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cANIMIDA Final Report: Summers 2004-2007

Long-Term Monitoring of the Kelp Community in the Stefansson Sound Boulder Patch: Detection of Change Related to Oil and Gas Development

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Submitted to:

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Project Organization Page

Dr. Kenneth H. Dunton is a biological oceanographer whose research is focused on estuarine and coastal processes. Although his work spans from the Arctic to the Antarctic, his continuous studies of the arctic coastal ecosystem has spanned three decades and over 3000 research dives. Dr. Dunton has been involved in the Shelf-Basins Interactions study funded through NSF's Arctic System Science (ARCSS) program since 1999. His component is focused on the distribution and biomass of benthic biota and the application of stable isotopic signatures to assess changes in trophic structure. Such measurements can help identify processes that are sentinel indicators of global change. He has also performed intensive studies of arctic benthic communities, with special focus on the dynamics of arctic kelp beds. Dr. Dunton has published more than 70 peer-reviewed papers and has supervised 18 graduate students and seven post-doctoral fellows. He obtained his B.S. in Biology from the University of Maine in 1975, his M.S. from Western Washington in 1977, and his Ph.D. in oceanography from the University of Alaska-Fairbanks in 1986. Dunton is currently a professor in Marine Science at The University of Texas at Austin.

Susan V. Schonberg (B.S. Biology, M.S. Computer Science) is a Research Associate II at The University of Texas Marine Science Institute, Port Aransas, Texas. She began training as an arctic taxonomist in 1978 as an undergraduate student worker on a project funded by OCSEAP to PI Dr. Carter Broad at Western Washington State University. In 1980 she moved to Fairbanks, Alaska and worked in Dr. Howard Feder's taxonomic laboratory at the University of Alaska-Fairbanks until 1984. During this period she worked on two major projects: benthic taxonomy of invertebrates collected following the Valdez oil spill and benthic and pelagic taxonomy of invertebrates collected from the northeastern Bering Sea and the southeastern Chukchi Sea. She also made collecting trips to the Beaufort Sea and was one of the research divers assigned to work on an area of boulders and cobbles located off the coast of Prudhoe Bay, Alaska, called the Boulder Patch. From 1984-1986 Schonberg worked in Dr. Don Schell's chemical oceanography lab processing natural abundance ^{13}C and ^{15}N isotope samples from the Chukchi and Beaufort Seas. In fall of 1985, Schonberg went to Leningrad (now St. Petersburg) as an exchange scientist with the National Academy of Sciences. She worked with Soviet invertebrate taxonomists in an effort to integrate scientific nomenclature of arctic species. In 1986, Schonberg began her current position at the UT Marine Science Institute and has continued her involvement in Arctic studies. Under the NSF Shelf Basin Interaction (SBI-I) project 2000-2002, Schonberg was in charge of compiling a historical database of all known benthic invertebrate species and their biomass values from cores taken in the Bering, Chukchi and Beaufort Seas. This massive project was completed in 2002 and the results published in the journal *Deep-Sea Research*. Schonberg participated in Shelf Basin Interaction (SBI-II) ice breaker cruises during spring and summer 2002 and 2004. She collected and identified infaunal and epifaunal invertebrates from grabs and trawls taken from stations just north of the Bering Strait through the western Beaufort Sea. During the summer of 2006 and 2007 Schonberg was aboard The University of Texas 27' Boston Whaler *RV Proteus*. She was involved in taking kelp bed productivity measurements at the Boulder Patch for MMS and sampling along the arctic coast collecting and identifying invertebrates for natural abundance ^{13}C and ^{15}N isotope studies for USF&WS.

Dr. Katrin Iken is an Associate Professor in Marine Biology at the School of Fisheries and Ocean Sciences at the University of Alaska Fairbanks. She started to work in polar benthic systems during her Ph.D., which she received at the Alfred Wegener Institute in Bremerhaven, Germany in 1995. Since then, she has participated in 16 field deployments in the Antarctic and Arctic, many of them international in scope, totaling 28 months field time. Her research interests are in benthic ecology and biodiversity, especially trophic interactions and food web studies. She is the author or co-author of 35 peer-reviewed publications. Dr. Iken is also a project leader of the Natural Geography in Shore Areas (NaGISA) program within the Census of Marine Life Project (CoML), which investigates nearshore biodiversity in hard-bottom, macroalgal-dominated nearshore ecosystems on a global scale. Within NaGISA, she leads the Arctic and Antarctic sampling efforts.

Dr. Dale W. Funk is Vice President and Senior Ecologist at LGL Alaska Research Associates, Inc. in Anchorage, Alaska. He joined LGL in March 1998. He received his Ph.D. in ecology from the University of Colorado and did postdoctoral work at Clemson University. Dr. Funk is an experienced scientist, project manager, and research coordinator. He has worked extensively in basic and applied research and has over 20 years of experience studying the arctic and taiga ecosystems of Alaska. Dr. Funk has managed and contributed to numerous large-scale multidisciplinary studies for both industry and government. Before joining LGL, Dr. Funk held research and teaching appointments at the University of Alaska-Anchorage and Clemson University where he was a Principal Investigator for projects funded by NSF and EPA.

EXECUTIVE SUMMARY

We examined benthic community structure and annual variations in kelp production in relation to physicochemical parameters, as well as biodiversity patterns, in the Boulder Patch, an isolated kelp bed community on the Alaskan Beaufort Sea coast. Long-term variations in kelp growth in coincidence with recent (2004-2006) measurements of underwater photosynthetically active radiation (PAR), light attenuation coefficients, chlorophyll and total suspended solids (TSS) were measured to determine the impact of sediment resuspension on kelp productivity. Attenuation coefficients exhibited distinct geographical patterns and inter-annual variations between 2004 and 2006 that were similar to that reported in 2001 and 2002 (ANIMIDA) that were largely correlated with similar temporal and geographical patterns in TSS (range 3-23 mg L^{-1}). Chlorophyll levels remained consistently low ($< 3\ \mu g\ L^{-1}$) in all three years and unlikely contribute significantly to periods of low water transparency. Blade elongation rates in the arctic kelp, *Laminaria solidungula*, are excellent integrators of water transparency since their annual growth is completely dependent on PAR received during the summer open-water period. We noted that blade growth at all sites examined steadily increased between 2004 and 2006, reflective of increased underwater PAR in each successive year. Blade growth at all sites was clearly lowest in 2003 (< 8 cm) compared to 2006 (18-47 cm). We attribute the low growth in 2003 to reports of intense storm activity that likely produced extremely turbid water conditions that resulted in low levels of ambient light. Examination of a 30-yr record of annual growth at two sites reveals other periods of low annual growth that are likely related to exceptional strong periods of storm activity. Although kelp growth is expected to be higher at shallower sites, the reverse occurs, since sediment re-suspension is greatest at shallower water depths. The exceptionally low growth of kelp in 2003 indicates that these plants are living near their physiological light limits, but represent excellent indicators of inter-annual changes in water transparency that result from variations in local climatology. Estimates of productivity obtained under ANIMIDA (0.1 to 0.8 g C g dwt^{-1} $year^{-1}$) also reflect the large range in kelp growth from 2003 to 2006 under nearly identical TSS loads. Biodiversity and community structure patterns varied among different locations within the Boulder Patch. Four new distribution records if macroalgae increased the total number of seaweeds for the region to 15. Main algal biomass contributors in both years and at all stations were the red algae *Phycodrys riggii* (possibly *P. rubens?*) and *Phyllophora truncata* and the brown alga *Laminaria solidungula*, and algal biomass ranged from 30 - 330 g $0.25m^{-2}$ for different sites and years. A total of 141 invertebrate taxa contributed to an average biomass of about 15 g m^{-2}, mainly from sponges, bryozoans and hydrozoans. Infaunal abundance and diversity was low, and aside from methodological considerations, the dense, consolidated substrate in the Boulder Patch may constrain infaunal species. It is suggested here that some of the long-lived macroalgal and invertebrate species most important in distinguishing community composition at different sites may be good indicators for environmental conditions, and subsequently environmental change. Further research will be needed to confirm environmental effects on these species and especially their recruitment before a monitoring plan can be fully developed.

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CHAPTER 1

INTERANNUAL AND SPATIAL VARIABILITY IN LIGHT ATTENTUATION: EVIDENCE FROM GROWTH IN THE ARCTIC KELP, *LAMINARIA SOLIDUNGULA*

Ken Dunton, Susan Schonberg, The University of Texas Marine Science Institute
Dale W. Funk, LGL Alaska Research Associates, Inc. Anchorage, Alaska

BACKGROUND

Introduction

Research studies conducted over the past two decades have clearly documented that kelp biomass, growth, and productivity in Stefansson Sound Boulder Patch are strongly regulated by light availability (photosynthetically active radiation, PAR). Results from a variety of experimental studies, including the linear growth response of kelp plants to natural changes in the underwater light field (Dunton, 1984; Dunton and Schell, 1986; Dunton, 1990), carbon radioisotope tracer experiments (Dunton and Jodwalis, 1988), and laboratory and field physiological work (Henley and Dunton, 1995; 1997) have been used successfully to develop models of kelp productivity in relation to PAR. Yet, until recently, the relationship between water turbidity (as measured by total suspended solids (TSS) or optical instruments) and benthic algal production was unknown. Aumack et al. (2007) were the first to establish the quantitative link between water column turbidity, PAR, and kelp production through a model that uses TSS data to estimate kelp productivity. This information is critical for evaluating how changes in water transparency are related to increased suspended sediment concentrations from anthropogenic activities near the Boulder Patch. The quantitative measurements of TSS collected under the Arctic Nearshore Impact Montioring In theDevelopment Area (ANIMIDA) project in summers 2001 and 2002 were a critical first step in the establishment of an accurate basin-wide production model for the Stefansson Sound Boulder Patch (Dunton et al., 2003).

Another component of this study includes the measurement of benthic biodiversity. Biodiversity is one potential measure of ecosystem health and biological interactions such as competition, disturbance, facilitation, predation, recruitment, and system productivity (Petraitis et al. 1989, Worm et al. 1999, Mittelbach et al. 2001, Paine 2002). On a larger scale, biodiversity measurements can serve as an indicator of the balance between speciation and extinction (McKinney, 1998 a, b; Rosenzweig, 2001). In the Boulder Patch, Dunton (1992) suggested an “arctic benthos paradox”, where most algal species are of Atlantic origin while many invertebrates are consistent with those found in the Pacific. This strange distribution pattern combined with the Boulder Patch’s isolated location suggests the potential of the area as a biogeographic stepping-stone. Thus, the Boulder Patch likely has large biological and ecological roles outside Stefansson Sound.

Project Design

The continuation of the ANIMIDA project had the following overarching objective for our field research:

To use synoptic and long-term measurements of PAR, light attenuation coefficients, total suspended solids (TSS; mg L^{-1}), and indices of benthic diversity and kelp biomass to determine the impact of sediment resuspension on kelp productivity and ecosystem status in the Stefansson Sound Boulder Patch.

To address this project objective, we initiated studies to monitor water quality, light, kelp growth and the associated invertebrate community in Stefansson Sound Boulder Patch. This research project was designed to address ecosystem change as related to anthropogenic activities from oil and gas development. The initial effort under the ANIMIDA project was focused on establishing a quantitative relationship between total suspended solids (TSS) and benthic kelp productivity (see Aumack et al., 2007). Under the continuation of this project (cANIMIDA), the specific objectives included efforts to:

1) define the spatial variability in annual productivity and biomass of kelp,

2) monitor incident and *in situ* ambient light (as photosynthetically active radiation [PAR]) and TSS,

3) establish the quantitative relationship between TSS, light attenuation, and kelp productivity,

4) measure benthic faunal community diversity,

5) incorporate historical datasets related to kelp productivity, ambient PAR measurements (both surface and underwater), and benthic diversity into ANIMIDA datasets to establish a long-term record available in digital format, and

6) develop a rationale and strategy for future Boulder Patch contaminant monitoring.

Three sampling strategies were used in summers 2004, 2005 and 2006: 1) semi-synoptic maps of TSS and light attenuation parameters were generated through sampling at 30 randomly-selected points in a 300 km^2 area that included the Boulder Patch and the region south of Narwhal Island to the Sagavanirktok Delta; 2) long-term variations in underwater PAR were monitored at three fixed sites and incident PAR at one coastal site during the summer open-water period; and 3) benthic faunal diversity was measured at seven monitoring stations established during the 1984-1991 Boulder Patch Monitoring Project (LGL Ecological Research Associates and Dunton, 1992). In addition to simultaneous measurements of PAR and TSS, other parameters measured included water column chlorophyll, ammonium, phosphate, silicate, nitrate + nitrite, temperature, salinity, dissolved inorganic nitrogen, and pH.

Data collected in 2004, 2005 and 2006 were added to the historic database we established for many of these sites (maintained in Excel by Dunton at the Univ. Texas Marine Science Institute). At the three fixed sites (DS-11, E-1, W-1), continuous PAR measurements were collected from 1986 to 1991, providing an important baseline from which to detect long-term change. We have added kelp biomass measurements to the collection of benthic diversity data at seven stations originally surveyed from 1984 to 1991 to improve model estimates of kelp production on spatial scales. Data collected in this project, when combined with historical measurements, will provide a valuable database from which to assess ecosystem change in response to oil and gas activities in the region.

METHODS

Overview

Because it is important to understand how changes in the light environment impact kelp productivity, we used surface light and underwater light to quantify the relationship between TSS and the attenuation coefficient, *k*. The Brouger-Lambert Law describes light attenuation with water depth:

$$k = \frac{\ln (I_o/I_z)}{z}$$

where I_o is incident (surface) light intensity, I_z is light intensity at depth *z*, and *k* is the light attenuation coefficient (m^{-1}).

In addition to measurements of water column transparency, we made coincident measurements of summer open water underwater irradiance and kelp growth (as a proxy for overall annual production) since the bulk of photosynthetic production occurs during summer (Dunton and Jodwalis, 1988). Specific hourly surface or bottom irradiances were collected and used to examine the effects of changing TSS loads on kelp blade growth.

Continuous PAR measurements at three fixed locations in the Boulder Patch were directly compared with annual blade growth. We used the quadratic relationship between blade length and dry weight (Figure 1.1) to estimate standing crop biomass based on in situ measurements of frond length. Mean TSS concentrations measured at three different times during the summer were used to examine the relationship with light attenuation and kelp growth.

Historical light data collected at seven locations in the Boulder Patch will be incorporated into our database to provide a measure of long-term interannual variability in both surface and underwater light. Since the same methodology was used to collect PAR measurements from 1986-1991 as conducted in this study (in some cases the exact same sensors and dataloggers are involved), no correction factors were needed for data comparison.

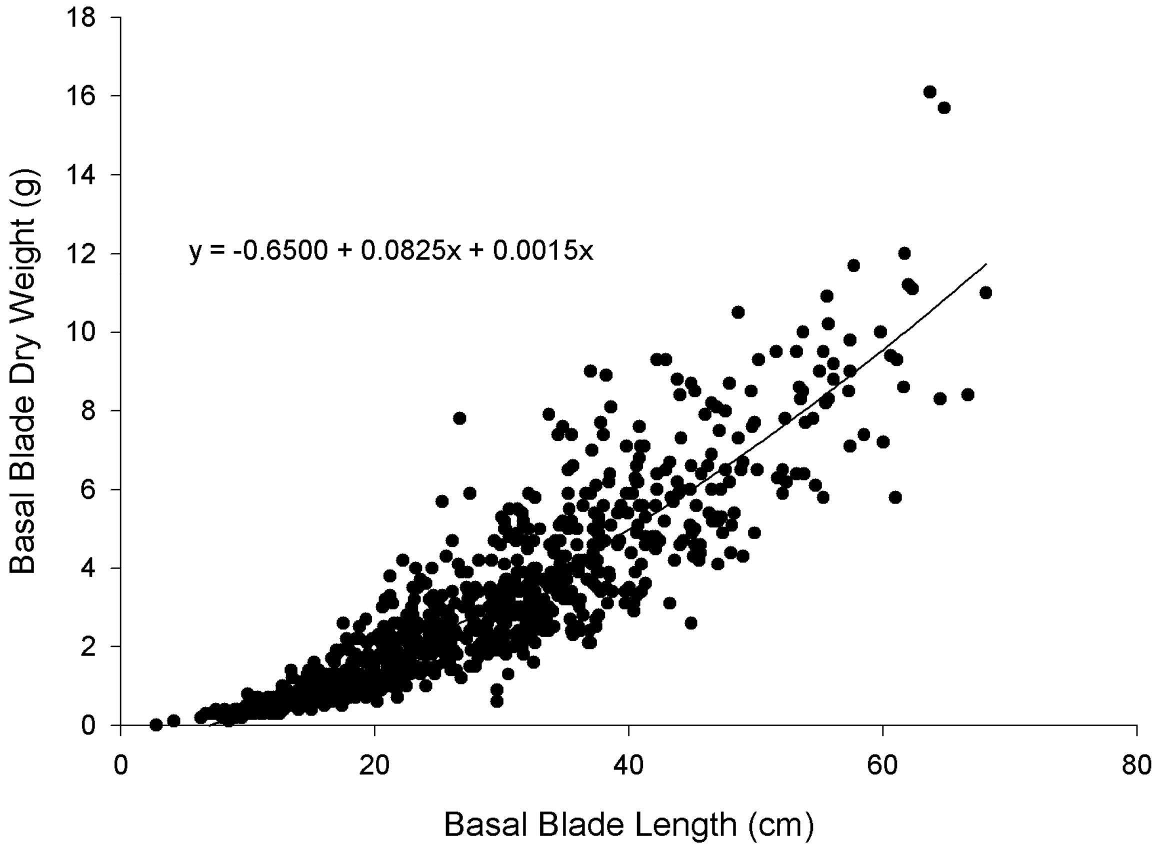

Figure 1.1 Correlation between basal blade dry weight (g) and basal blade length (cm) in *Laminaria solidungula.*

Synoptic Sampling

In order to describe the spatial extent and patterns of TSS, light attenuation, chlorophyll, nutrients, and physiochemical properties across Stefansson Sound, we sampled 30 sites across the monitoring area (Figure 1.2). The location for each site was chosen by laying a probability-based grid over the area and randomly choosing a location within each grid cell. This method allowed sampling locations to be spaced quasi-evenly across the landscape while still maintaining assumptions required for a random sample (i.e., all locations have an equal chance of being sampled). All 30 sites were visited on three separate occasions during summers 2004, 2005 and 2006 using a high-speed vessel (*R/V Proteus*). TSS, incident PAR, inorganic nutrients (ammonia, phosphate, silicate, nitrogen), water column chlorophyll, and physiochemical parameters (temperature, salinity, dissolved oxygen, and pH) were measured.

Replicate water samples were collected at 2 and 4 m depths using a van Dorn bottle. All samples were placed in pre-labeled plastic bottles, then sampling point geographic coordinates (Lat/Long) recorded using a handheld Garmin Global Positioning System, GPSMap 76S (Garmin International Inc., Olathe, Kansas, USA). Physiochemical measurements were made on the boat. All other samples were stored in a dark cooler and transported to a laboratory on Endicott Island for processing.

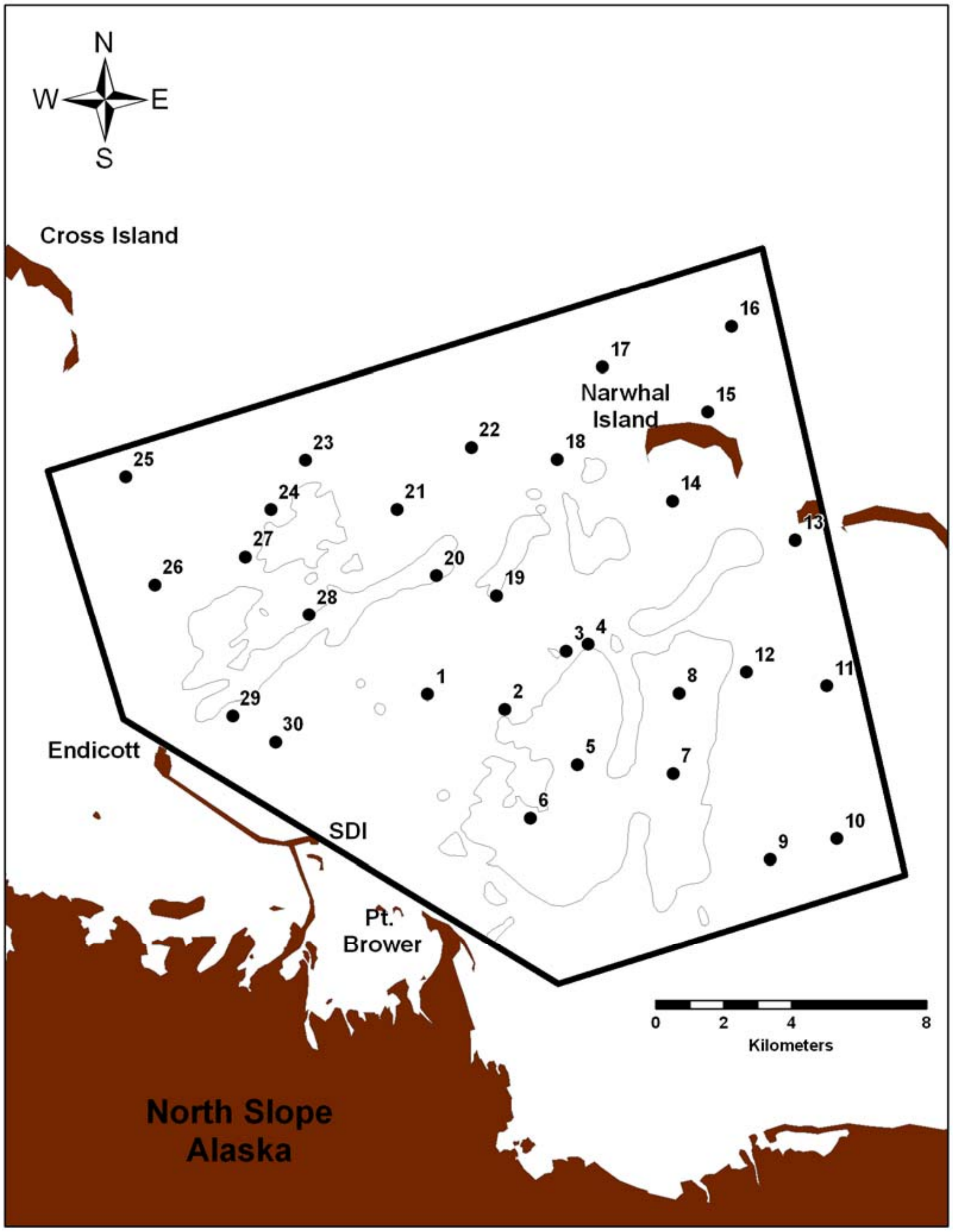

Figure 1.2 Map of the cANIMIDA 2004 - 2006 project study area showing the location of the 30 synoptic collection sites used in summers 2004, 2005 and 2006. SDI: Satellite Drilling

Light Attenuation (k)

Synoptic PAR data were collected using a LI-190SA underwater cosine sensor connected to a LI-1000 datalogger (LI-COR Inc., Lincoln, Nebraska, USA). The sensor was mounted on a lowering frame and light measurements recorded at the surface, 2 m, and 4 m depths. Care was taken to avoid interference from shading of the sensor by the vessel.

Total Suspended Solids (TSS)

To measure TSS, a known volume of water from each sample was filtered through pre-weighed, pre-combusted glass fiber filters (Pall Corporation, Ann Arbor, Michigan, USA) followed by a fresh water rinse with distilled water to remove any salts. Filters were oven dried to constant weight at 60^o C. The net weight of particles collected in each sample was calculated by subtracting the filter's initial weight from the total weight following filtration. Weights were determined with a microbalance (Denver Instruments APX-60, Arvada, Colorado, USA). TSS is measured with a precision of ±0.5 mgL^{-1}.

Chlorophyll a Concentrations

For chlorophyll measurement, 100 ml of water from each replicate sample was filtered through a 0.45 μm cellulose nitrate membrane filter (Whatman, Maidstone, England) in darkness. After filtration, the filters and residue were placed in pre-labeled opaque vials and frozen. The frozen filters were transported to The University of Texas Marine Science Institute (UTMSI) in Port Aransas, Texas for chlorophyll analysis. At UTMSI, filters were removed from the vials and placed in pre-labeled test tubes containing 5 ml of methanol for overnight extraction (Parsons et al., 1984). Chlorophyll *a* concentration, in $\mu g\ L^{-1}$, was determined using a Turner Designs 10-AU fluorometer (Turner Design, Sunnyvale, California, USA). Non-acidification techniques are used to account for the presence of chlorophyll *b* and phaeopigments (Welschmeyer, 1994). Chlorophyll is measured with a precision of ±5%.

