Bowhead Whale Health and Physiology Workshop

A Report of the Workshop held October 1-4, 2001 in Barrow, Alaska

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1. Introduction

1.1 The Workshop

The Bowhead Whale Health and Physiology Workshop was held in Barrow, Alaska on October 1-4, 2001. The workshop combined multiple disciplines and perspectives to improve the quality of the interpretation of existing data and the collection of future data from landed bowhead whales in northern Alaska. The overriding goals were to determine the measurable physical, chemical, biochemical and physiological parameters that would be used to assess the health of bowhead whales and to establish research priorities for further investigations of mysticete nutritional and health status as a model for other large baleen whales (i.e., right whales, gray whales). The specific objectives were to:

- describe the preliminary findings related to the chemical, physical, and structural properties of bowhead whale blubber and understand the dynamics, biochemistry and metabolism of blubber lipids;
- describe the preliminary findings related to morphometrics, biochemistry, mineral and heavy metals status, and histology of the bowhead whale related to health and condition;
- determine the influence of selected biological variables (i.e., age, season, sex) in the health assessment process and the proper collection of these data;
- develop sampling and analysis needs for a long term bowhead whale health and nutritional assessment;
- review findings to date on the assessment of health in bowhead whales and develop sampling protocols for future projects;
- identify existing data gaps and define projects necessary to fill them; and
- describe both ongoing and proposed uses of the bowhead whale as a model for determining the health and condition of other large mysticetes (i.e., right whale reproduction, gray whale condition and contamination).

Why be concerned about the health of the BCBS bowhead whale stock? Several reasons have become apparent over the last several years and are listed below.

- Mysticetes (baleen whales) are an intriguing group of mammals, and the bowhead whale stands apart from other members of this group. As an arctic species, they are relatively unique in distribution (associated with sea ice) and are highly specialized (i.e. feeding). The arctic adaptations of this species generate further scientific intrigue with regard to their health and physiology.
- Issues surrounding climate change have prompted concern about the response of the bowhead whale to anticipated variations such as temperature, sea ice thickness and extent, prey abundance, open water, and the subsequent implications these changes may have on their distribution, health and physiology.
- Human culture and welfare relies on access to bowhead whales for many subsistence-based Native communities in Alaska and Russia.
- Industrial impacts such as noise and hydrocarbon contaminants are of increasing concern as seismic oil exploration off the northern coast of Alaska expands into actual offshore oil development and production. Extraction of natural gas in the same area has been proposed and promises to bring similar concerns to light.
• The International Whaling Commission, with its intensive management paradigm, places many mandates on the management of the bowhead, including examination of landed animals.

• Determination of bowhead whale nutritional status is critical for understanding whale health and for understanding sources of nutrients for the people who use the bowhead whale as traditional food. Reduction in the quality of, and accessibility to, bowhead whale products could result in potentially adverse health and cultural effects in traditional whale hunting communities.

• Assuring that food is safe from chemical and biological contamination is a large component of assessing landed animals. This will very likely continue to be the case well into the future as additional sources of anthropogenic chemical and biological contamination become evident and cause concern.

• Population health status of the bowhead whale cannot be solely ascertained by census technologies. However, examination of landed animals can often identify, characterize, and quantify certain indicators of individual and population health. For example, a landed whale can be examined for basic health indices; tissues can be sampled to determine levels of chemical and biological contamination; and causes of scarring (e.g., ship strikes) can be surmised.

Justifying health research on the bowhead whale in northern Alaska is not difficult considering the importance of this whale to the Iñupiat culture. However, the importance of whale health research to national and international institutions is neither certain nor predictable. We hope this report will draw attention to the need for better and more long-term health assessment programs for the bowhead whale and other mysticetes.

1.2 The Bowhead Whale

Bowhead whales (Balaena mysticetus) of the Bering-Chukchi-Beaufort Seas (BCBS) stock provide an important cultural and subsistence resource for several Northern Alaskan Eskimo communities. This basic reality was emphasized repeatedly during opening remarks made by the Mayor of the North Slope Borough (George Ahmaogak, Sr.), Executive Director of the Alaska Eskimo Whaling Commission (Maggie Ahmaogak), the president of the Barrow Whaling Captains Association (Eugene Brower), and the Executive Director of the Barrow Arctic Science Consortium (Glenn Sheehan). This regional emphasis was reiterated throughout the workshop to assure that our discussions and findings remained relevant to hunters and consumers and to the local management of the bowhead whale.

The subsistence bowhead whale hunt occurs primarily in spring and fall as whales migrate between the Bering and Beaufort Seas. Throughout its range, this species is of cultural and nutritional importance to the Native communities in northern Alaska, Canada and Chukotka, Russia. This subsistence harvest is carefully regulated in most areas via international (International Whaling Commission or IWC) and national (National Marine Fisheries Service or NMFS) bodies. As in other villages, the spring (late April to mid-May) and fall (late September to early October) hunt in Barrow, Alaska is managed through an agreement between the Alaska Eskimo Whaling Commission (AEWC) and the National Oceanic and Atmospheric Administration (NOAA). Furthermore, the Barrow hunters have formed the
Barrow Whaling Captains Association (BWCA) to manage local hunters. Hunting, cultural, nutritional, and management issues were discussed and emphasized during the opening remarks of the workshop.

Bowhead whale hunts occur in the other Alaska villages at varying times of the year and are managed by the AEWC and NOAA, as well. However, Barrow is the only site where the hunt predictably occurs twice (fall and spring) each year. Russian Native hunters have recently reinitiated the harvest of bowhead whales in Chukotka (Far Eastern Russia). The level of allowable harvest—the "quota"—for the BCBS stock is determined under a quota system in compliance with the International Whaling Commission (IWC) (IWC, 1980; Gambell, 1982) and “strikes” (harvest attempts) are distributed by the AEWC among the Alaska villages based on the number of village residents and their associated need. The overall quota is based on the subsistence and cultural need of Alaskan Eskimos, and estimates of the size and growth of the bowhead whale population (Donovan, 1982; Braund, 1992).

The largest population of bowheads, and the focus of this workshop, is the Bering-Chukchi-Beaufort Seas (BCBS) stock which migrates annually between the eastern Beaufort Sea-Amundsen Gulf in summer and the Bering Sea in the winter (Lowry, 1993; Moore et al, 1993; Schell et al, 1989). In 1993 the population of this stock was estimated to be 8,200 (95% estimation interval 7,200-9,400) (Raferty and Zeh, 1998). The stock is gradually recovering from commercial exploitation in the late 1800’s and early 1900’s. The estimated annual rate of population increase since 1978 is 3.2%. Preliminary findings from the 2001 census are consistent with this rate of increase. The detailed knowledge of the population gained over the past 20 years provides critical support to health assessment efforts as it provides researchers with a means of interpreting results in context of the population’s status. Currently, much of the health information gathered for other cetaceans is from stranded animals, many of which are diseased and decomposed. It is a rare and unique combination to have reliable population trend data and the opportunity to examine and sample a large mysticete in fresh condition at predictable times of the year. This combination of factors greatly enhances the utility and interpretation of the data.

The natural history of the bowhead whale shows it to be a mammal of extremes. The following characteristics are particularly noteworthy.

- They may be the longest lived mammal on earth, perhaps living as long as 150 years.
- Sexual maturity occurs at a very advanced age (about 20 years).
- The body is rotund and the length can be up to 20 m (65.8 ft).
- The females are larger than the males and can reach masses of over 60 tons.
- The head represents approximately one third of the body length.
- The width of the flukes is equal to approximately a third of the body length.
- Maxillary bones are extremely telescoped, and the dorsum of the head is “bowed” or arched.
- The epidermis contains melanin and appears black. Commonly referred to as having black “skin.”
- The baleen is usually black and individual plates measure up to 4.8m (15.8 ft) in length.
- Their body temperature is very low (approximately 91.4-93.2°F, 33-34°C).
They have the thickest blubber of any mammal (>40cm, 15.8in).
They range farther north than any other Mysticete.

1.3 Reader’s Guide

This report is organized according to the structure of the Bowhead Whale Health and Physiology Workshop in October 2001. Following this introduction, sections are dedicated to summaries and conclusions of the workshop presentations and the subsequent discussion sessions. The first seven presentations summarize current work with blubber quality and quantity as an indication of nutritional and health status. This is followed by six descriptions of current research addressing body condition, nutrition, and reproduction as indicators of health status. Numerous biological variables influence the health and condition of bowhead whales, so the next three presentations address how biological parameters can be used in the assessment of bowhead whale health and condition. Bowhead whale researchers have predictable access to relatively fresh samples – something rare when studying other large mysticetes. Therefore, the subsequent section of this report pertains to comparative and collaborative research in other cetaceans. These initial sections of the report provide the context for the ensuing discussion of future research and monitoring which includes an industrial perspective and discussions regarding long-term sampling and minimum parameters needed to define nutritional status.

Following the presentations and their respective discussion sessions, four working groups were formed to address 1) blubber, nutrition, and energy, 2) general histology and disease assessment, 3) physiology, and 4) biological variables. The resultant conclusions and recommendations form the next section of this report.

The figures/tables and abstracts for each presentation appear in Sections 5 and 6, respectively, and the full reports from the four working groups can be found in Appendix D. Additional appendices provide such items as the workshop agenda, participants and their contact information, and papers distributed to participants.

It is envisaged that this report will provide guidance and direction for future research pertaining to the health of the bowhead whale population and other large cetaceans, and that it will illuminate needs such as “data gaps” that must be met in order to provide basic health and biological information.
2. Workshop Presentations – Summaries and Recommendations

2.1 Blubber quality and quantity as an indicator of nutrition and health status

The vast quantity of blubber on a bowhead whale, and therefore, energy depot, make it an intuitively obvious component requiring intensive assessment for determining health and nutrition status. The location from which a blubber sample is taken has proven to be critical to interpretation. Regardless of the measure being taken, the site and depth of the blubber sample affects the result. Further complications arise from the lack of a universal definition of bowhead whale blubber. A better understanding of the natural variability of blubber measures – both within an individual bowhead whale at a single time point and in the population over seasons and years – will assist in the standardization of methods and elucidate the limitations of less controlled sampling (remote biopsies) for which site and depth are not well controlled.

The many functions of blubber and the role of blubber morphology, physiology, and biochemistry in assessing the health of the bowhead whale present a huge realm of unique physiological scenarios and unanswered questions. Clearly, blubber is important to bowhead whales and maintaining it is an important factor in their life strategy. Thus, understanding blubber is essential to understanding the health and physiology of this whale.

Feeding habits and behavior have been documented during specific periods when stomach contents can be examined or aerial surveys are conducted. However, feeding during much of the year, especially the winter, is yet to be observed by western scientists. Chemically based tools to determine food habits and measures of basic nutrients have recently been utilized to study what and where bowhead whales eat, as well as to assess overall nutritive condition. Such tools include stable isotopes of carbon and nitrogen in muscle, contaminant levels and profiles in many tissues, and comparison of lipid levels in blubber.

2.1.1 A 3-D look at blubber and definition of blubber in general

(Abstract #1)

Blubber is key to many aspects of bowhead whale physiology, form, and function in that it:

- provides energy for metabolism, serving as “onboard fuel.”
- participates in thermoregulation by providing insulation.
- contributes to buoyancy control.
- provides structure for form and swimming and contributes to streamlining (hydrodynamics, biomechanics).
- provides a source of metabolic water for the whale. When lipid (fat) is broken down by the body, one of the resulting products is water.
- provides the animal with a protective shield against predators and other sources of injury.
- contains a complex collagen matrix (a web of protein fibers), which provides a framework within which the lipids are deposited.
2.1.2 Gross and histologic structure of bowhead whale blubber: defining the terms for cetaceans (Abstract #2)

*Blubber* is a slang, non-scientific term. It was originally used by European whalers and sealers when referring to the dermal and subcutaneous fat stores of cetaceans, pinnipeds, and polar bears (Parry, 1949). There is widespread disagreement and confusion about what actually constitutes “blubber.” There is also considerable surprise among some scientists when they learn that the blubber is part of the skin structure.

Three definitions of blubber have been used inconsistently throughout the literature. The discrepancy involves the structure of blubber, its relationship to the dermis and hypodermis, and how these definitions are interpreted. Since the earliest published works, blubber has been referred to as a) the entire combination of epidermis, dermis and hypodermis; b) solely the heavily lipid-laden hypodermis; or c) the dermis and epidermis.

1. D.A. Parry, 1949 - The term *blubber* is in popular and commercial use to denote the superficial tissues of whales and seals, which form a compact layer loosely fastened to the underlying muscle and easily stripped off for commercial purposes. Blubber comprises the animals’ *epidermis*, *dermis* and *hypodermal* tissues.

2. Lockyer, 1984 – A fatty layer of tissue which completely envelops the surface of the whale. The blubber layer underlies a relatively thin, dermal covering, with which it is intimately connected, and overlies the musculature from which it is separated only by a thin, loose layer of blood permeated connective tissue which is flexible and permits independent movement of the muscle and blubber.

3. Haldiman and Tarpley, 1993 – The layer usually called blubber comprises the majority of the skin. It is a highly modified reticular layer of the dermis....a true hypodermis extends between the tendinous layer denoting the innermost aspect of the dermis (blubber portion) and the underlying muscles and other organs...skeletal muscle fibers have been noted within the hypodermis...since the fibers are part of the cutaneous muscle (*panniculus adiposis*), everything external to this muscle layer, including the blubber, is skin.

Contention surrounds the issue of a) whether or not the hypodermis is a part of the blubber, and b) whether or not the hypodermis has been included in a particular sample or set of samples. The definition of blubber, and its relationship with dermis and hypodermis become important when depth measurements are being taken, lipid percentages or contaminant levels are being determined, or when anyone is referring to blubber. *Epidermis* is the outermost layer of the skin (Figure 1). It forms what is commonly referred to as the “black skin” that is strikingly obvious when viewing the exterior surface of the animal. Embryologically, *dermis* is mesodermal in origin (Figure 1). Dermis is a thick bed of dense, white fibrous connective tissue, blood vessels and adipose tissue. Its outer aspect has dermal ridges from which finger-like projections extend towards the external surface of the whale. The dermis comprises the majority of the skin, and has a highly modified reticular layer. *Hypodermis* is mesenchymal in origin. It lies between the innermost aspect of the dermis and the underlying muscles and other organs (Figure 1). Consisting of loose connective tissue, it provides a
loose and movable connection between the skin and the remainder of the body. Skeletal muscle fibers have been noted within some samples of this layer.

In order to further clarify the content of recently collected blubber samples, horizontal sections from each depth were stained for collagen, elastin and reticulin and are currently being analyzed. The relative percentages of each constituent will then be determined from microscopic images. An effort to study the embryological origins of “blubber” – specifically, the mesodermal and mesenchymal components of these layers, is underway. This will hopefully lend the clarification necessary to “define” blubber and standardize collection procedures across the cetacean research community.

2.1.3 Basic chemical and energetic composition of bowhead whale blubber and the effects of selected biological variables and within animal variability (Abstract #3)

The biochemical composition and energy density of blubber varies among individual whales and is influenced by intrinsic factors such as size, sex, nutritional condition, disease, and reproductive status, and by environmental factors such as season, ice-cover, and food availability. Variation is also evident within a single individual and depends on the location of the sampling site on the body and the depth of the sample within a site. Full thickness blubber columns were sampled at 1-6 sites per whale. These full thickness samples were then subdivided into five equal depths and analyzed for lipid and water content and energy density.

- The middle depths (2 and 3) contained the highest proportion of lipid and were the least variable. They are speculated to be long-term energy reserves, thermoregulatory, or for other unknown purposes.
- Inner depths (4 and 5) of blubber were the most variable in composition, and probably the most active site for fat deposition and mobilization.
- Samples from umbilical girth sites appear more variable in composition than samples from sites approximately 1 meter caudal to the blowhole girth. This suggests that umbilical girth sites are more sensitive indicators of changes in body condition than sites nearer the blowholes.
- Excluding pregnant females, the mean blubber lipid content at all sites and depths combined decreased as body length increased.
- Preliminary data suggest that pregnant females have a higher lipid blubber content than non-pregnant females, as well as higher lipid blubber content than males of similar body length (Figure 2). Conclusions about this are not yet possible given the very few pregnant whales sampled in this study.
- Long-term monitoring of lipid content and condition indices using blubber must consider within-animal variability, as well as differences based on age, sex, reproductive status, and season. Thus, standardized protocols for measuring thickness and selection of sites and depths for sampling are extremely critical.
2.1.4 Preliminary findings: bowhead whale regional heterothermy and energetics (Abstract #4)

Past theories and observations from experts pertaining to the thick lipid impregnated dermis of the bowhead include:

- J.E.I. Hokkanen, 1990 – “The insulation of the bowhead is good enough to allow it to swim in liquid oxygen! The blubber coats for large whales are obviously not dimensioned for thermal demands...For large whales, blood circulation to the dermal layer is essential for heat loss, if blood flow is decreased below a critical level, the animal will overheat...”
- J. Burns, 1993 – “The question of why bowheads are usually so fat...requires further inquiry...” “[Thick blubber] enables...whales to survive the occasional year when food is virtually lacking, or, more likely, back-to-back years of low food availability.”
- Eddie Hopson, Elder and Whale Hunter (2000) – “You’re going to find out that the bowhead is a thermos bottle.”

A thermal gradient has recently been determined within the whale and the blubber (Figure 3). The temperature of the blubber is near ambient at the outer surface, and it gradually increases with greater depths into the blubber. The temperature then stabilizes near the muscle-blubber interface at nearly core body temperature, which is a relatively low 33-34°C. The lowest thermal conductivity (TC) values occur in the mid-blubber column which contains the highest lipid concentrations. Blubber TC values in bowheads are similar to some odontocetes (Worthy and Edwards, 1990) but lower than other mysticetes (Kvadsheim, et al, 1996). Based on energy output, most body heat is lost from the fluke and the head, most of the latter probably from the tongue.

2.1.5 Lipid classes and organochlorines in bowhead whale blubber (Abstract #5)

Blubber is comprised of several different types of lipids (fat), as well as other constituents like protein and water. The lipids are categorized into different classes, which include wax esters, free fatty acids, triglycerides, cholesterol, and phospholipids. Recently generated data on blubber composition in bowhead whales revealed how much of blubber was actually lipid and what lipid classes were present. Analyses of the different blubber strata (layers at different depths) indicate that lipid concentration varies depending on depth (Abstract 13). This has been shown for other mysticetes, as well (Aguilar and Borrell, 1991). Additionally, the presence of organochlorine (OC) contaminants has been determined and, again, it varies with blubber depth. The OCs are persistent and lipophilic (fat loving), and therefore tend to bioaccumulate in lipid-rich tissues like blubber. OCs include chlorinated pesticides, polychlorinated biphenyls (PCBs), DDTs, and hexachlorobenzene (HCB). The proportion of neutral lipids (i.e., triglycerides, non-esterified free fatty acids) is a key factor affecting the accumulation of lipophilic OCs (Delbeke et al., 1995; Kawai et al., 1988), hence the importance of analyzing for both lipid concentration and OC content. Currently, it can be concluded that:

- In general, lipid concentrations of bowhead whale blubber samples ranged from 25 – 83%, and consisted primarily of triglycerides (94 – 100%).
• The mean lipid concentrations were significantly different among the three collection years (1998, 1999, 2000) and by season (fall versus spring) (see Abstract 13).
• The OC concentrations (Table 1 and Figure 4) in the bowhead blubber were low compared to those reported in blubber of most Alaskan marine mammals (Miles et al., 1992; Varanasi et al., 1992; Lee et al., 1996; Krahn et al., 1997; Beckmen et al., 1999) and are much lower than the concentrations of non-arctic marine mammals (Tilbury et al, 1999; Ross et al, 2000; Weisbrot et al, 2000)
• Concentrations of OCs slightly increased with length in male bowhead whales.
• Concentrations of $\sum$DDTs and $\sum$PCBs increased with length in female whales, up to the length of approximately 10 meters.
• Mean concentrations of $\sum$DDTs and $\sum$PCBs were generally lower for the adult female bowhead whales compared to juvenile animals.

2.1.6 Chemically determined feeding ecology and anthropogenic chemicals in bowhead whale blubber (Abstract #6)

Stable isotopes and the presence of OCs in blubber have recently been utilized to study the bowhead whale diet and location of feeding areas. The application of stable isotope data to feeding ecology requires an understanding that carbon (C) and nitrogen (N) isotopes fractionate in a predictable manner in biota. It is known that levels of $^{15}$N (a particular stable isotope of N) increase as one climbs the food chain; $^{15}$N increases from prey to predator. This allows for the assignment of relative trophic position, thus the ratio of $^{15}$N to $^{14}$N increases. The $^{13}$C/$^{12}$C signature is known to differ between geographical areas within the Bering-Chukchi-Beaufort Seas region and has been used historically to distinguish sources of bowhead whale prey as being from either the Bering Sea or Beaufort Sea sources of C. OCs were measured in blubber and other matrices to address bioaccumulation, seasonal and geographical variation, and aspects of metabolism.

