STUDY PLANS
FOR THE
ENVIRONMENTAL STUDIES PROGRAM
IN THE CHUKCHI & BEAUFORT SEAS
2010

v. Juterzenka,
Piepenburg,
Schmid

Olgoonik-Fairweather LLC
360 W. Benson Blvd., Suite 302
Anchorage Alaska 99503
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STUDY DESCRIPTION

1.0 INTRODUCTION

In February 2008, the Minerals Management Service (MMS), now known as the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE), held Lease Sale 193 of blocks in federal waters of the Chukchi Sea. ConocoPhillips (COP) obtained 98 lease blocks within two main former well sites areas, Klondike and Burger. Shell Exploration and Production Company (Shell) obtained 275 lease blocks near the Crackerjack, Shoebill, and Burger well sites. Statoil USA (Statoil) obtained 16 bids north of Burger. In the open water seasons of 2008 and 2009, COP operated, on behalf of itself and Shell, an integrated ecosystem-based environmental studies program to gather baseline, or pre-exploitation, exploration, and development data in the Chukchi Sea.

This year (2010), Olgoonik-Fairweather LLC (OLF) has been operating the Chukchi Sea environmental studies program funded by COP, Shell, and Statoil. The studies program includes various disciplines of the marine ecosystem including: physical oceanography, chemical oceanography (new this year), plankton ecology, benthic ecology (infaunal and epibenthic communities), seabird ecology, marine mammal ecology, pelagic and demersal fisheries, and the hydroacoustic environment.

In addition to the Chukchi Sea, OLF is providing logistical support for deployment of physical oceanography and hydroacoustic instruments in support of Shell operations in the Beaufort Sea. A brief discussion of the Beaufort Sea program is provided in Section X, but is not included in any earlier sections.

2.0 GENERAL OBJECTIVES

The overall purpose of the study is to provide to COP, Shell, and Statoil necessary baseline information about the marine environment in their respective lease areas that can be used in applications for permits, in a National Environmental Policy Act (NEPA) compliance document, and in other documents and to help manage these resources. The study will provide valuable information for the regulatory agencies to conduct realistic evaluations on the potential impacts of oil and gas activities and thus issue permits with reasonable stipulations and guidance. It will also contribute to the overall knowledge of the Chukchi Sea marine ecoystem. It is anticipated that future studies in the lease areas will involve additional collaborators including, but not limited to, the BOEMRE, the North Pacific Research Board (NPRB), the National Marine Fisheries Service (NMFS), United States Fish and Wildlife Service (USFWS), United States Geological Survey (USGS), Alaska Eskimo Whaling Commission (AEWC), Alaska Beluga Whale Committee (ABWC), Ice Seal Commission, and Alaska Eskimo Walrus Commission.

3.0 PROJECT AREA

The studies program is comprised of three study areas in the northeastern Chukchi Sea (Figure I-1). Each study area is 900 square nautical miles (nm^2) and is roughly centered around an area of greatest interest for the primary lease holder. The Klondike (Figure I-2) and Burger (Figure I-3) study areas consists of a 30 nm by 30 nm square; the Statoil study area (Figure I-4) is an irregularly shaped box with a maximum length of 30 nm north-south and 37.5 nm east-west. Each study area includes primary and secondary transect lines for seabird and marine mammal sampling every 1 nm, fixed and random stations for oceanographic samples, and clusters of hydroacoustic arrays for localizing marine mammal calls and measuring ambient noise levels. In addition to the study areas, several transitional oceanographic sample stations have been included in the event any of the study areas cannot be sampled (Figure I-1). The studies program also includes a regional acoustic array with recorders spaced from Cape Lisburne to Barrow, ranging from 5 to 50 nm offshore (Figure I-6).

4.0 PERIOD OF STUDY

The current 2010 schedule consists of two approximately 30 day cruises occurring between August and September in all three study areas and one ~15 day cruise in early October in only Burger. Physical oceanography, zooplankton, seabird ecology, and marine mammal ecology will be sampled in all three cruises; infaunal benthic ecology will be sampled only in the first cruise (August); and epifaunal benthic and fisheries ecology will be sampled only in the second cruise (September). All of the moorings (hydroacoustic, physical oceanography) will be deployed and retrieved at the beginning (late July) and end (mid-October) of the scientific cruises.

5.0 DESCRIPTION OF VESSELS

The data will be collected using two vessels: the *R/V Westward Wind* and *R/V Norseman II.* The *Westward Wind* is a 142-ft long aft-house vessel. This vessel was also used in 2009 for this program. The *Norseman II* is a 128-ft long foreward-house vessel. Both vessels have been outfitted with the appropriate cranes, winches, and navigation to allow safe efficient and safe deployment of all gear and equipment.

6.0 OUTLINE

This Studies Plan is separated into specific disciplines that will describe a brief history of the study region, methods and procedures for both data collection and analysis, and a description of the deliverables.

The Studies Plan is outlined as follows:

- Section II: Physical Oceanography
- Section III: Planktonic Communities and Chemical Oceanography
- Section IV: Benthic Communities
- Section V: Ocean Acidification
- Section VI: Fisheries Ecology
- Section VII: Seabirds Ecology
- Section VIII: Marine Mammal Ecology
- Section IX: Chukchi Sea Acoustic Monitoring
- Section X: Beaufort Sea Acoustic Monitoring

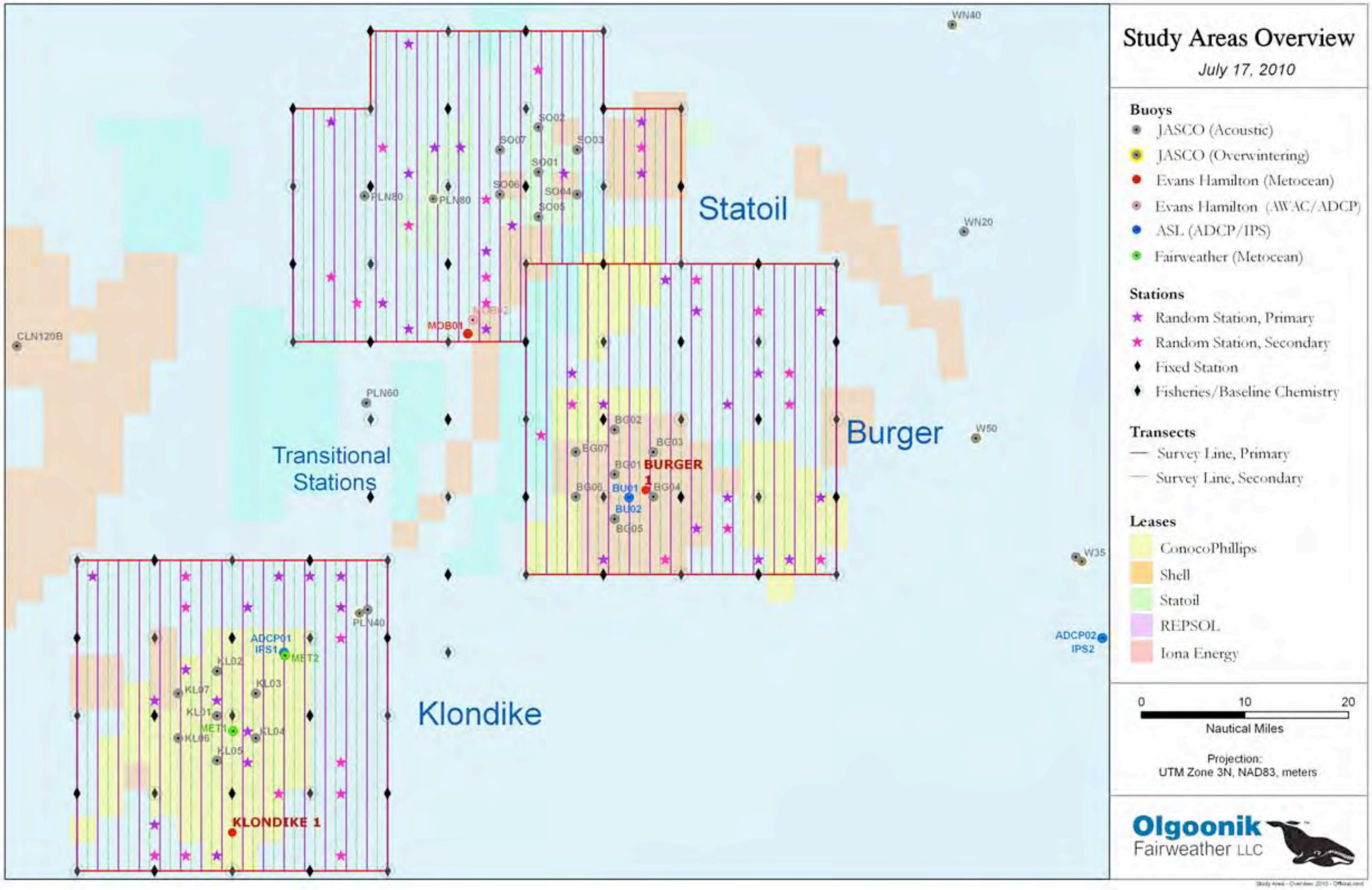

Figure I-1. Map showing the three study areas plus transitional stations with transect and sampling locations.

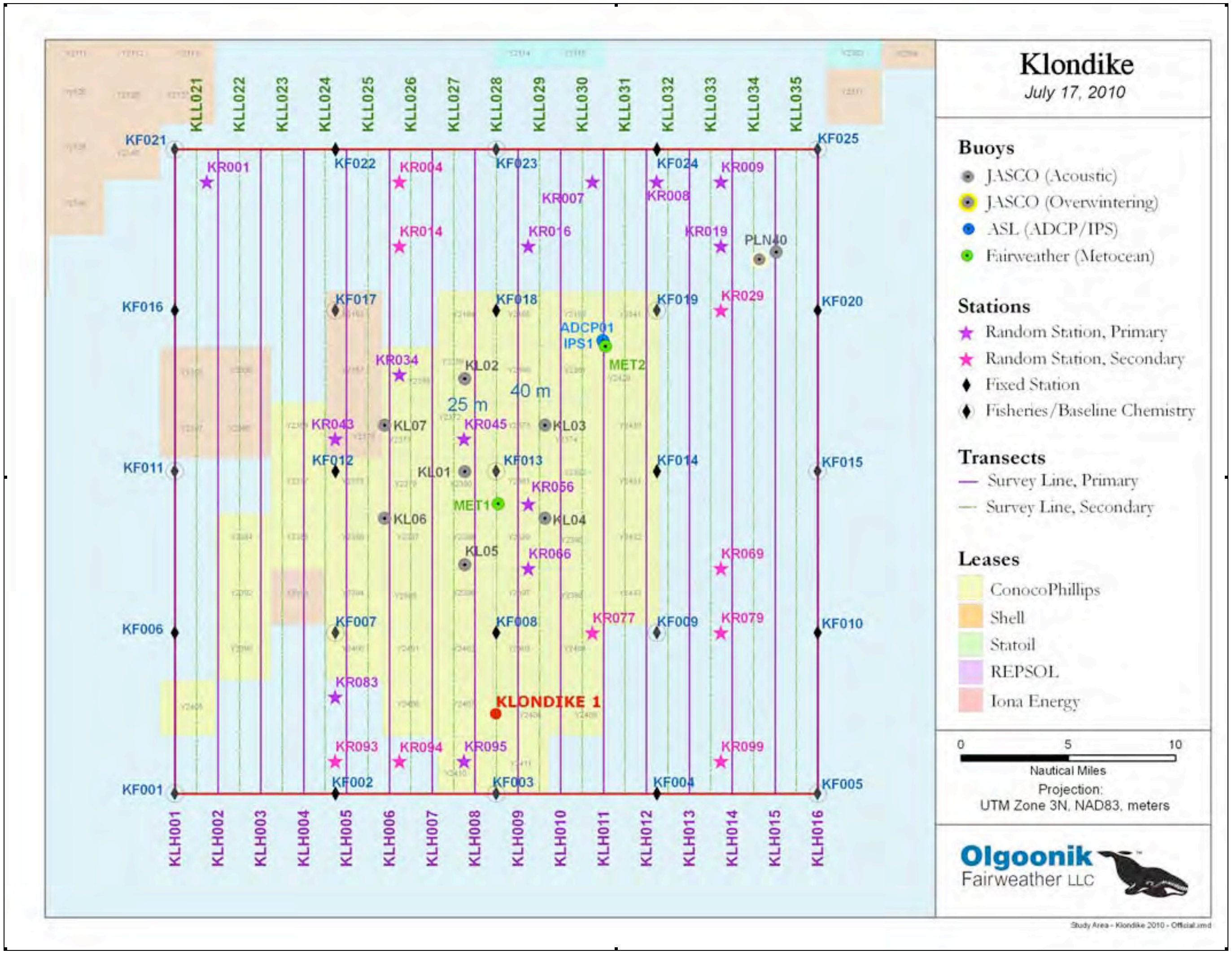

Figure I-2. Klondike study area in detail.

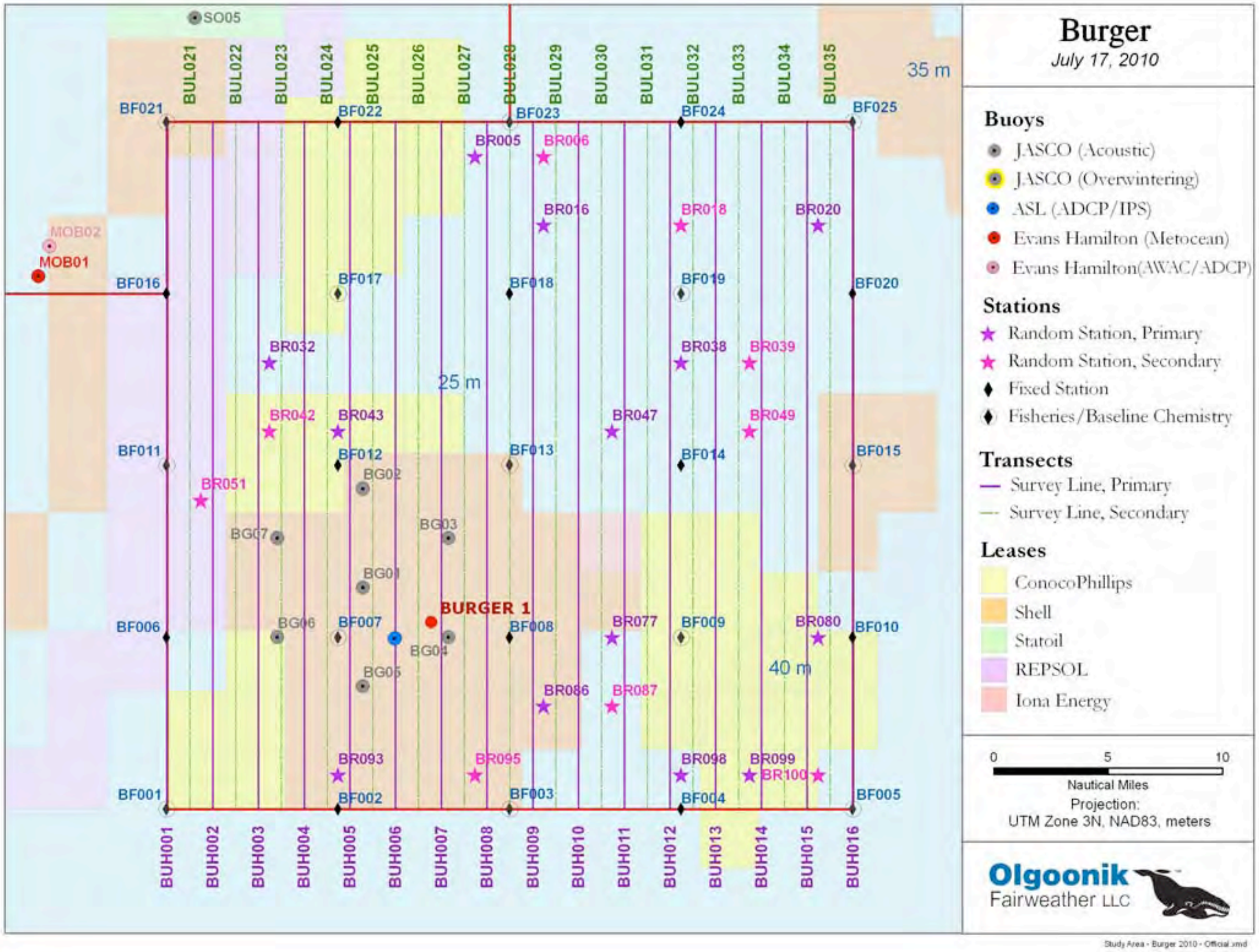

Figure I-3. Burger study area in detail.

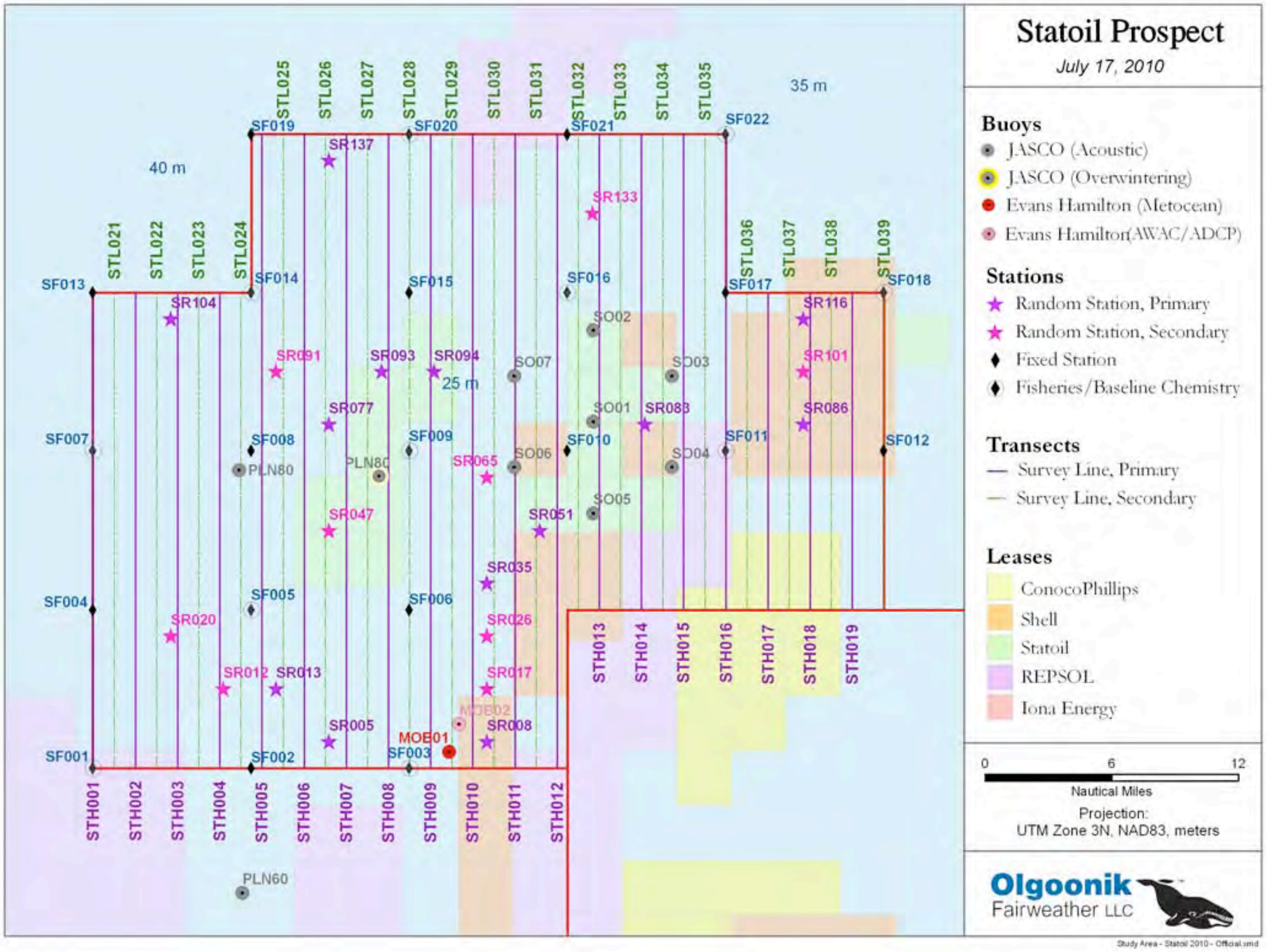

Figure I-4. Statoil study area in detail.

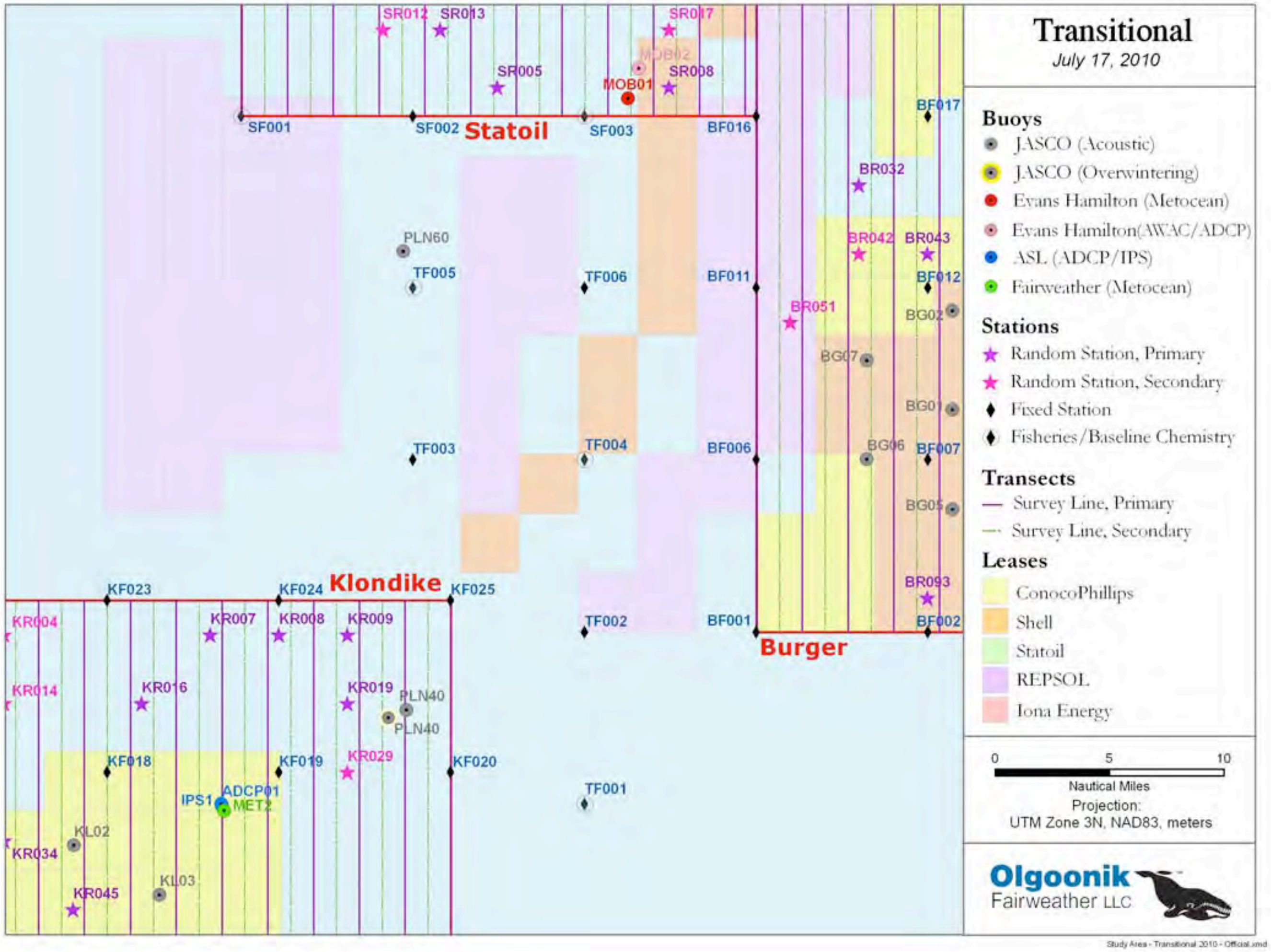

Figure I-5. Transitional sampling locations in detail.

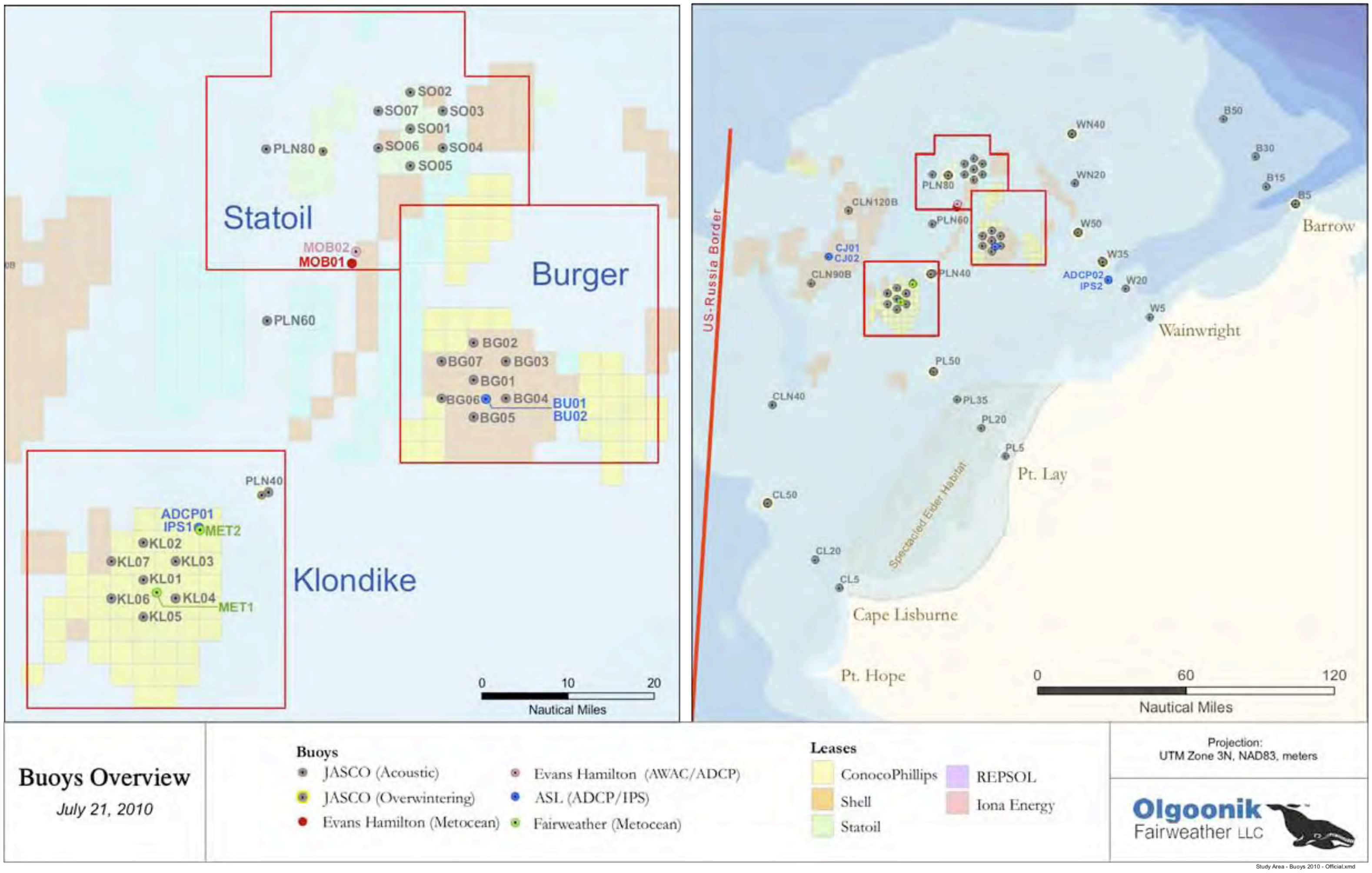

Figure I-6. Map showing all buoys in the Chukchi Sea.

SECTION II
PHYSICAL OCEANOGRAPHY

THOMAS J. WEINGARTNER
PRINCIPAL INVESTIGATOR
INSTITUTE OF MARINE SCIENCES, UNIVERSITY OF ALASKA
FAIRBANKS, AK

1.0 INTRODUCTION

The Chukchi Sea is properly a part of the western Arctic Ocean, but it is intimately linked, atmospherically and oceanographically, to the Pacific Ocean. The atmospheric connection is primarily via the Aleutian Low, whose varying position and strength and interactions with polar air masses affects the regional meteorology. The oceanographic connection is solely through Bering Strait, where the mean northward flow transports waters and organisms from the Bering Sea shelf and basin. This Pacific connection profoundly influences the wind and wave regimes, the seasonal distribution of sea ice, the regional hydrologic cycle, and the water masses and circulation characteristics of the Chukchi Sea

The shallow (~50 meters [m]) Chukchi Sea shelf extends ~800 kilometers (km) northward from Bering Strait to the shelf-break at about the 200-m isobath. The mean flow over much of the shelf is northward due to the Pacific–Arctic oceanic pressure gradient and opposes the prevailing northeasterly winds. The Bering Strait influx of heat, nutrients, carbon, and organisms bestows the Chukchi shelf with physical and ecological characteristics that are unique among arctic shelves.

Much of our understanding of the Chukchi shelf derives from the early syntheses of Coachman et al. (1975) and Walsh et al. (1989) and, more recently (since 1985), in the papers by Aagaard et al. (1985), Aagaard and Roach (1989), Weingartner et al. (1998), Weingartner et al. (1999), Münchow and Carmack (1997), Münchow et al. (1999), Münchow et al. (2000), Weingartner et al. (2005a), and Woodgate et al. (2005a). The physical oceanographic summary of the Chukchi shelf is drawn primarily from these papers.

