skin	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	F,p	Hg	0.34 (0.18)	n.d.	n.d.	skin	Wenzel, C., et al., 1993
West Coast of N. Germany	1988	F,a	Hg	0.59 (0.67)	n.d.	n.d.	skin	Wenzel, C., et al., 1993
Sea of Okhotsk	1989	n.d.	T-Hg	16.7 (15.8)	n.d.	15	liver	Himeno, S., et al., 1989
Sea of Okhotsk	1989	n.d.	I-Hg	14.3 (15.6)	n.d.	15	liver	Himeno, S., et al., 1989
Sea of Okhotsk	1989	n.d.	Se	34.7 (15.3)	n.d.	15	liver	Himeno, S., et al., 1989
Sea of Okhotsk	1989	n.d.	T-Hg	3.60 (1.55)	n.d.	15	kidney	Himeno, S., et al., 1989
Sea of Okhotsk	1989	n.d.	I-Hg	2.75 (1.30)	n.d.	15	kidney	Himeno, S., et al., 1989
Sea of Okhotsk	1989	n.d.	Se	66.5 (29.7)	n.d.	15	kidney	Himeno, S., et al., 1989
Skagerrak	1988	juv	Al	1	<0.02-3.83	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Ca	57	44-91	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Cd	0.04	<0.02-0.10	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Co	<0.002	<0.002-0.03	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Cr	0.025	0.017-0.035	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Cu	9.3	5.0-16	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Fe	369	248-642	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Hg	3.56	0.72-7.69	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Mg	156	135-186	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Mn	4.1	2.4-5.1	10	liver	Frank, A., et al., 1992

TableII.3. (continued)

General Location	Date	Sex/Age[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
Skagerrak	1988	juv	Ni	0.017	≤0.006-0.02	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Pb	0.12	0.09-0.25	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Se	2.04	1.17-4.88	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	V	0.045	0.018-0.173	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Zn	36	25-46	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Al	0.41	0.10-0.60	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Ca	65	59-78	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Cd	0.21	0.07-0.44	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Co	0.022	0.015-0.025	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Cr	0.07	0.056-0.110	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Cu	3.5	2.6-5.7	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Fe	169	118-274	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Mg	149	125-171	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Mn	0.9	0.7-1.1	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Ni	≤0.006	<0.006-0.01	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Pb	0.04	<0.02-0.07	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	V	0.018	0.011-0.040	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Zn	19	15-27	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	As	1.6	1.1-2.5	10	blubber	Frank, A., et al., 1992
Kattegat	n.d.	juv	Al	0.65	≤0.02-1.38	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Ca	58	48-69	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Cd	0.04	≤0.02-0.06	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Co	0.019	≤0.002-0.02	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Cr	0.032	0.023-0.058	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Cu	12	8.1-20	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Fe	319	204-668	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Hg	2.42	1.44-5.29	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Mg	179	147-202	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Mn	4.7	4.1-5.0	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Ni	0.02	0.008-0.033	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Pb	0.08	0.03-0.91	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Se	2.07	1.42-3.58	10	liver	Frank, A., et al., 1992

TableII.3. (continued)

General Location	Date	Sex/Age[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
Kattegat	n.d.	juv	V	0.042	0.022-0.077	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Zn	0.35	32-43	10	liver	Frank, A., et al., 1992
Kattegat	n.d.	juv	Al	0.29	0.18-1.75	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Ca	64	53-82	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Cd	0.23	0.12-0.57	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Co	0.018	<0.002-0.02	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Cr	0.044	0.020-0.140	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Cu	3.6	2.6-4.1	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Fe	155	139-193	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Mg	149	138-171	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Mn	0.9	0.7-1.2	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Ni	0.014	0.008-0.029	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Pb	0.04	<0.02-0.07	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	V	0.015	0.006-0.026	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	Zn	21	19-22	10	kidney	Frank, A., et al., 1992
Kattegat	n.d.	juv	As	2.3	1.4-3.4	10	blubber	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Al	1.88	0.23-5.64	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Ca	64	49-91	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Cd	0.02	≤0.02-0.06	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Co	0.008	≤0.002-0.02	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Cr	0.138	0.107-0.157	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Cu	4	2.2-9.2	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Fe	350	188-855	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Hg	0.44	0.20-0.85	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Mg	174	143-238	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Mn	3.7	1.4-6.2	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Ni	≤0.006	≤0.006-0.01	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Pb	0.1	0.04-0.22	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Se	1.02	0.69-1.42	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	V	0.024	0.015-0.056	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Zn	28	22-40	10	liver	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Al	0.59	0.17-2.08	10	kidney	Frank, A., et al., 1992

TableII.3. (continued)

General Location	Date	Sex/Age[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
Kalmarsund	n.d.	juv	Ca	69	61-82	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Cd	0.1	<0.02-0.24	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Co	0.017	0.005-0.036	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Cr	0.139	0.069-0.150	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Cu	3.3	2.8-4.0	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Fe	150	115-237	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Mg	163	139-187	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Mn	0.9	0.7-1.3	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Ni	≤0.006	<0.006-0.02	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Pb	0.07	0.03-0.21	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	V	0.018	0.010-0.066	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	Zn	21	19-47	10	kidney	Frank, A., et al., 1992
Kalmarsund	n.d.	juv	As	0.83	0.3-1.7	10	blubber	Frank, A., et al., 1992
Skagerrak	1988	juv	Al	0.14	0.03-0.36	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Ca	44	28-80	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Cd	0.03	<0.02-0.11	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Co	0.013	0.007-0.020	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Cr	0.07	0.053-0.170	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Cu	5.2	3.0-12	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Fe	353	189-546	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Hg	2.84	0.24-7.30	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Mg	161	129-213	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Mn	3.8	2.3-6.2	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Ni	≤0.006	≤0.006-0.02	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Pb	0.06	0.04-0.08	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Se	2.35	1.50-4.72	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	V	0.02	0.003-0.067	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Zn	36	23-62	10	liver	Frank, A., et al., 1992
Skagerrak	1988	juv	Al	0.1	0.07-1.13	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Ca	60	55-72	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Cd	0.32	0.16-0.78	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Co	0.017	0.011-0.022	10	kidney	Frank, A., et al., 1992

TableII.3. (continued)

General Location	Date	Sex/Age[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
Skagerrak	1988	juv	Cr	0.081	0.066-0.155	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Cu	6.4	4.2-12	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Fe	167	136-254	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Mg	155	142-168	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Mn	0.8	0.7-1.0	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Ni	0.04	0.024-0.071	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Pb	0.04	0.03-0.05	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	V	0.009	0.007-0.021	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	Zn	30	27-49	10	kidney	Frank, A., et al., 1992
Skagerrak	1988	juv	As	1.7	1.1-2.2	10	blubber	Frank, A., et al., 1992
Maklappen	1988	juv	Al	1.98	1.45-2.25	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Ca	58	44-72	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Cd	0.03	≤0.02-0.07	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Co	0.003	≤0.02-0.09	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Cr	0.106	0.091-0.125	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Cu	5.7	4.0-7.9	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Fe	698	409-751	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Hg	1.16	1.56-2.38	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Mg	156	146-166	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Mn	3.4	1.9-3.8	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Ni	≤0.006	≤0.006-0.01	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Pb	0.09	0.04-0.10	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Se	1.11	0.58-1.98	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	V	0.017	0.004-0.028	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Zn	45	42-49	10	liver	Frank, A., et al., 1992
Maklappen	1988	juv	Al	0.51	0.29-0.74	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Ca	60	49-75	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Cd	0.22	≤0.02-0.66	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Co	0.009	0.004-0.018	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Cr	0.13	0.121-0.154	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Cu	5.4	4.0-5.8	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Fe	168	133-281	10	kidney	Frank, A., et al., 1992

TableII.3. (continued)