Currently, conclusions are:
• Feeding on prey of both the Bering and Beaufort Seas is reflected by variations in C isotope and OC profiles in bowhead tissues.
• Bowhead whales feed at a much lower trophic level (lower $^{15}$N/$^{14}$N, Figure 5) than other arctic marine mammals in the region.
• Stable isotope ratios predictably change by season, likely reflecting variations in the C signature of the Bering-Chukchi Seas versus the eastern Beaufort Seas (Figure 6) with some recognized overlap. This provides evidence of feeding on prey from these chemically distinct regions.
• All three body length cohorts evaluated exhibit seasonal changes in the C isotope ratios in muscle, which reflects utilization of dietary sources from the respective regions (Figure 7) (Hockstra et al, 2002).
• For the contaminants studied, bioaccumulation is evident from water, to zooplankton, and to the bowhead whale (Figure 8).
• Sex plays a significant role in the types and amounts of accumulation of the OCs; males accumulate some OCs that females do not.
• Comparing contaminant profiles indicated that certain metabolic capabilities are absent (cytochrome P450 2B) while others appear to be intact (cytochrome P4501A). This is consistent with the metabolism of other cetaceans studied.

• Geographic differences exist in contaminant exposure and accumulation. Contamination varies by region, which is reflected in prey, then in tissue residues in blubber of the bowhead whale. This is very likely a result of feeding in the respective regions, i.e. the Bering and Beaufort Seas.

• The process of accumulation for some OCs is isomer-specific. Water and zooplankton normally contain a 50:50 (racemic mixture) of an OC isomer. However, bowhead whale tissues contained mixtures of isomers other than 50:50 for some chemicals (Figure 9). This indicates that the bowhead may be selectively metabolizing or biotransforming one of the isomers. This selectivity appears to be correlated with whale maturation for some chemicals (i.e., CB-91).

2.1.7 Heat loss in minke whales (*Balaenoptera acutorostrata*) (Abstract #7)

Whale subjects require indirect approaches to obtain data on energetic parameters like metabolic rate and cost of maintaining heat balance with the environment. Minke and bowhead whales are homeothermic (maintain core body temperature in a fixed range) which implies that their metabolic heat production rate equals their rate of heat loss. The calculation of heat loss requires detailed knowledge of the thermal conductivity of blubber. This can be measured accurately in blubber samples, but in live animals it will change with the amount of blood perfusion (heat carried by the blood) of the tissue.

Detailed data on surface area, blubber thickness and conductivity, as well as temperature difference across the blubber have been collected from minke whales, and minimum heat loss rates in ice water calculated. Similar data are being collected for bowhead whales (Abstract 4). A comparison of minke to bowhead whales could provide critical information on bowhead whale thermoregulation.

2.1.8 Discussions –

2.1.8.1 Blubber

Difficulty arises upon publishing when we try to reconcile or align our definitions of dermis, epidermis, and hypodermis with other widely used definitions of blubber. Fortunately, the cadre of researchers utilizing blubber sampled from Barrow can match samples to compare physical, morphological, and chemical measures.

• Current studies use bowhead whale blubber samples that are sampled from the skin surface (epidermis) to muscle, as removed by traditional Inupiaq butchering techniques, and are defined as such.

• The slab of blubber, which includes the epidermis-to-muscle slab removed during butchering, should be split into five equal layers (Figure 10). Each layer would represent 20% of the blubber depth/thickness.

• Layers 1–4 (the outer 80% of the blubber) are consistent and are very good representations of most of the blubber.
• By way of being torn away from the carcass, layer 5 (closest to the muscle) would not be sampled consistently. Some hypodermis remains on the animal and results in an incomplete sample if, indeed, hypodermis is included in our definition of blubber. Layer 5 would be identified as the most variable and would admittedly create the most uncertainty in any resulting data.

• A more rigorous sampling protocol from the muscle and outward would be required in order to solve the dilemma of Layer 5, which is affected by the butchering bias. However, the samples’ very existence is due to the generosity of the people who butcher the whale, whose priorities revolve around food, food processing, and food distribution...not around histological concerns of whether or not hypodermis is technically part of the blubber or completely included in scientific samples.

• Whether or not hypodermis is part of the blubber was not of major concern, assuming that investigators make clear just what tissues they are including in their analyses. The consensus was that epidermis and dermis are part of the blubber.

• Hypodermis may be important and should be studied in the future, as it may be a significant finding or indicator of nutritional status. The hypodermis certainly represents a relatively significant mass of tissue in the *ingutuk* and pregnant or lactating females.

• Seasonal changes in girth have been noted, yet blubber thickness is not changing. This could be due to the “hypodermal” variability, a loss or gain of muscle tissue, or inconsistent measurements due to the variability inherent in the butchering process. Blubber thickness is a less sensitive indicator of status than girth or percent lipid.

• Standardization of blubber measurement and sample collection is needed, however, as the “hypodermis issue” does introduce variability into the blubber thickness data. Such an issue would be well worth taking up with right whale and gray whale researchers, as well.

• We are refining our sampling and measuring of “blubber” to better address the hypodermis as a confounding variable.

Additional points related to blubber thickness

• Blubber thickness measurements are influenced by whether they are taken while the blubber is still on the animal or after having been removed. Do we measure blubber thickness on or off the whale? Or both? Blubber off the whale may not be as thick because it does not include all the hypodermis. The current protocol for right whales mandates that blubber thickness be measured off the whale to standardize the numbers (Dr. Mike Moore, pers. comm.).

• Judy Zeh suggested making a new protocol for blubber morphometrics but stressed that current methodology continue for the sake of consistency.

• Evidence indicates that blubber composition changes seasonally. The physical (i.e., thermal conductivity, girths) and chemical analyses (i.e., lipid content) parallel each other, suggesting that the fall whales are in better “condition.”

Fatty acids and lipid profiles of blubber:

• Data gaps exist concerning fatty acids and stratification in bowhead whale blubber. These components are known to vary in other cetaceans by site and depth, especially in polar species.
• The lipid next to the muscle layer is likely to be in an oil (liquid) state, whereas that next to epidermis is more solid. These thermal properties could change due to shifts in fatty acid proportions, but in the absence of fatty acid data, conclusions cannot be surmised. Interestingly, fatty acids will be addressed by an upcoming report by Stoskopf, et al., and by work currently underway by Reynolds and Wetzel at the Mote Marine Laboratory.

• Lipid profiles (including fatty acids) are influenced by the composition of the whales’ diet and thermal gradient. It may also be influenced by the site from which tissue samples are taken. Therefore, the tissue sampling site should be standardized—something typically not done for some studies.

2.1.8.2 The bowhead whale as a mysticete model

• The availability of samples and opportunity for sampling are not adequate reasons, by themselves, for using the bowhead whale as a model for other mysticetes. The bias of this workshop and the research presented therein is understandably slanted towards the bowhead, partly for those reasons. Care must be taken to assure that using the bowhead whale as a mysticete model is appropriate and scientifically justified.

• There is growing interest by the IWC Scientific Committee in avoiding the use of dead animals as research subjects and in relying on biopsy samples of free ranging cetaceans. There is a real need to know what comparisons can and cannot be made using these two sampling schemes. The bowhead whale and right whale sampling scenarios currently in effect offer the opportunity to elucidate what comparisons are feasible.

• Specific types of bowhead whale data were requested during a separate workshop on right whale health assessment (IWC, 2000).

2.1.8.3 Thermoregulation and metabolism

Bowhead whale thermoregulation was discussed in terms of what is known about minke whales since much of the cutting edge research has been conducted on the minke whale (by a workshop participant). Size, shape, blubber thickness, and probably metabolic rate, differ greatly between the two cetaceans, and they play major roles in the notable thermoregulatory differences between them. Minke whales exert energy to maintain their body temperature in arctic waters, and need to activate physiological mechanisms such as countercurrent heat exchange in flippers and fluke in order to reduce heat loss (Kvadsheim, et al 1996). Evidence suggests the opposite may be true for the bowhead whale.

• The bowhead has thicker blubber than the minke whale; it is bigger, longer, and more rotund; and its higher volume-to-surface area ratio results in less surface area from which to lose heat.

• A highly developed bowhead fluke vasculature and counter-current system is expected in order to control heat loss. The need for heat loss possibly varies between none (heat conservation) and a great need to dump heat during extreme exertion (heat dissipation).

• Bowhead whales face different thermal challenges than those of the minke when feeding. One third of the bowhead’s length is head, through which they must lose heat while filter feeding. Therefore, they may need to conserve heat as they continually take in huge amounts of cold water.
• Thermal regulation may vary for specific organs in that some may need to be cooled while others are conserving heat (i.e., different physiologically optimal temperatures). For example, gonads may require specialized thermal regulation (cooling) and, since bowheads have no dorsal fin, the fluke is likely an organ specific cooling or heating mechanism.

• Diving and thermoregulation constitute two different pressures or demands on fluke vascularization and the control of blood flow. The vascular structures do quite different things depending on the specific activity of the whale, whether it be diving, feeding, reproducing, etc.

• In addition to feeding, heat conservation may be required during times when minimal energy loss is necessary. For instance, these animals may be able to survive for 1-2 years with very little feeding because of the amount of energy stored in blubber and low metabolic rate. Such prolonged fasts may result in what is known as the “dry skin” state wherein the blubber has become very low in lipid and its TC has increased (heat is lost more readily across the blubber). In this instance, they may experience a thermal window during which they must implement this fluke vascular system to partly compensate for less insulation.

• There may be certain times when bowheads are obligated to decrease or increase blood flow to the periphery, as during dives; emergency situations; times of specific homeostatic needs (e.g., limited food for 1.5 years or getting trapped under ice); and gonad, fetal and/or neonatal development.

• Small body size may indicate the importance of this counter-current system, especially to neonates as they are born in ice water (-2°C) and must conserve heat. The blubber of a neonate or fetus offers little insulation based on histomorphology images of blubber and the near absence of lipids. Neonates need to very rapidly gain weight (fat) and fill blubber with lipid before developing hypothermia.

2.2 Body condition, nutrition, and reproduction in determining health status.

Assessing the condition of bowhead whales includes consideration of their robustness and nutritional and reproductive status. Necessary measurements range from the gross (visible to the naked eye), to the microscopic, and to the chemical level. Morphometrics (body measurements) are invaluable for describing specific groups or cohorts (for instance, a group of animals of similar body length) and can be related to possible changes in nutritive condition, reproductive status, and seasonal fluctuations in these various measures. Varying body types are well known by local hunters and relate to these various life stages and body conditions. Relatively new research addresses the use of the normal range of histologic findings and levels of elements to assess health, and utilizes a variety of tissues and physiological processes. For example, characterizing muscle can be used to assess the metabolic state and the nutritive status of the animal.

Body condition or nutritive status appear to vary by season. Many of the studies presented directly or indirectly indicate that the bowhead whales are actively feeding in the Beaufort Sea along the northern coast of Alaska between Barrow and Kaktovik. They are gaining girth (mass), significantly altering chemical composition of tissues, and increasing the lipid content of their blubber during the summer. This contrasts with animals examined in the
spring that are migrating past Point Barrow to the Beaufort Sea from the Chukchi and Bering Seas.

2.2.1 Morphometrics: how do bowhead whales measure up?
(Abstract #8)

Understanding the basic morphometrics of the bowhead whale provides a foundation for health and condition assessments. These basic characterizations of size, shape, and appearance describe the landed whales and help describe the “types” (i.e., length cohorts) of animals caught.

- The most commonly landed bowheads are between eight and ten meters long (26.3-32.9 feet) (Figure 11). This may well reflect hunter bias towards these smaller animals.
- Fetal morphometrics can help elucidate gestation length, breeding success, and neonatal (near term) development. They can also help establish a baseline or “zero point” for age related changes including blubber histomorphology and concentrations of contaminants. The fetal body length by day curve (0 = March 1, Figure 12) displays a highly synchronized breeding and calving period for whales landed at Barrow.
- Numerous indicators suggest that conditions are “better” for bowhead whales in the fall as opposed to the spring. Interestingly, spring blubber thickness does not appear to support this supposition. This may be explained by the proposed concept that the bowhead blubber matrix does not change in dimension even though composition does.
- Comparison of baleen length to blubber thickness reveals that ingutuk whales’ blubber thickness decreases until the time that their baleen is about 175 cm long (Figure 13). After this critical point, the blubber begins to thicken with increasing baleen length (longer baleen implies greater age).

2.2.2 Morphological types of bowhead whales as described by Iñupiaq traditional knowledge (no abstract)

Varying body types are well known by local hunters and relate to the various life stages. There are numerous and specific terms in the Iñupiaq language that refer to a wide variety of body types, as well as other characteristics like taste, blubber consistency, and degree of decomposition. A well-known and respected former whaling captain described the various body types that hunters have observed and their respective Iñupiaq designations (Table 2). As part of these descriptions he described the muktuk, meat, behavior, and other characteristics of the whale.

2.2.3 Histomorphology and health assessment in the bowhead whale
(Abstract #9)

Histological tools – microscopic examination and evaluation of tissues – are important for the health assessment of the bowhead whale. Histomorphology examines the appearance, size, and shape of microscopic structures in the tissue (Figures 14-18). Determining what constitutes normal histomorphology and the range of values for basic health and nutritional parameters is important in order to know what is abnormal in the bowhead whale.
• Histopathology (disease at the cellular level) can describe acute cell injury (degenerative changes), cell death (necrosis), pathological cell growth, neoplasia (cancer), inflammation, and pathology of infection or toxicity.

• Upcoming investigations will address cadmium and its possible effects in chronic lung disease (Figure 14) and kidney toxicity (nephrotoxicity, Figure 15). Specific inquiry will be directed at renal and pulmonary fibrosis...is it secondary to age or an effect of cadmium toxicity?  Cadmium is most likely naturally high in the diet of whales.

2.2.4 Traditional bowhead whale butchering techniques (no abstract)

The butchering is a very detailed and methodical procedure that takes into account the sharing of food with the community, individual crew shares, and the proper handling of the various food items (e.g., muktuk, muscle, organs). Figure 19 shows how the major portions are removed from the whale and shared. It is critical to recognize that examination and sampling revolves around this butchering process and is dependent on the cooperation of the hunters. This efficient butchering process allows for collection of high quality samples.

2.2.5 Heavy metals and minerals in bowhead whales (Abstract #10)

Animal tissue contains both essential and non-essential elements. Essential elements are considered nutrients, and contaminants such as some heavy metals (e.g. cadmium and mercury) are examples of non-essential elements. Both have been examined in a variety of bowhead whale tissues. Some heavy metals occur naturally in the environment while others are primarily or solely of human origin. Anthropogenic elements are of human origin; they occur in nature as a result of human activities. The challenge is to distinguish between those exposures that have occurred naturally and those that are anthropogenic.

• It is often very hard to differentiate between naturally occurring and anthropogenic metals, so quantification of the anthropogenic component or source is difficult.

• Many elements required as nutrients can also be toxic if accumulated in higher-than-normal concentrations. For example, selenium (Se) is a required nutrient but is toxic if too much accumulates in the tissues.

• Arctic marine mammals are known to have high levels of cadmium (Cd), mercury (Hg), and selenium (Se). These levels are influenced by their age, with levels being higher in older animals (Hansen et al, 1990; Wagemann et al, 1996). However, Hg and Se are comparatively very low in bowhead whales.

• The concentrations of Cd are highest in the bowhead kidney (Table 3) followed by, in decreasing order, the liver, muscle, blubber, and epidermis.

• The most common lesion observed in bowhead whale tissue was a form of kidney periglomerular fibrosis combined with interstitial fibrosis (increased or thickened connective tissue). Such fibrosis is not typical of a Cd-induced lesion—or of any increased metal—and may be an age-related change.

• Acute myofibrillar degeneration (muscle fiber disorganization) was presumptively diagnosed, and the lowest muscle Se concentration in the dataset was one of the affected whales. Did oxidative stresses overwhelm the Se antioxidant protection in these two cases of myopathy?
2.2.6 Using morphological and biochemical characterization of muscle to assess nutritional status (Abstract #11)

Muscle can be evaluated grossly, histologically, and biochemically to help determine the condition or health of an animal. Indeed, morphological and biochemical characterization of muscle has been used to assess the nutritional status in harbor porpoises (Phocoena phocoena). This provides a framework for beginning similar assessments of nutritional status for bowhead whales. Slow twitch fibers (Type I) are non-fatigable (do not easily weaken) and require oxygen to use energy (oxidative). Fast twitch fibers (Type II) are composed of Type IIA fibers that are fatigue-resistant and glycolytic/oxidative (use oxygen to use sugar for energy). Type IIB fibers are fatigable (do become weak) and glycolytic (use sugar for energy).

- Although the process of starvation impacts muscles differentially, the basic effects include muscle mass decreases with subsequent loss of body weight and atrophy of both slow and fast fibers (more pronounced in fast fibers). There is also an increase in percent area of slow fibers in a muscle.
- Starvation affects continuously and intermittently active muscles differently. An epaxial locomotor muscle, the longissimus, was chosen to represent a continuously rhythmic muscle. This muscle runs along the spine and serves to extend (arch) the back while swimming...an activity that occurs continuously during the life of a cetacean. The sternohyoid is a feeding muscle that extends between the sternum and the throat area. As feeding is an intermittent activity, so too is this an intermittently active muscle.
- The epaxial muscle of robust bowhead whales consisted of 45% slow (type I) fibers, 9% fast (type IIA) fibers, and 46% fast (type IIB) fibers. These preliminary data for robust animals provide a baseline to use in assessment of nutritional status for bowhead whales.
- Biochemical analysis of muscle can reveal the levels of a variety of enzymes, each of which indicates a particular physiological process. Muscle biochemical profiles were assayed using a suite of enzymes representing glycolysis, lipid oxidation, citric acid cycle, amino acid oxidation, and anaerobic metabolism (Table 4).
- Comparison of the longissimus muscle in emaciated and robust harbor porpoises indicated that starvation led to decreases in glycolytic and lipid oxidation enzymes, whereas amino acid oxidation enzymes increased. The percentage of fast fibers, fibril and mitochondrial density, and epaxial muscle mass all decreased by more than 30%.

2.2.7 Discussion - body condition

If blubber thickness is to be used as a health assessment tool and an indicator of body condition, there need to be strict guidelines as to how it's measured and what body sites are chosen. There are complicating factors intertwined with blubber and its reflection of body condition which revolve around age, blubber composition, and the responsiveness of body girth.

- Blubber thickness is less in animals with shorter baleen (and are therefore younger). Emphasis on the baleen aging of younger (smaller) whales was suggested to fine tune the assessment of young whale growth and development.
• Baleen length seems to be an important measure for the health and aging of young (smaller) animals. Although there is minimal increase in body length during the first four years of life, the baleen is enlarging, and longer baleen may result in more efficient feeding.

• Comparing blubber by season in very young whales is appropriate if one can assume the following: a 9m fall 2001 animal and a 9m spring 2001 animal are in the same age cohort (same year of birth). It then follows that if blubber thickness does not change by season, one needs to be sure this is not an effect of different age classes.

• Measurement of gross blubber thickness alone does not provide a sensitive indication of condition, because changes in thickness do not necessarily reflect changes in energy density or chemical composition (i.e. percent lipid, lipid classes present). The same blubber thickness of two compared whales does not imply that they are at a similar stage of nutrition or body condition.

• Even though girth measurements changed significantly, blubber thickness did not. Blubber thickness as indicator of health, needs testing further caudally as these sites were determined to be good indicators of body condition in Baleanopterids (Lockyer et al, 1984), and needs to account for the role of hypodermal fat. Posterior samples (i.e., umbilical girth) are likely most variable in thickness, and may be sites to detect subtle changes. If the matrix is fixed in depth and lipid content changes, we may need to understand how the hypodermis works.

• There may be a need to maintain cranial blubber thickness in order to preserve hydrodynamics, which might explain why axillary girths are less variable than other girth sites. Bigger changes in circumference occur at the umbilical girth, suggesting that it may be a better indicator of body condition and, therefore, a better site for collecting “condition” data.

2.3 Determining the role of biological parameters on the assessment of health and condition

Interpretation of health or physiology information requires a solid dataset on key biological variables. Many biological variables can alter condition or health indices, and the better they are understood, the more likely one can (dis)associate a potential cause of disease with the impact or effect of a biological parameter. One of the most intriguing and elusive measures for bowhead whales has been age. There are accepted techniques in use to determine the age of a bowhead whale – some of which have been proposed to test the longevity theory.

Analysis of stomach contents from whales landed in autumn at Kaktovik and Barrow indicate different dietary intake in the eastern Beaufort Sea versus the western Beaufort Sea (Lowry, 1993; Lowry et al, 2002). For the Arctic Ocean, the coupled physical-biological mechanisms that contribute to the development of such prey “hotspots” are poorly understood. Changes in these “hot spots” would affect the health of, and hunter access to, bowhead whales.

Inclusion of other biological variables, many dozens of which have been determined, requires integration in long-term monitoring schemes, and complicates statistical analyses because a data set is ideally evaluated intact (all data together). Because bowhead whale sampling design is not random (there is hunter bias) and multiple measures are made on a single whale,
care must be taken in how specific statistical tests are applied to the data. Environmental measures and larger scale physical influences are not typically collected or considered in intensive animal assessment, but they may well affect the animals, access to them by hunters, and prey availability.