1.1 Mean Circulation

The Bering Strait through-flow crosses the Chukchi Sea along three principal pathways associated with distinct bathymetric features (Figure II-1). A western branch flows northwestward from the strait and exits the shelf through Herald Valley. While most of this outflow probably descends through Herald Valley, some of it spreads eastward across the central shelf. A second branch flows northward across the central channel shelf and then probably splits; with some water continuing eastward toward the Alaska coast while the remainder flows northeastward toward the continental slope. The third branch flows northeastwards along the Alaska coast towards Barrow Canyon, which lies at the junction of the Chukchi and Beaufort shelves. In summer, this flow includes the northward extension of the Alaska Coastal Current (ACC) that originates south of Bering Strait. Within the canyon, the ACC is joined by waters flowing eastward from the central shelf; the merged flow then moves down-canyon toward the shelf-break. Mean current speeds within the Herald and Barrow canyons are swift (~25 centimeters per second [cm s^{-1}]), are more moderate in the central channel (~10 cm s^{-1}), but generally are ≤5 cm s^{-1} elsewhere on the shelf. Long-term transport estimates for these three pathways are only approximate but suggest that the flow across the central Chukchi shelf is ~200,000 cubic meters per second ($m^3 s^{-1}$) while the branches in both Herald Valley and Barrow Canyon carry ~300,000 $m^3 s^{-1}$. In summer and fall, the influence of the warm Bering Sea inflow along these pathways is manifested in the form of “melt-back embayments” indenting the ice edge (Paquette and Bourke 1981). Finally, there is also a small fraction of the strait through-flow that flows westward through Long Strait into the East Siberian Sea and appears to be an important nutrient source to this shelf (Codispoti and Richards 1968; Codispoti et al. 1991).

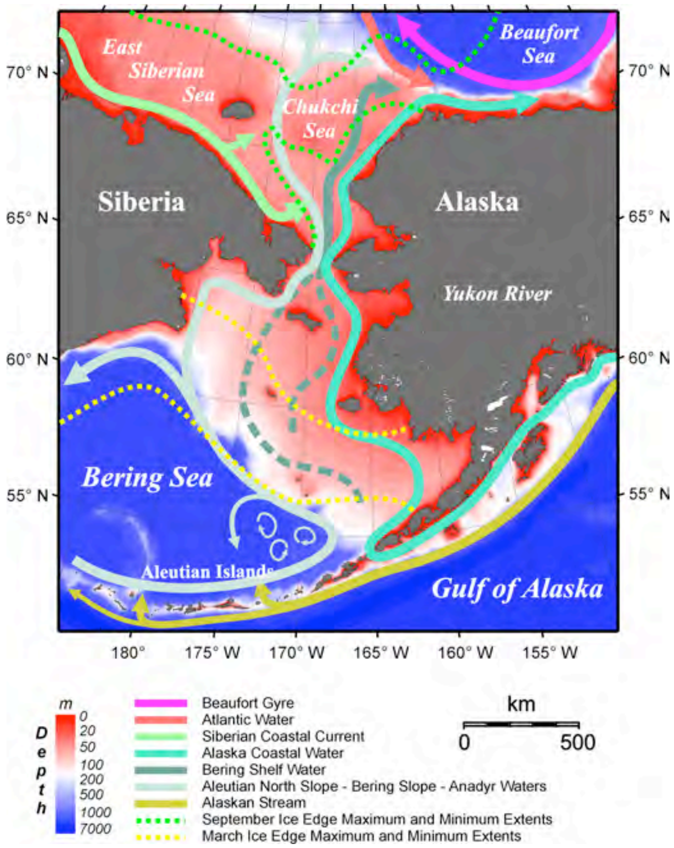

Figure II-2. Schematic circulation map of the Bering–Chukchi–Beaufort seas ecosystem.

The nutrient and carbon loads carried along these branches differ (Walsh et al. 1989, Hansell et al. 1993; Cooper et al. 1997). The Herald Valley outflow is saltier, colder, and richer in nutrients and marine-derived carbon than the waters transported in the ACC, whereas waters crossing the central shelf have intermediate properties. In winter, shelf waters decrease to the freezing point and salinities increase due to salt rejection from growing sea ice. These seasonal changes in shelf salinities have important implications on the fate of the nutrients and carbon in the Chukchi shelf waters that enter the basin. Low-density summer waters are confined to the upper 75 m of the shelf-break and slope, whereas denser winter waters descend to 100–150 m depth.

There are two other aspects of the Chukchi shelf circulation of importance. The first is the buoyancy-influenced Siberian Coastal Current (SCC) that originates in the East Siberian Sea and flows southeastward along the Siberian coast into the Chukchi Sea. The SCC carries cold, low-salinity, nutrient-poor ice-melt, and river waters that enter the East Siberian and Laptev seas. The SCC is confined to within ~60 km of the Chukotka coast and is bounded on its offshore side by an unstable front, which appears to be an important bowhead whale foraging zone (Moore et al. 1995). Nearing Bering Strait, the SCC narrows and turns offshore to mix with waters exiting the strait. Most of the resulting mix is most likely transported through Herald Valley and across the central shelf. It also appears likely that surface waters over the outer shelf and slope are flowing westward on average (Muench et al. 1991), bringing sea ice and cold, low-salinity waters of the polar mixed layer over the outer shelf and slope.

The mean circulation results from the large scale pressure field between the Pacific and Arctic oceans and opposes the mean winds, which are from the northeast. The winds are, however, the principal cause of flow variability. Wind forcing varies seasonally with both wind magnitude and variability being largest in fall-winter and smallest in summer. In particular, in fall and winter, the winds can frequently reverse the shelf flow field or re-distribute the flow from one branch to another (Weingartner et al. 1998). As a consequence of this seasonality, transit times along the three flow pathways across the Chukchi shelf are 3–6 months in spring and summer but are longer in fall and winter.

In general, wind-forced current fluctuations are coherent over much of the shelf, although, for reasons not known, the correlation is substantially weaker over the western shelf than for the eastern shelf (Woodgate et al. 2005b). Westward winds induce upwelling at the continental slope, which could be an important nutrient source at the shelf-break. While no measurements have been made of this phenomenon along the Chukchi slope, data from Barrow Canyon indicate that wind-forced upwelling carries waters from ~250 m depth or more toward the head of the canyon, which lies ~150 km from the canyon mouth (Aagaard and Roach 1990; Weingartner et al. 1998). Winds also appear to be important in the dynamics of the SCC. For example, in some years, the winds along the Chukotka coast are persistently upwelling and prevent the SCC from entering the Chukchi Sea (Münchow et al. 1999; Weingartner et al. 1999). The consequences of this variability are unknown, but if the SCC front is an important foraging zone for bowhead whales, its absence in some years could affect whale foraging behavior.

The other major sources of current variability are associated with mesoscale (10–50 km) instabilities associated with large cross-frontal density gradients. Mesoscale flows can be vigorous (>20 cm/s) and uncorrelated with winds. The instabilities initially appear as meanders along the front but can rapidly grow in strength and/or detach into eddies that move across the axis of the front. Eddies and meanders are very prominent within the SCC front and promote cross-shore mixing between SCC and Bering Strait waters flowing northward through the Hope Sea Valley. Eddies and cross-shore mixing result from frontal instabilities along the edge of polynyas due to the large salinity differences between high salinity polynya waters and less saline offshore waters (Gawarkiewicz and Chapman 1995). Finally, fronts associated with melting along the ice-edge often include vigorous three-dimensional mesoscale motions (Liu et al. 1994; Muench et al. 1991) that often lead to enhanced biological production at the ice edge. Moreover, the mixing and circulation fields associated with the mesoscale motions associated with the SCC and ice edge may also be important in establishing biologically-rich mesoscale patches.

1.2 Measurement History

Prior to the 1970s, several hydrographic expeditions were collected throughout the Chukchi Sea and summarized by Coachman et al. (1975). In the 1970s and 1980s, several year-round moored measurement programs were conducted in the U.S. Economic Exclusion Zone (EEZ) and supported by the Outer Continental Shelf Environmental Assessment Program (OCSEAP), as summarized by Aagaard (1988). Beginning in 1990, National Science Foundation (NSF), Office of Naval Research

(ONR), and BOEMRE supported a number of physical-oceanographic programs, the results of which were summarized above. Most recently, these included the NSF-ONR sponsored Shelf–Basin Interaction (SBI), which recently completed a three-year field program (2001–2004). The SBI program focused primarily upon biogeochemical processes over the outer shelf and shelf-break, and the data from this program are still undergoing analysis.

1.3 Objectives of Study

The primary objective of this study is to describe spatial and seasonal characteristics of the water masses and circulation in the three study areas. Physical oceanographic data from 2010 will be combined with the various biological measurements. This will help determine spatial and temporal patterns of biological production and the distribution and abundance of organisms in this region.

2.0 METHODS AND PROCEDURES

2.1 Sampling or Survey Design and Technical Rationale

Each study area will be sampled with a grid of 5 x 5 stations, at ~7.5. These will be conductivity-temperature-depth (CTD) stations at the same sites at which Dr. Hopcroft proposes to sample zooplankton, nutrients, and chlorophyll (Section III). The CTD includes a fluorometer (as an index of chlorophyll biomass) and a transmissometer (as index of water-column turbidity). The *R/V Westward Wind* has been mounted with a Teledyne acoustic Doppler current profile (ADCP), the current data will provide an estimate of the water-column current structure and its spatial and temporal variability.

2.2 Field Team Size and Composition

The marine-technician service group on the vessel will deploy, recover, and collect the various physical-oceanographic data sets. Dr. Weingartner's lab will provide analyses of these data.

2.3 Data-collection Procedures

CTD data will be collected with a Seabird system with a descent rate of no more than 30 meters/minute. The system also includes a flow monitor in the intake system, and the data stream will be blended with the ship's navigation system so that global positioning system (GPS) time and position are recorded. At each CTD cast, the operator records time of CTD deployment and position. The operator records the temperature and salinity values of the system once the CTD is ready to descend through the water column. (This will allow us to compare the underway system values with the CTD data; which is usually more accurate than the underway system.) Vessel-mounted ADCP (VM-ADCP) data will be collected from a Teledyne RDI system. The instrument will be run in bottom-track and broadband modes with a 2-m bin size and 2-second ping rate. Both raw (single-ping) and 10-minute averaged data will be stored (with duplicate copies). The ADCP data stream will also include the GPS position and time.

2.4 Analytical Procedures

All of the processing procedures used are routine and are based on common physical-oceanographic standard practices used at the Institute of Marine Sciences (IMS) and most other oceanographic institutions. Hydrographic processing of the CTD data will include application of calibration values and our standard quality-control routines used in processing CTD data sets. Standard procedures are to be used for assessing the

SSSTF and remotely-sensed images, which are all geo-referenced. Our analyses will include describing the seasonal (and, if possible, shorter-period) variations in fronts, water masses, geostrophic current fields, and water column stratification. At the very least, the analyses will provide COP, Shell, and Statoil with an estimate of data quality and simplified analyses of the circulation within the boxes (e.g., means and variances). Time permitting, we will examine shorter-period variations in the currents.

2.5 Data-storage Procedures

Data files collected during cruises will be backed up after each cast with multiple copies sent to University of Alaska Fairbanks (UAF). At UAF, data are backed up routinely onto departmental servers.

2.6 Quality-control Procedures

The manufacturer's pre- and post-season calibration values for the CTD temperature and conductivity sensors will be provided. The CTD will be sent to the manufacturer immediately after the October cruise so that the post-season calibration values are available as soon as possible after the end of the season. Final processed data sets cannot be made available until the post-season calibration values have been inspected and adjustments applied (if necessary). The underway sensors will also be calibrated prior to and after the cruise by the manufacturer. We will examine for systematic offsets between the CTD surface values and the underway system (usually in temperature). ADCP data-processing procedures include an exhaustive screening procedure based on ship accelerations, backscatter intensity, error values, etc. Bias and misalignment errors of the ADCP will be corrected for, following Joyce et al. (1989). Note, however, that ADCP quality control and data processing can be a time-consuming process if there are problems with the installation of the ADCP on the vessel.

3.0 COORDINATION

3.1 Olgoonik-Fairweather LLC

The Principal Investigator (PI) will attend all proposed meetings and interact regularly as needed with OLF.

3.2 Other Studies in the Chukchi Sea Program

Dr. Weingartner regularly interacts with other PIs involved in this program. He has a long collaborative relationship with Dr. Hopcroft (zooplankton) in particular through the Global Ocean Ecosystem Dynamics (GLOBEC) and NPRB Seward Line time-series, and has worked with Dr. Hopcroft on a recent interdisciplinary synthesis of studies from the Chukchi and Beaufort region. Drs. Norcross (fish) and Blanchard (benthos) and Dr. Weingartner have discussed fish and benthic biomass and abundance distributions in the Chukchi Sea and have a long-term working relationship. Drs. Day (seabirds) and Weingartner have consulted with each other on numerous occasions over the years, and we worked together during the GLOBEC program.

3.3 Current Studies in the Region

Recent and ongoing studies have been described in Section 1.1. Weingartner is a PI in the NSF and NOAA-funded Russian-American Long-term Census of the Arctic (RUSALCA) program that began in 2004 and that involves year-round current meter sampling in both the U.S. and Russian EEZs of Bering Strait. The PI will also begin to map the surface currents within 150 km of the coast between Wainwright and Barrow beginning August 2009, under a program jointly sponsored by BOEMRE, COP, and Shell. Dr. Weingartner is also involved with research in the Bering Strait and the Beaufort Sea in 2009.

4.0 DELIVERABLES

4.1 Field Data Summary

A list of sampling activities will be submitted within 30 days of reception of the data from the summer and fall 2010. This will consist of an inventory of the data sets that we have received from OLF.

4.2 Draft Report

The Draft Report, including CDs with the processed data, will be submitted 4 -6 months after receipt of the data sets and the post-season CTD calibration reports, assuming that neither have any unusual problems.

4.3 Final Report

The Final Report will be within 30 days of receipt of comments on Draft Report.

5.0 SCHEDULE WITH MILESTONES

5.1 Field Studies

Aug 2010—Cruise 1

Sept 2009—Cruise 2

Early-–mid-Oct 2009—Cruise 3

5.2 Coordination Meetings

- July 2010 - Health, Safety, and Environment (HSE) conference, Anchorage, AK
- Nov 2010—OLF Chukchi Sea scientific studies debriefing, Anchorage, AK (1 day).
- Jan 2011—Chukchi Sea scientific studies technical workshop at Alaska Marine Science Symposium (AMSS), Anchorage (2 days).

5.3 Deliverables

- Field data— within 3 months of receipt of complete data sets and post-season calibration reports from OLF.
- Draft Report— within 3 months of receipt of complete data sets and post-season calibration reports from OLF.
- Final Report— 1 month after receipt of comments on Draft Report.

6.0 REFERENCES

Aagaard, K. 1988. Current, CTD, and pressure measurements in possible dispersal regions of the Chukchi Sea. Outer Continental Shelf Environmental Research Program, Final Reports of Principal Investigators 57: 255–333.

Aagaard, K., and Roach. 1990. Arctic ocean-shelf exchange: measurements in Barrow Canyon, Journal of Geophysical Research 95: 18163–18175.

Aagaard, K., C. H. Pease, A. T. Roach, and S. A. Salo. 1989. Beaufort Sea Mesoscale Circulation Study—Final Report. NOAA Technical Memorandum ERL PMEL-90. 114 pp.

Aagaard, K., J. H. Swift, and E. C. Carmack. 1985. Thermohaline circulation in the Arctic mediterranean seas. Journal of Geophysical Research 90: 4833–4846.

AMAP (Arctic Monitoring and Assessment Programme). 2003. AMAP Arctic Pollution 2002: Persistent organic pollutants, heavy metals, radioactivity, Human health, changing pathways. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 112 pp.

Carmack, E. C. 1986. Circulation and mixing in ice-covered waters. In N. Unstersteiner (Ed.). The geophysics of sea ice. Plenum Press, New York, NY. Pp. 641–712.

Carmack, E. C., and D. C. Chapman. 2003. Wind-driven shelf/basin exchange on an Arctic shelf: the joint roles of ice cover extent shelf-break bathymetry. Geophysical Research Letters 30 (14): 1778. [available at: doi: 10.1029/203GL017526]

Coachman, L. K., K. Aagaard, and R. B. Tripp. 1975. Bering Strait: the regional physical oceanography. University of Washington Press, Seattle, Washington, Seattle, WA. 172 pp.

Codispoti, L., G. E. Friederich, C. M. Sakamoto, and L. I. Gordon. 1991. Nutrient cycling and primary production in the marine systems of the Arctic and Antarctic. Journal of Marine Systems 2: 359–384.

Codispoti, L., and F. A. Richards. 1968. Micronutrient distributions in the East Siberian and Laptev seas during summer 1963. Arctic 21: 67–83.

Cooper, L. W., J. Grebmeier, T. Whitledge, and T. Weingartner. 1997. The nutrient, salinity, and stable oxygen isotope composition of Bering and Chukchi sea waters in and near Bering Strait. Journal of Geophysical Research 102: 12563–12578.

Gawarkiewicz, G., and D. C. Chapman. 1995. A numerical study of dense water formation and transport on a shallow, sloping continental shelf. Journal of Geophysical Research 100: 4489–4508.

Joyce, T. 1989. On in situ “calibration” of shipboard ADCPs. 1989. Journal of Atmospheric and Oceanographic Technology 6: 169–172.

Hansell, D., T. E. Whitledge, and J. J. Goering. 1993. Patterns of nitrate utilization and new production over the Bering-Chukchi shelf. Continental Shelf Research 13: 601–627.

Liu, A. K., C. Y. Peng, and T. J. Weingartner. 1994. Ocean–ice interaction in the marginal ice zone using SAR. Journal of Geophysical Research 99: 22391–22400.

Muench, R. D., C. H. Pease, and S.A. Salo. 1991. Oceanographic and meteorological effects on autumn sea-ice distribution in the western Arctic. Annals of Glaciology 15: 171–177.

Münchow, A., E. C. Carmack, and D. A. Huntley. 2000. Synoptic density and velocity observations of slope waters in the Chukchi and East Siberian Seas. Journal of Geophysical Research 105: 14103–14119.

Münchow, A., T. Weingartner, and L. Cooper. 1999. The summer hydrography and surface circulation of the East Siberian Shelf Sea. Journal of Physical Oceanography 29: 2167–2182.

Münchow, A., and E. C. Carmack. 1997. Synoptic flow and density observations near an Arctic shelfbreak. Journal of Physical Oceanography 6: 461–470.

Paquette, R. G., and R. H. Bourke. 1981. Ocean circulation and fronts as related to ice melt-back in the Chukchi Sea. Journal of Geophysical Research 86: 4215–4230.

Walsh, J. J., C. P. McRoy, L. K. Coachman, J. J. Goering, J. J. Nihoul, T. E. Whitledge, T. H. Blackburn, P. L. Parker, C. D. Wirick, P. G. Shuert, J. M. Grebmeier, A. M. Springer, R. D. Tripp, D. A. Hansell, S. Djenedi, E. Deleersnijder, K. Henriksen, B. A. Lund, P. Andersen, F. E. Müller-Karger, and K. Dean. 1989. Carbon and nitrogen cycling within the Bering/Chukchi seas: source regions for organic matter affecting AOU demands of the Arctic Ocean. Progress in Oceanography 22: 277–359.

Walsh, J. J., D. A. Dieterle, F. E. Muller-Karger, K. Aagaard, A. T. Roach, T. E. Whitledge, and D. Stockwell. 1997. CO2 cycling in the coastal ocean. II: Seasonal organic loading of the Arctic Ocean from source waters in the Bering Sea. Continental Shelf Research 17: 1–36.

Weingartner, T., K. Aagaard, R. Woodgate, S. Danielson, Y. Sasaki, and D. Cavalieri, Circulation on the north-central Chukchi Sea shelf. 2005a. Deep-Sea Research (II) 52: 3150–3174.

Weingartner, T. J., S. R. Okkonen, and S. L. Danielson. 2005b. Circulation and water-property variations in the nearshore Alaskan Beaufort Sea. Final Report, OCS Study No. MMS 2005-028. 103 pp.

Weingartner, T. J., S. Danielson, Y. Sasaki, V. Pavlov, and M. Kulakov. 1999. The Siberian Coastal Current: a wind- and buoyancy-forced arctic coast current. Journal of Geophysical Research 104: 26697–29713.

Weingartner, T. J., D. J. Cavalieri, K. Aagaard, and Y. Sasaki. 1998. Circulation, dense water formation, and outflow on the northeast Chukchi shelf. Journal of Geophysical Research 103: 7647–7661.

Woodgate, R. A., K. Aagaard, and T. J. Weingartner. In press. Changes in the Bering Strait fluxes of volume, heat and freshwater between 1991 and 2004. Geophysical Research Letters.

Woodgate, R. A., and K. Aagaard. 2005a. Revising the Bering Strait freshwater flux into the Arctic Ocean. Geophysical Research Letters 32: L02602. [available at doi:10.1029/2004GL021747]

Woodgate, R. A., K. Aagaard, and T. Weingartner. 2005b. Monthly temperature, salinity, and transport variability for the Bering Strait throughflow. Geophysical Research Letters 32: L04601. [available at doi:10.1029/2004GL021880]

Woodgate, R. A., K. Aagaard, and T. Weingartner. 2005c. A year in the physical oceanography of the Chukchi Sea: moored measurements from autumn 1990–91. Deep-Sea Research (II) 52: 3116–3149.

SECTION III
PLANKTONIC COMMUNITIES

RUSSEL D. HOPCROFT
PRINCIPAL INVESTIGATOR
INSTITUTE OF MARINE SCIENCES, UNIVERSITY OF ALASKA
FAIRBANKS, AK

1.0 INTRODUCTION

1.1 Brief History of Planktonic Biological Oceanography in the Chukchi Sea

The Chukchi Sea, in particular, represents a complex gateway into the Arctic Ocean, where variation in climate may have profound impacts due to the complex interplay of several distinct water masses of Pacific origin with those of the central Arctic Ocean and its marginal seas. Large quantities of Pacific nutrients, phytoplankton, and zooplankton enter the region through the Bering Strait in a complicated mixture of water masses (i.e., Alaska Coastal, Bering Shelf, and Anadyr Water), each with unique assemblages and quantities of zooplankton (Springer et al. 1989; Coyle et al. 1996). This inflow is diluted by Coastal Arctic waters carried along by the East Siberian Current and water carried in from the deeper waters of the Canada Basin or Chukchi Plateau (Grebmeier et al. 1995). The influx of the "rich" Pacific water determines the reproductive success of both the imported and resident zooplankton communities (Plourde et al. 2005). Both interannual and long-term variation in climate will affect the relative transport of these various water masses and, hence, the composition, distribution, standing stock, and production of zooplankton and their predators within the Chukchi Sea.

Historically, the zooplankton of the Western Arctic and Northern Bering Sea have not been well studied compared with most U.S. oceanographic regions because of the remoteness and extensive seasonal ice coverage. Much of what is known of the region comes from sporadic, spatially-restricted, and non-repeated surveys that often undertake incomplete analysis of their samples. Consequently, much of the research conducted does not appear in the primary scientific literature but remains buried in the "gray literature." Although physical-oceanographic measurements typically have earlier histories, the first scientific records of planktonic work in the Bering Strait and Chukchi Sea appear to be those of Johnson (1934), Stepanova (1937), Bogorov (1939), and Jaschnov (1940), all of whom noted the significant influence of Pacific fauna in the Chukchi Sea.

Further work resumed after World War II, with the results of the early Russian sampling reported in Brodsky (1950, 1957), the English translation of which still remains a primary reference source for the region. Work more specific to this region appeared in Virketis (1952). North American work in the region initially maintained a quantitative and taxonomic dimension (Johnson 1953, 1956, 1958), but then interest waned. The results of the 1959 and 1960 Brown Bear cruises were never published as more than displacement volumes (English 1966) and, although the U.S. Coast Guard (USCG) Cutter *Northwind* appears to have sampled zooplankton in the Bering Strait and Chukchi Sea during the 1960s, the data are either unpublished or buried in the gray literature. Chukchi Sea collections by the USCG Glacier in 1970 as part of Western Bering Sea Ecological Cruise (WEBSEC) were reported quantitatively (Wing 1974), while samples collected in the Northern Bering and Chukchi seas (Cooney 1977) by the OCSEAP (1960–1981) were never published as more than presence–absence data (although raw data still exist at UAF). Only limited additional quantitative zooplankton sampling occurred in the Chukchi Sea under the OCSEAP program (English and Horner 1977), as most effort became focused on the nearby waters of the Beaufort Sea (ibid; Redburn 1974; Horner 1981; Horner and Schrader 1984) and the southeastern Bering Sea (Cooney 1977; followed by PROBES, FOCI). It was the mid-1980s before quantitative sampling resumed in Bering Strait and the Chukchi Sea with the Inner Shelf Transfer and Recycling (ISHTAR) program (see below). Russian research in this region has undoubtedly continued since the 1950s, but the results are often buried in their own gray literature and are generally unavailable to the international community (see Herman 1989). No doubt, the relative paucity of information north of Bering Strait is a consequence of limited commercial harvesting there in comparison with the Bering Sea.

From the North American perspective, post OCSEAP science begins with the ISHTAR program in 1985 and 1986 (Springer et al. 1989) and, more peripherally, the 1994 Trans-arctic Section (Thibault et al. 1999) and the Surface Heat Budget of the Arctic (SHEBA) drift across the Chukchi Plateau in 1997–1998 (Ashjian et al. 2003). In the past decade, our knowledge of plankton in the Chukchi Sea and Western Arctic has improved considerably due to ongoing efforts such as NSF’s SBI program (2002–2004) on the Beaufort and Chukchi shelves (e.g., Plourde et al. 2005; Llinas 2007; Lane et al. 2008), plus cross-sea cruises by NOAA’s RUSALCA Program (e.g., Lee et al. 2007; Hopcroft and Kosobokova, in review), and the Northward extension of the Bering–Aleutian Salmon International Survey (BASIS) into the Chukchi Sea beginning in 2006. More limited sampling in the Chukchi has occurred during northward transit of Canadian ice breakers during the past decade, and the Japanese ship Oshoro Maru began last year extending its annual cruise into northward into the Chukchi Sea.

A notable exception to the political boundaries imposed on most post-WWII sampling in the Bering and Chukchi seas has been the Joint U.S.-USSR Central Pacific Expedition (BERPAC) program. Five such cruises were executed between 1977 and 1993 (Tsyban 1999). BERPAC 1988 is particularly relevant to this proposal because it encompassed stations from the southern Bering Sea to the mid-Chukchi Sea (Kulikov 1992). The RUSALCA program, which begun sampling in 2004 and will re-sample in 2008 and 2012, continues this bi-national sampling effort.

A regional and basin-wide review of Arctic zooplankton, their composition, seasonal life cycles, and trophic interactions was completed nearly two decades ago (Smith and Schnack-Schiel 1990). The review emphasizes the larger copepods in the genus *Calanus*. A more recent effort emphasizing the Russian literature for just the Bering Sea has also been completed (Coyle et al. 1996). One common shortcoming of all this initial work is that sampling techniques were not standardized; in particular, the use of only a single net of 303 to ~600 micrometer (µm) mesh as employed in these studies missed the majority of the zooplankton community numerically and missed a substantial proportion of the community biomass and diversity. For the most part, Arctic studies have now standardized on 150-µm mesh nets (e.g., Kosobokova and Hirche 2000; Ashjian et al. 2003; SBI and OE program) that more completely sample the numerically-dominant copepods in the genera *Oithona*, *Oncaea*, *Microcalanus*, and *Pseudocalanus* (ibid; Auel and Hagen 2002; Hopcroft et al. 2005). In fact, to ensure that all developmental stages of these species, including nauplii, are sampled, a mesh as fine as 53 µm is required (Hopcroft et al. 2005). Furthermore, these more recent studies have been conducted primarily in deeper waters, while in the shallow target area of this project we can expect an even larger contribution of smaller neritic species in several of the water masses that will be encountered (e.g., Grice 1962; Conover and Huntley 1991).

Although we now have a fairly complete description of the species that have been found regionally in the Arctic (e.g., Sirenko 2001), we still lack unbiased and comprehensive estimates of the abundance, biomass, and composition of the zooplankton in the Chukchi Sea due to sampling inadequacies of the past. Significant progress was made toward this end by the RUSALCA and SBI programs. Within the Chukchi Sea, there is considerable diversity of both small and large jellyfishes, hydromedusae, and ctenophores that are often overlooked: more than a dozen species were encountered in RUSALCA 2004 (Hopcroft et al., in press), and more are reported from the nearby deep basins (Raskoff et al. 2005, in press). There were also considerable populations of larvaceans, particularly the large arctic *Oikopleura vanhoeffeni* throughout the sampling area. Larvaceans are increasingly implicated as key players in polar systems (e.g., Acuna et al. 1999; Hopcroft et al. 2005; Deibel et al. 2005) due to their high grazing and growth rates. At times, the biomass of larvaceans in 2004 rivaled that of the copepods, particularly at the ice-edge stations in Herald Valley, where some of the highest recorded densities for *Oikopleura vanhoeffeni* were observed. Shifts from copepod-dominated communities to larvacean-dominated can have large consequences on the export of phytoplankton to the benthos (Gorsky and Feanaux 1998; Alldredge 2005). As in many ecosystems, chaetognaths remain an important and neglected predatory group (Ashjian et al. 2003; Hopcroft et al. 2005; Lane et al. 2008; Hopcroft and Kosobokova, in press), The meroplanktonic larvae of benthic organisms were also exceptionally common throughout the sampling region in 2004, and better knowledge of their abundance and distribution is of high relevance to understanding recruitment to the rich benthic communities in this region. To a large extent, the spatial distribution of these zooplankton communities is tied to the different water masses present in this region (Hopcroft and Kosobokova, in review).

In terms of mechanisms, planktonic communities of the Chukchi Sea could undergo climate-related changes either through shifts in the absolute transport rate, and thus penetration, of Pacific species into the Arctic, or by environmental changes that ultimately affect their survival. It has been estimated that 1.8 million metric tons of Bering Sea zooplankton are carried into the Chukchi Sea annually (Springer et al. 1989) and that this, along with the entrained phytoplankton communities, are responsible for the high productivity of the Chukchi Sea in comparison with adjoining regions of the Arctic Ocean (e.g., Plourde et al. 2005). In the summer of 2004, one would characterize the southern Chukchi zooplankton fauna as primarily Pacific in character, and there were clear signs that Pacific species were carried northward as far as the eastern side of Wrangel Island and Harold Canyon (Hopcroft and Kosobokova, in review), while in the northeastern Chukchi transitions to fully Arctic communities did not occur until the shelf break (Lane et al. 2008). Future increases in transport could carry even more Pacific zooplankton through Bering Strait, with even further penetration into the Arctic. In contrast, a reduction in transport of Bering Sea water would not only decrease the overall productivity of the Chukchi Sea but would give it a more Arctic Ocean faunal character. Thus, changes in the transport rates ultimately affect the species-composition of this region as well as the absolute zooplankton biomass, and such shifts may result in changes in the size-structure of zooplankton communities. Since most higher trophic levels select their prey based on size, the consequences of size-structure shifts could be more important than changes in zooplankton biomass

1.2 Objectives of Study

The primary objective is to describe spatial, seasonal and inter-annual characteristics of the plankton (phytoplankton and zooplankton) communities with specific detail in the three study areas. Secondarily, we will obtain opportunistic samples of zooplankton where bowhead whales are observed feeding to determine both the type of prey as well as the concentration that elicits bowhead feeding activity.

