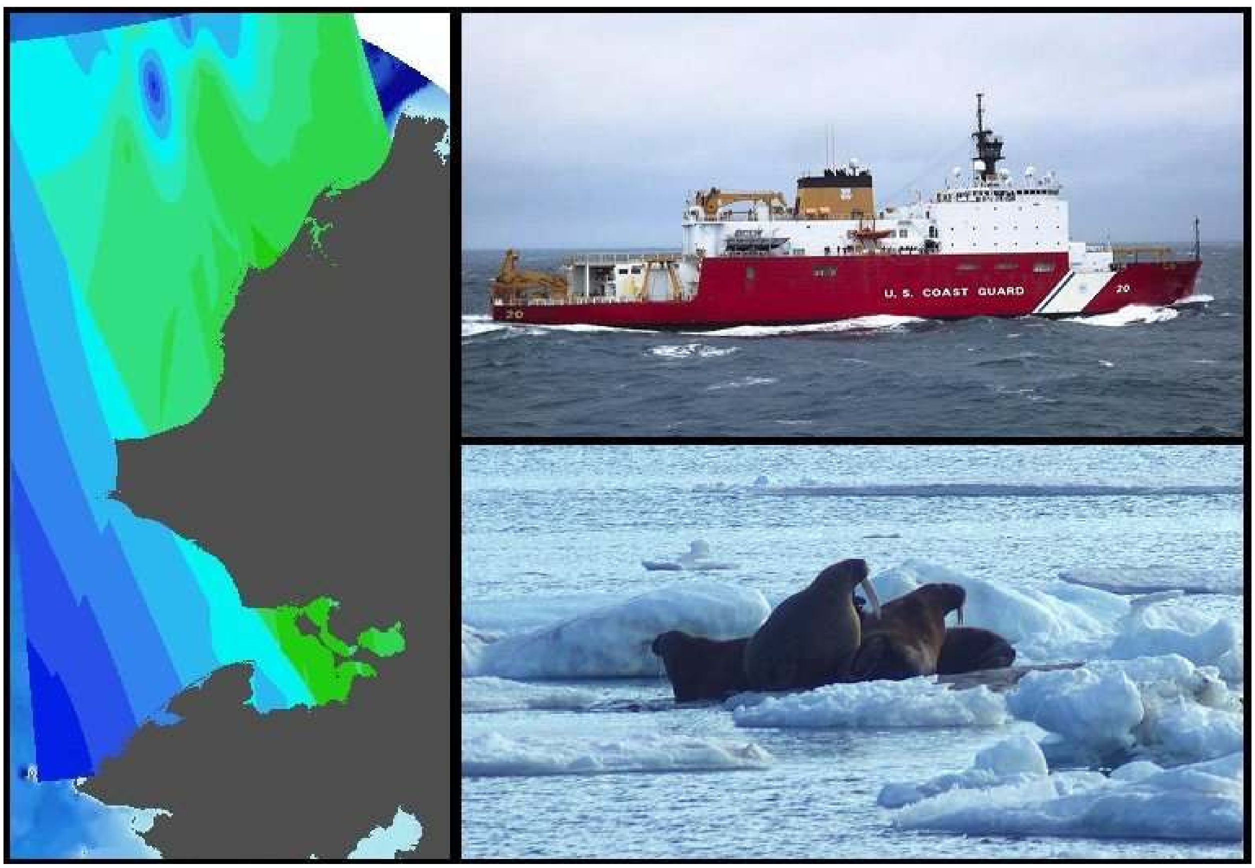
Sediment and Water Column Chlorophyll Levels and Salinity in the Chukchi Sea

COMIDA-Hanna Shoal Ecosystem Study



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GIS in Water Resources
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Introduction

The Chukchi Sea is a bordering sea of the Arctic Ocean located just north of the Bering Strait off the northwest coast of Alaska. The Chukchi and other Arctic-adjacent seas have hosted relatively few ecosystem studies compared to the world's more temperate oceans due to the remote location, inhospitable conditions and the difficulty of navigation in ice-covered seas (Grebmeier et al. 1995), and there is still much we do not know about the ecosystem dynamics of the Arctic Ocean and its associated seas.

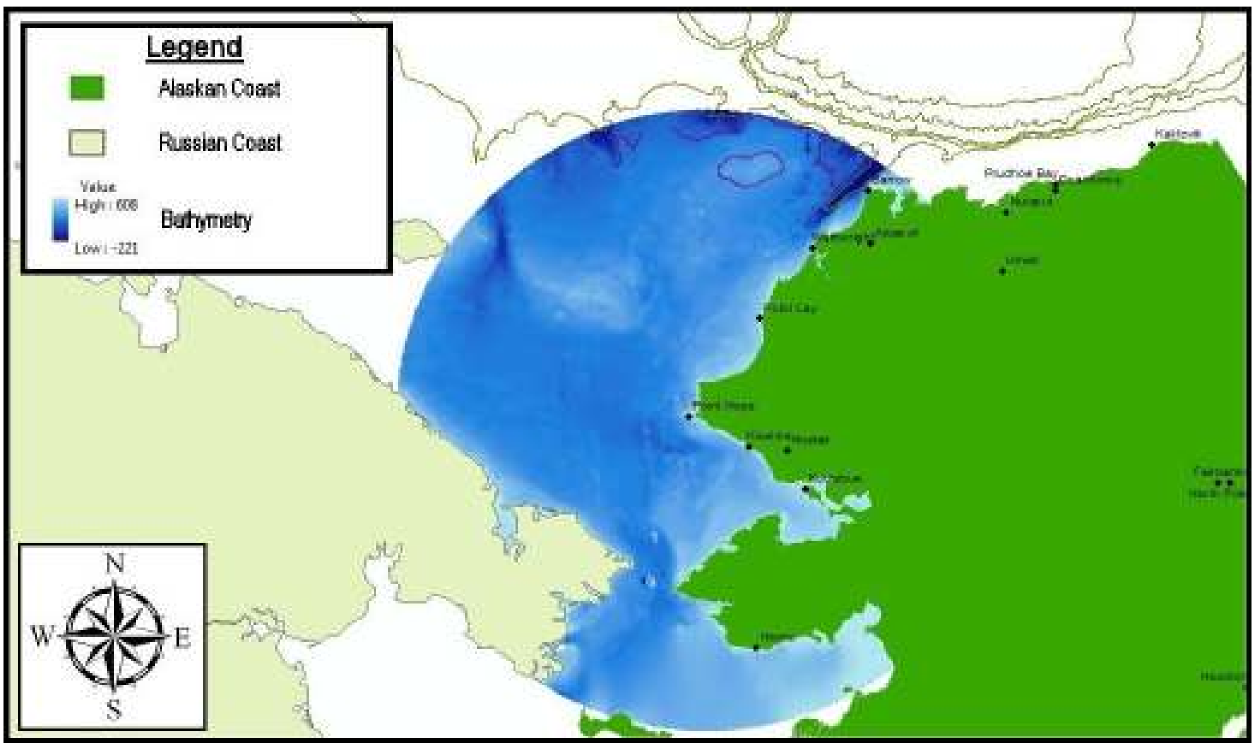

Figure 1. The Chukchi Sea with regional bathymetry.

