NORTH PACIFIC RESEARCH BOARD FINAL REPORT

Relating deep ocean habitat conditions to faunal distribution, diversity and abundance on the eastern Bering Sea slope

NPRB Project 1101 Final Report

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Abstract

Standardized bottom trawl samples from the eastern Bering Sea upper continental slope groundfish survey conducted by the Alaska Fisheries Science Center were used to examine the relationship between fish and invertebrate distributions and a suite of Benthic Oceanographic Variables (BOV). One hundred eighty-four bottom trawl hauls were successfully completed during June and July of 2012 at bottom depths ranging from 200 to 1200 m aboard the chartered commercial fishing vessel *Vesteraalen*. The survey area extended along the upper continental slope from the Aleutian Islands in the south to the Us-Russia convention line in the north. A ruggedized data logger (Seaguard-Aanderaa), light meter (Wildlife MK-9), and Seabird SBE-9 were attached to the trawl headrope for recording depth, temperature, light, salinity, pH, oxygen, and turbidity measurements from each trawl haul. Benthic oceanographic variables were coupled with the 25 most abundant fish and invertebrate species (by biomass) and examined for the patterns in faunal distribution. A piecewise regression model applied to the BOV data identified various break points corresponding to a shallow and deep environments. Break points in general occurred between 450 and 550 m. Specific break points for each variable were: light (293 m), temperature (447 m), pH (495 m), oxygen (524 m) and salinity (543 m). The shallow slope habitat was characterized as having higher variability and a linear relationship with depth while the deeper slope was a more uniform environment and nearly monotonic with depth. Further partitioning of the slope habitat into a northern (>57 °N) and southern (<57 °N) component suggested that oceanographic conditions were significantly different (means; students t-test) for temperature (shallow P = 0.0072), light (shallow, P = 0.0495 and deep P = 0.0210), salinity (deep P = 0.0396), and oxygen (deep P = 0.0003). Cluster analysis for CPUE weighted means for each oceanographic variable of the top 25 fish and invertebrate species showed a Shallow Group and Deep Group fauna separation. Correspondence analysis showed temperature and salinity were important for the Shallow Group while light, pH and oxygen unified the Deep Group. Individual species demonstrated changes in latitudinal gradients with the Shallow Group undergoing a greater change in depth with increased latitude when compared to the Deep Group. The general pattern showed the Shallow Group experienced a greater change in environment (depth, temperature, light, pH and oxygen) than the Deep Group with features such as light and oxygen as potential driving forces for latitudinal-depth distributions.

Key Words

Eastern Bering Sea, slope, oxygen, salinity, pH, temperature, habitat, bottom trawl, CPUE, groundfish

Citation

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Study Chronology

This NPRB funded project began in January of 2012. January-May was spent researching the latest oceanographic electronic data recorders to determine the best design and equipment for the purpose. The Aanderraa equipment was purchased during April-May of 2012. Data collection in conjunction with the 2012 eastern Bering Sea slope survey was completed in June and July 2012. Data processing and analysis was conducted from October 2012 to January 2013. A progress report was submitted in May of 2012. The outreach aspect of the project was conducted in January of 2013. A no-cost travel only extension was granted in December 2012 to attend the Marine Science Symposium in Anchorage to present the project results in January 2014.

Introduction

Deep ocean environments are in general stable systems that fluctuate little when compared to the upper shelf, estuarine and surface waters (Seibel and Walsh 2003). In general deep dwelling species have lower metabolic rates, late maturity and limited food resources leading to a scavenging lifestyle. They have adapted to relatively stable conditions and can be more sensitive to subtle changes in water conditions than most shallower occurring species (Seibel and Walsh 2003). Climate change and the associated CO_2 sequestration and ocean acidification, and expanding areas of decreased dissolved oxygen, will influence ocean diversity and the ecosystem and species interactions at all levels (Paulmier et al 2010, Walsh et al. 2009, Chen 2008). The effects are expected to be greater in shallower environments but effects are also predicted for the deep sea environments (Seibel and Walsh 2003). As fisheries expand into deeper environments a more detailed understanding of the synergistic effect of climate and fishing on deep sea organisms will lead to better informed management decisions (Gaichas 2008).

The eastern Bering Sea upper (EBS) continental slope contains some of the largest fish biomass in the world. The shelf slope interface is incised with a series of deepwater canyons several of which cut deeply into the shelf environment. The habitat is characterized as being homogeneous soft sand and mud with small patches of boulder fields or rock outcroppings. The EBS shelf-slope interface is a highly dynamic area where nutrient rich deep slope waters are up-welled onto the shelf, feeding primary production (Springer 1999). Light, and primary production do not penetrate into deeper waters beyond about 300 m, creating an environment that relies solely on the settlement of upper water column primary production to supply food resources to the deeper ecosystems. More than 500 fish and invertebrate species dwell along the EBS upper slope and all rely on the productivity of the shelf edge. Annual water temperatures vary little along the upper slope, buffered by deep water masses (Stabeno et al. 1999). During winter the shallow waters of the EBS shelf are covered by vast areas of ice and extremely cold water temperatures, altering the distribution of important upper trophic level species. Many shelf species find refuge in the deeper relatively “warm” waters of the upper slope and depend on this seasonal habitat to survive the harsh EBS winters (Springer 1999). Major disturbances to the upper photic zone, evident from climate change, may produce drastic and long lasting effects to deeper dwelling ecosystems due to this dependency. In addition because of the stability of the deep ocean systems, slight disturbances to conditions such as temperature, pH, dissolved oxygen and salinity may also affect recruitment, food availability, distribution, and behavior of a variety of deep water species at (Chen 2008).

The fauna of the EBS upper slope environment is dominated (by biomass) by the giant grenadier (*Albatrossia pectoralis*), Pacific ocean perch (*Sebates alutus*), arrowtooth flounder (*Atheresthes stomias*), and popeye grenadier (*Coryphaenoides cinereus*) (Hoff and Britt 2009). These four fish species constitute approximately 70% of the estimated total benthic faunal biomass. Demonstrating the relationships between faunal distributions and oceanographic conditions can provide a useful tool for ecosystem based management practices, and give insights into the influences of regime shift and climate change. This study examined a suite of Benthic Oceanographic Variables (BOV) measured with a bottom trawl and related the variables to fish distribution along the EBS slope.

Objectives

All objectives listed below were met completely or to some degree during this project.

Project objectives were:

1) obtain baseline oceanographic data from the eastern Bering Sea slope (200-1200 m) in conjunction with the AFSC groundfish bottom trawl survey in 2012
2) characterize the slope habitat using obtained oceanographic data
3) test the hypothesis that oceanographic conditions play a significant role to faunal distribution, life stages, abundance and diversity along the eastern Bering Sea slope.
4) Develop an index for ecosystem monitoring of the deep slope habitat

Objective 1 was met fully by the completion of the collection of the oceanographic data set in conjunction with the EBS slope survey and researching and choosing the most appropriate technologies for collecting BOV and methods that work using the trawl survey as a platform.

Objective 2 was met and is the focus of this final report detailing the data obtained.

Objective 3 was also the focus of this final report and this study and is detailed in this report.

Objective 4 was addressed during this study by relating oceanographic habitat variables to fish distribution and movement along the slope. The Oceanographic habitat response index of slope fishes from this study will provide useful data to fisheries models. The long term objective is further development of this index using a time series of BOV data from subsequent EBS slope bottom trawl surveys.