General Location	Date	Sex/Age[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
Maklappen	1988	juv	Mg	157	130-159	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Mn	0.9	0.7-0.9	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Ni	0.015	0.008-0.018	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Pb	0.04	0.03-0.04	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	V	0.007	0.004-0.009	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	Zn	34	31-47	10	kidney	Frank, A., et al., 1992
Maklappen	1988	juv	As	1.7	0.7-2.2	7	blubber	Frank, A., et al., 1992
Skagerrak	n.d.	a	Al	0.66	0.25-2.78	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Ca	53	39-71	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Cd	0.09	0.04-0.18	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Co	0.019	0.011-0.044	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Cr	0.049	≤0.002-0.12	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Cu	8.6	1.4-13	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Fe	808	586-1790	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Hg	26	1.31-66	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Mg	174	146-202	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Mn	3.7		8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Ni	0.026	≤0.006-0.17	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Pb	0.16	0.11-0.23	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Se	11	3.92-26	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	V	0.094	0.027-0.282	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Zn	54	19-62	8	liver	Frank, A., et al., 1992
Skagerrak	n.d.	a	Al	0.22	0.09-0.44	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Ca	65	50-66	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Cd	0.46	0.23-0.74	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Co	0.012	0.007-0.023	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Cr	0.154	0.126-0.190	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Cu	4.5	2.7-5.9	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Fe	201	138-300	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Mg	146	123-158	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Ni	≤0.006	≤0.006-0.02	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Pb	0.05	0.04-0.10	8	kidney	Frank, A., et al., 1992

TableII.3. (continued)

General Location	Date	Sex/Age[b]	Compound	Geometric Mean	Range	n	Tissue	Citation
Skagerrak	n.d.	a	V	0.028	0.008-0.120	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	Zn	29	25-40	8	kidney	Frank, A., et al., 1992
Skagerrak	n.d.	a	As	1.6	0.96-2.3	8	blubber	Frank, A., et al., 1992

[a] mg/kg wet mass (± 1 SD)

[b] M-male; F-female; juv-juvenile; p-pup; a-adult

[c] n.d.- not determined

Table II.4. Mean Concentrations of Persistant Organochlorine Contaminants in Harbor Seals, *Phoca vitulina*, from Alaska.[a]

General Location	Date	Sex[c]	Compound	Geometric Mean	Range	n	Tissue	Citation
Prince William Sound[b]	1993	F	sPCB	233 (7)	n.d.[d]	2	Blubber	Krahn, M., et al., 1996
Prince William Sound[b]	1993	M	sPCB	599 (143)	n.d.	3	Blubber	Krahn, M., et al., 1996
Prince William Sound[b]	1993	F	sDDT	139 (9)	n.d.	2	Blubber	Krahn, M., et al., 1996
Prince William Sound[b]	1993	M	sDDT	430 (67)	n.d.	3	Blubber	Krahn, M., et al., 1996
Prince William Sound[b]	1993	F	Chlordanes	91 (11)	n.d.	2	Blubber	Krahn, M., et al., 1996
Prince William Sound[b]	1993	M	Chlordanes	281 (38)	n.d.	3	Blubber	Krahn, M., et al., 1996
Prince William Sound	1993	F	HCB	9.0 (1.0)	n.d.	2	Blubber	Krahn, M., et al., 1996
Prince William Sound	1993	M	HCB	13.7 (2.6)	n.d.	3	Blubber	Krahn, M., et al., 1996
Prince William Sound	1993	F	dieldrin	3.5 (0.5)	n.d.	2	Blubber	Krahn, M., et al., 1996
Prince William Sound	1993	M	dieldrin	6.3 (2.1)	n.d.	3	Blubber	Krahn, M., et al., 1996
Kodiak, Alaska	1993	n.d.	4,4'-DDD	0	n.d.	5	Blubber	Lewis, J.P. 1995
Kodiak, Alaska	1993	n.d.	4,4'-DDE	14.8	n.d.	5	Blubber	Lewis, J.P. 1995
Kodiak, Alaska	1993	n.d.	4,4'-DDT	1.7	n.d.	5	Blubber	Lewis, J.P. 1995
Kodiak, Alaska	1993	n.d.	Endrin Aldehyde	1	n.d.	5	Blubber	Lewis, J.P. 1995
Kodiak, Alaska	1993	n.d.	Heptachlor	2.3	n.d.	5	Blubber	Lewis, J.P. 1995
Kodiak, Alaska	1993	n.d.	alpha-HCH	6.8	n.d.	5	Blubber	Lewis, J.P. 1995
Kodiak, Alaska	1993	n.d.	beta-HCH	7	n.d.	5	Blubber	Lewis, J.P. 1995
Kodiak, Alaska	1993	n.d.	gamma-HCH	46.5	n.d.	5	Blubber	Lewis, J.P. 1995
Kodiak, Alaska	1993	n.d.	4,4'-DDD	0.5	n.d.	5	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	4,4'-DDE	292.5	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	4,4'-DDT	3.6	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	Aldrin	0.4	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	Endosulfan I	10.4	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	Endosulfan II	0.3	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	Endrin	1	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	Endrin Aldehyde	38.1	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	Heptachlor	0.3	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	Heptachlor Epoxide	8.2	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	alpha-HCH	9.2	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	beta-HCH	8.4	n.d.	13	Blubber	Lewis, J.P. 1995
Southeast, Alaska	1993	n.d.	gamma-HCH	17.9	n.d.	13	Blubber	Lewis, J.P. 1995

Table II.4. (continued)

General Location	Date	Sex[c]	Compound	Geometric Mean	Range	n	Tissue	Citation
Alaska[b]	1989-1990	n.d.	PCBs	21.0 (2.0)	n.d.	9	Liver	Varanasi, U., et. al, 1993
Alaska[b]	1989-1990	n.d.	PCBs	340.0 (42.0)	n.d.	7	Blubber	Varanasi, U., et. al, 1993
Alaska[b]	1989-1990	n.d.	DDTs	9.0 (1.0)	n.d.	9	Liver	Varanasi, U., et. al, 1993
Alaska[b]	1989-1990	n.d.	DDTs	260.0 (38.0)	n.d.	7	Blubber	Varanasi, U., et. al, 1993
Alaska[b]	1989-1990	n.d.	Chlordanes	3.0 (0.4)	n.d.	9	Liver	Varanasi, U., et. al, 1993
Alaska[b]	1989-1990	n.d.	Chlordanes	110.0 (20.0)	n.d.	7	Blubber	Varanasi, U., et. al, 1993

[a]ng/g wet mass (± 1 SD)

[b]sum of compounds-See Appendix I

[c]M-male; F-female

[d] n.d. - not determined

Table II.5. Mean Concentrations of Persistent Organochlorine Contaminants in Harbor Seals, *Phoca vitulina*, from the U.S. Outside Alaska[a]