This shallow continental shelf sea experiences high levels of primary productivity during the annual melting of the sea ice and the brief open-water period that follows, and sea ice production, extent and duration is a major influence on primary production in the region (Grebmeier et al. 2006). Primary production plays a crucial role in shaping the benthic systems of continental shelves because it determines the amount of food available to the benthos (Feder et al. 1994). It has been shown that benthic production in polar regions is more tightly linked to pelagic primary production than in temperate and tropical regions (Grebmeier et al. 1995) and limited grazing in the Chukchi results in much of the carbon captured by primary productivity settling to the seafloor, where is supports a rich and diverse benthic community. Regions of high primary productivity in the shallow Chukchi tend to be characterized by short food chains, so disruptions that occur low in the food chain have the potential to disrupt the higher trophic levels quickly (Grebmeier et al. 2006). The higher trophic levels in the Chukchi include bowhead whales, seals, walrus, seabirds and polar bears, and subsistence-hunting human communities that depend on these animals for food.

The Chukchi ecosystem, with its numerous ice-dependent species and short food chain, is thought to be extremely vulnerable to environmental change, especially the effects of global climate change on sea ice coverage and water temperatures. Over the past three decades, annual sea ice coverage in the Arctic has shown a linear decline of approximately 11% per decade, with more dramatic decline in the past decade (Polyakov et al. 2012). The dramatic reduction in sea ice coverage over the past few years has opened the Arctic to exploitation and energy development, particularly in the areas of oil and natural gas exploration. A recent survey of the Arctic by the U.S. Geological Survey estimated that the region may hold up to 90 billion barrels of oil, 1669 trillion cubic feet of natural gas and 44 billion barrels of natural gas liquids, 84% of which is expected to be found offshore (USGS 2008). Shortly after the completion of this survey, the Chukchi Sea Oil and Gas Lease Sale 193 opened up the Chukchi to exploratory drilling for energy development by several companies, including Shell and ConocoPhillips.

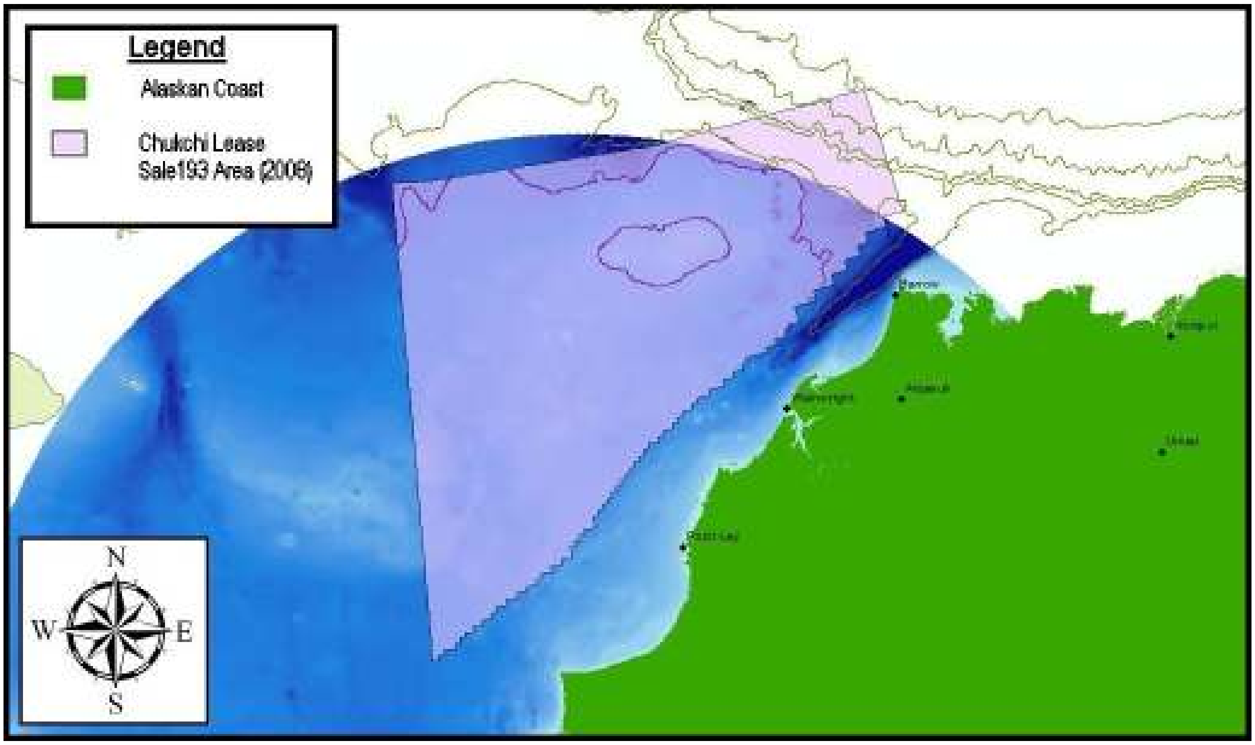

Figure 2. The Chukchi Lease Sale 193 Area.

To attempt to establish baseline ecological parameters prior to drilling, the Chukchi Offshore Monitoring in Drilling Area (COMIDA) projects were created. The goal of the first project, COMIDA - Chemistry and Benthos (COMIDA-CAB) was to establish baseline parameters for the chemistry and benthos of the region, and research expeditions for COMIDA-CAB were conducted in 2009 and 2010. In 2012 the current COMIDA-Hanna Shoal Ecosystem Study was launched. This project continues the ecological monitoring started under COMIDA-CAB and refocuses it to the highly productive Hanna Shoal ecosystem, which lies on the border between Chukchi and Arctic waters, and other biological hotspots in the drilling area. The COMIDA-Hanna Shoal study is a multidisciplinary effort involving many universities and government agencies, including the University of Texas, the University of Maryland, the University of Rhode Island, the University of Alaska Fairbanks, Old Dominion University, the Florida Institute of

Technology, Woods Hole Oceanographic Institute, the U.S. Fish and Wildlife Service, and NOAA.

In August of 2012 the first expedition of the COMIDA-Hanna Shoal Ecosystem Study took place aboard the USCGC Healy. The ship departed from Dutch Harbor in the Aleutian Islands, traversed the Bering Sea, and crossed into the Chukchi through the Bering Strait. The purpose of the expedition was to investigate the trophic structure, sediments, anthropogenic chemicals, benthic and epibenthic fauna, primary production, zooplankton standing stocks and physical parameters of circulation, salinity, ice conditions and other aspects of the region. Samples were taken from numerous stations across the Hanna Shoals and Barrow Canyon regions. The expedition is expected to continue in 2013. In this report, preliminary data on water column chlorophyll *a* levels, sediment chlorophyll *a* levels, surface and bottom salinity, and surface and bottom chlorophyll fluorescence from the 2012 Hanna Shoal cruise was analyzed and projected using ArcGIS.

Study Area

The study area was located in the Chukchi Sea off the northwest coast of Alaska. Hanna Shoal, a shallow 30-mile stretch of shelf off the Alaskan coast, and Barrow Canyon, a submarine canyon located offshore of Point Barrow, were the main areas of interest for this expedition. Thirty-two stations were included in the datasets for this study, including one in the Bering Strait. The rest of the stations were clustered in transects in the vicinity of Hanna Shoal and Barrow Canyon. Some of the stations were also stations included in the 2009-2010 COMIDA-CAB project, while others are new to the COMIDA projects. The stations for COMIDA-CAB were chosen using the EPA EMAP protocol for a general randomized tessellation stratified design (GRTS) in combination with a spatially oriented, nearshore-to-offshore, south to north grid overlying the

GRTS design. In contrast, many of the Hanna Shoal sites were set along orthogonal transects in the vicinity of Hanna Shoal and Barrow Canyon.