Nutrient Concentrations

Water samples were frozen and transferred to UTMSI for nutrient analysis. Nutrient concentrations for NH_4^+, PO_4^{3-}, SiO_4, $NO_2^- + NO_3^-$, and were determined by continuous flow injection analysis using colorimetric techniques on a Lachat QuikChem 8000 (Zellweger Analytics Inc., Milwaukee, Wisconsin, USA) with a minimum detection level of 0.03 μM and a precision of ±0.05 μM (NH_4^+), ±0.3 μM (PO_4^{3-}) and ±0.5 μM (SiO_4, $NO_2^- + NO_3^-$).

Physiochemical Parameters

Temperature (^oC), salinity (‰), dissolved oxygen ($mg\ L^{-1}$), pH, and water depth (m), were measured *in situ* using a YSI Data Sonde (YSI Inc., Yellow Springs, Ohio, USA). These variables were all measured with a precision of ±0.01.

Continuous Light Measurements

Continuous underwater PAR measurements were collected at three sampling sites (DS-11, E-1, and W-1) in the Boulder Patch study area (Figure 1.3) and terrestrial PAR measurements at one coastal location (Endicott Island). These sites have been the focus of previous long-term monitoring efforts; measurements of PAR and kelp growth are reported in published literature (Dunton, 1990). Site DS-11, established as a reference site, has been a primary research site for the Boulder Patch since 1978. This site lies well outside the area most likely impacted by sediment plumes originating from the originally proposed Liberty Project, including construction of a buried pipeline and Stockpile Zone 1 (Ban et al, 1999). All three Boulder Patch sites are

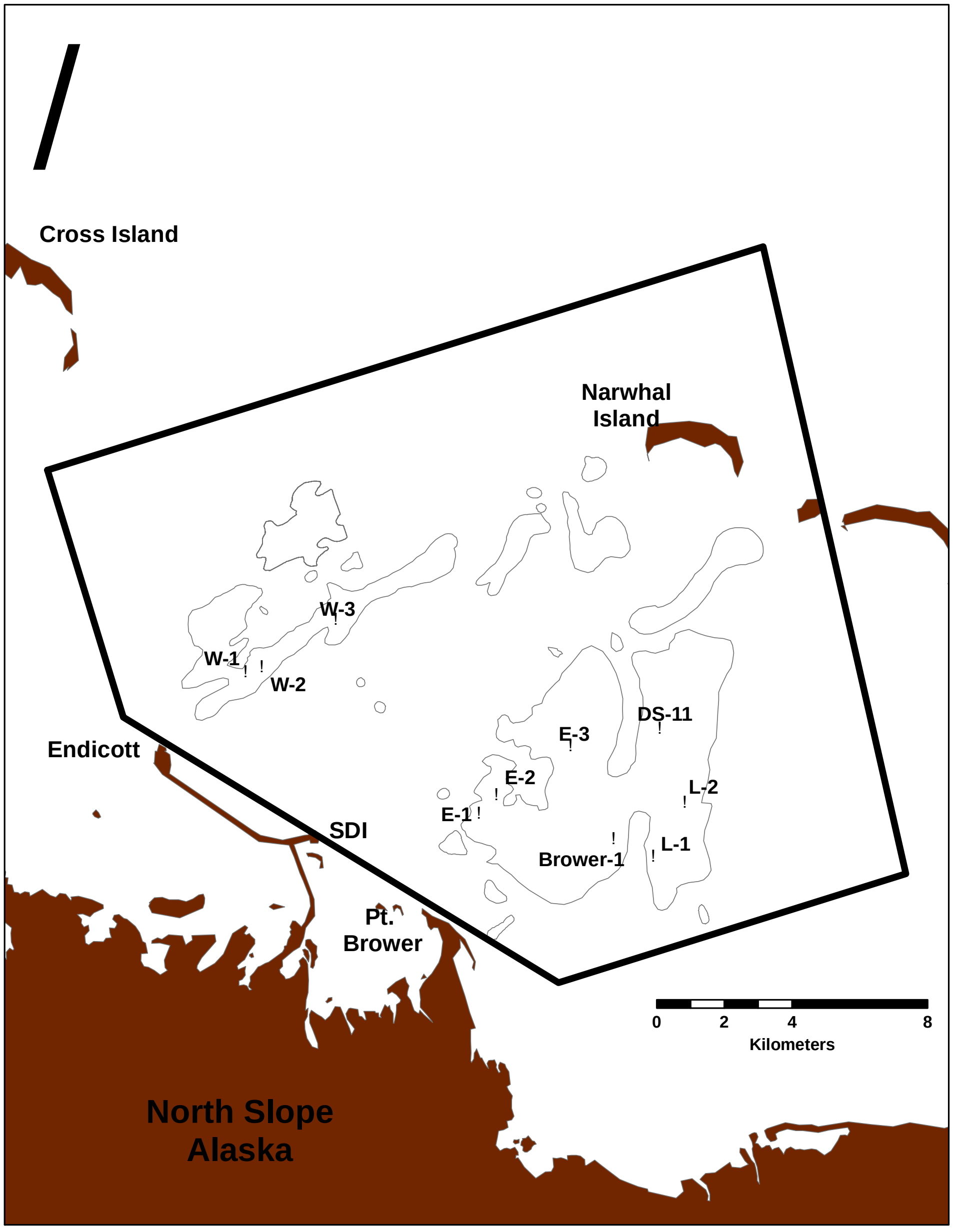

Figure 1.3 Map of the cANIMIDA 2004 - 2006 project study area. The indicated sites are historical Boulder Patch stations that have been visited repeatedly since 1984, and resampled for biodiversity in 2005 and 2006. During summers 2004, 2005 and 2006, long-term light was measured at sites DS-11, E-1, and W-1; kelp blade length data were also collected at these sites.

located on seabed characterized by >25% rock cover. Sites were chosen based on either their southern-most location in the Boulder Patch (W-1, E-1), existence of historical PAR data (W-1, E-1 and DS-11), and their likelihood of being impacted by oil and gas development through dredging activities associated with pipeline or island construction.

Underwater data were collected using LI-193SA spherical quantum sensors and LI-190SA underwater cosine sensors connected to a LI-1000 dataloggers (LI-COR Inc., Lincoln, Nebraska, USA). Sensors were mounted on PVC poles and positioned just above the kelp canopy to prevent fouling or shading by kelp fronds. The ratio between cosine and scalar PAR measurements provided an indirect measure of TSS importance relative to absorption and scattering. Instantaneous PAR measurements were taken at 1-min intervals and integrated over 1-hr periods. Coincident surface PAR measurements were taken with LI-190SA terrestrial cosine sensors connected to LI-1000 dataloggers located on Endicott Island. The light sensors used in this study (including for light attenuation) are accurate to ±5% (traceable to National Bureau of Standards), stability is ±2% over any 1-yr period, and data are recorded with a precision of ±0.01 μmol $m^{-2}s^{-1}$.

Benthic Biodiversity

A separate benthic biodiversity report by Katrin Iken is presented in Chapter 2.

Kelp Linear Growth

At each of the eight cANIMIDA dive sites within the Boulder Patch (DS-11, Brower-1, E-1, E-2, E-3, L-1, L-2 and W-1), SCUBA divers collected 15-30 individual specimens of *Laminaria solidungula* attached to large cobbles and boulders in summers 2004, 2005 and 2006. Samples were placed in pre-labeled black bags, transported to Endicott, and processed. Blade segments from every specimen, which corresponded to one year's growth (Dunton, 1985), were measured and recorded to produce a recent (3-4 yr) growth record of linear blade expansion at each site. Blades measured in summer reflect growth during both the present and previous calendar year since over 90% of a kelp's frond expansion occurs between November and June under nearly complete darkness (Dunton and Schell, 1986). Linear growth in *L. solidungula* from the Boulder Patch is heavily dependent on photosynthetic carbon reserves that accumulate during the previous summer in proportion to the underwater light environment. A growth year (GWYR) is indicated by the formation of a new blade segment, which begins in mid-November every year and is defined by the summer that precedes new blade formation (e.g. basal blade growth measured in summer 2007 depicts GWYR 2006). Blade growth is measure with a precision of ±0.5 cm.

Kelp Biomass

Frond lengths of *Laminaria solidungula* plants were measured at DS-11 and E-1 along four 25-m transects. Areal biomass at each site was calculated using a correlation coefficient between basal blade dry weight (g) and basal blade length (cm) developed for the Stefansson Sound Boulder Patch using specimens collected between 1980 and 1984 (n = 912; Figure 1.1). Transects radiated from a central point at random chosen directions at 280°, 80 °, 260°, and 110° Magnetic.

Statistics & GIS

TSS concentrations, chlorophyll *a* concentrations, and the attenuation coefficient (*k*) were matched with their respective geographic coordinates and plotted using GIS software ArcMap 9.2 (ERSI, Redlands, California). Data were interpolated across a polygon of Stefansson Sound, including the Boulder Patch following Aumack et al. (2007), but with some refinements. These refinements include using Geospatial Analyst extension and the kriging function in ArcMap. The polygon is also different than that of Aumack et al. (2007) in that we used straight borders to encompass the area around all existing sites so that interpolation was not accomplished in areas without data.

Data were analyzed using standard parametric models. Spatial and inter-annual significance among *k*, TSS, and chlorophyll measurements were determined using a paired t-test to examine significant differences ($p < 0.05$) among treatment variables using Microsoft Excel.

RESULTS & DISCUSSION

Synoptic Sampling

Light Attenuation (k)

Light attenuation (*k*) was derived from coincident in situ measurements of surface and underwater PAR at 2 and 4 m depths collected at 30 stations on three different occasions each summer (Appendix A1-a, A1-b, A1-c). Attenuation was consistently elevated in coastal zones with highest *k* values (1.4 m^{-1}) observed near Endicott Island and SDI indicating more turbid water closer to shore (Figure 1.4). Lower *k* values (0.4 m^{-1}) were recorded offshore along the eastern and northeastern sides of Stefansson Sound. In summer 2004, *k* ranged from 0.43 – 1.34 m^{-1} (mean 0.73 ± 0.14) throughout Stefansson Sound. In 2005 *k* ranged from 0.47 – 1.32 m^{-1} (mean 0.69 ± 0.03) and in 2006, *k* was 0.54 – 1.08 m^{-1} (mean 0.72 ± 0.01). The majority of the Boulder Patch, including areas with dense kelp populations (> 25% rock cover), were found predominantly in offshore waters where attenuation measurements were consistently less than 1.0 m^{-1}.

Total Suspended Solids (TSS)

TSS concentrations were much lower in summers 2004 and 2006 (generally all <7.0 mg L^{-1}) compared with 2005 (generally >7.0 mg L^{-1}), but the general trend of TSS decreasing offshore was still observed (Figure 1.5; Appendix A2). Since a paired t-test indicated that the TSS values measured at 2 and 4 m depths were not significantly different in either year (2004 $p = 0.065$; 2005 $p = 0.156$) the means of the two depths are displayed. In 2004 highest concentrations (7.6 - 8.3 mg L^{-1}) were found near Endicott Island and SDI and in a turbid area just north of Narwhal Island (5.7 – 6.1 mg L^{-1}). TSS ranged from 3.8 – 7.6 mg L^{-1} outside the Boulder Patch with a mean of 5.0 mg L^{-1}. Inside the Boulder Patch data ranged from 4.0 to 8.3 mg L^{-1} (mean 5.0 mg L^{-1}); the overall site average was 5.0 ± 1.8 mg L^{-1}.

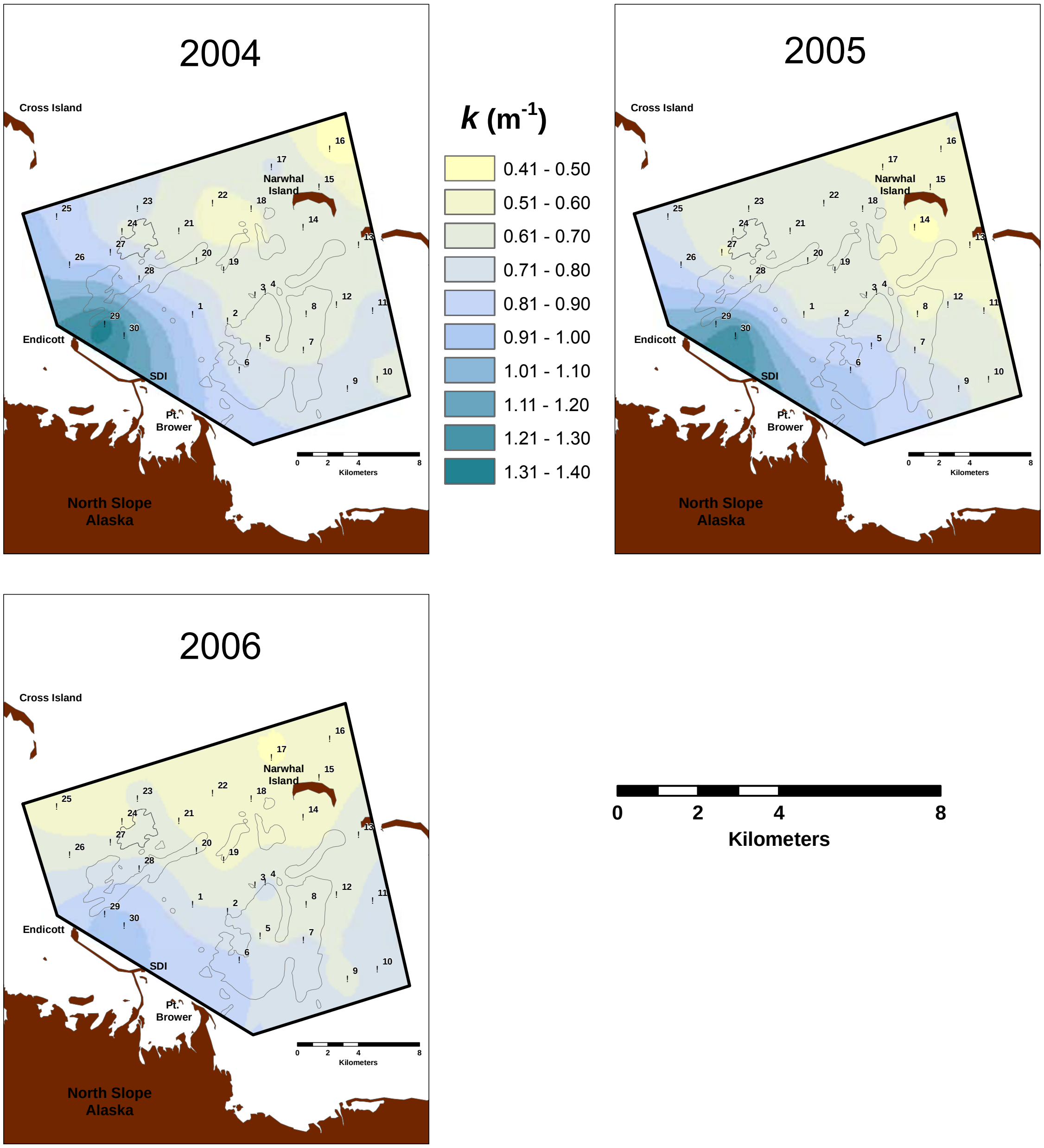

Figure 1.4 Combined mean attenuation coefficient (*k*) values calculated from measurements collected at 2 m and 4 m water depths in summers 2004, 2005 and 2006. Areas of >10% rock cover are outlined in black.

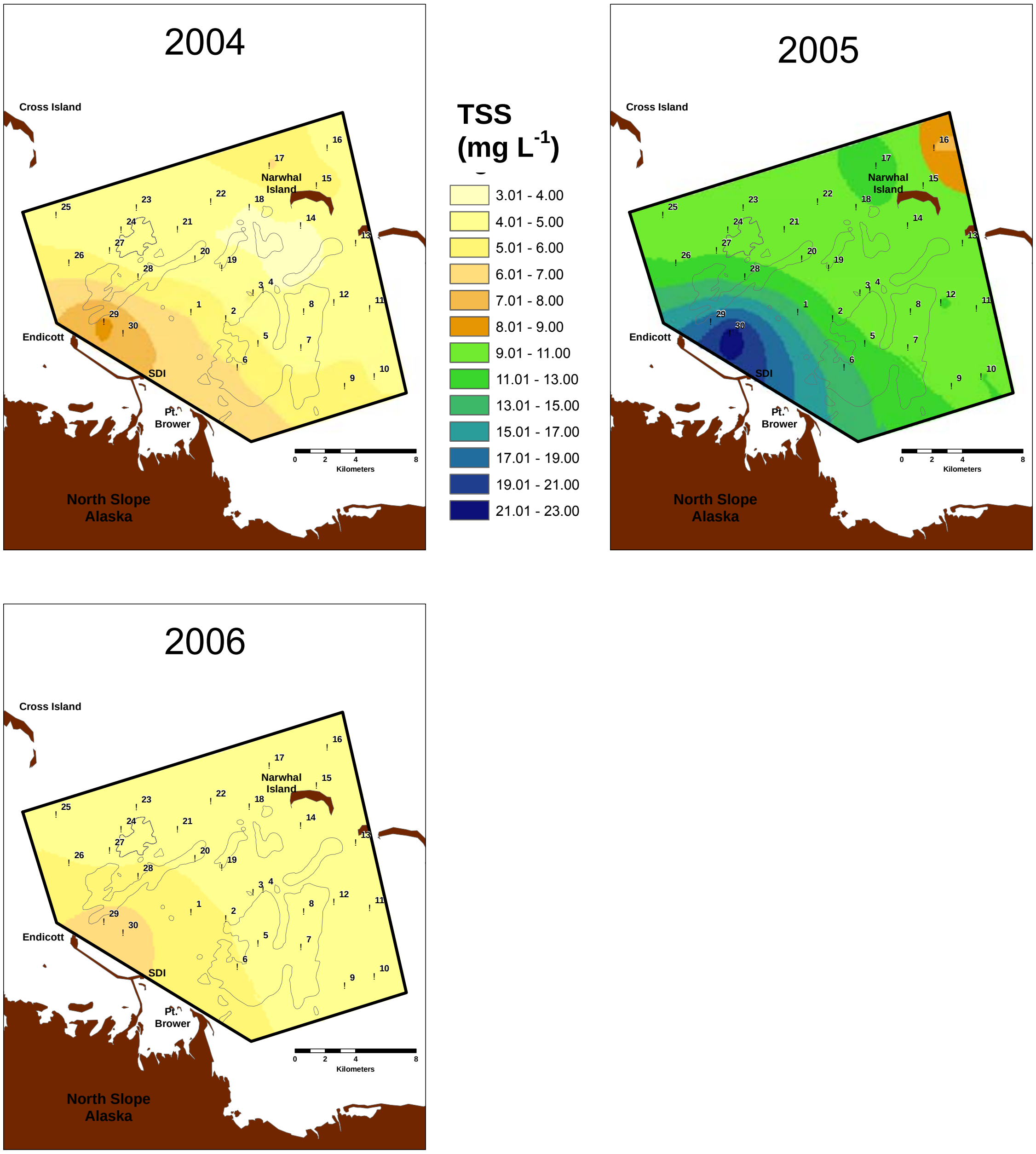

Figure 1.5 Combined mean total suspended solids (TSS) mg L^{-1} from samples collected at 2 m and 4 m water depths in 2004, 2005 and 2006. Areas of >10% rock cover are outlined in black.

TSS measurements were much higher and varied greatly throughout Stefansson Sound during summer 2005 (7.5 – 23.8 mg L^{-1}; mean 11.1 ± 1.1 mg L^{-1}). Highest values (17.6 – 23.8 mg L^{-1}) were located nearshore, adjacent to Endicott Island, SDI, and Point Brower. Outside the Boulder Patch, TSS ranged from 7.5 to 23.8 mg L^{-1} (mean 11.2 mg L^{-1}). Inside the Boulder Patch, values ranged from 9.0 to 17.6 mg L^{-1} (mean 11.0 mg L^{-1}).

TSS concentrations in 2006 were similar to those measured in 2004 (ranged of 3.5 -6.9 mg L^{-1}; mean of 4.7 ± 0.2 mg L^{-1}). The highest values were again adjacent to Endicott Island, SDI and Point Brower. Outside the Boulder Patch, TSS ranged from 3.6 to 6.9 mg L^{-1} (mean 4.6 ± 0.2

mg L^{-1}). TSS ranged from 3.5 to 5.9 mg L^{-1} inside the Boulder Patch with a mean of 4.6 ± 0.2 mg L^{-1}.

Chlorophyll a Concentrations

Chlorophyll *a* measurements from 2 and 4 m depths were significantly different from each other in 2004 ($p = 0.00006$), 2005 ($p = 0.008$), and 2006 ($p = 0.0000004$). In all three years, 4 m chlorophyll values were higher than the 2 m measurements (Figures 1.6a and 1.6b; Appendix A3). The 2005 chlorophyll means were the highest followed by 2004 means, with the lowest values occurring in 2006. In 2004 chlorophyll measurements ranged from 0.11 to 2.63 µg L^{-1} (mean 0.39 ± 0.2 µg L^{-1}). In summer 2005, values ranged from 0.11 to 3.54 µg L^{-1} (mean 0.76 ± 0.08 µg L^{-1}) compared to 0.11 – 0.41 µg L^{-1} (mean 0.18 ± 0.01 µg L^{-1}) in 2006.

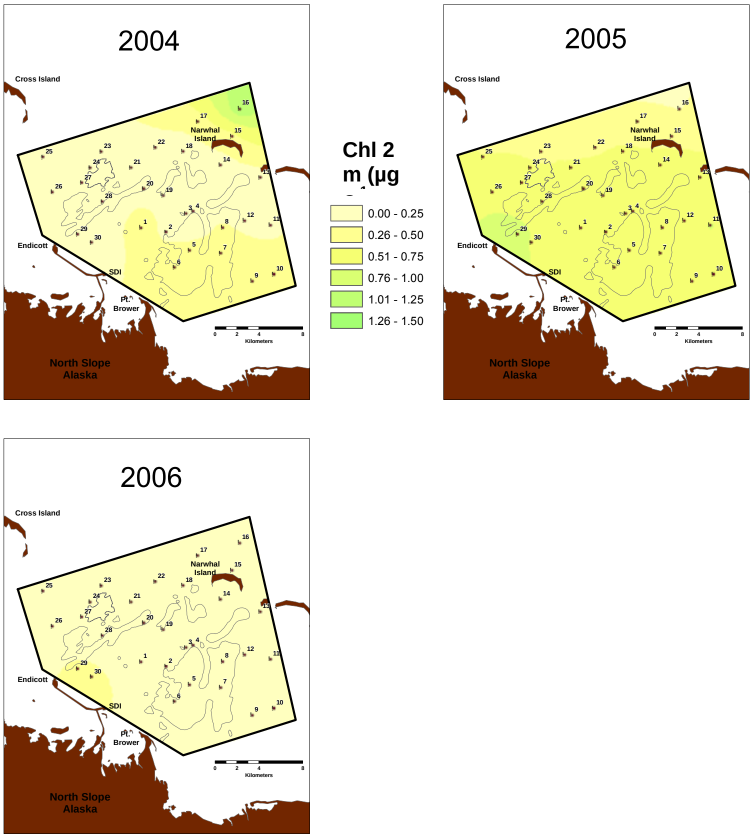

Figure 1.6a Chlorophyll (chl) µg L^{-1} values measured in 2004, 2005 and 2006. Samples were collected at 2 m water depth. Areas of >10% rock cover are outlined in black.

