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Visualizing Alaska Pollock (*Theragra chalcogramma*) Aggregation Dynamics

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ABSTRACT

Commercial echosounders are used to collect acoustic data from fishing vessels during normal fishing operations. In the winter of 2003 we collected approximately 32,000 km of backscatter data from three commercial fishing vessels participating in the southeastern Bering Sea Alaska pollock fishery. Although these data were not collected on a systematic grid, their broad temporal extent combined with a high spatial resolution facilitates investigations on the distribution and behavior of fished aggregations. Three-dimensional Kriging was used to produce snapshots of Alaska pollock (*Theragra chalcogramma*) distributions over the fishing season. Fleet movement and effort was tracked using vessel monitoring system data and on-board observer catch data. Integration of these data allows an unprecedented look at four-dimensional distributional changes in Alaska pollock aggregations and how aggregation behavior is reflected in the dynamics of the fishing fleet. Our snapshots reveal that Alaska pollock have a highly dynamic small-scale spatial structure, diurnally congregating to patchy, dense aggregations and nocturnally dispersing to a few uniform low-density aggregations. Changes in trawl tow duration and search patterns coincide with diel and successive changes in Alaska pollock distributions. Qualitative results suggest that rapid changes in distributions and local densities of Alaska pollock aggregations occur in areas of high fishing pressure.

Introduction

Commercial fishing vessels have long been used as sampling platforms for scientific studies. Today many national, state, and provincial agencies contract commercial fishing vessels to conduct scientific research to support fisheries management objectives. The relatively new aspect of this study is the use of commercial fishing vessels to collect acoustic data. Echosounders capable of collecting scientific quality acoustic data have recently become available to the commercial fishing industry. Acoustic data collected from commercial fishing vessels are being used in a broad range of fisheries research applications around the world (O'Driscoll and Macaulay 2005). Researchers have found that conducting acoustic surveys using commercial fishing vessels has the advantage of being inexpensive compared to research surveys that use a dedicated research vessel. Research activities have also been combined with commercial fishing operations to offset the running cost of the vessel (O'Driscoll and Macaulay 2005). Collecting acoustic data from commercial fishing vessels allows researchers to obtain data from multiple platforms during a single time period. This multiple platform approach potentially offers a more synoptic view of a population than a survey conducted on a single vessel. In an opportunistic study, where data are collected during normal fishing operations, the costs of collecting acoustic data from vessels is restricted to the price of the digital media used to record data (~$220 US for 120GB) and the staff time to install and collect media from the vessels. Although opportunistic data are not collected on a systematic grid and may not be used to obtain population abundance estimates, the broad temporal extent and high spatial resolution of the opportunistic data can facilitate investigations on the distribution and behavior of fished aggregations.

Simplification of fish distribution to two-dimensional maps does not include all factors important to fish behavior in their environment. Fish are distributed in space and time and react to endogenous, environmental, ecological, and anthropogenic cues with behavior evolved in a dynamic ocean. Two- and three-dimensional ordinary Kriging of acoustic survey data has been used to produce visualizations of phytoplankton and fish distributions (e.g. Green et al 1998; Rivoirard et al 2000; Simard et al 2003). In most cases acoustic surveys are limited to one, or at best a few snapshots of a distribution over time. In a large spatially-dynamic population, distributions estimated from single transects may be distorted and may not allow investigations into small-scale behavior of aggregations. In this paper ordinary three-dimensional Kriging was used to create sequential snapshots of fish distributions from opportunistic acoustic data. Where these snapshots overlap we can construct four-dimensional models of fish movement and distribution. The addition of spatially- and temporally-explicit commercial fishing data provides a means to explore the magnitude and duration of fishing impacts on Alaska pollock distributions.

Methods

Data Collection and Processing

In January 2002 the Alaska Fisheries Science Center (AFSC), in cooperation with the commercial fishing industry, and the Pollock Conservation Cooperative Research Committee, began the Opportunistic Acoustic Data (OAD) program to collect, process, and store acoustic data from selected factory trawlers participating in the southeastern Bering Sea Alaska pollock (*Theragra chalcogramma*) fishery. In June 2002 all vessels participating in the fishery were required to carry an operational Vessel Monitoring System (VMS). The VMS reports the vessels position to the nearest 0.001 degree every fifteen minutes via satellite. In addition, the National Marine Fisheries Service (NMFS) requires factory trawlers participating in this fishery to carry two certified fisheries observers during all fishing operations. The observers collect trawl location and time, total catch weight, catch composition, and Alaska pollock length and weight samples from every trawl haul. Otoliths for age samples are collected from selected hauls. Both the VMS and observer databases are stored on an ORACLE database managed by the AFSC.

