Seafacts 490 dm1

Schooling pattern of eastern Bering Sea walleye pollock and its impact on fishing behavior

Haixue Shen, Martin W. Dorn, Vidar Wespestad, and Terrance J. Quinn II

Shen, H., Dorn, M. W., Wespestad, V., and Quinn II, T. J., 2009. Schooling pattern of eastern Bering Sea walleye pollock and its impact on fishing behavior – ICES Journal of Marine Science, 69: 000-000

Walleye pollock (*Theragra chalcogramma*) form persistent midwater and near-bottom schools in the daytime during the winter spawning season in the eastern Bering Sea (EBS). Two spawning areas in the EBS, north of Unimak Island and near the Pribilof Islands, are also the main fishing grounds. To study the schooling pattern of pollock and its impact on fishing behavior on these two fishing grounds, a principal component analysis with instrumental variables (PCAIV) was done using acoustic and observer data from 2003 and 2005. Significant differences between the school descriptors made it possible to distinguish schooling patterns among areas and years. The harvester searched for fish aggregations which were caught in a different manner when the schooling pattern changed. School density had more effect than school size on fishing behavior. Aggregations were less dense in 2003 compared to 2005, and the harvester tended to fish with higher speed and longer tows when it encountered less dense aggregations.

Keywords: acoustic data, fishing behavior, observer data, pollock, principal component analysis, schooling pattern

Running heads: Pollock behaviour; Shen *et al.*

Received 7 August 2008; Accepted

H. Shen and T.J. Quinn II: Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 11120 Glacier Hwy., Juneau, AK 99801, USA. M.W. Dorn: Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, USA. V. Wespestad: Resources Analysts International, 21231 8th Pl. W, Lynnwood, WA 98038, USA. Correspondence to H. Shen: tel: +1 907 796 5463; fax: +1 907 796 5446; e-mail: h.shen@uaf.edu.

Introduction

Pelagic fish usually form different kinds of aggregations such as schools, clusters of schools, clouds, and layers (Reid, 2000). As a semi-pelagic species, walleye pollock (*Theragra chalcogramma*) form persistent midwater and near-bottom schools during the spawning season. Knowledge of the schooling pattern of pollock provides information about fish behavior that is essential for the management of the pollock fishery (Marchal and Petitgas, 1993). In addition to being the main target of a fishery, walleye pollock is also an important component of the eastern Bering Sea (EBS) ecosystem as a major prey species (NRC, 1996). Its schooling pattern may affect the predation success of species in higher trophic levels such as Steller sea lions (Wilson *et al.*, 2003). Thus understanding the schooling behavior of pollock is also important for ecological studies.

Acoustic methods have been commonly employed in pelagic fisheries to explore the schooling behavior of fish (Simmonds and MacLennan, 2005). Since 1979, acoustic methods have been used to estimate the pollock abundance in midwater during the echo-integration trawl (EIT) surveys of the EBS (Ianelli *et al.*, 2007). However, these surveys are mainly conducted in the summer, except for a few winter surveys conducted in 2001 and 2002 (Honkalehto *et al.*, 2002). Although the results may be less precise than those of scientific surveys, commercial vessels can be good platforms for collecting acoustic data for scientific purposes (Melvin *et al*. 2002, Mackinson and Kooij 2006), and are particularly useful for in-season monitoring of stock trends (Melvin *et al*. 2001). Since 2002, a joint opportunistic acoustic data (OAD) programme has been collecting, processing, and storing acoustic data from selected factory trawlers participating in the eastern Bering Sea pollock fishery (Barbeaux *et al.*, 2005).

Fish schools are formed when a number of fish aggregate together. Many descriptors are needed to describe a school, including morphometric, positional, and energetic descriptors, so univariate analysis alone cannot adequately describe this complex entity. In this paper, the schooling pattern of pollock is examined by comparing observations in the two fishing grounds (north of Unimak Island and areas around the Pribilof Islands) and two years (2003 and 2005) using a principal component analysis (PCA) of the school descriptors. The simultaneous fishing behavior was also analyzed using the PCA to study its relationship with the schooling pattern.

Materials and methods

The acoustic data were collected by a large factory trawler which mainly operated north of Unimak Island (UI) in the EBS from January to late February and in waters around the Pribilof Islands (PI) from late February to March (Figure 1). There were no changes in the way data were collected and logged. An uncalibrated 38 kHz Simrad ES60 split-beam echosounder with 1 ms nominal pulse length and 7.1º beam width was used for this work. Non-linear effects were removed using the SonarData software based on the algorithm of Ryan and Kloser (2004). While uncalibrated acoustic data are unsuitable for absolute fish-density estimation, the purpose of this study was to compare schooling patterns among years and fishing grounds detected by the same vessel, which should not be affected by the lack of calibration.

Echoview 3.30 software (SonarData, 2005) was used to process the raw data and classify the echo trace from 15 m below the surface to 0.5 m above the bottom. Pollock within the near-bottom zone are not included in this analysis, however, this problem is unimportant in the present study because all the schools are compared with the same methods. Walleye-pollock schools were detected and characterized using the school module in Echoview. The data collected only during the daylight hours when pollock show schooling behavior. To detect the schools, a volume-scattering strength (S_v) threshold of -70 dB re 1 m^{-1} was applied with other criteria as follows (Wilson *et al.*, 2003): The additional six input parameters for the school algorithm were minimum school length (40 m), minimum school height (5 m), minimum candidate length (5 m), minimum candidate height (2 m), maximum vertical-linking distance (5 m), and maximum horizontal-linking distance (20 m) (SonarData 2005).

The school descriptors generated by the Echoview software included morphometric descriptors (length *L*, thickness *T*, perimeter *P*, and area of schools *A*), positional descriptors (longitude, latitude, school depth *D*), and energetic descriptors (S_v and s_A, nautical area-scattering coefficient) (Simmonds and MacLennan, 2005). Based on these descriptors, two others namely the fractal dimension and the elongation were determined as follows. The fractal dimension (*F*) of a school is an index of shape complexity that depends on the relationship between the school perimeter and area (Nero and Magnuson, 1989). The elongation (*E*) is the ratio of school length to school thickness (Weill *et al.*, 1993). The Kolmogorov-Smirnov test (KS-test) (Zar, 1999) was used to test school descriptors for significant differences (at the level $\alpha = 0.05$) between the two years in the two fishing grounds. α was not adjusted for the multiple tests, because there were few descriptors and the aim was not to specify the significance level for the entire testing procedure (as one might do in a multiple-comparisons procedure).

To evaluate the effects of area and year, a PCA of the fish school descriptors was performed, using the statistical software 'R' (http://cran.r-project.org). The PCA was based on eight non-redundant variables: *L, T, P, A, D*, S_v, *F* and *E*. The schools were divided into four classes: U3 (Unimak Island in 2003), P3 (Pribilof Islands in 2003), U5 (Unimak Island in 2005) and P5 (Pribilof Islands in 2005). Prior to the PCA, outliers were identified by the multivariate method in **'**R**' (**Filzmoser *et al.*, 2008) which computes the Mahalanobis distances based on robust principal components. The distances were transformed so that a critical value from a chi-square distribution could be used to remove the outliers. To examine differences of the schooling pattern between classes, a between-class PCA which is a particular case of PCA with one qualitative instrumental variable (PCAIV) was performed (Dolédec and Chessel, 1994; Pélissier *et al.*, 2003). In this case, class was used as the instrumental variable so that the analysis focused on the differences that best distinguished the classes. This is done by minimizing the between-class inertia which is essentially the variance of the class determinations (Akhisar and Bener, 2002). A Monte-Carlo test was carried out to check the significance of differences between the classes (Romesburg, 1985).

Data collected simultaneously by a fisheries observer on the vessel were used to investigate how fishing behavior changes in response to the schooling pattern. The vessel track was separated into search and fishing paths by combining the observer-recorded deployment and retrieval times of the net with the acoustic data. In wintertime, the backscatter is mainly from pollock aggregations in both fishing grounds. Thus school density can also be indexed by the s_A for the whole water column averaged over 1 km as the elementary sampling distance unit (ESDU) for both search and fishing time. Similarly, the observer data were divided into 4 classes: U3, P3, U5 and P5. Seven variables were chosen for the PCA: fishing depth (*fd*), fish density during search (ss_A), fish density during fishing (fs_A), searching duration (*sD*), fishing duration (*fD*), searching speed (*sS*) and fishing speed (*fS*). The PCAIV and Monte-Carlo test were also carried out to examine the differences in fishing behavior between the school classes.

Results

A total of 2405 schools were identified after removing 216 outliers for the four classes: U3 (936); P3 (470); U5 (433), and P5 (566). The acoustic data were of generally higher quality in north Unimak in 2003 so there were many more schools in the U3 class. Univariate analysis of school descriptors revealed significant differences between the two years in the two fishing grounds for most descriptors (Table 1). The main Unimak-Island school descriptors were significantly different excepting school length and perimeter. The Pribilof-Islands schools were quite different between years except for the school length. There was no clear difference in the observed schools between fishing and searching periods (KS-test, $p>0.05$). Therefore, all schools were used to test for differences among the four classes using PCAIV.

Figure 2 shows the results of PCAIV in the factorial planes (1, 2) and (1, 3) from PCAIV. The eigenvalue histograms in Figure 2 give the percentage of the between-class inertia explained by different axes. The first axis accounted for 64% of the between-class inertia which was mainly defined by the school depth and area (on the left) and the elongation (on the right).

The second axis contributed 20% of the between-class inertia, mainly defined by the fractal dimension with little contribution from other descriptors. The third axis was positively related to elongation and negatively related to thickness. The school length and perimeter were unimportant variables as regards distinguishing the schools.

From the Monte Carlo test, the inertia percentage was significant ($p<0.001$), indicating important differences in the schools between classes. From the factorial planes in Figure 2, the four school classes were distinguished by different descriptors. P3 and P5 (Pribilof Islands 2003 and 2005) were both on the negative side of the first axis: in these years the Pribilof-Islands schools were deeper and larger in area than the Unimak-Island schools (Figure 3). Pollock form schools near the bottom, so the greater depth near the Pribilof Islands explains the deeper schools. The Pribilof-Islands schools were distinguished between years by the fractal dimension on the second axis (Figure 2). In 2005 the schools had a higher fractal dimension for both fishing grounds (Figure 3). U3 and U5 were situated on the positive side of the first axis which corresponds to shallower schools with smaller area. The Unimak-Island schools were distinguished between years by the elongation and thickness on the third axis. The schools in 2005 were less thick which resulted in a larger elongation for the same school length (Figure 3).

Most fishing-behavior variables differed significantly between the two years for both fishing grounds (Table 2). The results from PCAIV for fishing behavior are shown in Figure 4. The first axis accounted for 49% of the between-class inertia and was mainly a function of fishing depth and ss_A (on the left) and searching speed (on the right). An inverse relationship between ss_A and each of the descriptors fishing duration, searching and fishing speed occurred with both principle components (Figure 4), because the harvester tended to decrease the searching and fishing speeds and hauling time when denser fish aggregations were encountered. The search duration had a weaker relationship with searching speed and fishing duration. The second axis accounted for 43% of the between-class inertia, and was mainly defined by fishing duration and searching speed. The third axis accounted for only a small percentage of the between-class inertia and thus can be ignored.

The Monte-Carlo test also confirmed a significant difference in fishing behavior between classes ($p<0.001$). That in 2003 was distinguished from 2005 by longer fishing duration and higher searching speed (Figures 4 and 5). In 2003, the fishing behavior in the two areas was distinguished by fishing speed and search duration (Figure 4). The Pribilof tracks in 2003 had the highest fishing speed and fishing duration and the shortest search duration among the four classes (Figure 5). There was no significant difference between areas as regards the fishing behavior in 2005 although the fishing and searching speeds were slightly higher at Unimak Island (Table 2).

Discussion

The aim of this study was to examine the schooling pattern of pollock and to evaluate the relationship between fishing behavior and pollock-schooling patterns in the eastern Bering Sea. Acoustic data from only one factory trawler were used here because in order to avoid variability due to different acoustic systems and vessels. The same skipper and fishing mate have been on this vessel for the last 10 years. There were no material changes in the acoustic equipment or the vessel machinery during the study period, so the observions describe real differences in schooling patterns and fishing behaviors. Further, the application of a noise threshold and exclusion of problematic data ensured reliable results. The school descriptors mostly relative indicators that should be robust to calibration changes. That is not the case for the energetic descriptors, thus apparent changes in the fish density could be caused by calibration variability. Further, the presence or proximity of other fishing vessels may induce fish avoidance and thus a lower density of observed fish. Given the similar and consistent practices of the pollock fleet, however, this problem is not expected to have any strong impact on the present study. The results should be applicable to other fishing vessels operating in a similar manner in the EBS.

Nevertheless, it would be wise to study different vessels in the same area to assure this conclusion.

The schools had different structures between years in both fishing grounds. This may be due to changes in the physical environment, especially the water temperature. There was a larger biomass in 2003 than in 2005 (Ianelli *et al.*, 2007) which would certainly affect the schooling patterns. Although the winter temperature at the seabed in the study area is not known directly, there is some information from elsewhere concerning the winter conditions in 2003 and 2005. The mean sea-surface temperature (SST) for January through April at 56°52´N, 164°3´W, where a moored data buoy is maintained by the NOAA, was 2.44°C and 1.95°C in 2003 and 2005, respectively (http://www.beringclimate.noaa.gov). The winter SSTs at the Pribilof Islands were 2.46°C and 1.78°C in the same years. Both datasets indicate a warmer winter in 2003.

A higher biomass of fish may result in larger and denser schools or an expanded range of the stock itself (Aukland and Reid, 1998). In this study, higher biomass resulted in either larger schools or a greater area occupied by the stock, but did not result in higher school density in both areas in 2003 (Table 1). The schools at Unimak Island were larger in 2003 with no increase of the occupied area because the stock was constrained by ice cover. In the Pribilof Islands area, however, the stock occupied a larger area in 2003 (Figure 1) but the schools were smaller and of lower density. The lower density in that year is probably due to the warmer winter. Although both the size and density of schools may affect the fishing behavior, it is primarily motivated by density changes. In both fishing grounds, the fish densities were lower in 2003 which resulted in longer fishing durations and higher fishing speeds. The density of schools also affected fishing speed and fishing duration (Figure 4).

The results of PCAIV showed that three morphometric descriptors (fractal dimension, thickness, and elongation) were useful for distinguishing schools among the four classes. The fractal dimension is a smoothness measure of the school boundary; a higher value indicates a school with a more complex shape. In 2005 the schools had higher fractal dimensions in both fishing grounds, suggesting that cool conditions result in more complex school shapes especially for the large schools in the Pribilof Islands. There was an inverse relationship between thickness and elongation (Figure 2). Because the school length was much the same between the two years, pollock evidently form schools with different thicknesses rather than lengths in response to varying conditions. The water column is well mixed during winter in the EBS. The homogeneous vertical conditions may allow fish to spread in depth more easily than they could in stratified water.

Data from only one vessel were used to compare school patterns and their effect on fishing behavior. More studies are needed to examine the effect of different fishing practices among vessels and any interactions that might occur depending on the spatial activity pattern of the fleet.

Acknowledgements

This research is funded by a grant from the Pollock Conservation Cooperative Research Center to the University of Alaska Fairbanks (UAF). Additional funds for student support were provided by the Alaska Fisheries Science Center through the Cooperative Institute for Arctic Research (NA17RJ1224) at UAF.

References

Akhisar, İ., and Bener, A. 2002. Hierarchy analysis of three-way tables. Hacettepe Journal of Mathematics and Statistics, 31: 37-43.

Aukland, R., and Reid, D. 1998. The impact of changing stock size on the aggregative behaviour of North Sea herring. ICES CM 1998/J: 2. 19 pp.

Barbeaux, S.J., Dorn, M., Ianelli, J. and Horne, J. 2005. Visualizing Alaska pollock (*Theragra chalcogramma*) aggregation dynamics. ICES CM 2005/U: 01. 12 pp.

Dolédec, S., and Chessel, D. 1994. Co-inertia analysis: an alternative method for studying species-environment relationship. Freshwater Biology, 31: 277-294.

Filzmoser, P., Maronna, R., and Werner, M. 2008. Outlier identification in high dimensions. Computational Statistics and Data Analysis. 52: 1694-1711.

Honkalehto, T., Williamson, N., Hanson, D., McKelvey, D., and de Blois, S. 2002. Results of the echo Integration-trawl survey of walleye pollock (*Theragra chalcogramma*) conducted on the southeastern Bering Sea shelf and in the southeastern Aleutian basin near Bogoslof Island in February and March 2002. Alaska Fisheries Science Center Processed Report 2002-02. 47 pp.

Ianelli, J. N., Barbeaux, S., Honkalehto, T., Kotwicki, S., Aydin, K. and Williamson, N. 2007. Eastern Bering Sea Walleye Pollock. North Pacific Fishery Management Council, Bering Sea and Aleutian Islands Stock Assessment and Fishery Evaluation Report. pp.41-138.

Mackinson, S., and Kooij, J.V.D. 2006. Perceptions of fish distribution, abundance and behaviour: Observations revealed by alternative survey strategies made by scientific and fishing vessels. Fisheries Research, 81: 306-315.

Marchal, E., and Petitgas, P. 1993. Precision of acoustic fish abundance estimates: separating the number of schools from the biomass in schools. Aquatic Living Resources, 6: 211–219.

Melvin, G.D., Li, Y., Mayer, L.A., and Clay, A. 2002. Commercial fishing vessels, automatic acoustic logging systems and 3-D data visualization. ICES Journal of Marine Science, 59: 179–190.

Melvin, G.D., Stephenson, R.L., Power, M.J., Fife, F.J., and Clark, K.J. 2001. Industry acoustic surveys as the basis for in-season decisions in a comanagement regime. In: Funk, F., J. Blackburn, D. Hay, A.J. Paul, R. Stephenson, R. Toresen, and D. Witherell, (Eds.), Herring Expectations for a New Millennium. University of Alaska Sea Grant, AK-SG-01-04, Fairbanks, pp. 675–688.

NRC (National Research Council). 1996. The Bering Sea Ecosystem. National Academies Press, Washington, DC. 307 pp.

Nero, R.W., and Magnuson, J.J. 1989. Characterization of patches along transects using high-resolution 70-kHz integrated acoustic data. Canadian Journal of Fisheries and Aquatic Sciences, 46: 2056-2064.

Pélissier, R., Couteron, P., Dray, S., and Sabatier, D. 2003. Consistency between ordination techniques and diversity measurements: two strategies for species occurrence data. Ecology, 84: 242–251.

Reid, D.G. 2000. Report on echo trace classification. ICES Cooperative Research Report 238. 107 pp.

Romesburg, H. C. 1985. Exploring, confirming and randomization tests. Computers and Geosciences, 11: 19–37.

Ryan, T.E., and Kloser, R.J. 2004. (pers. Comm.) Quantification and correction of a systematic error in Simrad ES60 Echosounders. ICES FAST, Gdansk. 9 pp.

Simmonds, J., and MacLennan, D.N. 2005. Fisheries Acoustics: Theory and Practice, 2nd edn. Blackwell Science, Oxford. 437 pp.

SonarData 2005. Echoview. Version 3.30. <http://www.sonardata.com/webhelp/Echoview.htm>. Tasmania, Australia. May 2005.

Weill, A.C., Scalabrin, C., and Diner, N. 1993. MOVIES-B: an acoustic detection description software. Application to shoal species classification. Aquatic Living Resources, 6: 255–267.

Wilson, C.D., Hollowed, A. B., Shima, M., Walline, P., and Stienessen, S. 2003. Interactions between commercial fishing and walleye pollock. Alaska Fishery Research Bulletin, 10: 61-77.

Zar, J.H. 1999. Biostatistical analysis. Prentice-Hall, New Jersey. 663 pp.

Table 1. Average school descriptors in two areas (U: Unimak Island, P: Pribilof Islands) in two years (3: 2003, 5: 2005). The schools in two areas were compared within areas using the KS-test; the p-value (*p*) is the significance level of differences between the two years.

	U3	U5	*p*	P3	P5	*p*
L	61.5	64.1	0.08	63.2	68.9	0.06
T	11.9	10.3	0.00	11.5	13.9	0.00
P	276.5	279.2	0.46	273.9	361.9	0.00
A	332.2	284.9	0.00	359.7	391.9	0.02
D	86.2	87.4	0.23	102.2	101.0	0.01
S_v	-44.2	-43.2	0.00	-44.1	-43.6	0.02
F	1.47	1.51	0.00	1.45	1.52	0.00
E	5.4	7.1	0.00	6.2	5.4	0.00

Table 2. Average variables for fishing behavior in two areas (U and P) in two years (3: 2003, 5: 2005). The variables in two areas were compared within areas using the KS-test; the p-value (*p*) is the significance level of differences between the two years.

	U3	U5	*p*	P3	P5	*p*
fd	84.8	91.5	0.00	105.4	105.2	0.51
ss_A	1178.0	1461.6	0.07	840.2	2020.6	0.01
fs_A	1612.7	1331.3	0.26	1454.1	1824.4	0.43
sD	219.2	166.5	0.03	167.5	182.5	0.00
fD	135.1	106.2	0.04	187.3	82.2	0.00
sS	6.3	5.6	0.00	6.7	5.2	0.00
fS	5.3	5.0	0.00	5.7	4.8	0.00