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Southern Puget Sound[b]	1972-1981	M,p	PCB	31 (15-64)	n.d.[e]	3	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	M,sa	PCB	72 (38-130)	n.d.	4	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	M,a	PCB	240 (210-280)	n.d.	3	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	F,p	PCB	97 (58-160)	n.d.	4	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	F,sa	PCB	310 (170-570)	n.d.	5	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	F,a	PCB	21.00		1	Blubber	Calambokidis, J., et.al., 1984
Hood Canal[b]	1972-1981	M,p	PCB	12 (7.4-21)	n.d.	6	Blubber	Calambokidis, J., et.al., 1984
Hood Canal[b]	1972-1981	M,a	PCB	93 (82-100)	n.d.	2	Blubber	Calambokidis, J., et.al., 1984
Hood Canal[b]	1972-1981	F,p	PCB	8.30		1	Blubber	Calambokidis, J., et.al., 1984
Northern Puget Sound[b]	1972-1981	M,p	PCB	9.80		1	Blubber	Calambokidis, J., et.al., 1984
Northern Puget Sound[b]	1972-1981	M,a	PCB	27 (24-30)	n.d.	2	Blubber	Calambokidis, J., et.al., 1984
Northern Puget Sound[b]	1972-1981	F,p	PCB	8.3 (4.5-15)	n.d.	6	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	M,p	PCB	6.2 (3.1-13)	n.d.	5	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	M,sa	PCB	16 (9.4-28)	n.d.	11	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	M,a	PCB	24 (15-39)	n.d.	6	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	F,p	PCB	1.90		1	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	F,sa	PCB	13 (7.9-22)	n.d.	3	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	F,a	PCB	17 (6.5-43)	n.d.	7	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	M,p	DDE	2.6 (0.93-7.4)	n.d.	3	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	M,sa	DDE	6.7 (3.9-11)	n.d.	4	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	M,a	DDE	17 (15-20)	n.d.	3	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	F,p	DDE	12 (7.2-21)	n.d.	4	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	F,sa	DDE	30 (21-41)	n.d.	5	Blubber	Calambokidis, J., et.al., 1984
Southern Puget Sound[b]	1972-1981	F,a	DDE	1.30		1	Blubber	Calambokidis, J., et.al., 1984
Hood Canal[b]	1972-1981	M,p	DDE	1.8 (1.0-3.1)	n.d.	6	Blubber	Calambokidis, J., et.al., 1984
Hood Canal[b]	1972-1981	M,a	DDE	13 (12-14)	n.d.	2	Blubber	Calambokidis, J., et.al., 1984
Hood Canal[b]	1972-1981	F,p	DDE	1.00		1	Blubber	Calambokidis, J., et.al., 1984

Table II.5. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Northern Puget Sound[b]	1972-1981	M,p	DDE	2.60		1	Blubber	Calambokidis, J., et.al., 1984
Northern Puget Sound[b]	1972-1981	M,a	DDE	9.5 (8.4-11)	n.d.	2	Blubber	Calambokidis, J., et.al., 1984
Northern Puget Sound[b]	1972-1981	F,p	DDE	2.3 (1.1-4.8)	n.d.	6	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	M,p	DDE	2.9 (1.5-5.8)	n.d.	5	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	M,sa	DDE	9.3 (5.6-15)	n.d.	11	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	M,a	DDE	12 (9.5-16)	n.d.	6	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	F,p	DDE	0.80		1	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	F,sa	DDE	5.7 (1.9-17)	n.d.	3	Blubber	Calambokidis, J., et.al., 1984
Outer Coast[b]	1972-1981	F,a	DDE	6.3 (2.6-15)	n.d.	7	Blubber	Calambokidis, J., et.al., 1984
Washington/Oregon Coast[b]	1992	F	PCBs	2,077 (586)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast[b]	1992	M	PCBs	4,227 (1,414)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast[b]	1992	F	DDTs	2,313 (791)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast[b]	1992	M	DDTs	5,200 (1,855)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast[b]	1992	F	Chlordanes	439 (152)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast[b]	1992	M	Chlordanes	875 (236)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast	1992	F	HCB	11.4 (1.4)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast	1992	M	HCB	14.6 (5.0)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast	1992	F	dieldrin	8.4 (1.9)	n.d.	5	Blubber	Krahn, M., et al., 1996
Washington/Oregon Coast	1992	M	dieldrin	16.6 (5.8)	n.d.	5	Blubber	Krahn, M., et al., 1996
Boothbay Harbour, Maine	1971	M	p,p'-DDE	38.80	20.66-53.8	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDE	0.11	0.09-0.14	2	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDE	0.86	0.45-1.23	3	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDE	0.43	0.23-0.70	3	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDD	8.01	4.03-21.29	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDD	0.02	0.01-0.04	2	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDD	0.41	0.19-0.81	3	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDD	0.12	0.07-0.19	2	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	o,p'-DDT	0.31		1	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	o,p'-DDT	trace		1	Muscle	Gaskin, D.E. et al., 1973

Table II.5. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Boothbay Harbour, Maine	1971	M	o,p'-DDT	not detected	n.d.	n.d.	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	o,p'-DDT	not detected	n.d.	n.d.	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDT	24.83	11.98-64.0	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDT	0.03	0.02-0.04	2	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDT	0.16	0.11-0.26	3	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	p,p'-DDT	0.09	0.04-0.19	2	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	dieldrin	0.23	0.15-0.38	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	dieldrin	trace	n.d.	n.d.	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	dieldrin	0.04		1	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	M	dieldrin	0.01		1	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine[b]	1971	M	PCB	100.46	5.12-240.2	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine[b]	1971	M	PCB	0.37	0.28-0.50	2	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine[b]	1971	M	PCB	2.47	1.00-6.00	3	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine[b]	1971	M	PCB	1.28	0.62-2.8	3	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDE	23.64	14.86-32.1	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDE	0.07	0.04-0.09	3	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDE	0.16	0.05-0.40	2	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDE	0.28	0.21-0.38	2	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDD	3.44	1.14-11.20	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDD	0.01	0.01-0.01	2	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDD	0.10	0.02-0.25	3	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDD	0.07		1	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	o,p'-DDT	0.09	0.09-0.09	2	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	o,p'-DDT	not detected	n.d.	n.d	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	o,p'-DDT	not detected	n.d.	n.d	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	o,p'-DDT	not detected	n.d.	n.d	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDT	15.47	9.23-25.05	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDT	0.01		1	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDT	0.05	0.02-0.11	2	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	p,p'-DDT	not detected	n.d.	n.d	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	dieldrin	0.14	0.06-0.35	2	Blubber	Gaskin, D.E. et al., 1973

Table II.5. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Boothbay Harbour, Maine	1971	F	dieldrin	trace	trace	3	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	dieldrin	trace	trace	3	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine	1971	F	dieldrin	not detected	n.d.	n.d	Cerebrum	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine[b]	1971	F	PCB	44.68	27.93-99.7	3	Blubber	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine[b]	1971	F	PCB	0.17	0.10-0.25	3	Muscle	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine[b]	1971	F	PCB	0.30	0.10-0.68	3	Liver	Gaskin, D.E. et al., 1973
Boothbay Harbour, Maine[b]	1971	F	PCB	0.33		1	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDE	26.71	21.62-33.0	2	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDE	0.47	0.19-2.03	3	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDE	0.86	0.34-1.79	3	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDE	0.31	0.23-0.44	4	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDD	0.71	0.36-1.41	2	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDD	0.05	0.02-0.12	3	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDD	0.15	0.01-0.73	3	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDD	0.02	0.01-0.03	3	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	o,p'-DDT	n.d.	n.d.	n.d.	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	o,p'-DDT	n.d.	n.d.	n.d.	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	o,p'-DDT	n.d.	n.d.	n.d.	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	o,p'-DDT	n.d.	n.d.	n.d.	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDT	14.58	12.01-17.7	2	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDT	0.04	0.01-0.62	3	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDT	0.21		1	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	p,p'-DDT	n.d.	n.d.	n.d.	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	dieldrin	0.29	0.27-0.31	2	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	dieldrin	0.03		1	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	dieldrin	0.02	0.02-0.03	2	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	M	dieldrin	0.02		1	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick[b]	1971	M	PCB	46.83	43.00-51.0	2	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick[b]	1971	M	PCB	0.85	0.30-5.10	3	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick[b]	1971	M	PCB	2.02	0.80-4.50	3	Liver	Gaskin, D.E. et al., 1973