Methods

Survey Area and Sampling Design

Environmental data was collected in conjunction with the Eastern Bering Sea (EBS) upper continental slope groundfish survey conducted by the Alaska Fisheries Science Center during the summer of 2012. Data collection followed all protocols and methods developed for that standardized survey and brief descriptions of important methods followed are described here and expounded upon elsewhere (Hoff and Britt 2009, 2011; Stauffer 2004).

The survey area was divided into six geographic subareas running south to north along the upper continental slope (Fig. 1) to assist in the distribution of trawl effort in relation to estimated habitat area.

The subareas were based on distinct bathymetric types and underwater features: broad low slope areas, canyon areas, and steep slope inter-canyon faces. Geographic subareas were stratified by depth every 200 m from 200 to 1,200 m resulting in five depth strata for each geographic subarea (200-400 m; 400-600 m; 600-800 m; 800-1,000 m; 1,000-1,200 m). The total area of each substratum (km^2) was calculated using known bathymetry contour lines and used to determine sampling density. Two-hundred survey stations were selected using a stratified random sampling design from a pool of over 400 successful stations completed between 2000 and 2010. The F/V *Vesteraalen*, a 38-m commercial stern trawler was chartered and skippered by Captain Tim Cosgrove during the entire survey. A four-member crew aided in the operation of the vessel and in the use of the fishing gear. The research trawl net used was a Poly Nor'eastern high-opening bottom trawl equipped with mud-sweep roller gear was used to sample all stations. The trawl had a 27.2 m headrope with twenty-one 30 cm floats and a 24.3 m long-link chain fishing line attached to a 24.9 m footrope. The body of the net was constructed of 127 mm stretched-mesh polyethylene netting, with 89 mm stretched-mesh polyethylene netting in the codend, and a 32 mm stretched-mesh nylon codend liner. The mud-sweep roller gear was constructed of 203 mm solid rubber disks strung over 16 mm high-tensile chain. The net was fished with 1.83 m × 2.75 m (6 ft × 9 ft; 1,000 kg) steel V-doors rigged with four-point bridles to enhance their stability at slow towing speeds and 55 m bridles between the doors and wingtips. During fishing the height and width of the trawl were measured using a Scanmar (Scanmar, Asgardstrand, Norway) net measurement system. The GPS system recorded vessel location, tow duration, distance fished, and precise location (latitude and longitude). A tilt sensor (bottom contact sensor) attached to the footrope recorded bottom contact which was used to determine the precise beginning and end of the tow. Standard tow speed was 2.5 knots and standard tow duration was 30 minutes at all depths. Start and end trawl position was recorded for each tow and the beginning positions were used as the official location of the trawl for plotting and analysis. The mean depth (meters) during the entire tow duration while the net was in the standard fishing configuration was used as the official depth for that sampling location.

Collection of Biological Data

Catches from each trawl were sorted, weighed, and enumerated for all species of fishes and invertebrates and recorded. The catch was processed in one of two ways: either by sorting the entire catch and weighing each species in aggregate or by weighing the net codend and discarding the predominant species and the rest of the catch sorted and weighed by species. Total weight and numbers for each species were recorded onto a paper on-deck catch form. In cases where individuals could not be reasonably enumerated (i.e., corals, sponges, bryozoans, ascidians) only total weight was recorded. For large numbers of an individual species in a single haul, the total number was extrapolated from subsample weight and count of

50-200 individuals.

Collection of Benthic Oceanographic Data

All data was collected electronically and downloaded directly to onboard computers for data quality checks and to monitor equipment proper functioning. The oceanographic data logger Seaguard (Aanderaa data Instruments, Inc. Attleboro, MA, Xylem Brand, www.aadi.no) was used to collect the majority of the Benthic Oceanographic Variables (BOV) during this study (Figure 2). The system is a self contained autonomous ruggedized unit rated to 2,000 m depth and outfitted with a color LCD touch screen and windows operating system. The Seaguard was used to collect pressure (for depth, meters), temperature (°C), conductivity (for salinity, ppm), pH (U), oxygen (µmol/l), and turbidity (FTU) every 7 seconds. Table 2 details the capabilities for each of the probes used for the Seaguard data logger. Variables were depth and temperature compensated and output was used directly in converted form except for depth which was converted from pressure output based on latitude of collection. The pH meter used was manufactured by AMT Analysenmesstechnik GmbH (Joachim-Jungius-Strasse 9, Rostock, Germany) and fitted to stream analog data input into the Seaguard datalogger. Seaguard data was processed using Seaguard Studio 1.5 (Aanderaa data Instruments, Inc. Attleboro, MA, Xylem Brand, www.aadi.no) and exported to Excel. Ambient light was measured in relative units every 3 seconds and processed using Wildlife Computers software MK-9Host v 1.09.1028 (Wildlife Computers, Redmond, Washington, www.wildlifecomputers.com) (Figure 2). All instrumentation was mounted onto the forward headrope of the trawl and recorded data for the entire deployment, bottom trawl period and gear retrieval. Because of the slow response time for some instrumentation only the mean value calculated for the time the net was in fishing configuration was used for this analysis. The Aanderaa Seaguard data logger proved robust and reliable for successful BOV collection on 184 of the 195 hauls conducted during the 2012 EBS slope survey. Water column profiles and measurements approximately 7 meters above the bottom were collected from each successful haul for depth, light, salinity, temperature, oxygen, turbidity, and pH.

Data Analysis

Catch per unit effort (CPUE) was calculated for each species in each haul by dividing catch weight or number for each species by the estimated area swept of the trawl (area swept = distance fished and mean net width).

Benthic oceanographic variable means were calculated by using the beginning and ending times when the bottom trawl was in fishing configuration on the seafloor. Light levels were averaged in a similar manner except when extreme values were obtained due to high bioluminescence, then only the low values when constant for > 5 minutes were averaged. Turbidity lacked obvious relationships with depth or any other parameter, and due to its difficulty in interpretation was not used for further analysis.

Data was exported from instrumentation softwares and imported into Microsoft Office Excel

2007 (Microsoft Corporation, Redmond, Washington) for manipulation and statistical analysis. Cluster and Correspondence analysis and contour plots were produced in S-Plus 8.2 for Windows (TIBCO Software, Inc. Seattle, Washington www.spotfire.tibco.com). Piecewise model analysis, t-tests and weighted means as well as regression analysis and plotting were performed in Excel.

A piecewise linear model was applied to the BOV data to provided a statistically robust method of determining the approximate depth of a natural break between the shallow and deep habitats. Richness and evenness indices were calculated using methods of Ludwig and Reynolds (1988, Hoff 2004) for all species from each haul. Weighted means for BOV were calculated using species CPUE as a weighting factor in all cases.

Condition factor for four species (arrowtooth flounder, giant grenadier, shortraker rockfish, and Greenland turbot) was examined for the relationship between BOV and fish conditions. Methods for condition factors followed Keller et al (2010) in which mean residuals (per haul) from the non-linear least squared regression model of the weight at length data was used as a proxy for condition factor for each species. Linear relationships between condition factor and each of the 7 BOV (latitude, depth, temperature, light, salinity, pH, oxygen) were tested for significance using an ANOVA.

Multivariate analysis: Cluster analysis using Ward's Euclidean Distance and Correspondence Analysis was used to develop the group relationship between the top (by biomass) 25 species and the BOV that unify the groups. A mean temperature, light, salinity, pH and oxygen (weighted by CPUE Table 6) for each species was estimated and used for the multivariate analysis.

To examine the effect latitude has on species response to BOV for the EBS, the mean change was estimated for each of six BOV (depth, temperature, light, salinity, pH, and oxygen) for each species by latitude. The trawl data set was divided into four latitudinal regions each covering approximately 2 degrees of latitude except the southern most region which had the largest sample size (54.28 ºN -54.99 ºN, 55.00 ºN -56.95 ºN, 57.00 ºN -58.93 ºN, 59.24 ºN -60.61 ºN). A weighted mean was calculated for each BOV for each species (weighted by species CPUE) for each latitudinal region. The mean incremental change for each species and BOV with latitude from south to north was calculated to obtain a single value representing the magnitude and direction of incremental change with increasing latitude for each BOV.

Results

Habitat Conditions

One hundred and eighty four tows were successfully completed during the EBS slope survey and provided BOV and catch data available for analysis. The distribution of effort at each depth range is shown in Table 1. Due to the stratified random (stratified by area) survey design, sampling effort is not equal across all depth groups. Because of the bathymetry of the slope, the total area in each stratum decreases with depth and is reflected in fewer survey trawl hauls at deeper depths.

The general trend in the environmental data suggested the shallower environment (< ~ 550 m) was more variable than the deeper environment (> ~ 550 m) which showed moderate to no variability with depth (Figure 3 & 4). The depth breaks for each parameter from the piecewise model (Table 3) suggested a BOV shift between approximately 447-524 m for temperature, salinity, pH, and oxygen with the exception of light which separated much shallower at 293 m. Mean BOV were different between the shallow and deep environments identified from the piecewise model, with less variability in the deeper environment than shallow (Table 3). Integrated contour plots (Figure 3) of BOV demonstrated the variable nature of the shallow and mid depth eastern Bering Sea slope when compared to the deeper environment (> ~ 550 m).

Division of the EBS slope into a deep/shallow and north/south component provided insight into latitudinal and depth gradients along the slope. Mean values for each parameter between north and south EBS showed that temperature and light values were significantly different for the shallow depths (P = 0.007, P = 0.049 respectively) and light, salinity and oxygen differed for the deeper environment (P = 0.021, P = 0.039, P < 0.001 respectively; Table 4).

Fish Distribution and Environmental Variables

Approximately 136 fish species and 195 invertebrate species were identified during this survey. The summed catch weight of invertebrates accounted for approximately 6.7% of the total survey catch weight with the remaining 93.3% composed of fish weight, however invertebrates accounted for 59% of the species diversity. Examination of fish condition with 7 BOV (latitude, depth, temperature, light, salinity, pH and oxygen) showed no significant relationships for arrowtooth flounder, shortraker rockfish, or Greenland turbot. Several giant grenadier relationships were significant (P = 0.002 latitude; P = 0.086 depth; P = 0.02819 temperature) between latitude, depth and temperature with latitude showing the most significant relationship resulting in increasingly heavier fish at length with increased latitude.

Biodiversity indices of richness and evenness showed no significant relationships between any BOV for shallow (200-555 m) nor deep (> 555 m) environments. The single relationship of increasing richness with increasing oxygen for the deep environment produced a moderately strong relationship (R^2 = 0.334) although not significant (P = 0.655).

Mean BOV (weighted by CPUE, Table 6) showed that although many species occurred in a great range of depths they generally separated into relatively shallow or deep fauna with the shallow fauna having a mean weight near the shallower depth range and the deep fauna closer to the deeper depth range that they occurred. This trend followed for other parameters such as temperature, light and oxygen.

Cluster analysis (Ward's Euclidean Distance) (Figure 5) resulted in two major groups, Shallow Group (246-416 m) and a Deep Group (455-1033 m). Correspondence analysis (Figure 6) using the same data set shows the BOV temperature and salinity as influential in separating the Shallow Group while light, pH and oxygen were important to isolate the Deep Group.

Examination of the faunal response with latitude was consistent with previous analysis suggesting a shallow and deep component to the faunal distribution in the EBS. A general pattern of a greater depth change for the Shallow Group when compared to Deep Group was evident, however a clear gradient occurred in relation to mean depth of occurrence (Figure 7). Results showed most species (67%) occurred shallower in the north than in the south. Many more of the Shallow Group (80%) occurred shallower than the Deep Group (55%) with a greater depth of change for the Shallow Group compared to the Deep Group. Overall the Shallow Group (90%) fish experienced lower temperatures with increased latitude while many of the Deep Group (63.3%) experienced slightly warmer temperatures. Light and oxygen values followed the pattern of greater changes from north to south with the Shallow Group and lessened with the Deep Group. The Shallow Group experienced higher light and oxygen values with latitude while the Deep Group experienced more stable environments to slightly lower light and oxygen in the north when compare to the south. Salinity and pH showed some variability with the pattern for both groups of decreased salinity and increased pH with latitude and overall greater changes in the Shallow Group than the Deep Group.

Discussion

Recent trends in ecosystem based management strategies for the Pacific Northwest require a broader scope of parameters to fully characterize the deep ocean habitat. Studies off California and the North Sea found that oceanographic characteristics (depth, temperature, salinity, chlorophyll a, and water masses) had strong influences on species distribution, abundance, and assemblages (Juan-Jorda et al. 2009, Ehrich et al. 2009). These studies suggest that monitoring oceanographic conditions, in conjunction with survey trawls, are necessary to get a complete picture of species associations. An important goal of this study was to demonstrate the feasibility of collecting a suite of oceanographic conditions using the existing groundfish surveys as a platform. This accomplishes firstly an efficient less costly way of data collection, and most importantly it allows the direct comparison of habitat conditions and fauna associations with data collected simultaneously.

Benthic oceanographic condition data from the EBS slope showed strong gradients with depth for temperature, oxygen, salinity, pH and light with the upper slope (<~500 m) showing surface level influence and water mass stratifications dependent on depth and latitude with relatively stable conditions in deeper slope waters. This benthic data collected during this study agrees well with that of Alvarez-

Borrego (et al 1972) for the south eastern Bering Sea in which clines and minimums for oxygen, temperature and salinity were similar from water column profiles and benthic slope habitat.

Dissolved oxygen is a prominent feature in deep ocean systems which when depleted can limit tolerable habitat due to its toxic effect on routine metabolic processes, influencing nitrogen cycling and carbon sequestration (Imasato et al. 2000). Some of the world's largest oxygen minimum zones located in the eastern North Pacific create vast dead zones where few fish and invertebrates can survive (Keller et al. 2010). For deep waters it is estimated that in the North Pacific the oxygen minimum zone exists between depths from 700 to 1100 m (Imasato et al. 2000, Alvarez-Borrego et al. 1972). Hypoxic areas in the North Pacific may be transient and variable from year to year for relatively shallow shelf areas (Keller et al. 2010) but much more persistent in deeper waters (>200 m, Pane & Barry 2007) reflecting broader scale global changes than those that occur in shallow waters. The oxygen data collected for the EBS in 2012 suggests the oxygen minimum (~50 μmol/l) is reached around 500 to 600 m and is considered near or below hypoxic levels (Pane & Barry 2007, Whitney et al. 2007). These low levels are reached in relatively shallow waters along the slope due to the low mixing of deep slope waters and the consumption of oxygen in the highly productive upper layers (Whitney et al. 2007). Despite near hypoxic conditions the deeper slope possesses a unique fauna of large predatory fishes such as the giant grenadier, Greenland turbot and Kamchatka flounder. Deleterious effects to living in near hypoxic conditions are lessened by the low temperatures and the very slow metabolic processes indicative of deep water species.

The increased atmospheric CO_2 spurred by fossil fuel consumption is causing a decrease in calcium carbonate saturation and drop in ocean pH worldwide. As a result marine organisms, including many corals, sponges, and plankton species, are affected by the increased difficulty in shell and hard part calcifications and the physiological impacts on hypercapnia and acid-base regulation in deep living marine life may cause acidosis, metabolic suppression, respiratory stress and death (Seibel and Walsh 2003, Pane & Barry 2007). Alvarez-Borrego (1972) found eastern Bering Sea (EBS) waters to be under saturated in calcite and aragonite at depths greater than 200 m. In Alaskan waters important fish habitat such as deep water corals and sponges are vulnerable, and their collapse may create cascading effects in the ecosystem (Stone 2005). Surface waters are expected to have the greatest pH changes, but deep water ecosystems have increased sensitivity to pH changes which may have more long term effects on the fragile organisms that rely on a stable environment (Caldeira and Wickett 2003, Sigler et al. 2008). In this study pH varied by about 0.5 pH U for depths from 200 to 1200 m along the EBS slope. The pH minimum around 500 m, like oxygen, suggested a stable deep water environment when compared to the upper slope (<500 m). It is unclear how dropping pH levels may effect large deep water species (Caldeira and Wickett 2003) however, there is evidence of avoidance and death of some species when exposed to high levels of CO_2 in situ (Barry and Drazen 2007).

Salinity in the EBS waters is dependent on a range of factors such as ice formation and melting, continental drainage, currents, and water mass mixing (Luchin et al 1999). Salinity varied the greatest in the upper slope to about 450 m and was relatively monotonic with depth in deeper slope waters.

Light values varied greatest in the upper 300 m and was nearly monotonic with increased depth. This is expected as light is attenuated with depth and does not penetrate deeply into the slope environment. This was consistent with other variables in which there was a distinct depth break separating the upper slope habitat from the lower. Light is an important limiting factor in visual predators and species like the walleye pollock have been shown to have a behavioral response to light (Kotwicki 2009).

The EBS shows distinct water mass layers with depth in which maximum temperatures are reached around 400 m, and is overlaid by a cold intermediate water layer (Luchin et al. 1999). Temperature may be one of the strongest drivers of fish distribution (Ehrich et al. 2009, Kotwicki 2009) and may influence movement, recruitment, production and growth. Patterns from this study were similar to that found for the North Sea in which environmental habitat features describing water masses were used to determine distinct faunal assemblages within each water mass (Ehrich et al. 2009). Fish assemblages and distributions in the EBS were correlated with water masses and the analysis suggested that the fish in each assemblages responded to variability (or lack of) in the environment in similar ways. The Shallow Group showed much more movement along the slope with latitude than that of the Deep Group. This may be as a response to the decreased temperatures in the upper slope waters with increased latitude. Other features may also be the driving force for species to move shallower with increasing latitude as species tended to experience better conditions of higher oxygen, increased light, and higher pH in the north when compared to the south. The Deep Group did change depth with latitude however to a lesser degree than the Shallow Group possibly due to the greater homogeneity in the environment in deeper waters irrespective of latitude.

Recognition of distinct fish and invertebrate assemblages and how they may respond to the habitat as a unit are key to devising management strategies when faced with many unknown variables such as influences from climate change, fishing pressure, and other anthropogenic changes to the environment.

This study was a first at several levels for the eastern Bering Sea and the Alaska Fisheries Science center groundfish survey. This study demonstrated that the technology exists to collect critical oceanographic habitat data in conjunction with these types of standardized groundfish surveys. The equipment proved to be robust enough to withstand attachment to bottom trawls and equipment troubleshooting, data management, and post processing was straight forward. The routine collection of BOV such as this in conjunction with the eastern Bering Sea slope surveys scheduled for 2014, 2016, 2018 etc. will add to the growing dataset for long term monitoring of this ecosystem.

Conclusions

This study provided insight into the feasibility of oceanographic data collected during routine bottom trawl surveys conducted by the Alaska Fisheries Science Center. The electronic equipment used was robust and provided useful data with little effort. The oceanographic data collected during routine trawl operations was used to help characterize the slope environment and provide pattern of fish habitat use based on environmental conditions. The analysis suggested two major fish assemblages along the slope with each experiencing different environments and response.

Management or Policy Implications

A recent issue before the North Pacific Fisheries Management Council has been the growing concern for eastern Bering Sea undersea canyons conservation, particularly Pribilof and Zhemchug canyons. As a result of recent testimony a request from the council to a group of research scientists at the Alaska Fisheries Science Center has been made to analyze evidence of the uniqueness of these canyons. The data set of benthic ocean conditions and faunal associations collected during this NPRB funded study is an important element being used to examine questions outlined by the council. The results of this analysis will be presented before the NPFMC in June 2013 and the final analysis and decision on canyon conservation measures will have been aided through the utilization of data from this NPRB funded research project.

With consistent monitoring and development of a long term data set such as presented here from the EBS slope we will begin to understand the relationship between the complexity of environmental data and faunal response to a changing habitat. This will eventually be a useful tool as inclusion in fisheries models and ecosystem management.

Publications

There are no publications currently stemming from this research project.

Outreach

A curriculum for high school and college level students was developed using the data set collected during this NPRB project. A needs assessment survey of fifteen high school and college level teachers in Alaska and Washington states was conducted during January-February of 2013. Based on the results of the needs assessment, lessons were developed examining the relationship between eastern Bering Sea slope faunal distributions and the benthic environmental conditions they experience. Students will use Excel and Ocean Data View software to analyze and interpret the data sets and reach conclusions on how fauna respond to environmental variability. Lessons will be aligned to Alaska State Science Standards, Washington State Science Standards, and the new Common Core State Science Standards. Alaska Fisheries Science Center Education and Outreach will provide access to the lessons and data files on their webpage (http://www.afsc.noaa.gov/education/) to begin in the 2013 fall semester.

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Table 1. Distribution of successful trawls done during the 2012 eastern Bering Sea upper continental slope survey.

Target depth range (m)	Actual depth range (m)	Number of completed tows
200-400	206-390	57
400-600	411-589	51
600-800	613-781	31
800-1,000	808-961	23
1,000-1,200	1,007-1,170	22

Table 2. Details of sensitivity of four main oceanographic conditions measured by the Seaguard data logger attached to the headrope of the bottom trawl during the 2012 eastern Bering Sea upper continental slope survey.

Parameter	Resolution	Accuracy	Response time
conductivity (salinity)	0.0002 S/m	±0.0018 S/m	< 3 seconds
temperature	0.001 °C	±0.03 °C	< 2 seconds
pressure (depth)	0.0001% FSO	±0.02% FSO	
pH	0.003 pH	0.05 pH	1 second

‘

Table 3. Results of a piecewise regression model applied to 5 environmental variables collected during the 2012 eastern Bering Sea upper continental slope survey. Standard deviations in parenthesis.

Parameter	Depth of break point (m)	R^2 shallow	R^2 deep	R^2 Piecewise model	Mean shallow	Mean deep
Temperature	447	0.385	0.9102	0.6048	3.17 (0.47)	3.24 (0.33)
Light	293	0.2581	0.6473	0.7336	55.67 (17.85)	27.20 (8.31)
Salinity	543	0.7523	0.5311	0.8912	33.44 (0.33)	34.09 (0.15)
pH	495	0.6868	0.0856	0.8286	7.75 (0.12)	7.55 (0.04)
Oxygen	524	0.8256	0.5591	0.9325	200.36 (91.48)	31.25 (14.45)

Table 4. Mean values for each benthic oceanographic conditions for the shallow and deep and north (>57 N) and south (<57 N) latitude. Deep and shallow depth limits were determined by results of piecewise model for parameter. Standard deviations in parenthesis. Significantly different values in bold from students t-test comparisons.

Parameter	Shallow	Deep
temperature south	**3.31 (0.233)**	3.23 (0.326)
temperature north	**3.03 (0.614)**	3.26 (0.339)
P	0.0072	0.4105
light south	**60.93 (20.007)**	**27.16 (7.306)**
light north	**50.15 (13.400)**	**27.27 (9.510)**
P	0.0495	0.0210
salinity south	33.47 (0.329)	**34.13 (0.150)**
salinity north	33.42 (0.322)	**34.06 (0.138)**
P	0.4655	0.0396
ph south	7.75 (0.123)	7.55 (0.045)
ph north	7.76 (0.115)	7.56 (0.041)
P	0.5769	0.2348
oxygen south	198.52 (88.027)	**35.67 (15.454)**
oxygen north	202.45 (96.278)	**25.51 (10.713)**
P	0.8392	0.0003

Table 5. Top 25 species of fish and invertebrates by biomass from the 2012 eastern Bering Sea upper continental slope survey.

Common name	**Scientific name**	**Total weight (kg)**	**Cumulative % biomass**	**% Occurrence**
giant grenadier	*Albatrossia pectoralis*	114,339	47.55	71
Pacific ocean perch	*Sebastes alutus*	25,861	58.30	20
arrowtooth flounder	*Atheresthes stomias*	14,092	64.16	65
popeye grenadier	*Coryphaenoides cinereus*	11,926	69.12	50
walleye pollock	*Theragra chalcogramma*	7,726	72.33	45
Kamchatka flounder	*Atheresthes evermanni*	6,702	75.12	85
shortspine thornyhead	*Sebastolobus alascanus*	6,089	77.65	60
Aleutian skate	*Bathyraja aleutica*	4,567	79.55	78
flathead sole	*Hippoglossoides elassodon*	4,479	81.41	49
Alaska skate	*Bathyraja parmifera*	4,427	83.26	18
Greenland turbot	*Reinhardtius hippoglossoides*	3,797	84.83	70
western eelpout	*Bothrocara zestum*	3,351	86.23	33
rex sole	*Glyptocephalus zachirus*	2,663	87.34	48
sablefish	*Anoplopoma fimbria*	1,772	88.07	43
Pacific halibut	*Hippoglossus stenolepis*	1,492	88.69	34
shortraker rockfish	*Sebastes borealis*	1,176	89.18	15
whiteblotched skate	*Bathyraja maculata*	1,084	89.63	27
Triangle Tanner crab	*Chionoecetes angulatus*	982	90.04	41
Pacific cod	*Gadus macrocephalus*	871	90.40	23
commander skate	*Bathyraja lindbergi*	862	90.76	35
bigmouth sculpin	*Hemitripterus bolini*	783	91.09	28
Bering skate	*Bathyraja interrupta*	730	91.39	48
Pacific grenadier	*Coryphaenoides acrolepis*	648	91.66	20
roughtail skate	*Bathyraja trachura*	452	91.85	26
Golden king crab	*Lithodes aequispinus*	350	91.99	36

Table 6. Weighted mean (by CPUE) values for environmental parameters of the top 25 species encountered during the 2012 eastern Bering Sea upper continental slope survey. Mean values in parenthesis. Bold values indicate the separation of deep and shallow environments from the piecewise model for each variable.

Species	Depth	Temperature	Light	Salinity	pH	Oxygen
Pacific grenadier	648-1170 (1033)	**2.5-3.4 (2.82)**	**11.66-26.08 (16.78)**	**33.85-34.38 (34.20)**	**7.50-7.63 (7.55)**	**16.49-35.37 (20.30)**
Traingle tanner crab	289-1170 (927)	**2.5-3.8 (2.98)**	**11.66-46.21 (19.57)**	**33.05-34.38 (34.20)**	**7.50-7.83 (7.56)**	**16.49-270.88 (21.48)**
roughtail skate	517-1121 (933)	**2.5-3.5 (2.95)**	**14.52-36.54 (20.00)**	**33.85-34.38 (34.18)**	**7.50-7.98 (7.55)**	**17.25-43.17 (22.21)**
popeye grenadier	357-1170 876)	**2.5-3.8 (3.04)**	**11.66-41.08 (21.42)**	**33.22-34.38 (34.14)**	**7.50-7.81 (7.55)**	**16.49-191.55 (25.10)**
giant grenadier	254-1170 (709)	**2.2-3.8 (3.27)**	**11.66-65.19 (25.46)**	**33.11-34.38 (34.00)**	**7.50-7.87 (7.57)**	**16.49-315.02 (45.55)**
Commander skate	333-1170 (678)	**2.7-3.8 (3.33)**	**11.66-42.59 (25.75)**	**33.23-34.38 (33.99)**	**7.50-7.81 (7.57)**	**17.10-191.55 (41.92)**
sablefish	411-1079 (631)	**2.5-3.8 (3.38)**	**15.97-46.21 (28.05)**	**33.50-34.37 (33.97)**	**7.50-7.68 (7.56)**	**17.25-155.61 (50.82)**
western eelpout	354-1170 (600)	**2.5-3.8 (3.45)**	**11.66-46.21 (28.38)**	**33.44-34.37 (34.00)**	**7.51-7.72 (7.54)**	**17.39-193.27 (46.43)**
shortspine thornyhead	217-1170 (529)	**2.7-3.8 (3.48)**	**11.66-81.03 (32.30)**	33.05-34.37 (33.81)	**7.50-7.87 (7.60)**	**18.38-293.16 (86.89)**
Greenland turbot	217-1170 (517)	**2.0-3.8 (3.43)**	**11.66-78.01 (30.97)**	32.92-34.37 (33.80)	**7.50-7.95 (7.62)**	16.84-326.32 (86.43)
Kamchatka flounder	206-1170 (489)	**2.0-3.8 (3.47)**	**16.00-82.47 (32.11)**	32.46-34.37 (33.76)	7.50-7.95 (7.63)	19.38-332.37 (102.25)
whiteblotched skate	209-732 (455)	**2.2-3.8 (3.47)**	**19.77-82.47 (31.18)**	33.02-34.13 (33.69)	7.51-7.95 (7.65)	23.36-332.37 (119.89)
arrowtooth flounder	206-866 (392)	2.0-3.8 (3.42)	**18.03-82.47 (36.71)**	32.46-34.12 (33.56)	7.51-7.98 (7.69)	23.22-332.37 (151.17)
Aleutian skate	206-1170 (416)	2.1-3.8 (3.39)	**11.66-82.47 (38.21)**	32.46-34.38 (33.56)	7.50-7.95 (7.69)	17.25-332.37 (156.57)
Bering skate	206-1009 (356)	2.0-3.8 (3.26)	**18.03-82.47 (41.28)**	32.46-34.30 (33.44)	7.51-7.98 (7.74)	24.52-332.37 (190.66)
golden king crab	211-1079 (393)	2.2-3.8 (3.31)	**16.72-81.03 (37.27)**	33.00-34.25 (33.49)	7.51-7.95 (7.71)	24.77-319.39 (166.29)
Pacific halibut	206-589 (348)	2.0-3.8 (3.33)	**25.49-78.01 (45.69)**	32.90-34.09 (33.38)	7.51-7.98 (7.74)	34.72-326.32 (187.00)
flathead sole	206-555 (333)	2.0-3.8 (3.29)	**24.73-82.47 (44.09)**	32.46-33.91 (33.43)	7.54-7.98 (7.74)	46.75-332.37 (194.07)
rex sole	206-640 (344)	2.1-3.8 (3.42)	**23.13-82.47 (46.03)**	32.46-34.07 (33.44)	7.52-7.98 (7.72)	35.58-332.37 (186.53)
shortraker rockfish	248-662 (325)	3.0-3.8 (3.36)	**20.5-64.81 (52.83)**	33.05-34.06 (33.32)	7.53-7.84 (7.73)	41.14-272.08 (204.47)
bigmouth sculpin	209-542 (314)	2.0-3.8 (3.06)	**25.49-82.47 (46.89)**	32.92-33.91 (33.34)	7.55-7.95 (7.78)	46.75-332.37 (222.61)
Alaska skate	206-516 (298)	2.0-3.8 (2.80)	**25.49-82.47 (45.25)**	32.46-33.91 (33.29)	7.55-7.98 (7.82)	47.17-332.37 (244.45)
Pacific cod	206-432 (253)	2.0-3.7 (2.91)	25.52-82.47 (50.98)	32.46-33.58 (33.14)	7.63-7.98 (7.83)	116.42-332.37 (272.56)
walleye pollock	206-1121 (262)	2.0-3.8 (2.87)	15.18-82.47 (52.80)	32.46-34.28 (33.22)	7.50-7.98 (7.83)	16.84-332.37 (267.05)
Pacific ocean perch	206-613 (246)	2.1-3.8 (3.19)	18.03-82.47 (56.00)	32.46-34.04 (33.19)	7.53-7.98 (7.81)	43.04-332.37 (258.38)

Figure 1. Map of survey and study area in the eastern Bering Sea. Location of trawl survey is contained in the six sub-areas along the slope from 200-1200 m.

Figure 2. Electronic oceanographic data loggers used during this study. The Seabird SBE collected depth and temperature (upper left), the Seaguard oceanographic data logger used to collect depth, temperature, salinity, pH, oxygen, and turbidity (upper right) and the Wildlife MK9 light meter used to measure relative light levels.

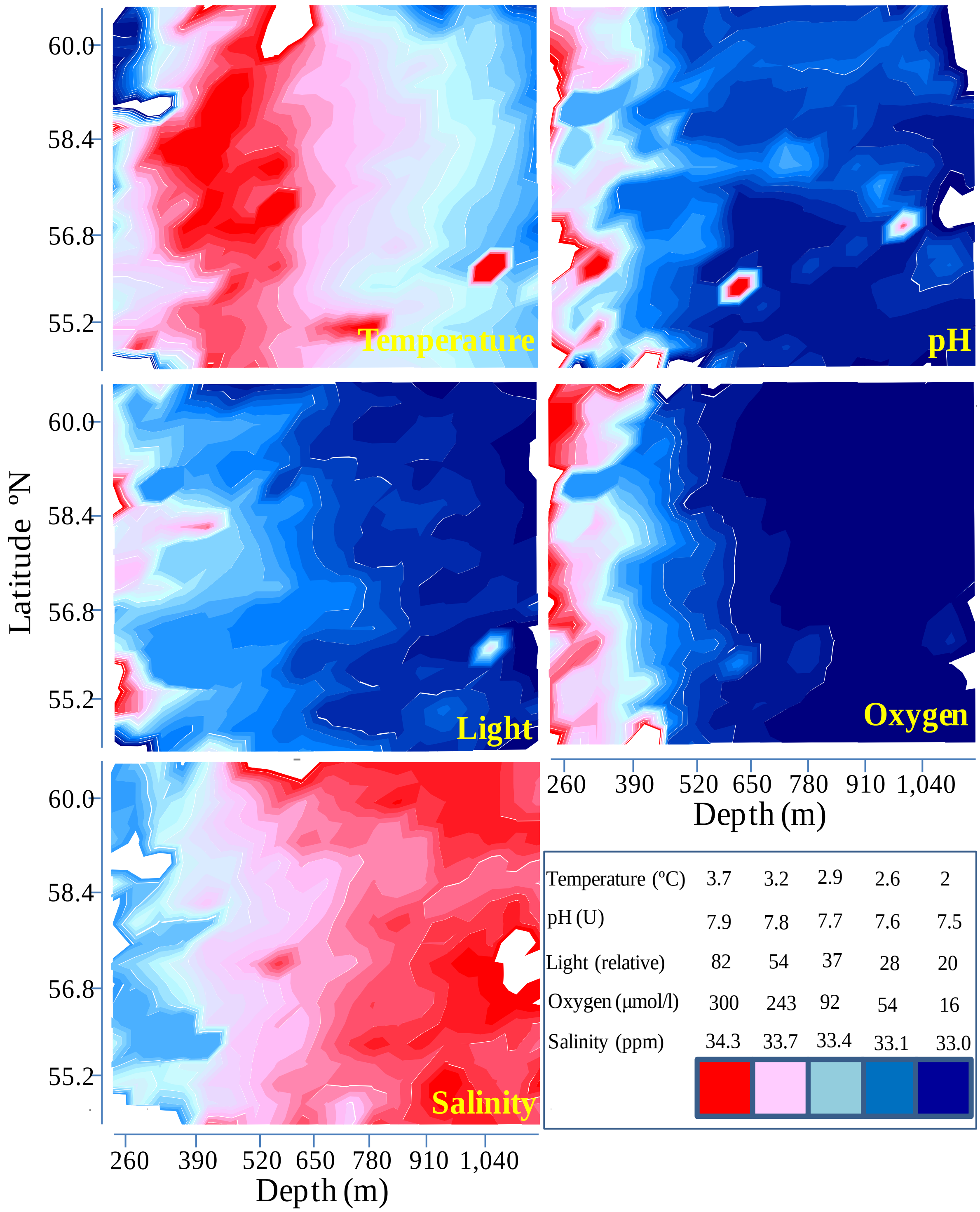

Figure 3. Contour plots of benthic oceanographic variables collected during the 2012 eastern Bering sea upper continental slope survey.

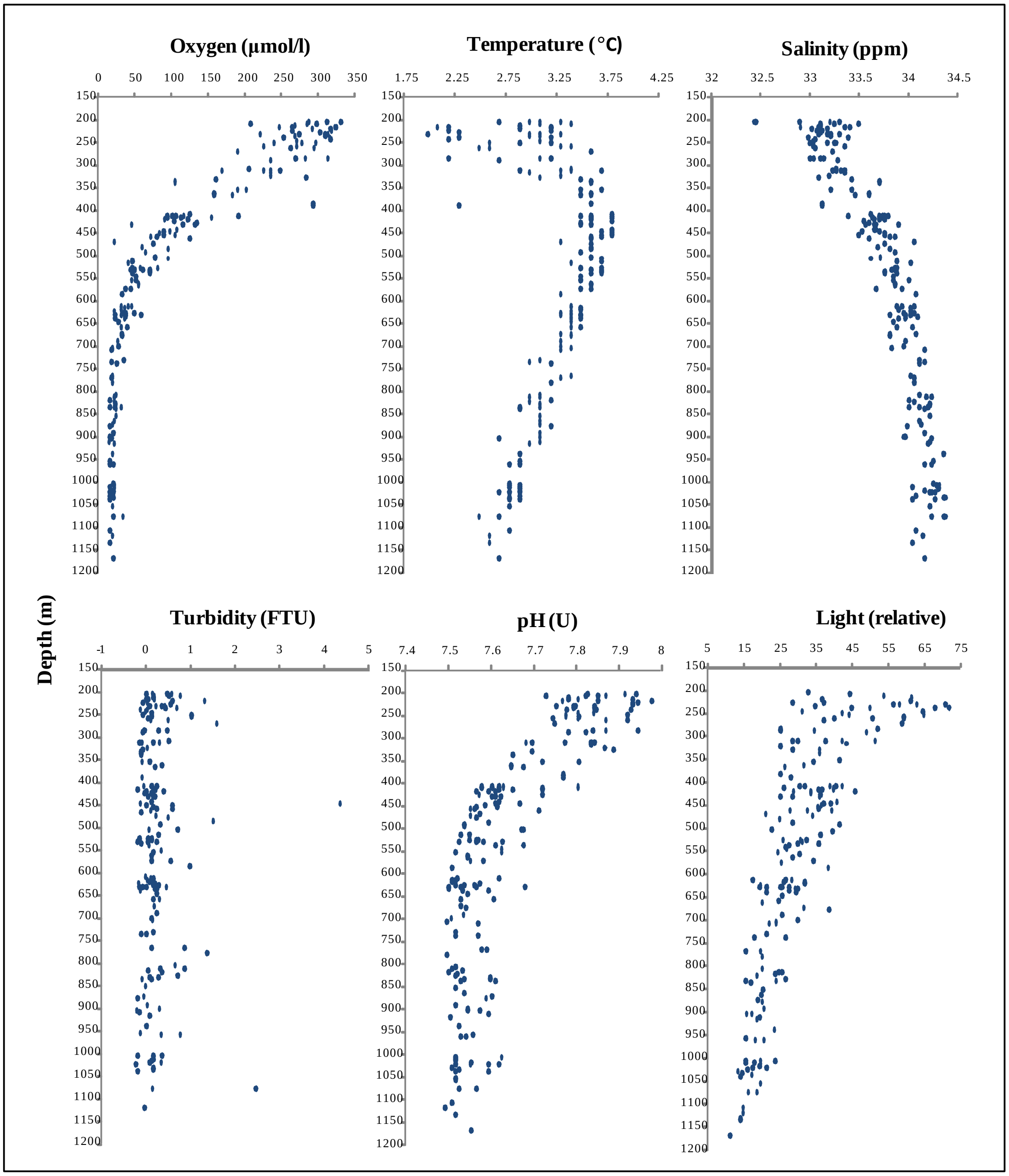

Figure 4. Mean values for each bottom trawl conducted along the eastern Bering Sea upper continental slope from 200-1200 m. Values are the mean for each 30 minute trawl and collected approximately 7 meters above bottom.

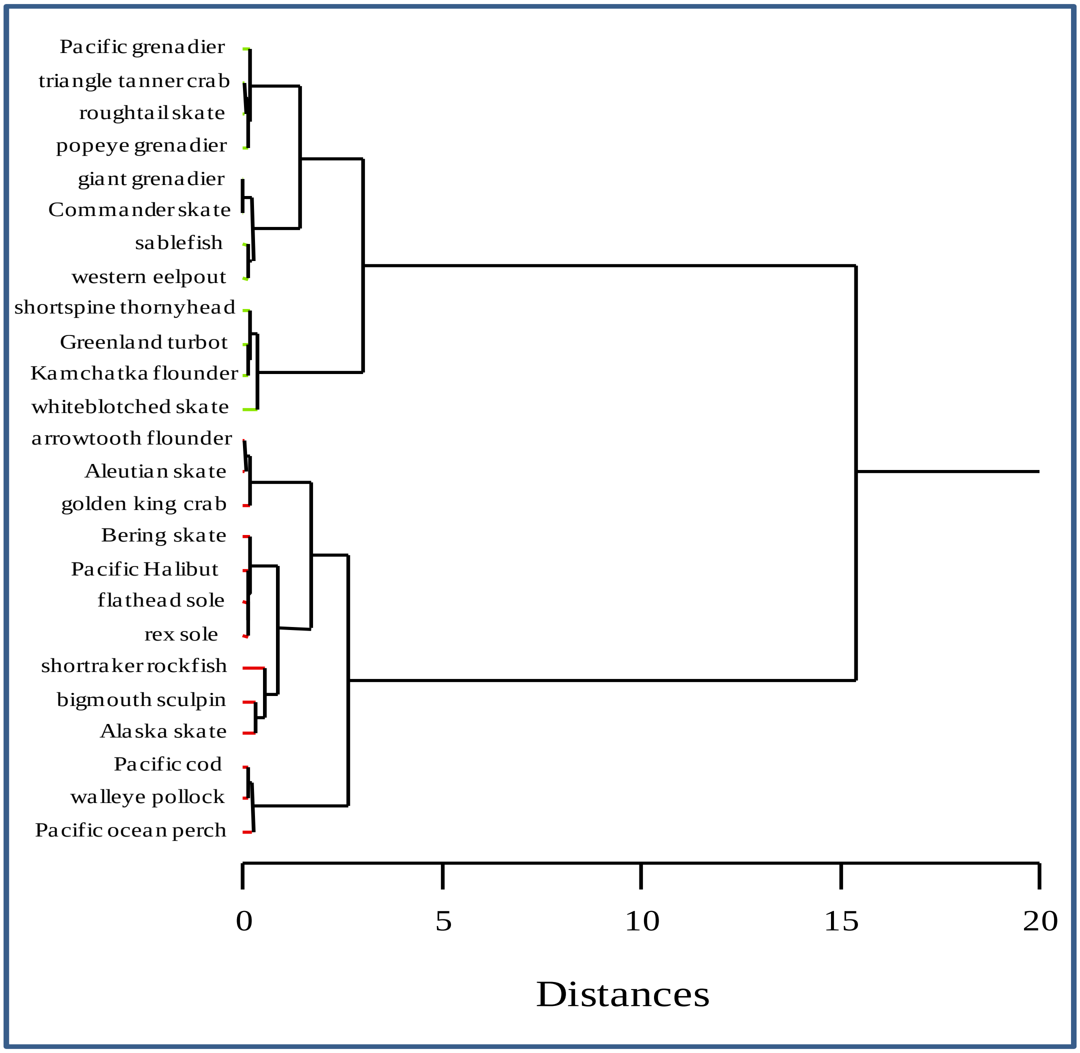

Figure 5. Cluster analysis results from mean weighted (CPUE) values of light, temperature, pH, salinity, and oxygen for 25 of the most abundant eastern Bering Sea upper continental slope species. Species clustered into a Shallow Group (bottom cluster) and Deep Group (top cluster).

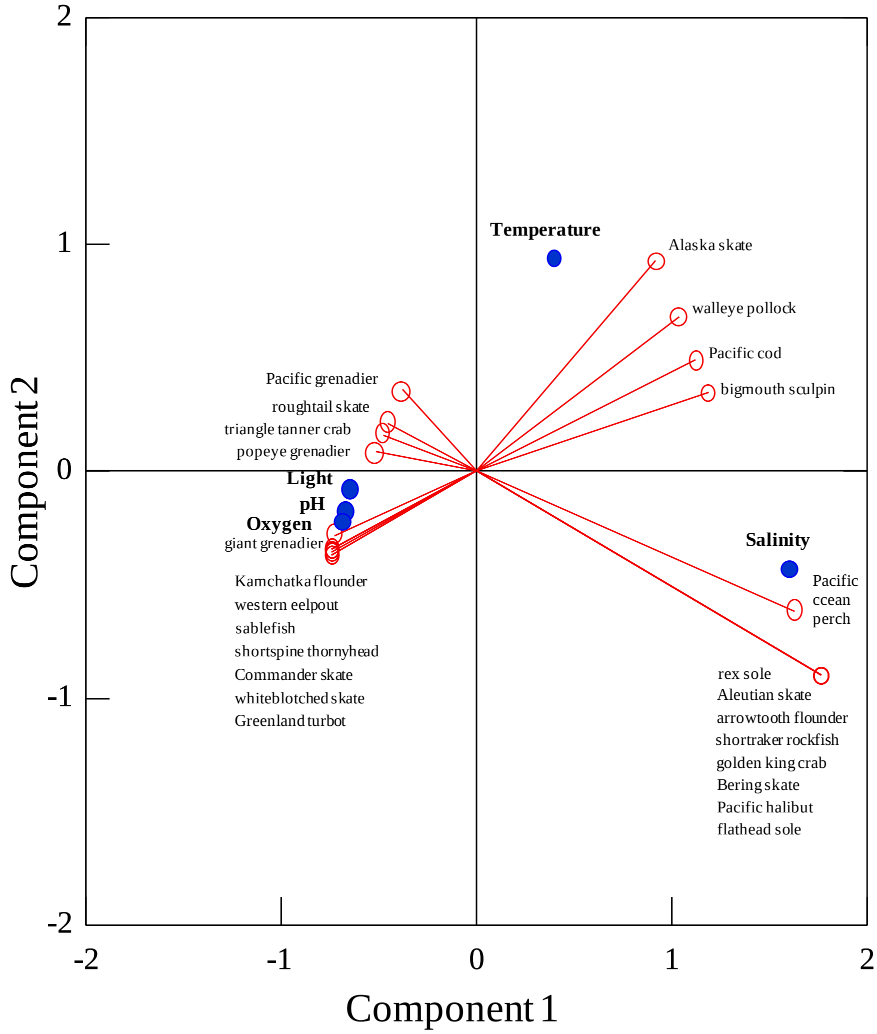

Figure 6. Correspondence analysis results from mean weighted (CPUE) values of light, temperature, pH, salinity, and oxygen for 25 of the most abundant eastern Bering Sea upper continental slope species. Environmental variables (solid blue) and fauna (red circles).

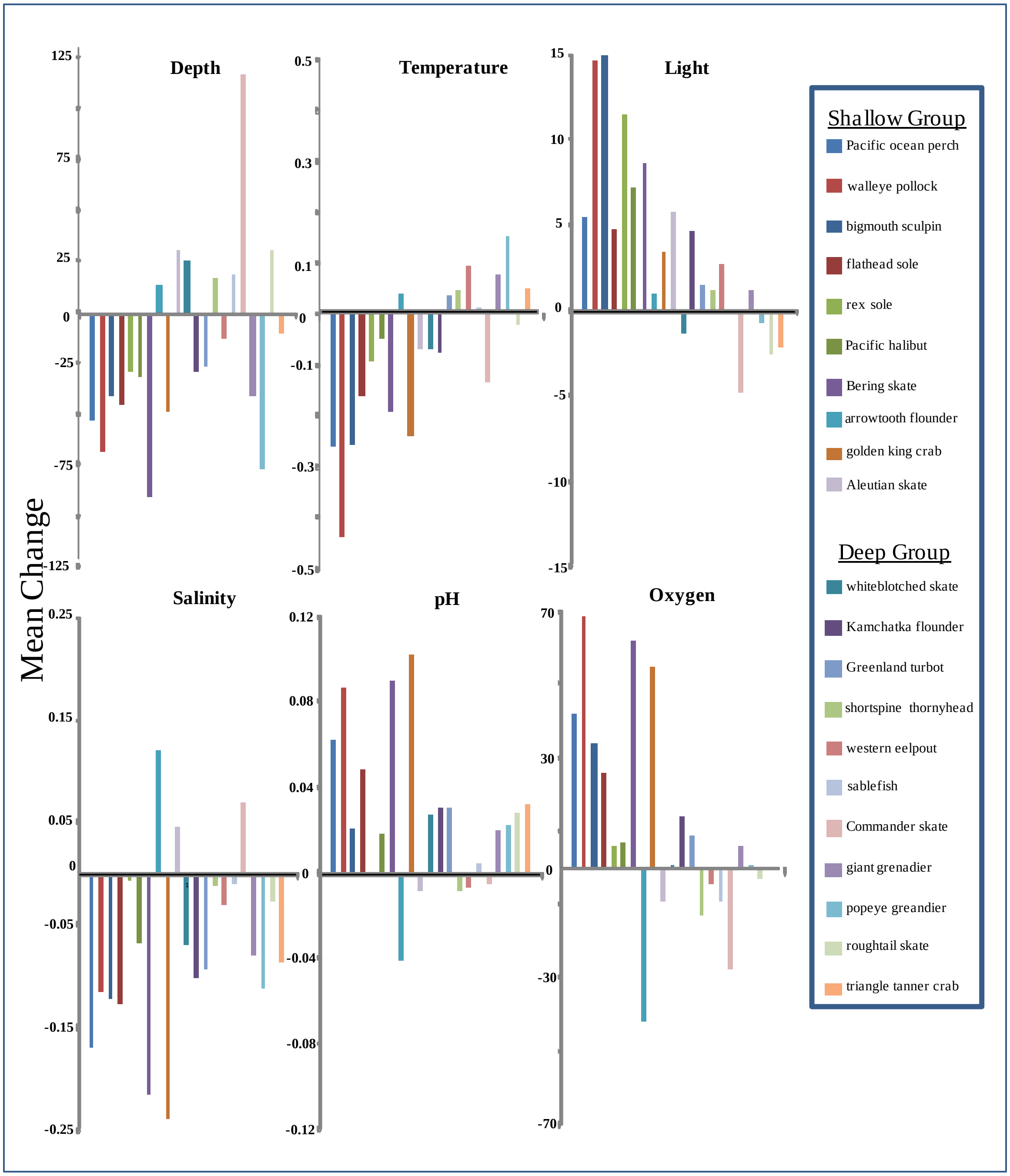

Figure 7. Relative incremental changes in benthic oceanographic variables with latitude (south to north) for 21 of the most abundant fish and invertebrates species on the eastern Bering Sea upper continental slope. Species alignment on the graph from left to right corresponds to the legend from top to bottom with the Shallow Group being the left most 10 species and the Deep Group the right 11 species.