In January through March 2003 the OAD successfully collected approximately 32,000 km of backscatter data from 38 kHz SIMRAD ES-60 echosounders on three factory trawlers. The software package Echoview (EchoView 3.1: SonarData Pty Ltd., Hobart, Tasmania, Australia) was used to integrate the uncalibrated backscatter data to uncalibrated nautical area scattering coefficient (s_A) at a 100m horizontal by 5m vertical resolution from 15 meters below the surface to 0.5m from the bottom. All backscatter was attributed to Alaska pollock. Although this assumption is a simplification, data from NMFS acoustic surveys conducted in the study area during February and March 2001 and 2002 show that ~98% of all backscatter can be attributed to Alaska pollock (Honkalehto et al. 2001; Honkalehto et al 2002). The integrated uncalibrated s_A data were then loaded to the AFSC's ORACLE database and linked to both the VMS and observer databases. VMS, observer, and OAD data were related to one another using date and time to the nearest second. For trawl haul location, the VMS data were used instead of the observer reported positions because the VMS data were recorded at higher spatial and temporal resolutions. Since the VMS data do not indicate when a vessel is fishing, the observer start and stop trawl times were used to identify fishing times. All VMS positions between the start and stop times for each trawl haul were identified as trawl locations and connected as polylines. The trawl track polylines were created using the ET GeoWizard "point to polyline" feature in ARCGIS (ET GeoWizard 9.4: ET Spatial Techniques, Faerie Glen, Pretoria, South Africa; ARCGIS 9.1: ESRI, Redlands, California, USA). Polylines were given unique identifiers allowing us to assign observer data for each individual trawl to the appropriate polyline.

We limited our visualizations to a 70 km by 40 km study area in the southeastern Bering Sea for which we have a large amount of acoustic data from two of the three vessels. The two vessels fished the area from 20 January to 29 January 2003 and again from 15 February to 27 February 2003.

Three-dimensional Ordinary Kriging and Visualization using EVS-PRO

We employed the ordinary three-dimensional Kriging module from the software package EVS-PRO to create three-dimensional semivariograms of our OAD data, fit semivariogram models, and produce visualizations of the modeled uncalibrated s_A distributions (Environmental Visualization System; Ctech Development Corporation, Huntington Beach, CA). We created two Krig uncalibrated s_A models for each day that we had data. Day and dark distributions were modeled separately. We defined day as astronomical twilight where the center of the sun was above 18° below the horizon. All sunset and sunrise data were obtained from the U.S. Naval Observatory for Dutch Harbor, Alaska at 166° 36´ West and 53° 55´ North (U.S. Naval Observatory 2005). At this latitude and season there were approximately 14 hours of astronomical twilight for each 24 hour period.

The EVS-PRO software package provides two methods to incorporate the vertical/horizontal density distribution gradients in our three-dimensional data. One method is to partition the data into depth bins and model each depth bin separately using ordinary two-dimensional Kriging. This method ignores relationships among depth bins and is analogous to the methods employed by Greene et al 1998 for visualizing plankton distributions. The second method weights the vertical and horizontal data differently such that the vertical relationship contributes less to the model fit than the horizontal relationship. In this study we attempted both methods, but will only be presenting the results of the weighting method.

The algorithm employed in the EVS-PRO ordinary three-dimensional Kriging module produces a least-squares model fit to the semivariogram and creates three-dimensional estimates of the spatial distribution of uncalibrated s_A and confidence. The confidence is the probability that a predicted density is within a factor of 10 (i.e. $\log_{10}(x)$) of the actual density based on a comparison of the standard deviation and the log density at a particular point in the domain. In our visualizations of the model output we limited the display to those points with a 80% confidence of being within 1.0 $\log_{10}(s_A)$ of the actual value.

Results

Diel Migration
Repeated passes of the two vessels over the same locations during day and night enabled us to capture diurnal changes in distribution. A change in distribution from a highly aggregated benthic distribution in the daylight hours to a less aggregated pelagic distribution during the nighttime (Fig. 1, Fig. 2, and Fig. 3) was observed in every 24-hour period. The diel change in distribution became less evident at two to three days prior to and concurrent with the full moon.

Anthropogenic Effects
Examining the acoustic data for times in which we had data prior to and after trawling allowed us to investigate possible effects on Alaska pollock aggregations caused by commercial fishing. In most cases, changes in aggregation density could not be separated from effects attributed to diel migration. In one area it is clear that there is a reduction in overall backscatter (Fig. 4) within a heavily fished area, but this effect does not appear to persist for more than 12 hours.

A total of 51,200 metric tons (MT) of Alaska pollock were removed from the area between 20 January 2003 and 26 February 2003 (Fig 5). Both the catch per unit effort and mean $\log(s_A)$ (Fig. 6) show a decline over the duration of the fishery. The snapshots provided by our modeled backscatter show a noticeable decline in density and aggregation distribution from a few large, highly dense aggregations in January to a larger number of smaller, less dense aggregations by the end of February (Fig. 7). There is a decline in the nighttime mean backscatter, but if this is difficult to discern in the visualizations since the fish appear to disperse into large diffuse aggregations at night. We can not attribute all changes in distribution observed from January to February to fishery interactions since seasonal emigration from the study area may also be a factor.