2.0 METHODS AND PROCEDURES

2.1 Sampling or Survey Design and Technical Rationale

We propose to sample two 30 X 30 nm box, with a grid of 5 X 5 stations, at ~7.5-nm spacing, within Klondike and Burger, and one irregular shaped box (Statoil) of ~900 sq nm consisting of 22 station at ~7.5 nm spacing in addition to 4 stations shared between Statoil and Burger. If time permits, due to ice coverage, six transition stations spaced ~7.5 nm apart located between Klondike and Burger will be sampled. Both phytoplankton (as chlorophyll) and zooplankton will be sampled because the phytoplankton is the major prey for the zooplankton and for the benthos once it settles. Together, nutrients, phytoplankton, and zooplankton form effective biological tracers of the waters masses present in this region. A coarser 5 X 5 grid at ~30 nm (i.e., from 161–167°W and from 70–72°N) is strongly suggested in the future to provide oceanographic context.

In general, re-sampling of fixed sampling locations over time along transects/grids (a model-based rather than a probability-based design) will provide the highest power for statistical comparisons between years (but limit inferences) and will result in spatially and temporally correlated data. Thus, statistical methodologies considered will include methods for analyzing data in the presence of correlated error structures (e.g., linear models through SAS Proc Mixed, SAS Institute, Cary, NC, or geostatistical methods) and multivariate procedures. Additional sets of collections will be conducted in any area where bowhead whales are observed to feed, with a pair of collections taken inside the feeding area and a pair taken outside for reference.

2.2 Field Team Size and Composition

The field team will consist of one person, Imme Rutzen on Cruise One and Jennifer Questel on biology Cruises Two and Three. Questel and Rutzen will travel to Seward in early July for setup and sampling logistics from the ship. Agreement has been reached that help with launch and recovery of gear can be obtained from Aldrich Offshore Services (AOS) technicians and other biology teams if/when needed.

2.3 Data-collection Procedures

Routine methods are nearly identical to COP's 2008 and 2009 program, as well as similar to those employed during the 2004 and 2009 RUSALCA expeditions and the 2006 and 2007 BASIS cruises. Phytoplankton will be assessed as chlorophyll *a* concentration from samples collected with a CTD rosette on upcasts at 6 depths/station (0, 5,10, 20, 30 m, and near-bottom). Samples (~500 milliliters [ml]) will be filtered under low pressure onto a Whatman GF/F filters, with extracted chlorophyll *a* being determined fluorometrically post-cruise from frozen samples (Parsons et al. 1984). Measurements will be used to calibrate the *in vivo* fluorescence profiles measured at all stations. Nutrient samples will be taken from the same bottles as chlorophyll, frozen immediately, and measured post-cruise using an Alpkem Rapid Flow Analyzer (Whitledge et al. 1981); analyses will conform to WOCE standards (Gordon et al. 1993).

Zooplankton will be collected routinely by a pair of 150-μm mesh Bongo nets of 60-cm diameter hauled vertically from within 3 m of the bottom; the volume of water filtered will be measured by SeaGear flow meters in each net that are rigged not to spin during descent. To target larger, more mobile zooplankton, a set of 60-cm-diameter 505-μm Bongo nets equipped with General Oceanic flow-meters will be deployed in a double-oblique tow while the ship is moving at 2 knots. Opportunistic samples of zooplankton where bowhead whales are observed feeding will employ only the 505-μm net because they exploit only larger prey items. Upon retrieval, one sample of each mesh size will be preserved in 10% formalin, and the other in 95% non-denatured ethanol (required for molecular identification).

2.4 Analytical Procedures

Formalin-preserved samples will be processed for quantitative determination of species - composition and biomass (predicted). During taxonomic processing, all larger organisms (primarily shrimp and jellyfishes) will be removed, enumerated, and weighed; then, the sample will be Folsom split until the smallest subsample contains about 100 specimens of the most abundant taxa. The most abundant taxa will be identified, copepodites will be classified to stage, and will be enumerated and measured (Roff and Hopcroft 1986). Each larger subsample will be examined to identify, measure, enumerate, and weigh the larger, less-abundant taxa. The three lead zooplankton technicians at UAF each have been working in Alaska waters from 8–20 years. When needed, specimens will be compared with the voucher set housed at UAF or will be sent to an appropriate taxonomic expert.

To estimate biomass, blotted wet weights of larger animals will be weighed directly, whereas the weight of smaller animals will be predicted from measurements of length using species-specific relationships. Wet-weight measurements are generally taken to ±10 micrograms (μg) (or as needed for length-weights to ±0.1 μm). Measured weights will be periodically compared to those predicted from length-weight equations to compare the two methods. The data will be uploaded to an Excel and/or Microsoft Access database for sorting and analysis. At present, multidimensional scaling of similarity or dissimilarities between samples has proven an effective method of revealing distributional patterns (Coyle and Pinchuk 2003, 2005; Hopcroft et al. in press) and will be conducted with the Primer software package.

Ethanol samples will be scanned for representatives of the species and contribute to a growing international “molecular bar-coding” effort by the Census of Marine Zooplankton (CMarZ) at the University of Connecticut for determination of the Cytochrome Oxidase I gene. This gene’s sequence has been identified for the universal molecular “bar-coding” of eucaryotic organisms (Hebert et al. 2003) and is currently being employed for global analysis of zooplankton (e.g., Bucklin et al. 2003, in press). Initially, these sequences will simply serve to catalogue the species encountered, but they ultimately will become the preferred method of ensuring taxonomic consistency of identification within long-term studies.

2.5 Data-storage Procedures

Data files collected during cruises will be backed up periodically, and multiple copies will be transported back to UAF at the completion of each cruise along with copies of notebooks. At UAF, data are backed up routinely onto departmental servers.

2.6 Quality-control Procedures

In the field, samples are always collected in duplicate, so any discrepancy in the flowmeter readings become readily apparent. Replicate samples are not routinely analyzed but serve as insurance in the event that one sample is compromised. Periodically, the same subsamples are processed by several technicians to ensure taxonomic consistency.. When questions arise, specimens will be compared with the voucher set housed at UAF, will be sent to an appropriate taxonomic expert, or will be identified through emerging molecular-identification libraries.

3.0 COORDINATION

3.1 Olgoonik-Fairweather

The PI, or an alternate team member, will attend all proposed meeting and interacts regularly as needed with OLF.

3.2 Other Studies in the Chukchi Sea Program

The PI regularly interacts with other PI currently at UAF and has a long collaborative relationship with Dr. Weingartner, in particular, through the GLOBEC and NPRB Seward Line time-series. Dr. Hopcroft oversaw a recent multidisciplinary synthesis of studies from the Chukchi and Beaufort region, which has connected him to investigators in may other disciplines.

3.3 Current Studies in the Region

Recent and ongoing studies have been described in Section 1.1. Hopcroft is a PI within the NOAA-funded RUSALCA program begun in 2004, which will be a re-sampling over a broad domain of the Chukchi Sea in September 2009. Dr. Hopcroft and his students are actively involved with the BASIS sampling program in the Chukchi Sea (which has stopped at 70°N), as well as in the deep Canada Basin. Dr. Hopcroft is also a lead PI in the ongoing Arctic Ocean Biodiversity project (www.arcodiv.org), which, among other goals, is compiling biological data from the Chukchi Sea, in conjunction with colleagues and ongoing efforts by NOAA-NMFS, ArcOD has digital access to much of the zooplankton data from OCSEAP, ISHTAR, WEBSEC, SBI, Ocean Exploration cruises. Recently, several of these datasets have been made available on-line at http://ak.aoos.org/op/data.php?region=AK&name=obis and http://www.st.nmfs.gov/plankton/content/area_bering/index.html.

4.0 DELIVERABLES

4.1 Field Data

A list of sampling activities will be submitted within 30 days of the final cruise.

4.2 Draft Report

Provided samples can be shipped to UAF at the completion of each cruise, the Draft Report, including appendices with sample analysis, will be submitted by 1 March 2009.

4.3 Final Report

The Final Report will be submitted 15 June 2011 or within 30 days of receipt of comments on the Draft Report.

5.0 SCHEDULE WITH MILESTONES

5.1 Field Studies

- July 8-9th 2010 – Ship walkthrough and inventory check in Seward
- July 13-17th 2010— Planning meeting, HSE and cold-water training (Anchorage)
- August–mid October 2009—Scientific Cruises 1-3

5.2 Coordination Meetings

- May 2010—OLF Chukchi Sea scientific studies kickoff meeting, and scientific studies coordination meeting. Fairbanks, AK (1 day)
- Mid July 2010—OLF training and coordination meeting (Anchorage)
- Nov 2010—OLF Chukchi Sea scientific studies debriefing. Anchorage, AK (1 day)
- Jan 2011—Chukchi Sea scientific studies technical workshop at AMSS, Anchorage (2 days)

5.3 Deliverables

- Final Study Plan for the plankton component—15 June 2010.
- Field data—within 30 days of final cruise.
- Draft Report—15 May 2011.
- Final Report—15 June 2011 or within 30 days of receipt of comments on Draft Report.

6.0 REFERENCES

Acuna, J. L., D. Deibel, A. B. Bochdansky, and E. Hatfield, E. 1999. In situ ingestion rates of appendicularian tunicates in the Northeast Water Polynya (NE Greenland). Marine Ecology Progress Series 186: 149–160.

Alldredge, A. 2005. The contribution of discarded appendicularian houses to the flux of particulate organic carbon form oceanic surface waters. In G. Gorsky, M. J. Youngbluth, and D. Deibel (Eds.). Response of marine ecosystems to global change: ecological impact of appendicularians. Gordon and Breach, Paris, France. Pp. 309–326.

Ashjian, C. J., R. G. Campbell, H. E. Welch, M. Butler, and D. V. Keuren. 2003. Annual cycle in abundance, distribution, and size in relation to hydrography of important copepod species in the western Arctic Ocean. Deep-Sea Research (I) 50: 1235–1261.

Auel, H., and W. Hagen. 2002. Mesozooplankton community structure, abundance and biomass in the central Arctic Ocean. Marine Biology 140: 1013–1021.

Bogorov, V. G. 1939. The characteristics of seasonal phenomena in the plankton of the Arctic seas and their significance for ice forecastings. Zoologicheskii Zhurnal 18 (5): XXX–XXX. [in Russian].

Brodsky, K. A., 1950. Copepods (Calanoida) of the far-eastern seas of the USSR and the polar basin. Zoological Institute of the Academy of Sciences of the USSR, Leningrad.

Brodsky, K. A., 1957. The copepod fauna (Calanoida) and zoogeographic zonation of the North Pacific and adjacent waters. Akademiya Nauk SSSR, Leningrad.

Bucklin, A., B. W. Frost, J. Bradford-Grieve, L. D. Allen, and N. J. Copley. 2003. Molecular systematic and phylogenetic assessment of 34 calanoid copepod species of the Calanidae and Clausocalanidae. Marine Biology 142: 333–343.

Bucklin, A., R.R. Hopcroft, K.N. Kosobokova, L.M. Nigro, B.D. Ortman, C.J. Sweetman and R.M. Jennings (in press) DNA barcoding of Arctic Ocean holozooplankton for species identification and recognition Deep-Sea Res.II.

Conover, R. J., and M. Huntley. 1991. Copepods in ice-covered seas—distribution, adaptations to seasonally limited food, metabolism, growth patterns, and life-cycle strategies in polar seas. Journal of Marine Systematics 2: 1–41.

Cooney, R. T. 1977. Zooplankton and micronekton studies in the Bering-Chukchi/Beaufort seas. NOAA OCSEAP Annual Reports 10: 275–363.

Coyle, K. O., V. G. Chavtur, and A. I. Pinchuk. 1996. Zooplankton of the Bering Sea: a review of Russian-language literature. In A. O. Mathisen and K. O. Coyle (Eds.). Ecology of the Bering Sea: a review of the Russian literature. Alaska SeaGrant College Program, University of Alaska, Fairbanks, AK. Pp. 97–133.

Coyle, K. O., and A. I. Pinchuk. 2003. Annual cycle of zooplankton abundance, biomass and production on the northern Gulf of Alaska shelf, October 1997 through October 2000. Fisheries Oceanography 12: 227–251.

Coyle, K. O., and A. I. Pinchuk. 2005. Cross-shelf distribution of zooplankton relative to water masses on the northern Gulf of Alaska shelf. Deep-Sea Research (II) 52: 217–245.

Deibel, D., P. A. Saunders, J. L. Acuna, A. B. Bochdansky, N. Shiga, and R. B. Rivkin. 2005. The role of appendicularian tunicates in the biogenic carbon cycle of three Arctic polynyas. In G. Gorsky, M. J. Youngbluth, and D. Deibel (Eds.). Response of marine ecosystems to global change: ecological impact of appendicularians. Gordon and Breach, Paris, France. Pp. 327–356.

English, T. S. 1966. Net plankton volumes in the Chukchi Sea. In N. J. Wilimovsky, and J. N. Wolfe (Eds.). Environment of the Cape Thompson region, Alaska. U.S. Atomic Energy Commission, Washington, DC. Pp. 809–915.

English, T. S., and R. Horner. 1977. Beaufort Sea plankton studies. NOAA OCSEAP Annual Reports 9: 275–627.

Gordon, C., A. A. Jennings, and J. M. Krest. 1993. A suggested protocol for continuous flow automated analysis of seawater nutrients (phosphate, nitrate, nitrite, and silicic acid) in the WOCE Hydrographic Program and the Joint Global Ocean Fluxes Study. Oregon State University, Corvallis, OR. P. 51.

Gorsky, G., and R. Fenaux. 1998. The role of Appendicularia in marine food chains. In Q. Bone (Ed.). The biology of pelagic tunicates. Oxford University Press, New York, NY. Pp. 161–169.

Grebmeier, J. M., W. O. Smith, Jr., and R. J. Conover. 1995. Biological processes on Arctic continental shelves: ice-ocean-biotic interactions. In W. O. Smith, Jr., and J. M. Grebmeier (Eds.). Arctic oceanography: marginal ice zones and continental shelves. American Geophysical Union, Washington, DC. Pp. 231–261.

Grice, G. D. 1962. Copepods collected by the nuclear submarine Seadragon on a cruise to and from the North Pole, with remarks on their geographic distribution. Journal of Marine Research 20: 97–109.

Hebert, P. D. N., A. Cywinska, S. L. Ball, and J. R. deWaard. 2003. Biological identifications through DNA barcodes. Proceedings of the Royal Society of London (B) 270: 313–321.

Hopcroft, R. R., C. Clarke, R. J. Nelson, and K. A. Raskoff. 2005. Zooplankton communities of the Arctic's Canada Basin: the contribution by smaller taxa. Polar Biology 28: 197–206.

Hopcroft, R. R., and K. N. Kosobokova. In press. Distribution and production of Pseudocalanus species in the Chukchi Sea. Deep-Sea Research (II).

Hopcroft, R. R., K. N. Kosobokova and A.I. Pinchuk. In press. Zooplankton community patterns in the Chukchi Sea during summer 2004. Deep-Sea Research (II).

Horner, R. 1981. Beaufort Sea plankton studies. NOAA OCSEAP Final Reports 13: 65–314.

Horner, R. 1984. Analysis of Harrison Bay zooplankton samples. NOAA OCSEAP Final Reports 25: 65–314.

Huntley, M. E., 1996. Temperature and copepod production in the sea: a reply. American Naturalist 148: 407–420.

Jaschnov, V. 1940. Plankton productivity of the northern seas of the USSR. Moscovskoe Obshestvo Ispytatelei Prirody Press, Moscow, Russia.

Johnson, M. W. 1934. The production and distribution of zooplankton in the surface waters of the Bering Sea and Bering Strait, Part II. Report of the oceanographic cruise U.S. Coast Guard Cutter Chelan—1934. Pp. 45–82.

Johnson, M. W., 1953. Studies on the plankton of the Bering and Chukchi Seas and adjacent areas. Proceedings 7th Pacific Science Congress (1949), Vol. 4, 'Zoology'. Pp. 480–500.

Johnson, M. W., 1956. The plankton of the Beaufort and Chukchi Sea areas of the Arctic and its relation to hydrography. Arctic Institute of North America, Montreal, Canada.

Johnson, M. W. 1958. Observations on inshore plankton collected during the summer 1957 at Point Barrow, Alaska. Journal of Marine Research 17: 272–281.

Kosobokova, K., and H.-J. Hirche. 2000. Zooplankton distribution across the Lomonosov Ridge, Arctic Ocean: species inventory, biomass and vertical structure. Deep-Sea Research (I) 47: 2029–2060.

Kulikov, A. S. 1992. Characteristics of zooplankton communities. In P. A. Nagel (Ed.). Results of the third Joint US–USSR Bering and Chukchi seas expedition (BERPAC), summer 1988. U.S. Fish and Wildlife Service, Washington, DC. Pp. 161–XXX.

Lane, P. V. Z., L. Llinás, S. L. Smith, and D. Pilz. 2008. Zooplankton distribution in the western Arctic during summer 2002: hydrographic habitats and implications for food chain dynamics. Journal of Marine Research 70: 97–133.

Lee, S. H., T. E. Whitledge, and S.-H. Kang. 2007. Recent carbon and nitrogen uptake rates of phytoplankton in Bering Strait and the Chukchi Sea. Continental Shelf Research 27: 2231–2249.

Llinás, L. 2007. Distribution, reproduction, and transport of zooplankton in the western Arctic, University of Miami, Coral Gables, FL.

Parsons, T. R., Y. Maita, and C. M. Lalli. 1984. A manual for chemical and biological methods in seawater. Pergamon Press, Toronto, Canada.

Plourde, S., R. G. Campbell, C. J. Ashjian, and D. A. Stockwell,. 2005. Seasonal and regional patterns in egg production of Calanus glacialis/marshallae in the Chukchi and Beaufort seas during spring and summer, 2002. Deep-Sea Research (II) 52: 3411–3426.

Raskoff, K. A., R. R. Hopcroft, K. N. Kosobokova, M. J. Youngbluth, and J. E. Purcell. In press. Jellies under ice: ROV observations from the Arctic 2005 Hidden Ocean Expedition. Deep-Sea Research (II).

Raskoff, K. A., J. E. Purcell, and R. R. Hopcroft. 2005. Gelatinous zooplankton of the Arctic Ocean: in situ observations under the ice. Polar Biology 28: 207–217.

Redburn, D. R. 1974. The ecology of the inshore marine zooplankton of the Chukchi Sea near Point Barrow, Alaska. M.S. thesis, University of Alaska, Fairbanks, AK.

Roff, J. C., and R. R. Hopcroft. 1986. High precision microcomputer based measuring system for ecological research. Canadian Journal of Fisheries and Aquatic Sciences 43: 2044–2048.

Sirenko, B. I. 2001. List of species of free-living invertebrates of Eurasian arctic seas and adjacent deep waters. Russian Academy of Sciences, St. Petersburg, Russia.

Smith, S. L. 1990. Egg production and feeding by copepods prior to the spring bloom of phytoplankton in Fram Strait, Greenland Sea. Marine Biology 106: 59–69.

Springer, A. M., C. P. McRoy, and K. R. Turco. 1989. The paradox of pelagic food webs in the northern Bering Sea. II: Zooplankton communities. Continental Shelf Research 9: 359–386.

Stepanova, V. S. 1937. Biological indicators of currents in the northern Bering and southern Chukchi Seas. Issled. Morei SSSR 25: 175–216 [in Russian].

Thibault, D., E. J. H. Head, and P. A. Wheeler. 1999. Mesozooplankton in the Arctic Ocean in summer. Deep-Sea Research (I) 46: 1391–1415.

Tsyban, A. V. 1999. The BERPAC pProject: development and overview of ecological investigations in the Bering and Chukchi seas. In T. R. Loughlin and K. Ohtani (Eds.). Dynamics of the Bering Sea. Alaska SeaGrant College Program, University of Alaska, Fairbanks, AK. Pp. 713–731.

Virketis, M. 1952. Zooplankton of the Chukchi Sea and Bering Strait. In K. A. Brodsky (Ed.). The extreme north-east of the USSR. 2. Fauna and flora of the Chukchi Sea. Akademiya Nauk SSSR, Moscow, USSR. XXX pp. [in Russian].

Whitledge, T. E., S. C. Malloy, C. J. Patton, and C. D. Wirick,. 1981. Automated nutrient analyses in seawater. Brookhaven National Laboratory, Upton, NY. 216 pp.

Wing, B. L. 1972. Preliminary report on the zooplankton collected on WEBSEC-70. In M. C. Ingham, B. A. Rutland, P. W. Barnes, G. E. Watson, G. J. Divoky, A. S. Naidu, G. D. Sharma, B. L. Wing, and J. C. Quast (Eds.). An ecological survey in the eastern Chukchi Sea. U.S. Government, Washington, DC.

SECTION IV
BENTHIC COMMUNITIES

ARNY L. BLANCHARD
PRINCIPAL INVESTIGATOR
INSTITUTE OF MARINE SCIENCES, UNIVERSITY OF ALASKA
FAIRBANKS, AK

1.0 INTRODUCTION

1.1 Brief history of Subject Research in Chukchi Sea

The last 30 years have seen tremendous development and resource use in Arctic Alaska. Development and extraction of petroleum reserves and associated industrial and urban growth has increased the potential for adverse anthropogenic effects on the environment (Naidu et al. 1997). Concern for the Arctic environment is growing and efforts continue to be directed towards understanding the Arctic and its seas, including the Chukchi Sea (Hopcroft et al. 2006). In the Chukchi Sea, cultural and subsistence resources of interest mainly include marine mammals and seabirds, some of which feed on sediment-dwelling (benthic) organisms (e.g., Lovvorn et al. 2003; Grebmeier et al, 2006). These resources in the Chukchi Sea are of great cultural and economic value to a broad variety of stakeholders including Native subsistence hunters, environmental organizations, and those interested in extracting resources of economic value. Disturbance to the short food chains in the arctic has the potential for large effects on higher trophic levels making assessment of benthic community species composition and structure important components for monitoring.

The first quantitative investigation of macrobenthic community structure in the northeast Chukchi Sea was performed in 1971 to 1974 by Stoker (1978). This study was followed in 1986 by investigations of benthos/environmental interactions by Feder et al. (1994b) who assessed community structure of infauna (organisms that live within the sediments) and of pelagic/benthic coupling by Grebmeier et al. (1988). A rich epifaunal community (organisms that live on top of the sediments) is also known for the area including mollusks, crabs, and echinoderms (e.g., Feder et al. 1994a; Ambrose et al. 2001). These studies provided insights into the benthic fauna present and factors structuring infaunal communities. The benthic biomass of the region is high in spite of the seasonal ice cover due to the tight coupling of pelagic and ice-edge primary production and benthic community structure and production (Grebmeier et al. 2006). In addition to the present environmental baseline study performed in 2008 and 2009, investigations in the region include the SBI study (http://sbi.utk.edu), and the RUSALCA investigating ecosystem dynamics, food-webs, and benthic ecology.

The northeastern Chukchi Sea is a productive shallow sea influenced by advective processes (Grebmeier et al. 2006). Water advected into the region includes Bering Shelf Water (BSW) and Alaska Coastal Water (ACW) (e.g., Coachman 1987). The BSW has relatively high nutrient concentrations (derived in part from water from the Gulf of Anydyr off Russia) that enhance benthic biomass whereas the ACW along the Alaska coast is comparatively nutrient poor (Feder et al. 1994b; Codispoti et al. 2005; Grebmeier et al. 2006). The differences in nutrient concentrations in water masses lead to substantial differences in primary production, and thus, benthic community structure (Feder et al. 1994b) and benthic food web structure (Iken et al. 2010). Factors influencing benthic community structure of the Chukchi Sea include sediment granulometry, and sediment organic carbon to nitrogen ratios (C/N ratio) (Feder et al. 1994b). Sediment granulometry (e.g., percent gravel, sand, or mud) reflects a number of environmental processes, including hydrodynamics (strong currents, storms, ice gouging, etc.), sediment deposition, and proximity to sediment sources. The C/N ratio in sediments reflects availability of particulate organic carbon to benthic animals, which is of particularly high nutrient value when derived from phytoplankton as opposed to terrigenous carbon.

The benthic fauna in the southern Chukchi Sea and northern Bering Sea are an important prey resource for higher trophic level organisms such as walrus and gray whales (e.g. Oliver et al. 1983; Moore et al. 2003; Highsmith et al. 2006; Bluhm et al. 2007). Traditional feeding hot spots are located south of St. Lawrence Island and the Chirikov Basin (both Bering Sea) and the south-central Chukchi Sea, but recent marine mammal observations have shown that these hotspots may be changing because of changes in sea ice as resting platforms for walrus and seals between feeding bouts and in the benthic community structure. While the survey areas of the northeast Chukchi Sea in the present study are not known as important feeding grounds for gray whales, there is the possibility that these areas may become feeding grounds in the future. Therefore, the benthic studies suggested here will be an opportunity to provide valuable baseline information, should these areas become more important for marine mammals and birds in the future.

1.2 Objectives

The objective of this study is to understand the ecology of macrobenthic fauna in the Burger, Klondike, and Statoil survey areas. This addresses the benthic ecology component of the 2010 environmental studies program in the Chukchi Sea. The scope of work includes field sampling for infauna with a van Veen grab and epifauna with a plumb staff trawl for taxonomic analysis, and collection of samples for tissue isotope analysis, sediments for isotope and chlorophyll *a* determinations. The scope of work also encompasses the non-field components including laboratory analyses of samples collected, statistical analyses of infauna and epibenthic data, photo archiving, and reporting.

Specific objectives of the proposed work are:

Task 1: Benthic ecology: Infauna.

- Sample the sediment-dwelling invertebrates (infauna) within the Chukchi Sea to assess species composition, abundance and biomass of communities within the study area and to document community structure.
- Sample the benthos where marine mammals might be observed feeding in the area.
- Continue measurement of tissue carbon and nitrogen isotope of key species for food web structure as necessary.
- Develop photo archive of infaunal species using digital microscopy.

Task 2: Benthic ecology: Epibenthos.

- Sample the epibenthos (large, mobile invertebrates living on the sediment surface) within the Chukchi Sea to assess species composition, abundance and biomass of epifaunal communities within the study area and document community structure.
- Continue measurement of tissue carbon and nitrogen isotope of key species for food web structure as necessary.
- Develop photo archive of epibenthic invertebrate species using macrophotography.

Task 3: Report results.

- Describe temporal variability of faunal communities.
- Determine associations of measured physical factors (as available from physical oceanography and contaminants) to faunal community structure.
- Provide preliminary assessments of the potential linkages between infaunal and epibenthic communities.
- Provide preliminary assessments of the potential linkages between macrofauna and higher predators.

A multi-year record of variability is required to understand benthic communities and to support this, sampling of selected sites will continue in 2010. Thus, Task 1 will be included in all years of sampling as the infauna are the primary means for identifying potential effects from anthropogenic or natural stressors in the Chukchi Sea. Sampling to support the successful completion of Task 2 will continue in 2010. Annual final reports summarize each year's data (Task 3).

2.0 METHODS AND PROCEDURES

2.1 Sampling or Survey Design and Technical Rationale

Benthic sampling will occur at sites within the Burger, Klondike, and Statoil survey areas. In 2008 and 2009, benthic sampling included fixed and random sites at the survey area sites (~26 locations at each site) and sampling at sites of interest. The mix of fixed and random sites is helpful in that an appropriate dispersion of stations will be achieved, some sites are linked to all disciplines (the fixed sites), and sampling allows for inferences over the whole study area. Sampling of infauna will be performed at 26 fixed and random stations in Burger and Klondike and 24 stations in the Statoil survey area. Sampling of the epibenthos will occur at 13 fixed stations in Burger and Klondike and 11 stations in the Statoil survey area. Ultimately, the synthesis of the data will include a joining of the fisheries and benthic data to assess interrelationships, food web structure (through isotope and stomach analyses), and the overall ecology of the benthos.

2.2 Field Team Size and Composition

The benthic ecology field team will consist of three personnel for sampling infauna and two UAF personnel for epifaunal sampling. Two UAF people will be provided for the epibenthic sampling team with additional personnel provided by OLF as needed. The teams will be led by research technicians trained in field sampling.

2.3 Data Collection Procedures

Benthic organisms will be sampled at the three survey area sites in the summer of 2010. Infaunal benthic invertebrates will be sampled with a double 0.1 m^2 van Veen grab sampler at the 26 fixed and 26 random benthic stations sampled in 2008 and 2009 within the Burger and Klondike survey areas (13 of each type in each survey area) and 11 fixed and 13 random at the Statoil survey area. Three samples will be collected at each station. Three replicate samples are generally considered as the minimum number for benthic studies due to the high variability within a station. Samples will be washed through a 1.0-millimeter (mm) mesh stainless-steel screen until all that is left is biological material and larger sediments. Samples will be preserved in 10% buffered formalin. Identifications of each organism will be made to the lowest practical taxon (likely family level with dominants identified to species), counted and weighed (blotted wet weight). Average faunal abundance (individuals m^{-2}) and biomass (g m^{-2}) will be estimated for each site. Additional information collected at time of sampling includes sampling depth and GPS coordinates. This information will be recorded for every grab sample taken. Samples will be shipped to Fairbanks from Wainwright at the appropriate crew change. Sediments for sediment-grain-size analyses will be collected from the first grab at each station. Surface sediments will also be collected for percent organic carbon and nitrogen determinations and separately for chlorophyll and phaeopigment concentrations. These sediment samples will be frozen until delivery to UAF.

Epifauna of the Chukchi Sea will be sampled using a plumb staff 3.05 m beam trawl with a 4 mm codend liner and 7 mm mesh. The beam trawl covers a swath that is 2.26 m wide. Trawls will be towed at a constant speed of 1.5 knotsfor 3 minutes to 5 minutes. The thirteen fixed stations sampled for benthic infauna at Burger and Klondike and the 11 fixed stations at the Statoil survey area will be trawled. Material from each trawl will be subsampled to a volume of approximately 2 gallons. Taxonomic identifications of benthic organisms will be performed by a trained taxonomist to ensure consistency of identifications. All organisms in the subsample will be counted and wet weights (weight after excess moisture is removed with an absorbent towel: Feder et al. 1990) measured. Colonial organisms such as ascidiaceans, hydrozoans, bryozoans, and sponges will be noted for presence and wet weights determined. Representatives of each taxa will be frozen for stable isotope analysis to determine the food web structure of the Chukchi Sea. Once weighed, all organisms, except those kept for voucher collection and stable isotope analysis, will be returned to the ocean. Data collected in the field will be recorded on Write-in-the-Rain paper and entered into a MS Access database and returned to IMS as a record of taxonomic changes.