Table II.5. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Grand Manan Island, New Brunswick[b]	1971	M	PCB	0.49	0.20-0.80	4	Cerebrum	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	p,p'-DDE	19.27		1	Blubber	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	p,p'-DDE	0.32		1	Muscle	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	p,p'-DDD	1.86		1	Blubber	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	p,p'-DDD	0.01		1	Muscle	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	o,p'-DDT	trace		1	Blubber	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	o,p'-DDT	not detected		1	Muscle	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	p,p'-DDT	8.00		1	Blubber	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	p,p'-DDT	not detected		1	Muscle	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	dieldrin	1.16		1	Blubber	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick	1971	M	dieldrin	0.01		1	Muscle	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick[b]	1971	M	PCB	63.00		1	Blubber	Gaskin, D.E. et al., 1973
Deer Island, New Brunswick[b]	1971	M	PCB	0.50		1	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDE	4.90		1	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDE	0.17		1	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDE	0.22		1	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDE	0.01		1	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDD	0.18		1	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDD	0.01		1	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDD	0.13		1	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDD	not detected		1	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	o,p'-DDT	not detected		1	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	o,p'-DDT	not detected		1	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	o,p'-DDT	not detected		1	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	o,p'-DDT	not detected		1	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDT	3.56		1	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDT	0.05		1	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDT	not detected		1	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	p,p'-DDT	not detected		1	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	dieldrin	0.04		1	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	dieldrin	trace		1	Muscle	Gaskin, D.E. et al., 1973

Table II.5. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Grand Manan Island, New Brunswick	1971	F	dieldrin	trace		1	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick	1971	F	dieldrin	not detected		1	Cerebrum	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick[b]	1971	F	PCB	7.10		1	Blubber	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick[b]	1971	F	PCB	0.02		1	Muscle	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick[b]	1971	F	PCB	0.13		1	Liver	Gaskin, D.E. et al., 1973
Grand Manan Island, New Brunswick[b]	1971	F	PCB	0.01		1	Cerebrum	Gaskin, D.E. et al., 1973
Southern Puget Sound	1977-78	n.d.	PCB	171 (162)	n.d.	20	Blubber	Calambokidis, J. et al., 1979
Southern Puget Sound	1977-78	n.d.	p,p'-DDE	15.2 (12.0)	n.d.	20	Blubber	Calambokidis, J. et al., 1979
Gertrude Island, S. Puget Sound	1977-78	n.d.	PCB	171.0 (81.0)	n.d.	11	Blubber	Calambokidis, J. et al., 1979
Gertrude Island, S. Puget Sound	1977-78	n.d.	p,p'-DDE	16.0 (7.7)	n.d.	11	Blubber	Calambokidis, J. et al., 1979
Northern Puget Sound	1977-78	n.d.	PCB	14.8 (8.73)	n.d.	8	Blubber	Calambokidis, J. et al., 1979
Northern Puget Sound	1977-78	n.d.	p,p'-DDE	4.64 (3.5)	n.d.	8	Blubber	Calambokidis, J. et al., 1979
Hood Canal	1977-78	n.d.	PCB	31.0 (3.63)	n.d.	9	Blubber	Calambokidis, J. et al., 1979
Hood Canal	1977-78	n.d.	p,p'-DDE	4.38 (5.0)	n.d.	9	Blubber	Calambokidis, J. et al., 1979
Grays Harbor	1977-78	n.d.	PCB	18.8 (14.5)	n.d.	28	Blubber	Calambokidis, J. et al., 1979
Grays Harbor	1977-78	n.d.	p,p'-DDE	9.00 (6.2)	n.d.	28	Blubber	Calambokidis, J. et al., 1979
Outer Coast	1977-78	n.d.	PCB	16.3 (11.4)	n.d.	6	Blubber	Calambokidis, J. et al., 1979
Outer Coast	1977-78	n.d.	p,p'-DDE	8.34 (4.1)	n.d.	6	Blubber	Calambokidis, J. et al., 1979
San Francisco Bay	1989-90	F	p,p'-DDE	7.5 (1.2)	0-15.0	19	Herapin	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay	1989-90	M	p,p'-DDE	17.0 (2.1)	6.0-48.0	22	Herapin	Kopec, A.D. and Harvey, J.T., 1995
San Nicolas Island	1990	M,sa	p,p'-DDE	17.0 (1.0)	15.0-18.0	3	Herapin	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay	1989-90	F	PCB Aroclor 1260	10.7 (5.9)	0-79.0	19	Herapin	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay	1989-90	M	PCB Aroclor 1260	77.7 (16.5)	0-330	22	Herapin	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay[b]	1991-92	F	PCB	47.9 (12.9)	12.0-152.0	10	Blood	Kopec, A.D. and Harvey, J.T., 1995
San Francisco Bay[b]	1991-92	M	PCB	57.0 (11.7)	30.0-79.0	4	Blood	Kopec, A.D. and Harvey, J.T., 1995
Monterey Coast[b]	1992	n.d.	PCB	175.0 (161.0)	14.0-336.0	2	Blood	Kopec, A.D. and Harvey, J.T., 1995
Smith Island[b,c]	1990	M,p	PCB	2.43	1.1-19	4	Blubber	Calambokidis, J. et al., 1991
Smith Island[b,c]	1990	F,p	PCB	1.80		1	Blubber	Calambokidis, J. et al., 1991
Gertrude Island[b,c]	1990	F,p	PCB	17.97	12.0-23.0	4	Blubber	Calambokidis, J. et al., 1991
Gertrude Island[b,c]	1990	M,p	PCB	22.00	n.d.	1	Blubber	Calambokidis, J. et al., 1991

Table II.5. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Smith Island[c]	1990	M,p	p,p'-DDE	1.06	0.4-6.5	4	Blubber	Calambokidis, J. et al., 1991
Smith Island[c]	1990	F,p	p,p'-DDE	1.00		1	Blubber	Calambokidis, J. et al., 1991
Gertrude Island[c]	1990	F,p	p,p'-DDE	2.15	1.5-2.8	4	Blubber	Calambokidis, J. et al., 1991
Gertrude Island[c]	1990	M,p	p,p'-DDE	2.60		1	Blubber	Calambokidis, J. et al., 1991
Northeastern Coast of U.S.[b]	1980	n.d.	PCB	12000 (6340)	7300-2430	6	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	p,p'-DDE	10900 (5790)	6520-2190	6	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	HCB	3.90 (2.37)	n.d.	6	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	alpha-chlordane	94.1 (36.3)	n.d.	5	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	trans-nonachlor	2740 (2180)	n.d.	5	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	mirex	56.7 (28.7)	n.d.	6	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	PCB 77	0.316 (0.145)	0.198-0.50	6	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	PCB 126	1.450 (0.868)	0.628-2.91	6	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	PCB 169	0.019 (0.023)	n.d.-0.050	6	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.[b]	1990-92	n.d.	PCB	6660 (2780)	2610-1130	9	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	p,p'-DDE	4120 (1890)	1830-7840	9	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	HCB	5.25 (2.46)	n.d.	9	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	alpha-chlordane	18.4 (14.6)	n.d	4	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	trans-nonachlor	1150 (467)	n.d	4	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	mirex	31.6 (13.5)	n.d	9	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1991-92	n.d.	PCB 77	0.073 (0.0055)	0.068-0.08	4	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1991-92	n.d.	PCB 126	0.533 (0.310)	0.326-0.99	4	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1991-92	n.d.	PCB 169	0.013 (0.0091)	n.d.-0.021	4	Blubber	Lake, C. A. et al., 1995
Northeastern Coast of U.S.[b]	1980	n.d.	PCB	9860 (3340)	6290-1600	6	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	p,p'-DDE	4690 (2180)	1930-7930	6	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	HCB	0.560 (0.190)	n.d.	6	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	alpha-chlordane	88.2 (47.2)	n.d.	6	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	trans-nonachlor	574 (193)	n.d.	6	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1980	n.d.	mirex	40.3 (14.0)	n.d.	6	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.[b]	1990-92	n.d.	PCB	6260 (8070)	528-25300	9	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	p,p'-DDE	3390 (4360)	94.8-13000	9	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	HCB	2.19 (3.03)	n.d.	9	Liver	Lake, C. A. et al., 1995