Recurring Aggregations
There are possible persistent or recurrent formations that appear throughout the season even under considerable fishing pressure. One of these formations is evident from data collected on the night of 22-23 January and again on 15-16 February (Fig. 8). The formation is nearly at the same geographic coordinates and depth for both time periods. The species composition samples collected by observers from the pelagic commercial hauls that intersected with the formation show an elevated proportion of Pacific cod (*Gadus macrocephalus*) bycatch, but this may be a result of increased Pacific Cod bycatch in the nighttime fishery (Alaska pollock observer catch data, 2003) and not related to the observed formation. The Alaska pollock length frequency samples collected by observers reveal that fish from these hauls may be slightly larger than those measured from surrounding hauls (Fig. 9).

Discussion

Advances in technology have greatly increased our ability to collect high resolution spatially and temporally referenced data sets. Unfortunately, development of techniques to interpret these complex data sets has lagged. In this paper we illustrate methods that concurrently visualize acoustic and other spatially and temporally explicit data sets in three and four dimensions. The complex data sets are rendered in a form that can be readily inspected for anomalies and possible trends. Three- and four-dimensional visualizations are used as tools for data exploration, allowing us to conceptualize fish distribution and relationships between fishing and fish aggregations. These methods also provide a means to identify persistent or recurrent aggregation formations that otherwise may not have been observed. Further statistical analysis and modeling is needed to quantify the possible relationships between fishing and fish distribution observed in this study.

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Figures

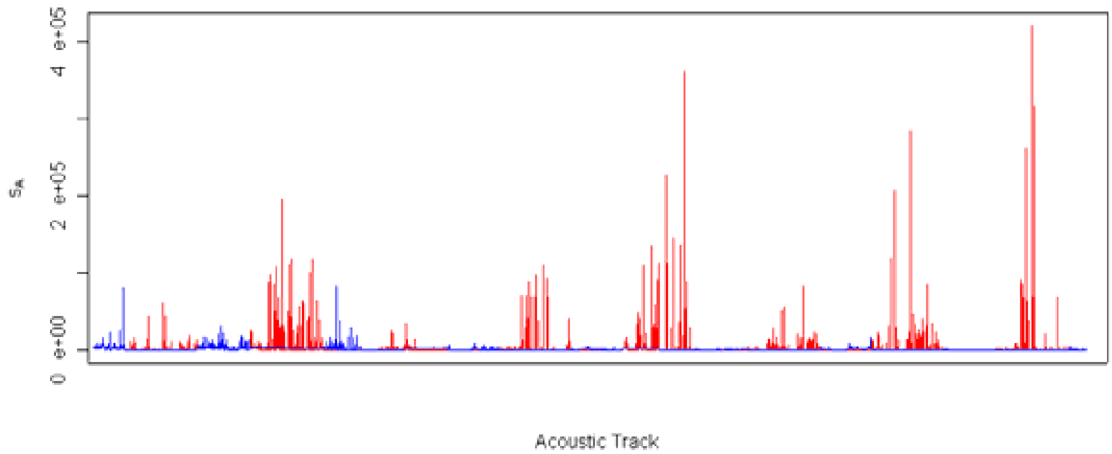

Figure 1: Whole water column uncalibrated s_A data for February 15-25, 2003 from a commercial fishing vessel showing differences in day and night distributions. Red indicates data collected during the day and blue indicates data collected at night.

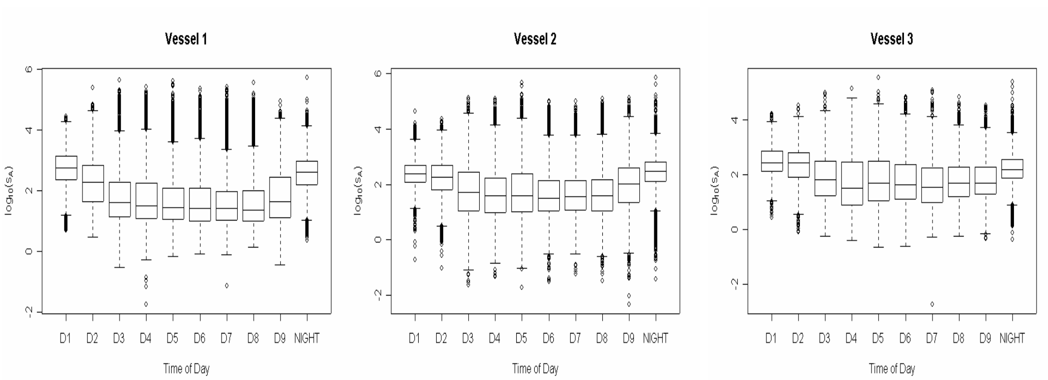

Figure 2: Whole water column uncalibrated s_A data for 20 January to 15 March 2003 from three commercial fishing vessels showing differences in backscatter at different periods of the day. Each day's astrologic twilight is divided into nine equal daylight intervals D1-D9 and NIGHT (encompassing all pre- and post-twilight hours).