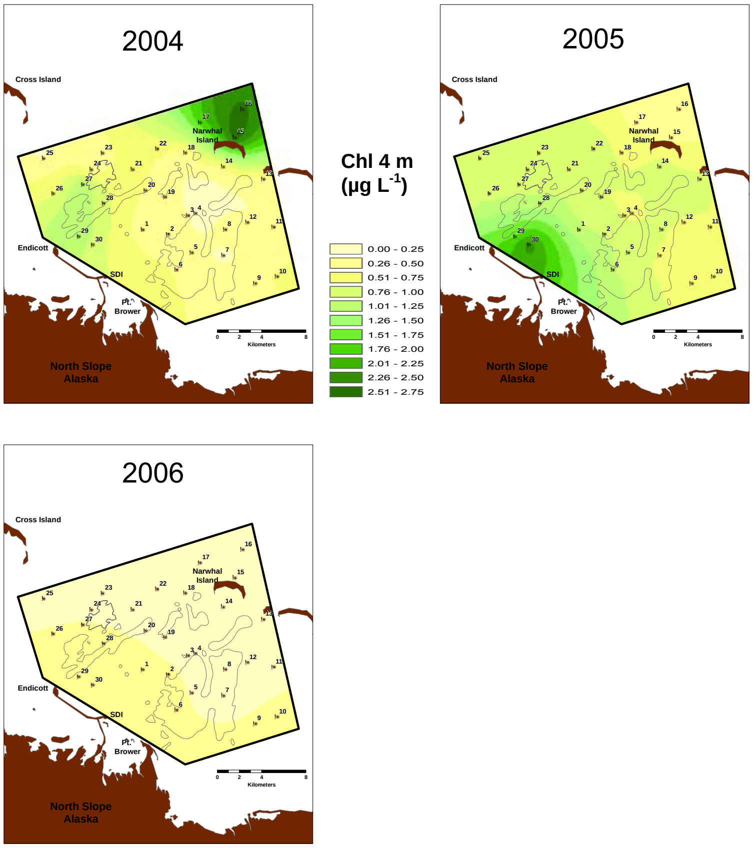

Figure 1.6b Chlorophyll (chl) µg L^{-1} values measured in 2004, 2005 and 2006. Samples were collected at 4 m water depth. Areas of >10% rock cover are outlined in black.

Nutrient Concentrations

Ammonium, phosphate, silicate, and nitrate + nitrite nutrient samples were collected in summers 2004, 2005 and 2006 (Table 1.1, Appendix A4).

Ammonium (NH_4^+)

Ammonium concentrations (Table 1.1) were significantly different among samples collected at 2 and 4 m in 2004, 2005 and 2006 ($p = 0.024$; $p = 0.00009$; $p = 0.00005$); all values were low (0.12 ± 0.06 µM at 2 m and 0.17 ± 0.07 µM at 4 m in 2004; 0.40 ± 0.04 µM at 2 m and 0.65 ± 0.04 µM at 4 m in 2005 and 0.25 ± 0.05 µM at 2 m and 0.12 ± 0.02 µM at 4 m). Ammonium ranged from 0.0 - 0.52 µM in 2006. Highest concentrations were noted at sites adjacent to barrier islands (Sites 13 and 15; Appendix A4); lowest values were noted offshore (0.0 - 0.02 µM).

Table 1.1 Measurements of ammonium, phosphate, silicate, and nitrate + nitrite at 30 sites measured on three occasions annually in July and August 2004 - 2006 in Stefansson Sound. Samples were collected at 2 and 4 m water column depths. Values are x ± SE.

YEAR μM	**Ammonium (NH_4^+) 2 m**	**Ammonium (NH_4^+) 4 m**	**Phosphate (PO_4^{3-}) 2 m**	**Phosphate (PO_4^{3-}) 4 m**	**Silicate (SiO_4) 2 m**	**Silicate (SiO_4) 4 m**	**Nitrate+ Nitrite (NO^{2-}+ NO^{3-}) 2 m**	**Nitrate+ Nitrite (NO^{2-}+ NO^{3-}) 4 m**
2004	0.12 ± 0.06	0.17 ± 0.07	0.24 ± 0.03	0.19 ± 0.05	1.76 ± 0.18	1.84 ± 0.26	0.14 ± 0.10	0.15 ± 0.01
2005	0.40 ± 0.04	0.65 ± 0.05	0.29 ± 0.01	0.35 ± 0.01	5.64 ± 0.19	5.19 ± 0.16	0.21 ± 0.04	0.29 ± 0.08
2006	0.25 ± 0.05	0.12 ± 0.02	0.17 ± 0.01	0.20 ± 0.01	7.05 ± 0.14	6.89 ± 0.16	0.07 ± 0.01	0.10 ± 0.02

Phosphate (PO_4^{3-})

In general, phosphate concentrations were low. Means in 2004 were 0.24 ± 0.03 µM at 2 m and 0.19 ± 0.05 µM at 4 m. Phosphate values ranged from 0.11 - 0.39 µM with the highest concentrations collected at sites adjacent to Endicott. Several other random sites displayed higher values at either 2 or 4 m (see Appendix A4). The lowest values were observed at sites seaward of Narwhal Island (0.0 - 0.02) µM. In 2005 phosphate measurements were lower in 2 m samples (mean 0.29 ± 0.01 µM) versus the 4 m samples (mean 0.35 ± 0.01 µM). The same pattern held for the 2006 (2 m mean 0.17 ± 0.01 µM; 4 m mean 0.20 ± 0.01 µM).

Silicate (SiO_4)

Silicate values collected from 2 and 4 m in 2004 were not significantly different ($p = 0.51$), ranging from 0.07 – 4.90 µM; mean 1.84 ± 0.26 µM (Table 1.1). Silicate was quite low at 2 and 4 m in 2004 compared to 2005 (2 m mean 5.64 ± 0.19 µM; 4 m mean 5.19 ± 0.16 µM) and 2006 (2 m mean 7.05 ± 0.14 µM; 4 m mean 6.89 ± 0.16 µM).

Nitrite + nitrate ($NO_2^- + NO_3^-$)

$NO_2^- + NO_3^-$ measurements throughout Stefansson Sound were generally low, with 2004 station means ranging from 0.0 – 0.29 µM at 2 m; 0.12 ± 0.21 µM at 4 m (Table 1.1). 2005 station means ranged from 0.0 – 0.61 µM at 2 m; 0.03 - 1.98 µM at 4 m, and 2006 means were 0.03 – 0.33 µM at 2 m; 0.02 - 0.44 µM at 4 m. In all three sampling years, the 4 m nitrate concentrations were slightly higher than the 2 m but were not significantly different.

Physiochemical Parameters

The four physiochemical parameters measured during synoptic sampling included temperature, salinity, dissolved oxygen, and pH (Table 1.2, Appendices A5a, A5b, A5c).

Table 1.2 Average temperature, salinity, dissolved oxygen, and pH measurements for 30 sites measured on three occasions in July and August 2004, 2005 and 2006 in Stefansson Sound. Samples were collected at 2 and 4 m water column depths. Values are means ± SE.

YEAR	**Temp (°C) 2 m**	**Temp (°C) 4 m**	**Salinity (‰) 2 m**	**Salinity (‰) 4 m**	**Dissolved O_2 (mg L^{-1}) 2 m**	**Dissolved O_2 (mg L^{-1}) 4 m**	**pH (m^{-1}) 2 m**	**pH (m^{-1}) 4 m**
2004	2.11 ± 0.55	0.88 ± 0.75	23.80 ± 0.99	26.81 ± 1.16	13.18 ± 0.35	14.22 ± 0.38	8.19 ± 0.05	8.22 ± 0.04
2005	2.62 ± 1.07	1.97 ± 1.32	23.85 ± 1.66	26.65 ± 1.36	11.48 ± 0.45	11.53 ± 0.39		
2006	4.64 ± 0.16	4.21 ± 0.22	16.91 ± 0.35	20.67 ± 0.49	11.45 ± 0.02	11.57 ± 0.05	7.90 ± 0.01	7.88 ± 0.01

Temperature (°C)

Mean sea surface temperature (2 m and 4 m) increased throughout the Boulder Patch each year between 2004 and 2006 (Table 1.2). Summer 2004 was characterized by frequent storm activity which was reflected to depressed surface water temperatures that were negative at some sites. The 2006 mean 2 m temperature (4.6 ± 0.2 °C) was more than double the value measured in 2004 (2.1 ± 0.6 °C). The 4 m mean temperature increased more than 4-fold between 2004 and 2006 (0.9 ± 0.7; 4.2 ± 0.2).

Salinity (‰)

Salinity measurements were homogeneous across the Boulder Patch and means were consistent between summers 2004 and 2005 at both 2 m (23.8 ± 1.0‰; 23.8 ± 1.7 ‰) and 4 m (26.8 ± 1.2 ‰; 26.6± 1.4 ‰) depths, but values dropped precipitously in 2006 (2 m 16.9 ± 0.35‰; 4 m 20.7± 0.5‰; Table 2). In 2004, the salinity range at 2 m was 20.4 – 27.4‰; the 4 m 2004 range was 23.5 to 31.7‰. In summer 2005, measurements at 2 m ranged from 17.7 to 26.21‰ and at 4 m salinity varied from 24.9 to 30.8‰. During 2006, the 2 m salinity low was measured at 11.3 ‰ and the high was 23.5‰; the 4 m low was 12.3 ‰ and high 30.0‰. At 2 m depths, waters were slightly fresher than at 4 m during all three years.

pH

We only report pH data from 2004 and 2006 since the probe malfunctioned during the 2005 field season (Table 1.2). In 2004, pH measurement means were remarkably constant at 8.2 ± 0.04 at both 2 and 4 m. The measurements in 2006 were also very consistent (7.9 ± 0.01 ‰) throughout the sampling area and between the 2 and 4 m depths, but were more acidic than the 2004 values.

Dissolved O_2 (mg L^{-1})

Dissolved oxygen concentrations were higher in 2004 than in 2005 and 2006 at both 2 and 4 meter water depths (Table 1.2). In 2004 the average value was 13.18 ± 0.35 mg L^{-1} at 2 m and 14.22 ± 0.38 mg L^{-1} at 4 m. In 2005, mean measurements were 11.48 ± 0.45 mg L^{-1} at 2 m and 11.53 ± 0.39 mg L^{-1} at 4 m. In 2006, mean measurements were similar to 2005 (11.45 ± 0.02 mg L^{-1} at 2 m and 11.57 ± 0.05 mg L^{-1} at 4 m). The standard errors associated with all means were small, indicating low variability. The higher concentrations of dissolved oxygen in 2004 are likely related to the lower water temperatures recorded in 2004 compared to 2005 and 2006, but the absolute values in both years are high.

Continuous Light Measurements

PAR measurements collected during summer 2004, 2005 and 2006 followed a typical cyclical pattern with terrestrial surface irradiances peaking between 1200 – 1400 µmol photons m^{-2} s^{-1} (Figure 1.7). Surface irradiance maximums always occurred between 1300 and 1400 hrs. The highest underwater PAR values measured by the underwater spherical quantum sensors also normally occurred around 1400 in all three summers. In 2004, from 31 July – 6 August, underwater irradiance dropped to near zero at all three sites (DS-11, E-1, and W-1) in conjunction with a series of intense storms. Extremely low underwater PAR concentrations continued through 9 August followed by four days of slightly higher values, at which point the dataloggers were removed. Prior to the storm, underwater cosine sensors measured peak downward irradiances ranging from 180 to 200 µmoles photons m^{-2} s^{-1}. In 2005, underwater PAR measurements were lowest between 15 July and 1 August although the surface irradiance was high on most days. In 2006, underwater PAR was lowest at W-1 but was generally consistent across all sites with no sustained periods of low PAR. Values recorded from both surface and underwater PAR sensors are similar to irradiance measurements made in Stefansson Sound during previous studies (Dunton, 1990).

Overall, water transparency, as reflected by consistently low *k* values (generally < 1.0 m^{-1}) and high light transmission (> 55% m^{-1}) at all three sites, was highest in 2006 as reflected by the absence of significant storm events during the study period (Figure 1.8). In all three years, mean irradiance was significantly ($p<0.05$) lower at site W-1 compared to all other sites (Table 1.4) for the period 26 July to 10 August although the surface irradiance was high on most days. Values recorded from both surface and underwater PAR sensors are similar to irradiance measurements made in Stefansson Sound during previous studies (Dunton, 1990). Lowest light transmission (< 10% m^{-1}) and highest k values (2-3 m^{-1}) were observed at all three sites in 2004. Conditions in 2005 improved considerably, with just one peak in water turbidity occurring in late July as noted earlier. The shallower depth at E-1, compared to W-1 and DS-11 amplifies the *k* values at this site for similar levels of underwater PAR recorded at all three sites.

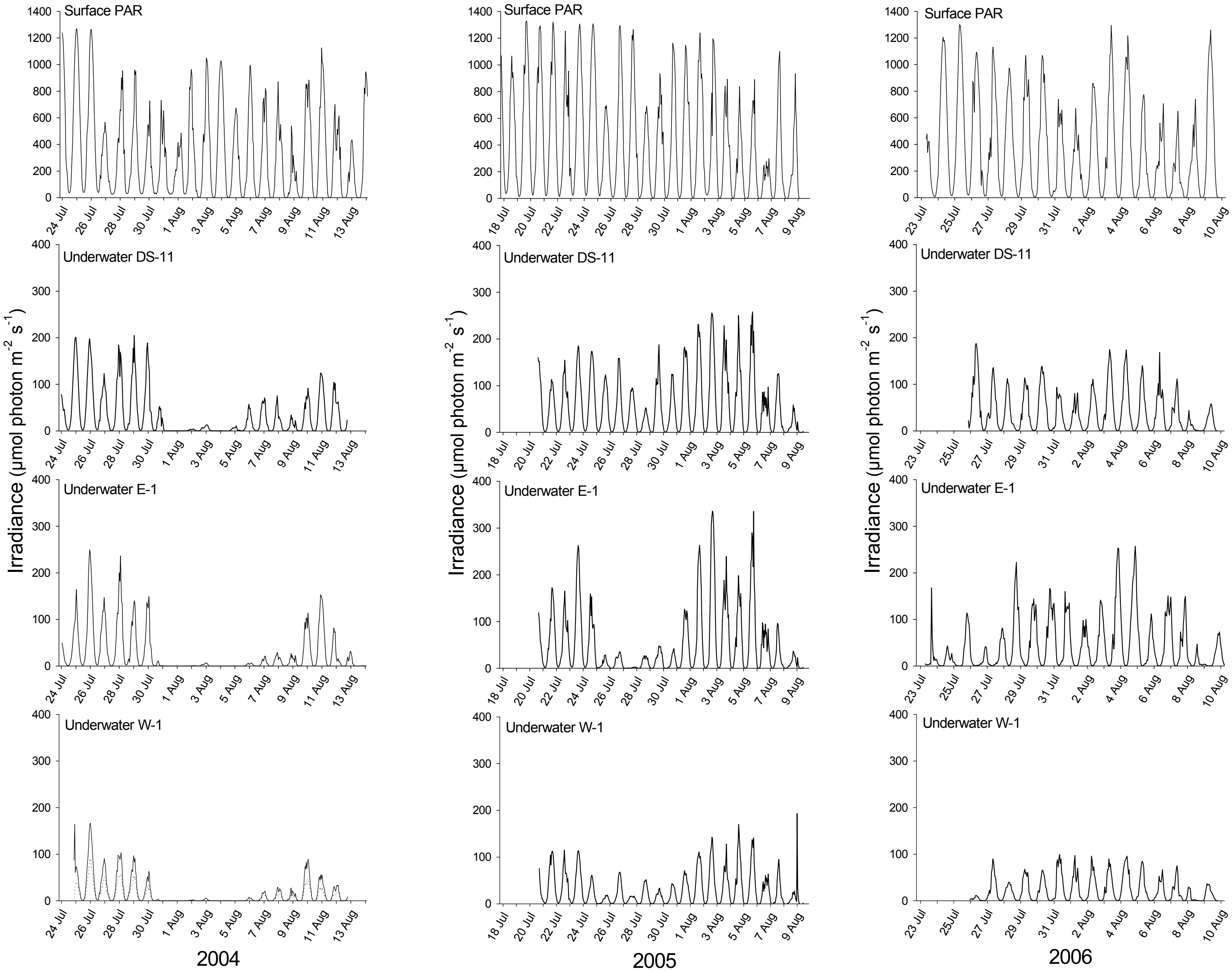

Figure 1.7 Continuous measurements of surface and underwater PAR in Stefansson Sound in summers 2004, 2005 and 2006. Water depths ranged from 5 m (E-1) to 6.5 m (DS-11 and W-1). Missing surface PAR data in 2004 and 2005 were obtained from an irradiance sensor maintained 5 km distant at SDI by Veltkamp and Wilcox (2007).

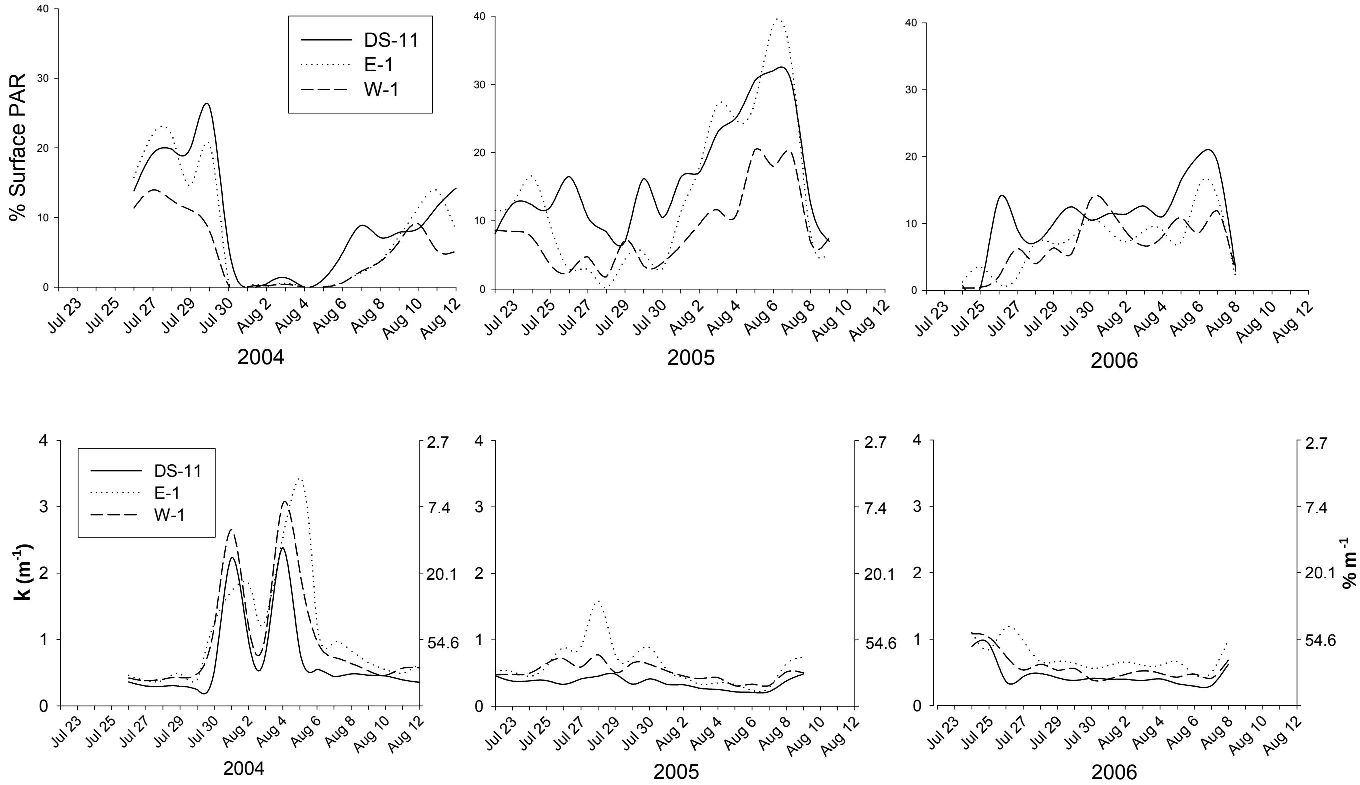

Figure 1.8 Measurements of water transparency at various sites in Stefansson Sound from 2004 to 2006. Top panel: percentage of surface irradiance (% SI); bottom panel: diffuse attenuation coefficient expressed as *k* values (left axis) and as % m^{-1} (right axis). Underwater measurements were made at kelp canopy levels at E-1 (4.6 m), W-1 (5.8 m), and DS-11 (6.1 m) with a spherical quantum sensor.

Kelp Measurements

Kelp Linear Growth

Blade elongation in *Laminaria solidungula* displayed large spatial and temporal variability as reflected in measurements from eight sites (Table 1.3; Figures 1.9 and 1.10). Mean site blade growth was lower at every site in GWYR 2003 compared to GWYR 2004 and GWRY 2005, reflecting the exceptionally poor weather conditions in summer 2003 that produced extremely low levels of ambient PAR. Kelp collected in 2004 (GWYR 2003) had annual blade lengths that ranged from 0.5 to 37.5 cm; mean = 7.2 ± 0.27 cm. Plants collected in 2005 had annual blade lengths that ranged from 1.0 to 51.5 cm (mean 17.7 ± 0.64 cm), comparable to previous studies (Dunton, 1990; Martin and Gallaway, 1994). Specimens from DS-11 had the greatest blade elongation in both years (11.6 cm in 2003 [n = 208]; 31.9 cm in 2004 [n =368]). An interannual comparison of growth years 1998 – 2005 at DS-11 and E-1 indicated that linear growth was lowest during GWYR 2003, highest in GWYR 2000, and that 2005 was similar to 1998-2000 (Figure 1.10). Changes in local climatology clearly have an important role in regulating kelp growth as a consequence of increased cloud cover and sustained winds that negatively impact kelp growth (Figure 1.11).

Table 1.3 Average Laminaria solidungula basal blade length from eight sites in Stefansson Sound. Blade lengths were measured during summers 2004-2006. A growth year (GWYR) is defined as the period beginning 15 November one year and ending 15 November the following year. Values are means ± SE.

GWYR	**DS-11 cm**	**E-1 cm**	**E-2 cm**	**E-3 cm**	**L-1 cm**	**L-2 cm**	**B-1 cm**	**W-1 cm**
2003	7.20 ± 0.05	3.99 ± 0.04	8.08 ± 0.04	5.21 ± 0.05	6.55 ± 0.06	3.87 ± 0.04	7.38 ± 0.07	7.93 ± 0.05
2004	25.99 ± 0.11	11.34 ± 0.06	9.70 ± 0.05	23.16 ± 0.11	17.67 ± 0.07	15.24 ± 0.07	19.13 ± 0.09	13.73 ± 0.07
2005	26.30 ± 0.18	19.47 ± 0.12	18.41 ± 0.21	28.11 ± 0.28	25.38 ± 0.21	21.75 ± 0.21	25.88 ± 0.24	18.49 ± 0.12

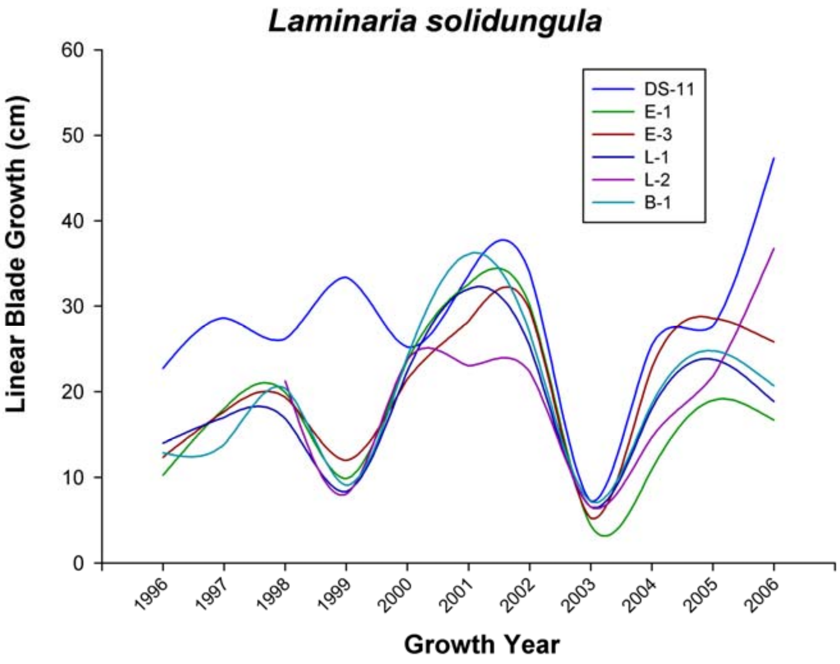

Figure 1.9 Variation in annual growth in *Laminaria solidungula* from 1996 to 2006 at sites occupied in the Stefansson Sound Boulder Patch. Measurements are based on blade lengths of plants collected between 2001 and 2006 under the ANIMIDA project. Values are means ± SE.