2.3.1 Aging: does the chemistry match up with the stone points and life history observations? (Abstract #12a and #12b)

Age in marine mammals may be determined by various methods ranging from simple photo re-identification to such methods as ear plug growth layer measurement, tooth growth layer group quantification, aspartic acid racemization in the teeth and eye lens nucleus, and the aging of baleen. However, bowhead whales do not have teeth, and appreciable ear plugs do not form, and the accuracy of a particular aging method is influenced by the age of the individual whale under scrutiny. Therefore, other methods have been evaluated for aging the bowhead whale, and are briefly discussed below.

- “Stone points” were found in whales landed in the 1980-90’s. Such implements were likely used in the previous century (late 1800’s) and provided preliminary evidence that bowhead whales may live longer than 100 years (Figure 20).
- Aspartic acid racemization (AAR) has been used to determine the age of several species of marine mammals (Bada and Brown 1980, 1981; Bada et al 1980, 1983; Bada 1984; Nerini 1983a, 1983b), including bowhead whales (George, et al 1999). Aspartic acid is an amino acid component of the protein in the eye lens. It can exist in two different forms, D-aspartic acid and L-aspartic acid, which are mirror images of each other (optical isomers). As a whale ages, that ratio of the two isomers in the eye lens approaches 1:1 at a known rate. By measuring the ratio, chemists can estimate how long it has been since the first layer of the eye lens was formed, thereby providing an approximation of the animal’s age. The relationship between AAR-determined age estimates and the body length of male and female bowhead whales appears in Figure 21.
- The age of younger bowheads, ≤ 11-15 years, can be estimated with considerable accuracy by counting the oscillations in the stable isotopes in the baleen (Schell et al, 1989). Bowhead whales have marked annual oscillations in stable isotope ratios of carbon (\(^{13}\)C) along the length of the baleen plates that result from the animals’ migration from wintering grounds in the Bering Sea to summering areas of the Canadian Beaufort Sea. Zooplankton along the migration route contain different carbon isotope ratios, with prey sources in the Beaufort Sea containing relatively less \(^{13}\)C than those in the Bering Sea. The isotope ratio in newly formed baleen mirrors the abundance of that isotope in the region in which the whale was recently feeding and exhibits an annual cyclicity. Therefore, each oscillation represents a year. At approximately 11-15 years of age this correlation breaks down as the lengthening baleen wears off at the ends (the oldest part of the baleen plate) and therefore is not a useful aging technique for older bowheads.
- Other evidence of long-lived animals includes corpus albancia counts from ovaries. A corpus albicans (CA) is a scar in the ovary that results when an egg is ovulated. A female bowhead whale presumably starts ovulating between 15 and 25 years of age (Schell et al, 1989; Schell et al, 1992; Koski et al, 1992; George, et al 1999; Tarpley and Hillmann, 1999) and appears to have a calving interval of around 3-5 years (Tarpley and Hillmann, 1999). As each pregnancy is necessarily preceded by at least one ovulation (bowheads
may be spontaneous ovulators) (Tarpley and Hillmann, 1999), the number of ovulations (and CA s) can be used to loosely estimate the age of the female bowhead. Barrow-caught whales 89B3 and 92B2 had 41 CAs and 20 CAs, respectively.

- Blubber collagen analysis is being investigated as a tool for age estimation. Collagen is the most abundant protein in the body and, along with elastin, is one of the two main fibrous components of supportive connective tissue. It is formed as an extracellular complex (tropocollagen) which then polymerizes to form any one of 16 types of collagen (Figure 22). Scientists have used the process of synthesis versus degradation of collagen to age some species.

- Collagen turnover varies with age and type of tissue, and there are many properties of aging collagen that could be assayed. Initially, cross-links and advanced glycation end products (AGE's, Figure 23), both of which increase with age, were tested (Sells et al, 1996). Current research focuses on a) pentosidine quantification and b) chemical and histological analysis of collagen in “blubber” (Figure 24). Pentosidine is a marker of glycooxidative stress in skin collagen, and it usually increases with age in a number of terrestrial mammals. However, preliminary data indicates that little or no pentosidine accumulation in bowhead whale collagen, which is intriguing given the potential life span of the species.

2.3.2. Statistical methods for including basic biologic, temporal, and spatial data in the health assessment process (Appendix 13)

Bowhead whale research poses unique statistical challenges. Sampling design is not random because there is hunter bias, and multiple measures are made on a single whale. The researcher has no control over the number of whales sampled in a given season, or the sex and size of the animals sampled. Therefore, care must be taken in how specific statistical tests are applied to the data. The factors that cannot be completely controlled undoubtedly affect the results obtained. Statistical methods utilizing basic biological, temporal, and spatial data in the health assessment process are required to account for the realities associated with sampling a subsistence harvested species.

- Consideration of environmental measures and larger scale physical influences (like ocean currents) were included in the statistics discussion.

- Restricting analyses to subsets of the data (various cohorts) reduces power to detect effects. It is better to adjust for such factors within a single analysis.

- Multiple samples from the same whale and multiple contaminants measured from the same samples also complicate analyses.

- When a single measurement is made on each whale, the Generalized Linear Model (GLM) provides a tool for including multiple factors and continuous predictors in a single analysis. If the response variable is continuous, a multiple regression model—one type of GLM—can be used. Another GLM, the logistic regression model, is appropriate for binary (0-1) data.

- When multiple measurements are made on the same whale, they can be summarized by a biologically relevant summary statistic. If one wishes to assess within-whale factors, these multiple measurements on the same whale must be included in the analysis. The likely correlation among them resulting from differences between one whale and other whales needs to be taken into account.
• When many different contaminants are measured in each sample and hypothesis tests are conducted on each contaminant, it is difficult to synthesize the results, particularly because a large number of hypothesis tests is likely to result in obtaining some "statistically significant" results purely by chance.

• Certain graphical methods for examining multiple factors and measurements can help one choose appropriate statistical models. These graphical methods include: box plots, stem-and-leaf diagrams, trees produced by a cluster analysis, scatter plots.

• At the modeling stage, multiple measurements of the same variable on a single whale can be handled by using linear mixed effects models, generalized estimating equations, or ordinary multiple regression or logistic regression models with jackknife variance estimates computed by omitting one whale at a time.

• Preliminary analyses (Fixed Effects Estimates) for lipids in bowhead blubber indicate that lipid concentrations vary by:
  - season (spring < fall),
  - sample site (dorsal < ventral < lateral)
  - depth (middle depths were highest)

• Similar analyses of OCs are soon forthcoming.

2.3.3 Environmental factors related to bowhead whale prey type and availability (Abstract 14)

As the only baleen whale endemic to the Arctic, bowhead whales have adapted to navigating through sea ice to feed on seasonal pulses of prey. Sea ice cover and transport (i.e. in-flow) at the Bering Strait are two aspects of Alaskan Arctic physical oceanography that may effect bowhead whale distribution and habitat selection.

• Sea ice can provide a refuge – or barrier – to whale movements, and the in-flow of Pacific water through the Bering Strait provides an advective pathway for nutrients and zooplankton between the productive Bering Sea and the Beaufort Sea. The influence of both factors on bowhead whale habitat selection was investigated through an analysis of ten years (1982-91) of autumn sighting data from aerial surveys offshore northern Alaska (Moore, 2000). In the Alaskan Beaufort Sea, bowheads selected 1) shallow inner-shelf (< 50m) waters during moderate and light ice conditions, and 2) deeper outer-shelf and slope (51-200m) habitat in heavy ice conditions.

• Seasonal and inter-annual environmental variability can be extreme yet localized. Recurrent prey "hot spots" exist offshore of northern Alaska where bowheads typically feed in late summer and autumn (Moore and Reeves, 1993). Examples of such regions occur near Barrow and Kaktovik, Alaska, and along the Chukotka coast. Analysis of stomach contents from whales landed in autumn at Kaktovik and Barrow indicate copepods are a large part of the diet in the eastern Beaufort Sea, but euphausiids dominate in the western Beaufort Sea (Lowry, 1993, Lowry et al, 2002).

• The coupled physical-biological mechanisms that contribute to the development of such prey "hot spots" in the Arctic Ocean are poorly understood. Changes in these "hot spots" would affect the health of, and hunter access to, bowhead whales.
2.3.4 Discussion – biological variables

Interest in climate change issues may bring more research efforts and dollars to northern Alaska (including bowhead research) but the data collections may be on a scale not useful for determining where bowheads feed.

- Currently, the scale of data collection is not fine enough (i.e. 100 km² vs. 1 km²) nor are physical oceanographic details adequate for predictive capabilities on bowhead feeding areas. Such data collection considerations are important to include during the start of large projects to ensure their relevance for habitat use by bowhead whales.
- Predicted global warming may represent a period of maximum distribution of bowheads across the Arctic, based on the historic record.
- Traditional knowledge indicates smaller whales arrive offshore of Barrow first in the spring while larger whales follow in June and July (after census) and likely go further north offshore (Jonathan Aiken, pers. comm.). In the fall the smaller age class feeds along the coast and older, larger whales feed farther offshore. In September, during the autumn hunt, hunters catch larger whales since smaller whales migrate past Barrow later, often after hunting ceases (i.e. October).
- Current North Slope Borough bowhead survey techniques do not detect animals more than approximately 20 km offshore.

2.4 Comparative and collaborative research in other cetaceans

The intensive examination of bowhead whales over the years has resulted in similar efforts for other mysticetes. Groups in Russia and Mexico have been trained to examine gray whales in a manner similar to that conducted on hunter killed bowhead whales in Barrow. Furthermore, sample collection for direct comparisons to the closely related North Atlantic Right Whale (Eubalaena glacialis; NARW) has occurred.

2.4.1 Reproductive studies of Northern Atlantic right whales (NARW) using fecal steroid hormone metabolites (Abstract 15)

The purpose of this collaborative project is to develop and apply a technique to analyze the metabolites of steroid hormones in fecal samples from NARW, and to conduct parallel comparative studies in bowhead whales to learn more about the reproductive physiology of these baleen whales and to validate assays biologically.

- Very little is known about reproductive physiology in baleen whales; there are even unanswered questions about reproductive morphology. Furthermore, studying reproduction in NARWs is problematic because no techniques are available to collect blood samples from large, free-ranging whales, and because stranded animal tissues often are decomposed and useless for most analyses.
- The bowhead whale is being used as a reference population for these studies because of its close taxonomic relationship with right whales, because of the dietary similarity with NARW, because the population is growing and reproductively healthy, and because fresh tissues and fecal samples can be taken during the hunts in Barrow. All these aspects ultimately provide a way to develop, validate, and interpret methods of laboratory assays.
• Validation of the aforementioned assays involves morphologic confirmation of maturation, pregnancy, and stress/disease in the bowhead whale, which cannot be conducted in the remotely sampled free ranging right whales. Parameters to be investigated include: 1) fecal and serum hormone profiles of reproductively active males and females compared to immature and reproductively inactive whales, 2) age at sexual maturation, 3) pregnancy determination, 4) use of glucocorticoids to measure generalized stress and investigate the possible suppression of reproduction (cortisol), 5) reproductive senescence or decline in function in older females, 6) relationship of fecal hormone metabolite levels to age, reproductive history and genetics, and 7) evidence of reproductive cyclicity or seasonality.

• Fecal samples are analyzed for the presence of reproductive and stress hormone metabolites (total estrogens, progestagens, testosterone, and glucocorticoids), the levels of which reflect the animal’s circulating hormone levels over the previous day or days, depending on gastrointestinal transit time.

2.4.2 Gray and bowhead whales

• Gray whale researchers from the U.S. and abroad visit Barrow periodically to participate in the examination of bowheads. In turn, experienced bowhead whale examiners and samplers have visited other areas to assist with gray whale examination or program development. Samples of gray whales have been analyzed in the same laboratories as bowheads to allow for some direct comparison of the two mysticetes. Several projects are underway for continued cooperation involving hunters of gray and bowhead whales. Since personnel and funding are usually limited, projects are developed on a short-term basis (1-2 year efforts). A longer-term perspective and “non”-crisis management approach is needed.

• Collaborative projects involving the gray whales include experts from Mexico (Baja), Far Eastern Russia (Chukotka), and the United States (California). Two workshops to establish a program to examine stranded gray whales were conducted in Baja California (Abstract 16) in March 2000 and 2001 to train participants in marine mammal stranding response and large whale necropsy techniques, respectively, as well as to enhance collaboration between the research groups. The Baja California efforts have resulted in 1) increased response to strandings, 2) more thorough post mortem examinations, 3) ongoing development of a network of laboratories and experts to enhance response effort and interpretation, and 4) encouraging international cooperation.

• Chukotka – Residents and hunters of Chukotka (Eastern Russia) have been involved in training by scientists in Barrow on the examination and sampling of bowhead whales that could result in a similar program for gray and bowhead whales in Chukotka. A recently established program in Chukotka for examination and sampling of gray whales involves significant hunter cooperation, and potential for high quality sampling. Unfortunately the political logistics are very difficult. Preliminarly, more than 19 subsistence-harvested gray whales were sampled in 2001 and represent a remarkable start by Gennady Zelensky (Table 5). It appears local interest is strong, but Alaska and U.S. support is required to expand or maintain this effort in Chukotka. This effort could easily be applied to bowheads landed in Chukotka but there is a limited strike quota at this time.
A well-established response to stranded gray whales exists in most of California and
Washington. The responders include partners in the international efforts mentioned above
and non-profit organizations and federal agencies. Alaska scientists have assisted in the
area of toxicology (mercury) in gray whales. Expansion of the California and Alaska
cooperation is likely and would benefit research in both gray and bowhead whales. The
success of California investigations is reflected in the thorough examination of stranded
gray whales, yet they require data on “normal” gray whales to assist with interpretation
(possibly from the Russian effort). The California experience offers a unique expertise
that could improve other gray and bowhead whale necropsy efforts (Alaska, Washington,
Mexico, Russia). Two manuscripts provided to the workshop address stranded gray
whales and the investigation into the causes and condition (health) of the whales (Krahn

2.5 Future research and monitoring

2.5.1 Industrial perspective

The use of habitat by bowhead whales continues to be assessed by BP (Alaska), Inc.,
Minerals Management Service, consultants (environmental, engineering, etc.), mining
companies, and others.

- Many industrial activities are concurrent but they are not assessed cumulatively; only one
  activity is assessed at a time (one project = one EIS). Studying the “cumulative impacts”
of a suite of industrial activities is more appropriate and would yield far more applicable
and holistic information. Applying for a permit for marine mammal research takes into
account all other ongoing activities in an area, and constitutes a federal precedent for
conducting a “cumulative assessment.”

- Industry and associated agencies have not supported much work in examining harvested
  animals. Their research focuses on movement, distribution, and feeding in the eastern
  Beaufort Sea.

- What has been done to address industrial impacts to the bowhead whale? Recently PCBs
  and heavy metals have been investigated, particularly in relation to bioaccumulation of
  contaminants and food safety. Behavioral work has been conducted to investigate the
deflection of the bowhead migration due to noise associated with seismic oil exploration.
However, no research involving hydrocarbons and other oil based products has been
conducted on landed whales to establish baseline data that would be necessary to have
available in the event of an oil spill.

2.5.1.1 Oil industry

The notable absence of oil related studies in the bowhead whale is obvious and surprising in
light of concerns of local residents and others related to offshore oil industry activities and
the likelihood of an oil spill.

- The tissues possibly impacted by oil are slightly different from those impacted by OCs
  and metals, and baseline hydrocarbon concentrations and assessment of target organs is
  virtually nonexistent in bowhead whales. There are no available data on baseline
  hydrocarbon concentrations in prey, stomach contents, or tissues of bowhead whales, or
data on the “normal” biochemical and histologic (microscopic) findings used to assess oil related exposure and impacts. No hydrocarbon baseline information on stomach contents, feces, liver, bile, and other bowhead matrices exists. Such an obvious data gap should be addressed since industry is currently producing oil offshore.

- Biomarkers for oil toxicity are not adequately assessed and the needed tissues and matrices are not archived to an adequate extent. Very limited toxicology and histomorphology have been conducted on the bowhead whale to directly address organ systems (lung, brain, etc.) potentially impacted by oil. There is a real need to outline the critical parameters related to oil impacts on the bowhead and to hunter concerns (OCS industrial activity), especially in light of increasing exploration and development pressure.

- If an oil spill occurs and subsequent analyses finds hydrocarbons in bowheads, it could be presumed that the local oil industry is the source of those hydrocarbons – which may or may not be the case, and was a critical point of contention following the Exxon Valdez oil spill. Therefore, it would be in the best interests of industry and conservationists to help investigate and document baseline data regarding the presence and effects of oil products in bowhead whales (and fellow habitat users) before a spill occurred. This could be to their advantage if the hydrocarbons present were not due to a particular spill or industry-related event.

- The primary concerns of whale hunters relate to the possibility of an oil spill. This can be directly addressed with basic baseline information on hydrocarbons.

- Whale hunters feel the biggest problem is the development in federal waters where the pipeline is built under the sea in heavy ice. Nearshore drilling is perceived as less of a problem now.

2.5.1.2 Fishing industry

- Fishing industry interactions need to be documented when mortality occurs.

2.5.1.3 Ship traffic

- Events “down south” in the Bering Sea may be more important factors in ongoing mortality than are oil industry activities. Recurring ship strikes, net entanglements, and changes in the quality of prey outside of Arctic waters may have more of a long-term impact on the health of the bowhead whale population than the occasional oil spill.

- Ship collisions are a major mortality factor for the NARW in the Atlantic Ocean. In light of the increasing ship traffic in the Arctic, baseline information is needed in order to detect possible increases in ship strikes involving bowheads.

- The effects of ship traffic noise on bowhead whale navigation and behavior has yet to be determined.

2.5.2 Minimum parameters needed to define individual nutritional status

Parameters considered crucial for determining individual status were gleaned from the recommendations set down by the working groups for blubber, nutrition, and energy and general histology and disease assessment. Details appear in the respective recommendations
for these working groups and are distilled into the list below. The use of blubber to infer knowledge about nutritive status may require first that questions be answered regarding a) the variability of composition and lipid content in relation to size, sex, season, disease, reproductive status, and b) what sampling sites best represent body condition. While it may be some time before these issues are clarified, it should be realized that it is from this milieu that nutrition data will be extracted in the meantime. The use of muscle as an indicator of nutrition status is promising and warrants its inclusion in nutritional status assessment, but as with blubber, some of the baseline data for bowheads needs to be determined.

Minimum parameters needed to define individual nutritional status include the following. It should be noted that several parameters will be significantly influenced by post mortem changes.

- blubber quantity and quality
- hypodermal characterization (quantity and quality)
- fatty acid profiles
- mineral and metals status
- muscle assessment – histology, biochemistry
- pancreatic zymogen quantification
- blood chemistry (keeping in mind post mortem effects)
- histological assessment of tissues exhibiting sentinel changes indicative of decreased feeding and limited prey availability (blubber, muscle, gastrointestinal epithelia, liver, pancreas).

- stomach contents
- hunter's perspective and terminology regarding body type and condition

### 2.5.3 Development of long-term protocols

The development of long-term protocols was not accomplished during the workshop. Such protocols are critical to the success of any health assessment of the bowhead whale population and should be rigorously pursued in a collaborative manner. As health assessment data are analyzed by the various collaborators in the projects described in this report, a clearer view of critical assessment parameters will be generated. Those indices providing the most important and reliable information will be determined and incorporated into recommendations for long-term protocols. More progress in this respect is anticipated in a future (Fall 2002) workshop to include North Atlantic Right Whale researchers.
3. Working Groups (Appendix D)

3.1 Blubber, nutrition, and energy

Clearly, blubber is important to bowhead whales and maintaining it is an important factor in the life strategy. Therefore, the use of blubber quantity and quality parameters as tools to monitor bowhead whale condition and health was discussed extensively. Furthermore, exploring the use of non-blubber tissues to describe the nutritional status of the bowhead whale (e.g. mineral and muscle status, and digestive functions) was considered a very important avenue. It was also deemed appropriate to determine energetic or thermoregulatory status as it relates to health of the whale.

Recommendations:

- Develop a standard definition of blubber.
- Hypodermal characterization on the whale is greatly needed. Full-scale characterization would include photographs, full thickness sampling to muscle (while on whale), macroscopic (gross thickness measurements) and histologic assessment, proximate composition and other chemical analysis. Changes in the hypodermis associated with sampling site, season, sex, reproductive status, and age would also be important to document.
- Continue “axillary” (one meter caudal to the blowhole) girth and blubber thickness measures, but include umbilical and anal girth and blubber thickness at the dorsal and ventral sites. Assessing girths of the abdominal region (caudal to cervical and cranial areas) may be more indicative of body condition changes.
- Blubber thickness measurements should be made both on the whale and on a flat surface (i.e., sea ice) in order to determine if a difference exists so that protocols can then be standardized to one method.
- The number of blubber samples taken from an individual whale can potentially be reduced. Proximate composition or other analyses (i.e., lipid classes) could be done on fewer layers and from fewer sites (e.g., from 5 depths to 3, using depths 1, 3 and 5; and from 6 sites to 4 sites). Preliminary results suggest that samples from lateral sites could be eliminated because those trends are similar to dorsal and ventral sites, but a final decision about this should be made only after statistical analyses are completed. Thus, 4 sites x 3 depths = 12 samples per whale (reduced from 30 samples per whale).
- Fatty acid profiles should be determined for describing feeding ecology and health.
- As in past years, the contaminants standard will be the sample collected from the blowhole dorsal site, full thickness.
- Normal ranges of mineral status (essential and non-essential elements) need to be identified in liver, kidney, and muscle. Histological and biochemical interpretation would help address potential deficiencies or toxicoses.
- Muscle is a nutritional source of lipids and proteins needed during negative energy states. Muscle histology, composition (lipid, protein, myoglobin, etc.), and biochemistry are potential sensitive indicators. This work should begin on archived samples and continue with future prospective studies.
- Continue measuring **body temperature** (core, hepatic), and relate this to hunt and gross examination. The data could relate to deterioration or changes in some of the parameters addressed (biochemistry, histology, etc.).