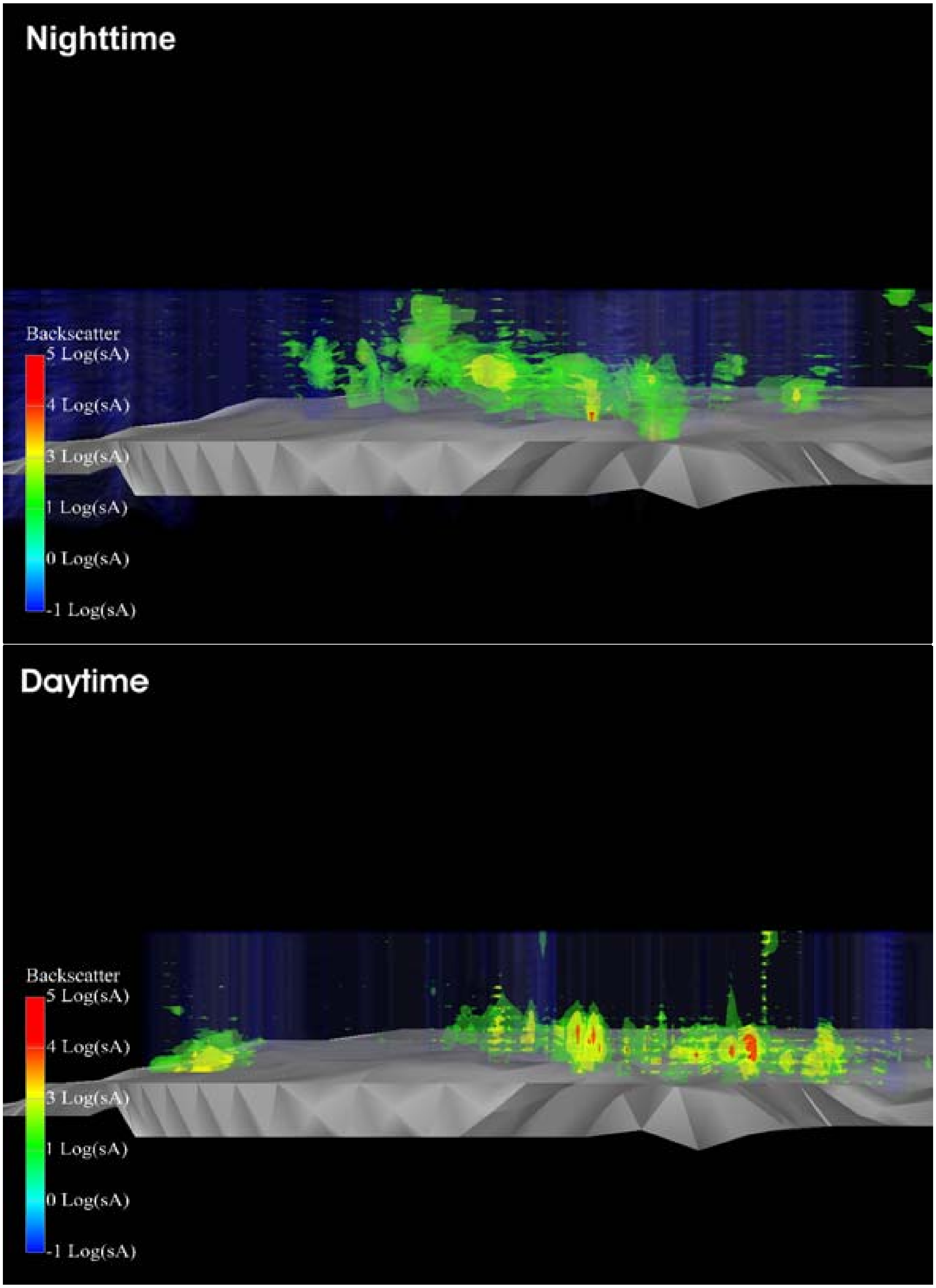

Figure 3: Diel migration observed in 4-dimensional visualization of opportunistic acoustic data top) 20-21 January nighttime distribution, bottom) 21 January daytime distribution showing change of fish distribution from more dispersed aggregations higher in the water column at night to a dense near bottom layer in the day.