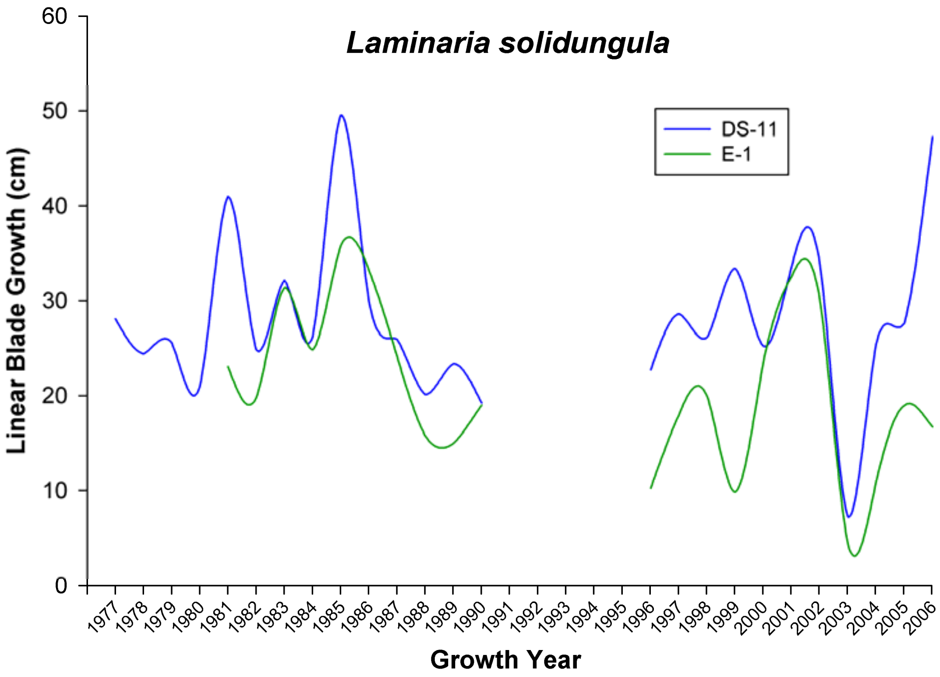

Figure 1.10 Mean annual linear growth of *Laminaria solidungula* from 1977 to 2006 at sites DS-11 (blue) and E-1 (green) in Stefansson Sound Boulder Patch.

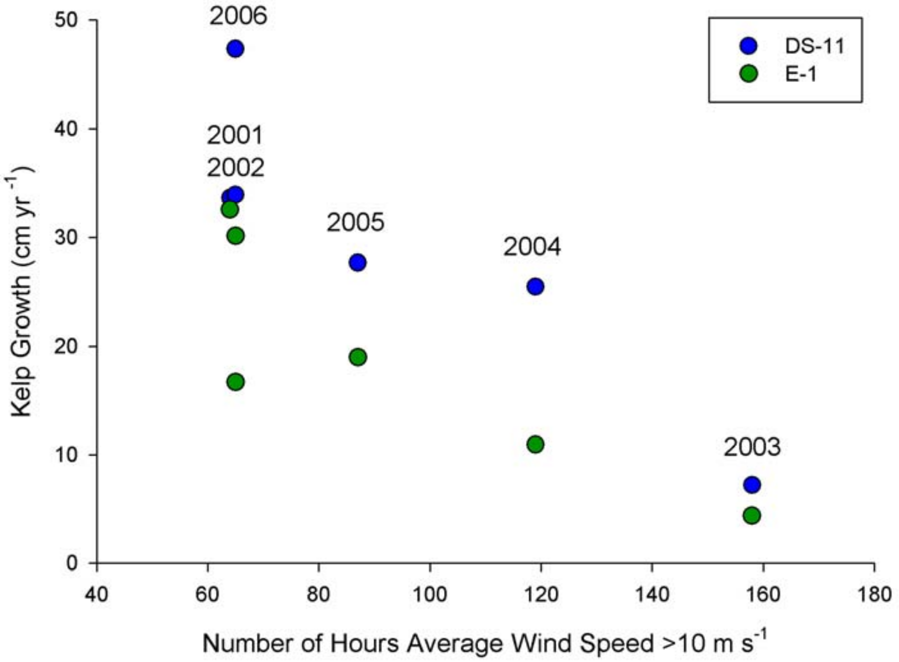

Figure 1.11 Annual mean linear growth of *Laminaria solidungula* as a function of the number of hours that wind speed exceeded 10 m s^{-1} at SDI in July and August, 2001 to 2006. Wind speed data from Veltcamp and Wilcox, 2007. Sites DS-11 (blue) and E-1 (green) are located in the Stefansson Sound Boulder Patch.

Kelp Biomass

In summer 2005, *Laminaria solidungula* plants were measured in situ at sites DS-11 (n = 226) and E-1 (n = 53) along four 25 m transects. A correlation coefficient between basal blade dry weight (g) and basal blade length (cm) developed for the Stefansson Sound Boulder Patch from specimens collected between 1980 and 1984 (n = 912) was used to obtain an estimate of kelp biomass at these sites. Biomass at DS-11 (> 25% rock cover) ranged from 5 to 45 g m^{-2} (mean 23 g m^{-2}) compared to a range of 0.5 to 2.7 g m^{-2} (mean 1.7 g m^{-2}) at site E-1 (10-25% rock cover). The range in biomass at DS-11 is within the estimates reported by Dunton et al., (1982). Estimates of benthic biomass at the ANIMIDA sites in Stefansson Sound are critical for calculation of realistic basin-wide benthic production models in relation to changes in PAR.

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CHAPTER 2

MONITORING THE BOULDER PATCH: BIODIVERSITY ASSESSMENTS

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INTRODUCTION

The nearshore Beaufort Sea seafloor is typically dominated by soft sediments (Barnes and Reimnitz 1974). The benthic communities in those sandy, silty or muddy sediments usually contain a low diversity fauna, dominated by bivalve mollusks, polychaete worms and amphipods (Feder and Schamel 1976, Carey and Ruff 1977, Carey et al. 1984). Amidst these relatively low-diversity areas, there are local hotspots of abundant and diverse marine life where boulders provide rare colonisable hard substrate for macroalgae and sessile epibenthic macrofauna. One of these regions is the Stefansson Sound Boulder Patch. One of the main reasons why this area has been identified as a focus area within the cANIMIDA project stems from the need to protect sensitive, biologically productive regions, while allowing oil exploration in the surrounding areas (Wilson 1979).

In the Boulder Patch, a variety of brown and red macroalgae have colonized the boulders forming one of the few known macroalgal beds along the Alaskan Arctic coast. Sessile fauna such as sponges, encrusting bryozoans, hydroids, soft corals, and tube worms thrive on the rocky and macroalgal substrates (Dunton et al. 1982, Dunton 1992, Konar and Iken 2005). This three-dimensionally structured, epilithic community provides habitat for a number of associated macro-organisms. More than 150 species of macroalgae, invertebrates and fishes were found in the Boulder Patch in the late 1970’s (Dunton et al. 1982, Dunton and Schonberg 2002) while only about 30 infaunal species, mainly polychaetes and amphipods, have been recorded from the adjacent soft-bottom areas in Prudhoe Bay (Feder and Schamel 1976). Thus, the Boulder Patch is a unique area of high biodiversity in the otherwise silt-mud dominated system of the Beaufort shelf that is devoid of the majority of these faunal and floral groups.

The uniqueness of the Boulder Patch ecosystem made it a center-piece of the cANIMIDA project in Task Order 006: “Monitoring the Boulder Patch”, with monitoring biodiversity as one measurement within this task order. Biodiversity is one potential measure of ecosystem health and of biological interactions such as competition, disturbance, facilitation, predation, recruitment, and productivity of a system (Petraitis et al. 1989, Worm et al. 1999, Mittelbach et al. 2001, Paine 2002). The goal of this study was to establish the recent biodiversity level of epilithic communities within the Boulder Patch with the purpose of evaluating further monitoring mechanisms for this sensitive habitat.

METHODS

A total of 7 Boulder Patch sites established by Martin and Gallaway (1994) were sampled: DS11, East1, East2, East3, West1, West2, and West3 (following DS11, E1, E2, E3, W1, W2, W3; see Fig. 1.3). Biodiversity samples were taken and processed between 30 July – 3 August 2005, and between 21 July – 31 July 2006. Sites were sampled following the standardized sampling protocols developed within the NaGISA program (Natural Geography in Shore Areas, Rigby et al. 2007), a field project within the Census of Marine Life (http://www.coml.org/). The NaGISA protocol assesses community composition from visual percent cover estimates of replicate, randomly distributed 1x1 m quadrats; macroalgal biomass is collected from 50x50 cm quadrats, and invertebrate abundance and biomass is collected from 25x25 cm quadrats (Rigby et al. 2007). Using SCUBA diving, replicate visual and epilithic scrape samples were taken from the rock-covered areas at each site. Percent cover of dominant taxa and substrata was determined with visual estimates of 10 1x1m quadrats at DS-11 in 2005, and of 10 quadrats at DS11, and 5 quadrats each at E3 and W3 in 2006. Macroalgae were sampled from 10 randomly placed 50x50 cm quadrats and placed in fine mesh bags. Macroalgae and associated invertebrates were additionally sampled from 10 randomly placed 25x25 cm quadrats and collected into fine mesh bags. In addition, 5 cores (5 cm diameter, 3 cm depth) per site were taken from the sediment between rocks and boulders.

All samples were carefully washed over 500 µm mesh and the retained fraction sorted. Macroalgae were identified to species level where possible and wet weight determined to 1 g precision. Herbarium vouchers were pressed and are stored at the University of Alaska Fairbanks. Macroalgal identifications were confirmed by Dr. Sandra Lindstrom, University of British Columbia, Canada. Invertebrates were sorted and identified live to species or higher taxonomic level in those cases where species identification was impossible. Invertebrate identifications were done by Susan Schonberg, The University of Texas. Invertebrates were counted where individuals could be distinguished. For some of the multidimensional analyses (see below), presence of colonial organisms was counted as 1 for abundance analyses. All invertebrates were preserved in 10% buffered formalin and later transferred into 50% isopropanol for long-term storage at the University of Alaska Fairbanks.

Data were analyzed using multivariate statistics in the software package PRIMER™ version 6 (Clarke and Gorley 2006). Specifically, similarity among samples, sites and years was analyzed using non-metric multidimensional scaling plots (MDS) and cluster analysis. Data were log-transformed to give more weight to less common species, except for interannual comparison of community structure based on percent cover data, which were square-root transformed because rare species contribute little to percent cover estimates. A SIMPROF routine was used to test the similarity profiles based on Bray-Curtis similarities within a cluster dendrogram where no groups are identified a priori. Analysis of Similarity (ANOSIM) was used to discern statistical differences of community structure among a priori groups such as sites or between years and sites (2-way crossed ANOSIM). The resulting R statistics ranges from 0 to 1 in which $R_{global} = 1$ indicates complete separation of groups and $R_{global} = 0$ indicates no separation (Clarke and Warwick 2001). A SIMPER routine was used to identify the species that most contribute to the dissimilarity between sites. Biomass and abundance patterns were analyzed using univariate statistics (SPSS), t-tests and ANOVA, on transformed data to meet normality requirements. Diversity indices included Shannon index, Simpson's index and Pilou's evenness index.

RESULTS

Percent cover estimates at DS11 were clearly different between the two years ($R_{global} = 0.734$, p=0.001, ANOSIM) (Figure 2.1a). This difference was mainly driven by the abundance of red algae in both years (30% of dissimilarity between years, SIMPER). Percent cover also differed among sites (DS11, W3, E3) sampled in 2006 ($R_{global} = 0.563$, p=0.001, ANOSIM) (Figure 2.1b), although with a lower R_{global}, which was mainly due to differences between E3 and the two other sites (R≈0.8 for both comparisons, ANOSIM). This difference was based on much higher percentage of gravel and lower rock cover at E3 compared to other sites (≈30% dissimilarity in both comparisons, SIMPER).

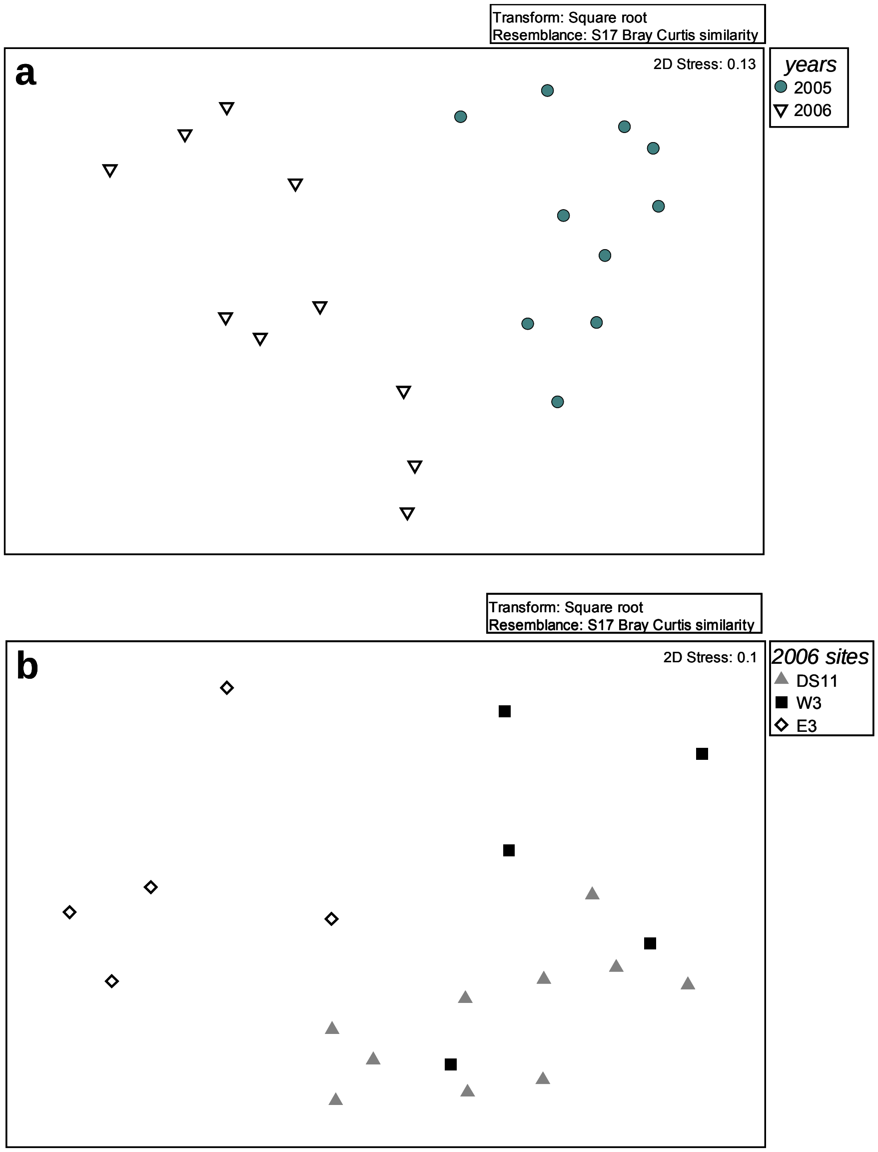

Figure 2.1 Multidimensional scaling (MDS) plot of percent cover of substratum and taxa a) at DS11 in 2005 and 2006, and b) at sites DS11, E3 and W3 in 2006. Replicate samples instead of site means are shown to represent within-site variability.

A total of 15 macroalgal species were collected in the Boulder Patch in both years (Table 2.1). New records for the area include the brown algae *Sphacelaria plumosa* and *Sphacelaria arctica*, and the red algae *Rhodomela tenuissima* and *Scagelia* cf *americana*. Also, the red alga *Phyllophora trucata* was often infested with what has been identified so far as an endophytic Chlorochytrium. The sampling protocol was suitable to exhaustively collect macroalgal biodiversity as species accumulation curves reached asymptote with 4-6 replicates (not shown).

Table 2.1 Macroalgal records from the Boulder Patch in 2005 and 2006.

Division	**Species**	**2005 sites**	**2006 sites**	**comments**
Chlorophyta (green algae)	*Chaetomorpha melagonium* (Weber et Mohr) Kützing	E1, E2, W3	E1, E2	
Rhodophyta (red algae)	*Phycodrys riggii* NL Gardner	DS11, E1, E2, E3, W1, W2, W3	DS11, E1, E2, E3, W1, W2, W3	
Rhodophyta (red algae)	*Phyllophora truncata* (Pallas) Zinova	DS11, E1, E2, E3, W1, W2, W3	DS11, E1, E2, E3, W1, W2, W3	
Rhodophyta (red algae)	*Dilsea socialis* (Postels et Ruprecht) Perestenko	DS11, E1, E2, E3, W1, W2, W3	DS11, E1, E2, E3, W1, W2, W3	
Rhodophyta (red algae)	*Odonthalia dentata* (Linnaeus) Lyngbye	DS11, E1, E2, E3, W1, W3	DS11, E1, E2, E3, W1, W2, W3	
Rhodophyta (red algae)	*Rhodomela sibirica* Zinova et KL Vinogradova	DS11, E1, E2, E3, W1, W2, W3	DS11, E1, E2, E3, W1, W3	
Rhodophyta (red algae)	*Rhodomela tenuissima* (Ruprecht) Kjellman	E2	E1	
Rhodophyta (red algae)	*Ahnfeltia plicata* (Hudson) Fries	E1, W3	DS11, E1, E2, E3	
Rhodophyta (red algae)	*Scagelia* cf *americana* (Harvey) Athanasiadis	DS11	DS11	
Rhodophyta (red algae)	Liththamnium sp	DS11, E2, E3, W1, W2, W3	DS11, E2, E3, W1, W2, W3	Particularly prominent at DS11, E3 and W3
Ochrophyta (brown algae)	*Laminaria solidungula* (C Agardh)	DS11, E1, E2, E3, W1, W2, W3	DS11, E1, E2, E3, W1, W2, W3	
Ochrophyta (brown algae)	*Laminaria saccharina* (C Agardh)	W3	DS11, E3, W1, W3	Was observed but not quantitatively collected at DS11 in 2005
Ochrophyta (brown algae)	*Alaria esculenta* (Linnaeus) Greville	-	DS11	Was observed but not quantitatively collected at DS11 in 2005
Ochrophyta (brown algae)	*Sphacelaria plumosa* Lyngbye	E1, E2, W2	DS11, E1, W1, W2, W3	
Ochrophyta (brown algae)	*Sphacelaria arctica* Harvey	E1, E2	E1, E2	

Main biomass contributors in both years and at all stations were the red algae *Phycodrys riggii* and *Phyllophora truncata* and the brown alga *Laminaria solidungula*. Lesser amounts were usually contributed by the three red algae *Dilsea socialis*, *Odonthalia dentata* and *Rhodomela sibirica* (Figure 2.2).

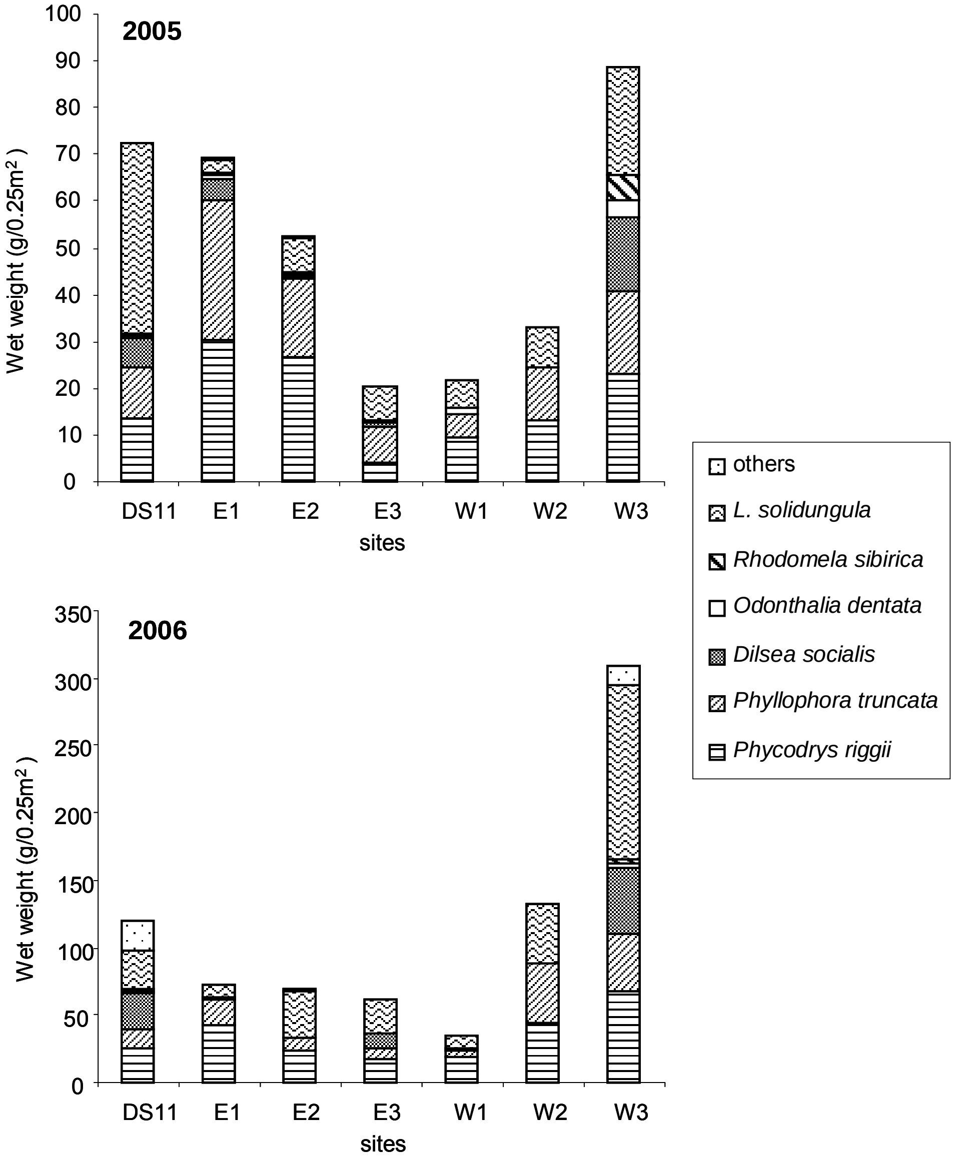

Figure 2.2 Absolute contribution of species to total macroalgal biomass (g ww/0.25m^2) across sites in 2005 and 2006. Note difference in scale in the two years.

Total macroalgal biomass was higher in 2006 than in 2005 at all sites (Figure 2.2, $p<0.001$, t-test), although relative proportions among sites were similar in both years. This higher biomass was particularly obvious at W2 and W3, which was mainly driven by significantly higher biomass contributions of *P. riggii* and *P. truncata* (p=0.033 and 0.005, t-tests) and also *L. solidungula* (ns, t-test), in 2006.

Overall algal community structure based on biomass did not differ among sites within a year (Figures 2.3 and 2.4) as seen by little separation of sites in MDS plots (Figure 2.3), a SIMPROF test on hierarchical clustering (graphs not shown), as well as by relatively low global R values ($R_{global} = 0.303$ in 2005 and 0.313 in 2006). If averaged by sites, none of the sites differed significantly in 2005 ($p>0.05$, SIMPROF test) but DS11 and W3 clustered differently from other sites in 2006 (Figure 2.4). In an interannual comparison (2-way crossed ANOSIM with sites and years as factors) sites had a larger influence on overall differences than year (R_{global} between years (across sites) = 0.103; R_{global} between sites (across years) = 0.31).