2.4 Analytical Procedures

2.4.1 Benthic Sampling

The number of replicate infaunal samples is estimated as 234 individual samples per year. It is anticipated that as many as 350 tissue isotope samples and 78 benthic chlorophyll a and sediment isotope samples will also be retained.

Benthic community data will be analyzed using appropriate and available statistical techniques. Descriptive measures, average abundance (individuals m^{-2}), biomass (g wet weight m^{-2}), and number of taxa, and diversity measures are useful for summarizing benthic infaunal information. Transformations of data are often required to meet assumptions of normality when using parametric statistical methods and will be considered. Expected transformations include the ln(x+1) transformation for abundance data and the ln(x) transform for biomass data. Data will be analyzed as appropriate using a range of methods including analysis of variance, linear regression, cluster analysis, and multidimensional scaling. Geostatistical methods may also apply. The emphasis in these analyses will be to document community structure of the benthic communities and determine their spatial variability. Depending on availability of results from the other components of the OLF Chukchi science team, such as contaminant concentrations, physical oceanography and zooplankton ecology, other methods including canonical correspondence analysis, may be performed to assess baseline associations between infaunal communities and environmental factors. Sediments will be analyzed for sediment-grain-size at a new UAF laboratory being established for this purpose. Surface sediments will be analyzed for percent organic carbon and nitrogen by the University of Alaska's Stable Isotope Laboratory. Chlorophyll will be determined using the flourometer purchased for zooplankton ecology and phaeopigment concentrations will be determined by trained IMS personnel.

Infaunal samples will be prioritized by station and replicate to provide data for the final report. First priority samples will include the first replicate of all fixed stations and random stations. Priority 2 will be the second replicates of the fixed and random stations and priority 3 will be the third replicates of the fixed and random stations. This will provide the data needed for the final report to draw conclusions about factors associated with benthic community structure (first priority) but will also allow completion of the remaining replicates to provide the data necessary for a full characterization of the infauna. Some epifaunal organisms will be retained for taxonomic analysis in the laboratory.

2.5 Data Storage Procedures

Data for this project will be entered and stored in computer systems at UAF. A MS Access benthic database entry system has been in use for a number of years at eliminating transcription and data entry errors by over 95%. The taxonomic names, counts, and wet biomass weights are entered and stored in the MS Access database but hard copies are printed out and archived as well. For the UAF system, backups of all data maintained there will be performed weekly. The data on the UAF computer system will be incorporated into MS Access databases and excel spreadsheets. The resulting data sets will be archived at COP as one of the project deliverables. The data archive at IMS also includes the original work in the Chukchi Sea performed by Dr. Howard Feder in 1986. These data are available and will be used for temporal comparisons. All data are georeferenced as longitude and latitude recorded for each sample collected.

Voucher collections will be maintained at the University of Alaska Fairbanks. The voucher collection will include at least one representative specimen of each species identified in the study. Specimens will be evaluated by a taxonomic specialist to ensure correct identification as necessary. Remaining biological specimens will be stored at IMS. Sorted sediment remains are not considered to be part of the biological samples and will be discarded once the sorting has been checked for accuracy. The identifications of voucher specimens will be confirmed by experts as necessary.

2.6 Quality Control Procedures

The following quality control procedures are followed in processing samples. The work of sorters is monitored throughout the project. At a minimum, 10%, but more often up to 50%, of samples sorted by student employees are checked as students are trained. Of the samples checked, the sorted material is examined to be certain that 100% of the organisms in each sample are removed. One hundred percent of the work performed by junior taxonomists is checked and verified by a senior taxonomist until trained. Work is verified to ensure that all counts are accurate and all organisms are correctly identified. A voucher collection is maintained at IMS and includes examples of organisms found throughout the thirty-year study period in Port Valdez. This collection is used to ensure that identification of organisms is consistent from year to year and may be sent to experts and museums for identifications and archiving. Sorted debris from each annual survey collection will be discarded once quality control checks have been performed.

3.0 COORDINATION

3.1 Olgoonik-Fairweather

The PI and research technicians will attend meetings and interact as needed OLF. Safety training will be provided by OLF. The epibenthic sampling will be coordinated with the Fisheries Ecology component ultimately providing a very powerful means to understand the ecology of the study area via the synoptic sampling.

3.2 Other Studies in the Chukchi Sea Program

Coordination and collaboration with scientists who are working on the Environmental Studies Program in the Chukchi Sea is expected through the coordination meetings and report preparation. It is anticipated that results from the other OLF Chukchi Sea projects will be available for determining factors associated with benthic community structure in the annual and final reports.

3.3 Current Studies in the Region

Dr. Arny Blanchard, a benthic biologist, invertebrate taxonomist, and statistician, will manage the project and ensure that the timeline deliverables are met. The field component for the 2008 and 2009 Chukchi Sea Environmental Baseline Studies programs were successfully completed and laboratory analyses performed under the supervision of Dr. Blanchard. Dr. Blanchard will oversee data collection, data entry, and provide guidance for the direction of the project. Dr. Blanchard will also oversee analysis and interpretation the data. Dr. Blanchard is the PI for the long-term environmental studies in Port Valdez, Alaska, assessing the influence of treated ballast-water discharges at the Valdez Marine Oil Terminal operated by Alyeska Pipeline Service Co. and has extensive experience in analyzing environmental data, and has served as lead taxonomist (i.e., RWJ Consulting, 2001) and statistician on projects in the Chukchi Sea (Naidu et al. 1997; Jewett et al. 1999; RWJ Consulting 2001; Feder et al. 2005, 2007). Dr. Blanchard is currently involved with the Alaska Monitoring and Assessment Program (AKMAP) which will be sampling in the nearshore Chukchi Sea in the summer of 2010. Collaboration includes consultation on taxonomy issues and eventually, analyses combining the historical data, results from the present multi-year investigation, and the AKMAP data may be performed.

4.0 DELIVERABLES

4.1 Field Data

Field data deliverables include the benthic abundance and biomass, sediment and tissue isotope ratios, and environmental data (chlorophyll, phaeopigments, grain size) for benthic stations sampled in 2010 in a spreadsheet format, to be included with the final report or as the data are verified.

4.2 Annual and Final Report

A draft report will be provided by May 15, 2011 summarizing findings of the 2010 environmental studies or as determined in association with OLF. The Final Report will be due within 30 days of reviewer comments being received by the investigator. The Final Report for the 2010 environmental studies will be comprised of the analysis of the benthic community data to describe benthic community structure from 2008 to 2010.

5.0 SCHEDULE WITH MILESTONES

5.1 2010 Field Studies

The schedule for field studies and related events:

- Final Study Plan — 22 June 2010.
- Field team will attend safety training in Anchorage July 14-17, 2010.
- Field work for the first cruise — estimated dates of 1 August to 1 September 2010 (32 days).

- Field work for the second cruise (epifauna) — estimated dates of 1 to 20 September 2010 (21 days).

5.2 2010 Coordination Meetings

The PI and research leads (as appropriate) will attend the coordination meetings including:

- Chukchi Sea scientific studies technical workshop during the AMSS in Anchorage, AK (2 days) — January 2011.

5.3 2010 Deliverables

The schedule for deliverables is:

- Monthly status reports (brief summaries of progress and budget details).
- Draft Report — due 15 May 2011. (Draft report based on 1st priority infaunal stations plus ½ 2nd priority stations completed.)
- Final Report — due 30 days after receipt of comments on Draft Report. (Final report based on infaunal data completed – taxonomic analyses may continue through fall.)
- Data submission for 1st priority stations plus completed 2nd priority stations — 30 June 2011.
- Data submission for remaining second and third priority stations — 31 October 2011

6.0 REFERENCES

Ambrose, W. G., Clough, L. M., Tilney, P. R., and Beer, L., 2001. Role of echinoderms in benthic remineralization in the Chukchi Sea. Marine Biology, 139: 937-949.

Barber, W. E., Smith, R. L., Vallarino, M., Meyer, R. M., 1997. Demersal fish assemblages of the northeastern Chukchi Sea, Alaska. Fishery Bulletin, 95: 195-209.

Blanchard, A. L., Feder, H. M., Shaw, D. G., 2002. Long-term investigation of benthic fauna and the influence of treated ballast water disposal in Port Valdez, Alaska. Marine Pollution Bulletin, 44: 367-382.

Blanchard, A. L., Feder, H. M., & Shaw, D. G., 2003. Variations of benthic fauna underneath an effluent mixing zone at a marine oil terminal in Port Valdez, Alaska. Marine Pollution Bulletin, 46: 1583-1589.

Blanchard, A. L., Feder, H. M., Hoberg, M. K., 2010a. Temporal Variability of Benthic Communities in an Alaskan Glacial Fjord, 1971-2007. Marine Environmental Research, 69: 65-107.

Blanchard, A. L., Nichols, H., Parris, C., 2010b. 2008 Environmental Studies Program in the Chukchi Sea: Benthic Ecology of the Burger and Klondike Survey Areas. Final report to ConocoPhillips, Inc. and Shell Exploration & Production Co. by the Institute of Marine Science, University of Alaska Fairbanks.

Blanchard, A. L., Parris, C., Nichols, H., 2010c. 2009 Environmental Studies Program in the Chukchi Sea: Benthic Ecology of the Burger and Klondike Survey Areas. Draft report to ConocoPhillips, Inc. and Shell Exploration & Production Co. by the Institute of Marine Science, University of Alaska Fairbanks.

Bluhm, B. A., Coyle, K. O., Konar, B., Highsmith, R., 2007. High gray whale relative abundances associated with an oceanographic front in the south-central Chukchi Sea. Deep Sea Research II, 54: 2919–2933.

Clarke, K. R., 1999. Nonmetric multivariate analysis in community-level ecotoxicology. Environmental Toxicology and Chemistry, 18: 118-127.

Coachman, L.K., 1987. Advection and mixing on the Bering-Chukchi Shelves. Component A. Advection and mixing of coastal water on high latitude shelves. ISHTAR 1986 Progress Report, Vol. 1. Institute of Marine Science, University of Alaska Fairbanks, pp 1-42.

Codispoti, L.A., Flagg, C., Kelly, V., Swift, J.H., 2005 Hydrographic conditions during the 2002 SBI process experiments. Deep-Sea Res. II 52: 3199-3226.

Colonell, J. M. (Ed.), 1980. Port Valdez, Alaska: Environmental Studies 1976-1979. Institute of Marine Science, University of Alaska, Fairbanks.

Feder, H. M., Jewett, S. C., & Blanchard, A., 2005. Southeastern Chukchi Sea (Alaska) epibenthos. Polar Biology, 28: 402-421.

Feder H. M, Jewett, S. C., Blanchard, A. L., 2007. Southeastern Chukchi Sea (Alaska) Macrobenthos. Polar Biology, 30: 261-275.

Feder, H. M., Foster, N. R., Jewett, S. C., Weingartner, T. J., Baxter, R., 1994. Mollusks of the northeastern Chukchi Sea. Arctic, 47: 145-163.

Feder, H. M., Naidu, A. S., Jewett, S. C., Hameedi, J. M., Johnson, W. R., Whitledge, T. E., 1994b. The northeastern Chukchi Sea: benthos-environmental interactions. Marine Ecology Progress Series, 111: 171-190.

Gray, J. S. and Christie, H., 1983. Predicting long-term changes in marine benthic communities. Marine Ecology Progress Series, 13: 87-94.

Grebmeier, J. M., Cooper, L. W., Feder, H. M., Sirenko, B. I., 2006. Ecosystem dynamics of the Pacific-influenced Northern Bering and Chukchi Seas in the Amerasian Arctic. Progress in Oceanography, 71: 331–361.

Grebmeier, J. M., McRoy, C. P., Feder, H. M., 1988. Pelagic-benthic coupling on the shelf of the norther Bering and Chukchi Seas. I. Food syupply source and benthic biomass. Marine Ecology Progress Series, 48: 57-67.

Highsmith, R. C., Coyle, K. O., Bluhm, B. A., Konar, B., 2006. Gray Whales in the Bering and Chukchi Seas. In Estes, J., DeMaster, D. P., Doak, D. F., Williams, T. M., Brownell, R. L. (eds) Whales, Whaling and Ocean Ecosystems. UC Press, pp 303-313

Hood, D. W., Shiels, W. E., Kelley, E. J. (Eds.), 1973. Environmental studies of Port Valdez. Institute of Marine Science, University of Alaska, Fairbanks, 495 pp.

Hopcroft, R., Bluhm, B., Gradinger, R., Whitledge, T., Weingartner, T., Norcross, B., Springer, A., 2006. Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research. Final report to North Pacific Research Board, 152 pp.

Iken, K., Bluhm, B., Dunton, K. Benthic food web structure serves as indicator of water mass properties in the southern Chukchi SeaDeep-Sea Research II, 75: 71-85.

Jewett, S.C., Feder, H.M., Blanchard, A., 1999. Assessment of the benthic environment following offshore placer mining in Northeastern Bering Sea. Marine Environmental Research, 48: 1-32.

Lovvorn, J. R., Richman, S. E., Grebmeier, J. M., Cooper, L. W., 2003. Diet and body condition of spectacled eiders wintering in pack ice of the Bering Sea. Polar Biology 26, 259-267.

May, S.J., Pearson, T.H., 1995. Effects of oil-industry operations on the macrobenthos of Sullom Voe. Proceedings of the Royal Society of Edinburgh (B) 103, 69-97.

Moore, S. E., Grebmeier, J. M., Davies, J. R., 2003. Gray whale distribution relative to forage habitat in the northern Bering Sea: current conditions and retrospective summary. Can. J, Zool, 81, 734-742.

Naidu, A. S., Blanchard, A., Kelley, J. J., Goering, J. J., Hameedi, J. M, Baskaran, M., 1997. Heavy metals in Chukchi Sea sediments as compared to selected circumpolar shelves. Marine Pollution Bulletin, 35:260-269.

Oliver, J. S., Slattery, P. N., O'Connor, E. F., Lowry, L. F., 1983. Walrus, Odobenus rosmarus, feeding in the Bering Sea: a benthic perspective. Fish. Bull. 81, 501-512.

Olsgard, F., Gray, J.S., 1995. A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. Marine Ecology Progress Series 122, 277-306.

Pearson, T.H., Mannvik, H-P., 1998. Long-term changes in the diversity and faunal structure of benthic communities in the northern North Sea: natural variability or induced instability? Hydrobiologia 375/376, 317-329.

RWJ Consulting, 2001. DeLong Mountain Terminal 2000 Environmental Studies. Final report to Cominco Alaska, Inc., 108 pp. + appendices.

Shaw, D. G., Hameedi, M. J. (Eds.), 1988. Environmental studies in Port Valdez, Alaska: A basis for management. New York: Springer-Verlag, 423

Stoker, S. W., 1978. Benthic invertebrate Macrofauna on the eastern continental shelf of Bering and Chukchi Seas. Ph.D. Dissertation. Institute of Marine Science, University of Alaska Fairbanks.

Weingartner, T. J., Aagaard, K., Woodgate, R., Danielson, S., Sasaki, Y., Cavalieri, D., 2005. Circulation on the north central Chukchi Sea shelf. Deep Sea Research II, 52: 3150-3174.

SECTION V
EVALUATING OCEAN ACIDIFICATION

JEREMY T. MATHIS
PRINCIPAL INVESTIGATOR
INSTITUTE OF MARINE SCIENCES, UNIVERSITY OF ALASKA
FAIRBANKS, AK

1.0 INTRODUCTION

1.1 The carbon cycle and ocean acidification in the Chukchi Sea

There have been relatively few studies of the marine carbon cycle in the Chukchi Sea (Bates et al. 2006; Semiletov 1999; Pipko et al. 2002; Murata and Takizawa 2003; Bates et al. 2005; Bates 2006; Chen and Gao 2007); however, it has been shown that shelf surface waters experience large seasonal drawdown of $p\text{CO}_2$ and dissolved inorganic carbon (DIC) during the open water season associated with high rates of phytoplankton primary production (PP) and cooling during water transit poleward (Bates et al. 2006). Early carbon mass balance estimates of the rate of air-sea CO_2 exchange suggested that the entire Arctic Ocean was a sink for CO_2 in the range of -70 to -129 Tg C year-^{1} (Anderson et al. 1990; Anderson et al. 1994; Lundberg and Haugen 1996) (note; negative values denote sink of CO_2; Tg = 10^{12} g), but subsequently revised downward to -24 to -31 Tg C yr^{-1} (Anderson et al. 1998; Kaltin and Anderson 2005). More recently, direct $\Delta\ p\text{CO}_2$ observations and air-sea CO_2 exchange rate estimates revised the Chukchi Sea shelf CO_2 sink alone as -36 to -53 Tg C yr^{-1} (Bates et al. 2006; Bates 2006; Kaltin and Anderson 2005). In comparison to the mean annual global ocean CO_2 uptake of approximately -1400 Tg C yr^{-1} (Takahashi et al. 2002; Takahashi et al. in press), the Arctic Ocean CO_2 sink potentially contributes ~5-14% to the global balance of CO_2 sinks and sources, and thus important for the global carbon cycle and climate change feedbacks.

The inorganic carbon cycle in the western Arctic Ocean is dominated by inter-ocean exchanges with Pacific derived water, with subsequent biogeochemical modifications and transformations of water while resident in the Arctic during transit between the north Pacific/Bering Sea and the central Arctic Ocean. In addition, river inputs (e.g. Cooper et al. 2005) of and materials, sea-ice production and melting, and atmosphere-ocean interaction and exchanges also have profound influence (Bates et al. 2009). The effect of physical and biological controls on the marine inorganic carbon cycle can be opposing or amplifying, dampening or variable in nature to the sink of CO_2 in the Arctic, making future predictions of the Arctic Ocean CO_2 sink/source trajectory difficult to make at present.

In the near-term, sea-ice loss is expected to increase the uptake of CO_2 by surface waters (Anderson and Kaltin 2001), but over time, inorganic carbon distributions, air-sea CO_2 disequilibrium and the capacity of the Arctic Ocean to uptake CO_2 is expected to alter in response to environmental changes driven largely by climate. The loss of sea-ice earlier this decade reduced % sea-ice cover (~36,000 $\text{km}^2\ \text{yr}^{-1}$; Cavalieri et al. 2003) and exposed undersaturated surface waters of the Chukchi Sea and central basin, thereby potentially increasing the Arctic Ocean CO_2 sink by 2.0 ±0.3 Tg C yr^{-1} (Bates et al. 2006). In 2007 and 2008, sea-ice extent reached a seasonal minima 25% lower than any previously observed in the satellite record constituting an additional exposure of

~600,000 km^2 of surface waters to air-sea gas exchange. Assuming a status quo of inorganic carbon distributions in surface waters of the Arctic, this recent loss of summertime sea-ice may have increased the ocean uptake of CO_2 in the Arctic by an additional -33 ±10 Tg C year^{-1} (Bates, 2009).

The loss of sea-ice in the Arctic and greater open water area should also enhance upwelling at the shelf-break and potentially increase the input of nutrients from subsurface waters to the Arctic shelves. In the Chukchi Sea, the phytoplankton-growing season has apparently increased in the last decade (Arrigo et al. 2008) with reduced sea-ice extent and longer open-water conditions, especially. As a consequence of increased phytoplankton PP, the drawdown of pCO_2 and DIC should increase the air-sea CO_2 disequilibrium (i.e., ΔpCO_2) and increase the net oceanic uptake of CO_2.

Other factors may also influence the marine inorganic carbon cycle and present-day CO_2 sink in the Arctic. Reduced sea-ice cover has been proposed to favor a 'phytoplankton–zooplankton' dominated ecosystem over the more typical 'sea-ice algae –benthos' ecosystem over the Arctic shelves in particular (Piepenburg 2005). At present on the highly productive Chukchi Sea shelf, ~10% of PP is converted to dissolved organic carbon (DOC) and ~15% of PP is converted to suspended particulate organic carbon (POC) (Mathis et al. 2007; Mathis et al. 2009) that gets exported from the shelf into the Canada Basin beneath the mixed layer (Bates et al. 2005). The remaining 75% of PP is exported from the mixed layer to the sea floor as sinking particles that sustain the rich benthos on the sea floor of the Chukchi Sea shelf. In the Bering Sea, earlier sea-ice loss has led to ecosystem changes and altered pelagic-benthic coupling (e.g. Grebmeier et al. 2008). If there are ecosystem shifts in the future, for example on the Chukchi Sea shelf, the export of organic carbon and pelagic-benthic coupling might decrease, despite concurrent increases in phytoplankton PP.

As a consequence of the ocean uptake of anthropogenic CO_2, surface pCO_2 and DIC contents have increased while pH has decreased in the upper ocean over the last few decades (Winn et al. 1994; Bates et al. 1996; Bates 2007; Bates and Peters 2007). This gradual process, termed ocean acidification, has long been recognized by chemical oceanographers (Broecker and Takahashi 1971; Broeker et al. 1973; Bacastow et al. 1973). The predicted ocean uptake of anthropogenic CO_2 using the IPCC (Intergovernmental Panel on Climate Change) scenarios is expected to increase hydrogen ion concentration by 185% and decrease pH by 0.3-0.5 units over the next century and beyond (Solomons et al. 2007; Caldeira and Wickett 2003; Caldeira and Wickett 2005; Doney 2006), with the Arctic impacted before other regions (Orr et al. 2005; Steinacher et al. 2009). The effects of ocean acidification are potentially far-reaching in the global ocean, particularly for calcifying fauna (Buddemeier et al. 2004; Royal Society 2005; Fabry et al. 2008) but its impact on Arctic Ocean ecosystems is uncertain at present.

Ocean acidification and decreased pH reduces the saturation states (Ω) of calcium carbonate ($CaCO_3$) minerals such as aragonite (Ωaragonite) and calcite (Ωcalcite), with many studies showing decreased $CaCO_3$ production by calcifying fauna and increased dissolution of $CaCO_3$ in the water-column and sediments. Recently, upwelling and impingement of corrosive waters to $CaCO_3$ has been demonstrated (Feely et al.,2008) on the west coast of the U.S. In the Arctic Ocean, potentially corrosive waters are found in the halocline layer of the central basin (Jutterstrom and Anderson 2005). On the Chukchi Sea, waters corrosive to $CaCO_3$ seasonally impact the shelf sediments and benthos due to summertime phytoplankton PP, vertical export of organic carbon and buildup of CO_2 in subsurface waters that has been amplified by ocean acidification over the last century (Bates et al. in press). Given the scenarios for pH changes in the Arctic

Ocean, the Arctic shelves will be increasingly impacted by ocean acidification and presence of carbonate mineral undersaturated waters, with implications for shelled benthic fauna, and those animals that feed on the benthos (Feder et al. 1994; Feder et al. 2005; Feder et al. 2007).

1.2 Objectives of Study

The primary objective is to describe spatial, seasonal and interannual variability in the marine carbon cycle to assess the extent and potential impacts of ocean acidification. It is critical to assess the extent and controls on ocean acidification concurrent with other physical and chemical (i.e., nutrients) oceanographic measurements to ensure that appropriate baselines are available for the water column. Secondarily, we will obtain data that will better characterize how much of a sink the Chukchi Sea provides for atmospheric CO_2, which will be critical to long-term projections of how the Arctic Ocean will responds under future climate scenarios.

2.0 METHODS AND PROCEDURES

2.1 Sampling or Survey Design and Technical Rationale

We propose to sample two 30 X 30 nm boxes, with a grid of 5 X 5 stations, at ~7.5-nm spacing, within Klondike and Burger, and one irregular shaped box (Statoil) of ~900 sq nm consisting of 22 stations at ~7.5nm spacing in addition to 4 stations shared between Statoil and Burger. Both DIC and total alkalinity (TA) will be measured. Together with nutrients and T/S data we can calculate water column pH to ±0.001. A coarser 5 X 5 grid at ~30 nm (i.e., from 161–167°W and from 70–72°N) is strongly suggested in the future to provide oceanographic context. In general, re-sampling of fixed sampling locations over time along transects/grids (a model-based rather than a probability-based design) will provide the highest power for statistical comparisons between years (but limit inferences) and will result in spatially and temporally correlated data as atmospheric CO_2 levels rise. Samples will be collected at every other station to coincide with inorganic nutrient analysis. Approximately 450 samples will be collected for DIC/TA and will be used to determine pH and water column carbonate chemistry including saturations for the two most important carbonate ions (calcite and aragonite).

2.2 Field Team Size and Composition

Field samples for this project will be collected by Jennifer Questel or Imme Rutzen on the three cruises in 2010. We are not requesting to send a dedicated person due to berthing limitations on the vessel. Sample collection for DIC/TA is straight forward and will not interfere with any other activities and will require a minimal amount of time.

2.3 Data-collection Procedures

Samples for DIC and TA will be drawn from the core hydrography CTD/hydrocast. Samples are fixed with saturated mercuric chloride solution (200 µl), the bottles sealed, and stored until analysis. To eliminate the handling of mercuric chloride onboard the vessel the sample bottles will be pretreated. The bottles will then be filled using a 12” piece of flexible Teflon tubing attached to the Nisken bottle. An effort will be made to reduce the amount of bubbling that occurs while the bottle is filled. We anticipate ~120 - 150 samples to be taken during each cruise (360 – 450 total samples).

2.4 Analytical Procedures

DIC and TA samples will be shipped back to UAF and analyzed using a VINDTA (Versatile Instrument for Detection of TA) DIC/TA analytical system in Mathis' Chemical Oceanography lab. High-quality DIC data is achieved using a highly precise (0.02%; 0.4 µmoles kg-1) VINDTA-coulometer system. Accuracy of DIC (and TA) measurements will be maintained by routine analyses of Certified Reference Materials (CRM's, provided by A.G. Dickson, Scripps Institution of Oceanography).

2.5 Data-storage Procedures

Data files collected during cruises will be backed up periodically, and multiple copies will be transported back to UAF at the completion of each cruise along with copies of notebooks. At UAF, data are backed up routinely onto departmental servers.

2.6 Quality-control Procedures

Inorganic carbon datasets from the project will be prepared expeditiously in post-cruise analysis and synthesis using established integrated steps. For water-column observations, QC/QA protocols follow established methods for the repeat hydrography and U.S. time-series programs. Routine CRM analyses provide high-quality data and initial QC/QA diagnostics for DIC and TA measurements from the field program. Subsequently, DIC and TA data will be merged with core hydrographic data (e.g., T, S, inorganic nutrients) and quality flagged as good, questionable and bad data (e.g., bottle misfires, analytical problems, etc.).

3.0 COORDINATION

3.1 Olgoonik-Fairweather LLC

The PI, or an alternate team member, will attend all proposed meeting and interacts regularly as needed with OLF.

3.2 Other Studies in the Chukchi Sea Program

The PI regularly interacts with other PIs currently at UAF and has a long collaborative relationship with Dr. Weingartner, in particular, through the GLOBEC and NPRB Seward Line time-series. Dr. Mathis is currently working on a multidisciplinary synthesis of the marine carbon cycle in the Chukchi and Beaufort region, which has connected him to investigators in may other disciplines.

3.3 Current Studies in the Region

Recent and ongoing studies have been described in Section 1.1. Dr. Mathis is a PI within the NASA-funded ICECAPES program beginning in July 2010, which will be sampling over a broad domain of the Chukchi Sea. Dr. Mathis and his students are actively involved with the BEST program in the Bering Sea, as well as synthesis efforts in the Pacific sector of the Arctic Ocean.

4.0 DELIVERABLES

4.1 Field Data

A list of sampling activities will be submitted within 30 days of the final cruise.

4.2 Draft Report

Provided there is no delay in shipping samples to UAF at the completion of the final cruise, the Draft Report, including appendices with sample analysis, will be submitted by 1 October 2011.

4.3 Final Report

The Final Report will be submitted 1 December 2011 or within 30 days of receipt of comments on the Draft Report.

5.0 SCHEDULE WITH MILESTONES

Field Studies

- Early July 2010— Planning meeting, ship walk-through, (Anchorage)
- Late July–mid October 2010 — 3 Cruises

Coordination Meetings

- May 2010 —Olgoonik-Fairweather Chukchi Sea scientific studies kickoff meeting, and scientific studies coordination meeting. Fairbanks, AK (1 day)
- Early July 2010 — Olgoonik-Fairweather training and coordination meeting (Seattle)
- Nov. 2010 — Olgoonik-Fairweather Chukchi Sea scientific studies debriefing. Anchorage, AK (1 day)
- Jan 2011 — Chukchi Sea scientific studies technical workshop at Alaska Marine Science Symposium, Anchorage (2 days)
- Deliverables
- Field data (i.e. # of samples collected and locations) — within 30 days of final cruise.
- Draft Report — 1 October 2011.
- Final Report—1 December 2011 or within 30 days of receipt of comments on Draft Report.

6.0 REFERENCES

Anderson, L.G., Dyrssen, D., and Jones, E.P., 1990. An assessment of the transport of atmospheric CO_2 into the Arctic Ocean. Journal of Geophysical Research, 95, 1703-1711.

Anderson, L.G., Olsson, K., and Skoog, A., 1994. Distributions of dissolved inorganic and organic carbon in the Eurasian Basin of the Arctic Ocean. In The Polar Oceans and Their Role in Shaping the Global Environment (O.M. Johannessen, .D. Muench, and JE. Overland, editors). American Geophysical Union, Geophysical Monograph, 85, 252-262.

Anderson, L.G., Olsson, K., and Chierici, M., 1998a. A carbon budget for the Arctic Ocean. Global Biogeochemical Cycles, 12 (3), 455-465.

Anderson, L.G., and Kaltin, S., 2001. Carbon fluxes in the Arctic Ocean - potential impact by climate change. Polar Research, 20 (2), 225-232.

Arrigo, K.R., van Dijken, G.L., and Pabi, S., 2008. The impact of a shrinking Arctic ice cover on marine primary production. Geophysical Research Letters, 35, L19603, doi:10.1029/2008GL035028.

Bacastow, R.D., and Keeling, C.D., 1973. Atmospheric carbon dioxide and radiocarbon in the natural carbon cycle: II. Changes from A.D. 1700 to 2070 as deduced from a geochemical model. In: Woodwell, G.M., and Pecan, E.V. (editors) Carbon and the biosphere. U.S. Atomic Energy Commission, pp. 86-135.