### 3.2 General histology and assessment of disease

It is very important to compile centralized data for individual whales and to be as consistent as possible in sampling protocols and in choosing sampling sites. The focus of this group centered on long-term sampling, sampling consistency, and prioritizing what samples are collected in order to conduct useful histological studies and assess any disease conditions present in landed bowhead whales.

**Recommendations:**

- **Develop long term sampling protocols** to assess: nutritional status, contaminant burdens and effects, reproductive status, age, immune status, disease, and any grossly abnormal tissue (Appendix D2, Table 6).
- The **minimum parameters needed to define individual nutritional status** include the following:
  - gross body and organ morphometrics,
  - quantity and quality of blubber and hypodermis,
  - liver glycogen stores,
  - intestinal functional morphology,
  - degree of pancreatic atrophy and zymogen quantification, and
  - blood chemistry.
- Less critical than the above mentioned parameters, evaluation of vitamin status, parasite load, and cortisol/hormonal levels would flesh out a nutritional status assessment.
- A **complete disease assessment** would include:
  - gross description of lesion(s),
  - cytology of selected organ(s),
  - photographs,
  - measurement of suspected lesions,
  - hunter’s description of abnormalities in behavior, movement, etc. surrounding capture,
  - blood smears for differential blood counts or histological exam of cellular components, and
  - appropriate sample collection for identification of pathogen (i.e. culture sample for bacteria, frozen sample for virology), and collect lesion for both freezing and histology.
- Collect information on body type according to the whale hunters’ traditional knowledge.
- Establish standard sampling sites for each organ. For example, transverse cross-sections should be taken from the midsection of sampled organs (Appendix D.2 and Table 6), unless obvious lesion is elsewhere.
- Freeze the following tissues or fluids* for contaminant analyses: liver, kidney, blubber, muscle, epidermis, lung, milk, urine, feces, blood, brain, bone, baleen, lymph nodes, and stomach contents. (*tissue and fluid selection depends on the contaminant of interest).
- Develop a standardized check list for all sample collection for use in the field.
• At a minimum, complete blood count, hematocrit, and serum chemistries should be done on every whale, along with histology. However, caution is indicated during subsequent interpretation due to the effects of varying postmortem times.
• Consistent, legible, and accurate labeling of all samples is critical.

3.3 Physiology

Much of what we have learned about bowhead whale biology has been generated through anatomical studies, upon which aspects of physiology and biochemistry are then inferred. While anatomical studies are necessary and will continue to provide insights into physiology, studies at the biochemical and molecular level can provide details of function and health status not obtainable through anatomy alone. Several studies at the biochemical level are already underway as noted throughout this report. However, there are a suite of powerful modern biochemical methods that can be used to collect data for long-standing questions about functional status and physiological endpoints that cannot be answered in other ways. Recommendations related to these methods are:

• **Hydrocarbons – Very High Priority.** Select a suite of tissues for collection based on the recommendations in scientific literature, as well as findings from the Exxon Valdez oil spill. Follow a very strict “clean” methodology. **It is absolutely critical to determine baseline levels in order to assess the impact of future oil spills,** as well as to conduct accurate risk assessments. This was one of the hardest lessons from the Exxon Valdez incident, and every effort must be extended to remedy this paucity of information for Alaskan Arctic waters and shores.

• Metal Chemistry – Interact with toxicology teams to select metals of interest, with ecologists for markers, nutritionists for essential elements, and with Native organizations for human health issues. Then continue tissue sampling, but expand to other tissues per their recommendations. Collect plasma/serum in metal free Vacutainers to examine circulating levels of metals.

• Serum Chemistry – Collect blood samples from whales at sea to assess quality of blood samples as compared to samples collected at the beach or sea ice (landed). This would serve to verify post-mortem changes that may occur in blood samples taken from the whales. This would involve perhaps a separate boat with some scientists or training a hunting crew member to take the blood samples.

• Parasites – Continue with sampling and possibly explore the option that parasites can be used to identify prey or feeding locations.

• Water Balance – Measure the osmolyte concentration of urine. The amount of blubber is partly controlled by demand for water balance in marine mammals.

• Reproductive Endocrinology – Reproduction studies would yield exceptionally critical data elucidating life history, age of first reproduction, last reproduction, inter-calf intervals, etc. The hormone levels in feces and serum should be determined because knowledge of the levels of reproductive hormones will complement ongoing reproductive morphology and histology studies in bowhead whales and contribute to our understanding of bowhead reproductive physiology. Fecal hormone levels are less variable than serum levels, giving an average level of hormone over the past day or days, and are not impacted by the stress of hunt and capture. Measurement of fecal levels allows comparisons with NARWs and also presents the opportunity to sample free-
swimming bowhead whales. Furthermore, assays should be developed specifically for bowheads. Such hormone assays would need to be validated specifically for bowhead whales to account for inter-specific variations in hormone metabolism.

- **Cell Culture** – The use of viable bowhead cell lines allows modern testing of molecular, cellular and genetics studies. It is important, therefore, to continue current work and collaboration and to encourage new scientists and new techniques.

### 3.4 Biological variables

Interpretation of health or physiology information requires a solid dataset on key biological variables. Many biological variables can alter condition or health indices, and the better understood, the more likely one can associate a potential cause of disease with the impact or effect. A wide variety of biological variables need to be integrated, and the issues of standardization of protocol and data gaps was recurring.

- **Food Habits**: As a minimum ongoing effort, stomach contents, including solids, should be collected. The sampling protocol should be standardized and include collection of at least one liter of stomach contents. Half of the sample should be stored in formaldehyde/fixative (species identification), and the other half frozen for chemistry (isotopes, fatty acids, contaminants). In order to assess the volume of the stomach relative to age and length, there should be a check list on which can be indicated, at a minimum, whether the stomach volume is: empty, trace, ⅛, ⅜, ⅜, or full.

- **Measurements of blubber** should be modified according to the recommendations of the blubber working group (see above). Morphometric measurements need to be calibrated, for instance indicating “half girths” and “stretched whales”. Just how the measurements were taken needs to be documented, as well (i.e. was the blubber measured on or off the carcass, or both?).

- **Age determination** requires expanded baleen and eye globe aging for those whales intensively sampled. Baleen and eye globes should be done on the same whale. Baleen archiving must improve so as to provide appropriate storage area and careful labeling. Sampling needs to be done in a uniform manner; plate(s) should routinely be taken from the same place in the rack, the longest plate should be collected, and the sample should extend to all the way to the gum.

- **Reproductive assessment** requires genital slit measurements and collection of ovaries and testes, and is a priority for animals over 10-11 meters long. Life phases which need to be assessed include the growth spurt at maturity, seasonality of reproduction, and the onset of sexual maturity. These are relatively easy to assess but research programs require relatively long time frames in order to obtain adequate sample sizes. Evaluation of the onset and cyclicity of spermatogenesis is currently underway. The analysis of existing reproductive data should be a major goal.

- Blood is collected from the rete on the palate, and must include at least 8 red and six purple top or green top tubes. This effort may need to expand because of the increasing requests for samples.

- In order to address genetics questions, every landed whale should be sampled with a standardized protocol; the current preference is that samples be put in salt solution in DMSO. Archiving tissues at the University of Alaska Fairbanks should continue, as well
as at other frozen archives. It would be ideal to obtain samples from all the whales landed at all villages, but this is far from feasible given logistical and cost restraints.

- The current harvest form needs to be reviewed and revised by all disciplines.
- An effort should be made to sample basic environmental variables associated with bowhead hunt. Sampling of environmental parameters at the time a whale is landed, on the same temporal and spatial scale, would provide information on large-scale physical influences, such as ocean currents. At a minimum, records should be made of wind direction and strength, basic hydrographys (CTD Casts), and prey field sampling (acoustics and tow). While these factors are not typically collected or considered in intensive animal assessment, they may well affect the animals, access to them by hunters, and prey availability.
4. References


5. Figures and tables
FIGURE 1. Anatomy of bowhead whale “blubber.”

EPIDERMIS

DERMIS

HYPODERMIS (+/- MUSCLE)

MUSCLE

“Skin” - anything external to the hypodermal layer
FIGURE 2. Mean lipid content of blubber in bowhead whales of increasing body length. As body length increases, the average blubber lipid content decreases. Furthermore, pregnant (reproductive) females have higher lipid blubber content than length-matched males or non-pregnant (non-reproductive) females.
FIGURE 3. Thermal conductivity of minke blubber (W/mK) at various locations.
FIGURE 4. Comparison of PCBs in bowhead whale blubber and other mammalian thresholds.

- Range of PCBs in bowhead blubber

- 100,000
- 80,000
- 60,000
- 40,000
- 20,000
- 0

PCBs (ng/g, lipid wt)

- 77,000
- 60,000
- 40,000
- 25,000
- 21,000

- Poor reproductive success, ringed seal blubber ¹
- EC50 litter size, mink muscle ²
- Poor reproductive success, harbor seal blood ³
- LOAEL immune effects, Rhesus monkey blood ⁴

Thresholds for mammalian effects (adapted from AMAP, 1998)

¹ Helle et al, 1976.
² Leonards et al, 1995
³ Boon, et al, 1987
⁴ Tryphonas, 1994
FIGURE 5. The nitrogen stable isotope ratio ($^{15}$N/$^{14}$N) in bowhead whale blubber indicates that it feeds at a much lower trophic level than other Northern Alaska marine species.
FIGURE 6. Stable isotope ratios for carbon (C) and nitrogen (N) by season, likely reflecting variations in the C signature of the Bering-Chukchi Seas versus the eastern Beaufort Seas.
FIGURE 7. Carbon (C) isotope ratios in muscle reflect the utilization of dietary sources from different regions by different age (length) cohorts. The stable isotope $^{13}\text{C}$ is known to differ between geographical areas within the Bering-Chukchi-Beaufort Seas region and has been used to distinguish sources of bowhead whale prey as being from either the Bering Sea (spring) or Beaufort Sea (fall) sources of C.
FIGURE 8. The geometric mean tissue concentrations in seawater, plankton, and bowhead whale blubber show that organochlorines bioaccumulate in the blubber of the bowhead whale.
FIGURE 9. Bioaccumulation of selected OCs in bowhead whale blubber is isomer-specific. The normally racemic (50:50) mixture (0.5 in plot) present in water and zooplankton is not reflected in bowhead whale tissues (*). This suggests that the bowhead may be selectively metabolizing or biotransforming one of the OC isomers. EF = enantiomer fraction.
FIGURE 10. Bowhead whale sampling sites and the division of a full-thickness sample into five equal layers.

Illustration courtesy of P. Folkens, Alaska Whale Foundation (modified by Mau).
FIGURE 11. Proportion of harvested bowhead whales relative to body length. Eight to ten meter bowhead whales are more commonly landed, probably reflecting hunter bias towards these smaller animals.
FIGURE 12. The fetal body length by day curve displays a highly synchronized breeding and calving period for whales landed at Barrow (0 = March 1).

\[ y = 0.0125x^{1.3785} \]
\[ R^2 = 0.8796 \]
FIGURE 13. Comparison of baleen length to blubber thickness. *Ingutuk* whales (?) appear to decrease blubber thickness until 1.7 meters in length of baleen. At this critical level the blubber begins to thicken with increasing baleen length (age).
FIGURE 14. “Abnormal” lung histomorphology possibly associated with cadmium toxicity, aging, or other process.

a) fibrotic change

b) patchy necrosis/apoptosis
FIGURE 15. Histomorphology of normal (a) and fibrotic (b) kidney.

a) normal kidney

b) renal fibrosis – areas of abnormal thickening indicated.
FIGURE 16. Abnormal histomorphology of the thyroid gland. This section of thyroid gland exhibits distended follicles (a) and hyperplasia.
FIGURE 17. Intestinal histomorphology – the intestinal lining consists of fingerlike projections (villi) that extend into the lumen*. In this micrograph, the villi are atrophied.

* cavity of a tubular organ
FIGURE 18. Histomorphology of bowhead whale ovary (a) and testis (b).

a) ovarian follicle

b) testicular tissue
FIGURE 19. Traditional distribution of the bowhead whale at Barrow, Alaska. (Adapted from North Slope Borough Inupiat History and Language Commission by J.C. George, E. Brower, H. Brower.)

Suqqaq (baleen)
Half is given to the crews who helped harvest and/or tow the whale; otherwise all goes to the successful crew.

Umïat Ninïgat
Shared by all whaling crews that participate in the butchering.

Tuval ("belt")
Half goes to the successful crew. Half is cooked and served to the public at the Captain's house.

Aqilkak (Flukes)
Cut into small (transverse) sections and served at the feasts.

Utïl
Served at the feasts (Nalukataq, Christmas, and Thanksgiving)

Talgooq (flipper)
One side goes to the harpooner. One side is used as taguan by all whaling crews.

Itâlgruk
Given to visitors at the Nalukataq

Pihaanâq
When the butchering is completed, the Captain gives go-ahead, and anyone can glean the remaining portions for their use.

Utchîk (tongue x-section). Half is used for crew shares. Half is served at the feasts.

Taqtu (kidney), Ingluoaq (small intestine), and Uumian (heart). These organ meats are served at the feasts.
FIGURE 20. The “stone points” that provided preliminary evidence that bowhead whales may live longer than 100 years. These points were found in the dorsal thoracic region of whales landed in the 1980-90’s and were likely used during the previous century (late 1800’s).

1) Ivory harpoon head with metal point recovered from a 58 ft. (17.7 m) bowhead whale. Points of this style were in use from the 1790s to the 1960s in the Chukotka region of the Russian Far East mainly for walrus.
2) Metal blade found in bowhead blubber that was stored in an ice cellar.
3) Broken section of slate end-blade recovered from a 52 ft 4in bowhead.
4) Two stone points recovered from the same bowhead whale (54ft 8in). Larger point is made of jade.
5) Slate harpoon tip recovered from a bowhead.
FIGURE 21. Aspartic acid racemization age relative to bowhead whale body length.
FIGURE 22. Collagen formation and degradation schematic.

**Synthesis** – fibroblasts are the major producers of collagen.

**Degradation** – macrophages produce:
- collagenase
- elastase
- plasminogen activator

hydrolyze connective tissue proteins.
FIGURE 23. Glycation of collagen and the formation of pentosidine.
FIGURE 24. Collagen analysis in “blubber” using histomorphology and special stains.
TABLE 1. Organochlorines in juvenile cetaceans from Eastern North Pacific. Bowhead whales have the lowest OC concentrations of the whale species compared.

<table>
<thead>
<tr>
<th>Site</th>
<th>Species</th>
<th>HCB</th>
<th>∑PCBs</th>
<th>∑DDTs</th>
<th>%Lipid</th>
</tr>
</thead>
<tbody>
<tr>
<td>AK</td>
<td>Bowhead whale (n=24)</td>
<td>120 ± 51∥</td>
<td>140 ± 75∥</td>
<td>130 ± 54∥</td>
<td>59 ± 11£</td>
</tr>
<tr>
<td>1998-2000</td>
<td>subsistence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bering Sea</td>
<td>Gray whale (n=17)</td>
<td>530 ± 75*</td>
<td>1,400 ± 130*</td>
<td>330 ± 53*</td>
<td>48 ± 5.2§</td>
</tr>
<tr>
<td>1994</td>
<td>subsistence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AK</td>
<td>Beluga whale (n=2)</td>
<td>1,500 ± 71*</td>
<td>4,100 ± 71*</td>
<td>1,800 ± 71*</td>
<td>68 ± 6.4§</td>
</tr>
<tr>
<td>1999-2000</td>
<td>Norton Sound</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AK</td>
<td>Killer whale (n=15)</td>
<td>1,700 ± 1,100∥</td>
<td>22,000 ± 19,000∥</td>
<td>19,000 ± 16,000∥</td>
<td>35 ± 9.5£</td>
</tr>
<tr>
<td>1995/99</td>
<td>resident - biopsy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

∥ Analyzed by HPLC/PDA
* Analyzed by GC/ECD
§ Lipids quantitated gravimetrically
£ Lipids quantitated by TLC-FID
TABLE 2. Bowhead whale morphological types – Iñupiaq terminology

Iqutupiaq  this small round female is slightly shorter than the male iqytuurapiaq. The peduncle is extremely short. The meat is so tender it is next to impossible to use a meat hook on it because it tears. The meat rips and falls off as it is being butchered with a long flensing knife. The meat spreads out more so than other types (niqaa siamniqturuq).

Iqutuq (Point Hope) this type of whale is unafraid. It has no discernable bow. The meat is tender. The blubber is white. Siggaa głuttauraq. The white to light-gray gum material that spaces the baleen plates is very tender.

Iqutuurapiaq  (Barrow) when it surfaces it looks like a grey whale. It is different from a qairalliuraq as it’s dive time is shorter. When it has not been inadvertently startled it does not try to get away. This male is approximately twenty-four feet long.

Iqutuuraq (Barrow) it is very round and very tender. When the harpoon tip has penetrated the whale all the way to the blubber you can hang onto it from the ice. It has a short peduncle. On occasion it will break under tension as it is being pulled atop the ice. It is approximately twenty feet long.

Iqutuvak the blubber of this big, round female is red. It is approximately 55 feet long. The meat is tangy.

Qaalioqik  mature male whale with white section at the base of flukes.

Qairaligruaq (Barrow) big whale with a very large head. The blowhole is long. The blubber is red and hard. The head is longer than the body, the tongue 20 feet long. The base of the tongue can be seven feet thick and ten to twenty feet wide. This male’s length can be anywhere from approximately 57 to 65 feet.

Qairalliuraq (Barrow) small male not much more than 24 feet long. The blubber is white. The blubber of whales of this type caught in the fall is red. It has a short peduncle and the rear ventral flanks are narrow. The area of the jaw is distinct and when it surfaces the bow is slender and high. When this type of whale is being butchered with a long flensing knife the blubber does not ooze oil.

Qagattaqsiyuuyich these whales surface underneath ice that is jutting out over the water to breathe. They are seldom seen until they dive.

Tiptulaayuk  The nostrils of this extremely large whale are so withered with age that when it breathes tiptulaaqtuq. These whales are not caught.

Usqquagrauaq (Wainwright) same as Barrow’s qairaligruaq.

Usqquatchiaq (Point Hope) narrow whale with a long bow. The maktak from the chin to the hind end of the whale is white.

Usiyyuatchiasugruk (Point Hope) very large version of usiyyuatchiaq.

Morphological descriptions provided by Elders at the 1991 North Slope Elders Conference and by Warren Matumeak.
**TABLE 3.** Concentrations of selected elements in Alaskan bowhead & beluga whales compared to “normal” levels in domestic species. Concentrations are denoted as either greater than (↑) or less than (↓) those found in domestic species (cattle, dogs).

<table>
<thead>
<tr>
<th>Liver</th>
<th>Bowhead</th>
<th>Beluga</th>
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<tr>
<td>Cd</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Cu</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Hg</td>
<td></td>
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<td>Se</td>
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<td>↑</td>
</tr>
<tr>
<td>Ag</td>
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**TABLE 4.** Biochemical analysis of muscle enzymes, each of which indicates a particular physiological process, can help determine the nutritional status of the animal. Comparison of the *longissimus* muscle in emaciated and robust harbor porpoises indicated that starvation led to decreases in glycolytic and lipid oxidation enzymes, whereas amino acid oxidation enzymes increased.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Indicator</th>
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<tr>
<td>Glycogen Phosphorylase (GP)</td>
<td>Glycolysis</td>
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<tr>
<td>Hexokinase (HK)</td>
<td>Glycolysis</td>
</tr>
<tr>
<td>B-hydroxyacyl-CoA Dehydrogenase (HOAD)</td>
<td>Lipid Oxidation</td>
</tr>
<tr>
<td>Carnitine A cyltransferase (CAT)</td>
<td>Lipid Oxidation</td>
</tr>
<tr>
<td>Aspartate Aminotransferase (AsAT)</td>
<td>Amino Acid Oxidation</td>
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<tr>
<td>Glutamate Dehydrogenase (GDH)</td>
<td>Amino Acid Oxidation</td>
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<tr>
<td>Citrate Synthase (CS)</td>
<td>Citric Acid Cycle</td>
</tr>
<tr>
<td>Succinic Dehydrogenase (SDH)</td>
<td>Citric Acid Cycle</td>
</tr>
<tr>
<td>Lactate Dehydrogenase (LDH)</td>
<td>Anaerobic Metabolism</td>
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### TABLE 5. Gray whales sampled in 2001 in Chukotka, Russia as part of ongoing comparative studies.