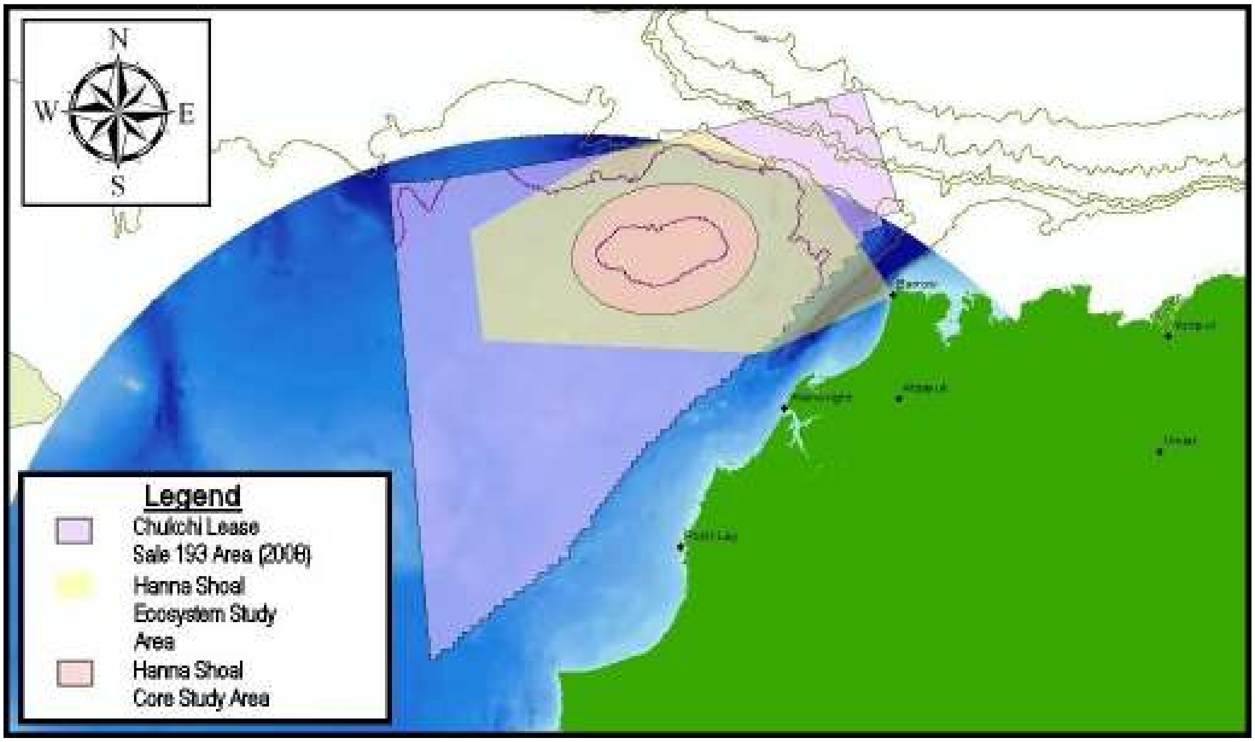

Figure 3. The Chukchi Lease Sale 193 Area, Hanna Shoal Ecosystem Study general area, and main area of interest.

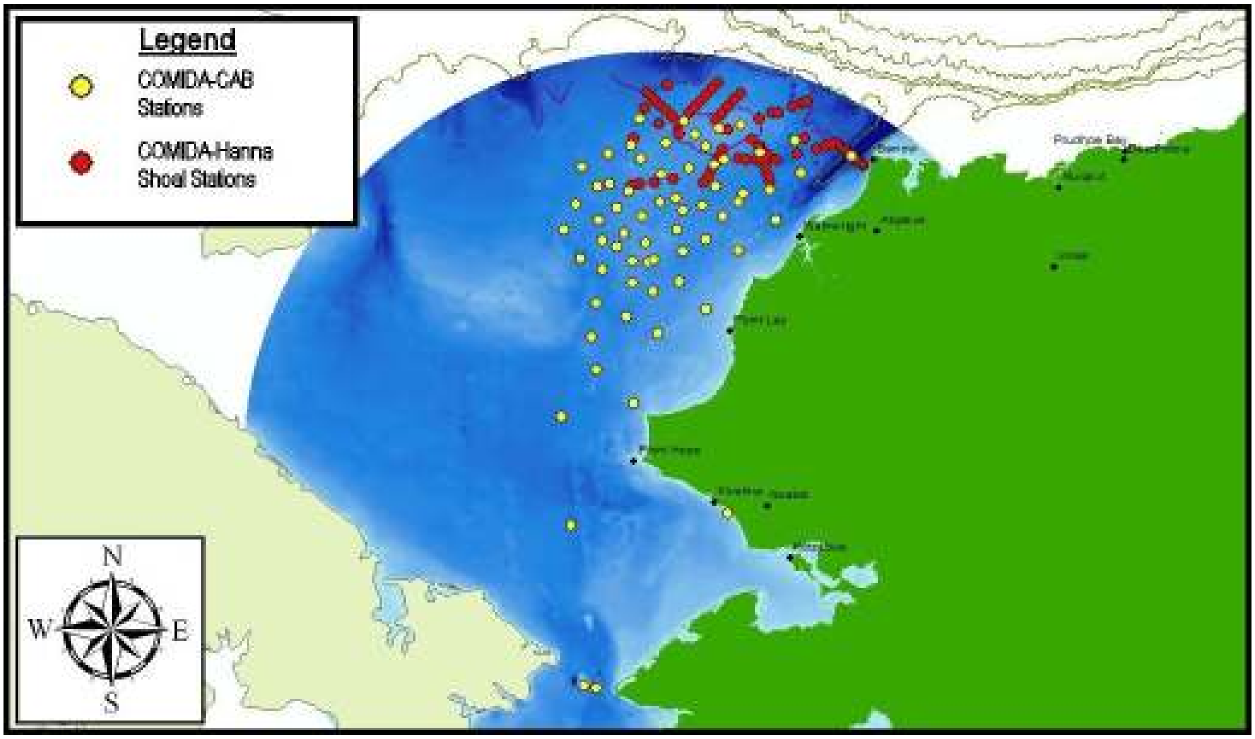

Figure 4. COMIDA-CAB and COMIDA-Hanna Shoal sampling stations.

Methods

Each site was surveyed between August 14 and August 24 by scientists aboard the USCGC Healy. Water sampling was typically done first at each station using CTD sampling, followed by a survey of the bottom conditions using a benthic camera. Next, plankton sampling with phytoplankton, Bongo and ring nets took place, and then benthic and sediment sampling. Benthic and sediment sampling was done using single and double van Veen grabs, HAPS single and multi-corers, box corers and gravity corers. Finally, a beam trawl was deployed to sample the benthic and epibenthic marine life. Mooring and drifting monitors were also deployed at a number of stations to survey the circulation and water mass properties of the region. All the samples for this project came from the CTD water sampling except the sediment chlorophyll *a* levels, which were taken using the double van Veen grab. The CTD deployed bottles to collect water samples from various depths at each station, and these depths varied from station to station.