Bates, N.R., Moran, S.B., Hansell, D.A., and Mathis, J.T., 2006. An increasing CO_2 sink in the Arctic Ocean due to sea-ice loss? Geophysical Research Letters, 33, L23609, doi:10.1029/2006GL027028.

Bates, N.R., 2009. The Arctic Ocean Marine Carbon Cycle: Estimates of Air-Sea CO_2 Exchanges and Potential Feedbacks. Chapter in review for the WWF report on Arctic Ocean Feedbacks.

Bates, N.R., Best, M.H.P., and Hansell, D.A., 2005. Spatio-temporal distribution of dissolved inorganic carbon and net community production in the Chukchi and Beaufort Seas. Deep-Sea Research II, 52, 3303-3323.

Bates, N.R., Hansell, D.A., Moran, S.B., and Codispoti, L.A., 2005b. Seasonal and spatial distributions of particulate organic matter (POM) in the Chukchi Sea. Deep-Sea Research II, 52, 3324-3343.

Bates, N.R., Michaels, A.F., and Knap, A.H., 1996. Seasonal and interannual variability of the oceanic carbon dioxide system at the U.S. JGOFS Bermuda Atlantic Time-series Site. Deep-Sea Research II, 43(2-3), 347-383.

Bates, N.R., 2006. Air-sea CO_2 fluxes and the continental shelf pump of carbon in the Chukchi Sea adjacent to the Arctic Ocean. Journal of Geophysical Research (Oceans), 111, C10013, doi 10.129/2005JC003083, 12 Oct. 2006.

Bates, N.R., 2007. Interannual variability of the oceanic CO2 sink in the subtropical gyre of the North Atlantic Ocean over the last two decades. Journal of Geophysical Research (Oceans), 112, doi:10.1029/2006JC003759.

Bates, N.R., and Peters, A.J., 2007. The contribution of atmospheric acid deposition to ocean acidification in the subtropical North Atlantic Ocean. Marine Chemistry, 107, 547-558.

Broecker, W.S., and Takahashi, T., 1966. Calcium carbonate precipitation on the Bahama Banks. Journal of Geophysical Research, 71, 1575–1602.

Broecker, W.S., Li, Y-H., Peng, T-H., 1971. Carbon dioxide—man's unseen artifact. In: Hood, D.W. (editor) Impingement of man on the oceans. John Wiley and Sons, Inc, pp 287-324.

Buddemeier, R.W., Kleypas, J.A., and Aronson, R.B., 2004. Coral Reefs and Global Climate Change: Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems, p. 44, (download report at http://www.pewclimate.org/global-warmingindepth/all_reports /coral_reefs/index.cfm). Pew Center on Climate Change.

Caldeira, K., and Wickett, M.E., 2003. Anthropogenic carbon and ocean pH, Nature, 425 (6956), 365-365.

Caldeira, K., and Wickett, M.E., 2005. Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean. Journal of Geophysical Research, Oceans, 110, (C9), C09S04, doi 10.1029/2004JC002671.

Cavalieri, D.J., Parkinson, C.L. and Vinnikov, K.Y., 2003. 30-year satellite record reveals contrasting Arctic and Antarctic decadal sea ice variability. Geophysical Research Letters, 30 (18), Art. No. 1970 SEP 30 2003.

Chen, L., and Gao, Z., 2007. Spatial variability in the partial pressures of CO_2 in the northern Bering and Chukchi Seas. Deep-Sea Research II, 54, 2619-2629.

Cooper, L.W., Benner, R., McClelland, J.R., Peterson, B.J., Holmes, R.M., Raymond, P.A., Hansell, D.A., Grebmeier, J.M., and Codispoti, L.A., 2005. The linkage between runoff, dissolved organic carbon, and the stable oxygen isotope composition of seawater and other water mass indicators in the Arctic Ocean. Journal of Geophysical Research, 110, G02013, doi:1029/2005JG000031.

Doney, S.C., 2006. The dangers of ocean acidification. Scientific American, March 2006, 58-65.

Fabry, V.J., Seibel, B.A., Feely, R.A., and Orr, J.C. 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. ICES Journal of Marine Science, 65, 414–432.

Feder, H.M., Naidu, A.S., Jewett S.C., Hameedi, J.M., Johnson, W.R., and Whitledge, T.E., 1994. The northeastern Chukchi Sea-benthos-environmental interactions. Marine Ecology Progress Series, 111, 171-198.

Feder, H.M., Jewett S.C., and Blanchard A., 2005. Southeastern Chukchi Sea (Alaska) epibenthos. Polar Biology, 28(5), 402-421.

Feder, H.M., Jewett S.C., and Blanchard A., 2007. Southeastern Chukchi Sea (Alaska) macrobenthos. Polar Biology, 30 3), 261-275.

Feely, R.A., Sabine, C.L, Hernandez-Ayon, J.M., Ianson, D., and Hales, B., 2008. Evidence for upwelling of corrosive "acidified" water onto the continental shelf. Science, 320, 1490-1492.

Grebmeier, J.M., Bates, N.R., and Devol, A. 2008. Continental Margins of the Arctic Ocean and Bering Sea. In North American Continental Margins: A Synthesis and Planning Workshop. U.S. Carbon Cycle Science Program, Washington D.C., (Editors, B. Hales, W.-J. Cai., B.G. Mitchell, C.L. Sabine and O. Schofield, 120 pp), p. 61-72.

Jutterström, S., and Anderson, L.G., 2005. The saturation of calcite and aragonite in the Arctic Ocean. Marine Chemistry, 94, 101-110.

Kaltin, S., and Anderson, L.G., 2005. Uptake of atmospheric carbon dioxide in Arctic shelf seas: Evaluation of the relative importance of processes that influence pCO_2 in water transported over the Bering-Chukchi Sea shelf. Marine Chemistry, 94, 67–79,

Lundberg, L., and Haugen, P.M., 1996. A Nordic Seas – Arctic Ocean carbon budget from volume flows and inorganic carbon data. Global Biogeochemical Cycles, 10, 493–510.

Mathis, J.T., Hansell, D.A., Kadko, D., Bates, N.R., and Cooper, L.W., 2007b. Determining net DOC production in the hydrographically complex western Arctic Ocean. Limnology and Oceanography, 52(5), 1789-1799.

Mathis, J.T., Hansell, D.A., and Bates, N.R., 2009. Interannual variability of dissolved inorganic carbon distribution and net community production during the Western Arctic Shelf-Basin Interactions Project. Deep-Sea Research II (in press).

Murata, A., and Takizawa, T., 2003. Summertime CO_2 sinks in shelf and slope waters of the western Arctic Ocean. Continental Shelf Research, 23 (8), 753-776.

Orr, J.C., Fabry, V.J., Aumont, O., Bopp, L., Doney, S.C., Feely, R.A., Gnanadesikan, A., Gruber, N., Ishida, A., Joos, F., Key, R.M., Lindsay, K., Maier-Reimer, E., Matear, R., Monfray, P., Mouchet, A., Najjar, R.G., Plattner, G. K., Rodgers, K.B., Sabine, C.L., Sarmiento, J.L., Schlitzer, R., Slater, R D., Totterdell, I.J., Weirig, M.F., Yamanaka, Y., and Yool, A., 2005. Anthropogenic ocean acidification over the twenty-first century and its impacts on calcifying organisms. Nature, 437, 681–686.

Piepenburg, D., 2005. Recent research on Arctic benthos: common notions need to be revised. Polar Biology, 28(10), 733-755.

Pipko I.I., Semiletov I.P., Tishchenko P.Y., Pugach S.P., and Christensen J.P., 2002. Carbonate chemistry dynamics in Bering Strait and the Chukchi Sea. Progress Oceanography, 55 (1-2), 77-94.

Royal Society, 2005. Ocean acidification due to increasing atmospheric carbon dioxide. The Clyvedon Press, Ltd, Cardiff, UK.

Semiletov, I.P., 1999. Aquatic sources of CO_2 and CH_4 in the Polar regions. Journal of Atmospheric Sciences, 56(2), 286-306.

Solomons, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M.M.B., Miller, H.L., and Chen, Z., 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge Univ. Press, Cambridge and New York, 2007).

Steinacher, M., Joos, F., Frolicher, T.L., Plattner, G.-K., and Doney, S.C., 2009. Imminent ocean acidification of the Arctic projected with the NCAR global coupled carbon-cycle climate model. Biogeosciences, 6, 515-533.

Takahashi, T., Sutherland, S.G., Sweeney, C., Poisson, A.P., Metzl, N., Tilbrook, B., Bates, N.R., Wanninkhof, R.H., Feely, R.A., Sabine, C.L., and Olafsson, J., 2002. Biological and temperature effects on seasonal changes of $p\mathrm{CO}_2$ in global ocean surface waters. Deep-Sea Research II, 49, 1601-1622.

Takahashi, T., Sutherland, S.C., Wanninkhof, R., Sweeney, C., Feely, R.A., Chipman, D.W., Hales, B., Friederich, G.E., Chavez, F.P., Watson, A.J., Bakker, D.C.E., Schuster, U., Metzl, N., Yoshikawa-Inoue, H., Olafsson, J., Arnarson, T.S., Tilbrook, B., Johannessen, T., Olsen, A., Bellerby, R.J., de Baar, H.J.W., Nojiri, Y., Wong, C.S., Delille, B., and Bates, N.R., 2009. Climatological mean and decadal change in surface ocean $p\mathrm{CO}_2$, and net sea-air CO_2 flux over the global oceans. Deep-Sea Research II (in press).

Winn, C.D., Mackenzie, F.T., Carillo, C.J., Sabine, C.L., and Karl, D.M., 1994. Air-sea carbon dioxide exchange in the North Pacific subtropical gyre: Implications for the global carbon budget. Global Biogeochemical Cycles, 6, 157-163.

SECTION VI
FISHERIES ECOLOGY

BENNY GALLAWAY & ROBERT MEYER
CO-PRINCIPAL INVESTIGATORS
LGL ALASKA RESEARCH ASSOCIATES, INC.
ANCHORAGE, AK

1.0 INTRODUCTION

1.1 Brief History of Subject Research in Chukchi Sea

Fishes are the least-studied biological group in the western Arctic, if one considers the number of gear deployments that have taken place. There have been far more observations of lower trophic levels such as zooplankton and benthos, and higher trophic levels such as seals and whales, than of fishes in Arctic regions. Most of what is known about the ecology and life history of Alaskan Arctic marine fishes comes from work associated with marine mammals (Frost and Lowry 1981, 1983, 1984) and oil and gas exploration (Craig and McCart 1976; Craig et al. 1982, 1984). The general consensus seems to be that little is known about the ecosystem in general and Arctic marine fishes in particular (e.g., Johnson 1997; Power 1997; Mecklenburg et al. 2002; MMS 2006). The paucity of information on fish distribution and ecology is a critical gap in the understanding of this changing ecosystem.

Very little is known about arctic fish species that have no commercial or cultural significance (Power 1997). It is important to note that no commercial fisheries target fishes in the offshore Chukchi Sea, and that fishes utilized by subsistence users are nearly all nearshore (defined as within 20 miles of shore). Existing information published on fish distribution in the northeastern Chukchi Sea, including online sources, peer-reviewed and gray literature, is based entirely on catches of demersal fish trawls and ichthyoplankton collected 1959 – 1992, and the 2004 –2008 research in which UAF participated. In the early 1990s, 72 fish species were thought to occupy the Chukchi Sea, and more recently FishBase (Froese and Pauly 2006) lists 80 species of fishes inhabiting the Chukchi Sea. The majority of these species are demersal (living on or near the bottom), many are benthopelagic (living or feeding near the bottom as well as in mid-water or near the surface), and far fewer are pelagic (at surface or mid-depths), bathydemersal (living below 200 m), or reef-associated. The dominant Arctic fish families are cods, eelpouts, snailfishes, sculpins, and salmonids. Arctic cod was the dominant species captured in all earlier surveys (Alverson and Wilimovsky 1966; Frost and Lowry 1983; Fechhelm et al. 1985; Barber et al. 1997).

As it has the highest commercial importance, Arctic cod is also the best studied species (Hop et al. 1997). Recent distributional, biological, and ecological knowledge about fishes in the northern Chukchi Sea comes from cruises in 1990 – 91 (Barber et al. 1997), 1991 – 92 (Hokkaido University 1992, 1993), the RUSALCA 2004 expedition (Mecklenburg and Sheiko 2006; Mecklenburg et al. 2007; Norcross et al. submitted) and our unpublished collections from three cruises in the northeastern Chukchi Sea in July-September 2007 and 2008. The 15,061 fishes caught by bottom trawl during those three recent cruises were predominantly (>80% by number) sculpins, pricklebacks, cods, and flatfishes. Other fishes such as eelpouts, ronquils, snailfishes, and poachers also were captured.

The Chukchi Sea has an extremely high biomass of benthic organisms for an Arctic area (Grebmeier and Dunton 2000). Until recently, the northern Bering Sea has been a benthic-dominated ecosystem, i.e., very similar to that of the Chukchi Sea. With Arctic warming (ACIA 2004, www.amap.no/acia), the composition of marine fish and benthic communities is expected to change. The northern Bering Sea is now shifting from a shallow, ice-dominated system in which bottom-dwelling fishes prevail to one more dominated by pelagic fishes (Grebmeier et al. 2006). It is possible that the Chukchi Sea may experience similar changes, but those changes cannot be detected without a baseline of the current state of ecosystem. Scientific collections in 2004 documented some species of demersal fishes in the Chukchi Sea north of where they had been observed in earlier years (Mecklenburg et al. 2007). This could be because of northward expansion of fishes or merely due to an increased northward effort of scientific sampling in the Chukchi Sea. Observed changes in distribution and abundance of walleye pollock (*Theragra chalcogramma*) and Arctic cod (*Boreogadus saida*), in response to changes in sea ice cover and subsurface temperatures, provide insight as to how Arctic climate change affects marine ecosystems (Wyllie-Echeverria and Wooster 1998). With the limited availability of information in the Chukchi Sea, we can only speculate what may be occurring in benthic and pelagic biological communities, and the proposed research will yield much needed baseline data necessary to describe and quantify potential changes in these communities.

1.2 Objectives

The objective of this study is to better understand the ecology of fishes in the study areas. Specific objectives of the proposed work are to assess:

Task 1: Fish ecology

- Sample demersal and midwater fishes within the Chukchi Sea and document distribution, abundance and community structure

Task 2: Fish ages

- Use otoliths to age demersal and pelagic fishes to document maximum age of fishes, size at age, and age-related changes in diet

Task 3: Fish feeding ecology

- Examine stomach contents to assess the relative importance of prey taxa in demersal and pelagic fish diets
- Document the seasonal and interannual trophic level of demersal and pelagic fishes
- Assess the trophic level of demersal and pelagic fish prey

Task 4: Synthesize results

- Relate physical characteristics within the Chukchi Sea to distribution and community structure of demersal and pelagic fishes
- Assess linkages between demersal and pelagic fish communities
- Relate age and size of fishes to feeding ecology
- Associate the overall fish ecology and feeding ecology of fishes in the three study areas to that of the broader Chukchi Sea area.

2.0 METHODS AND PROCEDURES

2.1 Field Team Size and Composition

The Fisheries field team will consist of 3 LGL personnel: Robert Meyer, Justin Priest, and Steve Crawford and one UAF personnel: Lorena Edenfield. Robert Meyer (LGL), co-PI and field party chief, a Fisheries Oceanographer with many years of working offshore and in the Arctic

2.2 Data Collection Procedures

We will use a beam trawl to collect demersal fishes and epibenthos and a small 10 x 8 midwater trawl to collect pelagic fishes. We are planning on working closely with the epibenthic invertebrate group by fishing their plumb staff trawl and sharing samples collected between the two groups.

Our objective is to collect representative samples of fishes within the study area while minimizing bycatch of non-target species and bottom disruption. Much of the area to be sampled is characterized by a veneer of soft mud with sand, gravel and some cobble-sized stones. It is also characterized by dense patches of epibenthic invertebrates, with brittle stars occurring arm-to-arm. The beam trawl we are proposing to use is designed to sample small demersal fishes. However, when this gear clogs with epibenthos and mud, fish sampling effectiveness is minimized. Therefore, as needed, towing time will be reduced to further reduce bycatch.

Historically, otter trawls have been used to sample fish in the Chukchi Sea, but in the soft bottom environments characteristic of our study area, standard otter trawls doors will sink into the mud as will the foot rope. The result is that both bottom impacts and bycatch would likely be high if we deployed otter trawls. Beam trawls were originally developed for sampling soft-bottom habitats where gears like otter trawls sink into the mud and we have designed a beam trawl to deal with the specific soft-bottom and bycatch issues characteristic of our area. However, concerns remain about the potential impacts of our proposed gear. We recognize and appreciate the concern for the possible impact of our beam trawling on the benthic in- and epifauna—especially given the direct experience of project personnel with the plumb-staff beam trawl. Let me outline the steps we have taken to minimize such impacts. First, we have reduced the size to about one third (5-m beam) of our original concept (15 m). Second, the shoes on each side into which the beam is inserted are equipped with wide “skies” designed to cause the net frame to skim over the sea bottom. Further, the trawl foot rope is equipped with rollers which raise the foot rope above the bottom and enable it to flow over the soft bottom, minimizing the collection of epibenthic invertebrates and bottom disruption. In addition, the floor and bottom of the trawl are constructed from light, synthetic webbing so that they too will float above the bottom, and minimize bottom habitat disruption and bycatch. By flying the net close to but not directly on the bottom, we believe we will take advantage of the fishes escape behavior by capturing them as they swim up off the bottom above the epibenthos. We believe these features will enable us to effectively collect fish and, at the same time, minimize bottom disruption and invertebrate bycatch.

While we believe our base plan is good, we have enough experience to know that on some occasions, events (currents, bottom change and topography, etc) will conspire against us and will cause the net to over sample the epibenthos. We have outfitted the net with a zipper so that when things go wrong we can empty the net quickly, minimizing mortality of the catch. Lastly, if all these design features somehow fail to work, we will modify our towing time to minimize by catch. We commit to working closely with the Chief Scientist to insure that our sampling is conducted in a manner that will minimize impacts on the benthic system.

After the epibenthic team has recovered their plumb staff trawl (we will conduct this sampling and help sort the catch which will be taken by other researchers) and the deck has been cleared, the fisheries team launch the 5 m beam trawl to capture demersal fishes. This will be followed, assuming time is available, with the launching of the 10 by 8 meter pelagic (midwater) trawl to sample pelagic fishes. The primary target of the pelagic net will be the scattering layer often observed between 10 to 20 meters off bottom.

Demersal fishes will be captured using a 5-m beam trawl having a 5-m tubular beam supported by steel beam heads at each end. The beam heads have wide shoes at the bottom which slide over the seabed thereby, reducing the by catch of epibenthic invertebrates. The beam and beam heads form a rigid framework that provides a constant trawl-mouth opening of 1 by 5 meters. The trawl net will have a graduated mesh ranging from 3-in mesh at the mouth, to 2-in mesh in mid-section, to 0.5-in mesh in the cod end. A small mesh liner will be placed in the cod end of the net.

The beam trawl will be towed in the direction of the current at approximately 2 kts for approximately 30 minutes of bottom time. Towing time may be adjusted depending on the catch rate and by catch. Total wire time will be on the order of an hour or so per tow.

In the pelagic fish study, as time permits, we plan to use a 10 by 8-m mid-water trawl, towing with the current at about 3 kts to collect pelagic fishes. The net will be towed at a depth to sample the the scattering layer commonly found at a depth 25 meters. The net will be towed for about 30 minutes. However, towing time may be adjusted depending on the catch rates. This net will be equipped with a time depth recorder (TDR) to verify the time spent sampling each depth strata. The pelagic fish community has seldom been sample but is likely a critical component of the Chukchi Sea ecosystem. The exact protocols will be developed at sea by Mr. Meyer.

Time, depth, latitude, longitude, speed over ground, and course over ground will be recorded by bridge personnel at four points during trawling, when the mouth of the net is at the surface (in), trawl warp is paid out (at depth), trawl warp begins to be pulled back (haul back), and the mouth of the net is hauled above the surface (out). In addition, a TDR will be attached to the trawl headrope to provide post-tow verification of the time that the trawl was on the bottom. The recorded TDR data are examined after each tow.

The beam trawl will be brought aboard, the entire catch photographed, and fishes and epibenthos will be processed. Animals will be sorted on deck into taxonomic groups, counted and a weight recorded for each taxon. Fishes will be identified to species, measured to the nearest mm of total length and frozen for subsequent laboratory examination; up to 100 fish of each species per site will be retained. Voucher samples of species having delicate tissues, e.g., snailfishes, will be retained in 10% buffered formalin. When time permits, photographs will be taken of fresh fish specimens.

Samples of fish from each station will be frozen and retained onboard for University of Alaska Researchers (Dr's. Brenda Norcross and Brenda Holladay). Associated epibenthic invertebrates will be provided to the epibenthic team.

2.3 Data Analysis Procedures

The data collected at sea will be entered into an electronic relational database for analysis. We will (1) analyze patterns of distributions and abundance and age-length structure for key species, and relate these to environmental and ecosystem attributes and (2) describe the overall fish community structure and diversity at each site. We will also, based on the location of the proposed drilling sites, divide the station arrays into stations most subject to potential impact (impact stations) versus those which are unlikely to be impacted by future drilling activities (control stations). These data will provide the "Before" component of a Before-After/Impact-Control or BACI impact assessment model which will ultimately be used to determine the actual level of impacts from each of the developments.

As noted, we will also describe baseline species diversity patterns. Species diversity can be separated into two components, richness (the number of species) and evenness. Most, if not all, diversity indices combine them in various ways to yield confounded results. It is not possible to tell whether one site yields a higher diversity index (e.g., the Shannon-Wiener index) relative to another because its individuals are more evenly distributed across species or because it possesses more species. Therefore, we will analyze species richness and evenness separately each as univariate metrics.

Another way of testing community level effects besides richness and evenness is to index assemblage structure. Species abundances in each sample will be converted to proportional abundances (abundance of a species in the sample/total abundance across all species in the sample). Proportional abundances represent a multivariate index that can be compared across categorical variables to assess whether subtle changes in the fish community are occurring.

In addition, at each station and for all stations combined, species composition number and weights and length frequencies per species will be compared and contrasted thereby providing a direct comparison with fish samples collected by this project in 2009. These catch statistics will also be compared directly with the historic fisheries research conducted in the area from 1989 through 1991 (Barber et al., 1994 & 1997) and other research in the area.

2.3.1 Laboratory and statistical analyses

In the Fisheries Oceanography lab at UAF in Fairbanks, the age structure of fishes will be assessed using fish ear bones (otoliths). Annually, alternating opaque (summer) and translucent (winter) rings are deposited on the otolith, and these alternating rings can be counted to determine fish age. We will follow the break and burn method of aging otoliths that is typically used by the Alaska Fisheries Science Center (AFSC 2008), where the otolith is cut in half and then held over a flame until the protein contained in the otolith reacts with the heat by changing color, emphasizing the annuli that can then be examined under a dissecting microscope. Length frequency will be analyzed of each species based on field data collections, and within each apparent size class of a species, 60 otoliths will be aged. If size classes are not evident, then we will examine up to 20 individuals within each 10 mm increment of fish length. Prior to the 2010 cruise, we will complete otolith aging of the most abundant fishes caught in 2009, thereby forming a baseline to assist the allocation of the aging effort on 2010 collections toward species and length ranges needing additional clarification. Over the course of the project, all fish species will be aged.

Analysis abundance, distribution and community composition of demersal and pelagic fishes is analogous to that planned for benthic communities; therefore statistical methods will generally follow those designed for benthic community analysis by Dr. Arny Blanchard. Statistical methods used may include regression, analysis of variance, correlation testing, geostatistical analyses, and multivariate methods such as cluster analysis, nonmetric multidimensional scaling and principal components analysis. The methods applied will be determined by the data quality but an emphasis will be placed on linear models (regression and ANOVA) wherever possible. Descriptive measures, average abundance (fish 1000 m-2), biomass (g wet weight 1000 m-2), and number of taxa, and diversity measures are useful for summarizing fish abundance and distribution. Transformations of data are often required to meet assumptions of normality when using parametric statistical methods and will be considered. Expected transformations include the ln(x+1) transformation for abundance data and the ln(x) transform for biomass data. Geostatistical methods may also apply. The emphasis in these analyses will be to document community composition of fishes and to determine their spatial and temporal variability. Depending on availability of results from the other components of the COP Chukchi science team, such as contaminant concentrations, physical oceanography and zooplankton ecology, other methods including principal component analysis, may be performed to assess baseline associations between fish communities and environmental factors, i.e., depth, temperature, salinity, sediment grain size.

The feeding ecology analysis will consist of a two-step approach, i.e., examination of stomach contents (diet) to assess the importance of prey taxa in fish diet, and documentation of the trophic level of prey taxa and predator fish. As our goal is to gain baseline understanding of the seasonal, interannual, and habitat-associated differences in feeding ecology, we have structured the laboratory sampling to examine a large number of fishes. Based on our 2004 – 2008 fish collections in the northeastern Chukchi Sea, we estimate collecting sufficient quantities of fishes to assess the diet and trophic level of 20 species of demersal fishes and 5 species of pelagic forage fishes (for a total of 25 species of fish for which we will examine stomach contents). Spatial and seasonal diet analysis will involve 10 individuals at 3 sites during 2 seasons in 2009 (25 x 10 x 3 x 2 = 1,500 individuals. We anticipate assessing interannual diet differences only for the most abundant species of fishes, i.e., approximately 10 species that should make up at least 80% of the fishes caught, 10 individuals at 3 sites during 2010 (10 species x 10 x 3 = 600 individuals). As with the aging analysis, development of the diet baseline from 2009 collections will guide the intensity and allocation of effort from 2010 collections, e.g., if ontogenetic prey switching is indicated or if it is unclear whether habitat or season is the driving factor for diets, we will stratify diet studies to include specimens throughout the fish size range and in appropriate habitats to assist in resolving these issues.

Diet analyses will assess the relative importance of prey taxa in the diet of each fish species. In the laboratory, a fish is thawed and then length, weight and proportional fullness of the stomach are recorded. The unpreserved prey are covered with water and separated into general groups, usually at the family level of taxonomic precision, which are assumed to be from the same life style, i.e., benthic infauna, epifauna, pelagic. A high-resolution dissecting microscope with a digital camera will be used for prey identification and documentation. Within the prey groups, animals with a large range of sizes will be separated into categories of small and large individuals, e.g., small and large copepods, small and large euphausiids. The number of individuals within each category will be counted, and each category will be weighed. The most prevalent taxa of prey will be identified to the most specific level that is reasonable, usually the genus or species; taxa will not be counted or weighed at this specific level, but vouchers of each prey taxon will be photographed, preserved and stored in 50% isopropyl alcohol at the Fisheries Oceanography in Fairbanks.

Diet, i.e., stomach contents, will be described using established methodology that assigns an index of relative importance (IRI) provided by each prey taxon (e.g., Holladay and Norcross 1995, Pinkas et al. 1971). The IRI considers weight of prey, count of prey, and the proportion of predators that consumed the prey. We will group prey for the IRI at the general taxonomic level described above, e.g., usually to family level of precision. Diet of each fish species will be analyzed to detect differences among and between species, seasons, years, habitats, and fish sizes by pooling standardizing square-root transformed IRI values within each of the five variables. Differences within and between the pooled values will be analyzed by Principal Components Analysis, followed by cluster analysis (e.g., Ward 1963). Differences in diet diversity (i.e., Shannon-Weiner diversity index, Smith 1986) and proportional gut fullness will be tested separately by one way analysis of variance (ANOVA) followed by Tukey Honest Significant Difference

(Tukey HSD) if warranted. For each fish species, effects on diet diversity and proportional stomach fullness of the interaction between season, year, habitat, and fish size will be tested using a two-way ANOVA.

Stable isotope analysis will be performed to assess the seasonal and interannual trophic level of the demersal and pelagic fishes (predators) caught in the Klondike and Burger prospects, and to assess trophic level of their prey. When possible the stable isotope analysis will be conducted on same specimens of fish whose stomach contents were processed. To control for differences in isotopic compositions across the spatial extent of collections, we will process euphausiids as a measure of underlying baseline composition. We estimate assessing stable isotope from 520 individuals of fish and euphausiids over the two years of collections (25 species of fish + 1 euphausiid x 5 replicates (individuals) x 2 prospects x 2 seasons = 520). We expect to examine 520 samples of benthic and of pelagic prey, i.e., 40 taxa x 5 replicates x collected during cruise 1 in each of 2 years = 400; seasonal analysis of prey trophic level will be limited to pelagic taxa, because the animals and size of animals anticipated to be available in the water column is more likely to change than the benthic prey availability, i.e., 12 taxa per year x 5 replicates x 2 years = 120.

For stable isotope analysis replicate individuals of fishes and prey will be subsampled for muscle tissue, or pieces of body wall where muscle tissue cannot be distinguished. Prey will be examined at the taxonomic level used for the IRI. Whole prey organisms will be used if tissue subsampling does not yield sufficient mass, and several individuals will be pooled if individual organisms are too small to constitute a sample. Samples will be frozen, and subsequently freeze dried for a minimum of 24 hours. Tissues will be analyzed for d15N and d13C by the Alaska Stable Isotope Facility at UAF following the procedure described by Dehn et al. (2005).

2.4 Data Storage Procedures

Data will be entered, proofed, and stored within a MS Access database at the Fisheries Oceanography Laboratory at IMS. Handwritten data sheets will be kept at IMS for 5 years, and electronic data will be archived at COP as one of the project deliverables. Ultimately, fish distribution data will be archived with the Arctic Ocean Diversity Census of Marine Life (ArcOD) and the Ocean Biogeographic Information System (OBIS) data portal. Voucher collections of fish and prey taxa will be archived in museums and other collections as detailed below (section 3.6).