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<tr>
<th>#</th>
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<th>Date (dd/mm/yy)</th>
<th>Sex</th>
<th>Length (cm.)</th>
<th>Samples Collected</th>
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<table>
<thead>
<tr>
<th></th>
<th>Liver</th>
<th>Kidney</th>
<th>Skin &amp; blubber</th>
<th>Muscle</th>
<th>Feces</th>
<th>Stomach contents</th>
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<td>17</td>
<td>17</td>
<td>10</td>
<td>14</td>
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¹ Lavrentiya
² Lorino
TABLE 6. Samples recommended for a variety of histologic analyses to determine health or disease status. The number of “Total x” reflects the importance or usefulness of a particular sample or tissue, but it does not necessarily reflect feasibility of obtaining the sample.

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<tr>
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<tr>
<td>baleen</td>
<td>x</td>
<td>x</td>
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<tr>
<td>cartilage</td>
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6. Abstracts
Abstract # 1

A 3-D Look at Blubber and Definition of Blubber In General

Dr. Michael Castellini
Institute of Marine Science
University of Alaska - Fairbanks

Beyond the sheer mass of a large whale, the most striking anatomical characteristic of the whale is the layer of blubber that surrounds it. It is very tempting at first observation to immediately assume that this is a thick layer of fat to keep the animal warm. However, blubber is not the familiar depot fat as seen in terrestrial mammals and it has a suite of ecological, physiological and biochemical demands on it that go beyond that of thermoregulation.

Blubber is a very structured material with a significant collagen matrix. It is a type of dynamic spongy material where the collagen matrix is the structure of the sponge and the lipids move in and out of the matrix based upon metabolic demand. We can easily infer from the observed anatomy and behavior of the whale that blubber serves the multipurpose functions of an energy store, thermal insulator, buoyancy regulator and source of metabolic water.

Blubber can compromise from 15 to over 50% of the mass of a great whale depending on the species and season. For example, Antarctic cetaceans will maximize their blubber content during the brief summer feeding period in polar waters to prepare for the breeding season in the more temperate, northern waters. This separation in time and space between feeding/fattening and breeding/fasting is a critical behavior that can be exploited to identify the animals biochemically. The combination of the great quantity of blubber along with its high lipid content provides a significant lipid store for energetic requirements. In phocid seals, we know that lipid metabolism can account for over 90% of the energetic requirements of the seals. But, the isotope turnover techniques necessary to arrive at such values are not possible in whales. Rather, we infer that lipid metabolism provides the vast majority of energy in cetaceans based upon their total body lipid content, the seasonality of blubber quantity and the high lipid content of their prey.

Upon dissection, it becomes immediately obvious that cetacean blubber is not homogenous with either depth or position along the body. The lipid content can vary significantly with depth such that the blubber next to the muscle in fin whales can have a high protein content while the blubber next to the skin can be very high in lipid. Biochemical profiling of these layers provides some insight into the advantage of such layering, but since we cannot follow the in vivo changes in the blubber, we are left to infer the physiology from the anatomy.

Biochemical analysis of the lipids in these layers demonstrate differences in their lipid fatty acid composition with variances in chain length and saturation. Some researchers have proposed that the blubber layer near the skin in fin whales is more metabolically stable and acts as a long term storage site vs the more dynamic base layer. There does not appear to be a consistent pattern in the fatty acid type, but we may infer that the lipids next to the muscle should be more liquid at core body temperatures than the lipids near the cooler skin layer. However, given logistical and theoretical constraints, it is not yet possible to test these hypotheses in living animals.

The ultimate end product of the quantity and quality analysis is that the energetic content
of the blubber will vary with depth and position along the body of the whale. Because of the elevated lipid content, the gross calorimetry of the blubber can be very high with values approaching the theoretical limit of about 9 kcal/gm for pure oil. Here it is vital to remember the sponge analogy. The collagen matrix in the blubber is a constant. It is not metabolized and is either filled or emptied of lipid and only the lipid is oxidized for energy. The blubber itself is not metabolized as an entity—it is only the lipid that is extracted from the matrix that moves through metabolic catabolic pathways. Thus, the energy content of a section of blubber is best defined by the amount of lipid and the ability for that lipid to be mobilized.

Beyond the energetic profiles of blubber, the tissue has a clear role in thermoregulation as it is the only source of insulation for these mammals in polar, ice-laden waters. Interestingly, there is also a problem of how to dump heat when the animal is active, which is the opposite problem for smaller cetaceans which may need to conserve heat. The thermal mass of a large whale is such that cooling may be a significant problem and the adaptation to solve this problem is a series blood vessel networks act as heat exchangers and can be used to either dump heat to the environment or to shut off blood flow to conserve heat.

Blubber also has a role in buoyancy regulation as the quantity of lipid in the animal will impact total body specific gravity. This impacts diving models at the level of the cost of diving and relative diving lung volumes. All of these factors are part of the hydrodynamic considerations for diving.

Finally, the lipid in blubber is essential to water balance in these species. The metabolism of lipid produces enough water as a by-product that fasting seals can live for months with no outside sources of food or water. They metabolize their blubber for energy and produce the water they need to remain hydrated. It is most likely that whales follow the same metabolic pathways to some extent and can produce water by utilizing their large blubber stores. However, we do not know if large whales are capable of drinking salt-water.

Taken together, these four defining characteristics of blubber (energy, insulation, buoyancy and water balance) are significant factors in determining how much blubber a whale will have at any given time.

There is one last aspect of blubber chemistry that is important to note. Blubber acts as a significant site for lipophilic organochlorine contaminants (OC) such as the PCBs and DDTs. These compounds dissolve most readily in the blubber. Future research will need to study how OC compounds distribute within the blubber layers and if there are preferential lipid classes where they sequester. These data must then be applied to our models of which lipids are mobilized for energy and which remain in the blubber for long-term storage. At what point do these contaminants begin to harm the animal and what are the implications to human subsistence hunters who gather the animals for food? These are all important and critical issues that are not related to diving physiology, but may have a significant impact on the animals and humans associated with the whales.

All of these issues will be discussed at this workshop with specific references to bowhead whales. The collaborations between the Alaska native hunters and scientists on the study of the bowhead are a rare opportunity to examine these animals in detail and to begin to answer questions about the biology of these whales.
Abstract # 2

Gross and Histologic Structure of Bowhead Whale Blubber: Defining the Terms for Cetaceans

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Institute of Arctic Biology
University of Alaska - Fairbanks

Since the earliest published works, blubber has been referred to as the entire epidermis, dermis and hypodermis or sometimes as the heavily lipid-laden hypodermis only. This terminology becomes an important factor when depth measurements are being collected, lipid percentages or contaminant levels are being determined and when anyone is referring to “blubber” in general. Clarification of what blubber truly is and how it relates to cetacean health assessment will be discussed.
Abstract #3

Basic Chemical and Energetic Composition of Bowhead Whale Blubber and the Affects of Select Biological Variables and Within Animal Variability

Tami Mau and Dr. Michael Castellini
Institute of Marine Science
University of Alaska Fairbanks - Fairbanks

The lipid rich blubber layer of baleen whales serves as an important energy store. Changes in the thickness and lipid content of blubber have been utilized as indicators of nutritional status and body condition. Most whales fatten seasonally in response to a changing food supply and energetic demands associated with migration and reproduction. However, the quantity and quality of blubber may also be influenced by other functions of blubber including insulation, adjusting buoyancy and streamlining, as well as by biological variables such as sex and age. It is therefore important to establish the natural variability of blubber composition before conclusions about nutritional status or body composition can be made.

In this study, we examined the chemical and energetic composition of bowhead whale blubber. We measured blubber quantity (thickness) at six sites and blubber quality (% lipid, %water and energy density) at the same six sites, five depths per site from subsistence harvested bowhead whales landed near Point Barrow or Kaktovik, Alaska in spring and fall. We evaluated factors that could affect blubber quantity and quality by comparing results across season, age, sex and reproductive status, as well as within animal variation.

Preliminary results suggest that blubber thickness correlated positively with body length, a proxy for age, but did not vary with season, making it a poor indicator of body condition. However, mean blubber lipid content was found to negatively correlate with body length and did vary with season, sex and age class. Lipid contents also varied by depth of blubber, ranging from 8-96% and averaging 80.1%. Middle depths were high in lipid and relatively stable across season, perhaps serving as a long-term reserve, whereas inner depths were quite variable and are probably the most important depths for active fat utilization. The variation in the mean lipid content between body sites was generally small with dorsal sites generally having the highest mean lipid contents and ventral sites having the lowest. Thus, it may be possible to evaluate nutritional status from analysis of just 1-2 sites. Some seasonal differences are starting to emerge, for example, mean blubber lipid contents in immature whales were generally higher in fall than in spring. However, too few adult whales have been analyzed to date to make any seasonal comparisons.

These data are important for establishing typical ranges of blubber quality and for future establishment of seasonal and annual trends in bowhead whale health. These data are also critical for energetic models in bowheads.
Abstract # 4

Some Aspects of Regional Heterothermy and Energetics of the Bowhead Whale
J. C. George¹, Goering, D.², Elsner, R.³, Sturm, M., Follmann, E.³

1. North Slope Borough, Department of Wildlife Management, Barrow, AK 99723
2. Dept. of Engineering, University of Alaska Fairbanks, AK
3. Army Cold Regions Research and Engineering Laboratory, Fairbanks, AK

The bowhead whale (Balaena mysticetus) is a large paeophylic Balaenid which inhabits the ice-associated regions of the Arctic and sub-Arctic seas and is harvested by Alaskan Natives. We conducted energetic investigations via postmortem exams on harvested whales. Data on body temperature, gross morphology, body mass and the thermal conductivity of the blubber were collected. These data were used to estimate basal metabolic rates as well as to model heat loss and dissipation. The thermal conductivity of the blubber was measured using a needle probe. The blubber is the thickest of any cetacean ranging from (18->35 cm) and therefore is a mammalian maximum. Mean deep body temperature was 33.6 C, SD = 0.82, n = 30. Time series measurements (to 9 hr postmortem) indicated no change in deep body temperature even while the animal was in 0 C water. This is lower than reported for other large cetaceans and for other non-hibernating mammals other than the Monotremes. Thermal conductivity for the thoracic blubber was 0.19 Wm⁻¹k⁻¹ (range 0.18-0.22) which is consistent with other cetaceans. There were strong thermal gradients through the blubber. The muscle-blubber interface was several degrees below core temperature and the skin was essentially at ambient temperature. Heat loss estimates for a 13 m bowhead whale at rest are estimated to be very low 2,700 Watts. This is not unexpected due to the very thick blubber. Even after correcting the metabolic rate for body temperature ("Q10"), this value is only about half that predicted by the "Kleiber curve." We suggest that the primary function of the blubber is for energy storage and perhaps that bowheads run a "heat load" even at rest. Life history information coupled with morphological and physiological data suggest the bowhead whale is a well insulated cetacean with very low metabolic rates, slow reproduction, and protracted longevity; all of which are adaptations to a cold, highly variable environment with relatively modest prey densities.
Abstract # 5

Lipid Classes and Organochlorines in Bowhead Whale Blubber

Gina M. Ylitalo\textsuperscript{1}, Todd M. O’Hara\textsuperscript{2}, Gladys K. Yanagida\textsuperscript{1}, Lawrence C. Hufnagle, Jr.\textsuperscript{1}, Teri Rowles\textsuperscript{3}, John E. Stein\textsuperscript{1} and Margaret M. Krahn\textsuperscript{1}

\textsuperscript{1} NOAA, NMFS, NWFSC, ECD, Seattle, WA
\textsuperscript{2} North Slope Borough, Department of Wildlife Management, Barrow, AK
\textsuperscript{3} NOAA, NMFS, Office of Protected Resources, Silver Spring, MD

Organochlorines are ubiquitous, persistent contaminants that frequently occur in the marine environment. These compounds are lipophilic and tend to bioaccumulate in lipid-rich tissues (e.g., blubber) of top level predators of the marine food web. Studies indicate that certain OCs primarily enter the Alaskan marine ecosystem via atmospheric transport from the lower and middle latitudes (Barrie \textit{et al.}, 1992; Iwata \textit{et al.}, 1993). These compounds can also enter the marine environment from direct input (e.g., transformer spill) into the far northern marine environment but these sources appear to be less significant than atmospheric deposition (AMAP, 1998; Iwata \textit{et al.}, 1993). Many OCs (i.e., PCBs, DDTs) are not readily eliminated from an animal; however, these contaminants can be transferred from a reproductive female to her offspring during gestation and lactation (Aguilar and Borrell, 1994; Beckmen \textit{et al.}, 1999; Krahn \textit{et al.}, 1999). Exposure of marine mammals to these lipophilic compounds has been linked to various deleterious biological and physiological effects, including reproductive impairment and immune suppression (Addison, 1989; Reijnders, 1986; Ross \textit{et al.}, 1995; Ross \textit{et al.}, 1996).

Analyses of different blubber strata indicate that there may be differences in vertical distribution of organochlorines as well as lipid content. For example, Aguilar and Borrell (1991) examined the distribution of organochlorines in two strata (inner and outer) of blubber of fin and sei whales. They found that the concentrations of OCs (PCBs and DDTs) were higher in the outer layer compared to the corresponding inner blubber layer but these differences could not be explained by variation in lipid content. They attributed the differences in OC levels between the two blubber layers of these baleen whales to the differential role of blubber during the fattening period, the heterogeneous lipid composition of blubber throughout the strata and different turnover rates of pollutants in the blubber layers. In contrast, a harbor porpoise study on the distribution of OCs and lipids in three layers of blubber showed that there were significant differences in the levels of OCs among the blubber layers, with the section nearest the muscle containing higher OC levels than either of the other two layers (Tilbury \textit{et al.}, 1997). However, the differences in OC levels among the different porpoise blubber sections were related to differences in lipid content but were proposed to be the result of nutritional or other physiological properties of each individual animal. These data indicate that there are interspecies differences in the vertical distribution of OC and lipid concentrations that may be related to various physiological or biological factors affecting the animals.

A number (approximately 350 samples) of high quality blubber samples from bowhead whales from the Western Arctic/Bering Sea were collected during subsistence harvests in 1998-2000 and analyzed for lipid content as well as various classes of lipids (e.g., triglycerides,
phospholipids) using thin-layer chromatography with flame ionization detection (TLC-FID) (Shantha 1992). The proportion of neutral lipids (i.e., triglycerides, non-esterified free fatty acids) in a tissue is a key factor affecting the accumulation of lipophilic OCs (Delbeke et al., 1995; Kawai et al., 1988). In addition, a subset of these blubber samples (blubber from 29 animals) was also analyzed for selected organochlorines [e.g., PCBs, DDTs, hexachlorobenzene (HCB)] using a high-performance liquid chromatography photodiode array detection (HPLC/PDA) method (Krahn et al., 1994).

Using the TLC-FID method, the lipid concentrations of the bowhead blubber ranged from 25 – 83%. The blubber contained primarily triglycerides (94 – 100%) and, in some cases, there was a small portion of phospholipids (equal to or less than 6%). The mean lipid concentrations were significantly different among the three collection years (1998, 1999, 2000). Similarly, the mean proportions of triglycerides were significantly different among whales collected in 1998, 1999 and 2000. In contrast, the mean proportion of phospholipids in bowhead whales collected in 1998 was higher than the mean phospholipid proportion values of whales collected in 1999 and 2000. These differences may be related to the time of year (season) the samples were collected. We also analyzed the data based on season and year collected. We found that the mean lipid content in the fall 2000 animals were significantly higher than the mean lipid concentrations in bowhead whales collected in fall 1998, spring 2000, spring 1999 or fall 1999. Furthermore, the mean lipid concentration of whales collected in spring 1999 was significantly lower than the lipid levels of whales collected in fall 1999, fall 1998 and spring 2000. Both mean proportions of triglycerides and phospholipids were significantly lower in the whales collected in fall 1998 compared to the mean proportions of these lipid classes in animals harvested in spring 1999, fall 1999, spring 2000 or fall 2000. However, no significant differences in lipid content among the dorsal, ventral and lateral positions of bowhead whales were found.

Wide ranges of OC concentrations were measured in the bowhead whale blubber samples. In the current study, the OC concentrations were not significantly correlated with lipid content so the contaminant data were reported on a wet weight basis. In all bowhead blubber samples, HCB was the analyte present in the highest concentrations; o,p-DDT and p,p'-DDE were the predominant DDTs present. HCB was the analyte present in the highest concentrations; o,p'-DDT and p,p'-DDE were the predominant DDTs present in bowhead blubber. Among the polychlorinated biphenyl (PCB) congeners, PCB 153 was present in the highest concentrations. The PCB concentrations in these samples were in agreement with PCB concentrations previously reported for bowhead whale samples that were analyzed by a comprehensive analytical method (O’Hara et al., 1999). However, as expected, the OC levels were low compared to the levels reported in blubber of most other marine mammals from Alaska (Miles et al., 1992; Varanasi et al., 1992; Lee et al., 1996; Krahn et al., 1997; Beckmen et al., 1999; Ylitalo et al., in press).

Biological factors such as age, gender and reproductive status can influence OC burdens in marine mammals. Bowhead whale length (surrogate for age) was plotted against ∑PCBs and ∑DDTs. In general, concentrations of these compounds slightly increased with length in male bowhead whales. Concentrations of ∑DDTs and ∑PCBs also increased with length in female whales, up to the length of approximately 10 meters. In this study, it appears that female animals longer than 10 meters in length have reduced OC concentrations that continued to decrease slightly with increasing length. Furthermore, when we compared the mean concentrations of OCs in juvenile bowhead whales (males and females < 13 meters long) to the mean levels in
reproductive females, we found that the mean concentrations of \( \sum \text{DDTs} \) and \( \sum \text{PCBs} \) were generally lower for the adult female bowhead whales compared to juvenile animals.

Other factors such as year collected and season appeared to influence the OC concentrations in bowhead whales. Animals collected in 1998 contained significantly higher mean levels (based on wet weight) of certain OCs in blubber than did the 1999 or 2000 animals. In addition, bowhead whales collected in the fall (1998, 1999 and 2000) usually contained significantly higher mean OC concentrations (based on either wet weight or lipid content) than did the spring 1998 or spring 2000 animals.

This study provides baseline chemical contaminant data as well as information on lipid content for free-ranging bowhead whales, for which there is little information. Combining these data with data from our co-investigators and anatomical measurements from harvest reports, we will be able to evaluate the body condition and health of bowhead whales.
Abstract # 6

Chemically Determined Feeding Ecology and Anthropogenic Chemicals in the Bowhead Whale

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Bowhead whales (Balaena mysticetus) are the largest baleen whales found in Arctic waters. The Bering-Chukchi-Beaufort Sea stock migrates intra-annually between the Beaufort and Bering Seas. This project was designed to elucidate the trophic ecology of this species and relate these findings to accumulation of organochlorine contaminants in liver and blubber tissues. Bowhead whale tissues were collected during the Native subsistence harvests (1997 – 2000) in Barrow, AK, USA. Stable carbon isotope analysis of muscle tissue revealed shifts in $^{13}$C/$^{12}$C ratios with season of harvest. However, stable nitrogen isotope ratios did not vary with season and suggests that the low trophic position of the bowhead whale relative to other marine mammals is consistent throughout its habitat. Blubber and liver tissues from seven consecutive migrations were analysed to provide detailed analysis on 120+ individual OC compounds. Contaminant concentrations in the bowhead whale were characterized by relatively low levels of OCs, and higher proportions of more polar compounds such as HCHs compared to beluga whales. While OC concentrations did not significantly vary with season, contaminant patterns suggest that OC exposure to the bowhead whale may fluctuate with seasonal migration between the Bering-Chukchi-Beaufort Seas. Achiral chemical residue analysis suggests that the ability of the bowhead whale to biotransform OCs may be low. However, the quantification of chiral compounds suggests that accumulation pathways may be more complex than previously believed.
Abstract # 7

Heat loss rates in minke whales compared to harp seals

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Even though the minke whale (*Balaenoptera acutorostrata*) is the smallest of the baleen whales, and a lot smaller than the bowhead whale (*Balaena mysticetus*), it is still by far large enough to make it impossible to do laboratory experiments on them. We therefore need indirect approaches to obtain data on energetic parameters like metabolic rate and cost of maintaining heat balance with the environment. Minke whales are homeothermic and metabolic heat production rate and heat loss rate should therefore be equal. Calculations of the animals heat loss can therefore be a suitable approach to obtain such information. Since calculations of heat transfer from the surface of the animal into water involves calculations of convective heat transfer, which is very sensitive to variations in input parameters, estimates of heat transfer through the blubber is a more reliable approach. However, this approach implies detailed knowledge of the thermal conductivity of the blubber. This can be measured accurately in blubber samples, but in live animals it will change with the amount of blood perfusion of the tissue. Studies on harp seals (*Phoca groenlandica*) show that in animals that are conserving heat, there is essential no blood perfusion in blubber and the thermal conductivity is therefore equal to that of blubber samples. These studies also show that the presence of countercurrent vascular heat exchanger in the flippers can reduce heat loss rates to barely detectable levels. If we extrapolate this information from seals to whales, minimum heat loss rate in a specific thermal environment can be estimated using the Fourier equation. Detailed data on surface area, temperature difference across the blubber, blubber thickness and blubber conductivity were collected from eight minke whales ranging in size from 2000 to 6000 kg, and minimum heat loss rates in ice water were calculated. The minimum heat loss rates were on average 30% higher than the basal metabolic rate (BMR) for similar sized terrestrial mammals, and only animals bigger than 7000 kg could maintain heat production rates as low as BMR and maintain thermal balance. Minke whales might therefore have an energy cost associated with the maintenance of a constant body temperature in Arctic waters.