For each station surface salinity and chlorophyll fluorescence data was chosen using 5m as the standard depth, while the bottom salinity and chlorophyll fluorescence data was chosen using the deepest measurement available for each site. Therefore, while the surface depth is fairly standardized for all datasets, bottom depth varies from site to site, ranging from approximately 25 meters to over 100 meters in depth.

The data was analyzed using ArcMap 10.1 and projected using the Lambert Azimuthal Equal-Area Polar Projection and the WGS 1984 geographic coordinate system. The Lambert Azimuthal Equal-Area Polar Projection was chosen in order to minimize the distortion caused by the high latitude of the study area. After the stations were plotted, the data was displayed using various techniques. Water column and sediment chlorophyll *a* levels were compared using pie chart symbols, and then individually projected as surface rasters using Kriging interpolation. Surface and bottom salinity and chlorophyll fluorescence were also converted into surface rasters using Kriging interpolation, which was useful for displaying spatial variation in the study area.

Results

The surface salinity raster revealed a trend of decreasing salinity with increasing latitude, while the bottom salinity raster did not appear to display any noticeable trends. Integrated water column chlorophyll *a* was greater than sediment chlorophyll *a* at all stations, with Barrow Canyon having the highest levels of sediment chlorophyll *a*. Analysis of chlorophyll *a* surface rasters revealed that chlorophyll *a* levels in both the water column and the sediment appeared to correspond to distance from the Alaskan coast, with chlorophyll *a* levels rising as distance from the coast increased. Integrated chlorophyll *a* levels demonstrated a notable spike in the vicinity of the Hanna Shoal region; a less pronounced spike was also evident in the sediment chlorophyll *a* map. The fluorescence map for surface waters showed a trend of decreasing fluorescence with increasing latitude, with no spike in the Hanna Shoal region. However, the fluorescence map for bottom waters did show a spike in fluorescence in the Hanna Shoal region.

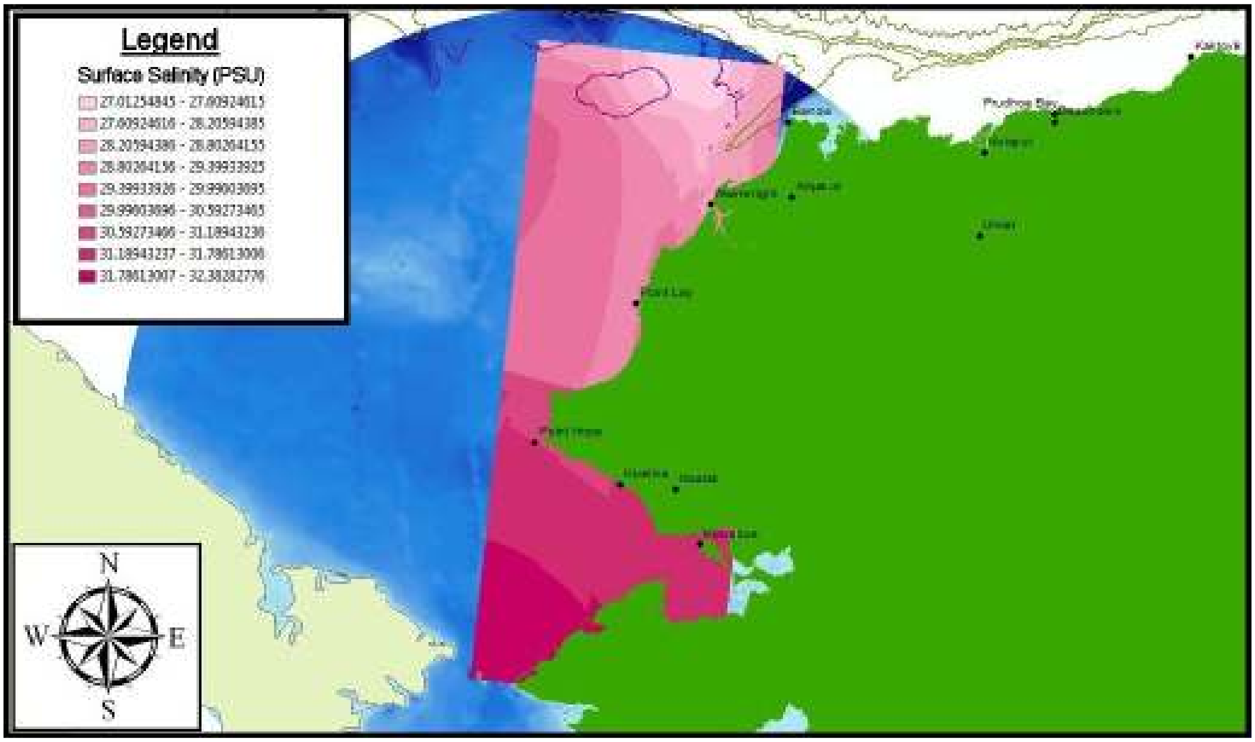

Figure 5. Surface salinity (PSU). Higher salinity areas are shown in darker red. Sampling depths listed in Table 2.

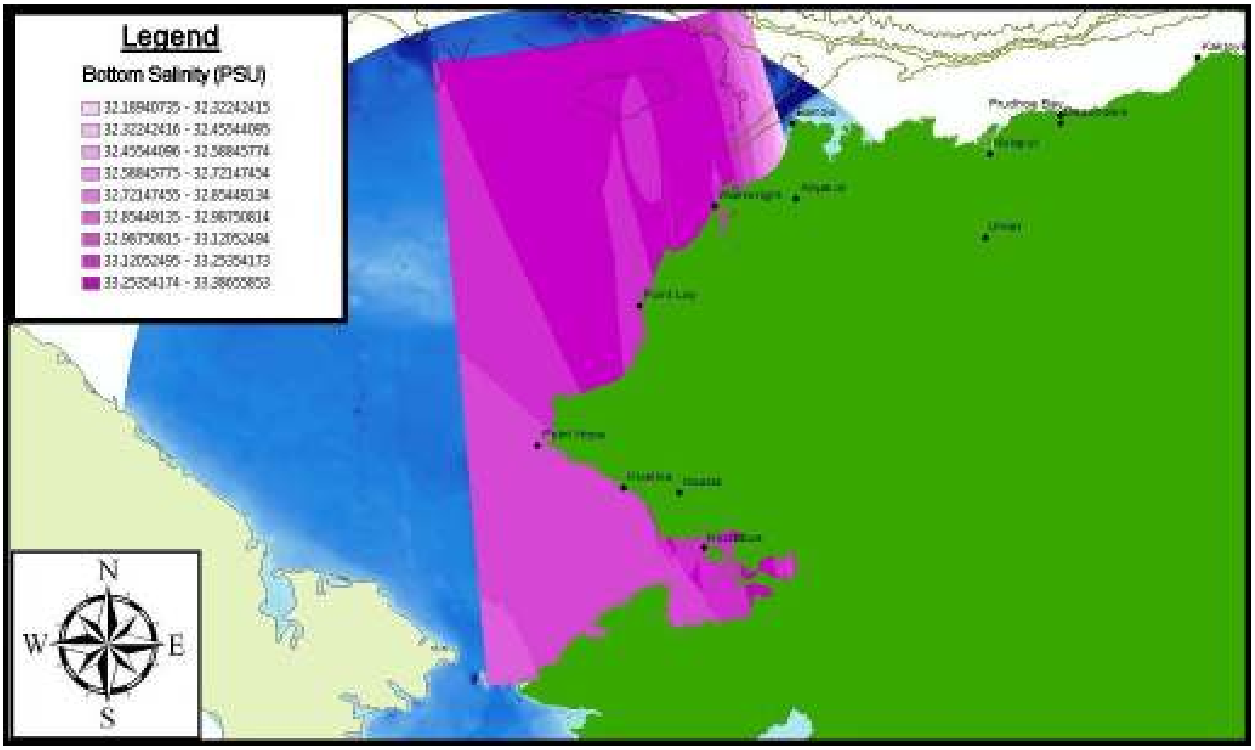

Figure 6. Bottom water salinity. Higher salinity areas are shown in darker purple. Sampling depths listed in Table 3.