2.5 Quality Control Procedures

The following quality control procedures will be followed during sample processing. Each taxon will be verified by expert taxonomists or by comparison with voucher specimens in museums or the collection held at the Fisheries Oceanography Laboratory at IMS. Specimens of each fish species will be verified by Catherine Mecklenburg, a taxonomist with considerable expertise with Arctic fishes, and author of “Fishes of Alaska,” the most complete and current key for Alaskan fishes. Voucher specimens of each fish species caught will be archived in the University of Alaska Museum of the North (UAMN) and the Fisheries Oceanography Laboratory at IMS (FOL/IMS); specimens also will be made available for the growing collection of Arctic fishes held at the California Academy of Sciences. Muscle tissue from each fish species will be available for genetic examination by the Fish Barcode of Life Initiative, a global effort to develop a standardized reference sequence library including all fish species, thereby further substantiating the species identification. Voucher specimens of each prey species will be held at the Fisheries Oceanography Laboratory, IMS. Samples processed for stable isotopes will be subject to standard QA/QC measures of the Alaska Stable Isotope Facility at UAF. Otolith aging will be subject to the QA/QC measures of the AFSC (AFSC 2006), where a random subsample of 20% of otoliths will be aged by a second reader; the ages assigned by the two readers are compared and differences between reader findings are resolved between the readers. Identification of prey will be supervised by a senior taxonomist, and 5% of specimens will be verified to ensure that counts are accurate and organisms are correctly identified.

3.0 DELIVERABLES

3.1 Field Data

A list of sampling activities will be submitted within 30 days of the final cruise.

3.2 Draft Report

Provided there is no delay in shipping samples to UAF at the completion of the final cruise, the Draft Report, including appendices with sample analysis, will be submitted by 1 October 2011.

3.3 Final Report

The Final Report will be submitted 1 December 2011 or within 30 days of receipt of comments on the Draft Report.

4.0 SCHEDULE WITH MILESTONES

Field Studies

- Early July 2010— Planning meeting, ship walk-through, (Anchorage)
- Late July–mid October 2010 — 3 Cruises

Coordination Meetings

- May 2010 —Olgoonik-Fairweather Chukchi Sea scientific studies kickoff meeting, and scientific studies coordination meeting. Fairbanks, AK (1 day)
- Early July 2010 — Olgoonik-Fairweather training and coordination meeting (Seattle)
- Nov. 2010 — Olgoonik-Fairweather Chukchi Sea scientific studies debriefing. Anchorage, AK (1 day)
- Jan 2011 — Chukchi Sea scientific studies technical workshop at Alaska Marine Science Symposium, Anchorage (2 days)
- Deliverables
- Field data (i.e. # of samples collected and locations) — within 30 days of final cruise.
- Draft Report — 1 October 2011.
- Final Report—1 December 2011 or within 30 days of receipt of comments on Draft Report.

5.0 REFERENCES

ACIA (Arctic Climate Impact Assessment) (2004) Impacts of a warming Arctic. www.amap.no/acia. Cambridge University Press.

AFSC (Alaska Fisheries Science Center, National Marine Fisheries Service – NOAA Fisheries) (2006) Age and Growth Program: Procedure for otolith examination – break and burn preparation. http://www.afsc.noaa.gov/refm/age/procedures.htm Webpage created 12-July-2006, accessed 22-Jan-2009.

Alverson DL, Wilimovsky NJ (1966) Chapter 31. Fishery investigations of the southeastern Chukchi Sea. In: Wilimovsky NJ and Wolfe JN (eds.) Environment of the Cape Thompson region, Alaska. U.S. Atomic Energy Commission, Washington D.C., pp 843-860.

Atkinson EG, Percy JA (1992) Diet comparison among demersal marine fish from the Canadian Arctic. Polar Biology 11:567-573.

Barber WE, Smith RL, Vallarino M, Meyer RM (1997) Demersal fish assemblages of the northeastern Chukchi Sea, Alaska. Fishery Bulletin 95: 195-209.

Bentzen TW, Follmann EH, Amstrup SC, York GS, Wooller MJ, Muir DCG and O'Hara TM (2008) Dietary biomagnification of organochlorine contaminants in Alaskan polar bears. Canadian Journal Of Zoology-Revue Canadienne De Zoologie 86: 177-191.

Bentzen TW, Follmann EH, Amstrup SC, York GS, Wooler MJ and O’Hara TM (2007) Variation in winter diet of southern Beaufort Sea polar bears inferred from stable isotope analysis. Canadian Journal of Zoology 85: 596-608.

Cabana G, Rasmussen JB (1996) Comparison of aquatic food chains using nitrogen isotopes. Proceedings of the National Academy of Sciences, USA 93: 10844-10847.

Coyle KO, Gillispie JA., Smith RL, Barber WE (1997) Food habits of four demersal Chukchi Sea fishes. American Fisheries Society Symposium 19: 310-318.

Craig PC, Griffiths WB, Haldorson L, McElderry H (1982) Ecological studies of Arctic cod (Boreogadus saida) in Beaufort Sea coastal water. Canadian Journal of Fisheries and Aquatic Sciences 39: 395-406.

Craig PC, Griffiths WB, Johnson SR, Schell DM (1984) Trophic dynamics in an Arctic lagoon. In: Barnes PW, Schell DM, Reimnitz E (eds) The Alaskan Beaufort Sea: ecosystems and environments. Academic Press, New York, pp 347-380.

Craig PC, McCart P (1976) Fish use of nearshore coastal waters in the western arctic: emphasis on anadromous species. In: Hood DW, Burrell DC (eds) Assessment of the arctic marine environment: selected topics. Institute of Marine Science, University of Alaska, Fairbanks, pp 361-388.

Dehn L-A, Sheffield GG, Follmann EH, Duffy LK, Thomas DL, Bratton GR, Taylor RJ, O’Hara TM (2005) Trace elements in tissues of phocid seals harvested in the Alaskan and Canadian Arctic – Influence of age and feeding ecology. Canadian Journal of Zoology 83: 726-746.

Dunne JA, Williams RJ, Martinez ND (2002) Network structure and biodiversity loss in food webs: robustness increases with connectance. Ecological Letters 5: 558-567.

Fechelm P, Craig C, Baker JS, Gallaway BJ (1985) Fish distribution and use of near shore waters in the northeastern Chukchi Sea. USDOC NOAA OCSEAP Final Report 32, pp. 121-297.

Froese R, Pauly D (eds) (2006) FishBase. World Wide Web electronic publication. www.fishbase.org, version (05/2006).

Frost KJ, Lowry LF (1981) Trophic importance of some marine gadids in northern Alaska and their body-otolith size relationships. Fish Bull 79: 187-192.

Frost KJ, Lowry LF (1983) Demersal fishes and invertebrates trawled in the northeastern Chukchi and western Beaufort Seas, 1976-77. NOAA Tech Rep NMFS SSRF-764, 22 pp.

Frost KJ, Lowry LF (1984) Trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea. In: Barnes PW, Schell DM, Reimnitz (eds) The Alaskan Beaufort Sea: ecosystems and environments. Academic Press, New York, pp 381-401.

Grebmeier JM, Dunton KH (2000) Benthic processes in the northern Bering/Chukchi Seas: status and global change. In: Impacts of changes in sea ice and other environmental parameters in the Arctic, Rept. Marine Mammal Commission Workshop, 15-17 Feb 2000, Girdwood, AK, Available: Marine Mammal Commission, Bethesda, MD.

Grebmeier JM, Cooper LW, Feder HM, Sirenko BI (2006) Ecosystem dynamics of the Pacific-influenced Northern Bering and Chukchi Seas in the Amerasian Arctic. Progress in Oceanography 71: 331–361.

Greenberg R, Marra PP, Wooller M (2007) Stable-isotope (C, N, H) analyses help locate the winter range of the coastal plain swamp sparrow (Melospiza georgiana nigrescens). In "Auk," pp. 1137-1148.

Hobson KA, Alisauskas RT, Clark RG (1993) Stable-Nitrogen isotope enrichment in avian-tissues due to fasting and nutritional stress - implications for isotopic analyses of diet. Condor 95: 388-394.

Hobson KA, Welch HE (1992) Determination of trophic relationships within a high Arctic marine food web using delta-C-13 and delta-N-15 analysis. Marine Ecology-Progress Series 84: 9-18.

Hobson KA, Schell DM, Renouf D, Noseworthy E (1996) Stable carbon and nitrogen isotopic fractionation between diet and tissues of captive seals: implications for dietary reconstructions involving marine mammals. Canadian Journal of Fisheries and Aquatic Science 53: 528-533.

Hokkaido University (1992) The "Oshoro-Maru" cruise 38 to the northern North Pacific Ocean, the Bering Sea, the Chukchi Sea and the Gulf of Alaska in June-August 1991. In: Data record of oceanographic observations and exploratory fishing No. 35. Faculty of Fisheries, Hokkaido University, Hakodate, Hokkaido, Japan, pp. 73-204.

Hokkaido University (1993) The "Oshoro-Maru" cruise 44 to the northern North Pacific Ocean, the Bering Sea, the Chukchi Sea and the Gulf of Alaska in June-August 1992. In: Data record of oceanographic observations and exploratory fishing No. 36. Faculty of Fisheries, Hokkaido University, Hakodate, Hokkaido, Japan, pp. 73-188.

Holladay BA, Norcross BL (1995) August diet of age-0 Pacific halibut in nearshore waters of Kodiak Island, Alaska. Environmental Biology of Fishes 44: 403-416.

Hop H, Welch HE, Crawford RE (1997) Population structure and feeding ecology of Arctic cod schools in the Canadian high Arctic. In: Reynolds JB (ed) Fish ecology in Arctic North America. American Fisheries Society Symposium 19, Bethesda, Maryland, pp 68-80.

Johnson L (1997) Living with uncertainly. In: Reynolds JB (ed) Fish ecology in Arctic North America. American Fisheries Society Symp 19, Bethesda, Maryland, pp 340-345.

Kelly JF (2000) Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. Canadian Journal of Zoology 78: 1-27.

Knoche MJ, Powell AN, Quakenbush LT, Wooller MJ, Phillips LM (2007) Further evidence for site fidelity to wing molt locations by king eiders: Integrating stable isotope analyses and satellite telemetry. Waterbirds 30: 52-57.

Lowry LF, Frost KJ (1981) Distribution, growth and foods of Arctic cod (Boreogadus saida) in the Bering, Chukchi and Beaufort Seas. Canadian Field-Naturalist 95(2): 186-191.

Manabe S, Stouffer RJ (1994) Multiple-century response of a coupled ocean-atmosphere model to an increase of atmospheric carbon dioxide. Journal of Climatology 7: 5-23.

Mecklenburg CW, Mecklenburg TA, Thorsteinson LK (2002) Fishes of Alaska. American Fisheries Society, Bethesda, Maryland, xxxvii + 1,037 pp + 40 plates.

Mecklenburg CW, Stein DL, Sheiko BA, Chernova NV, Mecklenburg TA, Holladay BA (2007) Russian-American long-term census of the arctic: benthic fishes trawled in the Chukchi Sea and Bering Strait in August 2004. Northwest Naturalist 88: 168-187.

Mecklenburg CW, Sheiko BA (2006) RUSALCA 2004: Fishes of the Northern Bering Sea and Chukchi Sea Results Presented at Kotor, Serbia-Montenegro Postcruise Workshop, 26 October 2005 and Recommendations for Future Research. http://www.arctic.noaa.gov/aro/russian-american/2004_2005/FishDiversity2Feb06.pdf Accessed 1-October-2008.

Minerals Management Service (2006) Alaska Annual Studies Plan, Final FY 2007, September 2007.

Moles A, Norcross BL (1995) Sediment preference in juvenile Pacific flatfishes. Netherlands Journal of Sea Research 34: 177-182.

Moles A, Rice S, Norcross BL (1994) Non-avoidance of hydrocarbon laden sediments by juvenile flatfishes. Netherlands Journal of Sea Research 32: 361-367.

Norcross BL, Holladay BA, Busby MS, Mier KL (Submitted) Frontal structure in the Chukchi Sea determines small demersal and larval fish communities. Deep-Sea Res. II.

Norcross BL, Hose JE, Frandsen M, Brown E (1996) Distribution, abundance, morphological condition and cytogenetic abnormalities of larval herring in Prince William Sound, Alaska, following the Exxon Valdez oil spill. Canadian Journal of Fisheries and Aquatic Science. 53: 2376-2387.

Pauly D, Trites AW, Capuli E, Christensen V (1998) Diet composition and trophic levels of marine mammals. ICES Journal of Marine Science 55: 467-481.

Phillips DL, Gregg JW (2003) Source partitioning using stable isotopes: coping with too many sources. Oecologia 136: 261-269.

Phillips DL, Koch PL (2002) Incorporating concentration dependence in stable isotope mixing models. Oecologia 130: 114-125.

Phillips DL, Newsome SD, Gregg JW (2005) Combining sources in stable isotope mixing models: alternative methods. Oecologia 144: 520-527.

Pinkas L, Oliphant MS, Iverson ILK (1971) Food habits of albacore, bluefin tuna, and bonito in California waters, 152. California Department of Fish and Game, Fisheries Bulletin, 105 pp.

Power G (1997) A review of fish ecology in Arctic North America. In: Reynolds JB (ed) Fish ecology in Arctic North America. American Fisheries Society Symposium 19, Bethesda, Maryland, pp 13-39.

Smith RL (1986) Elements of Ecology. Harper and Row Publishers, New York, NY.

Sterner RW, Bajpai A, Adams T (1997) The enigma of food chain length: absence of theoretical evidence for dynamic constraints. Ecology 78: 2258-2262.

Suthers IM, Frank KT (1991) Comparative persistence of marine fish larvae from pelagic versus demersal eggs off southwestern Nova Scotia, Canada. Marine Biology 108: 175-184.

Ward JH (1963) Hierarchial grouping to optimize an objective function. Journal of the American Statistical Association 58: 236.

Wyllie-Echeverria T, Wooster WS (1998) Year-to-year variations in Bering Sea ice cover and some consequences for fish distribution. Fisheries Oceanography 7: 159-170.

SECTION VII
SEABIRD ECOLOGY

ROBERT H. DAY & ADRIAN E. GALL
CO-PRINCIPAL INVESTIGATORS
ABR, INC. – ENVIRONMENTAL RESEARCH & SERVICES
FAIRBANKS, AK

1.0 INTRODUCTION

1.1 Brief History of Subject Research in the Chukchi Sea

Data on seabirds in the northeastern Chukchi Sea during the open-water season are limited, primarily because of the area's historic inaccessibility. Much of the interest in seabirds in this area has concentrated on mainland seabird colonies and on seabirds at sea in the vicinity of the Hope Basin, which lies immediately north of Bering Strait, in the southern Chukchi Sea. The focus of seabird colony research has been Cape Lisburne, which is part of the Alaska Maritime National Wildlife Refuge; data also have been collected at irregular intervals ~50 miles south of there at Cape Thompson. These colonies have been studied periodically since 1976 by David Roseneau (USFWS), who built on earlier work begun on nesting seabirds by Swartz (1966) during the Cape Thompson environmental studies of the U.S. Atomic Energy Commission.

Another area of research has been use of the coastal-lagoon systems of the northeastern Chukchi Sea by birds. The earlier work by Johnson (1993) and Johnson et al. (1993) described baseline use of the Chukchi lagoon systems by birds, whereas recent work has focused on monitoring population trends of birds in all lagoon systems in northern and northwestern Alaska annually (e.g., Dau and Larned 2004 and related annual reports). There also have been extensive studies of eider migration at Barrow, which has perhaps the highest concentration of migrating waterfowl on this continent (Thompson and Person 1963; Woodby and Divoky 1982; Suydam et al. 1997, 2000a, 2000b; Day et al. 2004), and studies of migrating Ross's Gulls, which concentrate at Barrow in the fall (Divoky et al. 1988). Aerial surveys for and satellite telemetry of migrating and staging Spectacled (*Somateria fischeri*) and Steller's eiders (*Polysticta stelleri*), both of which are protected under the Endangered Species Act (ESA), in the Chukchi Sea have indicated that shallow, nearshore waters of Ledyard Bay and Peard Bay form important stopover areas for migrating Spectacled and King (*S. spectabilis*) eiders in both the summer and fall (Balogh 1997, Oppel et al. 2009).

In contrast to the well-known coastal seabird community, few historical data on the at-sea distribution and abundance of seabirds are available for the northern Chukchi Sea. The first research was conducted by Jacques (1930), who surveyed birds in the Bering Sea and western Chukchi Sea in July–August 1928. Later, Swartz (1967) examined the at-sea distribution of seabirds in the southern and central Chukchi during the environmental studies at Cape Thompson. The interest in oil development in arctic Alaska in the 1970s prompted a decade of research on seabirds and other marine organisms in this region. The main seabird studies in areas important for oil development were conducted by (1) Watson and Divoky (1972), who studied seabirds in the eastern Chukchi Sea from a USCG icebreaker; (2) Divoky (1979), who described some aspects of the Chukchi Sea open-water and ice-edge avifauna; and (3) Divoky (1987), who studied seabirds throughout the Chukchi Sea in the early 1980s as part of the OCSEAP. The latter report was never released by OCSEAP as part of its

"Environmental Assessment of the Alaskan Continental Shelf" publication series, so it is not widely available or widely known. Another source of information on seabirds near this area is found in Divoky and Springer (1988), who provided an overview of the data available on seabirds in the southern Chukchi Sea for an BOEMRE synthesis report.

Although limited historical data exist for the region (Hopcroft et al. 2008), studies conducted during the past five years are filling in the gaps in knowledge about the ecology of the northern Chukchi Sea. Most recently, there has been some ship-of-opportunity sampling of seabirds in the Chukchi Sea conducted primarily by the USFWS. These data have not been published yet, but they have been contributed to the North Pacific Pelagic Seabird Database (NPPSD), a publicly available information resource maintained by the USGS that is updated periodically. The current version includes data from USFWS surveys as recent as October 2009. Other ongoing studies that are providing detail on the use of nearshore and offshore waters by birds include satellite telemetry studies of Long-tailed Ducks (*Clangula hyemalis*) and King Eiders (Dickson and Bowman 2008) and of Yellow-billed Loons (*Gavia adamsii;* Rizzolo and Schmutz 2008). The present study conducted in 2008, 2009, and continuing in 2010 will provide information on the distribution and abundance of marine birds in the northern Chukchi Sea.

1.2 Objectives of Study

The specific objectives of the seabird component of this study are to:

- describe spatial, seasonal, and interannual characteristics of the seabird community in the overall development area and the area covered by the EIS;
- describe community-level attributes such as species-richness and species-composition;
- provide detailed information on species that are of conservation concern (e.g., endangered, threatened, candidate species); and
- when possible, integrate the data on distribution and abundance of seabirds in this area with the data on physical and biological oceanography that are collected concurrently by the survey vessel.

2.0 METHODS AND PROCEDURES

2.1 Sampling or Survey Design and Technical Rationale

We will survey seabirds (and other observers will survey marine mammals concurrently) along a series of parallel survey lines that run north–south through these 900-nm^2 boxes. Within a study-area box, lines will be spaced 1 nm apart, creating a set of 31 parallel survey lines in Klondike and Burger and 38 parallel survey lines in Statoil. Each survey line is 30 nm long, and every seventh line will coincide with a line of oceanographic stations that will be sampled by other researchers on the boat. At a ship's speed of ~8 knots, each of the 30-nm lines can be surveyed in ~3.5 hours, so several lines may be sampled in a day if weather and daylight permit. However, if inclement weather is limiting our ability to sample the entire area, the top priority on a cruise will be those lines that include the core parts of each study-area box. If possible, the Klondike and Statoil study areas will be surveyed at least once over a period of ~10 days on each of the first two cruises. The Burger study area will be surveyed on all three cruises, if weather and ice conditions permit. The same survey lines will be surveyed on each subsequent cruise, so that inter-cruise comparisons can be made.

An important aspect of the study design is the use of line-transect sampling within a zone ~300 m wide. The use of this sampling design allows the calculation of the bias in detectability of individual species (i.e., a small phalarope is much more difficult to detect than is a large albatross or a medium-sized gull), so that numbers of individuals seen can be corrected. Thus, the bias in detectability of individual species will be incorporated into the density estimates, increasing the accuracy of the estimates.

2.2 Field Team Size and Composition

The seabird team will consist of 6 observers total who will rotate through the three cruises planned for the summer, with each individual cruise team consisting of two observers who will trade off observation duties throughout the day. One member of the seabird team will function as the crew leader and will be primarily responsible for assessing survey conditions, managing data collection and processing, submitting daily and weekly progress reports to the Chief Scientist/Program Manager, and coordinating with other research groups and crew on the vessel.

2.3 Data-collection Procedures

The survey will be conducted in 10-min counting periods (hereafter, transects) when the ship is moving along a straight-line course at a minimal velocity of 5 kt. Data will be collected 9–12 hours/day, weather permitting; surveys generally will be stopped when sea height is greater than Beaufort 5 (seas to ~6 feet [ft]), although sampling may occur in higher seas if observation conditions are still workable. At the beginning of each transect, observers will record start time, sea ice cover (to nearest 10%), sea height (Beaufort scale), visibility, observation conditions, and transect width. If the ship's course or speed changes substantially during a transect, that sample will be discarded if <5 minutes long, and a new transect will be started on the new course/with the new speed.

One observer stationed on one side of the vessel's bridge will record all birds seen within a radius of 300 m and in a 90° arc from the bow to the beam on one side of the ship. For each bird or group of birds, the observer will record:

- species (to lowest possible taxon);
- total number of individuals in the observation;
- distance from the observer when sighted (use reticule binoculars to determine distance);
- radial angle of the observation from the ship (to the nearest 1°);
- number in each age-class (juvenile, subadult, adult, unknown age);
- immediate habitat (air, water, flotsam/jetsam, ice); and
- behavior (sitting, swimming, feeding, comfort behavior, courtship behavior, interacting with marine mammals, other).

For birds on the water, all birds seen within the defined survey area will be counted. For flying birds, however, observers will conduct scans for them once every minute and record a "snapshot" count of all birds flying within the 90° arc from the bow to the beam of the ship and within 300 m of the ship (Tasker et al. 1984; Gould and Forsell 1989). Birds that enter the count zone ahead of the ship are counted during the snapshot counts, whereas birds that enter from behind the ship (i.e., the area that already has been surveyed) are not counted, to avoid the possibility of counting birds that may be following the ship. This snapshot method reduces the bias of overestimating the density of flying birds.

Observations of all birds will be entered directly into a computer that is connected to a GPS by using TigerObserver software (TigerSoft, Las Vegas, NV), so that every observation will be time-stamped and geo-referenced. The time stamp will be synchronized with data from on-board computers to facilitate matching bird observations with other environmental measurements (e.g., depth, sea-surface temperature, sea-surface salinity).

2.4 Analytical Procedures

We will estimate density (birds/km^2) for each species or species-group by using distance-sampling analyses available in the program DISTANCE (Thomas et al. 2010). The analysis consists of three steps. First, a detection function for each species is fitted to the observed distances of sightings from the transect line to estimate probability of detection for each species separately. Next, the observed flock sizes are used to estimate the mean flock size for the population. Finally, the density of birds is estimated for the entire study area by incorporating the probability of detection, the area surveyed, and the mean flock size. Results will be presented by study area and season.

In addition to the bird observation data, we will use data from the physical and biological oceanography disciplines to investigate relationships between oceanographic conditions and seabird distribution and abundance. Examples of data related to individual records that we have collected include GPS locations, positional accuracy of those readings, sea-surface temperature, sea-surface salinity, fluorometry reading, and water depth. Examples of data that may be summarized for all data collected within a study area and cruise include zooplankton species-composition, abundance, and distribution; and fish species-composition, abundance, and distribution.

We will summarize species-richness and species-composition of the bird community by cruise and area to examine temporal and spatial patterns in these community-level attributes (Magurran 1988). In addition, we will use the geo-located observations to generate maps of distribution and abundance for all birds combined, for individual species of interest, and for species-groups of interest.

Additional perspective on the distribution and abundance of seabirds in this general area will be gained by a retrospective analysis of historical data on seabirds in this region. We will calculate uncorrected densities of birds (birds observed/km2) to compare our data with historical data (e.g., Divoky 1987) compiled in the NPPSD which is maintained by the USGS–Alaska Science Center in Anchorage, AK. This database is available to the public.

We will partition out those historical data that apply to the general vicinity of the study-area boxes and will summarize the data to determine the abundance of seabirds in the general area and, if needed, in the three study areas separately. We also will compare species composition and richness between the historical dataset and the results of the current study.

2.5 Data-storage Procedures

We will enter data electronically on a laptop computer real-time during the surveys. Data managers aboard the vessels will back up those data files onto the ship’s RAID array and a portable hard drive at least once every 24 hr in the field. We will review the data collected using TigerObserver and saved into the project database for data proofing, management, and archiving every day. Upon conclusion of each cruise, we will receive the observational data from OLF and will load them onto the secure server at ABR, Inc.

We will deliver proofed and archived data to OLF as a deliverable item, following the guidelines in COP document "Data Protocols Version 6.4 March 2010."

2.6 Quality-control Procedures

Prior to surveys, the Co-PIs or their designee will conduct data-collection, identification, and data-entry training for personnel who will be participating on these cruises. The data-collection training will emphasize procedures for detecting and quantifying bird observations within the survey area. The identification training will emphasize the primary species that may occur in the study area and molt sequences for aging birds in the field. When possible, photographic slides or written documents will be used. The data-entry training will emphasize an understanding of the data-entry software itself and entry procedures.

Data will be entered on the laptop real-time during the surveys. A field notebook and digital voice recorder also will be kept at the observation station, so that the observer can record any adjustments or corrections that may arise during the surveys. Each survey file will be reviewed for accuracy and completeness at the end of a survey line, and any corrections noted during the surveys will be made to the survey file at that time. Each record will be identified with the initial of the observer, and any changes to records will be noted in a separate table within the Microsoft Access database.

3.0 COORDINATION

3.1 Olgoonik-Fairweather

We will coordinate with OLF on all aspects of the study. We will attend a pre-cruise meeting to coordinate planning. The Co-PI or their designee (the "Seabird Lead" on each cruise) also will provide daily information to the Chief Scientist/Project Manager on each cruise so that a daily report can be sent to OLF from the field. In addition, we will attend a post-field meeting in Anchorage to discuss the research program.

3.2 Other studies in the Chukchi Sea Program

This research will be conducted at sea as part of an interdisciplinary team of oceanographers and ecologists who are part of the Chukchi Sea program. We will make every attempt to coordinate the sampling with the other researchers who will be aboard at that time. The seabird sampling will be coordinated with the marine-mammal observers, in particular, because of the similarity in sampling methods and requirements.

The Co-PIs have conducted collaborative research with some of the other members of the Research Team. Co-PI Dr. Day has conducted research at sea with Dr. Weingartner (physical oceanographer) as part of the oceanographic study GLOBEC which was a joint research program of the NSF and the NOAA. He also has been involved in research on seabirds at sea for nearly 35 years and on the effects of the Exxon Valdez oil spill with the hydrocarbon-chemistry team. Co-PI Adrian Gall conducted research at sea with the other members of the research team in the Chukchi Sea during the 2008 and 2009 field seasons.

3.3 Current studies in the region

There are few, if any, dedicated at-sea studies of seabirds occurring at this time in the Chukchi Sea. The USFWS conducts ship-of-opportunity data collection on seabirds at sea in Alaska, but it is not clear at this time whether they will be doing any in the Chukchi Sea in 2010 (K. Kuletz, in litt.).

4.0 DELIVERABLES

4.1 Field Data

Three primary types of data will be generated, and copies of them will be provided to OLF. These data files will include:

- Seabird-observation database; this file will contain the bulk of the data that we collect, including the bird and environmental field described above and the data downloaded from the ship's system.
- GIS database and maps, following the guidelines in COP document "Data Protocols Version 6.4 March 2010."
- Photo files, following the guidelines in COP document "Data Protocols Version 6.4 March 2010."

4.2 Draft Report

The primary deliverable will consist of a Draft Report that will contain a summary of the data collected in both 2008–2010 and the retrospective analysis of historical data (including the addition of any new data to the NPPSD. This report will describe background information on seabirds in the general area, methods of both the 2008–2010 field studies and the analysis of historical data, the results of both sets of analyses, and a discussion of those results. This Draft Report will be submitted to OLF electronically, including an editable electronic copy of text and tables (in MS Word) and a PDF of figures.

4.3 Final Report

After review of the Draft Report, we will provide a Final Report that has been revised after input from reviewers. This Final Report will be submitted in both electronic format (PDF and Word versions on 9 CD copies) and as hard copies (12 copies).

5.0 SCHEDULE WITH MILESTONES

5.1 Field Studies

- Complete first cruise—about 31 August 2010
- Complete second cruise—about 30 September 2010
- Complete third cruise—about 13 October 2010

5.2 Coordination Meetings

- Call in to the weekly scientific-studies coordination teleconferences beginning in mid-May 2010.
- Attend a pre-cruise safety-training meeting in Anchorage—mid-July 2010
- Attend an OLF Chukchi Sea Scientific Studies meeting and technical workshop in Anchorage, tentatively scheduled to be concurrent with the AMSS—January 2011.

5.3 Deliverables

- Draft Study Plan—22 June 2010.
- Final Study Plan—about 6 July 2010.
- Submission of data and photo deliverables—1 March 2011, assuming that the raw data are released to ABR, Inc., no later than 5 business days after the completion of

the last research cruise (i.e., no later than 15 October 2010). Any delay in access to the data will result in a subsequent delay of submission of these deliverables.

- Draft Report will be submitted electronically—by 15 April 2011, assuming that all data are released to ABR, Inc., no later than 5 business days after the completion of the final research cruise (i.e., no later than 15 October 2010). Any delay in access to the data will result in a subsequent delay of report submission.
- Final Report will be submitted in electronic format (PDF and Word versions)—by 15 June 2011, or within 3 weeks following receipt of comments, whichever comes first. As with the Draft Report, any delay in access to the data will result in a subsequent delay of report finalization.
- Archiving and completion of project—31 July 2011.

6.0 REFERENCES

Balogh, G. R. 1997. Status report of the Spectacles Eider (*Somateria fischeri*), a threatened species. Unpublished report prepared by U.S. Fish and Wildlife Service, Anchorage, AK. 62 pp.

Dau, C. P., and W. W. Larned. 2004. Aerial population survey of Common Eiders and other waterbirds in near shore waters and along barrier islands of the Arctic Coastal Plain of Alaska, 24–27 June 2004. Unpublished report prepared by U.S. Fish and Wildlife Service, Anchorage, AK. 19 pp.

Day, R. H., J. R. Rose, A. K. Prichard, R. J. Blaha, and B. A. Cooper. 2004. Environmental effects on the fall migration of eiders at Barrow, Alaska. Marine Ornithology 32: 13–24.