In harp seals however, direct measurements of heat production rates by respirometry, as well as calculations of minimum heat loss rates in 5 animals showed that they are in perfect heat balance with ice water at heat production rates even lower than BMR. Harp seals therefore have no energy cost of regulating body temperature.

Given the size advantage of minke whales compared to harp seals this result might seem surprising. However, the thermal conductivity of harp seal blubber is much lower than that of minke whales (0.18 W/mK for harp seals and 0.25 W/mK for minke whales) and the harp seal blubber is also thicker than the blubber of minke whales (45 mm for harp seals, 40 mm for minke whales). This difference in quality and quantity of the insulation of harp seals compared to minke whales, more than compensates for the size difference.
The difference in thermal performance of these two species might explain the presumed migration of minke whales into warmer waters to give birth to their calves in the winter, while the harp seals stay in their Arctic feeding area year around.
Abstract # 8

Observations on some basic morphometric characters of the Bowhead Whale

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The bowhead whale has been the subject of intense scientific study over the past two decades, however little work has focused on the basic morphological relationships of the bowhead whale. Tomilin (1967) in his classic work on Cetacea described some basic body relationships of the bowhead whales. More recently, Marquette summarized some basic body relationships in his early work on bowhead whales in the BCBS stock.

The bowhead whale has a fuseform body shape with telescoping maxillary bones typical to other large mysticetes but is often an "outlier" in many basic body morphometric relationships (Nerini, 1984). Prominent body length relationships include a) a snout-to-blowhole ("head") vs. body length ratio that is 0.3 (which is greater than for other mysticetes), b) a fluke-to-body length ratio 0.34 greater than all other mysticetes, and c) pectoral flippers averaging about 20% of body length. It appears that bowhead whales put great emphasis on growing their heads and baleen apparatus during early life even at the expense of growth in body length. A "growth hiatus" has been noted by traditional Iñupiaq subsistence hunters and has been quantified by Schell and Saupe (1993). They noted "growth is very rapid during the first year of life, but is followed by a period of several years in which little or no growth occurs." For whales less than 11 meters, age can be estimated using baleen length wherein age = 2.14*baleen length(m)\(^{2.71}\). This relationship is dramatically visible when the body length/baleen length ratio is plotted as a function of body length.

The length at sexual maturation is roughly 12-13 m for male bowheads (O'Hara et al, in prep.). For females, sexual maturity is achieved at ~14 m for landed whales caught by hunters (Tarpley and Hillmann, 1999) and 13-13.5 m for whales photogrammetrically measured by aircraft (Koski et al., 1993).

George et al. (1999) used aspartic acid aging to estimate the age of whales. This technique proved to be impractical for whales less than about 10 years of age but offers useful age estimates for older animals. Regression analysis indicated that age at maturity (assuming about 13 m for both sexes) is roughly 25 years. This very advanced age agrees with estimates using photogrammetry (late teens to mid-twenties (Koski et al., 1992) and is similar to baleen age estimates (Schell and Saupe, 1993).

The blubber coat of a bowhead is fairly uniform in thickness in the thoracic region between the axilla to the peduncle and ranges from about 18 to 38 cm in post-neonates. The blubber thickness in the head, flukes, and pectoral limbs, however, is much less than the thorax. Since the 1970s, blubber thickness has been measured at two sites on the whale. These sites are approximately 1 meter posterior to the blowhole on the dorsal midline and immediately ventral to that position on the ventral midline. When blubber thickness is examined as a function of body length, some unusual features appear. The blubber is quite thick (% of body length) for whales less than 10 m and then becomes essentially a linear function of body length for whales
>10m. The great blubber thickness of the young whales is likely a function of their thicker hypodermis layer. However, the blubber thickness does not vary significantly with season (p > 0.05) suggesting that blubber in bowheads is a somewhat dimensionally “fixed” tissue and it is the percent of lipid that varies (see T. Mau abstract).

Bowheads of both sexes tend to have a higher girth to body length ratios in autumn than in spring for whales before they reach sexual maturity and only if ingutuks are excluded. This is an indication that summer feeding is important for young whales but perhaps less important for adult whales. If ingutuks are considered in this analysis, the seasonal differences are not evident. Our explanation for this difference is that the ingutuks are carrying a large amount of maternal fat and are extremely ‘girthy’ for their length. This large contribution of maternal fat masks any seasonal changes in girth.
Abstract # 9

Histomorphology and Health Assessment in the Bowhead Whale

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In addition to blubber, other organ tissues are collected during necropsy. A collection of common tissues will be reviewed with photos and photomicrographs of organs from the bowhead whale in both normal and pathological states. An overview of pathological and histopathological data interpretation will be given with insight into how these data will aid in the determination of the health status of cetaceans.
Abstract #10

Concentrations & Interactions of Selected Elements in Bowhead Whales of Arctic Alaska with Reference to Potential Health Effects

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Many elements are essential to animals and serve important roles, particularly as functional groups in a number of enzymes. However, metals can also cause toxic effects, either directly, or through antagonism with an essential element that results in a functional deficiency. Consequently, it is untenable to infer the nutritional adequacy or toxic potential with respect to various elements based solely upon tissue concentrations, without consideration of other indices of health status.

Concentrations of selected essential and non-essential elements were evaluated by atomic absorption spectrophotometry (AAS) in tissues of bowhead whales (Balaena mysticetus), harvested in subsistence hunts from coastal villages (primarily Barrow) on Alaska's North Slope. As, Cd, Co, Cu, Pb, Mg, Mn, Hg, Mo, Se, Ag, and Zn, were analyzed in liver, kidney, muscle, blubber, and epidermis. Data from 20 bowheads harvested 1995-97 were compared with previously collected data from 41 whales harvested during 1983-90. Tissue metal concentrations did not differ between genders. Cadmium concentrations were highest in kidney followed by liver. Levels of lead (Pb) and Hg were consistently low in all tissues. Hepatic Cu, Ag, and Mn concentrations were negatively correlated with body length (age). Selenium and Cd were positively correlated in liver. Cadmium increased with body length (age) in liver, kidney, muscle, and blubber; also, the Cd:Zn ratio increased with age in liver and kidney. Selenium increased with age in liver, kidney and epidermis. Hepatic Se was strongly correlated with Hg, reflecting a well accepted mode of Hg detoxification in marine mammal liver.

Cadmium in liver and kidney was elevated compared to normal tissue concentration ranges in domesticated species such as dogs and cattle (Puls, 1994). However, the Cd concentrations found in this study are well within ranges previously reported for arctic marine mammals. Observed associations between Cd, Zn, and Cu are probably due to binding by a common ligand such as metallothionein.

All five bowhead whale kidneys examined histologically exhibited a generalized, non-inflammatory renal periglomerular and interstitial fibrosis. While Cd was at elevated concentrations in bowhead kidney, the lesion was not typical of Cd-induced nephropathy but was believed to be a normal aging change for this species. Acute myodegeneration observed in cardiac and/or skeletal muscle of a few bowheads was consistent with exertional myopathy. One whale with acute skeletal myodegeneration had the lowest muscle Se observed among the 42 bowhead whales sampled. While there were no lesions indicative of chronic Se deficiency, the lesions of acute myodegeneration suggests that the oxidative stress associated with the hunt may have overwhelmed the protection against oxidative injury afforded by marginal Se levels.
Overall, subsistence-harvested bowhead whales from Alaska's North Slope appeared in good body condition with no lesions that would substantiate a diagnosis of chronic heavy metal toxicosis, despite concentrations of Cd and Se that were elevated in comparison to normal ranges for domestic terrestrial species.
Abstract # 11

Using Morphological and Biochemical Characterization of Muscle to Assess Nutritional Status

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Morphological and biochemical characterization of muscle was used to assess nutritional status of harbor porpoises, *Phocoena phocoena*, which provided the framework for beginning the assessment of nutritional status for bowhead whales, *Balaena mysticetus*. Harbor porpoises in the northwest Atlantic provide a rare opportunity to study apparent starvation in a wild cetacean because the body conditions of stranded, emaciated porpoises can be compared to those of robust porpoises killed in fishing operations. Body mass and skeletal muscle morphology and biochemistry were used to characterize porpoise body condition. Because the process of starvation impacts muscles differentially, an epaxial locomotor muscle was chosen to represent a continuously rhythmic muscle, and the sternohyoid, a feeding muscle, an intermittently active muscle. Emaciated porpoises weighed 38% less than robust porpoises and had lost 35% of their epaxial muscle mass. Fast twitch fiber diameters of emaciated longissimus muscle were 31% smaller and slow twitch diameters 14% smaller, which resulted in a 15% increase in area of slow twitch fibers relative to that in robust porpoises. Emaciated longissimus muscle fibers also possessed 33% less fibrils than those of robust porpoises. Contrarily, the sternohyoid of emaciated and robust porpoises had similar masses and fiber type profiles. The only change measured in the sternohyoid was a 24% decrease in diameter of fast glycolytic fibers. Muscle biochemical profiles were assayed using a suite of enzymes representing glycolysis, lipid oxidation, citric acid cycle, amino acid oxidation, and anaerobic metabolism. Interestingly, although the longissimus had suffered significant atrophy while the sternohyoid displayed morphological conservation, the enzyme activities of both muscles suggested a transition to the use of the oxidative pathways in slow and fast fibers, perhaps as metabolic fuel use changed from glucose to the simultaneous degradation of lipid and protein. The magnitude of morphological and biochemical changes seen in epaxial muscle of emaciated porpoises is consistent with the clinical definition of phase III of starvation, which strongly supports the hypothesis that starvation is the cause of mortality for some harbor porpoises in the mid-Atlantic.

Robust bowhead whale epaxial muscle exhibited a fiber-type profile consisting of 45% slow twitch fibers and 55% fast twitch fibers (9% fast oxidative, glycolytic fibers and 46% fast glycolytic fibers). Muscle biochemical profiles showed the following mean enzyme activities (µmoles min\(^{-1}\) g wet weight\(^{-1}\)): glycogen phosphorylase (1.92), hexokinase (20.07), β-hydroxyacyl-CoA dehydrogenase (2.10), carnitine acyltransferase (70.27), glutamate dehydrogenase (0.60), and aspartate aminotransferase (0.34). Aerobic capacity was determined by determining the ratios of mean enzyme activity (µmoles min\(^{-1}\) g wet weight\(^{-1}\)) for both citrate synthase (5.15) and succinic dehydrogenase (405.86) to lactate dehydrogenase (17.39), which resulted in 0.30 and 23.34, respectively. This preliminary data for robust animals provides a baseline to use in assessment of nutritional status for bowhead whales.
Abstract #12a

Ageing Bowhead Whales (*Balaena mysticetus*) using the Aspartic Acid Racemization Technique

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With the aspartic acid racemization technique, age is estimated based on intrinsic changes in the D and L enantiomeric isomeric forms of aspartic acid in the eye lens nucleus. Racemization rate (Kasp) for aspartic acid was based on data from earlier studies of humans and fin whales. The D/L ratio at birth (D/L₀) was estimated using animals ≤ 2 yr since variability in the D/L measurements is large enough that differences among ages in this range are unmeasurable. Based on these data growth appears faster for females than males and age at sexual maturity (age at length 12 -13 m for males and 13 - 13.5 m for females) occurs at ages of around 25 yr. Growth slows markedly for both sexes at roughly 40-50 yr. Four individuals (all males) exceed 100 yr in age. The standard error increased with estimated age, but the age estimates had lower coefficients of variation for older animals. Recoveries of “traditional” whale hunting tools from five recently harvested whales also suggest life spans in excess of 100 yr in some cases.
Abstract #12b

Collagen aging: potential applications in cetaceans

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Age in marine mammals may be determined by various methods, ranging from simple photo re-identification to such methods as ear plug growth layer measurement, tooth growth layer group quantification, aspartic acid racemization in the teeth and eye lens nucleus and the aging of baleen. In bowhead whales (*Balaena mysticetus*), teeth are not present, ear plugs do not appear to form and baleen aging is reliable only up to eleven to fifteen years of age due to wear at the distal ends of the baleen plates.

The potential to age whales via the analysis of a small amount of skin (from a biopsy dart sample or collection at necropsy) is examined in this research. It is thought that the manifestations of aging are most pronounced in the extracellular matrix, the primary component of which is collagen. Skin undergoes dramatic age-related changes in its mechanical properties, including changes in tissue hydration and resiliency. Research has shown that collagen cross-links steadily increase with age. Advanced glycation end-products, such as pentosidine and carboxy-methyl lysine (CML), accumulate in long-lived tissue proteins. Methods employed as indicators of aging include measuring the level of pentosidine and other collagen related chemicals in the skin. Pentosidine, a marker of glycoxidative stress in skin collagen, has been found to form at a rate inversely related to maximum life span across several mammalian species. Pentosidine is one of the advanced products of the Maillard reaction and serves as an indicator of the extent of chemical modification, oxidation and cross-linking of tissue protein caused by reducing sugars. Pentosidine can be measured in the skin via extraction, hydrolyzation and HPLC.

Results include the quantification of pentosidine and other collagen related products from the dermal collagen of 48 bowhead whales.
Abstract #13

Statistical Methods for Including Basic Biological, Temporal, and Spatial Data in the Health Assessment Process

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Samples for assessing lipid content and organochlorines (OCs) in bowhead blubber are collected from harvested animals. Thus, such factors as the number of whales sampled in a given season and year from a given village and the sex and size of each whale are not under the control of the researchers even when they have devised a careful protocol for sampling each whale in order to answer scientific questions of interest. The factors that cannot be completely controlled may affect the results obtained. Restricting analyses to subsets of the data in which such factors do not vary results in small sample sizes that reduce power to detect effects, so in many cases it is better to adjust for such factors within a single analysis. Multiple samples from the same whale and multiple OCs measured from the same samples also complicate analyses.

When a single measurement is made on each whale, the Generalized Linear Model (GLM) provides a tool for including multiple factors and continuous predictors in a single analysis. If the response variable is continuous, a multiple regression model—one type of GLM—can be used. Another GLM, the logistic regression model, is appropriate for binary (0-1) data. This can be used for an OC that is below detectable levels in many samples. The data are coded as 1 if the OC is above some level, 0 otherwise, and logistic regression is used to estimate the odds of finding the OC at detectable levels as a function of sample characteristics such as where the sample was obtained.

When multiple measurements are made on the same whale, they can be summarized by a biologically relevant summary statistic into a single measurement for each whale so that a straightforward GLM analysis can be done. In other cases, one wishes to assess within-whale factors such as the depths in the blubber at which the samples were taken, so it is not appropriate to combine the measurements by computing a summary statistic such as the mean for the whale. When multiple measurements on the same whale are included in an analysis, the likely correlation among them that results from differences between this whale and other whales needs to be taken into account. When many different OCs are measured in each sample and hypothesis tests are conducted on each OC, it is difficult to synthesize the results, particularly because a large number of hypothesis tests is likely to result in obtaining some “statistically significant” results purely by chance.

In this talk, I show some graphical methods for examining multiple factors and measurements as an aid to choosing appropriate statistical models. These include box plots, stem-and-leaf diagrams, trees produced by a cluster analysis, and scatter plots. All can be used on data in the original units or after an appropriate transformation. The latter can be as simple as
taking logs of variables or as complicated as computing principal components. At the modeling stage, multiple measurements of the same variable on a single whale can be handled by using linear mixed effects models, generalized estimating equations, or ordinary multiple regression or logistic regression models with jackknife variance estimates computed by omitting one whale at a time. I will present results for lipids and OCs based on these techniques.
Abstract # 14

Bowhead Whales and Environmental Variability

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Bowhead whales migrate and feed in one of the most extreme environments on the planet. As the only baleen whale endemic to the Arctic, bowheads display unique adaptations for navigation through sea ice and for feeding on seasonal pulses of prey. Sea ice cover and transport (i.e. in-flow) at Bering Strait are two aspects of Alaskan Arctic physical oceanography that may affect bowhead whale distribution and habitat selection. Sea ice affects productivity and can act as a physical barrier to migrating whales. Transport provides an advective pathway for nutrients and zooplankton between the productive Bering Sea and the Beaufort Sea. The influence of both factors on bowhead whale habitat selection were investigated though an analysis of ten years (1982-91) of autumn sighting data from aerial surveys offshore northern Alaska (Moore, 2000). In the Alaskan Beaufort Sea, bowheads selected shallow inner-shelf (< 50m) waters during moderate and light ice conditions, but shifted offshore to deeper outer-shelf and slope (51-200m) habitat in heavy ice conditions (X^2, p<0.05-0.001). In the northern Chukchi Sea, bowheads were associated with specific depth habitat only in light ice conditions (X^2, p<.005), probably as an extension of the inner-shelf distribution in the Alaskan Beaufort Sea during those years. Transport variability did not affect bowhead habitat selection, although this result could be due to the coarse scale of sampling.

Bowheads must find dense aggregations of prey to feed efficiently. Prey aggregations can result from advection (zooplankton riding currents to an area), or from local on-site primary and secondary production. No matter the mechanism, prey are usually aggregated by physical discontinuities (fronts and eddies) in the water column that can be identified by abrupt shifts in water temperature and salinity. In this regard, sea ice can be considered the “ultimate” front. Fronts and eddies are created through physical forcing mechanisms, all of which are ultimately tied to the wind. Thus, bowhead distribution, relative abundance and availability to Native subsistence hunters are influenced by oceanographic structure resulting from inter-annual variability in both local weather patterns and longer-term atmospheric fluctuations such as the Arctic Oscillation.

While seasonal and inter-annual environmental variability is usually extreme in the Arctic, localized and recurrent prey "hot spots" exist offshore northern Alaska where bowheads typically feed in late summer and autumn (Moore and Reeves, 1993). Examples of such regions occur near Barrow and Kaktovik, Alaska, and along the Chukotka coast. Analysis of stomach contents from whales landed in autumn at Kaktovik and Barrow suggest that copepods make up a large part of the diet in the eastern Beaufort Sea, but that euphausiids dominate in the western Beaufort Sea (Lowry, 1993). The types of copepods that bowhead eat near Kaktovik are (mostly) Arctic species, while the principal euphausiid (Thysanoessa rachii) found in bowhead stomachs at Barrow is common in the northern Bering Sea and likely advected to the Barrow area by northward flowing currents (Niebauer and Schell, 1993). Of note, some whales in
Kaktovik do have stomachs nearly full of euphausiids, with mysids and gammarid amphipods also common; and in spring, copepods are common in the stomachs of bowheads landed at Barrow (Lowry, 1993). For the Arctic Ocean, the coupled physical-biological mechanisms that contribute to the development of such prey "hot spots" are poorly understood.

Arctic sea ice now covers 15% less area than it did in 1978 and has thinned to an average of 1.8 m (5.7 ft), compared to 3.1 m (9.9 ft) in the 1950s (Krajick, 2001). Ocean-atmosphere general circulation models suggest that on-going climate changes will result in the greatest net warming, and ecosystem change, in the Arctic (e.g., Manabe et al., 1994). One prediction resulting from these models is that global warming will lead to “cascading trophic dynamics” (Tynan and DeMaster, 1997), which will dramatically alter marine production and food web structure in the Arctic. Untested in this prediction are the complex linkages included under the “trophic cascade” banner, including those that lead to animal aggregations. Theoretical work on animal aggregations thus far has focused on conditions that lead to flocking or schooling (e.g., Parrish and Edelstein-Keshet, 1999), rather than the “cascading dynamics” that underlie these behaviors. Conversely, the importance of animal aggregation to human hunters of marine mammals is clear, even while the influence of ecosystem variability on subsistence hunting is less well defined (e.g., Krupnik and Bogoslovskaya, 1999).
Abstract # 15

Determining Reproductive Status in Right Whales: The Bowhead Whale As the Model for Confirmation of “New” Technologies and Applications

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\textsuperscript{3} Department of Wildlife Management, North Slope Borough, Barrow, AK

The purpose of this collaborative project is to develop and apply a technique to analyze steroid hormones in fecal samples from North Atlantic Right Whales (\textit{Eubalaena glacialis}; NARWs), and to conduct parallel comparative studies in the Bering-Chukchi-Beaufort Sea Stock of bowhead whales (\textit{Balaena mysticetus}) to learn more about the reproductive physiology of these baleen whales. Analysis of the metabolites of the major reproductive hormones (estrogen, testosterone, and progesterone) and stress hormones (glucocorticoids) from fecal samples has been applied to many terrestrial wildlife species, but has never been applied before to free-ranging whales. The impetus for this research is to study the possible mechanisms behind the decrease in reproductive success seen in the NARW over the past decade. The causes of this reproductive decline are unknown. The NARW is critically endangered, and this decline in reproduction is believed to be one of the factors preventing recovery of the population.

Very little is known about reproductive physiology in baleen whales. Knowledge of the hormone status of NARWs is needed to determine which part of the reproductive cycle is being affected in order to better characterize the nature of the reproductive dysfunction, to target research into possible causes and to develop mitigation and management strategies. Studying reproduction in NARWs is problematic because no techniques are available to collect blood samples from large, free-ranging whales, and because stranded animals are so decomposed that the tissues are useless for analysis. Therefore, analysis of fecal steroid hormones provides a unique non-invasive method to learn about the reproductive status of this population.