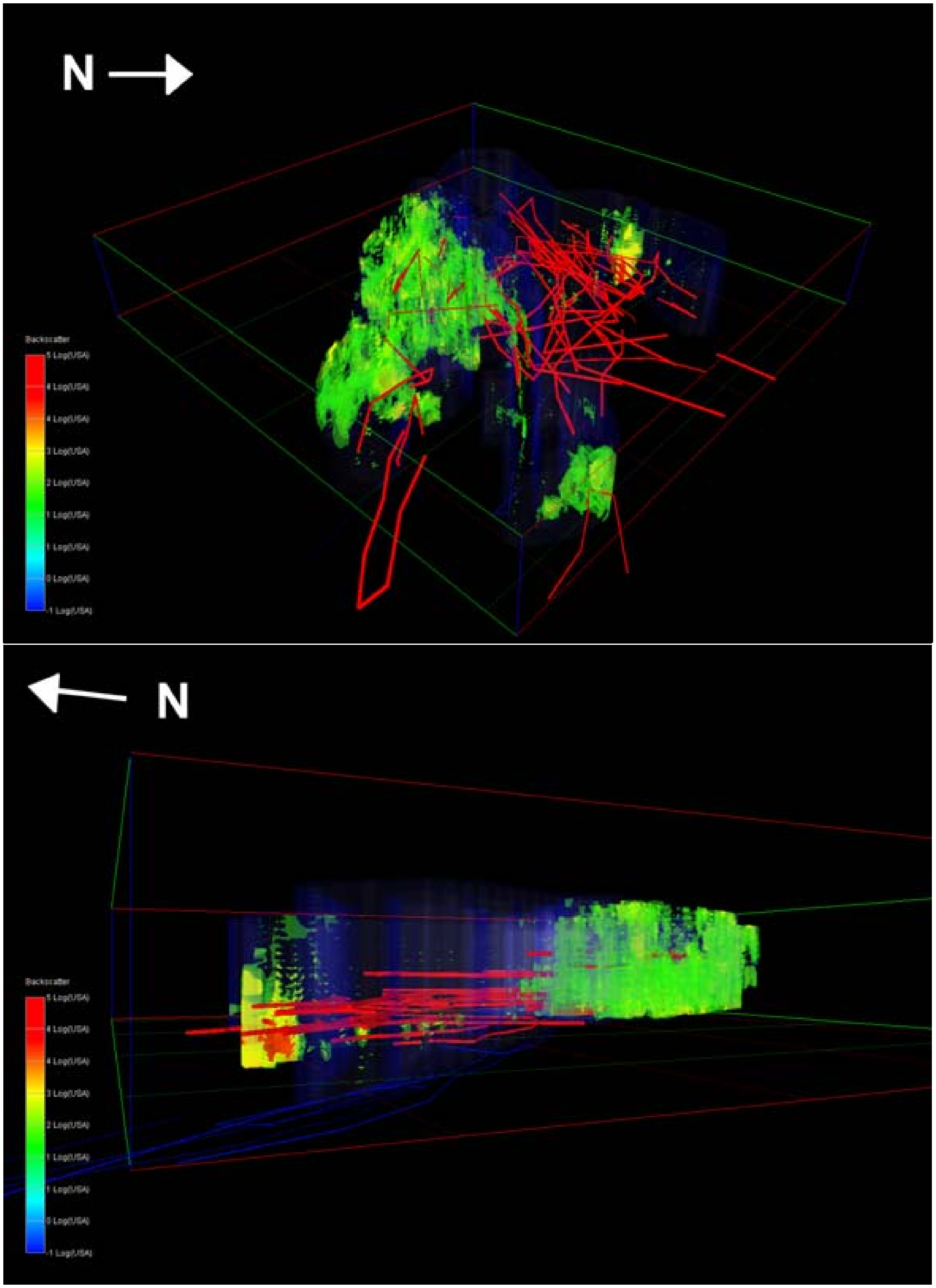

Figure 4: Fishing trawl locations in conjunction with 3d model of uncalibrated s_A for 15-17 February 2003. The tubes are trawl tracks for 16 February 2003, blue are bottom trawl tracklines, red are pelagic trawl tracklines. The two panels show different viewing angles of the same aggregation.