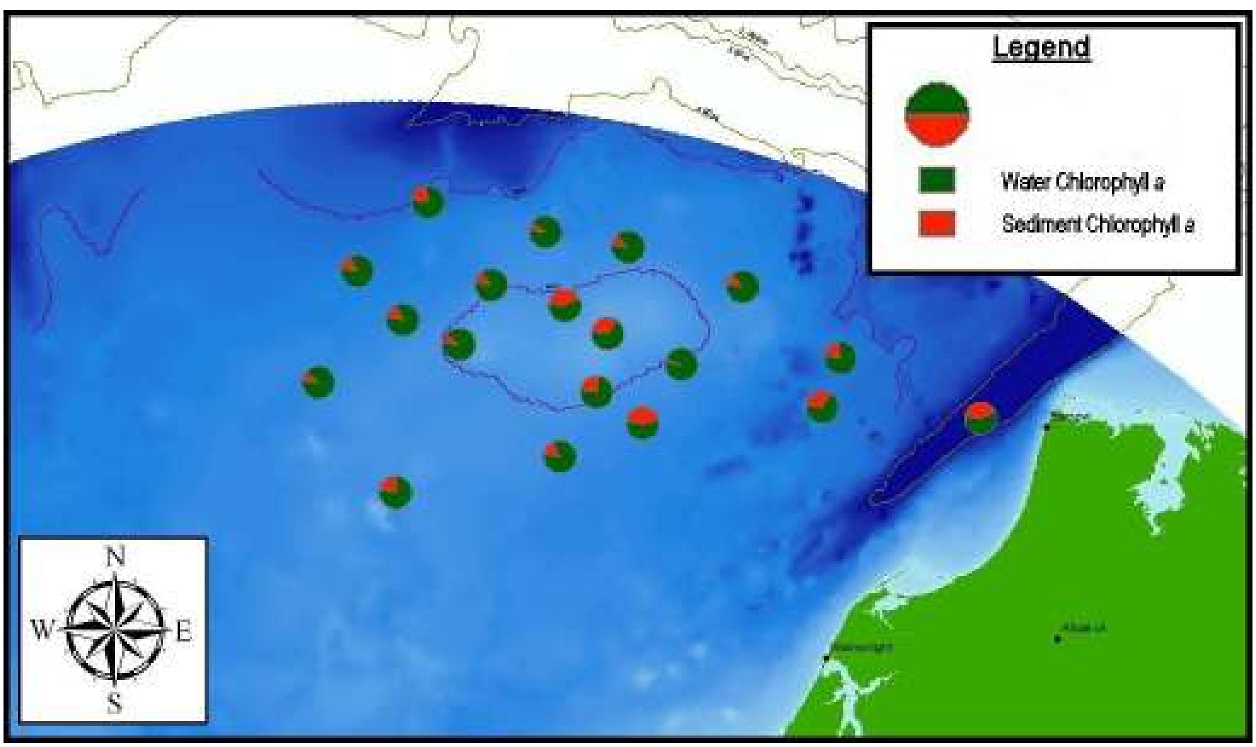

Figure 7. Comparison of integrated water column and sediment chlorophyll *a* levels.

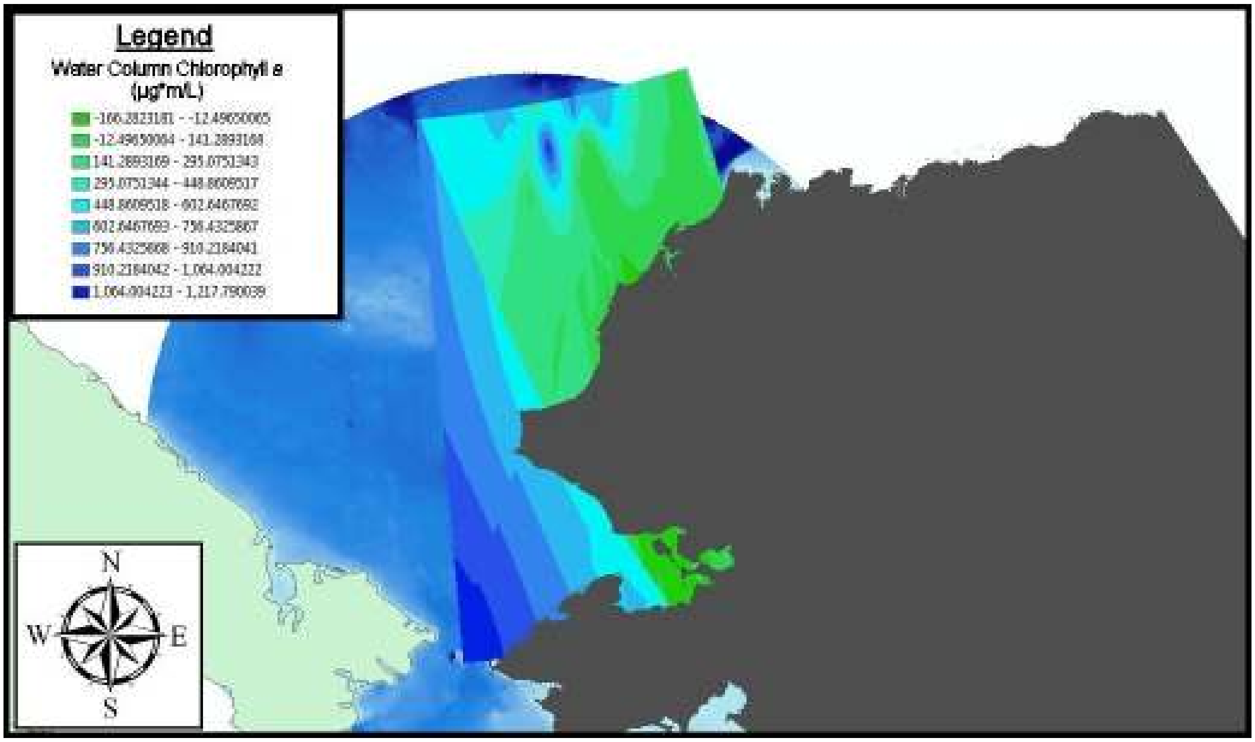

Figure 8. Integrated water column chlorophyll a levels, with spike in the Hanna Shoal region.