Table II.5. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Northeastern Coast of U.S.	1990-92	n.d.	alpha-chlordane	54.0 (103)	n.d.	5	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	trans-nonachlor	686 (755)	n.d.	5	Liver	Lake, C. A. et al., 1995
Northeastern Coast of U.S.	1990-92	n.d.	mirex	29.5 (33.8)	n.d.	9	Liver	Lake, C. A. et al., 1995

[a]ng/g wet mass (± 1 SD)

[b]sum of compounds-See Appendix I

[c]mg/kg wet mass (± 1 SD)

[d]M-male; F-female; p-pup; sa-subadult; a-adult

[e] n.d. - not determined

Table II.6. Mean Concentrations of Persistent Organochlorine Contaminants in Harbor Seals, *Phoca vitulina*, from Regions Outside of the U.S.[a]

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Skageraak[b,c]	1988	n.d.[g]	sDDT	4.1	2.3-6.3	5	Blubber	Blomkvist, G., et.al., 1992
Kattegat[b,c]	1988	n.d.	sDDT	6.9	2.4-13.0	5	Blubber	Blomkvist, G., et.al., 1992
Kalmarsund (Baltic)[b,c]	1988	n.d.	sDDT	27	12.0-60.0	5	Blubber	Blomkvist, G., et.al., 1992
Skageraak[c]	1988	n.d.	PCB Aroclor 1254	18	18.0-60.0	5	Blubber	Blomkvist, G., et.al., 1992
Kattegat[c]	1988	n.d.	PCB Aroclor 1254	15	6.3-29.0	5	Blubber	Blomkvist, G., et.al., 1992
Kalmarsund (Baltic)[c]	1988	n.d.	PCB Aroclor 1254	36	16.0-98.0	5	Blubber	Blomkvist, G., et.al., 1992
Limfjord, Denmark[b]	1988	n.d.	PCB	4.8	2.97-6.08	7	Blubber	Storr-Hansen, E. and Spliid, H., 1993
Wadden Sea[b]	1988	n.d.	PCB	17.52	11.9-34.0	7	Blubber	Storr-Hansen, E. and Spliid, H., 1993
Kattegat[b]	1988	n.d.	PCB	9.94	5.87-14.0	7	Blubber	Storr-Hansen, E. and Spliid, H., 1993
Limfjord[b,h]	1988	n.d.	nCB	255.53	199-334	7	Blubber	Storr-Hansen, E. and Spliid, H., 1993
Wadden Sea[b,h]	1988	n.d.	nCB	458.01	338-631	7	Blubber	Storr-Hansen, E. and Spliid, H., 1993
Kattegat[b,h]	1988	n.d.	nCB	464.15	383-577	7	Blubber	Storr-Hansen, E. and Spliid, H., 1993
Southern Coast of Norway[b]	1988	M	PCB	960	560-4300	10	Brain	Bernhoft, A. and Skaare, J.U., 1994
Southern Coast of Norway[b]	1988	M	PCB	6,600	4,200-22,000	10	Kidney	Bernhoft, A. and Skaare, J.U., 1994
Southern Coast of Norway[b]	1988	M	PCB	10,000	4,500-33,000	10	Liver	Bernhoft, A. and Skaare, J.U., 1994
Southern Coast of Norway[b]	1988	M	PCB	15,000	3,400-29,000	10	Blubber	Bernhoft, A. and Skaare, J.U., 1994
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	1.14	0.53-1.53	3	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	167.8	27.3-480.7	24	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	135.5	61.0-208.0	12	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	1.38	0.252-2.96	4	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	162.8	28.5-564.0	11	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	87.3	50.3-136.0	4	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	0.48		1	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	71.1		1	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	164.6	32.3-256.0	4	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	0.093	0.058-0.127	3	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	10.3	4.4-23.3	24	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	7.7	2.9-14.7	12	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	0.1	0.039-0.161	11	Brain	Drescher, H.E., et al., 1977

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
German North Sea Coast[b,c]	1974-76	n.d.	DDT	8.8	2.2-27.2	11	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	6	5.5-6.2	4	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	0.038		1	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	4.6		1	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	6.3	4.6-7.8	4	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	trace		n.d.	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.19	0.06-0.56	24	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.35	0.14-0.8	12	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	trace	n.d.	n.d.	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.14	0.04-0.36	11	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.54	0.14-0.9	4	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	trace	n.d.	n.d.	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.31		1	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.15	0.1-0.2	4	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	trace	n.d.	n.d.	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.31	0.04-0.78	24	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.36	0.24-0.98	12	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	trace	n.d.	n.d.	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.29	0.16-0.54	11	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.34	0.26-0.56	4	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	trace	n.d.	n.d.	Brain	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.34		1	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.27	0.24-0.35	4	Blubber	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	0.87	n.d.	2	Kidney	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	2.02	n.d.	2	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	0.38	n.d.	2	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	0.22	n.d.	2	Kidney	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	PCB Aroclor 1254	0.49		1	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	0.25	n.d.	2	Kidney	Drescher, H.E., et al., 1977

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
German North Sea Coast[b,c]	1974-76	n.d.	DDT	0.25	n.d.	2	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	0.11	n.d.	2	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	0.05	n.d.	2	Kidney	Drescher, H.E., et al., 1977
German North Sea Coast[b,c]	1974-76	n.d.	DDT	0.06		1	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	trace	n.d.	n.d.	Kidney	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.016	n.d.	2	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.01	n.d.	2	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	trace	n.d.	n.d.	Kidney	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	dieldrin	0.024		1	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	trace	n.d.	n.d.	Kidney	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.006	n.d.	2	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.005	n.d.	2	Liver	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	trace	n.d.	n.d.	Kidney	Drescher, H.E., et al., 1977
German North Sea Coast[c]	1974-76	n.d.	lindane	0.006		1	Liver	Drescher, H.E., et al., 1977
Dutch Wadden Sea[b,c]	n.d.	M	PCB	6.85	1.5-36.0	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[b,c]	n.d.	M	PCB	8.34	1.4-46	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[b,c]	n.d.	M	PCB	109.03	22-576	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[b,c]	n.d.	M	PCB	7.04	1.6-31	2	Kidney	Duinker, J.C., et al., 1979
Dutch Wadden Sea[b,c]	n.d.	M	PCB	2.35	1.1-5.0	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[b,c]	n.d.	M	PCB	9.17	2.1-40	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[b,c]	n.d.	F	PCB	120.5	41.0-220.0	3	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[b,c]	n.d.	F	PCB	28		1	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	alpha-HCH	0.01	0.001-0.02	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	alpha-HCH	0.13	0.08-0.16	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	alpha-HCH	0.15	0.03-0.34	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	alpha-HCH	0.01	0.001-0.01	2	Kidney	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	alpha-HCH	0.01	0.001-0.01	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	alpha-HCH	0.006	0.004-0.01	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	alpha-HCH	0.41	0.22-0.95	3	Blubber	Duinker, J.C., et al., 1979

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Dutch Wadden Sea[c]	n.d.	F	alpha-HCH	0.06		1	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	gamma-HCH	0.003	0.001-0.01	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	gamma-HCH	0.13	0.001-0.13	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	gamma-HCH	0.07	0.03-0.23	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	gamma-HCH	0.03	<0.001-0.03	2	Kidney	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	gamma-HCH	0.003	0.001-0.01	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	gamma-HCH	0.013	0.006-0.03	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	gamma-HCH	0.21	0.14-.039	3	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	gamma-HCH	0.02		1	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	dieldrin	0.016	0.009-0.04	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	dieldrin	0.009	<0.003-0.02	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	dieldrin	0.19	<0.02-.26	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	dieldrin	0.01	<0.001-0.01	2	Kidney	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	dieldrin	0.004	0.002-0.01	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	dieldrin	0.03	0.012-0.07	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	dieldrin	0.76	0.46-1.4	3	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	dieldrin	0.03		1	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	o,p'-DDD	<0.001-0.004	n.d.	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	o,p'-DDD	0.006	<0.003-0.02	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	o,p'-DDD	0.06	<0.02-1.18	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	o,p'-DDD	<0.001	<0.001-0.002	2	Kidney	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	o,p'-DDD	<0.001	<0.001	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	o,p'-DDD	0.003	<0.001-0.007	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	o,p'-DDD	0.035	<0.02-0.07	3	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	o,p'-DDD	0.001		1	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDD	0.13	0.048-.046	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDD	0.08	<0.01-0.22	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDD	0.43	<0.05-4.5	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDD	0.017	<0.003-0.1	2	Kidney	Duinker, J.C., et al., 1979