Over the past two years we have tested and validated an immunoassay technique that measures the metabolites of reproductive (estrogen, testosterone and progesterone) and adrenal steroid (glucocorticoid) hormones in fecal samples from NARW. The level of a given hormone metabolite in the feces reflects an average value for the secretion pattern of the parent hormone over a period of the previous day to days. Collection of fecal samples is coordinated with photo-identification studies of the population, allowing identification of the whale in many cases and correlation of the hormone results with the age, sex, genetic information and reproductive history of the individual based upon data available from the North Atlantic Right Whale Catalogue. This extensive data set puts the fecal hormone values into context on both an individual and population level, and presents a unique opportunity to study reproduction in mysticetes.
We have also initiated comparative studies of the Bering-Chukchi-Beaufort Sea Stock of bowhead whales, and we are currently validating the same four hormone assays for bowheads. The bowhead whale is being used as a reference population for these studies because of its close taxonomic relationship with right whales, because of the dietary similarity with NARW, because the population is growing and reproductively healthy, and because fresh tissues and fecal samples can be taken during the Alaskan Eskimo hunts. Availability of these samples from the subsistence hunt presents a unique opportunity to conduct comparative studies of reproduction in bowhead whales. The comparative work with bowhead whales will shed light upon the relationship between fecal steroid hormone metabolites, circulating levels of hormones and the morphological status of the reproductive tract. This will provide us with baseline data with which to assess the relationship between fecal steroid levels and reproductive condition in a large baleen whale that can serve as a model for NARW reproduction studies. These studies will be valuable to interpreting the fecal hormone levels from right whales, as well furthering our understanding of reproduction in the bowhead whale.
Abstract #16

Gray Whales Strandings: Perspectives in Baja California

Lorenzo Rojas-Bracho¹, Jorge Urbán², Hector Pérez-Cortés¹

¹ Programa Nacional de Mamíferos Marinos, Instituto Nacional de Ecología-SEMARNAT
² Programa de Investigación de Mamíferos Marinos, Universidad Autónoma de Baja California Sur

In 1999 and 2000 stranded gray whales were reported in record numbers along the coast of North America from Baja California to Alaska. In Mexican waters the mortality count in 1999 was 274 animals and in 2000 it came up to 207 animals. Why or what was provoking these the killing of these whales? There has been intense speculation. To be able to approach to an answer it’s fundamental that carcasses be examined all along the distribution range of gray whales. That is from their breeding grounds to their feeding grounds. To take as much advantage of the collected data as possible it is important that researchers of the countries involved standardize techniques from the field to the lab work. To accomplish this, the NMFS, Wildlife Trust, Ocean Conservation, Department of Wildlife Management North Slope Borough, the Mexican Society for Marine Mammalogy (SOMEMMA) and Mexico’s National Marine Mammal Program sponsored and organized a couple of workshops to train students and researchers to obtain data from stranded whales. Currently, two laboratories in Mexico have the research capacity to analyze different kinds of pollutants. However, there are still physical, chemical, biochemical and physiological parameters that could be used to assess the health of gray whales. Expertise in one or other area could be missing in some of the Countries that include this species distribution range. Joint long-term research efforts are fundamental to understanding and assessing in a more comprehensive way the nutritional and health status of gray whales.
7. Appendices
Appendix A. Workshop Participants

George Ahmaogak, Sr.
Mayor
North Slope Borough
P.O. Box 69
Barrow, AK 99723
Phone: (907) 852-0200
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Website: http://www.fm.uit.no/info/imb/aab/

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NOAA/NMFS/AFSC  
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National Oceanic and Atmospheric Administration  
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Steller Sea Lion Program  
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Environmental Conservation Division  
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Fax: (206) 685-7419  
Email: zeh@stat.washington.edu
Bowhead Whale Health And Physiology Workshop

AGENDA

October 1-4, 2001
Inupiat Heritage Center
Barrow, Alaska

Workshop Goal

To determine the measurable physical, chemical, biochemical and physiological parameters that would be used to assess the health of bowhead whales, and to establish priorities for further investigations for research of mysticete nutritional and health status in general as a model for other large baleen whales (i.e., right whales, gray whales).

Objectives

1. To describe the preliminary findings related to the chemical, physical, and structural properties of bowhead whale blubber (to understand the dynamics, biochemistry and metabolism of blubber lipids).
2. To describe the preliminary findings related to morphometrics, biochemistry, mineral and heavy metals status, and histology of the bowhead whale related to health and condition.
3. Determine the influence of selected biological variables (i.e., age, season, gender) in the health assessment process and the proper collection of these data.
4. Develop sampling and analysis needs for a long term bowhead whale “health and nutritional assessment.”
5. Review combined findings to date on the assessment of health in bowhead whale and develop sampling protocols for future projects.
6. Develop list of data gaps and define projects that need to be addressed.
7. Describe ongoing and proposed uses of the bowhead whale as a model for determining the health and condition of other large mysticetes (i.e., right whale reproduction, gray whale condition and contamination).

* In the event that a bowhead whale is landed and it is possible for us to visit the butchering site, we will adjust this schedule accordingly. This is a rare opportunity for most people so we thank you for your patience and flexibility.
# OPENING

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Organizer/Presenter</th>
</tr>
</thead>
</table>
| 9:00 – 10:00 | Opening Remarks                           | George N. Ahmaogak, Sr.  
Mayor, North Slope Borough  
Captain, Ahmaogak Crew  
Maggie Ahmaogak  
Executive Director, Alaska Eskimo Whaling Commission  
Ahmaogak Crew  
Eugene Brower  
President, Barrow Whaling Captains Association  
Captain, Aalaak Crew  
Glenn Sheehan  
Executive Director, Barrow Arctic Science Consortium |
| 10:00 – 10:20 | Meeting Overview & Terms of Reference: “Grad-student-centricity” and the Bowhead Model | Todd O’Hara  
North Slope Borough  
Dept of Wildlife Management |
| 10:20 – 10:30 | Logistical Update                         | Carla Willetto  
Barrow Arctic Science Consortium |
| 10:30 – 10:45 | **BREAK**                                |                                                          |

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# REVIEW OF CURRENT WORK

**Blubber Quality and Quantity as an Indication of Nutritional and Health Status**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Organizer/Presenter</th>
</tr>
</thead>
</table>
| 10:45 – 11:15 | A 3-D Look at Blubber and Definition of Blubber in General          | Mike Castellini  
Institute of Marine Science  
University of Alaska Fairbanks |
| 11:15 – 11:45 | Gross and Histologic Structure of Bowhead Whale Blubber: Defining the Terms for Cetaceans. | Cheryl Rosa  
Institute of Arctic Biology  
University of Alaska Fairbanks |
| 11:45 – 12:15 | Basic Chemical and Energetic Composition of Bowhead Whale Blubber and the Affects of Select Biological Variables and within Animal Variability. | Tami Mau  
Institute of Marine Science  
University of Alaska Fairbanks |
| 12:15 – 1:15 | **LUNCH at NARL Cafeteria**                                         |                                                          |

Bus departs 12:15 for NARL cafeteria. Leaves NARL at 1:15 to return to workshop.

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Organizer/Presenter</th>
</tr>
</thead>
</table>
| 1:30 – 2:00 | Preliminary Finds: Bowhead Whale Regional Heterothermy and Energetics | Craig George  
North Slope Borough  
Dept of Wildlife Management |
| 2:00 – 2:30 | Lipid Classes and Organochlorines in Bowhead Wh Blubber               | Gina Ylitalo  
NOAA/National Marine Fisheri Service  
NWFSC/ECD |

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<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:30 – 3:00</td>
<td>Chemically Determined Feeding Ecology and Anthropogenic Chemicals in Bowhead Whale Blubber</td>
<td>Todd O'Hara</td>
<td>North Slope Borough Dept of Wildlife Management</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(for Paul Hoekstra, Environment Canada)</td>
</tr>
<tr>
<td>3:00 – 3:15</td>
<td>Break</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:15 – 3:45</td>
<td>Heat Loss in Minke Whales</td>
<td>Petter Kvadsheim</td>
<td>University of Tromsø Department of Arctic Biology</td>
</tr>
<tr>
<td>3:45 – 5:00</td>
<td>Discussion of Blubber</td>
<td></td>
<td>Led by Co-Chairs</td>
</tr>
<tr>
<td></td>
<td>For workshop report.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5:00 – 6:30</td>
<td>Dinner break</td>
<td></td>
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<tr>
<td></td>
<td>5:15 bus leaves for Brower's Restaurant</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group Photo</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6:30 bus leaves Brower's for Heritage Ctr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7:00</td>
<td>“Whales of the Bering Sea”</td>
<td>Sue Moore</td>
<td>NOAA/Alaska Fisheries Science Center</td>
</tr>
<tr>
<td></td>
<td>Open to the public</td>
<td></td>
<td>National Marine Mammal Laboratory</td>
</tr>
<tr>
<td></td>
<td>Sponsored by Barrow Arctic Science Consortium (BASC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:30</td>
<td>Bus leaves Heritage Ctr for NARL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BREKFAST: Available from 6:30 – 8:30am at the NARL cafeteria, all-you-can-eat for $8.00. There will be coffee, fruit, and baked goods at the meeting room.

8:10

Bus departs NARL for the Heritage Center.

Body Condition, Nutrition, and Reproduction in Determining Health Status

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 – 9:00</td>
<td>Morphometrics: How do Bowhead Whales Measure up?</td>
<td>Craig George</td>
<td>North Slope Borough Dept of Wildlife Management</td>
</tr>
<tr>
<td>9:00 – 9:30</td>
<td>Morphological Types of Bowhead Whales as Described by Inupiaq Traditional Knowledge</td>
<td>Warren Matumeak</td>
<td>Barrow Elder</td>
</tr>
<tr>
<td>9:30 – 10:00</td>
<td>Histomorphology and Health Assessment in the Bowhead Whale</td>
<td>Cheryl Rosa</td>
<td>University of Alaska Fairbanks Institute of Arctic Biology</td>
</tr>
<tr>
<td>10:00 – 10:30</td>
<td>Traditional Bowhead Whale Butchering Techniques</td>
<td>Eugene Brower</td>
<td>Barrow Whaling Captains Assn. Captain, Aalaak Crew</td>
</tr>
<tr>
<td>10:30 – 10:45</td>
<td><strong>BREAK</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:15 – 11:45</td>
<td>Using Morphological and Biochemical Characterization of Muscle to Assess Nutritional Status</td>
<td>Vicki Stegall (via teleconference)</td>
<td>University of North Carolina at Wilmington</td>
</tr>
<tr>
<td>11:45 – 1:00</td>
<td>LUNCH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 – 2:15</td>
<td>Group Discussion: Body Condition and Reproduction For workshop report</td>
<td>Led by Co-Chairs</td>
<td></td>
</tr>
<tr>
<td>2:15 – 2:30</td>
<td><strong>BREAK</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# DETERMINING THE ROLE OF BIOLOGICAL PARAMETERS ON THE ASSESSMENT OF HEALTH AND CONDITION

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Presenter/Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:30 – 3:00</td>
<td>Aging: Does the Chemistry Match Up With the Stone Points and Life History Observations?</td>
<td>Craig George NSB Dept of Wildlife Mgt Cheryl Rosa University of Alaska Fairbanks</td>
</tr>
<tr>
<td>3:00 – 3:30</td>
<td>Statistical Methods for Including Basic Biologic, Temporal, and Spatial Data in the Health Assessment Process</td>
<td>Judy Zeh University of Washington</td>
</tr>
<tr>
<td>3:30 – 4:00</td>
<td>Environmental Factors Related to Bowhead Whale Prey Type and Availability</td>
<td>Sue Moore NOAA/Alaska Fisheries Science Center National Marine Mammal Laboratory</td>
</tr>
<tr>
<td>4:00 – 4:30</td>
<td>TBA</td>
<td></td>
</tr>
<tr>
<td>4:30 – 5:00</td>
<td>Set up tables/chairs for dinner</td>
<td>Any &amp; all workshop participants</td>
</tr>
<tr>
<td>5:00 – 7:00</td>
<td>Free time</td>
<td></td>
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<tr>
<td></td>
<td>• Look around the Inupiat Heritage Center. Whaling exhibit will be open until 6:00pm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Tuzzy Consortium Library is open until 9:00pm. Grab one of their free books for your flight home.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Grocery store across the street: lattes, postcards, some souvenirs/crafts, incidentals.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Bus out to NARL available. Departs 5:30 and returns 6:45.</td>
<td></td>
</tr>
<tr>
<td>6:45</td>
<td>Bus leaves NARL for Heritage Center</td>
<td></td>
</tr>
<tr>
<td>7:00 – 9:30</td>
<td>Banquet – Inupiat Heritage Center</td>
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<tr>
<td></td>
<td>Program</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Whaling 2001 - A Collection of Photographs</td>
<td>Jana Harcharek Manager, Bilingual &amp; Multicultural Instruction North Slope Borough School District</td>
</tr>
<tr>
<td></td>
<td>• Nuvukmiut Dancers</td>
<td>Larry Kaleak, President</td>
</tr>
<tr>
<td></td>
<td>Nuvukmiut means &quot;the people of Point Barrow,&quot; referring to the community that lived out at Point Barrow as recently as the 1940's. This dance group commemorates their Nuvukmiut relatives and ancestors.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sponsors: Alaska Eskimo Whaling Commission BP Exploration (Alaska), Inc. Arctic Slope Regional Corporation</td>
<td></td>
</tr>
<tr>
<td>9:30</td>
<td>Bus leaves for NARL</td>
<td></td>
</tr>
</tbody>
</table>

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**DAY THREE**

**Wednesday, October 3, 2001**

**BREAKFAST:** Available from 6:30 – 8:30am at the NARL cafeteria, all-you-can-eat for $8.00. There will be coffee, fruit, and baked goods at the meeting room.

**NOTE:** For those departing on tonight’s flight, bring your luggage with you to the meeting this morning. You can store it at the conference room. We’ll take you directly to the airport when we finish up this afternoon.

8:30  Bus departs NARL for Heritage Center.

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**COMPARATIVE AND COLLABORATIVE RESEARCH IN OTHER CETACEANS**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Presenter</th>
<th>Institution/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 – 9:30</td>
<td>Determining Reproductive Status in Right Whales: The Bowhead Whale as the Model for Confirmation of “New” Technologies and Applications</td>
<td>Todd O’Hara</td>
<td>North Slope Borough</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dept of Wildlife Management</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(for Rosalind Rolland, New England Aquarium)</td>
</tr>
<tr>
<td>9:30 – 10:00</td>
<td>Opportunities for Examining and Sampling Gray Whales in Mexico</td>
<td>Todd O’Hara</td>
<td>North Slope Borough</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Dept of Wildlife Management</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(for Lorenzo Rojas-Bracho,</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Programa Nacional de Mamíferos</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Marinos)</td>
</tr>
<tr>
<td><strong>10:00 –</strong></td>
<td><strong>BREAK</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10:15</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>FUTURE RESEARCH &amp; MONITORING</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:15 – 10:45</td>
<td>An Industrial Perspective on Maintaining the “Health” of the Bowhead Whale and Possible Insight to Long Term Monitoring Efforts of Individuals and the Proverbial &quot;Cumulative Impacts.&quot;</td>
<td>Ray Jakubczak</td>
<td>BP Exploration (Alaska), Inc.</td>
</tr>
<tr>
<td>10:45 – 12:00</td>
<td>GROUP DISCUSSION</td>
<td></td>
<td>Led by Co-Chairs</td>
</tr>
<tr>
<td></td>
<td>• Development of Long-Term Sampling Protocols.</td>
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<td>• What are the Minimum Parameters Needed to Define Individual Nutritional Status?</td>
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<td>• Identify Working Groups for this Afternoon.</td>
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<td><strong>12:00 –</strong></td>
<td><strong>LUNCH</strong> at Inupiat Heritage Center.</td>
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<td><strong>1:00</strong></td>
<td>Sandwiches and Salad.</td>
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WORKSHOP REPORT

1:00 – 4:00
- Four Working Groups will be identified during the course of the workshop. It is during this afternoon that they will be asked to draft their sections of text for the workshop report.
- The workshop report will summarize workshop findings and provide guidance for future bowhead whale health assessment work.
- Currently, the proposed working groups include:
  1. Blubber/Nutrition/Energy
  2. Gross and Histologic Examination and Evidence/Indicators of Disease
  3. Physiology
  4. …and a fourth group yet to be determined

4:15
Bus departs IHC.
Everyone should get on the bus. People departing this evening will be dropped off at the airport 2 hours ahead of time (per Alaska Airlines recommendations). The remaining people will then be taken out to NARL.

5:00
Dinner at NARL Cafeteria
Steak Night!

6:15 – 7:45
Archaeology Tour of Barrow
Bus departs from NARL

Anne Jensen
Senior Scientist
Ukpeagvik Iñupiat Corporation
Real Estate Science Division

DAY FOUR
Thursday, October 4, 2001

BREAKFAST: Available from 6:30 – 8:30am at the NARL cafeteria, all-you-can-eat for $8.00. There will be coffee and baked goods at the meeting room.

NOTE: Today's activities will be based out of the UIC Conference Room (Rm L-217, in the hall between NARL Hotel and cafeteria).

8:15
Shuttle leaves NARL for the airport.

9:00
Editor’s Meeting
Writing session: continue drafting report, formatting, etc.
All Are Welcome!

5:00
Shuttle leaves NARL for the airport.
Appendix C. Letter of invitation

September 21, 2001

Dear Colleague;

This correspondence is intended to introduce you to a proposed gathering of bowhead whale (*Balaena mysticetus*) hunters and researchers at the “Bowhead Whale Health and Physiology Workshop” in the fall (October 1-4, 2001) in Barrow, Alaska. At least two decades of cooperation among local bowhead hunters and scientists has resulted in the accumulation of a large amount of data related to the examination and sampling of bowhead whales. Recent efforts by many investigators, especially the tireless efforts of many graduate students, have made a “synthesis” effort and update of findings greatly needed for our work on the bowhead whale. The students themselves have requested that we all meet to discuss their findings and help with interpretation of their data. This is an exciting moment for these students and we should encourage them to work together and to work with the hunting community.

In light of the recent problems in understanding the health and nutritional status of the endangered right whale, and of increased strandings of gray whales (Mexico, western U.S.) the status of “new” knowledge needs to be reviewed and future research developed to better define critical parameters that are useful to describe mysticete (baleen whale) health and nutritional status. Access to the subsistence harvested bowhead whale in Barrow offers this opportunity. The bowhead whale itself requires a well defined health assessment in light of known occurrences of climate change, contaminants, possible disease and injury (including human related), offshore and coastal oil and gas exploration and development, possible increases in shipping traffic, fisheries interactions, international mandates (i.e., killing methods, basic biologic data and samples) and other activities.

The inclusion of the North Slope Borough (NSB), Alaska Eskimo Whaling Commission (AEWC) and local whaling Captains in this workshop is essential for many reasons. The hunters support bowhead whale research by allowing us to collect data and samples from their landed whales, thus offering us the unique opportunity to examine a large mysticete in fresh condition. Local support of scientists who live in Barrow and visiting scientists has a longstanding history of cooperation and has been financially supported by the NSB and encouraged by the AEWC. The hunters and residents are very interested in the health of this large whale as it is tightly linked to their physical (nutritional) and spiritual (culture) well-being. Despite the added cost for travel for participants outside of Barrow, we consider the inclusion of local residents critical and their assistance in interpretation of data and future research efforts needed. The visiting participants would also benefit, as they will see first hand the context in which the subsistence hunt and research are conducted. Because the workshop is scheduled during what is typically fall whaling season, observing the butchering of a locally harvested whale may possibly be inserted into the agenda.
The overall goal of the workshop is to determine the measurable physical, chemical, biochemical and physiological parameters that would be used to assess the health of bowhead whales, and to establish priorities for further investigations for research of mysticete nutritional and health status in general as a model for other large baleen whales (i.e., right whales, gray whales).

The specific objectives are:

- To describe the preliminary findings related to the chemical, physical, and structural properties of bowhead whale blubber [to understand the importance, dynamics, biochemistry and metabolism of blubber and its constituents].
- To describe the preliminary findings related to morphometrics, biochemistry, mineral and heavy metal status, and histology of the bowhead whale related to assessing health and condition.
- Discuss the influence of selected biological variables (i.e., age, season, gender) in the health assessment process and the proper collection of these data.
- Develop sampling and analysis needs for a long-term bowhead whale “health and nutritional assessment” of local, national, and international importance and application.
- Review and combine preliminary findings on the assessment of health of bowhead whales and develop sampling protocols for future “health and physiology” projects.
- Develop list of data gaps and define projects that need to be addressed.
- Describe ongoing and proposed uses of the bowhead whale as a model for determining the health and condition of other large mysticetes (i.e., right whale reproduction, gray whale condition and contamination).