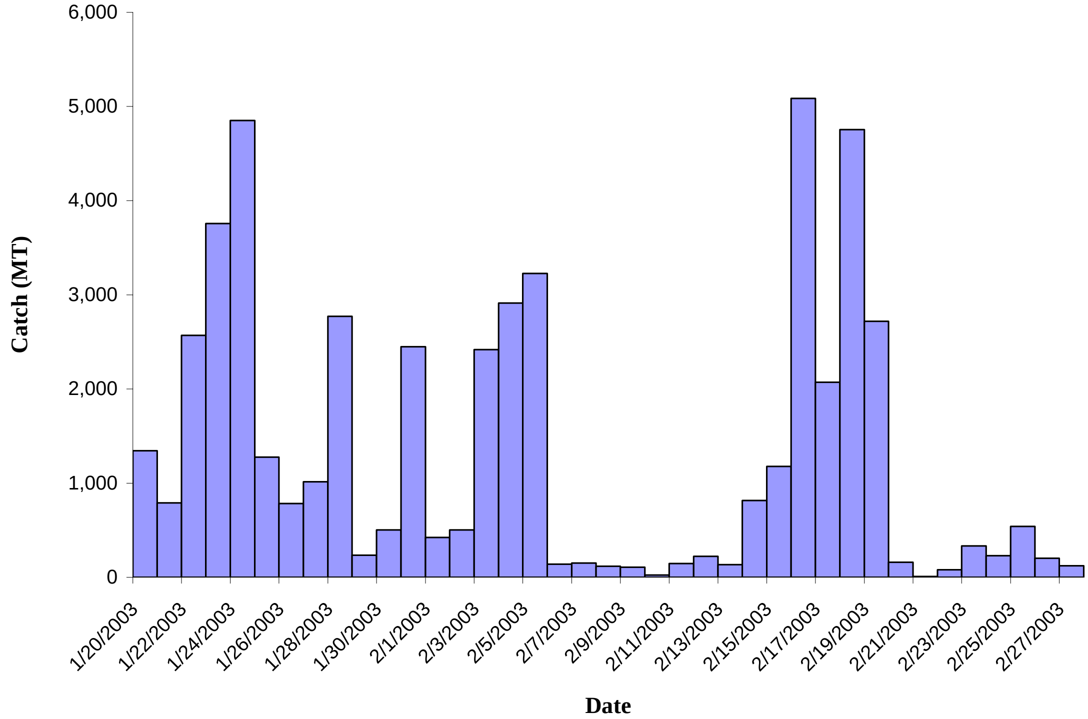

Figure 5: Total observed Alaska Pollock catch in the 70 km by 40 km southeastern Bering Sea study area from 20 January to 26 February 2003 for all vessel types.

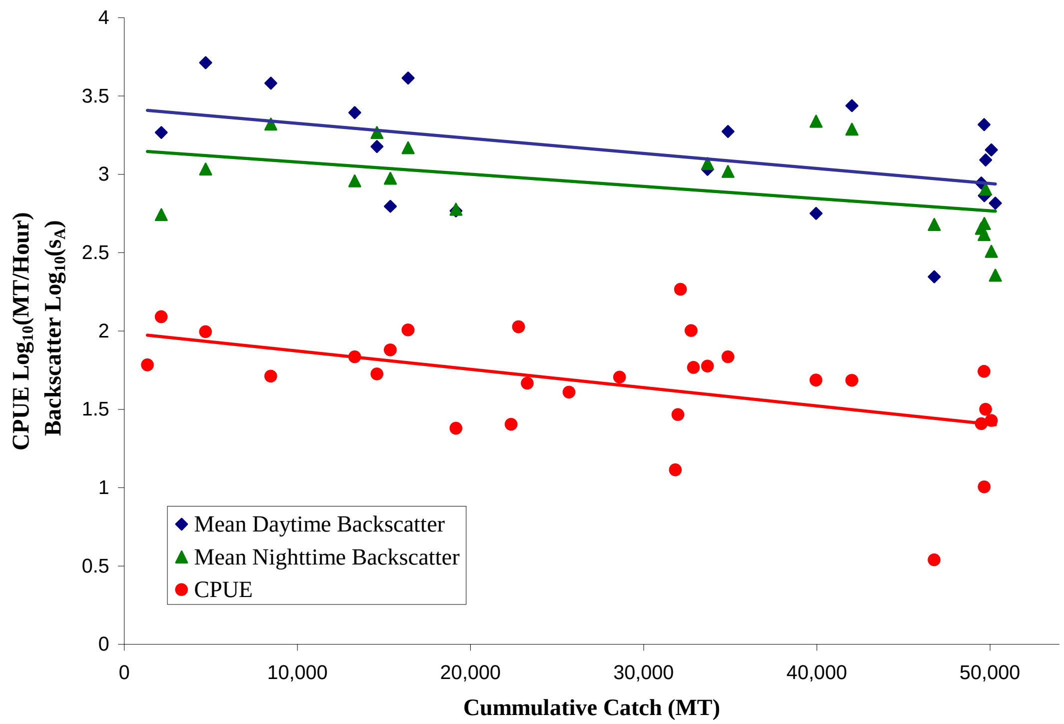

Figure 6: Catcher/Processor vessel Catch per Unit Effort and Backscatter versus cumulative catch of Alaska pollock in the study area for 20 January to 27 February 2003.