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDD	0.008	<0.001-0.07	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDD	0.09	0.051-0.12	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	p,p'-DDD	0.2	0.096-0.55	3	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	p,p'-DDD	0.08		1	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDT	0.05	<0.08-0.06	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDT	0.04	<0.01-0.9	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDT	0.56	<0.1-2.5	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDT	0.007	<0.006-<0.008	2	Kidney	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDT	0.003	<0.003-<0.004	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDT	0.106	0.08-0.14	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	p,p'-DDT	3.06	0.92-6.9	3	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	p,p'-DDT	0.05		1	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDE	0.24	0.07-0.88	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDE	0.38	0.06-1.97	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDE	4.37	0.51-20.3	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDE	0.18	0.05-0.66	2	Kidney	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDE	0.06	0.03-0.122	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	p,p'-DDE	0.2	0.12-0.34	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	p,p'-DDE	4.52	1.63-9.4	3	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	p,p'-DDE	0.23		1	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	mirex	0.005	<0.0010.05	4	Liver	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	mirex	0.03	<0.01-.25	3	Brain	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	mirex	0.31	<0.1-1.1	4	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	mirex	0.006	<0.006-0.006	2	Kidney	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	mirex	0.003	<0.003-0.003	2	Spleen	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	M	mirex	0.023	<0.005-0.11	2	Heart	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	mirex	0.95	0.6-1.3	3	Blubber	Duinker, J.C., et al., 1979
Dutch Wadden Sea[c]	n.d.	F	mirex	0.02		1	Liver	Duinker, J.C., et al., 1979
The Wash, England[c]	1988	M	4,4'-DDE	0.204	0.16-0.26	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	4,4'-DDD	0.000	0	2	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
The Wash, England[c]	1988	M	4,4'-DDT	0.059	0.05-0.07	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB28	0.005	0.005-0.005	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB52	0.005	0.005-0.005	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB101	0.056	0.024-0.130	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB118	0.005	0.005-0.005	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB138	0.332	0.22-0.50	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB153	0.555	0.35-0.88	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB180	0.179	0.08-0.40	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	Aroclor 1254 equiv.	3.244	1.818-5.787	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	dieldrin	0.003	0.001-0.012	2	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	4,4'-DDE	0.140	0.10-0.23	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	4,4'-DDD	0.000	0	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	4,4'-DDT	0.035	0.02-0.07	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB28	0.005	0.005-0.005	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB52	0.005	0.005-0.005	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB101	0.024	0.020-0.030	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB118	0.005	0.005	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB138	0.207	0.11-0.45	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB153	0.323	0.28-0.67	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB180	0.094	0.05-0.21	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	Aroclor 1254 equiv.	1.873	1.069-3.411	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	dieldrin	0.001	0.001-0.001	3	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	4,4'-DDE	0.43		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	4,4'-DDD	0		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	4,4'-DDT	0.09		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB28	0.005		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB52	0.032		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB101	0.073		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB118	0.03		1	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
The Wash, England[c]	1988	n.d.	PCB138	0.52		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB153	0.71		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB180	0.18		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	Aroclor 1254 equiv.	3.567		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	dieldrin	0.014		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	4,4'-DDE	2.853	1.6-4.6	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	4,4'-DDD	0.030	0.01-0.09	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	4,4'-DDT	1.431	0.76-3.3	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB28	0.011	0.006-0.033	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB52	0.578	0.350-0.840	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB101	0.243	0.150-0.400	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB118	0.203	0.140-0.490	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB138	1.883	1.10-3.00	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB153	1.752	0.60-3.60	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	PCB180	0.806	0.80-1.10	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	Aroclor 1254 equiv.	17.204	16.048-21.419	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	M	dieldrin	0.227	0.120-0.530	5	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	4,4'-DDE	1.954	0.70-3.1	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	4,4'-DDD	0.030	0.02-0.05	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	4,4'-DDT	0.969	0.27-2.2	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB28	0.010	0.005-0.014	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB52	0.673	0.45-1.1	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB101	0.166	0.29-0.17	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB118	0.144	0.08-0.29	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB138	1.338	0.65-2.2	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB153	1.888	0.90-2.80	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	PCB180	0.715	0.26-1.2	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	Aroclor 1254 equiv.	15.944	6.794-24.26	4	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	F	dieldrin	0.133	0.076-0.26	4	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
The Wash, England[c]	1988	n.d.	4,4'-DDE	4.2		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	4,4'-DDD	0.04		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	4,4'-DDT	1.8		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB28	0.014		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB52	1.1		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB101	0.42		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB118	0.18		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB138	2.5		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB153	3.2		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	PCB180	1.1		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	Aroclor 1254 equiv.	23.668		1	Blubber	Hall, A.J., et al., 1992
The Wash, England[c]	1988	n.d.	dieldrin	0.19		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	4,4'-DDE	1.394	0.03-3.2	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	4,4'-DDD	0.044	0.02-0.22	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	4,4'-DDT	0.386	0.3-1.9	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB28	0.001	0.001-0.001	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB52	0.010	0.001-0.17	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB101	0.090	0.001-0.9	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB118	0.279	0.001-4.9	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB138	2.553	0.02-14.0	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB153	3.893	0.03-17.0	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB180	2.663	0.00-12.0	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	Aroclor 1254 equiv.	21.523	0.273-99.694	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	dieldrin	0.159	0.087-0.53	10	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	4,4'-DDE	3		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	4,4'-DDD	0.33		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	4,4'-DDT	1.5		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB28	0.001		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB52	0.001		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB101	0.97		1	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Strangford Lough, N. Ireland[c]	1988	F	PCB118	1.7		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB138	9.5		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB153	13		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB180	4.8		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	Aroclor 1254 equiv.	44.861		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	dieldrin	0.52		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	4,4'-DDE	1.4		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	4,4'-DDD	0.33		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	4,4'-DDT	0.79		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB28	0.005		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB52	0.026		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB101	0.084		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB118	0.032		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB138	1.3		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB153	1.7		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	PCB180	0.69		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	Aroclor 1254 equiv.	10.096		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	M	dieldrin	0.007		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	4,4'-DDE	0.341	0.04-2.9	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	4,4'-DDD	0.067	0.05-0.09	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	4,4'-DDT	0.771	0.54-1.1	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB28	0.005	0.005-0.005	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB52	0.085	0.056-0.085	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB101	0.183	0.16-0.21	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB118	0.076	0.059-0.097	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB138	2.291	1.5-3.5	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB153	3.589	2.3-5.6	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	F	PCB180	2.408	2.0-2.9	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[e]	1988	F	Aroclor 1254 equiv.	34.708	30.902-38.98	2	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Strangford Lough, N. Ireland[c]	1988	F	dieldrin	0.024	0.02-0.03	2	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	4,4'-DDE	3.5		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	4,4'-DDD	0.08		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	4,4'-DDT	1.5		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	PCB28	0.005		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	PCB52	0.13		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	PCB101	0.27		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	PCB118	0.081		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	PCB138	3.3		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	PCB153	4.1		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	PCB180	2		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	Aroclor 1254 equiv.	31.567		1	Blubber	Hall, A.J., et al., 1992
Strangford Lough, N. Ireland[c]	1988	n.d.	dieldrin	0.024		1	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	4,4'-DDE	0.860	0.43-1.68	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	4,4'-DDD	0.041	0.013-0.09	3	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	4,4'-DDT	0.567	0.28-1.12	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB28	0.000	0.000	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB52	0.118		1	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB101	0.244	0.198-0.37	3	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB118	0.047	0.019-0.09	3	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB138	0.678	0.31-1.23	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB153	0.959	0.47-1.56	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB180	0.425	0.02-46.0	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	Aroclor 1254 equiv.	3.944	0.797-9.573	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	dieldrin	0.011	0.001-0.1	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	4,4'-DDE	0.504	0.04-1.12	11	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	4,4'-DDD	0.048	0.03-0.14	10	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	4,4'-DDT	0.380	0.18-0.85	11	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB28	0.000	0.000	11	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
The Moray Firth, Scotland[c]	1988	F	PCB52	0.000	0.000	11	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB101	0.238	0.062-17.0	9	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB118	0.028	0.018-0.045	8	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB138	0.539	0.24-0.97	11	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB153	0.783	0.47-1.87	11	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB180	0.243	0.09-0.56	11	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	Aroclor 1254 equiv.	4.939	2.34-11.47	11	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	dieldrin	0.024	0.001-0.059	11	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	4,4'-DDE	1.500	0.89-2.8	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	4,4'-DDD	0.268	0.05-0.78	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	4,4'-DDT	1.209	0.36-2.49	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB28	0.000	0.000	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB52	0.124		1	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB101	0.320	0.194-0.556	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB118	0.069	0.038-0.095	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB138	2.035	0.61-3.82	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB153	2.819	0.8-5.14	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	PCB180	1.191	0.28-2.49	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	Aroclor 1254 equiv.	17.728	5.027-40.67	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	M	dieldrin	0.470	0.022-0.069	4	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	4,4'-DDE	1.126	0.47-2.68	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	4,4'-DDD	0.152	0.07-0.43	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	4,4'-DDT	0.630	0.16-1.35	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB28	0.000	0.000	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB52	0.057	0.012-0.157	5	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB101	0.243	0.113-0.605	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB118	0.094	0.038-0.239	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB138	1.155	0.46-2.53	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB153	1.860	0.71-4.42	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	PCB180	0.955	0.25-3.03	6	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
The Moray Firth, Scotland[c]	1988	F	Aroclor 1254 equiv.	17.041	6.228-46.079	6	Blubber	Hall, A.J., et al., 1992
The Moray Firth, Scotland[c]	1988	F	dieldrin	0.057	0.033-0.172	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	4,4'-DDE	0.845	0.68-1.25	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	4,4'-DDD	0.080		1	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	4,4'-DDT	0.217	0.17-0.26	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB28	0.000	0.000	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB52	0.044		1	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB101	0.129		1	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB118	0.016		1	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB138	0.582	0.54-.063	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB153	0.916	0.8-0.99	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB180	0.249	0.21-0.32	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	Aroclor 1254 equiv.	5.385	4.039-6.732	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	dieldrin	0.019	0.001-0.087	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	4,4'-DDE	0.435	0.38-0.53	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	4,4'-DDD	0.040		1	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	4,4'-DDT	0.206	0.17-0.25	2	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB28	0.000	0.000	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB52	0.000	0.000	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB101	0.097	0.081-0.116	2	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB118	0.024	0.016-0.035	2	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB138	0.487	0.35-0.6	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB153	0.863	0.65-1.02	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB180	0.402	0.32-0.45	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	Aroclor 1254 equiv.	7.669	6.145-9.37	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	dieldrin	0.011	0.001-0.05	3	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	4,4'-DDE	1.352	0.65-4.34	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	4,4'-DDD	0.181	0.11-0.47	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	4,4'-DDT	0.828	0.6-1.65	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB28	0.010	0.006-0.016	2	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
West Coast of Scotland[c]	1988	M	PCB52	0.035	0.009-0.088	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB101	0.381	0.211-0.567	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB118	0.102	0.036-0.833	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB138	2.437	1.63-5.49	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB153	4.336	2.45-8.42	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	PCB180	1.977	1.07-4.34	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	Aroclor 1254 equiv.	27.719	19.07-54.865	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	M	dieldrin	0.044	0.01-0.099	4	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	4,4'-DDE	1.515	0.76-3.29	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	4,4'-DDD	0.167	0.12-0.31	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	4,4'-DDT	0.543	0.13-2.45	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB28	0.006	0.001-0.031	5	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB52	0.064	0.018-0.199	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB101	0.321	0.11-1.203	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB118	0.114	0.051-0.198	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB138	1.383	0.95-2.62	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB153	1.995	1.38-3.63	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	PCB180	0.756	0.47-1.07	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	Aroclor 1254 equiv.	12.902	10.11-20.46	6	Blubber	Hall, A.J., et al., 1992
West Coast of Scotland[c]	1988	F	dieldrin	0.041	0.004-0.127	6	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	4,4'-DDE	0.654	0.3-1.28	15	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	4,4'-DDD	0.092	0.01-0.31	15	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	4,4'-DDT	0.484	0.17-1.84	9	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	PCB28	0.000	0.000	15	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	PCB52	0.028	n.d.	1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	PCB101	0.112	0.061-0.226	11	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	PCB118	0.008	0.002-0.023	5	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	PCB138	0.776	0.22-2.08	14	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	PCB153	1.222	0.32-3.88	15	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	PCB180	0.427	0.1-1.56	15	Blubber	Hall, A.J., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Orkney Islands, Scotland[c]	1988	M	Aroclor 1254 equiv.	8.217	2.699-24.841	15	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	M	dieldrin	0.017	0.001-0.057	15	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	4,4'-DDE	0.84		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	4,4'-DDD	0		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	4,4'-DDT	0.5		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	PCB28	0		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	PCB52	0		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	PCB101	0.068		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	PCB118	0		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	PCB138	0.45		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	PCB153	0.7		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	PCB180	0.74		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	Aroclor 1254 equiv.	12.373		1	Blubber	Hall, A.J., et al., 1992
Orkney Islands, Scotland[c]	1988	F	dieldrin	0.001		1	Blubber	Hall, A.J., et al., 1992
Coast of Norway[b,c]	1988	n.d.	PCB	7.1 (3.8)	n.d.	33	Blubber	Skaare, J.U., et al., 1990
Coast of Norway[b,c]	1988	n.d.	Total DDT	2.6 (1.3)	n.d.	33	Blubber	Skaare, J.U., et al., 1990
Coast of Norway[b,c]	1988	F	PCB	8.2 (3.6)	n.d.	17	Blubber	Skaare, J.U., et al., 1990
Coast of Norway[b,c]	1988	F	Total DDT	3.1 (1.5)	n.d.	17	Blubber	Skaare, J.U., et al., 1990
Coast of Norway[b,c]	1988	M	PCB	14.5 (2.1)	n.d.	26	Blubber	Skaare, J.U., et al., 1990
Coast of Norway[b,c]	1988	M	Total DDT	3.9 (2.1)	n.d.	26	Blubber	Skaare, J.U., et al., 1990
Oslofjord, Norway	1988	n.d.	alpha-HCH	82	39-240	n.d	Blubber	Skaare, J.U., et al., 1990
Southern Coast of Norway	1988	n.d.	alpha-HCH	54	17-95	n.d	Blubber	Skaare, J.U., et al., 1990
Northwestern Coast of Norway	1988	n.d.	alpha-HCH	72	8-119	n.d	Blubber	Skaare, J.U., et al., 1990
Oslofjord, Norway	1988	n.d.	beta-HCH	53	14-352	n.d	Blubber	Skaare, J.U., et al., 1990
Southern Coast of Norway	1988	n.d.	beta-HCH	57	7.0-21	n.d	Blubber	Skaare, J.U., et al., 1990
Northwestern Coast of Norway	1988	n.d.	beta-HCH	68	13-167	n.d	Blubber	Skaare, J.U., et al., 1990
Oslofjord, Norway	1988	n.d.	gamma-HCH	28	7-116	n.d	Blubber	Skaare, J.U., et al., 1990
Southern Coast of Norway	1988	n.d.	gamma-HCH	37	5-123	n.d	Blubber	Skaare, J.U., et al., 1990
Northwestern Coast of Norway	1988	n.d.	gamma-HCH	21	7.0-32	n.d	Blubber	Skaare, J.U., et al., 1990
Oslofjord, Norway	1988	n.d.	Oxychlordane	160	35-395	n.d	Blubber	Skaare, J.U., et al., 1990
Southern Coast of Norway	1988	n.d.	Oxychlordane	176	99-418	n.d	Blubber	Skaare, J.U., et al., 1990