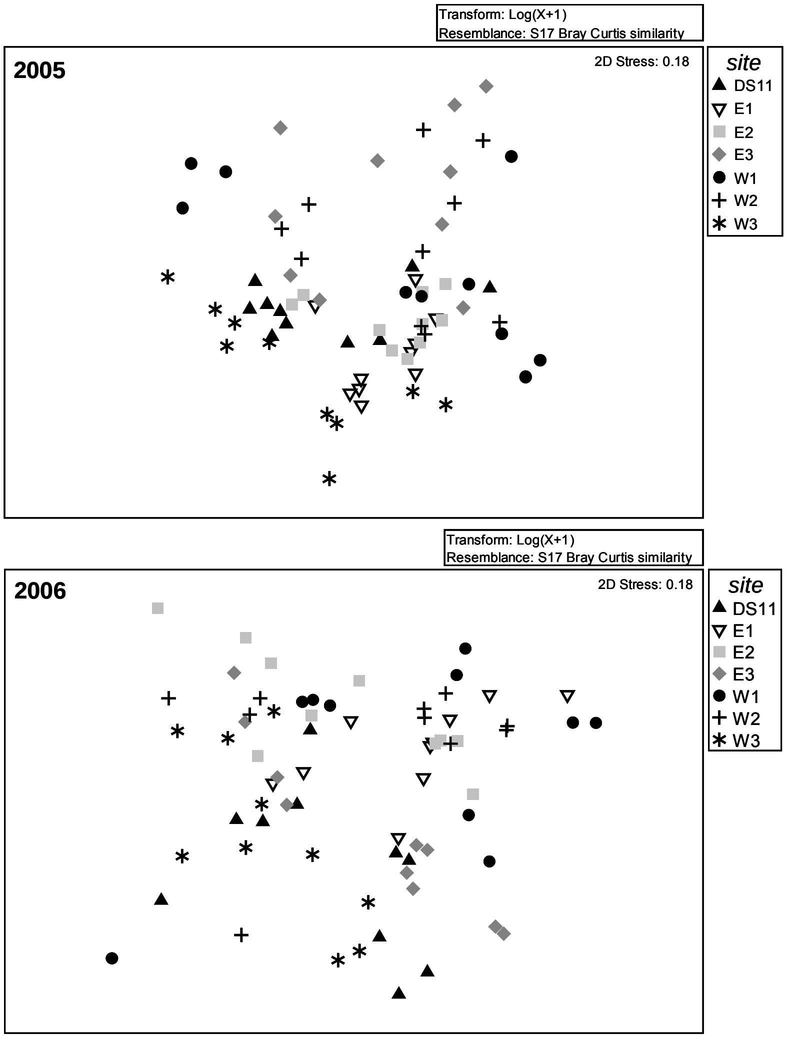

Figure 2.3 Multidimensional scaling (MDS) plot of macroalgal community composition (based on log (X+1) transformed biomass data) at 7 study sites in 2005 and 2006. Replicate scrape samples per site instead of site means are shown to demonstrate within-site variability.

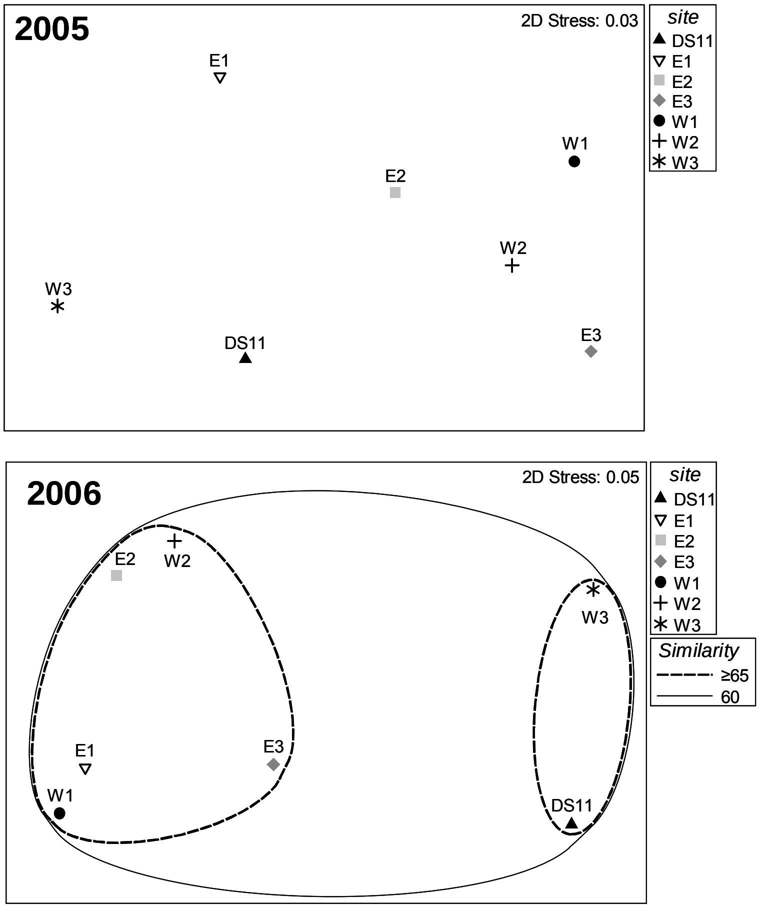

Figure 2.4 Multidimensional scaling (MDS) plot of macroalgal community composition averaged per site (based on log (X+1) transformed biomass data) at 7 study sites in 2005 and 2006.

A total of 86 invertebrate species or higher taxonomic groups were identified in 2005 and 120 in 2006. Of the 86 taxa in 2005, 21 were not found in 2006 and of the 120 taxa in 2006, 47 were not sampled in 2005. In the two collection years combined, 141 invertebrate taxa were identified. Taxa encountered in only one year were always rare and never dominant in either biomass or abundance. Invertebrates belonged to eight major phyla: Porifera, Cnidaria (Anthozoa, Hydroidea), Mollusca (Polyplacophora, Gastropoda, Bivalvia), Annelida (Polychaeta), Arthropoda (Pycnogonidae, Amphipoda, Isopoda, Cumacea, Decapoda, Cirripedia, [in 2006 also Copepoda, Insecta and Acari]), Bryozoa, Echinodermata (Asteroidea), and Tunicata (Ascideacea).

Average invertebrate biomass (across all sites) was very similar between both years (15.96 g wet/m^2 in 2005; 14.77 g wet/m^2 in 2006). Invertebrate biomass in both years was clearly dominated by sponges, bryozoans and hydrozoans (Figure 2.5).

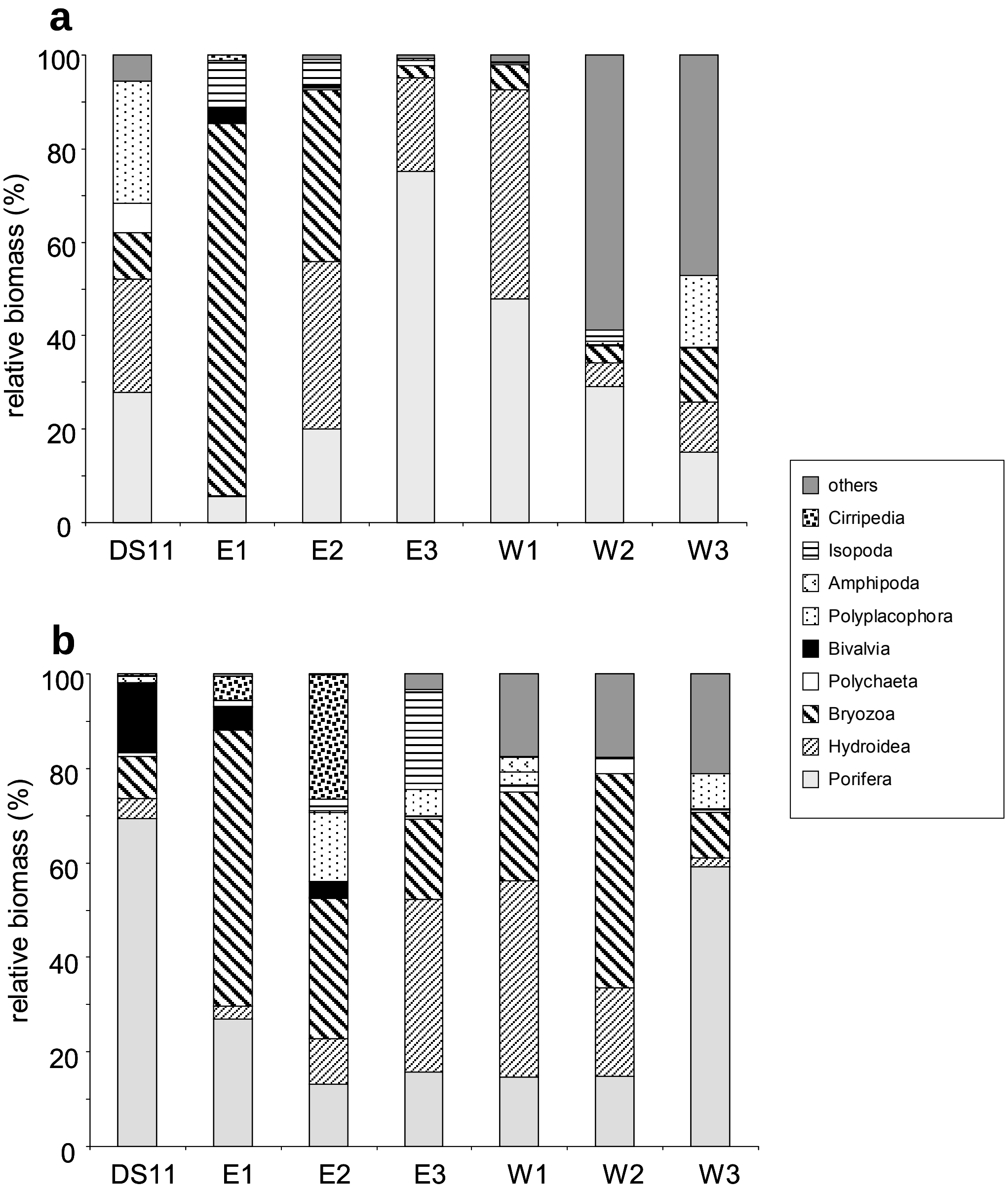

Figure 2.5 Relative biomass contributions of major invertebrate taxa in a) 2005 and b) 2006. “Others” includes Anthozoa, Crustacea, Echinodermata and Nemertea.

Invertebrate abundance averaged across sites within a year was much higher in 2006 (56.08 ind/m^2 in 2005 versus 207.26 ind/m^2 in 2006), which was entirely driven by the very high numbers of barnacles in some replicates at sites E1 and E2. Abundance was dominated by polychaetes, bivalves and barnacles (Figure 2.6). Within the first two groups, it was one taxon each that caused high abundances, *Spirorbis* sp. and *Musculus* sp. This overall pattern does not include non-countable encrusting and colonial organisms such as sponges, bryozoans, hydrozoans and ascideans, which made up much of the biomass. Sites E1 and E2 differed most from other sites in both years because of high abundances of bivalves (*Musculus* sp) in 2005 (Figure 2.6a) and high abundances of barnacles in 2006 (Figure 2.6b).

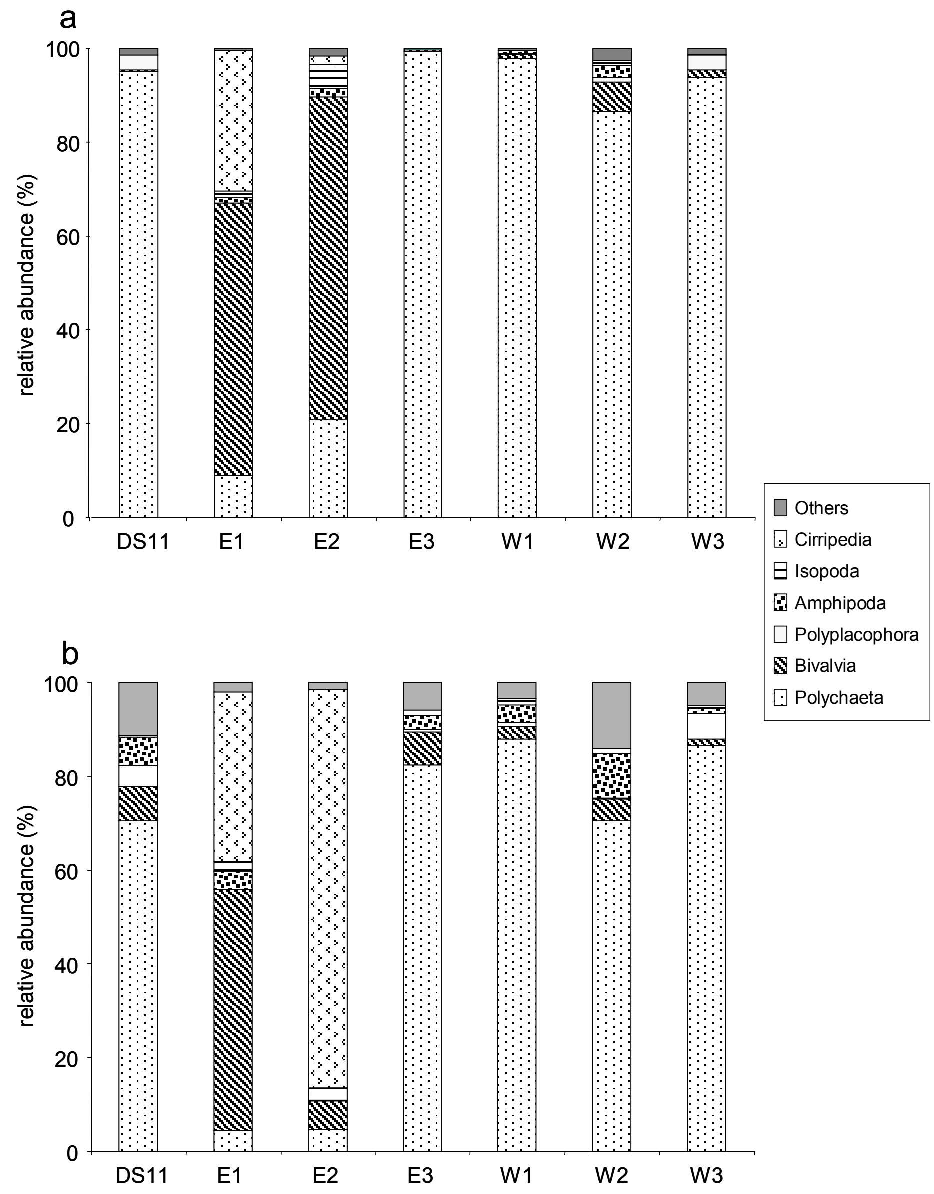

Figure 2.6 Relative abundance contributions of major invertebrate taxa in a) 2005 and b) 2006. Encrusting and colonial taxa are excluded. "Others" includes Anthozoa, Crustacea, Echinodermata and Nemertea.

Invertebrate community composition based on biomass did fall into distinct groupings in 2005 (Figure 2.7a), but all E-sites were distinctly different from other sites in 2006 (Figure 2.7b). This separation of E-sites in 2006 was mostly due to the high biomass of barnacles and bivalves at these sites, as well as less biomass of polychaetes compared to the other sites. Community composition based on abundance differed most between sites E1 and E2 and the other sites in both years (Figure 2.7c, d). In 2005 these two station groupings were similar only at a 30% similarity level, and in 2006 on a 35% similarity level. In both years, this dissimilarity between E1 and E2 and the other sites was driven by the high abundance of barnacles and bivalves.

Dissimilarity between invertebrate communities (based on biomass) at different sites was mainly driven by the following species: *Eucratea loricata* (Bryozoa), *Sertularia albimaris* and *S. cupressoides* (both Hydrozoa), *Haliclona gracilis* and *H. panicea* (Porifera), and to a lesser extent the two polyplacophorans *Ishnochiton albus* and *Amicula vestita*. Community composition based on abundance was mainly distinguished by *Balanus crenatus* (Cirripedia), *Musculus* spp. (Bivalvia), and *Spirorbis* sp. and *Exogone* spp. (Polychaeta).

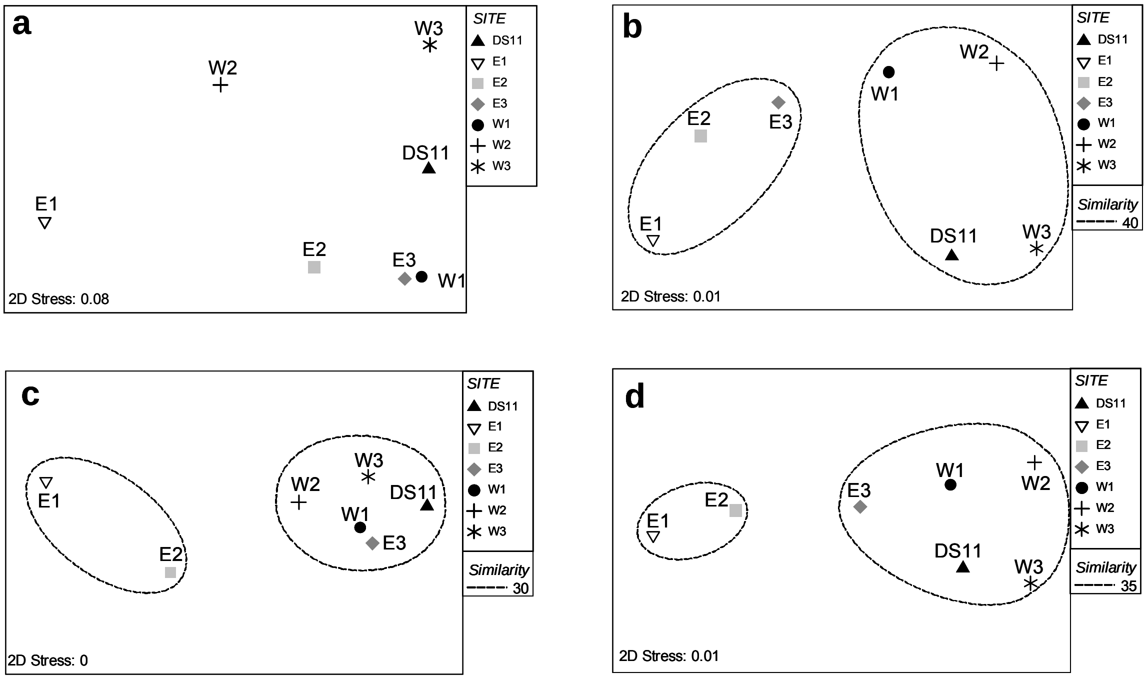

Figure 2.7 Similarity of invertebrate communities based on biomass in a) 2005 and b) 2006, and invertebrate community similarity based on abundance in c) 2005 and d) 2006. Significant differences between groupings and their similarity level are indicated by circles as identified in cluster analyses (SIMPROF test).

Algal and invertebrate biomass was not significantly correlated (Pearson correlation, $\alpha=0.05$) in either year. Separation of invertebrates into functional groups (mobile, sessile) also did not yield any significant relationship with macroalgal biomass.

Diversity measures based on combined invertebrate and algal biomass data did not differ among sites within a year or between years (Table 2.2). Maximum possible Shannon values are 1.99 for 2005 and 2.17 for 2006, indicating that Shannon diversity values encountered in our samples were intermediate. Similarly, Simpson values were also about half the maximum possible values (0.99 in both years). Evenness (Pielou’s index), which is always constraint between 0 and 1, had values that were in the lower range owing to the fact that most species, especially among the invertebrates, were highly uneven in distribution.

While overall diversity indices did not differ among sites or between years, diversity of algae and invertebrates respectively differed within each year. In both years, the Shannon index was significantly higher for invertebrates than for algae ($p<0.001$ for both years), although Pielou’s evenness index was higher in algae than in invertebrates (not significant in 2005, $p<0.001$ in 2006). Therefore, while the invertebrate portion of the community was much more diverse than the algal portion, the algal taxa were much more evenly distributed than invertebrate taxa.

Table 2.2 Diversity and Evenness indices of epilithic communities (invertebrates and algae) in 2005 and 2006.

	2005			**2006**		
Site	**Shannon**	**Simpson**	**Pielou**	**Shannon**	**Simpson**	**Pielou**
DS11	1.118±0.47	0.640±0.37	0.449±0.18	1.298±0.39	0.623±0.17	0.431±0.10
E1	1.061±0.28	0.579±0.16	0.446±0.12	1.169±0.19	0.609±0.08	0.449±0.07
E2	0.777±0.40	0.457±0.26	0.372±0.17	1.107±0.45	0.569±0.20	0.444±0.16
E3	0.821±0.28	0.616±0.31	0.391±0.12	1.021±0.32	0.554±0.15	0.429±0.19
W1	1.037±0.26	0.668±0.15	0.493±0.12	1.081±0.38	0.612±0.29	0.391±0.14
W2	1.119±0.27	0.619±0.16	0.473±0.11	0.889±0.34	0.479±0.18	0.287±0.11
W3	1.057±0.46	0.641±0.38	0.467±0.21	1.097±0.23	0.570±0.13	0.401±0.08
Annual average	**0.999±0.14**	**0.603±0.07**	**0.442±0.04**	**1.095±0.13**	**0.574±0.07**	**0.405±0.04**

Core samples were generally poor in invertebrate species, biomass and abundance in both years. Several core replicates did not contain any organisms in 2005 (54%) and no invertebrates were found in any of the cores at W1 in 2005. More fauna was found in 2006 where only 3 replicates (8.5%) did not contain any invertebrates and invertebrates were found in at least several of the replicates at all sites. Only 17 taxa were found in 2005, 11 of which were polychaetes and 3 were bivalves. In contrast, 42 taxa were identified from core samples in 2006, 28 of which were polychaetes and 7 were bivalves (Table 2.3). Core biomass in both years was mainly dominated by bivalves (Figures 2.8 and 2.9). Abundance in 2005 was dominated by polychaetes and at some stations by anthozoans and tanaids, and in 2006 by polychaetes, amphipods and tanaids (Figures 2.8 and 2.9).

Table 2.3 Occurrence of invertebrate taxa in core samples

2005	**DS11**	**E1**	**E2**	**E3**	**W1**	**W2**	**W3**
Anthozoa	-	-	-	-	-	-	X
Hydroidea	-	-	-	X	-	-	-
Polychaeta	X	X	X	-	-	X	X
Bivalvia	-	X	X	-	-	-	X
Tanaidacea	-	-	-	-	-	X	-
2006	**DS11**	**E1**	**E2**	**E3**	**W1**	**W2**	**W3**
Polychaeta	X	X	X	X	X	X	X
Bivalvia	-	-	X	-	-	X	X
Tanaidacea	-	-	X	-	X	X	X
Amphipoda	X	X	-	-	X	X	-
Cumacea	X	-	-	X	X	X	-
Ascideacea	-	X	-	-	-	-	-

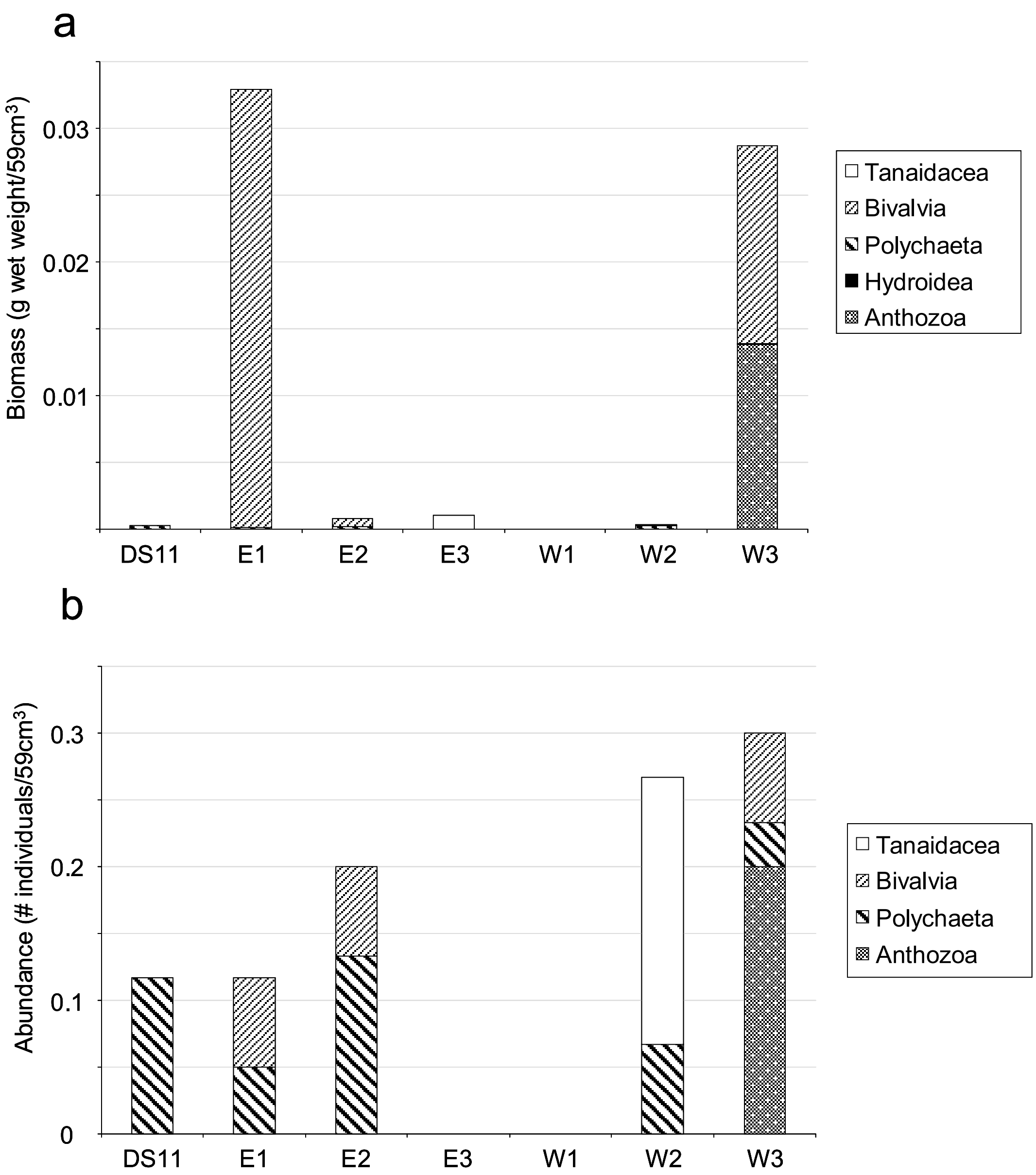

Figure 2.8 Biomass (a) and abundance (b) of invertebrate taxa in cores in 2005.