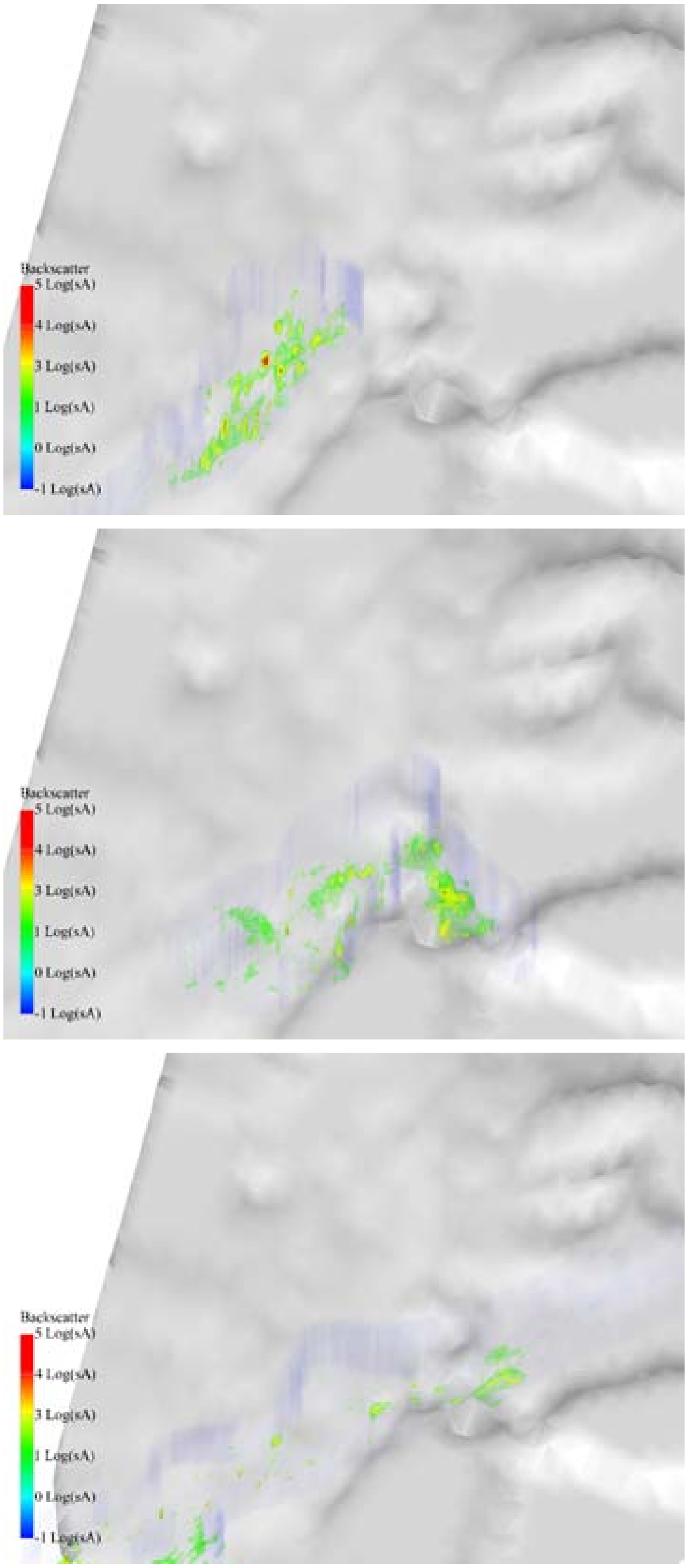

Figure 7: Gradual decline in daytime backscatter density over the duration of the fishery top) 21 January 2003, middle) 15 February 2003, and bottom) 22 February 2003.