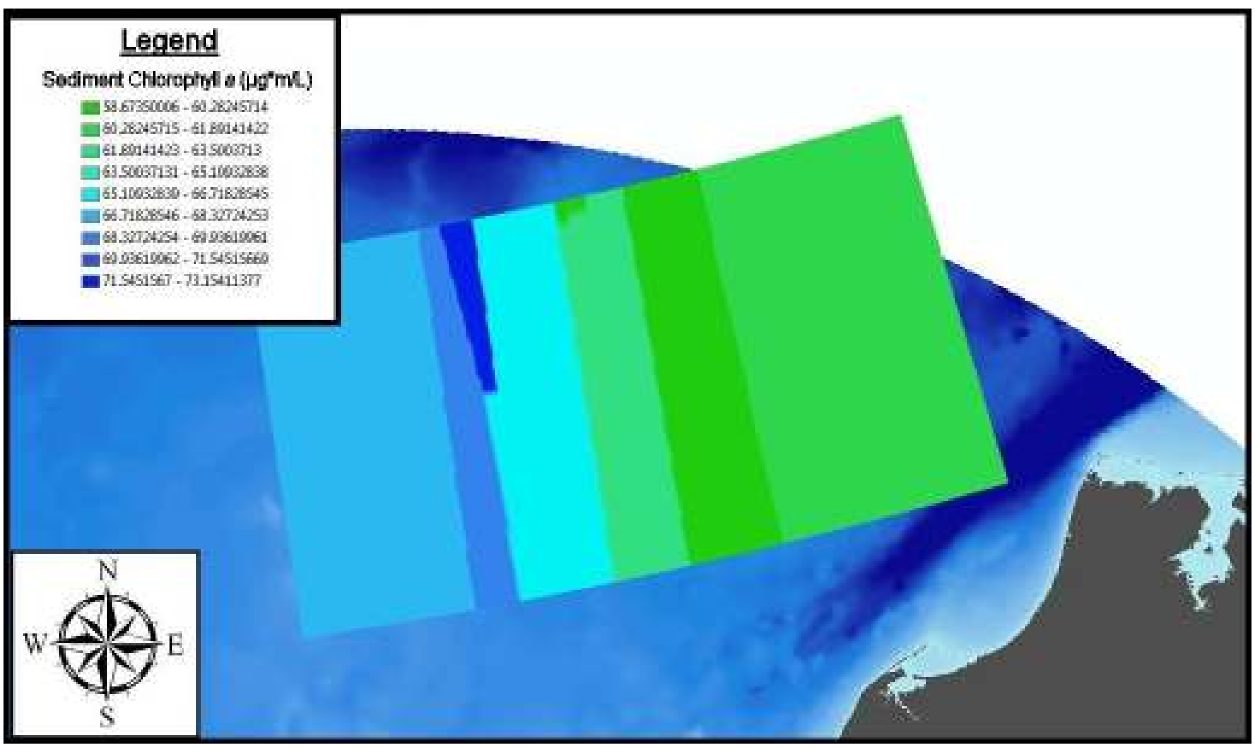

Figure 9. Sediment chlorophyll *a* levels, with slight spike in the Hanna Shoal region.

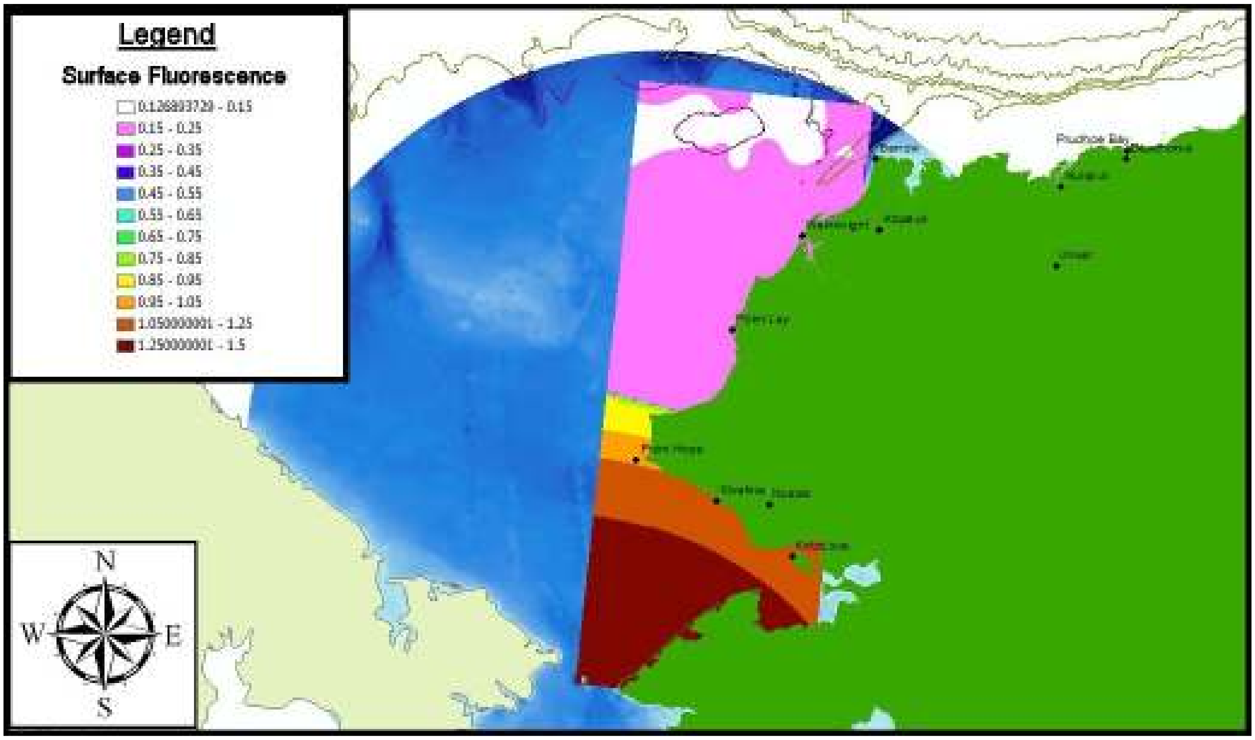

Figure 10. Surface fluorescence levels. Sampling depths listed in Table 2.