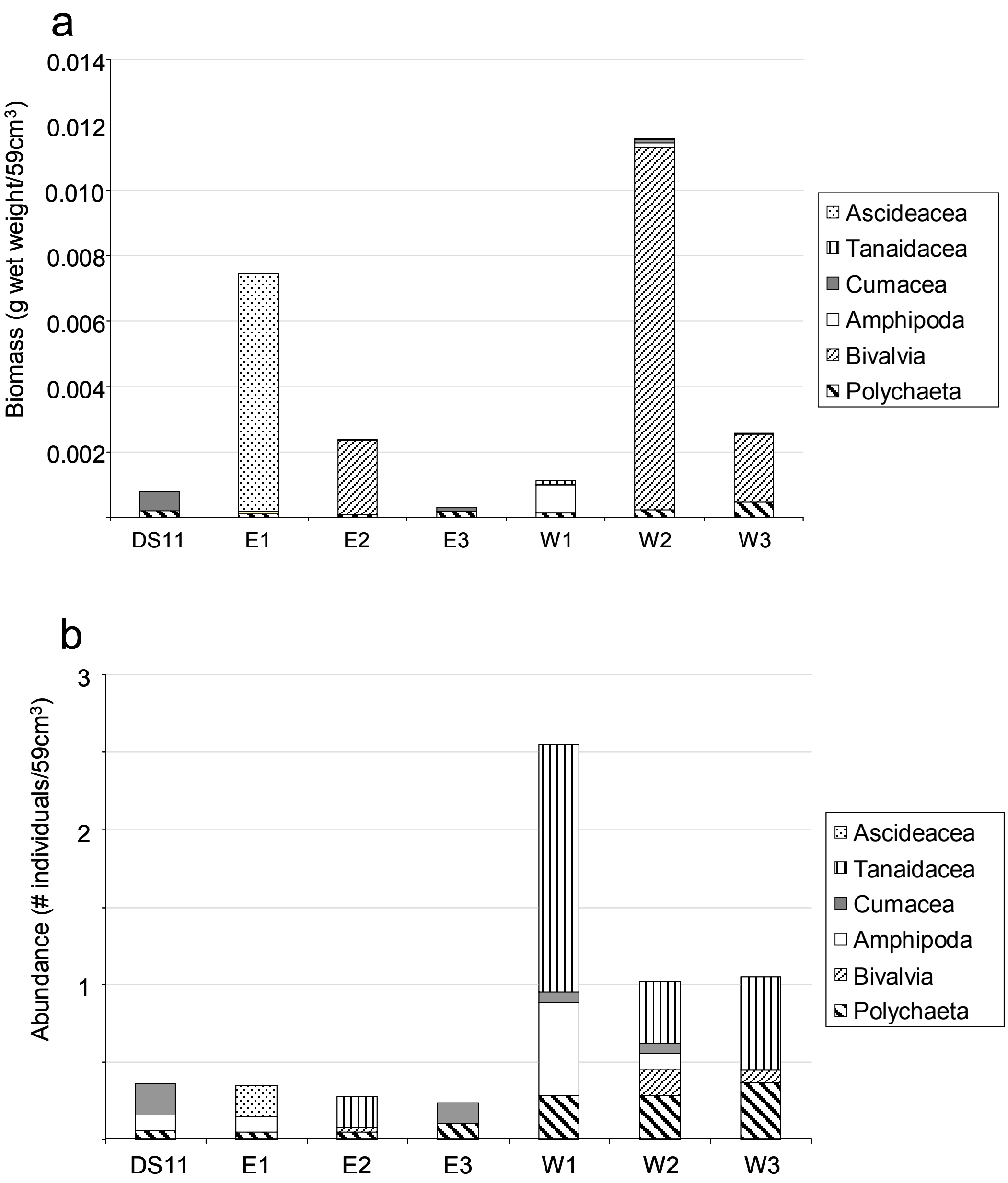

Figure 2.9 Biomass (a) and abundance (b) of invertebrate taxa in cores in 2006.

DISCUSSION

The Boulder Patch is an isolated macroalgal-dominated rocky bottom habitat within the usually soft-sediment environment of the Beaufort Sea. Such algal systems are known to fulfill many diverse habitat functions in other regions of the world's coastal oceans, such as providing three-dimensional space, protection, food, and nursery areas for juvenile life stages (e.g., Iken 1999, Iken et al. 1997, Dean et al. 2000, Beck et al. 2003). These habitat provisions often increase the number of associated fauna within such algal habitats (Taylor 1998). In the Boulder Patch, for example, it is known that an important portion of carbon channeling through the Boulder Patch food web is derived from macroalgae (Dunton and Schell 1987). However, the lack of correlation between algal and invertebrate biomass found here indicates that flora and fauna are at least in part responding to different environmental drivers.

Environmental factors influencing macroalgae in general are mostly light, nutrients, sedimentation, competitive interactions and grazing pressure (Worm et al. 1999, Burkepile and Hay 2006, Liess and Kahlert 2007, Gruner et al. in press), all of which can work on the adult or early life history stages of algae. In the Boulder Patch, light limits growth of kelp in the winter when nutrient levels are high and nutrients limit summer growth when light levels are high (Dunton and Schell 1986). However, even in summer light levels can be severely compromised locally because of high loads of suspended particles in the water column from river discharge or resuspension due to storm events (Aumack et al. 2007). Sedimentation in the Boulder Patch can be large as can be noted from the large build-up of fine sediments on top of boulders and algal thalli (Iken, pers. obs.). Detrimental effects of sedimentation for macroalgae include light reduction, smothering of small stages and abrasion of microscopic life stages important for dispersal and recolonization (Kendrick 1991, Konar and Robert 1996, Airoldi and Cinelli 1997). Macroalgae also are under competitive constraints for space as many other encrusting organisms (mainly invertebrates) are competitively dominating in these interactions (Konar and Iken 2005). Grazers can have strong structuring effects on macroalgal communities in temperate and tropical ecosystems (e.g., Schiel and Foster 1986) but little is known about their influence on algal community structure in the Arctic (Konar 2007). In the Antarctic, several invertebrate and fish species are known to be algal consumers with the potential to influence biomass and species distribution (Iken 1999, Iken et al. 1997). Unique to polar environments, ice gouging also can have a considerable impact on algal communities as grounding ice can overturn large boulders and bury attached organisms but also expose new substratum (Conlan et al. 1998). In the Boulder Patch, such overturning events can be inferred from the occurrence of bleached (dead) encrusting coralline algae at the underside of boulders (Dunton et al. 1982).

The diversity indices reported here are subject to change based on final confirmation of the taxonomic identity of some of the red algae. For example, there has been debate and considerable uncertainty regarding the genus *Rhodomela, Phycodrys* and *Dilsea*. The changes in species names between this report and that reported by Dunton et al. (1982) and Dunton and Schonberg (2000) include *Rhodomela sibirica* and/or *R. tenuissima (*from *R. confervoides), Phycodrys riggi (*from *P. rubens),* and *Dilsea socialis* (from *D. integra*). These changes either reflect (1) a definite shift in species composition over the last two decades which can be interpreted as possible effects of climate change or simply (2) disagreement among algal taxonomists regarding these particular genera (confirmation by S. Lindstrom here vs. R.T. Wilce in previous studies; note that in contrast, S. Schonberg has participated in all the taxanomic studies of the Boulder Patch fauna to date).

The macroalgal community in the Boulder Patch was characterized by high biomass compared to invertebrate biomass, relatively even distribution (high Pielou's index) and relatively low diversity measures. This pattern was mainly caused by the high occurrence of the two dominating red algae at all sites, *Phycodrys riggii* (possibly *P. rubens?*) and *Pyllophora truncata*. It seems that these species are competitively dominants and are able to capitalize on the available space (Konar and Iken 2005). It also may indicate higher reproductive success in these species, possibly through vegetative regrowth in addition to sexual reproduction. The abundance of *Phycodrys riggii* (or *P. rubens*) and *Pyllophora truncata* at all sites and independent of year indicate that environmental conditions for the most part are suitable to sustain these species. In contrast, some of the rarer species may not only be less competitive but may also be more limited by physiological constraints in the environment, such as low growth and reproduction due to low light or high sedimentation (Dunton and Schell 1986, Dunton and Dayton 1995).

The algal species that showed distinct differences between sites was the kelp, *Laminaria solidungula*. This may indicate that the kelp is more sensitive to local environmental conditions. While overall environmental conditions in the Boulder Patch are relatively similar, there are distinct local differences in light and sedimentation regime, which are likely reflected in the differing kelp biomass. *Laminaria solidungula* is a perennial species but produces distinct annual blade sections during the winter, which are indicative of the light conditions experienced the previous summer (Dunton and Schell 1986). If conditions were to change over time, this would likely be traced by diminished or increased kelp biomass. It has to be cautioned, however, that recruitment patterns and inter-annual variability in recruitment and post-recruitment mortality may influence adult distribution patterns. Current knowledge is that recruitment of all taxa is very slow in the Boulder Patch (Dunton et al., 1982; Konar 2007). It is suggested here that *L. solidungula* may be particularly suitable as an environmental indicator for monitoring purposes, as also investigated by other activities within cANIMIDA Task Order 6 (for example, see Aumack et al. 2007).

Compared to other geographical regions, macroalgal biomass and diversity is lower than what occurs in cold-temperate waters along south-central Alaskan coasts in the northern Gulf of Alaska (Konar et al. 2009). There, macroalgal biomass at the same depth as the Boulder Patch is about an order of magnitude higher with about 100 g wet weight 0.25m^2, compared to an average of about 10 g wet weight 0.25m^2 the Boulder Patch. Also macroalgal diversity is higher in the Gulf of Alaska with 20-50 macroalgal species at 5 m depth, depending on location (Konar et al. 2009). Comparative quantitative macroalgal data from other Arctic regions are rare, but species diversity seems to be similar to that encountered along the Russian Arctic coast where kelps like *Saccharina latissima*, *Laminaria digitata, Alaria esculenta* and *Saccorhiza dermatodea* dominate the subtidal community (Tzetlin et al. 1997) and red algae such as *Phycodrys rubens* as well as *Odonthalia dentata*, *Ahnfeltia plicata, Palmaria palmata*, and *Devaleraea ramentacea* build much of the understory (Makarov et al. 1999). Also, the seaweed flora of the Canadian high Arctic, mainly the Baffin Bay area, is similar to that found in the Boulder Patch sublittoral kelp zone contains *Saccharina latissima*, *Laminaria solidungula* and also the red algae *Dilsea integra*, *Devaleraea ramentacea*, *Rhodomela confervoides*, other brown algae such as *Punctaria glacialis*, *Desmarestia* sp. and *Chorda* sp, and green algae of the genus *Chaetomorpha* (Ellis and Wilce 1961, Cross et al. 1987). In comparison, species diversity in western Svalbard is much higher, likely because of the strong influence of Atlantic species carried in by the Gulf Stream (Hop et al. 2002).

The epilithic invertebrate community had distinctly different characteristics compared to the macroalgal community. Invertebrate biomass was much lower than for algae; however, this is not unusual in systems where algae are the foundation taxon. The invertebrate community had significantly higher diversity and lower evenness indices than the algal community. This is owing to the patchy distribution of invertebrates in the Boulder Patch with many rare taxa and some taxa being extremely abundant on small spatial scales. This small scale can be at the size of individual boulders, as exemplified by the two orders of magnitude higher barnacle abundance in two replicates at E2 in 2006 than in any other sample. Similarly, high patchy abundances in some but not all replicates per site were found for the bivalve, *Musculus* sp. at the E1 site in both years. Other invertebrate taxa seem to vary on slightly larger spatial scales than barnacles and bivalves. For example, sponges, hydroids and bryozoans always contributed considerably to invertebrate biomass at all sites and usually occurred regularly in most replicate samples within a site.

Some bryozoans, hydroids and sponges were identified in the present study to be major drivers of differences in invertebrate community composition among sites (*Eucratea loricata*, *Sertularia* spp., *Haliclona* spp.). Similarly, some polychaetes, bivalves and barnacles were important in differentiating among sites when invertebrate abundances were regarded. As discussed above for macroalgae, it is these differentiating species that will likely make good monitoring species as they likely indicate responses to differing conditions on the scale of sites within the Boulder Patch, and may respond to changing environmental conditions. As the kelp *Laminaria solidungula*, these invertebrates are long-lived, which should dampen some of the effects that inter-annual variability in recruitment and post-recruitment mortality have on adult abundance. However, more information is needed on the specific effects that environmental conditions have on recruitment processes and how this could influence patterns detected from monitoring adult populations. If cost-effective monitoring efforts are to be developed, especially the sessile species should be considered as likely candidates as they can be distinguished readily *in situ*, thus avoiding labor-intensive scrape collections and time-consuming identifications in the laboratory. It is suggested here that feasible monitoring efforts can be done effectively by quantitative percent cover estimates using SCUBA. Naturally, the details of such monitoring design would need to be rigorously tested in future work.

In a larger geographical comparison, a similar invertebrate taxon composition was found to be associated with macroalgae in an Arctic fjord in Spitsbergen (Lippert et al. 2001). While actual species were different, sponges, hydroids and bryozoans were important sessile taxa and were represented in similar species numbers as in the Boulder Patch. Among the mobile fauna, polychaetes, bivalves and amphipods were the most speciose groups in Spitsbergen, which is similar to our results from the Boulder Patch, although amphipods seemed to be more species rich in Spitsbergen. Similarly high amphipod species numbers were found in Bjornøya, close Spitsbergen (Weslawski et al. 1997). It may be that amphipods may be more dominant in Arctic regions under Atlantic influence, or that local differences in habitat structure (e.g. high abundance of filamentous green algae, Lippert et al. 2001) favor amphipods in the Spitsbergen regions.

Infaunal abundance in the Boulder Patch was very low and there were distinct differences between the two sampling years. It is suggested here that these interannual differences likely stem from methodological differences applied in both years. The sediment in the Boulder Patch is highly consolidated and has a high fraction of clay, which presented difficulties during the sieving process when clay portions were broken up. We assume that organisms were lost during the sieving process in 2005. In 2006, we employed a more gentle method by slowly stirring sediments in large volumes of water until clay clumps dissolved. While we believe this has resulted in much better capture of the infaunal community, it is not a feasible method that could be employed routinely for large sample quantities.

Comparison with pre-ANIMIDA data

Both epilithic taxon composition as well as relative contributions of taxa to the overall community are similar to what has been reported previously (Dunton and Schonberg 2000) with mollusks and polychates being dominant taxa by abundance. Sponges, hydroids, bryozoans and ascideans are major contributors to invertebrate biomass, as also identified by Dunton and Schonberg (2000). The total number of epilithic invertebrate taxa identified here (~140) was much higher than previously found by Dunton et al. (1982) and Martin and Gallaway (1994), which is mainly due to the lack of polychaetes reported in those studies. The taxon number was similar though to those reported by Dunton and Schonberg (2000) for "between rocks infauna", which included a significant amount of epifaunal organisms. In all studies, however, the main biomass and abundance contributors were the same and differences existed mainly for the rarer taxa.

Core-infaunal species biomass was similar to earlier results on core infauna between rocks (Dunton and Schonberg 2000). In both studies, mollusks (mainly bivalves) were the main biomass contributor (only 2006 results considered here), followed by polychaetes. Remaining taxonomic groups differed between studies but this was likely due to the very low presence of other taxa, which may be too patchily distributed to be sampled effectively by a limited number of small cores. However, overall infaunal taxon richness was only about half of what was found during the Dunton and Schonberg (2000) study. Sampling effort was larger in the previous study as a much larger core ($0.01m^2$ area versus $0.001m^2$ area) was used and sampled with an airlift, likely contributing to some of the observed differences. Mesh size, another important factor when comparing community composition, was the same in both studies (500 µm) and thus did not contribute to differences in infaunal diversity between the studies.

In summary, the Boulder Patch is characterized by high diversity, abundance and biomass of macroalgae and invertebrates compared to the surrounding soft sediments. Both macroalgal and invertebrate components of the community are dominated by few, very common species. Interestingly, some of these species have distinct site distributions within the Boulder Patch, and if these distributional patterns can be linked to major environmental factors such as light availability or sedimentation, then these species may be good candidates for monitoring purposes.

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Appendix A1-a Average PAR at the surface, 2 and 4 m depths (µmol photons m^{-2} s^{-1}) and light attenuation at 2 and 4 m depth for 30 sites measured on three occasions in July and August 2004 in Stefansson Sound. Values are means ± SE.

			2004 Synoptic PAR and Light Attenuation (*k*) (µmol photons m^{-2} s^{-1})							
Site	**Latitude**	**Longitude**	**Surface**	**SE**	**2m**	**SE**	**2m *k***	**4m**	**SE**	**4m *k***
1	70.35	-147.745	698.1	234.5	112.1	54.4	0.914	49.3	34.2	0.663
2	70.34	-147.691	695.5	235.4	221.7	101.1	0.572	150.3	93.1	0.383
3	70.35	-147.632	793.2	228.2	212.1	84.8	0.660	85.0	24.5	0.558
4	70.35	-147.614	752.4	236.4	200.3	86.5	0.662	89.8	30.9	0.531
5	70.32	-147.650	738.9	220.9	192.1	89.6	0.674	95.1	41.1	0.513
6	70.31	-147.697	765.7	244.7	186.3	86.5	0.707	75.4	35.2	0.579
7	70.31	-147.581	705.2	243.2	146.6	33.4	0.785	70.2	23.0	0.577
8	70.33	-147.558	628.5	290.9	145.9	61.8	0.730	56.9	22.4	0.601
9	70.28	-147.529	666.0	282.0	169.4	110.8	0.685	46.5	28.8	0.665
10	70.28	-147.475	718.7	269.7	177.5	91.9	0.699	74.8	32.5	0.566
11	70.32	-147.447	972.4	225.2	274.6	116.5	0.632	120.0	71.4	0.523
12	70.33	-147.503	791.2	213.6	232.0	94.7	0.613	104.7	46.9	0.506
13	70.36	-147.436	924.4	132.3	244.4	64.6	0.665	106.7	38.2	0.540
14	70.38	-147.518	901.0	185.9	247.1	78.3	0.647	106.1	26.7	0.535
15	70.40	-147.471	881.2		201.8		0.737	95.4		0.556
16	70.42	-147.433	876.4		353.0		0.455	171.8		0.407
17	70.42	-147.539	525.2		102.6		0.816	39.0		0.650
18	70.40	-147.594	757.4	161.5	217.6	67.3	0.624	86.1	17.6	0.544
19	70.37	-147.671	986.7	328.3	225.8	71.5	0.737	83.0	11.1	0.619
20	70.38	-147.711	929.7	336.3	220.1	71.8	0.720	81.7	14.0	0.608
21	70.40	-147.725	925.9	373.1	226.7	78.1	0.704	77.4	18.6	0.620
22	70.41	-147.655	834.7	299.7	225.5	77.8	0.654	82.3	22.4	0.579
23	70.42	-147.782	593.6	228.6	149.7	80.1	0.689			
24	70.41	-147.819	589.9	251.4	144.2	83.6	0.704	48.9	27.5	0.623
25	70.43	-147.920	797.2	328.6	119.0	75.7	0.951	30.2	12.8	0.818
26	70.40	-147.923	770.1	325.3	104.1	62.4	1.001	35.2	18.4	0.771
27	70.40	-147.849	779.3	308.8	119.9	65.5	0.936	40.3	17.3	0.741
28	70.38	-147.815	753.3	264.3	131.7	57.5	0.872	38.8	12.4	0.742
29	70.36	-147.895	705.4	286.2	32.1	16.4	1.545	6.2	2.9	1.184
30	70.35	-147.869	724.4	311.2	35.0	14.6	1.515	10.3	5.5	1.063

Appendix A1-b Average PAR at the surface, 2 and 4 m depths (µmol photons m^{-2} s^{-1}) and light attenuation at 2 and 4 m depth for 30 sites measured on three occasions in July and August 2005 in Stefansson Sound. Values are means ± SE.

			2005 Synoptic PAR and Light Attenuation (*k*) (µmol photons m^{-2} s^{-1})							
Site	**Latitude**	**Longitude**	**Surface**	**SE**	**2m**	**SE**	**2m *k***	**4m**	**SE**	**4m *k***
1	70.35	-147.745	666.34	134	137.23	8.8	0.790	109.67	73.2	0.451
2	70.34	-147.691	723	181.6	141.73	21.2	0.815	53.73	13.1	0.650
3	70.35	-147.632	742.6	32.3	190.47	23.8	0.680	67.93	10	0.598
4	70.35	-147.614	593.93	211	137	41.6	0.733	58.8	11.7	0.578
5	70.32	-147.650	697.4	191.3	103	29.9	0.956	37.87	11.4	0.728
6	70.31	-147.697	723.4	176.5	100.13	12.2	0.989	23.73	3.2	0.854
7	70.31	-147.581	812.1	92.9	174.27	5.3	0.770	64.93	2.5	0.632
8	70.33	-147.558	789.63	98.6	249.33	63	0.576	92.73	8	0.535
9	70.28	-147.529	605.2	83.7	134.73	47	0.751	47.6	11.1	0.636
10	70.28	-147.475	455.4	96.1	130.53	44.9	0.625	47.53	3.8	0.565
11	70.32	-147.447	418	48.2	108.27	13.7	0.675	50.73	5.8	0.527
12	70.33	-147.503	451.73	64.1	108.53	5.7	0.713	51.07	3.3	0.545
13	70.36	-147.436	409.27	52.5	116.33	7.6	0.629	65.4	4	0.458
14	70.38	-147.518	423.47	75.5	154.87	31.3	0.503	78.07	16.5	0.423
15	70.40	-147.471	407.3	143.3	113.9	15.9	0.637	54.9	0.9	0.501
16	70.42	-147.433	1002		254.2		0.686	130.6		0.509
17	70.42	-147.539	1141.6		344.8		0.599	153.2		0.502
18	70.40	-147.594	889.7	232.1	211.75	89.8	0.718	89.9	46.3	0.573
19	70.37	-147.671	590.93	150.6	131.97	37.8	0.750	59.37	10.3	0.574
20	70.38	-147.711	475.13	38.5	117.98	20.3	0.697	52.03	11.4	0.553
21	70.40	-147.725	506.33	107.5	108.27	6.2	0.771	58.47	12.2	0.540
22	70.41	-147.655	369.13	45.2	87.67	1.6	0.719	57	20.6	0.467
23	70.42	-147.782	511.6	85	123.2	30.1	0.712	64.65	6.6	0.517
24	70.41	-147.819	466.67	88.2	95.1	16.8	0.795	47.87	4.8	0.569
25	70.43	-147.920	461.7	79.3	80.93	12.9	0.871	44.67	4.6	0.584
26	70.40	-147.923	403.85	103.9	63.8	15.6	0.923	25.2	2.5	0.694
27	70.40	-147.849	336.87	63.8	97.3	10	0.621	40.67	4.3	0.529
28	70.38	-147.815	333.4	66.2	71.4	14.1	0.771	28.07	3.8	0.619
29	70.36	-147.895	282.07	26.9	36.74	23.3	1.019	8.35	6.6	0.880
30	70.35	-147.869	329.47	50.4	35.74	23	1.111	8.14	7.5	0.925

Appendix A1-c Average PAR at the surface, 2 and 4 m depths (µmol photons m^{-2} s^{-1}) and light attenuation at 2 and 4 m depth for 30 sites measured on three occasions in July and August 2006 in Stefansson Sound. Values are means ± SE.

			2006 Synoptic PAR and Light Attenuation (*k*) (µmol photons m^{-2} s^{-1})							
Site	**Latitude**	**Longitude**	**Surface**	**SE**	**2m**	**SE**	**2m *k***	**4m**	**SE**	**4m *k***
1	70.35	-147.745	636.47	204.58	128.00	36.99	0.802	52.93	12.51	0.622
2	70.34	-147.691	804.60	207.56	167.67	61.30	0.784	57.80	14.74	0.658
3	70.35	-147.632	832.13	153.80	186.27	60.23	0.748	64.87	13.89	0.638
4	70.35	-147.614	868.73	190.31	185.07	65.25	0.773	71.87	13.12	0.623
5	70.32	-147.650	716.93	170.79	156.07	37.14	0.762	67.93	12.47	0.589
6	70.31	-147.697	866.67	192.81	131.20	14.98	0.944	62.47	7.81	0.657
7	70.31	-147.581	784.93	225.32	176.40	78.22	0.746	69.13	23.45	0.607
8	70.33	-147.558	939.67	135.93	215.20	35.61	0.737	75.53	7.43	0.630
9	70.28	-147.529	830.87	186.44	191.73	78.51	0.733	79.73	28.74	0.586
10	70.28	-147.475	797.67	116.78	174.73	66.13	0.759	76.33	24.99	0.587
11	70.32	-147.447	928.07	56.19	206.53	92.35	0.751	94.20	23.33	0.572
12	70.33	-147.503	961.60	60.25	255.27	32.49	0.663	127.07	12.97	0.506
13	70.36	-147.436	731.20	208.77	174.33	62.36	0.717	85.80	31.16	0.536
14	70.38	-147.518	826.87	170.04	262.93	76.94	0.573	115.57	20.84	0.492
15	70.40	-147.471	856.73	268.02	233.07	92.97	0.651	114.67	44.82	0.503
16	70.42	-147.433	881.40	214.91	264.27	97.73	0.602	122.60	38.29	0.493
17	70.42	-147.539	500.00	141.42	180.50	77.43	0.509	77.00	25.46	0.468
18	70.40	-147.594	650.40	143.39	194.80	61.23	0.603	69.60	5.89	0.559
19	70.37	-147.671	769.00	215.51	240.87	96.22	0.580	101.00	32.44	0.507
20	70.38	-147.711	747.07	251.79	200.33	93.06	0.658	85.33	30.85	0.542
21	70.40	-147.725	771.07	315.58	201.00	97.35	0.672	84.60	35.84	0.552
22	70.41	-147.655	756.27	239.71	236.27	85.46	0.582	98.80	22.29	0.509
23	70.42	-147.782	809.67	239.73	223.67	82.15	0.643			
24	70.41	-147.819	747.13	212.42	196.67	58.18	0.667	66.47	9.89	0.605
25	70.43	-147.920	808.40	169.16	254.20	88.39	0.578	104.93	21.53	0.510
26	70.40	-147.923	638.13	97.84	119.40	3.74	0.838	50.53	5.13	0.634
27	70.40	-147.849	758.20	221.55	208.27	72.60	0.646	63.87	17.16	0.619
28	70.38	-147.815	743.60	238.38	162.73	75.60	0.760	46.00	15.93	0.696
29	70.36	-147.895	704.53	234.41	102.33	49.26	0.965	24.80	10.42	0.837
30	70.35	-147.869	464.27	51.21	43.80	6.55	1.180	14.33	1.49	0.870

Appendix A2 Average total suspended solids (TSS) for 30 sites measured on three occasions in July and August 2004, 2005 and 2006 in Stefansson Sound. Values are means ± SE.

Total Suspended Solids (mg L^{-1})

			2004				2005				2006			
Site	Latitude	Longitude	2m mean	2m SE	4m mean	4m SE	2m mean	2m SE	4m mean	4m SE	2m mean	2m SE	4m mean	4m SE
1	70.35	-147.745	6.87	2.20	4.91	1.50	8.80		14.60	2.65	4.73	0.77	5.23	1.33
2	70.34	-147.691	4.86	2.03	4.98	1.86	8.02		9.83	1.95	5.26	1.32	4.86	1.17
3	70.35	-147.632	5.11	1.41	5.26	1.67	10.42	1.06	11.68	0.20	4.70	1.58	5.07	0.80
4	70.35	-147.614	4.10	1.68	3.90	1.46	10.19	1.70	8.98	0.83	5.85	2.51	4.54	1.24
5	70.32	-147.650	5.33	2.28	4.80	1.65	10.26	0.98	11.66	0.87	4.15	0.78	4.86	0.74
6	70.31	-147.697	6.05	2.65	5.99	2.30	12.72	1.35	14.81	1.23	5.52	2.04	4.55	0.87
7	70.31	-147.581	3.90	1.77	4.31	1.14	10.73	1.44	10.89	1.79	4.92	0.82	4.46	0.40
8	70.33	-147.558	4.44	1.72	4.42	2.01	10.79	0.87	8.25	0.70	4.69	1.02	3.34	0.60
9	70.28	-147.529	6.24	1.47	5.41	1.47	10.47	0.62	10.30	0.48	4.36	1.09	4.90	0.31
10	70.28	-147.475	5.12	1.81	4.35	1.61	14.07	1.71	8.23	0.30	4.86	0.26	5.04	0.20
11	70.32	-147.447	4.73	2.63	4.50	2.63	11.18	4.25	9.55	0.71	4.38	1.15	4.66	1.58
12	70.33	-147.503	4.72	2.42	4.17	2.20	10.76	3.37	12.26	0.91	3.91	0.72	3.39	0.28
13	70.36	-147.436	4.02	1.58	4.41	1.66	10.03	0.96	10.08	0.67	5.69	2.40	5.19	1.68
14	70.38	-147.518	3.74	1.71	3.77	1.09	8.13	1.14	13.31	1.32	2.85	0.28	5.28	1.52
15	70.40	-147.471	6.74		4.62		7.52	0.28	11.31	0.26	4.13	1.36	3.95	0.24
16	70.42	-147.433	3.91		4.92		7.10		7.87		3.54	0.73	4.43	0.75
17	70.42	-147.539	6.85		5.43		17.02		8.86		6.04	2.76	3.80	0.24
18	70.40	-147.594	3.95	1.60	3.79	0.75	10.03	2.66	11.61	3.50	3.56	0.40	4.97	0.43
19	70.37	-147.671	4.12	1.35	4.50	1.97	8.87	1.12	9.62	0.39	3.29	0.34	5.60	2.31
20	70.38	-147.711	4.65	1.10	3.97	1.10	9.57	1.09	9.46	0.52	4.11	0.60	5.36	1.31
21	70.40	-147.725	4.01	1.48	4.23	1.11	8.78	0.81	10.73	0.19	5.04	0.86	4.69	1.34
22	70.41	-147.655	4.27	1.67	4.48	0.86	8.31	0.56	10.60	0.47	3.54	0.47	4.15	0.15
23	70.42	-147.782	4.93	2.27			10.55	1.34	9.29	0.18	4.01	0.06		
24	70.41	-147.819	5.12	2.61	4.71	1.59	9.49	0.64	11.68	1.18	3.64	0.25	3.40	0.25
25	70.43	-147.920	4.21	2.22	4.16	1.03	7.93	0.44	9.83	0.53	2.96	0.43	6.44	2.00
26	70.40	-147.923	5.61	3.45	5.35	1.04	10.07	0.13	11.80	0.70	4.50	0.20	5.56	1.12
27	70.40	-147.849	4.91	2.74	4.15	1.77	11.48	0.77	9.77	0.54	3.97	0.23	3.96	0.20
28	70.38	-147.815	5.76	2.29	4.17	1.42	11.94	1.07	10.85	1.13	5.14	1.21	6.70	2.46
29	70.36	-147.895	8.18	2.39	8.46	2.07	18.08	5.36	17.08	7.37	5.82	0.54	7.75	1.42
30	70.35	-147.869	7.45	2.15	5.75	1.10	16.45	4.17	31.23	12.93	7.28	1.17	6.54	0.40

Appendix A3 Average water column chlorophyll at 2 and 4 m depths chlorophyll for 30 sites measured on three occasions in July and August 2004, 2005 and 2006 in Stefansson Sound. Values are means ± SE. Missing values indicate ice cover.

				Water Column Chlorophyll ($\mu g\ L^{-1}$)											
				2004				2005				2006			
Site	Latitude	Longitude	Depth (m)	2m mean	2m SE	4m mean	4m SE	2m mean	2m SE	4m mean	4m SE	2m mean	2m SE	4m mean	4m SE
1	70.35	-147.745	6.10	0.30	0.13	0.36	0.19	0.54	0.23	0.80	0.56	0.16	0.06	0.03	0.13
2	70.34	-147.691	6.10	0.22	0.13	0.41	0.28	0.83	0.52	1.15	0.57	0.20	0.11	0.33	0.10
3	70.35	-147.632	6.10	0.21	0.12	0.27	0.15	0.58	0.21	0.71	0.31	0.22	0.11	0.21	0.05
4	70.35	-147.614	7.32	0.21	0.09	0.11	0.04	0.57	0.25	0.57	0.29	0.22	0.10	0.16	0.05
5	70.32	-147.650	6.10	0.26	0.13	0.31	0.18	0.63	0.28	0.85	0.49	0.21	0.12	0.25	0.11
6	70.31	-147.697	4.88	0.31	0.16	0.49	0.28	0.67	0.28	0.95	0.44	0.22	0.09	0.24	0.04
7	70.31	-147.581	7.32	0.26	0.13	0.21	0.04	0.82	0.51	0.74	0.37	0.20	0.10	0.22	0.08
8	70.33	-147.558	7.62	0.26	0.18	0.36	0.22	0.52	0.21	0.81	0.38	0.22	0.10	0.14	0.05
9	70.28	-147.529	7.62	0.34	0.23	0.38	0.27	0.72	0.37	0.46	0.16	0.16	0.04	0.27	0.06
10	70.28	-147.475	7.01	0.40	0.25	0.53	0.36	0.59	0.43	0.54	0.20	0.21	0.08	0.29	0.09
11	70.32	-147.447	6.71	0.19	0.07	0.31	0.19	0.90	0.51	0.74	0.34	0.20	0.09	0.23	0.07
12	70.33	-147.503	7.62	0.23	0.14	0.28	0.18	0.65	0.44	0.68	0.28	0.12	0.02	0.15	0.02
13	70.36	-147.436	5.49	0.17	0.10	0.39	0.23	0.56	0.23	0.88	0.43	0.22	0.12	0.25	0.07
14	70.38	-147.518	5.79	0.18	0.08	0.51	0.26	0.61	0.24	1.12	0.60	0.11	0.02	0.19	0.08
15	70.40	-147.471	10.36	0.43		2.63		0.57	0.41	0.30	0.19	0.11	0.02	0.19	0.05
16	70.42	-147.433		1.18		2.53		0.11		0.13		0.12	0.02	0.20	0.04
17	70.42	-147.539		0.35		1.85		0.12		0.26		0.11	0.01	0.18	0.04
18	70.40	-147.594	9.45	0.16	0.05	0.39	0.31	0.74	0.59	0.64	0.43	0.11	0.03	0.20	0.03
19	70.37	-147.671	9.14	0.21	0.11	0.39	0.31	0.69	0.33	0.65	0.33	0.12	0.01	0.16	0.04
20	70.38	-147.711	9.14	0.23	0.14	0.48	0.21	0.64	0.27	0.72	0.41	0.12	0.01	0.25	0.03
21	70.40	-147.725	4.88	0.15	0.02	0.64	0.28	0.55	0.24	0.98	0.75	0.11	0.01	0.16	0.03
22	70.41	-147.655	9.14	0.20	0.08	0.59	0.44	0.36	0.25	1.14	0.41	0.12	0.02	0.21	0.05
23	70.42	-147.782	3.66	0.15	0.03	0.00		0.36	0.17	0.94	0.42	0.13	0.02		
24	70.41	-147.819	7.32	0.19	0.10	0.36	0.24	0.55	0.28	0.81	0.38	0.11	0.01	0.20	0.04
25	70.43	-147.920	7.92	0.15	0.05	0.25	0.09	0.41	0.19	0.77	0.33	0.11	0.01	0.14	0.01
26	70.40	-147.923	6.40	0.18	0.05	0.72	0.62	0.77	0.35	0.70	0.35	0.13	0.02	0.28	0.06
27	70.40	-147.849	7.32	0.13	0.01	1.23	0.65	0.69	0.32	0.75	0.37	0.11	0.02	0.28	0.05
28	70.38	-147.815	6.40	0.18	0.07	0.82	0.45	0.55	0.28	1.00	0.61	0.17	0.05	0.30	0.10
29	70.36	-147.895	4.88	0.24	0.07	1.28	0.40	0.99	0.68	1.34	0.58	0.28	0.09	0.42	0.05
30	70.35	-147.869	4.88	0.16	0.01	0.87	0.42	0.67	0.41	3.54	2.27	0.28	0.08	0.35	0.05

Appendix A4-a Average ammonium, phosphate, silicate, and nitrate + nitrite at 2 and 4 m depths for 30 sites measured on three occasions in July and August 2004 in Stefansson Sound. Values are means ± SE.

			Water Nutrient Measurements 2004															
Site	**Latitude**	**Longitude**	**Ammonium (NH_4^+) 2m**		**Ammonium (NH_4^+) 4m**		**Phosphate (PO_4^{3-}) 2m**		**Phosphate (PO_4^{3-}) 4m**		**Silicate (SiO_4) 2m**		**Silicate (SiO_4) 4m**		**Nitrate+Nitrite ($NO^{2-}+NO^{3-}$) 2m**		**Nitrate+Nitrite ($NO^{2-}+NO^{3-}$) 4m**	
			mean	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**Mean**	**SE**	**mean**	**SE**
1	70.35	-147.745	0.17	0.09	0.19	0.05	0.26	0.02	0.21	0.08	2.44	0.34	1.48	0.05	0.19	0.11	0.13	0.01
2	70.34	-147.691	0.04	0.01	0.16	0.05	0.23	0.02	0.17	0.06	1.57	0.16	1.70	0.16	0.13	0.11	0.13	0.01
3	70.35	-147.632	0.19	0.07	0.19	0.05	0.23	0.01	0.16	0.04	1.49	0.05	1.69	0.12	0.17	0.10	0.13	0.01
4	70.35	-147.614	0.15	0.09	0.15	0.04	0.25	0.03	0.13	0.07	1.82	0.13	1.64	0.14	0.15	0.09	0.13	0.01
5	70.32	-147.650	0.11	0.07	0.24	0.15	0.29	0.03	0.16	0.08	1.85	0.29	1.49	0.16	0.16	0.09	0.17	0.01
6	70.31	-147.697	0.06	0.01	0.11	0.02	0.20	0.05	0.15	0.07	1.29	0.27	1.50	0.04	0.16	0.12	0.13	0.00
7	70.31	-147.581	0.13	0.04	0.21	0.02	0.27	0.05	0.20	0.05	2.15	0.22	1.62	0.11	0.12	0.10	0.13	0.01
8	70.33	-147.558	0.06	0.05	0.10	0.02	0.18	0.01	0.26	0.11	1.36	0.15	1.76	0.13	0.15	0.12	0.12	0.01
9	70.28	-147.529	0.09	0.07	0.15	0.01	0.23	0.04	0.16	0.05	1.58	0.18	1.70	0.18	0.16	0.11	0.14	0.02
10	70.28	-147.475	0.08	0.05	0.23	0.04	0.31	0.07	0.15	0.05	1.73	0.14	1.58	0.06	0.15	0.13	0.15	0.01
11	70.32	-147.447	0.13	0.05	0.31	0.14	0.25	0.01	0.11	0.06	2.70	0.60	4.90	3.14	0.15	0.09	0.14	0.03
12	70.33	-147.503	0.09	0.09	0.30	0.12	0.23	0.05	0.15	0.04	1.76	0.17	1.82	0.13	0.14	0.11	0.15	0.02
13	70.36	-147.436	0.06	0.01	0.32	0.16	0.23	0.04	0.16	0.08	1.78	0.07	1.39	0.05	0.22	0.10	0.18	0.02
14	70.38	-147.518	0.06	0.05	0.15	0.05	0.23	0.06	0.11	0.05	1.89	0.18	1.63	0.23	0.11	0.07	0.12	0.01
15	70.40	-147.471	0.06		0.52		0.27		0.19		1.48		1.92		0.04		0.21	
16	70.42	-147.433	0.16		0.00		0.39		0.39		1.65		3.01		0.00		0.18	
17	70.42	-147.539	0.02		0.01		0.28		0.30		1.50		2.20		0.03		0.16	
18	70.40	-147.594	0.16	0.08	0.10	0.07	0.20	0.04	0.20	0.04	1.68	0.13	2.14	0.12	0.11	0.09	0.17	0.02
19	70.37	-147.671	0.07	0.03	0.17	0.09	0.24	0.02	0.13	0.03	1.70	0.12	1.38	0.14	0.12	0.11	0.12	0.01
20	70.38	-147.711	0.09	0.05	0.29	0.11	0.26	0.02	0.12	0.06	1.64	0.07	1.68	0.19	0.12	0.11	0.17	0.01
21	70.40	-147.725	0.30	0.21	0.16	0.07	0.18	0.04	0.17	0.06	1.53	0.08	1.58	0.08	0.13	0.09	0.14	0.02
22	70.41	-147.655	0.06	0.01	0.07	0.06	0.20	0.05	0.31	0.05	1.74	0.07	1.78	0.16	0.12	0.07	0.17	0.02
23	70.42	-147.782	0.10	0.05	0.14		0.20	0.05	0.03		1.88	0.18	2.17		0.29	0.11	0.14	
24	70.41	-147.819	0.09	0.07	0.13	0.06	0.21	0.03	0.15	0.05	1.75	0.11	2.10	0.31	0.11	0.09	0.16	0.03
25	70.43	-147.920	0.18	0.11	0.11	0.05	0.20	0.04	0.17	0.01	1.93	0.19	2.18	0.29	0.09	0.08	0.14	0.01
26	70.40	-147.923	0.09	0.03	0.13	0.03	0.25	0.01	0.15	0.04	1.87	0.21	1.64	0.06	0.14	0.12	0.15	0.02
27	70.40	-147.849	0.16	0.02	0.14	0.04	0.23	0.00	0.15	0.04	1.83	0.20	1.42	0.10	0.14	0.11	0.16	0.01
28	70.38	-147.815	0.09	0.05	0.19	0.06	0.24	0.01	0.22	0.03	1.69	0.17	1.80	0.44	0.13	0.12	0.16	0.01
29	70.36	-147.895	0.34	0.12	0.11	0.09	0.24	0.02	0.39	0.00	2.08	0.41	1.02	0.08	0.22	0.09	0.16	0.01
30	70.35	-147.869	0.07	0.04	0.10	0.09	0.37	0.03	0.34	0.02	1.50	0.10	1.18	0.02	0.19	0.13	0.16	0.00

Appendix A4-b Average ammonium, phosphate, silicate, and nitrate + nitrite at 2 and 4 m depths for 30 sites measured on three occasions in July and August 2005 in Stefansson Sound. Values are means ± SE.

			Water Nutrient Measurements 2005															
			Ammonium (NH_4^+) 2m		**Ammonium (NH_4^+) 4m**		**Phosphate (PO_4^{3-}) 2m**		**Phosphate (PO_4^{3-}) 4m**		**Silicate (SiO_4) 2m**		**Silicate (SiO_4) 4m**		**Nitrate+Nitrite (NO^{2-}+NO^{3-}) 2m**		**Nitrate+Nitrite (NO^{2-}+NO^{3-}) 4m**	
Site	**Latitude**	**Longitude**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**Mean**	**SE**	**mean**	**SE**
1	70.35	-147.745	0.33	0.19	0.64	0.39	0.34	0.05	0.32	0.05	7.06	1.64	5.28	0.62	0.23	0.18	0.29	0.24
2	70.34	-147.691	0.32	0.12	0.60	0.22	0.37	0.04	0.39	0.03	6.05	0.76	5.52	0.41	0.38	0.26	0.17	0.12
3	70.35	-147.632	0.34	0.25	0.76	0.43	0.33	0.04	0.36	0.05	5.98	0.71	5.64	0.64	0.26	0.17	0.11	0.08
4	70.35	-147.614	0.77	0.32	0.74	0.35	0.24	0.09	0.36	0.06	7.04	2.29	5.81	0.66	0.61	0.26	0.13	0.07
5	70.32	-147.650	0.27	0.13	0.84	0.45	0.33	0.06	0.37	0.08	6.45	0.65	6.02	0.80	0.44	0.34	0.30	0.17
6	70.31	-147.697	0.32	0.06	0.65	0.33	0.33	0.05	0.35	0.06	5.57	0.44	5.87	0.43	0.31	0.29	0.32	0.32
7	70.31	-147.581	0.44	0.17	0.87	0.38	0.33	0.05	0.37	0.06	8.38	2.50	5.78	0.80	0.56	0.32	0.14	0.03
8	70.33	-147.558	0.64	0.11	0.63	0.35	0.30	0.01	0.37	0.07	5.78	1.46	5.63	0.82	0.31	0.06	0.13	0.07
9	70.28	-147.529	0.26	0.10	0.67	0.35	0.31	0.06	0.40	0.09	6.86	1.52	6.51	0.70	0.58	0.45	0.48	0.37
10	70.28	-147.475	0.39	0.23	0.75	0.42	0.33	0.02	0.43	0.09	6.36	0.54	6.50	0.69	0.40	0.33	0.52	0.32
11	70.32	-147.447	0.23	0.02	0.69	0.29	0.28	0.04	0.36	0.04	5.41	0.56	5.64	0.69	0.31	0.20	0.08	0.02
12	70.33	-147.503	0.32	0.06	0.57	0.26	0.35	0.05	0.32	0.03	6.11	0.81	5.06	0.62	0.30	0.23	0.18	0.15
13	70.36	-147.436	0.29	0.12	0.74	0.39	0.32	0.03	0.33	0.02	5.96	0.66	5.02	0.66	0.19	0.09	0.17	0.03
14	70.38	-147.518	0.29	0.05	0.39	0.18	0.30	0.04	0.30	0.08	5.58	0.81	4.77	1.29	0.05	0.03	0.08	0.06
15	70.40	-147.471	0.13	0.06	0.47	0.38	0.21	0.04	0.55	0.26	5.16	1.48	6.04	2.68	0.02	0.02	1.98	1.88
16	70.42	-147.433	0.31		0.18		0.23		0.18		4.06		2.97		0.00		0.23	
17	70.42	-147.539	0.51		0.03		0.21		0.28		3.90		3.42		0.00		0.03	
18	70.40	-147.594	0.39	0.01	0.49	0.46	0.23	0.01	0.29	0.02	5.79	1.34	5.02	1.17	0.05	0.04	0.07	0.00
19	70.37	-147.671	0.42	0.06	0.55	0.32	0.24	0.02	0.25	0.06	5.33	0.79	4.59	0.85	0.07	0.02	0.00	0.00
20	70.38	-147.711	0.38	0.11	0.74	0.36	0.29	0.02	0.29	0.03	4.24	0.22	5.17	1.08	0.06	0.05	0.06	0.03
21	70.40	-147.725	0.28	0.03	0.91	0.49	0.22	0.01	0.30	0.08	5.10	1.02	4.31	1.00	0.06	0.04	0.22	0.20
22	70.41	-147.655	0.44	0.17	0.44	0.16	0.27	0.03	0.33	0.02	5.06	0.65	5.17	0.80	0.03	0.02	0.09	0.04
23	70.42	-147.782	0.29	0.14	0.74	0.40	0.23	0.02	0.36	0.03	4.61	0.82	4.21	1.08	0.02	0.02	0.05	0.03
24	70.41	-147.819	0.33	0.17	0.58	0.25	0.30	0.05	0.28	0.04	4.98	0.93	4.93	0.53	0.00	0.00	0.10	0.03
25	70.43	-147.920	0.59	0.24	0.45	0.24	0.26	0.02	0.29	0.03	4.88	0.84	4.60	0.65	0.09	0.07	0.05	0.01
26	70.40	-147.923	0.38	0.02	0.65	0.24	0.27	0.05	0.30	0.07	5.14	0.40	4.85	0.95	0.10	0.05	0.06	0.06
27	70.40	-147.849	1.00	0.55	0.67	0.34	0.29	0.03	0.27	0.04	4.83	0.55	3.98	0.14	0.09	0.04	0.09	0.07
28	70.38	-147.815	0.28	0.09	0.81	0.33	0.28	0.05	0.31	0.06	4.96	0.61	4.50	0.87	0.04	0.03	0.15	0.06
29	70.36	-147.895	0.24	0.06	0.66	0.37	0.32	0.05	0.48	0.20	5.31	0.45	5.39	1.61	0.09	0.08	1.43	1.41
30	70.35	-147.869	0.70	0.41	0.68	0.18	0.33	0.05	0.50	0.19	4.93	0.99	5.15	1.22	0.28	0.19	1.21	1.11

Appendix A4-c Average ammonium, phosphate, silicate, and nitrate + nitrite at 2 and 4 m depths for 30 sites measured on three occasions in July and August 2006 in Stefansson Sound. Values are means ± SE.

Site	Latitude	Longitude	**Water Nutrient Measurements 2006**															
			Ammonium (NH_4^+) 2m		**Ammonium (NH_4^+) 4m**		**Phosphate (PO_4^{3-}) 2m**		**Phosphate (PO_4^{3-}) 4m**		**Silicate (SiO_4) 2m**		**Silicate (SiO_4) 4m**		**Nitrate+Nitrite (NO^{2-}+NO^{3-}) 2m**		**Nitrate+Nitrite (NO^{2-}+NO^{3-}) 4m**	
			mean	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**mean**	**SE**	**Mean**	**SE**	**mean**	**SE**
1	70.35	-147.745	0.36	0.30	0.05	0.03	0.21	0.03	0.20	0.08	7.65	0.36	8.28	0.62	0.13	0.07	0.04	0.02
2	70.34	-147.691	0.14	0.11	0.08	0.04	0.17	0.05	0.22	0.08	7.42	0.53	7.60	1.09	0.06	0.01	0.44	0.37
3	70.35	-147.632	0.13	0.08	0.09	0.04	0.18	0.06	0.19	0.05	7.91	0.67	7.35	0.92	0.07	0.00	0.12	0.07
4	70.35	-147.614	0.04	0.04	0.14	0.10	0.18	0.00	0.18	0.03	6.29	0.33	6.99	0.90	0.03	0.03	0.07	0.00
5	70.32	-147.650	0.04	0.04	0.05	0.05	0.19	0.02	0.19	0.05	6.61	0.52	7.37	0.40	0.05	0.00	0.09	0.02
6	70.31	-147.697	0.39	0.33	0.31	0.20	0.14	0.04	0.21	0.05	7.83	0.88	7.21	0.95	0.05	0.02	0.07	0.01
7	70.31	-147.581	0.12	0.06	0.11	0.06	0.15	0.04	0.23	0.01	7.11	0.77	6.88	1.99	0.04	0.02	0.08	0.03
8	70.33	-147.558	0.60	0.27	0.48	0.22	0.18	0.04	0.16	0.04	7.51	0.23	6.86	1.31	0.04	0.02	0.14	0.08
9	70.28	-147.529	0.17	0.10	0.20	0.15	0.17	0.04	0.24	0.14	7.21	0.50	6.06	0.20	0.07	0.00	0.08	0.01
10	70.28	-147.475	0.13	0.05	0.22	0.11	0.16	0.04	0.21	0.05	7.47	0.47	7.09	1.30	0.08	0.05	0.05	0.02
11	70.32	-147.447	0.29	0.23	0.00	0.00	0.14	0.02	0.19	0.05	6.84	0.89	6.85	0.67	0.03	0.02	0.04	0.02
12	70.33	-147.503	0.00		0.15	0.11	0.16		0.18	0.03	5.91		7.64	1.25	0.05		0.09	0.02
13	70.36	-147.436	0.16	0.09	0.18	0.10	0.15	0.01	0.20	0.04	6.32	0.52	6.33	1.02	0.05	0.00	0.09	0.02
14	70.38	-147.518	0.18	0.10	0.06	0.04	0.20	0.07	0.16	0.01	5.99	0.40	5.48	0.33	0.05	0.02	0.05	0.03
15	70.40	-147.471	0.16	0.13	0.22	0.18	0.14	0.01	0.25	0.06	5.79	0.29	6.42	0.33	0.06	0.01	0.09	0.01
16	70.42	-147.433	0.18	0.15	0.06	0.03	0.14	0.02	0.27	0.07	5.55	0.35	6.04	0.41	0.07	0.04	0.07	0.00
17	70.42	-147.539	1.80	1.75	0.11	0.03	0.10	0.01	0.21	0.06	5.55	0.94	5.70	0.10	0.33	0.27	0.06	0.01
18	70.40	-147.594	0.26	0.03	0.02	0.02	0.18	0.01	0.21	0.03	7.64	0.74	7.17	1.23	0.06	0.01	0.07	0.01
19	70.37	-147.671	0.09	0.03	0.10	0.06	0.17	0.04	0.19	0.02	6.59	0.41	6.95	0.49	0.03	0.03	0.07	0.01
20	70.38	-147.711	0.07	0.00	0.07	0.07	0.19	0.07	0.23	0.01	6.70	0.94	7.01	0.79	0.03	0.03	0.09	0.01
21	70.40	-147.725	0.06	0.01	0.10	0.10	0.15	0.01	0.20	0.01	6.23	0.21	6.90	0.74	0.06	0.01	0.11	0.04
22	70.41	-147.655	0.28	0.25	0.02	0.02	0.15	0.02	0.24	0.03	6.26	0.85	7.50	0.74	0.08	0.02	0.02	0.02
23	70.42	-147.782	0.64	0.52			0.16	0.02			7.03	1.61			0.03	0.03		
24	70.41	-147.819	0.11	0.05	0.13	0.07	0.18	0.04	0.21	0.02	6.81	0.20	6.77	1.30	0.06	0.01	0.09	0.01
25	70.43	-147.920	0.13	0.06	0.04	0.02	0.15	0.02	0.18	0.02	6.58	0.24	6.19	1.65	0.06	0.03	0.07	0.01
26	70.40	-147.923	0.52	0.49	0.09	0.06	0.16	0.04	0.17	0.05	7.20	0.43	6.26	0.68	0.07	0.05	0.07	0.01
27	70.40	-147.849	0.06	0.00	0.12	0.09	0.20	0.04	0.20	0.04	6.50	1.02	7.13	1.05	0.08	0.06	0.19	0.14
28	70.38	-147.815	0.28	0.20	0.11	0.03	0.20	0.06	0.19	0.05	8.57	1.06	7.85	0.57	0.04	0.02	0.09	0.02
29	70.36	-147.895	0.27	0.21	0.12	0.05	0.17	0.05	0.16	0.08	9.12	0.51	7.58	0.71	0.09	0.02	0.06	0.00
30	70.35	-147.869	0.07	0.01	0.10	0.10	0.25	0.12	0.25	0.09	9.36	0.55	5.93	0.71	0.08	0.02	0.28	0.18

Appendix A5-a Average temperature, salinity, dissolved oxygen, and pH at 2 and 4 m depths measurements for 30 sites measured on three occasions in July and August 2004 in Stefansson Sound. Values are means ± SE.

Water Column Physiochemical Parameters
2004

Site	Temp (°C) 2m		Temp (°C) 4m		Salinity (‰) 2m		Salinity (‰) 4m		Dissolved O_2 (mg L^{-1}) 2m		Dissolved O_2 (mg L^{-1}) 4m		pH (m^{-1}) 2m		pH (m^{-1}) 4m	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
1	2.6	0.8	0.4	0.1	24.4	0.6	27.5	0.5	13.6	0.2	14.6	0.3	8.1	0.1	8.1	0.1
2	2.3	0.8	1.4	0.4	24.4	0.4	25.6	0.3			14.0	0.2	8.2	0.1	8.2	0.0
3	2.4	0.8	2.1	0.8	23.8	0.5	24.3	0.6	13.4	0.5	13.8	0.4	8.1	0.2	8.2	0.1
4	2.4	0.8	2.1	0.8	23.7	0.6	24.2	0.7	13.6	0.3	13.8	0.2	8.2	0.1	8.2	0.0
5	2.0	0.5	1.2	0.5	24.7	0.4	26.0	1.3	13.8	0.3	14.4	0.4	8.2	0.0	8.2	0.0
6	2.6	0.5	1.6	0.2	24.7	1.0	25.9	0.6	13.5	0.5	14.0	0.2	8.2	0.1	8.2	0.0
7	2.4	0.8	2.1	0.9	24.5	0.8	25.2	0.6	13.4	0.4	13.8	0.5	8.2	0.1	8.2	0.0
8	2.1	0.6	1.8	0.8	23.6	0.7	24.8	1.1	13.8	0.3	13.9	0.3	8.2	0.0	8.2	0.0
9	3.3	1.3	1.6	0.8	25.0	0.6	26.2	0.7	13.0	0.6	13.9	0.4	8.2	0.1	8.2	0.0
10	2.4	0.8	1.7	0.9	24.7	1.0	26.1	1.0	13.6	0.4	14.0	0.4	8.2	0.1	8.2	0.0
11	2.3	0.2	1.7	1.0	22.5	0.6	25.2	1.4	13.6	0.2	13.8	0.4	8.2	0.0	8.2	0.0
12	2.2	0.3	2.2	1.0	23.2	0.6	24.4	1.1	13.6	0.2	13.7	0.4	8.2	0.0	8.2	0.0
13	1.8	0.1	0.7	0.1	22.1	1.9	25.4	0.6	13.8	0.2	14.3	0.1	8.2	0.0	8.3	0.0
14	1.7	0.1	1.2	0.4	21.4	1.9	23.5	1.3	13.6	0.4	13.8	0.3	8.2	0.1	8.2	0.0
15	0.0		-1.4		27.6		31.7		14.3		15.0		8.2		8.3	
16	-0.8		-1.2		29.9		32.1		15.0		15.2		8.3		8.3	
17	0.9		-1.2		25.1		31.9		14.3		15.0		8.2		8.3	
18	1.9	0.4	0.4	1.2	21.3	2.0	27.6	2.0	13.6	0.5	14.4	0.7	8.2	0.0	8.2	0.0
19	2.6	0.7	1.7	0.7	23.5	0.9	24.8	1.0	13.6	0.4	14.0	0.3	8.2	0.0	8.2	0.0
20	2.3	0.6	1.6	0.7	24.0	0.4	24.9	0.9	13.8	0.3	14.1	0.2	8.2	0.0	8.2	0.0
21	2.3	0.6	0.4	1.0	21.9	1.7	27.9	1.9	13.5	0.4	14.2	0.4	8.2	0.0	8.2	0.0
22	1.9	0.4	-0.5	0.4	20.5	2.3	28.3	2.0	13.7	0.4	14.4	0.3	8.2	0.0	8.2	0.0
23	1.9	0.2			20.4	2.0			13.6	0.2			8.2	0.0		
24	2.1	0.1	0.4	0.8	22.1	0.8	26.6	1.2	13.3	0.5	14.2	0.4	8.2	0.0	8.2	0.0
25	2.2	0.2	1.7	1.2	20.6	1.5	25.3	1.7	13.6	0.4	13.7	0.4	8.2	0.1	8.2	0.0
26	3.0	0.5	1.1	1.6	23.7	0.8	27.3	2.0	13.3	0.2	14.1	0.6	8.2	0.1	8.2	0.0
27	3.2	0.8	1.4	1.2	23.2	0.4	26.5	1.9	13.3	0.4	14.0	0.4	8.2	0.0	8.2	0.0
28	3.0	1.1	0.0	1.0	24.4	0.6	28.9	1.7	13.3	0.5	14.4	0.5	8.2	0.0	8.2	0.0
29	2.4	0.5	-0.6	0.5	25.8	0.9	30.0	1.0	13.3	0.1	14.8	0.3	8.2	0.0	8.3	0.0
30	1.9	0.4	-0.2	0.5	27.4	0.8	29.3	1.2	13.7	0.2	14.9	0.6	8.2	0.0	8.3	0.0

Appendix A5-b Average temperature, salinity, dissolved oxygen, at 2 and 4m depths measurements for 30 sites measured on three occasions in July and August 2005 in Stefansson Sound. The pH measurements were not included because of a probe malfunction. Values are means ± SE.

Water Column Physiochemical Parameters 2005

Site	Temp (°C)		Temp (°C)		Salinity (‰)		Salinity (‰)		Dissolved O_2 (mg L^{-1})		Dissolved O_2 (mg L^{-1})	
	2m		4m		2m		4m		2m		4m	
	mean	SE	mean	SE	mean	SE	mean	SE		mean	SE	mean
1	2.73	1.10	2.48	1.35	25.31	1.46	26.58	1.00	11.01	0.25	10.91	0.27
2	2.27	0.86	2.55	1.34	24.96	1.74	25.95	1.26	11.10	0.08	10.90	0.20
3	2.43	0.89	2.17	1.22	24.84	1.63	26.11	1.14	11.01	0.12	10.95	0.09
4	2.51	0.94	2.33	1.17	24.77	1.59	25.78	1.15	11.25	0.40	11.26	0.26
5	3.11	1.82	2.93	1.88	25.39	1.64	26.48	1.12	10.85	0.08	10.85	0.06
6	3.23	1.82	3.02	1.72	25.88	1.31	26.60	1.09	10.90	0.27	10.93	0.24
7	2.83	1.49	2.43	1.45	25.09	1.81	25.98	1.25	11.33	0.42	11.40	0.35
8	2.54	1.02	2.37	1.20	24.76	1.77	25.53	1.35	11.45	0.64	11.45	0.45
9	3.02	1.76	2.82	1.87	25.15	1.55	26.17	1.22	11.10	0.35	11.07	0.28
10	2.84	1.61	2.55	1.64	24.68	1.87	25.62	1.44	11.21	0.33	11.22	0.22
11	2.55	1.04	2.48	1.14	24.32	1.96	24.88	1.73	11.40	0.57	11.42	0.39
12	2.39	0.91	2.38	1.06	24.60	1.82	25.08	1.73	11.58	0.48	11.52	0.34
13	1.96	0.90	1.57	0.74	24.74	1.61	26.13	1.68	11.80	0.92	11.95	0.80
14	1.75	0.53	1.28	0.70	22.77	2.35	26.96	1.07	12.29	0.69	11.69	0.51
15	2.48	1.43	0.10	1.42	17.68	0.89	30.85	1.66	12.67	0.69	12.50	1.06
16	3.12		1.73		22.70		26.99					
17	3.00		1.05		20.00		29.78					
18	2.56	0.94	1.10	0.72	19.78	1.90	26.13	0.65	12.20	0.50	12.30	0.66
19	2.80	1.01	2.24	1.17	23.61	1.67	25.21	1.19	11.61	0.08	11.62	0.18
20	2.68	0.96	2.18	1.23	24.05	1.79	25.34	1.16	11.46	0.05	11.54	0.08
21	2.34	0.82	1.46	1.07	22.62	1.57	26.56	0.44	12.08	0.16	11.92	0.22
22	1.82	0.70	0.75	1.26	22.55	3.04	27.50	2.26	11.50	0.40	11.47	0.56
23	1.86	0.24	0.61	0.82	22.30	2.19	30.38	0.95	11.97	0.98	12.24	
24	2.45	0.93	1.99	0.74	23.76	1.51	25.35	0.98	11.37	0.45	11.43	0.39
25	2.08	0.48	1.82	0.37	23.69	0.84	25.52	1.51	11.33	0.81	11.43	0.70
26	2.95	1.13	2.25	1.49	24.58	1.22	25.87	1.76	10.95	0.41	11.04	0.33
27	2.74	1.08	2.45	1.26	24.20	1.50	25.17	1.28	10.92	0.55	11.02	0.45
28	2.69	1.17	2.40	1.44	24.57	1.53	25.80	1.18	10.96	0.47	10.99	0.45
29	3.48	1.23	1.67	2.65	26.21	1.31	29.50	2.39	10.47	0.65	10.70	0.42
30	3.49	1.22	2.04	2.72	25.98	1.29	29.64	2.50	10.45	0.68	10.66	0.47

Appendix A5-c Average temperature, salinity, dissolved oxygen, and pH at 2 and 4 m depths measurements for 30 sites measured on three occasions in July and August 2006 in Stefansson Sound. Values are means ± SE.

Water Column Physiochemical Parameters
2006

Site	Temp (°C) 2m		Temp (°C) 4m		Salinity (‰) 2m		Salinity (‰) 4m		Dissolved O_2 (mg L^{-1}) 2m		Dissolved O_2 (mg L^{-1}) 4m		pH (m^{-1}) 2m		pH (m^{-1}) 4m	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
1	4.74	0.89	5.45	0.46	17.56	3.29	18.74	3.43	11.35	0.09	11.28	0.20	7.90	0.01	7.92	0.01
2	5.14	0.38	4.97	0.73	16.74	2.54	18.83	3.07	11.34	0.01	11.47	0.07	7.91	0.01	7.91	0.01
3	5.27	0.44	5.65	0.47	16.66	2.33	17.52	2.34	11.47	0.04	11.27	0.18	7.90	0.01	7.90	0.01
4	4.79	0.42	5.58	0.38	16.71	2.24	17.44	2.14	11.46	0.03	11.35	0.04	7.91	0.01	7.91	0.01
5	5.27	0.89	5.34	0.20	16.79	2.34	17.83	2.81	11.33	0.16	11.46	0.13	7.93	0.01	7.92	0.01
6	5.09	0.40	5.56	0.46	17.62	2.64	20.26	3.03	11.54	0.04	11.52	0.42	7.93	0.01	7.93	0.01
7	5.07	0.59	4.86	0.95	16.78	2.31	18.45	2.86	11.52	0.13	11.54	0.22	7.93	0.01	7.93	0.02
8	4.34	0.56	4.65	0.82	16.73	2.08	17.48	2.29	11.61	0.08	11.56	0.09	7.91	0.02	7.92	0.01
9	4.86	0.28	5.49	0.36	17.96	2.78	21.08	3.11	11.74	0.12	11.46	0.21	7.93	0.01	7.93	0.02
10	5.54	0.54	5.15	0.60	18.92	2.71	22.21	3.72	11.38	0.15	11.59	0.10	7.93	0.01	7.68	0.25
11	4.59	0.71	4.73	0.72	16.46	1.55	19.50	2.52	11.65	0.04	11.60	0.00	7.91	0.01	7.92	0.01
12	3.94	0.60	4.56	0.83	16.45	1.63	17.92	2.22	11.59	0.11	11.49	0.17	7.92	0.01	7.91	0.01
13	5.04	0.62	4.43	0.49	16.79	0.88	19.60	1.61	11.63	0.04	11.56	0.01	7.90	0.01	7.92	0.00
14	4.02	0.67	4.14	0.95	15.57	1.00	19.15	2.11	11.55	0.01	11.50	0.13	7.90	0.03	7.89	0.01
15	3.15	0.53	2.43	1.17	15.74	0.39	24.62	3.26	11.51	0.09	11.72	0.17	7.90	0.03	7.89	0.01
16	1.47	0.64	0.60	0.91	16.23	0.14	24.74	3.21	11.60	0.14	11.75	0.06	7.93	0.03	7.88	0.01
17	3.09	0.62	1.58	2.42	15.61	0.04	24.23	5.83	11.63	0.04	11.73	0.29	7.89	0.00	7.88	0.00
18	3.86	1.11	3.08	1.56	15.56	1.01	23.57	1.50	11.51	0.18	11.55	0.30	7.91	0.02	7.91	0.01
19	4.79	0.91	4.66	1.38	16.68	2.30	19.56	1.70	11.37	0.04	11.33	0.04	7.91	0.02	7.91	0.01
20	4.85	0.97	3.97	1.45	17.01	2.60	21.15	1.05	11.41	0.01	11.41	0.06	7.91	0.01	7.90	0.01
21	4.10	1.16	4.08	1.74	16.42	1.70	22.35	1.65	11.45	0.04	11.25	0.06	7.91	0.03	7.91	0.01
22	4.02	1.32	2.70	1.88	16.15	1.04	24.68	2.24	11.44	0.15	11.59	0.37	7.91	0.03	7.89	0.01
23	3.98	1.32			15.70	1.49			11.44	0.11			7.91	0.03		
24	4.87	1.11	3.95	1.91	17.16	2.53	22.59	1.69	11.31	0.05	11.35	0.02	7.90	0.03	7.92	0.01
25	4.56	1.14	3.85	2.27	16.41	1.54	20.74	2.64	11.39	0.04	11.31	0.02	7.91	0.03	7.92	0.03
26	5.30	1.09	3.45	0.96	17.93	2.70	20.73	2.21	11.25	0.18	11.81	0.51	7.93	0.01	7.93	0.02
27	4.99	1.29	4.02	1.12	17.89	2.83	20.25	1.81	11.30	0.16	11.61	0.13	7.92	0.03	7.92	0.02
28	5.87	1.09	4.75	0.61	17.79	2.97	20.22	1.93	11.23	0.26	11.60	0.04	7.94	0.01	7.94	0.01
29	6.04	0.24	3.61	1.38	18.63	3.27	23.01	5.11	11.32	0.07	12.31	0.22	7.93	0.02	7.91	0.03
30	6.01	0.33	3.81	1.09	18.32	3.51	22.29	5.06	11.34	0.08	12.59	0.55	7.92	0.04	7.67	0.27

Appendix B, Publications and Presentations resulting from cANIMIDA and ANIMIDA work.

Publications

Dunton, K. H., S. V. Shonberg, and D. W. Funk. 2009. Interannual and spatial variability in light attenuation: Evidence from three decades of growth in the kelp *Laminaria solidungula. In*: Krupnik, I., M. A. Lang, and S.E. Miller (eds.), *Smithsonian at the Poles: Contributions to International Polar Year Science* p. 271-284.

Aumack, C. F., K. H. Dunton, A. B. Burd, D. W. Funk and R. A. Maffione. 2007. Linking light attenuation and suspended sediment loading to benthic productivity within an arctic kelp bed community. *Journal of Phycology* 43: 853-863.

Abstracts and Conference Presentations

Dunton, K., K. Iken, S. Shonberg, and D. W. Funk. 2009. Long-term monitoring of the kelp community in the Stefansson Sound Boulder patch: Detection of change related to oil and gas development. OCS Study MMS 2009-040. Continuation of Arctic Near shore Impact Monitoring in the Development Area (cANIMIDA) Task 006, Final Report to the U.S. Department of the Interior, Minerals Management Service, 56 pp.

Dunton, K. H., S. V. Shonberg, and D. W. Funk. 2009. Interannual and spatial variability in Light attenuation: Evidence from three decades of growth in the kelp *Laminaria solidungula. In*: *Smithsonian at the Poles: Contributions to International Polar Year Science*, pp.271-284. Smithsonian Institution Scholarly Press, Washington DC.

Dunton, K. H., and S. V. Schonberg. 2008. The Ecology Of Arctic Lagoons In A Changing Climate: Are Terrestrial Inputs Of Organic Matter Important? [Abstract]. In 2008 Ocean Sciences Meeting, https://www.sgmeet.com/aslo/orlando2008/viewabstract2.asp?AbstractID=2566Orlando, FL: American Society of Limnology and Oceanography.

Dunton, K.H. 2008. The Boulder Patch. In: D. Sanzone, B. Streever, B. Burgess, and J. Lukin (eds.) Long-term Ecological Monitroing in BP's North Slope Oil Fields: 2007 Annual Report. BP Exploration (Alaska), Inc., Anchorage, AK. Pp. 65-69.

Dunton, K. H., C. F. Aumack, and D. W. Funk. 2007. The productivity of arctic kelp populations: linkages among climate, light attenuation, and suspended sediment loading. Alaska Marine Science Symposium, Anchorage, AK.

Dunton, K. H., D. W. Funk and K. Iken. 2005. Long-term monitoring of the kelp community in the Stefansson Sound Boulder Patch: Detection of change related to oil and gas development. Tenth Information Transfer Meeting, Minerals Management Service, Alaska OCS Region, March 14, 15, 16 2005, Anchorage, Alaska. OCS Study MMS 2005-036: 39-42

Appendix C. Monitoring Indicator Matrix for Decision Making

cANIMIDA Monitoring Indicator Matrix for Decision Making

Task Order	MMS Issue Addressed	Monitoring Hypotheses	Methods	Key Monitoring Results
6. Montoring the Boulder Patch	Will offshore oil and gas development at Northstar and/or Liberty result in increased suspended sediment load in the water column and will this in turn affect the Boulder Patch biological communities.	The resuspension of sediment into the water column by oil and gas development activities does not alter kelp biomass and productivity, benthic biodiversity, or light attenuation in the Stefansson Sound Boulder Patch.	To use synoptic and long-term measurements of PAR, light attenuation coefficients, total suspended solids (TSS; mg L^{-1}), and indices of benthic diversity and kelp biomass to determine the impact of sediment resuspension on kelp productivity and ecosystem status in the Stefansson Sound Boulder Patch.	Annual datasets on the water column sediment levels (TSS), PAR, light attenuation, kelp biomass, benthic diversity (species lists) for the Stefansson Sound Boulder Patch.