In light of the above, certain aspects of the workshop are meant to be “graduate student-centric.” We will highlight and try to tie together (synthesize) the intensive effort of four graduate student’s research projects on the bowhead whale to develop the "health and condition assessment" protocol. We are proposing that the following graduate students present their work:

Craig George (morphometrics and energetics)
Paul Hoekstra (chemical feeding ecology and organic contaminants)
Tami Mau (blubber constituents and natural biovariability)
Dr. Cheryl Rosa (microscopic or histologically based health assessments and metals/minerals)

Furthermore, in order to best describe current and potential use of the bowhead whale as a model for other mysticetes for assessing condition and health status, we propose inviting representatives of both right whale and gray whale research. Possible participants include:

Greg Donovan (IWC)
Dr. Rosalind Rolland (determining reproductive status in free swimming right whales)
Dr. Lorenzo Rojas(examination/sampling of stranded gray whales in Mexico)
Gennady Zelensky (examination/sampling of harvested gray whales in Chukotka, Russia)
The Steering Committee Co-Chairs are Dr. Todd O’Hara (NSB) and Dr. Teri Rowles (National Marine Fisheries Service or NMFS). The proposed Steering Committee will likely include:

Mrs. Maggie Ahmaogak (Alaska Eskimo Whaling Commission)
Dr. Greg Donovan (proposed Chair of Meeting)
Dr. Phil Clapham (National Marine Fisheries Service)
Mr. Craig George (North Slope Borough Department of Wildlife Management)
Dr. Doug DeMaster or Dr. Sue Moore (National Marine Fisheries Service)
Dr. Carla Willetto (Barrow Arctic Science Consortium).

Proposed sponsors to be contacted include: MMHSRP/OPR/NMFS (Dr. Rowles), North Slope Borough, New England Aquarium, BP Alaska, Inc., Barrow Arctic Science Consortium, National Science Foundation, Phillips Inc. Any suggestions on additional funding sources are welcome!

Please respond directly to Todd O’Hara (contact information below) at your earliest convenience. We look forward to hearing from you and hope that you can participate in this workshop.

Sincerely,

Todd O’Hara, D.V.M., Ph.D., Dipl ABVT  
Co-Chair

tohara@co.north-slope.ak.us

toddohara@hotmail.com

(ph) 907-852-0350
(fax) 907-852-0351

Teri Rowles, D.V.M., Ph.D.  
Co-Chair

Teri.Rowles@noaa.gov
(ph) 301-713-2322 ext 178
(fax) 301-713-0376
Appendix D. Working group reports as submitted

Appendix D1. Group 1 - Blubber, Nutrition, and Energy

Tami Mau, Petter Kvadsheim, and Todd O’Hara.

A general comment: Is the gray whale a canary for the bowhead and does the recent “stranding events” for gray whales justify a vigilant monitoring of bowhead whale condition and health over the next few years?

What we want to do:
1. Blubber - Use blubber quantity and quality to monitor bowhead whale condition and health.
2. Nutrition - Use of non-blubber tissues to describe the nutritional status of the bowhead whale, e.g. mineral and muscle status, and digestive functions (stomach and intestine).
3. Energy - Determine energetic or thermoregulatory status as it relates to health of the whale.

Blubber -
Blubber thickness is a critical measure

In the field:
- Continue “axillary” girth and blubber thickness measures, but include umbilical and/or anal girth and blubber thickness at the dorsal and ventral sites. Four to six sites per whale would be more ideal than 2.
- Hypodermal characterization on the whale, photographs, full thickness sampling to muscle (while on whale), macroscopic (gross thickness measurements) and histologic assessment, and proximate analysis.
- Cetacean blubber or skin – define it? Does the hypodermis function as blubber (energy, insulation), yes. But it is distinct histologically and embryologically? How often is epidermis included in blubber thickness measures (physical and ultrasonic techniques)? The CIFAR team measure thickness both with and without epidermis.
- Is thickness measure to be on whale or on flat surface or both? We suggest both to determine if a difference exists.

In the laboratory:
Lipids- proximate composition, on a reduced number of samples. Go from 5 depths to 3 (because 2+3 are usually the same), use depths 1, 3 and 5. Go from 6 sites to 4 sites, eliminate lateral sites as they are similar to dorsal.

Contaminants- have to stay with BD, or axillary girth.

Collagen- histologically we need to examine the development in Ingutuk into a juvenile (fiber size, density, type, etc.).

Blubber consistency, “organoleptic” assessment.
Fatty acid profiles are likely useful in feeding ecology (source determination), and recognizing some (but unknown) are nutritionally essential and they are obviously important for health but we are unsure what to exactly measure for a mysticete. [J. Reynolds will be measuring fatty acids in liver and blubber, these data may help.]

Kilocalories- a possible surrogate for lipid analyses. Very correlated, and quality control test for lipid assay.

**Nutrition-**

Mineral status- normal ranges need to be identified, and histology can address this (other groups).

Energy balances need to be addressed;

The muscle is a nutritional source and contains lipids and proteins needed during negative energy states and muscle histology, composition (lipid, protein, myoglobin, etc.), and biochemistry have potential as sensitive indicators that may relate to changes in girth differences and condition assessment. This would be a new initiative that can begin on archived samples. If they are using the muscle as a source, why??

Feeding ecology- biological variables group.

Histology- atrophy and digestive functions of gut, pancreas, liver, etc. (histo group).

Antioxidant/Vitamin status (including fatty acids)- very little data to consider here for bowhead whale, however obviously important for a mammal in general. Nursing calf development may rely on maternal blubber vitamin status and transfer. Blubber, liver, muscle, blood (serum), and kidney samples are possible for analyses, but the importance of monitoring is uncertain, but a comparison of adults versus young animals may provide insight. This could easily be a human food quality study!

**Energy-**

Measure epidermal thickness, temperature, and thermal conductivity to assess potential heat loss at the surface.

Lung volume in various age/length cohorts to address oxidative metabolism.

Continue measuring body temperature (core, hepatic) and relate this to chase times and post mortem examination times. Could relate to deterioration or changes of some of the parameters addressed.
Appendix D2. Group 2 - General Histology and Assessment of Disease

Very important to compile centralized data for individual whales!
Be as consistent as possible, site-wise, for sampling protocols.
Collect information on body type (per traditional knowledge)

1) Development of long term sampling protocols to assess:
   Nutritional status
   Contaminants
   Reproductive status
   Age
   Immune Status
   Any grossly abnormal tissue
   Document/collect gross descriptions, scars, wounds, injuries.

Important to establish consistency in sampling sites. We propose…
Transverse cross-section at midsection of
   Adrenal
   Thyroid
   Lymph node
   Pancreas
   Spleen
Lung – dorsal cranial, superficial and “deep” (15-20cm)
Liver – dorsal cranial, superficial and “deep” (15-20cm)
Heart – interventricular septum (ideal), left ventricular free wall (2nd best)
Kidney – renicles from cranial pole
Muscle – which ones? Pick one or two and stick with it.

2) What are minimum parameters needed to define individual nutritional status?
   Morphometrics, blubber/hypodermal quantity/quality, liver glycogen store, intestinal
   atrophy, pancreatic zymogen/condition, blood chemistry, (vitamin status)(parasite
   load)(cortisol/hormonal levels)

3) Disease assessment:
   Gross description of lesion(s), cytology, photos, measurements, description/hunter
   mention of abnormalities in behavior, movement, etc. surrounding capture, blood
   smears for cbc's, culture as needed, collect lesion (and label!!!), frozen tissue for
   bacteriology/virology.

4) Bodily fluids:
   Blood/Serology: blood smear (if possible), whole blood* (spin! And freeze), serum,
   purple tops* (process soon…)
   Urine*: specific gravity, urine strip within a few hours
   stomach contents: freeze, formalinize individual prey of interest
   milk: frozen
   semen*: evaluate asap and freeze
feces: frozen, other?
* = TIME SENSITIVE

At a minimum, CBCs, hematocrit, serum chemistries should be done on every whale, along with the histology above. Secondarily, serology/virology.

5) ectoparasites/endoparasites: formalinize samples asap, freeze for contaminant analyses.

6) ear plugs: find?

7) Antioxidants:

8) Tissues frozen for contaminant analyses (depending upon contaminant of interest): liver, kidney, blubber, muscle, epidermis, lung, milk, urine, feces, blood, brain, bone, baleen, lymph nodes, stomach contents
Appendix D3. Group 3 – Physiology

1) Serum chemistry
Value: Metabolic status for lipid, protein and carbohydrate metabolism (Nutritional status). Metal chemistry and circulating hormones (reproductive cortisol, etc).
Problem. All blood samples are long post-mortem and almost every metabolite changes with time.
Possible solution: Accompanying boats with scientists to take blood samples on site at sea. Secondary solutions: Train crew to take samples, last solution take samples on beach.
Good idea: Take samples at sea and compare with beach samples.
Ties in with: nutrition, health and disease.

2) Metal chemistry
Value: Mostly natural, but also metals are from anthropogenic sources. Alaska samples would tell you what the natural levels are and adaptations evolved to handle metals. Also, metal cycling through trophic levels. High levels or low levels would tie in with histology and toxicology and metabolism. Food safety for human consumption and human nutrition.
Used as biomarkers: example vanadium is associated with crude oil.
Problems: Since this comes from tissues of dead animals, how do you apply to living animals? However, in bowheads, sample collection opportunities are excellent. Also, metals are organ and site specific within organ. Must collect with very careful methods to prevent contamination. (ie) need large organ samples to allow for clean subsequent sub-sampling. Critical to understand species of metals (ie, organic vs inorganic, bound vs free).
Solutions: Becker sampling protocol for big samples, clean, etc. Need very specific sampling protocols and whole organ surveys. Important to examine metallothioneins to assess metal detoxification mechanisms. Expand sampling beyond liver, kidney, muscle, skin to brain and lymph nodes, pancreas, lung, etc.
Preliminary suggestions: interact with toxicology teams to select metals of interest. Or with ecologists for markers and with Natives for health issues.
Ties in with: health and disease, immunosuppression, feeding and industrial impacts.

3) Parasites:
Value: General health and spread of infectious diseases. Human health from food safety perspective. Use parasites to identify food items. Most likely, parasites not an issue since Native community does not report bad parasite problem in whale samples.
Problems: From live animals, hard to get samples. If looking for intestinal parasites, must wait for samples to be taken late in butchering for bowheads. Post-mortem movement of parasites through different organs.
Solutions: As rapid sampling as reasonably possible in light of butchering process.
Ties in with: health and disease and ecology, metal chemistry if parasites impede detoxification.
4) Viral and bacterial sampling.
Do not know what is known and unsure of methods, samples, etc. Could be important for spread of infectious disease.

5) Water balance:
Issue: Water demands tie in with blubber quality and quantity since blubber metabolism produces water. Do whales drink seawater? Unknown. However, invertebrate diet is same salt concentration as sea water.
Problem: Nothing substantial. Requires tie in with blubber study. But, if looking at water balance, may require study and collection of urine or collection of kidney.
Solutions: Collection of urine on site for measurement of water and osmolytes. Collection of kidney slices for structure and function.
Ties in with: Histology on kidney side and blubber on water balance side.
Question: Has anyone examined bowhead urine?

6) Reproductive endocrinology:
Value: Critical to understanding of determination of reproductive status, and basic life history questions relative to age of first reproduction, last reproduction. Essential to understanding cycling in production of calves, ties in with food availability, etc. Corpus albicans (CA) interpretation into population discussion. Do we need to study males? (ie) Cadmium with testes histology or seasonal sexual status of males. Many metals can mimic reproductive hormones. Organochlorines can impact reproductive biology through direct effects and through hormone mimicking. Possible calf survival due to dumping of Ocs during lactation to first born.
Problems: Development of species specific hormone assays. Interpretation to live animals with tissue or serum levels. However, great potential at fecal level if can establish correlations with levels in feces and circulation.. The use of feces for stress hormone assays could be very important.
Solutions: Fecal sampling is easy and should be pursued. Could collagen assays be done in CA to establish age or some proxy of age? Autolysis of testes is rapid...need to sample ASAP.
Ties in with: life history, population biology and aging studies and metal chemistry

7) Hydrocarbons:
Value: Baseline levels critical in tissues for industrial impact. However, also dealing with hydrocarbon mechanisms of action for tissue or metabolic disruption. If juveniles are collecting food from sediments, hydrocarbons could be ingested. Could look into both blood and tissues. Could these hydrocarbons be fingerprinted to localize source of contamination or feeding areas?
Problems: Very clean sampling; expense of hydrocarbon assays. Again, extrapolations to living animals. Tissue and site specific hydrocarbon deposition.
Solutions: Clean sampling, look into industrial support for assay costs.
Ties in with: health and disease, industrial impacts.
8) Metabolism:
Value: Gives information on metabolic demand which ties in with food demand, heat production (insulation, blubber etc). Cost of transport, growth and ageing.
Solutions: Extrapolation from body mass predictions and hydrodynamic morphology for cost of transport.
Ties in with: Blubber, repro history, feeding ecology and behavior (swimming behavior), ie, does moving off shore cost or is it insignificant? How does this tie in with prey distribution?

9) Cell culture
Value: Can apply modern molecular and biochemical methods to studies of cell metabolism, nutrient and contaminant chemistry, genetics, etc. Possible collection of living cells for basic metabolism.
Problems: Careful harvesting of viable cells. Problems with post-mortem autolysis. Probable need for high tech laboratory methods or supplies in Barrow.
Ties in with: Metal chemistry, reproductive biology, hydrocarbons, contaminants, metabolism.
Notes: Already established by NASA.
Appendix D4. Group 4 - Biological variables

Craig George, Sue Moore, John Burns, Warren Matumeak, Judy Zeh, Steve Braund

Terms of Reference:
- Workshop report – summarize workshop findings and provide guidance for future bowhead whale assessment work
- Identifying the main issues in the topic
- Identify main parameters needed to Define Individual Nutritional Status
- Long-term sampling protocols that have to be in place to standardize anything that needs to do
- The what, where, why and how for priorities that are taken for undertaking
- Categories group considered:
  - Data collected
  - Minimum ongoing effort:
  - Communities
  - Sampling Protocol (standardize it)
  - Method of Sample Collection
  - Storage
  - Analysis considerations

General List of Topics:
- Food Habits
  - Data collected: stomach contents, including solids
  - Minimum ongoing effort: collection, initial analysis, archive
  - Communities
    - Currently Barrow and Kaktovik (Kaktovik will continue if NSB has the money)
    - Importance of eastern Beaufort as feeding area – Kaktovik is important
  - Personnel/Data collectors (applies to several Topics)
    - Work with local whaling captains’ association to select appropriate local individual(s); possible older person
    - Compensation – potentially “subcontract” with local whaling captains’ association to administer local data collection
    - Seek balance on payment/honorarium amount (e.g., relatively smaller amount from Barrow perspective but large from Gambell perspective
    - Sampling Protocol (standardize it)
      - Collect at least one liter from stomach
      - Standardize how the one liter is collected
      - Estimate whale size: e.g., small whale, medium whale, large whale and/or Inupiat classification (Warren Matumeak)
      - Review sample sheet to confirm all data categories are appropriate
      - Make sure fill in all parts of the form; do not leave blank spaces
• Method of Sample Collection
  • Scope the bottom of the stomach; 1 liter sample with hard parts (mollusks, pebbles)
  • Include description of anything unusual: plastic or wood
• Storage:
  • 1/2 in formaldehyde/fixative: species identification
  • 1/2 gets frozen to do chemistry (contaminants)
• Analysis considerations
  • How to assess the volume of the stomach (relative to age and length)?
  • Minimum: empty, trace, ¼, ½, ¾, full
  • Desirable: actual volume
  • Production of volatile fatty acids; fermentation; stomach microbes (remains a question, but NOT to be investigated by us)
  • Winter/late spring feeding (e.g., April @ St Lawrence Island); seasonality; feeding in Bering Sea or not feeding in Bering Sea) High priority for genetic samples. May see a different story.

• Morphometrics – evaluate existing protocol
  • Data collected
    • Blubber
  • Minimum ongoing effort:
  • Communities
  • Sampling Protocol (standardize it)
  • See existing protocol; review by workshop members
  • Need to calibrate morphometric measurements (get tape all the way around a couple of whales to verify “half girths”)
  • “Stretched whales” - measured 3 whales in and out of water; they stretch 8-10% out of water
  • Need strict protocol for measuring blubber thickness
  • Robert & Craig will document exactly how take measurements
  • Discussion of where blubber ends (measure from top of skin to muscle; hypodermis area)
    • Add sampling location (measure blubber thickness @ umbilicus)
  • Add a new measurement: two measurements
    1. one measurement to the base of the dermis
    2. second measurement – to the meat
  • Judy Zey - summary
    • standardize – present locations to measure after maktak is off of the animal
    • new location (umbilicus) measure whole thing on the animal
  • Take two measurements at the new location (Judy recommended a 3rd – replicate what doing at old locations)
  • New location: 3 measurements
    1. measure to base of dermis
    2. measure to the meat
    3. do off the animals measurement like old locations
Method of Sample Collection
  - Conclusion (?)
    - Do off the animal measurement the way always been done for top two layers
    - Use new method to measure the hypodermis
    - Then make decision – move to new way entirely if figure out way to calibrate the new way to the old way
  - Storage
  - Analysis considerations
    - To analyze fatty acids, need a sample of hypodermis blubber layer
    - Sample = Plug – that includes an end of the muscle so they know which end is up

Field data/basic data/specimen condition:
  - Date
  - Village
  - Captain
  - Location
  - Sex
    - Measure genital slit length
    - May need clarification for St Lawrence Island if data collection there
  - Season
  - Time of strike
  - Length
  - Whale size (ingutuk (standardization of Inupiat classification
  - Gross Assessment (lines wounds; killer whale bites; ship strikes; presence of lesions and scars)

Age/reproductive biology
  - Aging
    - Baleen aging
      - Baleen aging on all whales intensively sampled
    - Eye globs
    - Need to do baleen and eye globs on the same whale
  - Baleen
    - archiving has to improve: storage area; carefully label baleen
    - If start taking baleen from every animal whaler compensation is an issue
    - Protocol: get from same place in the rack; get the longest plate; take all the way to the gum; compensation
    - Baleen sampling depends on length and age of animal (e.g., ingutuk different than older animal)
    - Need a very well defined protocol
    - 3 meter plate, growth is way less; sampling interval should be decreased
• Careful thought needs to be given to baleen sampling (no design sampling here/now)
• Also need to consider costs of lab analysis ➔ develop sampling protocol to get you representative sample of the population instead of sampling every whale
• Currently do not have a random sample of bowhead population when take every harvested whale
• It may be possible to design a scheme that may get random sample of the population that would save money
• For some purposes (e.g., age) like to have random sample of population; do not currently have this; hence design sub-sample that would get at that
• Analytical sampling: How finely need to sample baleen (first get baleen plate; cut into intervals for isotope analysis – how finely cut it up?)
  • Eye
    • Freeze eye as quickly as possible
    • Lab prep of eye (Cheryl)
    • Ear bones? Difficult to sample

• Reproductive Biology
  • Measure genital slit
  • Cannot determine maturity unless pregnant
  • Collect ovaries
  • Discussion of whether should collect ovaries/testes from immature animals (storage problem)
    • Ovaries and testes – important - looking at growth spurt at maturity; seasonality of reproduction; onset of sexual maturity; easy to assess
    • Collect them, weigh and measure them and discard them
    • Looking at onset of spermatogenesis; easy to measure; know length of spermatogenesis already? Confirm with Todd
    • Not an issue with whalers; non utilized locally
  • Any female over 12 meters ➔ weigh and measure the ovaries
  • Keep ovaries on mature females
  • Any male over 12 meters sample also (most males are maturing at larger size than 12 meters
  • 12 meters gives you one meter of safety net
  • Goal: analyze reproductive data that exists; this has not been done
  • If not analyzed, reduce data collection
  • Always take: muscle, kidney, liver, blubber
  • Liver is huge; up to several hundred lbs
    • Need to standardize where take liver

• Blood
  • Protocol
  • Bleed the rete (on palate)
  • At least six red and six green
• Cool the blood
• Green tops (hepron)
• Red tops (serum tubes)
• Take blood back early
• Spin it
• Separate serum off of top
• Freeze it
• Archived @
• Continue what doing

• Genetics
  • Protocol
  • Storage
    • Get sample of tissue from every whale that is landed
    • Can decide at any point which ones you want to analyze
  • Put in DMSO
  • Continue archiving tissues in UAF frozen archive
  • Need samples from all the whales landed at all villages
  • Extra effort to get SLI genetic samples; did it one year; sent down tubes; had return address box; tubes had DMSO in it; put in meat and mail back; got four samples
  • Get Native people trained and paid to do some of this gathering
    • Skin sample, sample stomach and measure properly
  • Will be high turn over in communities
  • Analysis considerations
    • What does genetic data say related to local view of different categories of bowheads
      • Locals have opinion of multiple species of bowheads

• Review current harvest form by all disciplines
  • Include present harvest form with this report and send out with workshop report to participants

• Contaminants

• Data gaps
  • Ages: Baleen age estimates (carefully collect and archive and analyze baleen)

• Environmental Parameters
  • Do environmental sampling at the same time taking a whale
  • Need to be able to pull out environmental sampling at the same scale
  • An effort should be made to sample basic environmental variables associated with bowhead hunt. At a minimum, records should be made of:
    1. Wind direction and strength
    2. Basic hydrography (CTD Casts)
3. Prey field sampling (acoustics and tow)
   - Items 2 and 3 should be conducted along a simple grid that encompasses the hunting area. This will require a dedicated skiff and technical staff.
   - Precise nature and scale of the hydrographic measurements should complement hydrographic and prey sampling planned for the NSF/SBI program (2002-2007).
   - PI contacts
     - Tom Weingartner (UAF) = hydrography
     - Prey field: Carin Ashjian (WIIOI) & Sharon Smith (Miami Rickenbaker)
   - Example of grid: