

Final Report

Deployment of an acoustic data logger on commercial fishing vessels to evaluate the potential of fishing-induced declines in local pollock abundance

by

Professor Terrance J. Quinn II, Principal Investigator
SFOS, University of Alaska Fairbanks, Juneau AK
(Phone: 907-796-5457, Email: Terry.Quinn@uaf.edu)

Ms. Haixue Shen, PhD Graduate Student
SFOS, University of Alaska Fairbanks, Juneau AK

Dr. Martin Dorn, Co-Investigator
Alaska Fisheries Science Center, Seattle WA

Dr. James Ianelli, cooperator
Alaska Fisheries Science Center, Seattle WA

Mr. Steven Barbeaux, cooperator
Alaska Fisheries Science Center, Seattle WA

Dr. Vidar Wespestad, cooperator
Resource Analysts International, Lynnwood WA

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ABSTRACT

The main goal of this project was to determine if hydroacoustic data collected from sounders on commercial factory trawlers could be utilized to investigate temporal-spatial changes in the abundance and distribution of walleye pollock and the potential for local depletion in the Bering Sea. Since 2001 the PCC Research Center has funded this project for a total of \$288,459.

In 2001, we developed a prototype data logger that interfaces with the ship's 38 kHz echo sounder and captures the acoustic backscatter returns. In 2002, we installed it on three catcher/processors (Island Enterprise, Kodiak Enterprise, and Alaska Ocean). The system worked quite satisfactorily. The backscatter data were post-processed and integrated with observer and logbook data. Preliminary analysis showed that the hydroacoustic information is correlated with pollock catch (Dorn et al. 2002). In 2003, an additional 4 vessels (American Dynasty, American Triumph, Ocean Rover, Starbound) were equipped with acoustic data logging systems, bringing the total number of PCC vessels equipped to 7, or nearly half the fleet.

Work since 2005 concentrated on the analysis phase of the project. This work includes classifying the searching behavior of the vessel, integrating the acoustic biomass, identifying pollock aggregations detected while searching, and evaluating what inferences, if any, can be made concerning the rate at which those aggregations are reduced in abundance. The project developed sophisticated analytical tools for inferring the temporal dynamics of pollock spatial pattern using multiple data sources. This project was a cooperative program between the University of Alaska and the University of Washington and will result in two PhD dissertations: Haixue Shen at UAF and one by Steven Barbeaux at the University of Washington. Two research papers have been accepted for publication, several more are in preparation. As these reports become published, they will be sent to PCCRC. Numerous presentations of research results have been given, including a poster presentation at an international symposium on hydroacoustics in Bergen, Norway in 2008.

This project demonstrated the feasibility of installing acoustic data loggers on catcher/processors in the EBS pollock fishery to study localized depletion of pollock. There were clear changes in pollock school characteristics during the course of the A fishing season. However, it is not known whether these changes are due to biological characteristics, oceanographic effects, or fishing. Therefore, there will be need for time series of hydroacoustic data to determine whether changes are due to particular effects.

BACKGROUND/RELEVANCE

Walleye pollock (*Theragra chalcogramma*) is the target of one of the world's largest fisheries and is also an important prey species in the eastern Bering Sea (EBS) ecosystem. Little is known about the potential effects of fishing on the school characteristics and spatial distribution of walleye pollock. Few dedicated research surveys have been conducted during the pollock fishing seasons, so analysis of fishery data is only feasible approach to study these potential effects.

This project is clearly relevant to PCCRC Research Priority 2: Alaska Pollock Stock Dynamics. This project started as a simple proof of concept project to investigate if data collected from

commercial vessel acoustic sounders could be utilized to investigate temporal-spatial changes in the abundance and distribution of walleye pollock in the Bering Sea. Since the inception of the project in 2001, the project has grown to include researchers at the Universities of Alaska and Washington, the Alaska Fisheries Science Center, and others. Originally the scope was to see if localized depletion could be investigated, but now the program encompasses this relationship as well as looking at school formation and changes during the course of fishing.

The project has also come to include development of software for converting some of the research innovations into tools that the fishing fleet can utilize to examine the data in similar ways as researchers and allow them to access collected historical data while fishing in real time to compare with prior conditions on the same grounds.

Since 2001 the PCC Research Center has funded this project for a total of \$288,459. This money has been used for equipment, travel, 4.5 months of salary for Quinn, 1.75 years of salary for PhD student Haixue Shen, and 2 years of salary for a technician. In addition, a NOAA Technology Grant provided equipment for 3 vessels (Island Enterprise, Kodiak Enterprise, and Alaska Ocean) for data collection in 2002 and beyond. A grant of \$72,000 from the Alaska Fisheries Science Center through CIFAR provided 2 additional years of student support for Shen.

OBJECTIVES/HYPOTHESES

This collaborative project between UAF, Alaska Fisheries Science Center (AFSC), and the pollock industry investigated whether localized depletion of pollock is occurring by the eastern Bering Sea pollock fishery. Acoustic data loggers were installed on 7 catcher/processors (about half the fleet); each data logger interfaced with the ship's 38 kHz echo sounder and captured the acoustic backscatter. The backscatter data was post-processed and integrated with observer and logbook data. The research goals were to develop variables related to pollock school density, composition, and frequency, and to examine changes in these variables during the course of the fishing season and between years.

METHODS/ ANALYSES

1. Focus on small scale processes, and in particular, on fishing impacts on pollock distributions.
2. Address the localized depletion issue as the primary objective.
3. Use the school descriptor module in Echoview® to evaluate changes in school structure due to fishing impacts. Echoview is a software product from Sonardata. We collaborated with its creator, Ian Higgenbottom, who is extremely interested in our data and uses it in training sessions.
4. Obtain observer data from all vessels to determine the magnitude of catch and effort near the vessels with data loggers.
5. Classify the searching behavior of the vessels, identify pollock aggregations detected while searching, and evaluate what inferences, if any, can be made concerning the rate at which those aggregations are reduced in abundance or altered in size and shape.

Analysis of Pollock Schools

The analytical work on this project is the focus of the PhD dissertation of Haixue Shen under the primary supervision of Quinn; the dissertation should be completed in Spring or Summer 2009. As such, she had the responsibility of performing the analyses and giving presentations. She has presented posters of her work at the Alaska Marine Science Symposia in Anchorage in January 2006 and 2007. In summer 2006 she participated in research aboard the *Oscar Dyson*. In November 2007, Ms. Shen gave an oral presentation from the first chapter of her dissertation at the Lowell Wakefield Symposium. A manuscript from this work was accepted for publication in the proceedings of the symposium and appended to this report (Shen et al. 2008). The major conclusions from the manuscript are now briefly summarized.

We used acoustic data collected continuously by one fishing vessel from January to February 2003, which operated north of Unimak Island. Results from comparisons between early and late fishing periods showed that there were significant changes of pollock distribution at different scales. The schools were smaller and denser in the second period. Furthermore, the spatial distribution of schools became sparser, as evidenced by the lower frequency of occurrence of schools per elementary distance sampling unit and the increase in the averaged next neighbor distances (NNDs). However the average NND between schools within the cluster and the average abundance of a cluster did not change significantly. Variography was used to investigate the changes at the scale larger than 1 nmi. The increased range, nugget effect, and sill in the second period indicated changes of pollock spatial distribution, however it is unclear whether these changes are attributable to fishing or ecological process.

Our results suggest the following operative hypothesis of pollock schooling behavior during the A season. Pollock aggregate into schools in the daytime and disperse at night during the spawning season. After about two weeks of fishing, the aggregation pattern changes both at the school scale and the scale larger than 1 nmi. Pollock aggregate in smaller but denser schools that have a patchier distribution in space. The changed aggregation pattern may be due to commercial fishing or to biological changes in behavior and movement. It is unknown whether the increased patchiness of pollock is a persistent feature of the A season. This study is a first look at pollock schooling and the affects of fishing on pollock school distribution. The observations are somewhat limited, so it is difficult to draw strong conclusions. However, the results of this study suggest fishing may alter school distribution and density. We recommend further research be undertaken to better understand the relationship between fishing removals and the subsequent reduced spatial extent of the pollock is affecting the foraging ability of Steller sea lions and other predator species dependent on pollock.

The synthesis of research findings from this work awaits the completion of the two dissertations by Haixue Shen and Steve Barbeaux. Shen's dissertation focuses on the distributions of pollock schools and will be structured as follows. The main goal of this dissertation is to investigate whether local depletion of pollock can be inferred from hydroacoustic data collected aboard commercial fishing vessels. The objectives to support this goal are: 1) to preprocess the hydroacoustic data using Echoview 3.30, 2) to identify schools and extract school descriptors using the school module within Echoview, 3) to investigate changes in distribution of schools using one dimensional and two dimensional spatial statistics, 4) to investigate the harvester's behavior related to pollock distribution, 5) to undertake catch depletion analysis.

Chapter 1: Preprocessing the hydroacoustic data

All available acoustic data (from 2002 to 2006) were preprocessed for the further analysis. The Echoview 3.30 is the main software used to process the acoustic data. All echograms were integrated by regions by cells (5m×100m). Consequently, the school module is used to identify the schools and extract the school parameters for further analysis. Some basic statistics will be done here to investigate the changes of average school density and size in different fishing periods.

Chapter 2: Analysis the changes of schools in one dimension, two dimensions

The post-processing of the hydroacoustic data is the main objective. Based on the results of chapter 1, some post processing tools are used to analyze the fishing impact on fish schools in one dimension at first and then in two dimensions. The main tools are spatial point processes and geostatistics. This work was presented at Lowell Wakefield in 2006 and submitted to publication. It was accepted in 2007 and published (Shen et al. 2008). Furthermore, a common measure, EDSU (elementary distance sampling unit), was used to study the fish spatial structure on a large scale and the results were presented as a poster at the Marine Science Symposium in Anchorage 2007 (Shen et al. 2007).

Chapter 3: Study of the searching behavior of harvesters

This part focused on the searching behavior of harvesters. Levy flight (Bertrand et al. 2005) was used to analyze the searching behavior given the GPS information accompanied with acoustic data and the observer data. The relationship between fishing behavior and fish distribution was examined with multivariate analysis. The results from multivariate analysis were presented as a poster at the SEAFACETS meeting in June 2008. A manuscript of this work (Shen et al. in press) will be in the proceedings to be published in the ICES Journal of Marine Science (a pre-print is appended to this report. Preliminary results from Levy flight were presented as a poster at the Marine Science Symposium in Anchorage 2008. Another manuscript is under preparation and will be completed this fall.

Chapter 4: Catch depletion analysis

Rather than using hydroacoustic data, observer data from 2002 to 2006 will be used to study whether catch depletion is present. DeLury (1947) models are commonly used for depletion analysis. DeLury depletion estimators will be obtained for individual or several fishing vessels in different fishing areas to investigate the local depletion caused by fishing, thereby, extending previous analysis of Battaile and Quinn (2006). This will be done between during September and December, 2008.

Analysis of Backscatter Data

Steve Barbeaux presented his analytical work from his dissertation to the ICES Annual Science Meeting in Aberdeen, Scotland, 2006. His abstract follows: 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 the investigations on the distribution and behavior of fished aggregations.

Three-dimensional kriging was used to produce three-dimensional 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 behavior of aggregations 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.

Since these preliminary results were presented at the ICES conference in Aberdeen Scotland, Barbeaux's dissertation has expanded to include more advanced statistical modeling methodologies in an attempt to standardize the data from multiple vessels without conducting traditional acoustical inter-ship calibrations. Generalized additive mixed models (GAMM; Hastie and Tibshirani, 1990; Wood, 2006) provide a powerful tool that Barbeaux has used to account for linear differences in calibration among different vessels, to analyze possible non-linear temporal and spatial trends in pollock temporal and spatial distribution, and to investigate possible effects on the distribution due to fishing. GAMM is a non-parametric regression method which relaxes the assumptions of normality and linearity inherent in linear regression. The flexibility of non-parametric regression for the continuous predictor variables coupled with linear models for predictor variables provides a means to uncover structure within the data that may be missed using linear assumptions.

Barbeaux's dissertation has been expanded to two areas of investigation; a focused study developing a means of using the data from multiple vessels in a quantitative framework and a broader application of the technique to assess the migration and abundance of pollock among partitions of the Eastern Bering Sea Shelf. The specific objectives of the preliminary focused study are to: a) verify the generalized additive mixed model approach as a means of handling opportunistically collected acoustic data from multiple uncalibrated vessels by treating vessel as a random effect within the model, and b) use the GAMM method to describe temporal and spatial patterns observed in pollock aggregations within an area of high fishing intensity. The objectives of the second portion of the project are to: a) develop a depletion model that can use estimates of mean backscatter obtained from GAMM analyses in combination with total catch to estimate the fluctuation of pollock abundance among regions, b) test the sensitivity of this model to noise in the GAMM results, and c) apply the model to tracking the migration and abundance of pollock on the Eastern Bering Sea shelf during the spawning season and characterize the uncertainty around these estimates.

Preliminary results from the GAMM analyses conducted by Barbeaux reveal that changes in the density and distribution of pollock are scale dependent in both time and space. At small temporal scales (hours) a strong diel cycle is evident with a higher mean backscatter during the night moving towards a lower mean backscatter during the day. Further, the backscatter data are highly heteroskedastic between night and day with a more left skewed, platykurtic distribution of backscatter during the day. This is consistent with a dispersal of pollock both horizontally and

vertically during the nighttime and formation of dense near bottom aggregations during the day.

At small spatial and temporal scales (100-1000 meters and minutes to hours) a decline in pollock density caused by fishing although initially observable is not apparent after 6 to 24 hours. At larger scales (days to weeks) seasonal migration into the study area and fluctuations in pollock distribution and density due to the lunar phase were also evident. It was found that pollock tended not to disperse as widely at night when the moon was approaching full and particularly at full moon. An overall decline in density of pollock in the study area over the fishing season is also apparent, consistent with the amount of removals from the area in the commercial fishery.

There is a seasonal depletion of S_A with pulses of immigration. The apparent pulse pattern may in part be due to vessels leaving the area, then returning. The pulses of immigration may in actuality be constant immigration, but appear as pulses due to lack of data in the interim. Removals in the area lessen in two periods due to fishing vessels leaving the study area and therefore we no longer have data. When the vessels return fishing resumes, we again have data and the increase in abundance shows up in the model as a sudden pulse of fish. In the Southeastern Bering Sea region predictions of daily backscatter from the GAMM models are consistent with patterns observed in the CPUE and catch data from the commercial fishery.

There is significant correlation between total daily catch in this area and predicted daily mean S_A . This consistency of pattern among data sources provides further evidence that the patterns observed through the GAMM analyses are real and not artifacts of the modeling process.

Barbeaux is exploring means of using the differences in catch rates combined with the fluctuations in backscatter over time in distinct areas of the Eastern Bering Sea to create a Eularian model of pollock flow on the Eastern Bering Sea shelf during the pollock A season (20 January through 15 April). By monitoring the fluctuations in pollock density in the face of varying levels of exploitation these opportunistic backscatter data provide a high resolution data source that may provide a means of estimating pollock abundance and net migration rates among regions. This effort will see further development in 2009 and 2010.

Data collections in 2007 and 2008 were minimal (Table 1) due to several factors, not the least of which was lack of communication with the vessel operators that the project was on-going. On two vessels, operators failed to turn the loggers on during fishing operations, and on two others, the ES-60 computers failed at some point prior to the A season and data loggers were not reinstalled. In addition one vessel that was included in the program no longer participates in the A season Bering Sea pollock fishery. In 2009 four vessels participating in the Bering Sea pollock fishery have been provided with data loggers and the vessel operators informed that the program was still on-going.

RESEARCH PRODUCTS

Oral Presentations

Steven J. Barbeaux, Martin Dorn, James Ianelli, and John Horne. 2005. Visualizing Alaska pollock (*Theragra chalcogramma*) Aggregation Dynamics. Presentation to the ICES Annual Science Meeting, Aberdeen, Scotland.

Shen, H., T.J. Quinn II, V. Wespestad, M.W. Dorn, and M. Kookesh . 2006. Schooling changes of EBS walleye pollock during fishing. Lowell Wakefield Symposium on Resiliency of Gadid Stocks to Fishing and Climate Change, Anchorage AK, October/November 2006.

Poster Presentations

Shen, H., M. Kookesh and T.J. Quinn II. Interaction between commercial fishing and walleye pollock in eastern Bering Sea. Marine Science in Alaska: 2006 Symposium, Anchorage, Alaska, January 2006.

Shen, H., T.J. Quinn II, V. Wespestad, M.W. Dorn, and M. Kookesh. 2007. Using EDSU to investigate the spatial structure of walleye pollock (*Theragra chalcogramma*) schools in the eastern Bering Sea. Marine Science in Alaska: 2007 Symposium, Anchorage, Alaska, January 2007.

Shen, H., M.W. Dorn, V. Wespestad, and T.J. Quinn II. 2008. Using acoustic data to study the searching behavior of harvesters in eastern Bering Sea pollock fishery. Poster presentation at the Alaska Marine Science Symposium, Anchorage, Alaska, January 2008.

Shen, H., M.W. Dorn, V. Wespestad, and T.J. Quinn II. 2008. Schooling pattern of eastern Bering Sea walleye pollock in relation to fishing pattern. Poster presentation at the ICES International SEAFACETS Symposium, Bergen, Norway, June, 2008.

Reports/Manuscripts

Dorn, M.W., W.A. Karp, V.G. Wespestad, J. Ianelli, and T.J. Quinn, II. 2002. Using fishing vessels to collect acoustic data for scientific purposes: preliminary results from midwater trawlers in the eastern Bering Sea walleye pollock fishery. Contribution 67 of the ICES Symposium on Acoustics in Fisheries and Aquatic Ecology, Montpellier, France, 10-14 June 2002. 11 pp.

Steven J. Barbeaux, Matthew Kookesh, Martin Dorn, Chris Wilson, and Alex De Robertis. 2004. Calibration of Simrad ES60 echosounders on a commercial fishing vessel. Alaska Fisheries Science Center, National Marine Fisheries Service, Seattle WA. 12 p.

Shen, H., Quinn, T.J., II, Wespestad, V., Dorn, M.W., and Kookesh, M. 2008. Using acoustics to evaluate the effect of fishing on school characteristics of walleye pollock. Pages 125 – 140 In Resiliency of Gadid Stocks to Fishing and Climate Change, Alaska Sea Grant College Program, AK-SG-08-01, Fairbanks AK.

Shen, H., Dorn, M.W., Quinn, T.J., and Wespestad, V. *in press*. Schooling pattern of eastern Bering Sea walleye pollock and its impact on fishing behavior. Proceedings of the SEAFACETS Symposium, Bergen, Norway, June 2008. ICES Journal of Marine Science.

Spin-offs from this project

The opportunistic acoustic data collection from fishing vessels has helped raise the potential for additional data collections aboard chartered vessels employed for trawl surveys. In fact, a large scale project was initiated in 2006 and this has lead to a detailed evaluation of the potential to

create an alternative index for pollock in the EBS (Ressler et al. 2008). Their findings provided good justification for comparison of backscatter data collected during summer 2006 using calibrated Simrad ES60 echosounders on the two BT survey charter vessels and a Simrad EK60 aboard the acoustic-trawl survey vessel, NOAA Ship Miller Freeman. The new opportunistic acoustics-based index of midwater pollock abundance agreed well with the directed acoustic survey estimate. Agreement between platforms during the summer 2007 provides further justification for the use of acoustic data from commercial fishing vessels and other platforms of opportunity to augment more traditional acoustic survey methods.

This project has led to a number of fruitful collaborations between the PIs and the Midwater Assessment and Conservation Engineering (MACE) Program at AFSC. Meetings are arranged periodically to ensure that all researchers at AFSC who are active in this area are informed of new developments. A document detailing a standard set of protocols for collecting opportunistic acoustic data has been prepared. This document has been used extensively for ensuring that standard data collection procedures are followed, and that the acoustic data collected is the highest quality possible. These protocols have been used successfully for acoustic data collected during fishing operations, from fishing vessels during chartered to conduct acoustic surveys, and from fishing vessels doing bottom trawl surveys in the Eastern Bering Sea. Significant progress has been made towards developing software to automate data processing of opportunistically collected acoustic data. Automated software would greatly expand the potential applications of opportunistic acoustic data, and would help to alleviate data storage issues. Development of suitably robust software is not a simple task, however, and progress to date has not resulted in software with the necessary functionality.

Collaborations With International Researchers

The ICES Fisheries Acoustics Science and Technology Working Group (WGFAST) met in Dublin Iceland April 23-27, 2007. Vidar Weststad attended the working group and discussed the work being conducted by PCCRC funded researchers and collaborating scientists at the University of Alaska Fairbanks, University of Washington, and the Alaska Fisheries Science Center (AFSC). He participated in a joint gear technology and acoustics working group session that was focused on improving sampling and analytical tools for incorporating spatial data, rapid non-lethal identification and quantification methods, and combining all monitoring data. In that session the need to combine data access, fusion, analysis, and visualization was recognized, and it was noted that this is not available in existing software such as GIS and Google Earth. The current PCCRC work was discussed with several participants and there was interest in collaborative work on improving analytical methods and visualization of acoustic data. Based on several of the presentations at the Working Group meeting and workshops, it is clear that the work proceeding under the PCCRC is cutting edge and will generate further interest after presentations at the International Acoustics Symposium in Bergen, Norway in 2008.

Also at the FAST meeting a report was approved for publication and published in August of this year as: **ICES. 2007. Collection of acoustic data from fishing vessels. ICES Cooperative Research Report No. 287. 83 pp.** The report was edited by William Karp of the AFSC. Martin Dorn, also of the AFSC and a PI on this grant, and Weststad participated in the workgroup sessions that formulated the information that formed the report. Martin reported on the North Pacific cooperative acoustic work between the University of Alaska PCCRC and the

AFSC.

This project gained international recognition. Several institutions around the world are engaged in collecting and compiling the same data, and we have been in communication with them. Dorn and Wespestad are members of the ICES Study Group on Collection of Acoustic Data from Fishing Vessels. The Study Group is preparing a Cooperative Research Report on data collection methods and recommendations, and will meet for the final time in 2006 to finalize the report. Quinn, Dorn, Wespestad, and Shen all attended the international hydroacoustics symposium in Bergen, 2008, so we had the opportunity to share our work with people from all over the world.

Dorn is a co-convenor of a theme session that will be held at the ICES 2009 Annual Science Conference on: monitoring requirements, observation technologies and methods (e.g. acoustics) for pelagic organisms at local and basin scale for input into ecosystem based fisheries

Recommendations for Future Directions and Research

This project was designed to explore the feasibility of utilizing commercial fishing vessels to collect information on the dynamics of fishing operations on pollock spatial patterns and behavior. To date the data have been beneficial and has shown that fishery acoustic data can be used to explore fishery effects on the resource and midwater environment. The original project has spun off several related projects that uses other acoustic data or explores the same data set from different perspectives. This is a valuable set of data from monitoring interannual variation in the midwater scattering that can help in the understanding of interannual variation. It is also an effective eye on the fishing process and its effect on the environment; and provides researchers with a fisherman's view of the resource.

The major bottleneck in the process is data collection, storage and retrieval. This is a massive amount of data, but new technology is making this simpler, but if this valuable data is to be continually collected there needs to be an archiving and retrieval system developed. This may be an activity that PCCRC could help facilitate. Likewise, the industry needs to assist with maintenance and servicing of on-board data storage devices.

There are many questions still to be addressed before this data can be used for quantitative assessment of the pollock resource, but in the short term it can help answers on movements and behavior in relation to fishing and environment. It also provides a broader temporal frame of reference than surveys which cover a very narrow temporal frame.

This project has shown that commercial fisheries acoustic data can be used to augment and enhance data collection and resource assessment. Acoustics is a rapidly evolving field with new technology that will make it a more powerful research tool. The PCC vessels offer researchers an cutting edge platform to continue this work, and those who have participated in this work hope the PCCRC will continue to support this research by maintaining the data time series and funding the additional work identified.

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Table 1: Data collection by year.

Vessel	Year	Raw File Size GB
Alaska Ocean	2002	156.9
Island Enterprise	2002	132.1
Kodiak Enterprise	2002	30.3
American Dynasty	2003	14.2
American Triumph	2003	29.6
Island Enterprise	2003	95.6
Kodiak Enterprise	2003	63.8
Ocean Rover	2003	32.6
Star Bound	2003	90.2
American Dynasty	2004	96.2
American Triumph	2004	248.0
Island Enterprise	2004	44.7
Star Bound	2004	0.8
American Dynasty	2005	98.5
Island Enterprise	2005	49.4
Kodiak Enterprise	2005	42.6
Ocean Rover	2005	40.1
Star Bound	2005	45.8
American Triumph	2006	81.9
Island Enterprise	2006	100.0
Pacific Glacier	2006	114.0
Starbound	2007	86.0
Kodiak Enterprise	2008	85.0
Island Enterprise	2008	85.0
All Years Total		1863.3

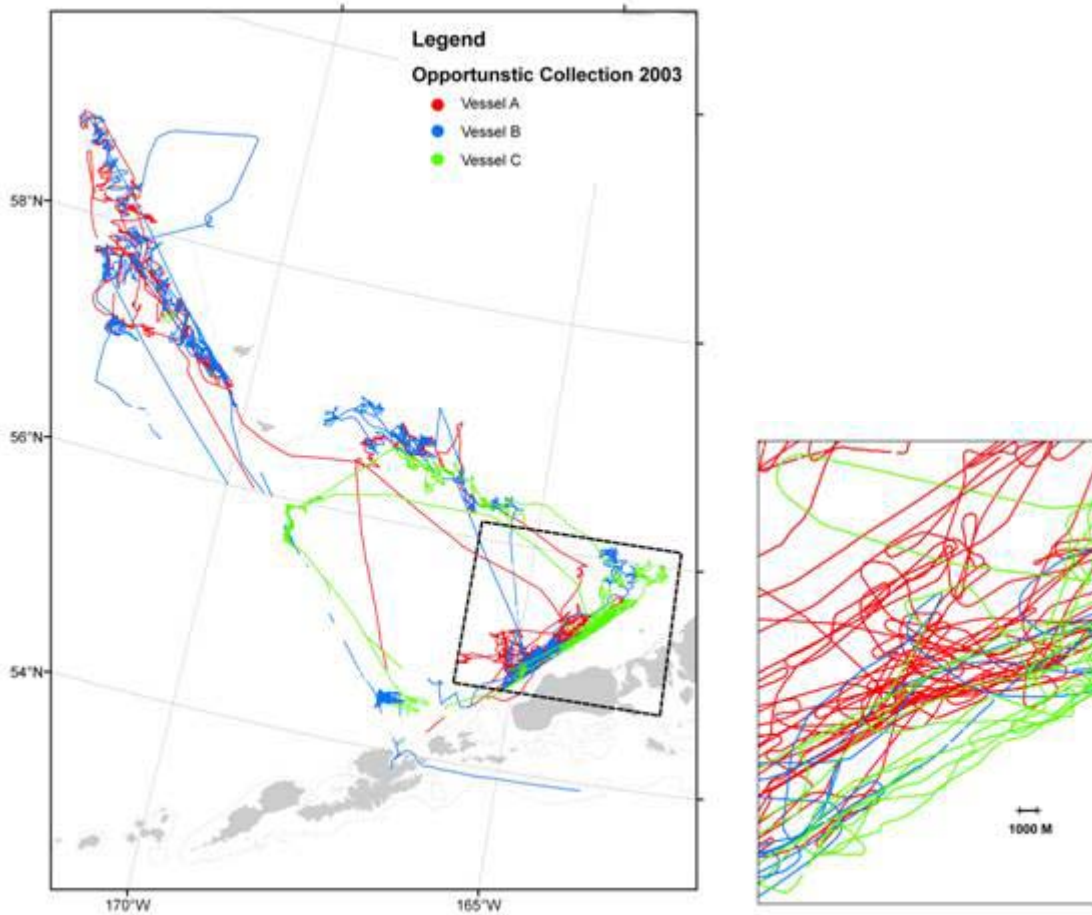


Figure 1 Opportunistic acoustic data collections for January through March 2003 with the GAMM analysis sub-area in the dashed box and a view of a subsection of this sub-area illustrating the concentration of data within the sub-area.

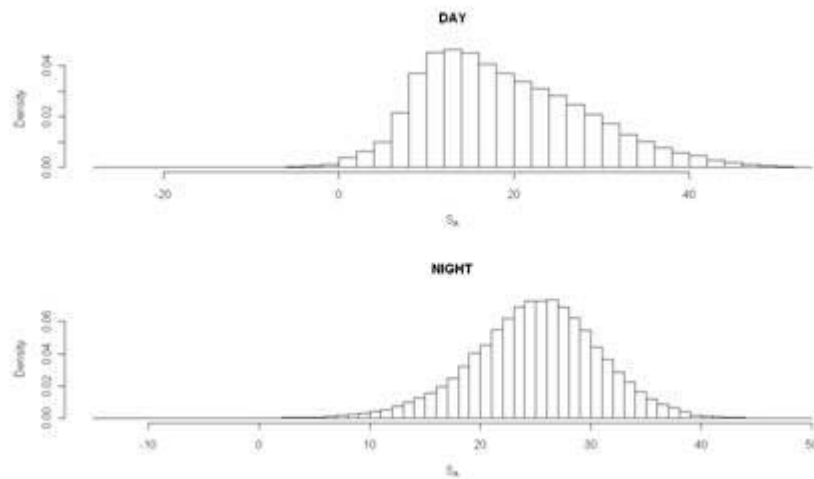


Figure 2 Histogram of nautical area scattering strength (S_A) for day (top) and night (bottom) for all data in the study area.

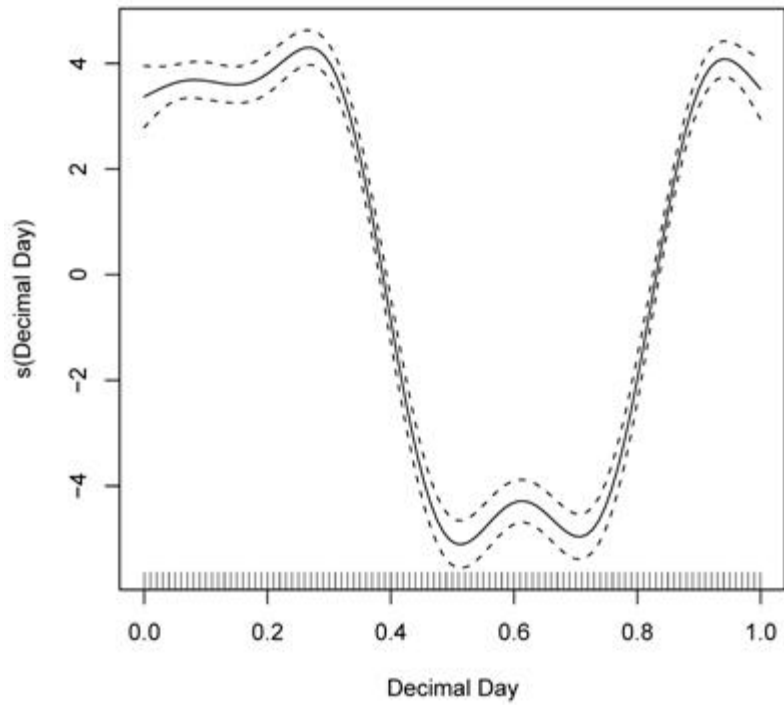


Figure 3: GAMM results for the effect of time of day on backscatter strength (S_A ; db re $1(m^2 nmi^{-2})$).

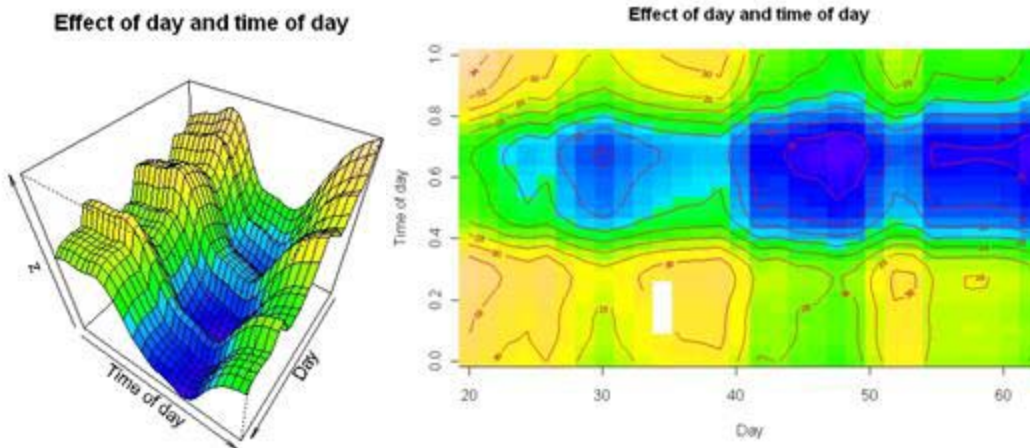


Figure 4 Plot of predicted S_A values from the GAMM for day and time of day for the mean latitude and longitude.

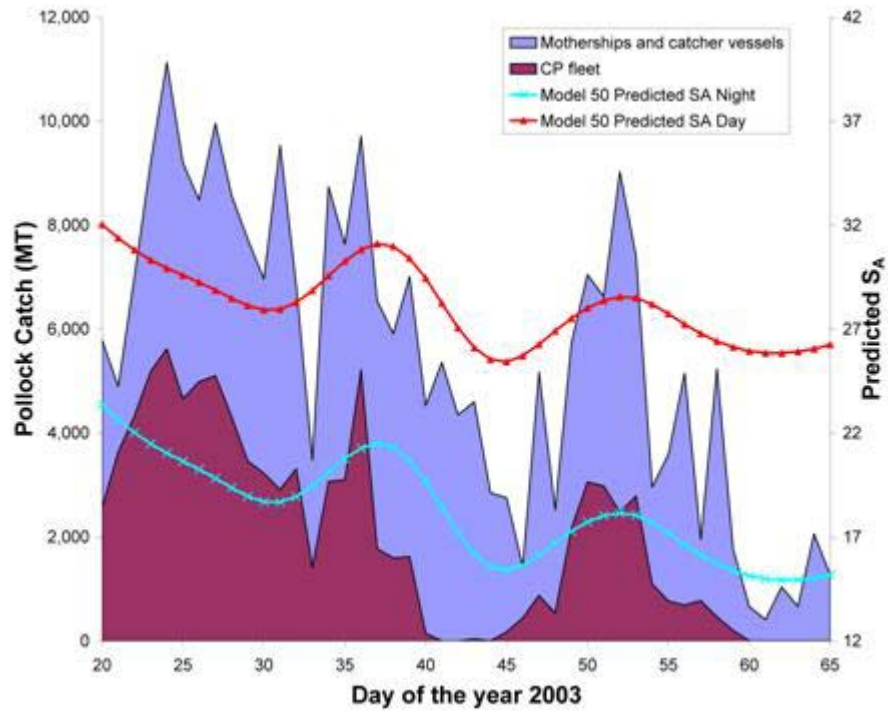


Figure 5 Plot of total observed pollock catch (metric tons) by catcher-processor fleet and by all other vessels in the study area and GAMM predicted S_A for day and night by day of the year.

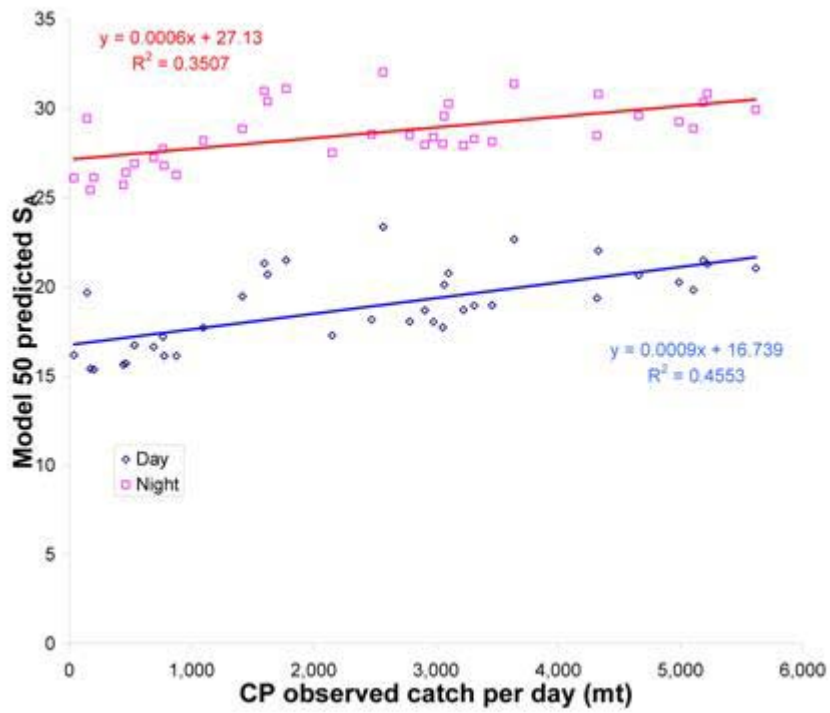


Figure 6 Plot of GAMM predicted S_A by daily pollock catch (metric tons) by catcher processor vessels for days 20 to 59 for the study area with linear regression fits.