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Northwestern Coast of Norway	1988	n.d.	Oxychlordane	186	11-440	n.d	Blubber	Skaare, J.U., et al., 1990
Island of Sylt, North Sea[c,e]	1990	F	PCB-052	0.092	0.005-0.17	1	Blubber	Rimkus, G., et al., 1993
Island of Sylt, North Sea[c,e]	1990	F	PCB-101	0.33	0.08-0.43	1	Blubber	Rimkus, G., et al., 1993
Island of Sylt, North Sea[c,e]	1990	F	PCB-138	5.6	2.22-7.0	1	Blubber	Rimkus, G., et al., 1993
Island of Sylt, North Sea[c,e]	1990	F	PCB-153	7.8	4.9-10	1	Blubber	Rimkus, G., et al., 1993
Island of Sylt, North Sea[c,e]	1990	F	PCB-180	1.8	0.71-3.0	1	Blubber	Rimkus, G., et al., 1993
Island of Sylt, North Sea[c,e]	1990	F	4,4'-DDT	0.2	0.1-0.36	1	Blubber	Rimkus, G., et al., 1993
Island of Sylt, North Sea[c,e]	1990	F	4,4'-DDE	1.35	0.96-11.8	1	Blubber	Rimkus, G., et al., 1993
Skagerrak[f]	1988	n.d.	PCB 49	0.07		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 52	0.3		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 101	0.51		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 118	0.26		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 138	3.6		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 153	3.8		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 180	0.96		1	Blubber	Haraguchi, K., et al., 1992
Kattegat[f]	1988	n.d.	PCB 49	n.d.		1	Blubber	Haraguchi, K., et al., 1992
Kattegat[f]	1988	n.d.	PCB 52	0.24		1	Blubber	Haraguchi, K., et al., 1992
Kattegat[f]	1988	n.d.	PCB 101	0.76		1	Blubber	Haraguchi, K., et al., 1992
Kattegat[f]	1988	n.d.	PCB 118	n.d.		1	Blubber	Haraguchi, K., et al., 1992
Kattegat[f]	1988	n.d.	PCB 138	5.1		1	Blubber	Haraguchi, K., et al., 1992
Kattegat[f]	1988	n.d.	PCB 153	5.7		1	Blubber	Haraguchi, K., et al., 1992
Kattegat[f]	1988	n.d.	PCB 180	2		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 49	0.06	0.06-0.07	5	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 52	0.21	0.19-0.24	5	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 101	0.34	0.20-0.44	5	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 118	0.21	0.16-0.27	5	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 138	1.96	1.6-2.3	5	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 153	2.1	1.6-2.4	5	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 180	0.57	0.40-0.67	5	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 49	0.07		1	Blubber	Haraguchi, K., et al., 1992