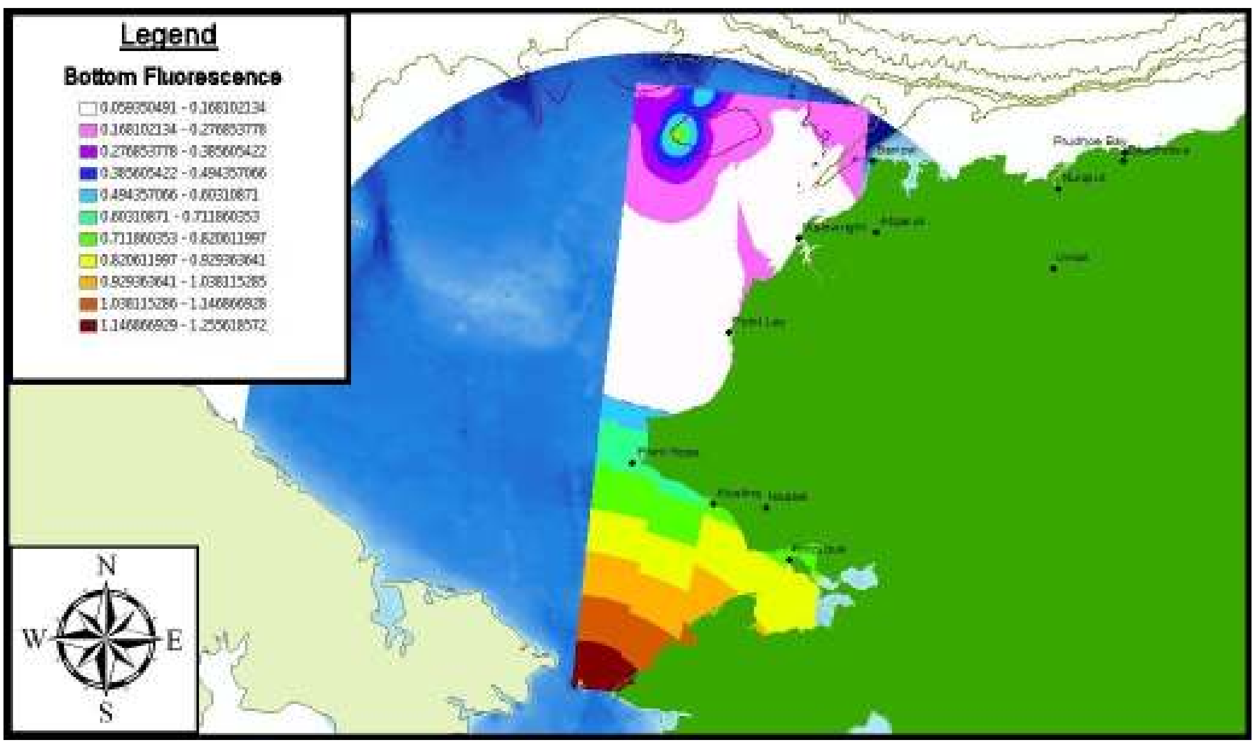

Figure 11. Bottom water fluorescence levels. Note the large spike in Hanna Shoal region. Sampling depths listed in Table 3.

Discussion

Examination of the surface raster map of surface salinity reveals a trend of decreasing salinity with increasing latitude that is absent from the map of bottom salinity. Salinity trends in the region are dominated by three main water masses: saline, nutrient rich Anadyr Water (AW) that moves along the Russian coast, and fresher, nutrient limited Alaskan Coastal Water (ACW) which moves north along the Alaskan coast in the eastern Chukchi (Weingartner et al. 2005, Grebmeier et al. 2006). Lastly, during the open water season a water mass of intermediate salinity develops between the AW and the ACW, often referred to as Bering Strait Water (BSW) (Grebmeier et al. 2006). The salinity trend that appears on the map may reflect the presence of both AW and BSW in the south, and ACW in the north and east. These trends are absent from the surface raster depicting bottom water salinity, but this may be due to the natural stratification of seawater, which layers dense high salinity water beneath lighter, fresh water. The fairly uniform depth of the continental shelf would be likely to have fairly uniform bottom salinities, with more saline waters being found in deeper areas as one moves north towards the Arctic Basin.

The maps reveal that there is a great deal of chlorophyll *a* in both the water column and the sediments at Hanna Shoal, though the sediment levels are lower overall. Pie chart comparisons of water column and sediment chlorophyll *a* levels reinforce this observation. Because it has been established that the Chukchi experiences limited grazing (Grebmeier et al. 2006), the relatively lower levels of sediment chlorophyll *a* levels suggest that sampling may have been conducted during the early stages of a bloom, before the majority of the water column chlorophyll could sink to the bottom (Nathan McTigue, personal correspondence). When the sea ice recedes each summer in the Chukchi, the area experiences a brief period of extremely high productivity (Grebmeier et al. 2006), and the large amounts of open water and fractured nature of the sea ice during the August cruise suggests that this might have been the case. In addition, despite having the same units (µg*m/L), the water column measurement of chlorophyll *a* concentration is an integrated value that incorporates all the chlorophyll present in a one meter square column of water extending from the bottom to the surface, while the sediment chlorophyll measurement only estimates the chlorophyll present in the one meter square area at the bottom of said column. Any comparison of these measurements should keep this fact in mind, because under this measurement system, sediment chlorophyll levels will naturally be lower than integrated water column chlorophyll levels. Examination of the surface chlorophyll *a* raster reveals a spike in chlorophyll *a* levels in the vicinity of Hanna Shoal, which is consistent with the region's reputation for high productivity and may help explain its rich benthic and epibenthic communities. This same increase in chlorophyll *a* levels is present, though less pronounced, in the sediment chlorophyll *a* surface raster.

Both water column and sediment chlorophyll *a* surface raster reveals a gradual increase in chlorophyll as one moves farther from the Alaskan shore. Alaskan coastal waters are typically nutrient-limited (Grebmeier et al. 2006), which may explain the decrease in coastal primary production shown on the map. The Chukchi Sea and the Arctic Ocean receive a supply of nutrient-rich Pacific waters that are advected over the continental shelves into the Chukchi Sea through the Bering Strait (Grebmeier et al. 2006), which also supports the hypothesis that the Chukchi's reduced nearshore primary production is influenced by nutrient availability.

Fluorescence is a non-integrated measurement of chlorophyll *a* levels that is similar to a snapshot of the phytoplankton levels in the water for a given depth. Surface fluorescence was found to be low in the Hanna Shoal region; however, the map depicting fluorescence for the deeper bottom waters showed a pronounced spike in fluorescence levels in the Hanna Shoal area.

This observation supports the hypothesis that sampling occurred in the early stages of a bloom, before the phytoplankton had finished settling to the bottom. It may have even been in the process of settling when sampling occurred, which would explain both the high levels of integrated water column and deep water chlorophyll *a* as well as the low levels of chlorophyll *a* in the surface waters.

The information presented here is only a small portion of the data produced by the 2012 COMIDA-Hanna Shoal Ecosystem study. However, GIS has proven to be a useful tool for visually highlighting the uniqueness of the Hanna Shoal region. In several of the maps produced, Hanna Shoal clearly stood out as a hotspot of biological activity. Once the data becomes available, it would be interesting to map species richness and other ecological parameters in the shoal and surrounding areas using GIS to see if this trend continues. With the impending energy development of the Chukchi Sea and the high potential for ecological disruption inherent in this development, the data collected during the COMIDA projects will be invaluable for establishing baseline parameters for the Chukchi Sea.

Acknowledgements

The author would like to thank Dr. Ken Dunton, Dr. Lee Cooper and Dr. David Maidment for their help in providing and analyzing data for this project; Gonzalo Espinoza, Eric Hersh, Johnny Sullivan, Fengyan Yang and Tim Whiteaker for this assistance with ArcGIS; Nathan McTigue for his help in chlorophyll analysis and sediment chlorophyll data processing; and Captain Beverly Havlik and the crew of the USCGC Healy for their research support in the Arctic.

Table 1. Water column and sediment chlorophyll *a* levels by station. Water column chlorophyll *a* data provided by Dr. Jackie Grebmeier and Dr. Lee Cooper (University of Maryland). sediment chlorophyll *a* data provided by University of Texas Marine Science Institute, Dunton Lab.