Dickson, L. and T. Bowman. 2009. Identification of Chukchi and Beaufort Sea migration corridor for sea ducks. Unpublished annual project summary submitted to the Sea Duck Joint Venture by U.S. Fish and Wildlife Service, Anchorage, AK. 6 pp. Date of use: 14 April 2010. http://www.seaduckjv.org/studies/pro3/pr02B.pdf

Divoky, G. J., 1979. Sea ice as a factor in seabird distribution and ecology in the Beaufort, Chukchi, and Bering Seas. Pp. 9–17 in Conservation of marine birds of northern North America (J. C. Bartonek and D. N. Nettleship, Eds.). U.S. Fish and Wildlife Service, Wildlife Research Report No. 11.

Divoky, G. J. 1987. The distribution and abundance of birds in the eastern Chukchi Sea in late summer and early fall. Unpublished report prepared for National Oceanic and Atmospheric Administration/Outer Continental Shelf Environmental Assessment Program (NOAA/OCSEAP), Boulder, CO, by Arctic Environmental Information and Data Center, Anchorage, AK. 96 pp.

Divoky, G., G. A. Sanger, S. A. Hatch, and J. C. Haney. 1988. Fall migration of Ross' Gull (*Rhodostethia rosea*) in Alaska Chukchi and Beaufort seas. U.S. Fish and Wildlife Service, Anchorage, AK. OCS Study MMS 88–0023. 120 pp.

Divoky, G. J., and A. M. Springer. 1988. Pelagic and coastal birds. Pages 69–83 in The environment and resources of the southeastern Chukchi Sea (M. J. Hameedi and A. S. Naidu, eds.). National Oceanic and Atmospheric Administration, Anchorage, AK.

Hopcroft, R., B. Bluhm, and R. Gradinger (eds.). 2008. Arctic Ocean synthesis: analysis of climate change impacts in the Chukchi and Beaufort seas, with strategies for future research. Unpublished report to the North Pacific Research Board, Anchorage, AK, by the Institute of Marine Sciences, University of Alaska, Fairbanks, AK. 184 pp.

Gould, P. J., and D. J. Forsell. 1989. Techniques for shipboard surveys of marine birds. U.S. Fish Wildlife Service Technical Report No. 25. 22 pp.

Jaques, F. L. 1930. Water birds observed on the Arctic Ocean and the Bering Sea in 1928. Auk 47: 353–366.

Johnson, S. R. 1993. An important early-autumn staging area for Pacific Flyway Brant: Kasegaluk Lagoon, Chukchi Sea. Journal of Field Ornithology 64: 539–548.

Johnson, S. R., D. A. Wiggins, and P. F. Wainwright. 1993. Late-summer abundance and distribution of marine birds in Kasegaluk Lagoon, Chukchi Sea, Alaska. Arctic 46: 212–227.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ. 179 pp.

Oppel, S., D. L. Dickson, and A. N. Powell. 2009. International importance of the eastern Chukchi Sea as a staging area for migrating King Eiders. Polar Biology 32: 775–783.

Rizzolo, D. J., and J. A. Schmutz. 2008. Monitoring marine birds of concern in the eastern Chukchi nearshore area (loons). U.S. Geological Survey, Alaska Science Center, Anchorage, AK. OCS Study MMS 2008. 36 pp.

Suydam, R. S., D. L. Dickson, J. B. Fadely, and L. T. Quakenbush. 2000a. Population declines of King and Common eiders of the Beaufort Sea. Condor 102: 219–222.

Suydam, R. S., L. T. Quakenbush, D. L. Dickson, and T. Obritschkewitsch. 2000b. Migration of King, *Somateria spectabilis*, and Common, *S. mollissima v nigra,* eiders past Point Barrow, Alaska, during spring and summer/fall 1996. Canadian Field–Naturalist 114: 444–452.

Suydam, R., L. T. Quakenbush, M. Johnson, J. C. George, and J. Young. 1997. Migration of King and Common eiders past Point Barrow. Pages 21–28 in King and Common eiders of the western Canadian Arctic (D. L. Dickson, ed.). Canadian Wildlife Service, Occasional Papers No. 94.

Swartz, L. G. 1966. Sea-cliff birds. Pp. 611–678 in Environment of the Cape Thompson Region (N. J. Wilimovsky and J. N. Wolfe, Eds.). U.S. Atomic Energy Commission, Oak Ridge, TN.

Swartz, L. G. 1967. Distribution and movement of birds in the Bering and Chukchi seas. Pacific Science 21: 332–347.

Tasker, M. L., P. H. Jones, T. J. Dixon, and B. F. Blake. 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. Auk 101: 567–577.

Thomas, L., J. L. Laake, S. Strindberg, F. F. C. Marques, S. T. Buckland, D. L. Borchers, D. R. Anderson, K. P. Burnham, S. L. Hedley, J. H. Pollard, J. R. B. Bishop, and T. A. Marques. 2010b. Distance Version 6.0 (Release 2). Research Unit for Wildlife Population Assessment, University of St. Andrews, St. Andrews, United Kingdom. [available at http://www.ruwpa.st-and.ac.uk/distance/]

Thompson, D. Q., and R. A. Person. 1963. The eider pass at Point Barrow, Alaska. Journal of Wildlife Management 27: 348–356.

Watson, G. E., and G. L. Divoky. 1972. Pelagic bird and mammal observations in the eastern Chukchi Sea, early fall 1970. Pages 111–172 in WEBSEC–70: An ecological survey in the eastern Chukchi Sea, September–October 1970. U.S. Coast Guard Oceanographic Report No. 50 (CG 373–50).

Woodby, D.A., and G. J. Divoky. 1982. Spring migration of eiders and other waterbirds at Point Barrow, Alaska. Arctic 35: 403–410.

SECTION VIII
MARINE MAMMAL ECOLOGY

LISANNE AERTS, PRINCIPAL INVESTIGATOR
OASIS ENVIRONMENTAL, INC.
ANCHORAGE, AK

1.0 NTRODUCTION

1.1 Brief History of Marine Mammal Research in Chukchi Sea

Marine mammal research in the Chukchi Sea has been limited and scattered. Research in the mid ‘80s and in the ‘90s was conducted by NMFS, USFWS, and BOEMRE to obtain information on the status of marine mammal species (e.g., Ljungblad et al. 1984, 1986, 1987, 1988; Gilbert 1985; Gilbert et al.1992; Moore and Reeves 1993). Other marine mammal monitoring during these years occurred in conjunction with industrial activities (e.g., Brueggeman et al. 1990, 1991, 1992a, 1992b). In recent years there is again an increased focus on marine mammal distribution and abundance research in the Chukchi Sea, mainly due to a renewed interest in offshore oil and gas developments and also possible threats on Arctic species from global warming. For example, recent distribution and abundance surveys in the Chukchi Sea were conducted for bearded and ringed seals (Bengtson et al. 2005), polar bears (Evans et al. 2003), beluga whales (Suydam et al. 2005), bowhead whales (George and Suydam 2009, Quakenbush et al. 2009), and gray whales (Moore et al. 2006).

BOEMRE initiated a long-term aerial survey program of marine mammals in the Chukchi Sea in 2008 under the COMIDA (Chukchi Offshore Monitoring In Development Area) project. This aerial survey is coordinated through NOAA’s National Marine Mammal Lab (NMML), and is designed to document marine mammal distribution in the Chukchi Sea Planning area during the open-water months, from mid-June to the end of October. In addition, COP and Shell started an interdisciplinary monitoring program in 2008, focusing on their respective offshore lease areas. Monitoring marine mammal distribution and abundance through vessel-based line transect surveys is one of the components of this program. Nearshore marine mammal aerial surveys and vessel-based marine mammal observations were also conducted during 2006–2009 as part of a monitoring and mitigation program for seismic and shallow hazard surveys.

1.2 Objectives

The main goal of this marine mammal survey is to increase current knowledge about the movements and distribution of marine mammals in the study areas for assessing impacts and planning offshore oil and gas development activities. There are four general objectives identified to achieve this main goal as listed below.

- Determine what marine mammal species occur in the study areas;
- Determine the abundance and distribution of marine mammal species within the study areas;
- Identify use and importance of the study areas for marine mammals, based on distribution and behavioral data (e.g. feeding areas, migration routes);
- Integrate results with the other components of this Chukchi research program (i.e., benthic, fish, plankton, and acoustic information) to increase our understanding of ecological relationships;

2.0 METHODS AND PROCEDURES

2.1 Sampling Design

Trained marine mammal observers (MMOs) will record all marine mammals sighted during daylight hours along transect lines that cover each of the three study areas. In each study area the transect lines run from north to south, are spaced 2 nm apart, and have a total length of 480 nm (Burger and Klondike Study area) and 465 nm (Statoil Study area). Transect lines will be surveyed sequentially from east to west or from west to east. If conditions and time permit, additional transect lines located midway between the planned transect lines will be surveyed in each study area to increase coverage.

The intention is to conduct at least two full marine mammal surveys in each of the three study areas during the 2010 season, weather depending. The order of the surveys will depend on ice conditions and possible industrial activity in the study area. Currently it is anticipated that during Cruise 1 and 2 the survey will start in the Klondike Study Area (southernmost area), move to the Burger Study Area and then to the Statoil Study Area (northernmost area). Ideally, the surveys will be coordinated for each cruise in such way that no study area is surveyed consecutively between sequential cruises. Based on previous year's experience, it is anticipated that a minimum of 5 days will be required to complete a full survey, assuming a cruising speed of 9 to 10 knots. The number and sequence of transect lines surveyed may be modified to accommodate changing weather or sea ice conditions to ensure the surveys cover most if not all of the study areas for each cruise period.

2.2 Field Team Size and Composition

A total of four MMOs will participate in the 2010 marine mammal survey. All MMOs participated in the 2008 and/or 2009 program, which provides consistency, continuity, and on-site experience. An additional MMO will be available as back-up. All MMOs will attend a refresher MMO training session before initiation of the research program coordinated and provided by the marine mammal PI. The training will consist of evaluating previous year's experiences and reviewing the current protocols and procedures for data collection, data recording and quality control. Species identification and equipment use will also be discussed during this training.

2.3 Data-collection Protocols and Procedures

A total of two MMOs will be present on each cruise. At least one MMO will watch for marine mammals from the best available vantage point on the vessel, which is the bridge or flying bridge. The MMOs will scan systematically with the naked eye and Fujinon 7×50 reticule binoculars. While the vessel is moving forward with a constant speed of 9 to10 knots, the MMOs will scan the 180° area centered on the vessel's trackline. Fujinon 16× gyroscopically-stabilized binoculars will be used to verify species identification and behavior. A Canon SLR camera with a 120-400 mm zoom lens will also be available for capturing photographs of marine mammals and can be used as an additional tool for marine mammal identification. Marine-mammal observations will occur for up to 16 hours/day, depending on weather conditions and day length. MMOs will alternate watches, so each observer is on watch for no more than 8 hours/day. Observations will begin one hour before sunrise. Data will be entered and stored using Panasonic Toughbook computers and TigerObserver data acquisition software developed specifically for the science program. Data collection codes and the equipment list are provided in Appendix 1 to 3.

When a marine mammal (or group of animals) is sighted, the following information will be entered into a Toughbook with TigerObserver software:

- Sighting info: species, group size, number of juveniles, behavior, heading, bearing and distance of the animal relative to the vessel, sighting cue, and identification reliability;
- Environmental data: sea state, ice cover (10% increments), visibility, and sun glare; and
- Other: the position(s) of any other vessel(s) in the vicinity of the research vessel.

Distances to marine mammals will be estimated visually or with sighting aids (e.g., laser range-finder, clinometer, or reticule binoculars). Observers will use these sighting aids to test and improve their abilities for visually estimating distances to objects in the water.

Sea state, ice cover, visibility, and sun glare will also be recorded at the start and end of each transect line, every 30 minutes, and whenever there is a change in one or more of those variables.

Observations will generally be suspended if (i) sea states exceed Beaufort scale 4, because the probability of detecting marine mammals in high seas is too low or (ii) visibility along the transect is less than 1.0 km or less than 50% of the horizon is visible.

As in 2009, TigerNav, a navigation based software system, will be used to record all vessel position information on a real time basis. This information includes date, time, vessel position, speed, and heading, water depth, sea surface temperature and salinity, and weather. Both TigerObserver and TigerNav are synchronized to a server system present on the vessel. This allows for all marine mammal sighting data to be automatically linked to the relevant navigational and weather data. Data collection codes, the Beaufort wind force scale, and equipment list are provided in Appendix 1, 2 and 3.

2.4 Analytical Procedures

The data analyses approach will mainly be determined by the sample size of the marine mammal data collected in 2010, in combination with available data from 2008 and 2009. As a minimum, the analyses will include the use of Chi-square and regression analysis for spatial and temporal relationships and line transect analysis for density estimates. Depending on the data quality and sample sizes, density plots or kernel density maps will be generated that could show effort corrected 'hot spot' areas of certain marine mammal groups or, if possible, for each species. Ideally, the marine mammal data from historical studies and from other ongoing surveys in the area would be integrated in these density maps. Whether this is possible will, among other, depend on the survey designs and sighting sample sizes.

2.5 Data-storage Procedures

Each day, after the end of the observation period, the field data collected on the Toughbooks and the TigerNav data will be synchronized to the server. A copy of the raw marine mammal data will remain stored on the Toughbook, as well as in the master database on the server computer. The main server contains a system containing a redundant array of independent disks to preserve storage reliability and data integrity. Furthermore, the server is connected via USB to a 2TB external hard drive, used as a third backup of all data files.

2.6 Quality-control Procedures

The lead MMO or PI are responsible for checking the integrity of their own data. The TigerObserver software contains a function that allows the lead MMO or PI on the vessel to perform a quality control of the database entries in either Microsoft Access or Excel formats. Additional checking will occur in the office after the field season.

3.0 PROGRAM COORDINATION

3.1 Marine Mammal Study Organization

The offshore Chukchi Sea Research Program is funded by COP, Shell, and Statoil. They have contracted OLF to coordinate and execute the program and are in direct communication with their program managers on field logistics data analysis, and reporting. The MMOs and the marine mammal PI are contracted by OLF. The MMOs report directly to the PI, who is responsible for scheduling, training requirements, data discussions, and reporting. The PI communicates with OLF on all these aspects and works directly with the OLF project manager to resolve any potential concerns or issues.

3.2 Chukchi Sea Study Integration

The marine-mammal study will be closely coordinated with the other studies in the research program. The coordination effort will be discussed between investigators of the studies prior to the field work, during fieldwork, and during data analyses and will include:

- Seabird study: the bird observers will work closely with the MMOs on the vessel, sharing sighting information.
- Fish, Zooplankton and Benthic studies: close communications between the scientists of these disciplines will occur during the field season and data analyses to allow correlation between prey composition, prey abundance and marine mammal distribution and abundance.
- Acoustic study: close communications between the acoustic scientists will occur during data analyses to allow linking of visual records with acoustic detection of calling marine mammal species.

3.3 Other Studies in the Region

The integration of research information is important in obtaining an increased understanding of the ecology of marine mammals and the environment that they inhabit. Efforts will be made to establish close communication with scientist from other programs that conduct marine mammal, benthic and acoustic studies in the Chukchi Sea. These include the COMIDA surveys, Shell's nearshore aerial surveys, and satellite tagging surveys.

4.0 DELIVERABLES

4.1 Field Data

Throughout the entire period of data collection, daily reports, 72-hour reports, and weekly reports will be compiled by the Chief Scientist on board the vessel. This field data will be provided to the Fairweather project manager who will distribute it to the clients as required. The daily reports will summarize information on marine mammal sightings over the previous 24-hour period. The 72-hour reports will serve to forecast what marine mammal transects will be surveyed over that period, and the weekly reports will comprise a compilation of the daily report information plus any quantitative information on observations where applicable.

4.2 Final Report

At the end of the field season all marine mammal data will be analyzed and summarized in a final report. This final report will include data from previous years and data from other disciplines where possible. The marine mammal PI will be responsible for writing this final report. After the field season a schedule for review and submission of report deliverables will be developed and agreed upon between the PI and OLF.

The final report will be prepared according to standard format for scientific documents and will conform to project guidelines. In general, the format will include a Summary, Introduction, Purpose and Objectives, Study Area, Results, Discussion, Conclusions, and Literature Cited.

5.0 REFERENCES

Bengston, J. L., L. M. Hiruki-Raring, M. A. Simpkins, and P. L. Boveng. 2005. Ringed and bearded seal densities in the eastern Chukchi Sea, 1999–2000. Polar Biology. 28: 833–845.

Brueggeman, J. J., R. A. Grotefendt, M. A. Smultea, G. A. Green, R. A. Rowlett, C. C. Swanson, D. P. Volsen, C. E. Bowlby, C. I. Malme, R. Mlawski, and J. J. Burns. 1992a. 1991 Marine Mammal Monitoring Program, Walruses and Polar Bears, Crackerjack and Diamond Prospects, Chukchi Sea. Shell Western E&P, Inc., and Chevron USA, Inc. 109 pp. + appendices.

Brueggeman, J. J., R. A. Grotefendt, M. A. Smultea, G. A. Green, R. A. Rowlett, C. C. Swanson, D. P. Volsen, C. E. Bowlby, C. I. Malme, R. Mlawski, and J. J. Burns. 1992b. 1991 Marine Mammal Monitoring Program, Whales and Seals, Crackerjack and Diamond Prospects, Chukchi Sea. Shell Western E&P, Inc., and Chevron USA, Inc. 62 pp. + appendices.

Brueggeman, J. J., D. P. Volsen, R. A. Grotefendt, G. A. Green, J. J. Burns, and D. K. Ljungblad. 1991. 1990 Walrus Monitoring Program, Popcorn, Burger, and Crackerjack Prospects in the Chukchi Sea. Shell Western E&P. Inc. 53 pp. + appendices.

Brueggeman, J. J., C. I. Malme, R. A. Grotefendt, D. P. Volsen, J. J. Burns, D. G. Chapman, D. K. Ljungblad, and G. A. Green. 1990. 1989 Walrus Monitoring Program, Klondike, Burger, and Popcorn Prospects in the Chukchi Sea. Shell Western E&P, Inc . 121 pp. + appendices.

Evans, T. F., A. S. Fischbach, S. Schliebe, S. Kalxdorff, G. York, and B. Manly. 2003. Polar Bear Aerial Survey in the Eastern Chukchi Sea. Arctic 56: 359–366.

George, J.C. and R. Suydam. 2009. Preliminary Report of the Spring 2009 Ice-Based Bowhead Whale Census Activities Near Barrow, Alaska. IWC SC/61/BRG23

Gilbert, J.R. 1989. Aerial census of Pacific walruses n the Chukchi Sea, 1985. Marine Mammal Science.5(1):17-28.

Gilbert, J., G. Fedoseev, D. Seagars, E. Razlivalov, and A. Lachugin. 1992. Aerial Census of Pacific Walrus, 1990. USDI U.S. Fish and Wildlife Service. Marine Mammal Management. Anchorage, Alaska.

Quakenbush, L.T., J.J. Citta, J.C. Craig, R. Smith, and M.P. Heide-Jorgensen. 2009. Fall movements of bowhead whales in the Chukchi Sea. Paper presented at the Alaska Marine Science Symposium, January 19-23, 2009, Anchorage, AK.

Ljungblad, D. K., S. E. Moore, and D. R. Van Schoik. 1984. Aerial surveys of endangered whales in the Beaufort, eastern Chukchi, and northern Bering seas, 1983: with a five year review, 1979–1983. Report from Naval Ocean Systems Center, San Diego, CA, for U.S. Minerals Management Service, Anchorage, AK. NOSC Technical Report No. 955. 356 pp. [NTIS AD-A146 373/6]

Ljungblad, D. K., S .E. Moore, and D. R. Van Schoik. 1986. Seasonal patterns of distribution, abundance, migration, and behavior of the Western Arctic stock of bowhead whales, Balaena mysticetus, in Alaskan seas. Reports of the International Whaling Commission, Special Issue 8: 177–205.

Ljungblad, D. K., S.E. Moore, J. T. Clarke, and J. C. Bennett. 1987. Distribution, abundance, behavior, and bioacoustics of endangered whales in the Alaskan Beaufort and eastern Chukchi seas, 1979–86. Report from Naval Ocean Systems Center, San Diego, CA, for U.S. Minerals Management Service, Anchorage, AK. NOSC Tech. Rep. 1177; OCS Study MMS 87-0039. 391 pp. [NTIS PB88-116470]

Ljungblad, D. K., B. Würsig, S. L. Swartz, and J. M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41: 183–194.

Moore, S.E., K.M. Stafford, D.K, Mellinger, and J.A. Hildebrand. 2006. Listening for large whales in the offshore waters of Alaska. BioScience 56(1):49-55.

Moore, S. E., and R. R. Reeves. 1993. Distribution and movement. In J. J. Burns, J. J. Montague, and C. J. Cowles (Eds.). The bowhead whale. Society of Marine Mammalogy, Lawrence, KS. Special Publication No. 2. Pp. 313–386

Suydam, R. S., L. F. Lowry, and K. J. Frost. 2005. Distribution and movements of beluga whales from the eastern Chukchi Sea stock during summer and early autumn. Final Report, OCS Study No. MMS 2005-035. 48 pp.

APPENDIX 1

Data Recording Field Codes for MMOs

Field Name	Codes	Description		
MARINE MAMMAL EFFORT				
Vessel Name		Name of vessel on which data were collected		
Cruise ID		Cruise Identifier		
	WWW1002	Science Leg 1 (1-31 August)		
	NII1002	Science Leg 2 (1-23 September)		
	WWW1004	Science Leg 3 (1-15 October)		
Line ID	KLH	Klondike high-priority line	KLL	Klondike low-priority line
	BUH	Burger high-priority line	BUL	Burger low-priority line
	STH	Statoil high-priority line	STL	Statoil low-priority line
	KHN/KHS	Klondike deadhead line (northern or southern end of high-priority line)		
	BHN/BHS	Burger deadhead line (northern or southern end of high-priority line)		
	SHN/SHS	Burger deadhead line (northern or southern end of high-priority line)		
	KOT	Klondike other line (for other movements within the box)		
	BOT	Burger other line (for other movements within the box)		
	SOT	Statoil other line (for other movements within the box)		
	KNN	"near-Klondike" line (in case ice prevents sampling within the box)		
	BNN	"near-Burger" line (in case ice prevents sampling within the box)		
	SNN	"near-Statoil" line (in case ice prevents sampling within the box)		
	KBT	Klondike-Burger transit line		
	KWT	Klondike-Wainwright transit line		
	BWT	Burger -Wainwright transit line, Statoil -Wainwright transit line		
	OTH	other transit line generally far from study area		
Line Replicate	number	If line is re-surveyed.		
Num Observer		Number of observers on watch (max. 2)		
Observer Location	BR	Bridge	ST	Stern
	FB	Flying Bridge	SD	Ship's deck
Observer Port		MMO's initials on port side		
Observer Center		MMO's initials in the center of the ship		
Observer Starboard		MMO's initials on the starboard side		
Sea State / Wind Force		See Appendix 2 for Beaufort windforce scale codes and descriptions		
Visibility	0 - 10 km	use 10 km if horizon is visible		
	> 3.5	variable but more than 3.5 km		
	< 3.5	variable but less than 3.5 km		
Glare Amount	NO	None	SE	Severe (> 50% of viewing area)
	LI	Little (< 25% of viewing area)	VA	Variable
	MO	Moderate (25-50% of viewing area)		
Glare Position From		Clockface position where glare begins (1200 is at the bow of the vessel)		
Glare Position To		Clockface position where glare ends (1200 is at the bow of the vessel)		
Ice Percent		Ice cover within 2 km of vessel 0 - 100 %		
Pack Ice Distance		Distance (km) from vessel to pack ice edge, if visible		
MARINE MAMMAL OBSERVATIONS				
Sighting ID		Consecutive number for each new marine mammal sighting (start at 1 for each vessel each seaso		
Sighting Record Number		For resighting of the same animal or goup of animals. Include the original Sighting ID in this field		
Species		*Mysticetes/Odontocetes*		*Pinnipeds*
	BHW	Bowhead whale (BW)	RS	Ringed seal
	GW	Gray whale	SS	Spotted seal
	HW	Humpback whale	RSS	Ringed/Spotted seal
	MW	Minke whale	BS	Bearded seal
	FW	Fin Whale	RBS	Ribbon Seal (RB)
	NPRW	North Pacific right whale	HBS	Harbor seal
	WW	Beluga whale	NFS	Northern fur seal
	NW	Narwhal	SSL	Steller's Sea Lion (SL)
	HP	Harbor porpoise	US	Unidentified seal
	DP	Dall's porpoise	UP	Unidentified pinniped
	UMW	Unidentified baleen (mysticete) whale		
	UTW	Unidentified toothed (odontocete) whale		*Fissipeds*
	UW	Unidentified whale or dolphin	PB	Polar bear
Individuals		Total number of animals in the group		
Juveniles		Number of juveniles within the group (subset of individuals)		

Marine mammal observations continued

Field Name	**Codes**	**Description**		
Where at		Clockface position where marine mammal was first observed (1200 is at the bow of the vessel)		
Where to		Animal's direction of movement, in clockface coordinates		
Behavior 1/2	BL	Blow	MI	Milling
	BO	Bow Riding	NO	None (Seen sign only)
	BR	Breach	OT	Other
	DE	Dead	RE	Resting
	DI	Diving	SA	Surface Active
	FE	Feeding	SH	Spyhop
	FL	Fluking	SW	Swim
	FS	Flipper Slap	TR	Travel
	LO	Look	UN	Unknown (U)
	LT	Lobtail	WK	Walking
	MA	Mating		
Movement	SA	Swimming away	PE	Swimming perpendicular to vessel
	SP	Swimming parallel to vessel	FL	Flee
	ST	Swimming towards	U	Unknown
Pace		Animal's travel speed		
	SE	Sedate	VI	Vigorous
	MO	Moderate	U	Unknown
Reaction		Reaction to vessel		
	CD	Change direction	SP	Splash
	IS	Increase in speed	SG	Interactions with gear
	DS	Decrease in speed	RH	Rush
Water or Ice	W	Animal observed in water		
	IL	Animal observed on ice or land		
Reticles		Number of reticles, or use "E" when estimated by eye		
Sighting Distance		Distance in meter to animal(s) when first sigthed		
Sighting Cue	HE	Head	SP	Splash
	FL	Fluke	BL	Blow
	BO	Body	BI	Birds feeding
	DO	Dorsal fin/ridge		
ID Reliability	MA	Maybe		
	PR	Probably		
	PO	Positive		
Sighting Observed By		Initials of observer that first sighted the marine mammal		
Notes		Any additional information on sighting, e.g. presence of boats during sighting		
Recorded through Tiger Nav				
Date				
Time				
Vessel position (lat, long)				
Water depth				
Sea surface salinity				
Sea surface temperature				

APPENDIX 2

Beaufort Wind Force Scale Codes

Sea State Code	Wind speed		Wave Height		Description
	(km/hr)	(knots)	(meter)	(feet)	
0	0 – 2	0 – 1	0	0	Calm, sea like a mirror.
1	2 – 5.5	1 – 3	0 – 0.2	<0.5	Ripple with the appearance of scales are formed, but without foam crests.
2	7.5 – 11	4 – 6	0. – 0.5	0.5 – 1	Small wavelets, still short, but more pronounced. Crests have a glassy appearance and do not break.
3	13 – 18.5	7 – 10	0.5 – 1	2 – 3	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white caps.
4	20.5 – 30	11 – 16	1 – 2	3 – 5	Small waves, becoming larger; fairly frequent white caps.
5	31.5 – 39	17 – 21	2 – 3	6 – 8	Moderate waves, taking a more pronounced long form; many white caps are formed. Chance of some spray.
6	41 – 50	22 – 27	3 – 4	9 – 12	Large waves begin to form; the white foam crests are more extensive everywhere. Spray probable.
7–12	> 50	> 27	> 4	> 13	7 is near gale, 10 is storm, and 12 is hurricane

SECTION IX
CHUKCHI SEA ACOUSTIC MONITORING

DAVID HANNAY
PRINCIPAL INVESTIGATOR
JASCO APPLIED SCIENCES
VICTORIA, BC

1.0 INTRODUCTION

The objectives of the acoustics program are to quantify the soundscape of the Chukchi Sea and to identify and localize marine mammal vocalizations to provide improved understanding of marine mammal habitat usage, migration paths and temporal and spatial presence. The results of the program will be used to assist in the assessment of potential noise effects of industrial activities associated with oil and gas exploration and production on marine mammals.

The 2010 acoustics program will involve deploying 44 autonomous acoustic recorders, including a regional array of 20 recorders and three focused arrays of 7 recorders each. The regional deployment pattern will be similar to that used by COP and Shell for acoustics programs in the Chukchi Sea in the 2006-2009 open water seasons. The regional recorders will be augmented by three sets of clusters of 7 recorders each in hexagonal grid patterns centered over Shell's Burger prospect, COP's Klondike prospect, and Statoil's prospect in 2010. The acoustic data acquired by all 44 recorders will be analyzed to detect vocalizations and classify the calling species using approaches similar to that employed for analysis of the previous seasons' data. Call localizations will be performed for calls detected on the two cluster arrays.

1.1 Program Description

Marine mammal species in the Chukchi Sea use sound for communication, navigation, predator avoidance, defense, breeding, care of young and feeding. Industrial activities by ConocoPhillips and other operators in the Chukchi will generate underwater noise that could interfere with the natural uses of sound listed above. Noise exposures can also induce physiological responses that could lead to secondary effects such as habitat abandonment and reduction of foraging or breeding efficiency.

The arctic seas have historically experienced less industrial activity than most other marine environments. Marine mammals in the Chukchi consequently have had less opportunity to habituate to anthropogenic noise. Regulatory permitting for recent projects has acknowledged this and as a result applied rather strict requirements for operators working in the Chukchi to quantify and mitigate sound exposures of marine mammals. Acoustic programs have been performed by COP and Shell and other operators since 2006 to address these permitting requirements related to noise for offshore operations there. OLF's 2010 program has been designed to extend the multi-year dataset and to provide new information about detailed call locations near the lease block areas where work is expected to be focused over the next few years.

1.2 Acoustics Program Purpose

The proposed acoustics program has been designed to address the following main goals: 1) to assess ambient and industrial noise levels and 2) to detect, classify species and localize vocalizing marine mammals over the Alaskan Chukchi Sea and in vicinity of the Burger and Klondike prospects. The proposed field program involves continuing the measurement programs performed by JASCO Research Ltd and Bioacoustics Research Program at Cornell University in 2006-2009 for COP and Shell. The 2010 acoustics program will also be supported by Statoil and includes a focused cluster of 7 recorders over a set of their lease blocks to the north of Klondike and Burger. The 2010 program will be fully performed by JASCO Research Ltd.

The regional program will instrument a large area of the Chukchi Sea off the Alaskan coast out to approximately 160 km (100 miles) offshore. The focused programs will use three arrays of 7 recorders each deployed as follows: six systems will be placed on the vertices of a hexagon with 8 km (5 mile) separations and the 7th at the hexagon's geometric center. Statoil may be performing a 3-D seismic survey program to the north of Burger and extending to approximately 72 degrees North. We expect to capture those sounds on a large number of recorders, and likely on all three of the focused arrays. The acoustic field measurement program will directly measure seismic survey sounds and it will detect vocalizations from several marine mammal species. Detections are expected from belugas (*Delphinapterus leucas*), bowheads (*Balaena mysticetus*), gray whales (*Eschrichtius robustus*), fin whales (*Balaenoptera physalus*), killer whales (*Orcinus orca*), walruses (*Odobenus rosmarus*) and several species of ice seals. It is noted that the acquisition program includes data collection only. The analyses for detection, classification and localization will occur under a separate contract.

2.0 FIELD METHODS

2.1 Equipment and Sampling Parameters

All acoustic measurements will be performed using JASCO's calibrated autonomous multi-channel acoustic recorders (AMARs) that are shown in Figures IX-1 and IX-2. These recorders sample continuously or on a pre-programmed schedule. We plan to set the programmable sample rate to 16,384 samples per second using 24-bit samples. This is the sampling rate that JASCO has employed in 2007 to 2009 (though at 16-bit samples in 2007) and it is higher than the frequencies used by most other long-period sound recording programs in the Chukchi Sea. The recorders can also be programmed to sample at much higher rates but the proposed 16,384 Hertz (Hz) rate provides 8 kiloHertz (kHz) of acoustic bandwidth which is sufficient to capture a sufficient component of beluga vocalizations and most of the frequency content of the other present species' vocalizations. It is not high enough to capture click sounds from harbor porpoises.

AMARs can be configured with omni-directional sensors and directional sensors. We will utilize omni-directional hydrophones for all 44 recorders deployed in 2010. Even though the hydrophones are non-directional we will be able to localize calls on the focused deployment areas by examining arrival time differences on the synchronized recorders. Detections on at least three synchronized omni-directional systems are required to localize vocalizations. The localization accuracy depends on the signal to noise ratio of received signals. Greater positional accuracies will be obtained if signals are received simultaneously on greater numbers of systems.

The hydrophones are calibrated in the lab prior to deployment, and a final calibration is performed in the field immediately prior to deployment and upon retrieval using a pistonphone calibrator that generates a reference signal accurate to 0.1 decibel (dB) at 250 Hz. The calibration signals are recorded into the data stream for confirmation of overall recording system gain upon data analysis.

Figure IX-1. Photograph of AMAR acoustic buoy.

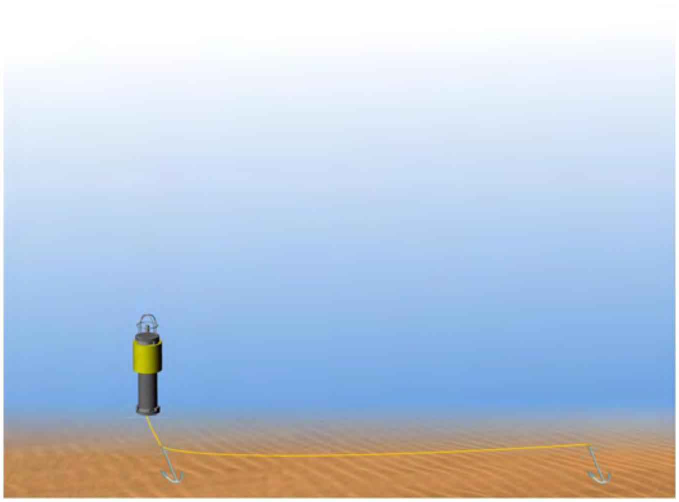

Figure IX-2. AMAR deployment configuration planned for OLF 2010 acoustics program. Retrievals are made by grappling the line between the two anchors. This method has been used successfully in the previous Chukchi season programs and nothing is left on the seafloor.

2.2 Deployment Geometry and Schedule

The recorders will be deployed on the seabed as shown in the diagram in Figure IX-2 at similar locations to the configurations employed by COP and Shell in their 2007-2009 regional programs and COP's 2008 and 2009 focused program at the Burger and Klondike areas. The planned deployment locations are shown in Figure IX-3. A regional array of 23 recorders will be deployed in four strings of between 5 and 7 recorders each at Cape Lisburne, Point Lay, Wainwright, and Point Barrow. Most of these deployment locations are at the same sites instrumented in 2007 to 2009.

The focused cluster arrays of 7 AMAR recorders each will be deployed at the study areas in late July 2010 before Statoil's 3-D survey program is planned to start. The planned deployment configuration will positions recorders in a hexagonal pattern with perimeter recorders spaced at 8 km (5 miles) with a single recorder at the hexagon center to allow for vocalization call detections on multiple units simultaneously so that localization can be performed. The AMAR recorders will be set to record continuously until mid-October 2010. In early October the recorders will be retrieved and a subset of the recorders will be redeployed to record on extended duration mode for up to a full year. This approach was used successfully in 2007-2009 by JASCO.

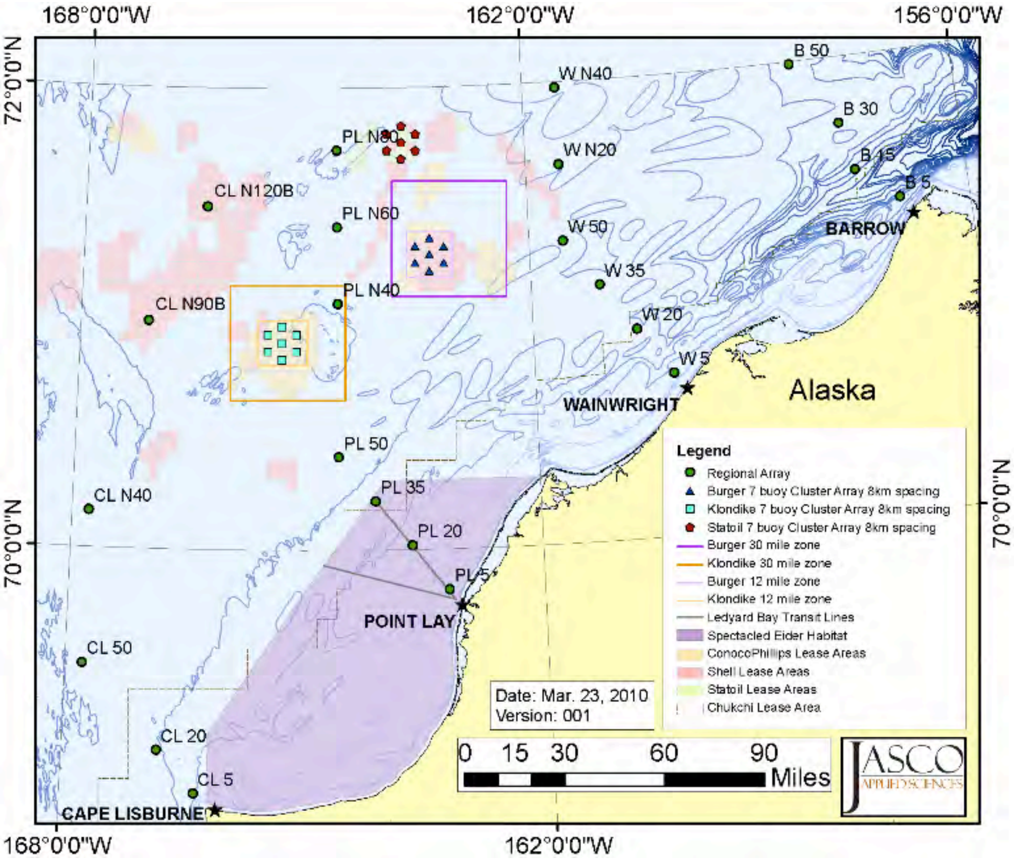

Figure IX-3. Planned AMAR acoustic recorder deployment locations for 2010. The circles indicate locations for regional array buoy deployments. The cyan squares, blue triangles and red hexagon symbols respectively represent the focused array buoy locations at Klondike, Burger and Statoil's survey area.

Table IX-1: Planned geographic coordinates of Regional AMAR deployments for summer 2010

Site	Depth (m)	Longitude	Latitude	UTM Easting (N4)	UTM Northing (N4)
CL 5	29.0	-166.37506797	68.94154544	204850.71875000	7665422.50000000
CL 20	34.7	-166.83663243	69.12756867	189109.73437500	7688312.50000000
CL 50	45.4	-167.78370432	69.49563211	157627.75000000	7734092.50000000
CL N40	47.8	-167.78341821	70.15899058	168271.63314749	7807403.85076878
CL N90B	42.1	-167.10000000	70.98819873	206272.00000000	7895750.00000000
CL N120B	44.9	-166.35000000	71.48573000	240077.90000000	7947406.40000000
PL 5	14.6	-163.20331881	69.82357532	338302.12500000	7751593.00000000
PL 20	29.1	-163.65622939	70.01797811	322561.12500000	7774483.00000000
PL 35	34.4	-164.11766298	70.21117547	306820.15625000	7797373.00000000
PL 50	42.5	-164.58781993	70.40313001	291079.15625000	7820263.00000000
PL N40	40.0	-164.58763108	71.06699952	297898.79675715	7894028.43162860
PL N60	42.3	-164.58781780	71.39892456	301308.61701072	7930911.14744290
PL N80	39.5	-164.58820071	71.73084320	304718.43726430	7967793.86325719
W 5	23.2	-160.18006593	70.70823963	456488.03125000	7845107.50000000
W 20	49.3	-160.62339064	70.91015233	440747.03125000	7867997.50000000
W 35	47.1	-161.07581434	71.11096837	425006.06250000	7890887.50000000
W 50	48.1	-161.53758290	71.31065034	409265.06250000	7913777.50000000
W N20	45.6	-161.53749811	71.64269686	410823.16812095	7950784.71425444
W N40	37.4	-161.53749688	71.97473276	412381.27374190	7987791.92850888
B 5	75.0	-156.93722834	71.36311003	573564.50000000	7918980.00000000
B 15	101.5	-157.50104845	71.50413259	553071.30694375	7934112.96369108
B 30	63.8	-157.64861331	71.71163843	547329.50000000	7957130.00000000
B 50	62.2	-158.23675428	71.98850796	526341.56250000	7987650.00000000

Table IX-2: Planned geographic coordinates of Burger Focused Array AMAR deployments for summer 2010

Site	Depth (m)	Longitude	Latitude	UTM Easting (N4)	UTM Northing (N4)
BG01	43.9	-163.34978297	71.27738885	559113.25000000	7909140.50000000
BG02	44.9	-163.34366876	71.34908629	559113.25000000	7917140.50000000
BG05	43.0	-163.35584967	71.20569063	559113.25000000	7901140.50000000
BG07	45.0	-163.54041284	71.31483593	552185.06250000	7913140.50000000
BG06	43.7	-163.54579039	71.24313155	552185.06250000	7905140.50000000
BG03	44.8	-163.15308669	71.31144061	566041.43750000	7913140.50000000
BG04	44.1	-163.15988951	71.23975014	566041.43750000	7905140.50000000

Table IX-3: Planned geographic coordinates of Klondike Focused Array AMAR deployments for summer 2010

Site	Depth (m)	Longitude	Latitude	UTM Easting (N4)	UTM Northing (N4)
KL01	35.7	-165.32875087	70.89726745	487992.12500000	7865971.50000000
KL02	35.5	-165.32994295	70.96899651	487992.12500000	7873971.50000000
KL05	34.9	-165.32756787	70.82553782	487992.12500000	7857971.50000000
KL07	39.5	-165.51936345	70.93269721	481063.90625000	7869971.50000000
KL06	34.8	-165.51749085	70.86096961	481063.90625000	7861971.50000000
KL03	39.6	-165.13932208	70.93337218	494920.31250000	7869971.50000000
KL04	37.0	-165.13881970	70.86164187	494920.31250000	7861971.50000000

Table X-4: Planned geographic coordinates of Statoil Focused Array AMAR deployments for summer 2010

Site	Depth (m)	Longitude	Latitude	UTM Easting (N4)	UTM Northing (N4)
SO01	39.7	-163.69688354	71.76515292	545508.00000000	7963229.00000000
SO02	40.0	-163.69191600	71.83685790	545508.00000000	7971229.00000000
SO05	39.5	-163.70181148	71.69344726	545508.00000000	7955229.00000000
SO07	39.9	-163.89311816	71.80224767	538579.81250000	7967229.00000000
SO06	39.9	-163.89731320	71.73053715	538579.81250000	7959229.00000000
SO03	40.0	-163.49572121	71.79955875	552436.18750000	7967229.00000000
SO04	39.1	-163.50142118	71.72785949	552436.18750000	7959229.00000000

3.0 DATA ANALYSIS PROCEDURES

3.1 Data Extract and Backup

The acoustic data will be downloaded from the recorders after they arrive at JASCO's laboratory in Halifax. The data will be extracted from internal RAM memory and checked for quality, and then copied to a hard disk drive array for delivery to the client. Two copies will be provided. One copy may be retained in Halifax for analysis upon approval by client.

3.2 AMAR Acoustic Recorders

JASCO Applied Sciences's AMARs will be deployed for this acoustics program. These systems are designed with very low power draw to facilitate long deployments using relatively small battery packs. They use solid state memory instead of hard drives, and can accommodate up to 1 TB of memory. Solid state memory is much less sensitive to temperature and vibration extremes than hard drive storage systems. The AMARs can record 24-bit audio and 3-axis water particle acceleration (vector sensors) with sample rate up to 500 MHz (divided by number of channels). These systems also log temperature and include serial inputs for other sensor types (e.g. GPS, CTD). For OLF's 2010 Chukchi Acoustics Program we plan to record only single channel 24-bit audio continuously at 16 kHz for 3 months.

3.3 Quality-control Procedures

All AMAR buoys will be subjected to an acceptance test plan prior to sending to the field. The test plan involves comprehensive environmental testing including subjecting to cold water temperatures that are typical of the near-freezing conditions of the Chukchi Sea. The hydrophones and recording systems are calibrated prior to leaving the laboratory, and pistonphone calibrations will be carried out immediately prior to deployment and upon retrieval. These pistonphone tests involve recording a 1-minute calibrated pressure signal into the AMAR data stream to provide calibration signals directly in the data.

SECTION X
BEAUFORT SEA ACOUSTIC MONITORING

CHARLES GREENE JR. & SUSANNA BLACKWELL
CO-PRINCIPAL INVESTIGATORS
GREENERIDGE SCIENCES, INC.
SANTA BARBARA, CA

1.0 INTRODUCTION

The objectives of the acoustics program are to characterize industrial sounds and marine mammal vocalizations in the Alaska Beaufort Sea (Blackwell et al. 2008, 2009, and 2010). This work has been performed annually since 2007 in support of Shell's acoustic research program to provide an improved understanding of marine mammal habitat usage, migration paths and temporal and spatial presence. The results of the program will be used to assist in the assessment of the potential effects of sound associated with oil and gas exploration and production on marine mammals.

The 2010 acoustics program will involve deploying 35 directional autonomous seafloor acoustic recorders (DASARs), including an array of seven recorders at five sites between Harrison Bay and Kaktovik, Alaska (see Figure X-1).

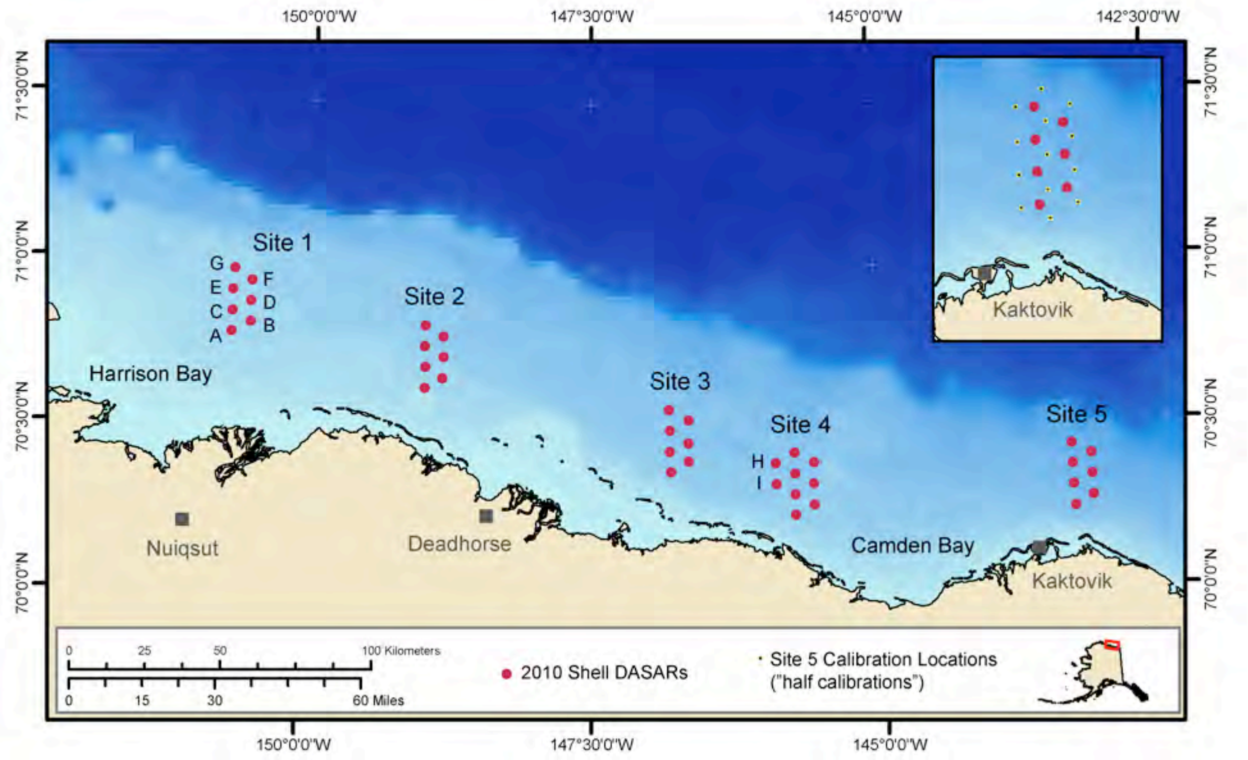

FIGURE X-1. DASAR deployment locations planned for the 2010 field season. The five sites are labeled 1–5 from west to east, and A–G from south to north (as shown for site 1). Two additional deployment locations are planned in 2010, labeled "H" and "I" at site 4. The insert shows how 13 calibration locations were placed in relation to the DASARs at site 5. The same relative locations, with three

calibrations locations around each DASAR, will be used at each site. The distance from site 1 to site 5 is ~280 km (~174 mi or ~151 n.mi.).

1.1 Acoustics Program Purpose

The objective of this study is to investigate possible effects of anthropogenic sounds on measurable aspects of bowhead whale behavior, such as call detection rates and whale movements. Using passive acoustics with directional autonomous recorders, the locations of calling whales will be observed at five coastal sites. The 2010 field season is planned for approximately August 1 through September 26.

2.0 METHODS

2.1 Equipment

Recordings will be made using Directional Autonomous Seafloor Acoustic Recorders model C08 (DASAR-C08). A picture and schematic representation of such a DASAR are shown in Figure X-2. The DASAR consists of a pressure housing (17.8 cm high and 32.4 cm in diameter, or ~7 inches and 12.75 inches, respectively) containing the recording electronics and alkaline batteries. A sensor suspended elastically about 12.7 cm (5 inches) above the pressure housing includes two particle motion sensors mounted orthogonally in the horizontal plane for sensing direction. It also includes a flexural pressure transducer for the omnidirectional sensor. Because of corrosion concerns during the 2008 deployments, spherical sensors on all DASARs were treated by the manufacturer with an anti-corrosion coating before the 2010 field season.

The DASAR pressure housing is bolted to a square frame with 66 cm (26”) sides. A spandex “sock” stretched over the tubular “cage” surrounding the pressure housing (see Figure X-2B) protects the sensors from motion in water currents. The total in-air weight is ~32.2 kilogram (kg) (71 pounds [lb]) and the in-water weight is ~15 kg (33 lb).

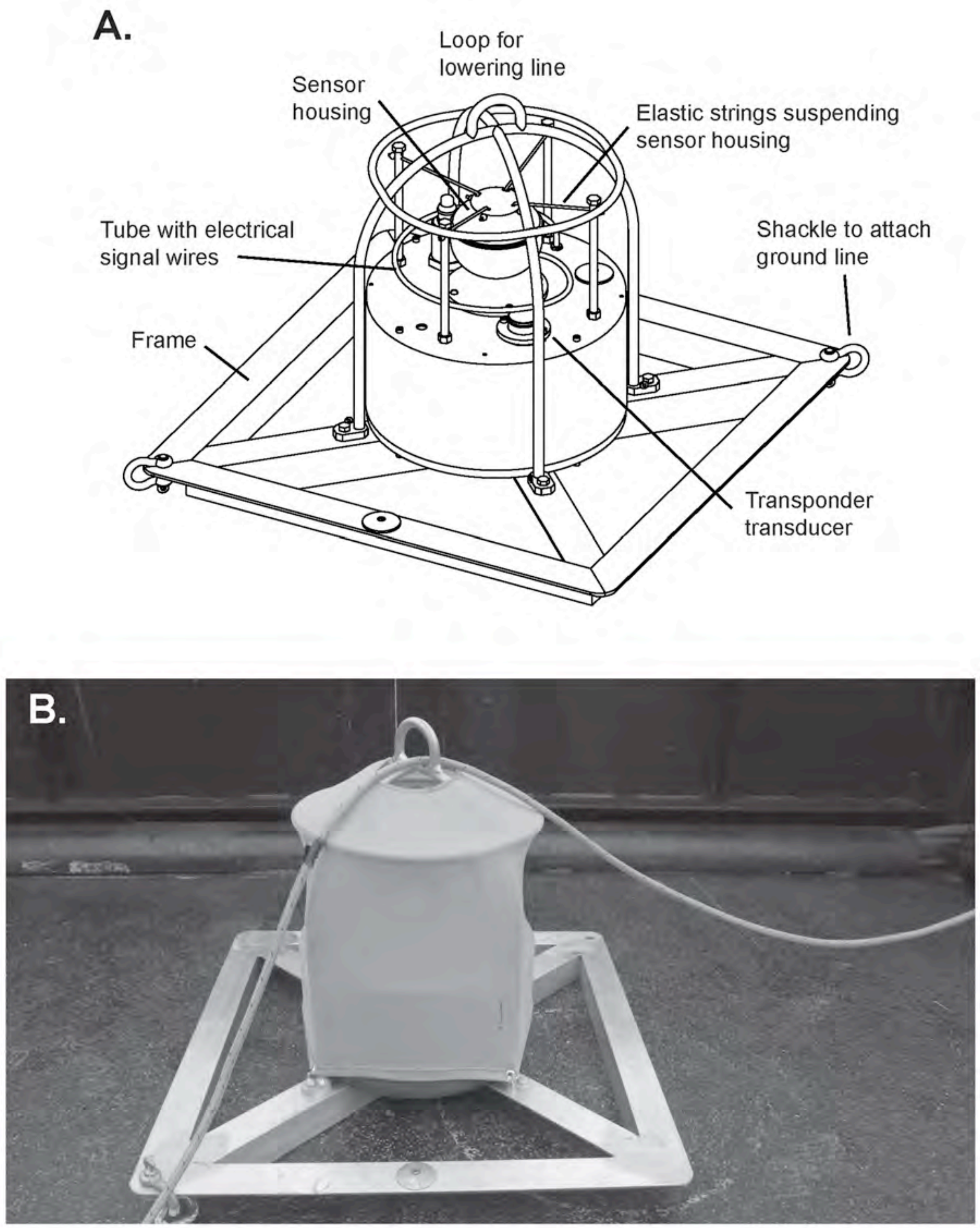

FIGURE X-2. DASAR recorder (model C08). ***(A)*** **Schematic diagram of the components of the DASAR-C08 recorder.** ***(B)*** **A DASAR about to be deployed. The lowering line (shown) is looped through the top of the frame and is removed after the DASAR is set on the ocean floor. The ground line is attached with a shackle to the bottom left corner of the DASAR frame on the picture. At the end of its 110 m length, this line is connected to a chain and Danforth anchor, which are deployed last.**

DASARs record sound at a 1 kHz sampling rate (1000 samples / s) on each of three data channels: (1) an omnidirectional channel, (2) a "cosine channel" on the primary horizontal axis, and (3) a "sine channel" on the axis perpendicular to the cosine channel. Each channel has maximum sensitivity in its primary direction, and the sensitivity falls off with the cosine of the angle away from the axis. The recorder includes a signal digitizer with 16-bit quantization. The samples are buffered for about 45 minutes, then written to an internal 60 GB hard drive, which takes about 20 s. Allowing for anti-aliasing, the 1 kHz sampling rate allows for 116 days of continuous recording and a data bandwidth of 450 Hz.

2.2 DASAR Hydrophone Calibration

The omnidirectional hydrophone in each DASAR, an acoustic pressure sensor, will be used for sound pressure measurements of the background and whale calls. The hydrophone was procured with information from the manufacturer permitting their sensitivity to be computed. In addition, in Spring 2008 two DASARs were taken to the U.S. Navy's sound transducer calibration facility TRANSDEC at San Diego, for calibration. The two DASARs calibrated at TRANSDEC were then used as secondary standards for comparison with the remaining DASARs. The DASAR sensitivities are very stable and do not vary significantly from year-to-year.

2.3 Field Procedures

DASARs will be installed on the seafloor with no surface expression, which is important to avoid entanglement with ice floes. One corner of the DASAR frame will be attached with a shackle to 110 m (360 ft) of "ground line", which will end with 1.5 m (5 ft) of chain and a small Danforth anchor. During deployment, the DASAR will be lowered onto the seafloor using a line passed through the loop at the top of the "cage" (see Figure IX-2B). One end of the lowering line will then be released from the vessel and the line retrieved. The vessel will then move away from the DASAR location while laying out the ground line in a straight line. As the end of the ground line was reached, the Danforth anchor will be dropped into the water. GPS positions will be obtained of both the DASAR and anchor locations.

The DASARs will be retrieved by grappling. The grappling setup will consist of either one or two four-prong grappling hooks interconnected with a four-foot section of long-link chain. The grappling setup will be determined by the crew of the Norseman II. It will be dragged over the center of the ground line and perpendicular to it.

2.4 Clock and Bearing Calibrations in the Field

When DASARs are lowered to the seafloor there is no way to control their orientation in relation to true north. In addition, each DASAR contains a clock that has a small but significant drift, which needs to be compensated for over the course of the deployment period (Greene et al. 2004). Field calibrations consist of projecting test sounds underwater at known times and known locations, and recording these sounds on the DASARs. After processing, the collected data allow us to determine each DASAR's orientation on the seafloor, so that the absolute direction of whale calls can be obtained. The calibration transmissions also will allow us to synchronize the clocks from the various DASARs, so that the bearings from a call heard by more than one DASAR can be combined, allowing an estimate of the caller's position by triangulation. Calibration transmissions will be projected at six locations around each DASAR, at a distance of about 4 km.

Equipment used for calibrations included a J-9 sound projector, an amplifier, a computer to generate the projected waveform, and a GPS to control the timing of the sound source. The waveform projected will consist of a 2-s tone at 400 Hz, a 2-s linear sweep from 400 to 200 Hz, a 2-s linear sweep from 200 to 400 Hz, a 2-s linear sweep from 400 to 200 Hz, and finally a 4-s long section of pseudo-random noise, i.e., an m-sequence with 255 chips, repeated once every second and on a 255 Hz carrier frequency. Each site will be calibrated directly following the deployment of its seven DASARs, and again before retrieval.

2.5 Health Checks

To insure that the recorders and their software are functioning as expected, a health check will be performed on each DASAR during the calibrations following deployment. Each DASAR will therefore be health-checked after it had had the chance to write data to disk one or more times (this happens about every 45 min during normal recording). A surface-deployed transducer (a line-mounted Benthos DRI-267A Dive Ranger Interrogator) will be placed in the water at the recorded GPS location of each DASAR. The transducer interrogates an acoustic transponder (Benthos UAT-376, operational range 25–32 kHz) in each recorder, which respond on one channel if it is recording and on another channel if it is not.

3.0 DATA ANALYSIS

After retrieval, the DASARs will be opened up and dismantled. The sampling program will be shut down, the 60 GB hard drives removed and hand-carried back to Greeneridge headquarters where they are backed up. Data will be transferred to workstations running MATLAB and custom analysis software.

The analysis portion of this program is funded directly by Shell and is therefore not included as part of this study plan prepared by OLF.

4.0 REFERENCES

Blackwell, S.B., C.R. Greene, Jr., T.L. McDonald, M.W. McLennan, C.S. Nations, R.G. Norman, and A. Thode. 2008. Beaufort Sea bowhead whale migration route study. (Chapter 8) *In*: Funk, D.W., R. Rodrigues, D.S. Ireland, and W.R. Koski (eds.). Joint monitoring program in the Chukchi and Beaufort seas, July-November 2007. LGL Alaska Report P971-1, Report from LGL Alaska Research Associates, Inc., LGL Ltd., JASCO Research, Ltd., and Greeneridge Sciences, Inc., for Shell Offshore, Inc., ConocoPhillips Alaska, Inc., and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 445 p. + Appendices.

Blackwell, S.B., C.S. Nations, T.L. McDonald, K.H. Kim, C.R. Greene, Jr., A. Thode., and R.G. Norman. 2009a. Beaufort Sea acoustic monitoring program. (Chapter 9) *In*: Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). Joint Monitoring Program in the Chukchi and Beaufort Seas, open water seasons, 2006–2008. LGL Alaska Report P1050-1, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc., and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 488 p. + Appendices.

Blackwell, S.B., C.S. Nations, T.L. McDonald, K.H. Kim, C.R. Greene, Jr., A. Thode., and R.G. Norman. 2010. Beaufort Sea acoustic monitoring program. (Chapter 6) *In*: Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). Joint Monitoring Program in the Chukchi and Beaufort Seas, open water seasons, 2006–2009. LGL Alaska Report P1050-1, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc., and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service.

Greene, C.R., Jr., M.W. McLennan, R.G. Norman, T.L. McDonald, R.S. Jakubczak, and W.J. Richardson. 2004. Directional frequency and recording (DIFAR) sensors in seafloor recorders to locate calling bowhead whales during their fall migration. Journal of the Acoustical Society of America 116(2):799–813.