Table II.6. (continued)

General Location	Date	Sex[d]	Compound	Geometric Mean	Range	n	Tissue	Citation
Skagerrak[f]	1988	n.d.	PCB 52	0.27		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 101	0.5		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 118	0.26		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 138	3.2		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 153	3.3		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	1988	n.d.	PCB 180	0.8		1	Blubber	Haraguchi, K., et al., 1992
Baltic Maklappen[f]	1988	n.d.	PCB 49	0.09		1	Blubber	Haraguchi, K., et al., 1992
Baltic Maklappen[f]	1988	n.d.	PCB 52	0.6		1	Blubber	Haraguchi, K., et al., 1992
Baltic Maklappen[f]	1988	n.d.	PCB 101	1.8		1	Blubber	Haraguchi, K., et al., 1992
Baltic Maklappen[f]	1988	n.d.	PCB 118	0.93		1	Blubber	Haraguchi, K., et al., 1992
Baltic Maklappen[f]	1988	n.d.	PCB 138	5.8		1	Blubber	Haraguchi, K., et al., 1992
Baltic Maklappen[f]	1988	n.d.	PCB 153	5.5		1	Blubber	Haraguchi, K., et al., 1992
Baltic Maklappen[f]	1988	n.d.	PCB 180	1.5		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	n.d.	M	PCB 49	0.02		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	n.d.	M	PCB 52	0.18		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	n.d.	M	PCB 101	0.47		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	n.d.	M	PCB 118	0.22		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	n.d.	M	PCB 138	15		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	n.d.	M	PCB 153	22		1	Blubber	Haraguchi, K., et al., 1992
Skagerrak[f]	n.d.	M	PCB 180	66		1	Blubber	Haraguchi, K., et al., 1992

[a]ng/g wet mass (± 1 SD)

[b]sum of compounds (PCB, DDT, etc.)

[c]mg/kg wet mass (± 1 SD)

[d]M-male; F-female

[e]mean and range values based on results from 10-15 laboratories for one animal

[f]ng/g extracted lipid mass

[g] n.d. - not determined

[h]pg/g wet mass (± 1 SD)

RECOMMENDATIONS

RECOMMENDATIONS

1. Annual trend count surveys should continue in the Sitka, Kodiak, and Bristol Bay regions. The Ketchikan survey should remain on a biennial schedule, with the next survey conducted in 2000. Alternative methods of obtaining an accurate estimate of the number of harbor seals at large glacial sites should be explored; combining terrestrial and glacial sites within the same trend survey route should be discouraged.

2. Methods for the statistical analysis of population trend should be further refined, and the Bayesian approach to estimate trends should be investigated.

3. Complete the analysis of movement and dive data from all satellite tagged seals from 1993-1996 to determine the strength of such data in the description of harbor seal foraging ecology. Bathymetry data, if available, should be integrated in the analysis to examine spatial and temporal differences in diving behavior among seals. The results of this analysis should be used to: (1) investigate which aspects of foraging behavior are most likely to indicate differences in foraging effort and prey availability; and (2) determine the most appropriate method to detect such behaviors for future research.

4. A third year of studying the movement patterns and dive behavior of harbor seal pups should be conducted, with accompanying physiological studies.

5. Harbor seal sera should continue to be archived for future disease testing. Relationships of ages of animals and exposure rates should be investigated when adequate samples are available.

6. Tissue samples for genetic analyses should be routinely collected from all capture efforts and sent to the SWFSC of NMFS to be archived. Samples from those areas that are most needed to increase the statistical power necessary for further refinement of stock identification should be collected and analyzed.

7. A stronger relationship with the Alaska Native Harbor Seal Commission should be developed, including the discussion of future research objectives and cooperative projects. Collection of appropriate specimens in cooperation with Alaska Native subsistence hunters should continue and be expanded to assist in studies of diet, fine tooth structure, and genetics.

8. Methods to estimate harbor seal survival rates should continue, including photo-identification as an application of the mark-recapture technique.

9. There is a need to further develop capture methods for seals on glacial ice, with subsequently tagged seals to be used for studies of haulout behavior, movements, and censusing on glacial haulouts.

10. Research on the diet of harbor seals should be expanded to examine seasonal and geographical differences in major prey species.