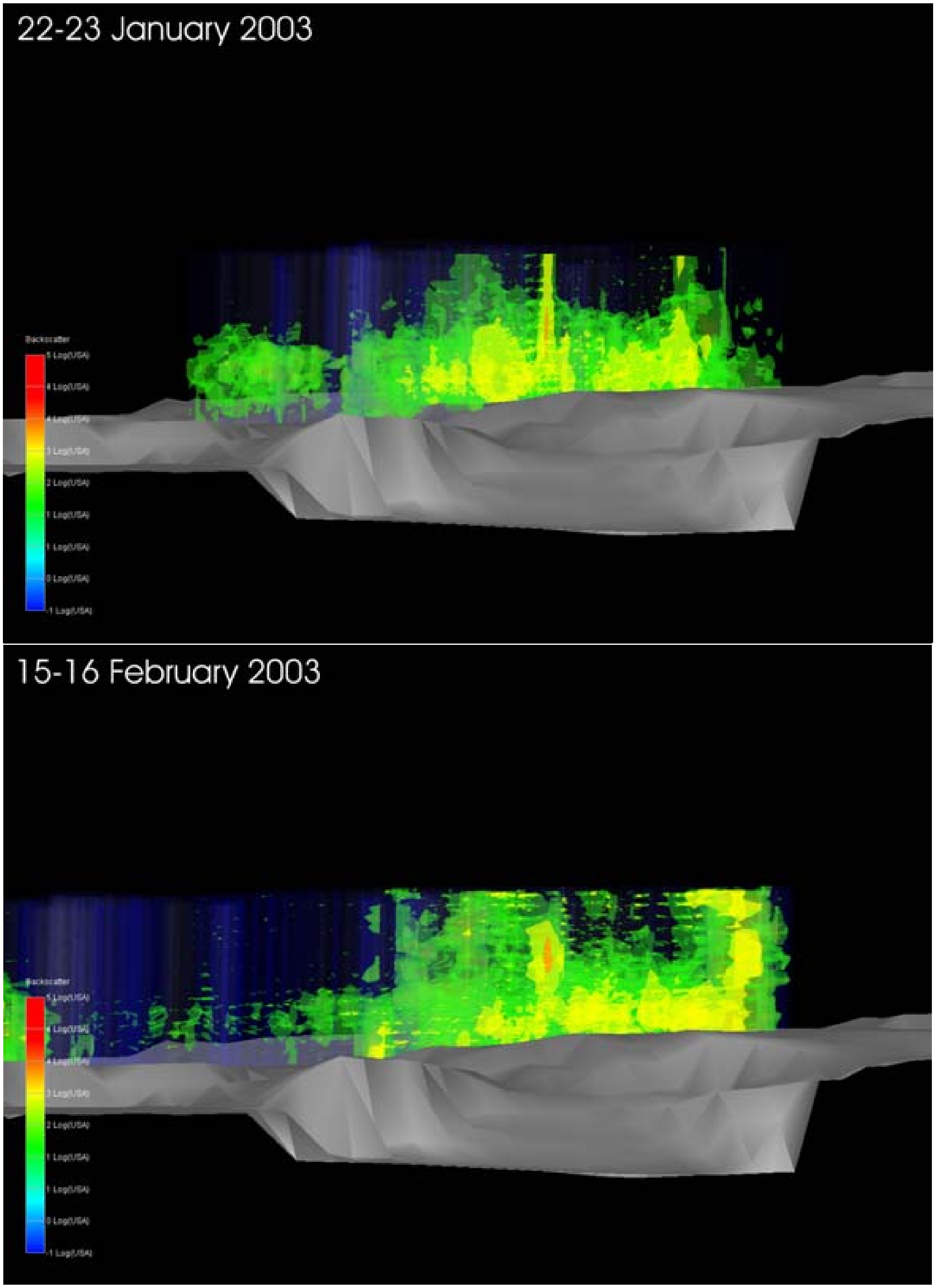

Figure 8: Interesting structure within an aggregation modeled near the same location during different nighttime periods. Top) 22-23 January 2003, and Bottom) 15-16 February 2003.

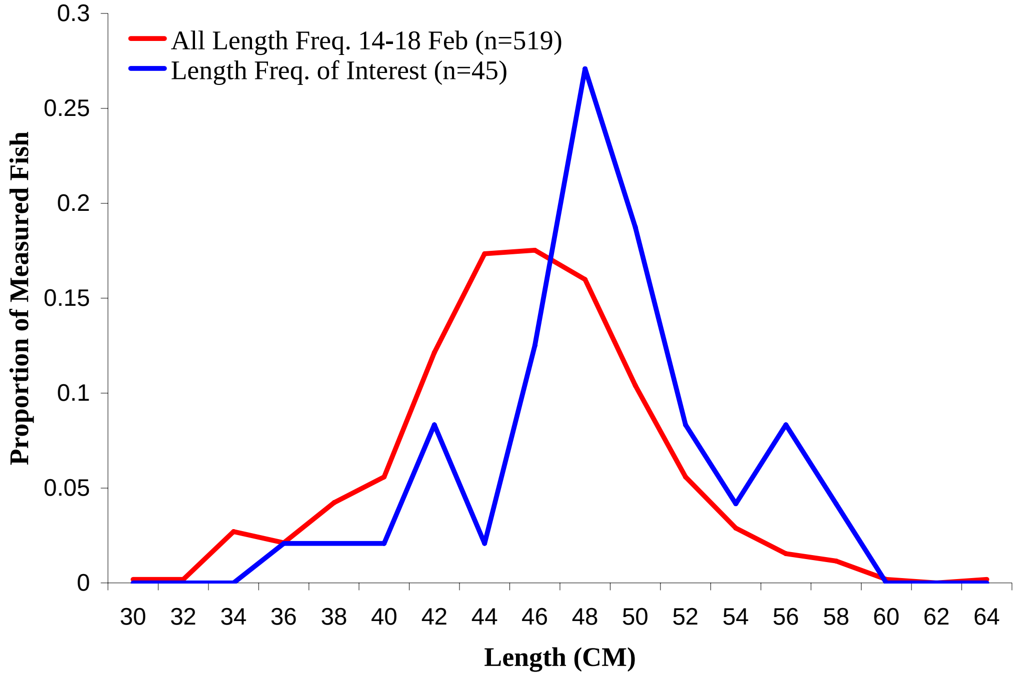

Figure 9: Length frequency data for the interesting formation observed on 15-16 February 2003 in compared to length frequency data from surrounding hauls.