Date of Collection	Station Number	Station Name	Lat (DecDeg)	Long (DecDeg)	Water Column Chl. *a*	Sediment Chl. *a*
8/11/2012	1	BR55	65.712	-168.890	1217.79	null
8/13/2012	6	H24	71.628	-164.695	105.93	33.57
8/13/2012	7	CBL11	72.105	-165.434	579.05	64.12
8/14/2012	9	H21	72.520	-164.727	608.44	112.09
8/14/2012	10	H10	72.298	-164.253	382.83	73.75
8/15/2012	11	H30	72.741	-163.673	286.37	82.09
8/16/2012	19	H6	72.164	-163.603	1120.63	107.02
8/16/2012	20	H8	72.373	-163.067	484.52	71.06
8/17/2012	25	H4	72.537	-162.248	809.17	82.88
8/17/2012	26	H14	72.409	-161.252	715.89	91.33
8/18/2012	30	H2	72.226	-162.115	120.30	82.04
8/18/2012	31	H5	72.091	-161.742	105.60	52.15
8/18/2012	32	H3	71.873	-162.028	90.92	29.28
8/19/2012	37	H1	71.652	-162.633	114.56	23.10
8/19/2012	38	H19	71.713	-161.552	84.82	71.06
8/20/2012	45	H16	71.909	-160.926	457.45	16.01
8/20/2012	46	H20	72.152	-159.949	295.13	40.89
8/21/2012	52	H32	71.782	-158.987	116.60	29.54
8/22/2012	53	BarC1	71.245	-157.190	109.27	null
8/22/2012	54	BarC2	71.282	-157.256	52.62	null
8/22/2012	55	BarC3	71.305	-157.378	93.74	null
8/22/2012	56	BarcC4	71.366	-157.421	265.72	null
8/22/2012	57	BarC5	71.401	-157.536	79.25	55.83
8/23/2012	58	BarC6	71.450	-157.609	128.69	null
8/23/2012	59	BarC7	71.493	-157.675	140.62	null
8/23/2012	60	BarC8	71.534	-157.760	63.59	null
8/23/2012	61	BarC9	71.575	-157.839	40.44	null
8/23/2012	62	BarC10	71.613	-157.916	85.86	null
8/23/2012	66	H38	71.611	-159.360	219.16	104.99
8/23/2012	67	CBL14	71.373	-159.414	55.50	null
8/23/2012	70	H37	71.547	-160.671	null	80.82

Table 2. Surface salinity and chlorophyll fluorescence by station.

StationNum	StationName	LatDecDeg	LongDecDeg	DepthM	Salinity	Fluorescence
1	BR55	65.712	-168.890	5.271	32.5173	1.7705
6	H24	71.628	-164.695	4.678	29.9993	0.1837
7	CBL11	72.105	-165.434	4.965	30.1809	0.1268
9	H21	72.520	-164.727	4.978	29.112	0.1487
10	H10	72.298	-164.253	5.11	29.4571	0.1412
11	H30	72.741	-163.673	5.035	27.9906	0.1677
19	H6	72.164	-163.603	4.638	30.1679	0.1378
20	H8	72.373	-163.067	5.094	28.7901	0.1312
25	H4	72.537	-162.248	5.535	28.8824	0.1518
26	H14	72.409	-161.252	5.338	27.6542	0.1636
30	H2	72.226	-162.115	5.142	27.9779	0.1465
31	H5	72.091	-161.742	5.016	27.6893	0.1408
32	H3	71.873	-162.028	4.567	28.8422	0.1532
37	H1	71.652	-162.633	5.089	29.6984	0.1595
38	H19	71.713	-161.552	4.943	28.1575	0.1395
45	H16	71.909	-160.926	5.638	27.5915	0.1409
46	H20	72.152	-159.949	4.785	26.7241	0.1278
52	H32	71.782	-158.987	4.494	27.0238	0.1387
53	BarC1	71.245	-157.190	4.656	28.8344	0.2788
54	BarC2	71.282	-157.256	5.477	30.0317	0.2183
55	BarC3	71.305	-157.378	5.064	30.9519	0.1518
56	BarcC4	71.366	-157.421	4.318	29.6836	0.145
57	BarC5	71.401	-157.536	5.154	28.4269	0.1636
58	BarC6	71.450	-157.609	5.144	27.9276	0.1404
59	BarC7	71.493	-157.675	4.549	27.7715	0.1388
60	BarC8	71.534	-157.760	5.081	28.1107	0.1486
61	BarC9	71.575	-157.839	5.009	28.6775	0.1619
62	BarC10	71.613	-157.916	4.651	28.8164	0.1649
66	H38	71.611	-159.360	5.578	27.5924	0.1281
67	CBL14	71.373	-159.414	4.606	27.814	0.162
70	H37	71.547	-160.671	5.26	28.7999	0.1626
71	CBL15	71.722	-160.701	4.823	28.3169	0.1764

Table 3. Bottom salinity and chlorophyll fluorescence by station.

StationNum	StationName	LatDecDeg	LongDecDeg	DepthM	Sal	Fluor
1	BR55	65.712	-168.890	44.383	32.7984	1.2568
6	H24	71.628	-164.695	35.435	33.0861	0.2408
7	CBL11	72.105	-165.434	40.081	33.5149	0.1967
9	H21	72.520	-164.727	46.746	33.4395	0.353
10	H10	72.298	-164.253	38.814	33.4577	0.3122
11	H30	72.741	-163.673	57.785	33.3065	0.1808
19	H6	72.164	-163.603	36.183	33.3689	0.8726
20	H8	72.373	-163.067	36.107	33.35	0.4836
25	H4	72.537	-162.248	39.784	33.3515	0.6217
26	H14	72.409	-161.252	38.848	33.3754	0.2543
30	H2	72.226	-162.115	29.087	33.3161	0.1957
31	H5	72.091	-161.742	25.211	33.0265	0.2556
32	H3	71.873	-162.028	36.699	33.0699	0.1918
37	H1	71.652	-162.633	39.042	33.2397	0.1957
38	H19	71.713	-161.552	41.183	33.1609	0.1705
45	H16	71.909	-160.926	34.915	33.3757	0.2046
46	H20	72.152	-159.949	38.777	33.3886	0.165
52	H32	71.782	-158.987	47.023	33.3616	0.1533
53	BarC1	71.245	-157.190	44.999	30.4031	0.198
54	BarC2	71.282	-157.256	51.423	31.3251	0.1973
55	BarC3	71.305	-157.378	74.938	32.167	0.2044
56	BarcC4	71.366	-157.421	106.898	32.7799	0.3434
57	BarC5	71.401	-157.536	114.736	33.3954	0.1963
58	BarC6	71.450	-157.609	105.286	33.4377	0.1973
59	BarC7	71.493	-157.675	87.613	33.2907	0.1896
60	BarC8	71.534	-157.760	66.344	32.8145	0.1487
61	BarC9	71.575	-157.839	59.33	32.7572	0.1439
62	BarC10	71.613	-157.916	58.092	32.8427	0.1902
66	H38	71.611	-159.360	48.091	33.3598	0.1524
67	CBL14	71.373	-159.414	47.385	33.304	0.1459
70	H37	71.547	-160.671	46.473	33.3361	0.148
71	CBL15	71.722	-160.701	42.338	33.34	0.1607

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