Tracking and Speed Evaluation of cod Schools in the 2014 Nordic Seas Experiments

By

Mordechai Ben Mordechai

Submitted to the Department of Mechanical Engineering in Partial fulfillment of the Requirements for the Degree of

Master of Science in Mechanical Engineering

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Signature redacted

Signatures of Authors..........................................................

Department of mechanical engineering

Jan 15, 2018

Signature redacted

Certified by........................................................................

Nicholas C. Makris
Director of the Center for Ocean Engineering
Thesis Supervisor

Signature redacted

Accepted by.................................................................

Rohan Abeyaratne, professor
Department of mechanical engineering
Chairman, Committee on Graduate Students
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ABSTRACT

Observing and tracking fish shoals over long periods enables us to understand and establish the behavior processes of fish shoals in their ecosystem and different phases of migration, spawning and feeding. In the past, researchers have observed fish shoals for days and even weeks for that purpose. However, previous studies were limited by conventional methods such as echosounders and acoustic tagging of fish, which are only able to track one or a few schools at a time with low spatial sampling.

In 2014, the Ocean Acoustic Waveguide Remote Sensing system (OAWRS) was employed in the Nordic Seas for the study of fish shoal behavior in that region. The OAWRS system enables the study of multiple shoals simultaneously over long periods. The experiment took place in three main spawning areas on the shores of Norway, and lasted from Feb 18 to Mar 8 for the study of three commercially important species: cod, herring, and capelin.

In this paper, we use the data gathered by the OAWRS system in the Nordic Seas experiment to track fish schools in the Lofoten area by comparing two methods of calculating their track: 1) calculating and tracking the centroid of the school, and 2) calculating the shift of the school between pings to establish its new position. We calculate the speed of schools along theirs tracks and compare it with known cod speeds. We find that the general heading of all the schools investigated here is towards offshore. We suggest that the speed calculated for these small scale schools might aid in identifying a school’s species, when lacking other means.

Thesis Supervisor: Nicholas C. Makris
Title: Director of the Center for Ocean Engineering
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Table of Content

ABSTRACT....................................................................................................................... 3

Acknowledgements......................................................................................................... 4

1 Introduction ............................................................................................................... 11

2 Method....................................................................................................................... 11

   2.1 Frequency response analysis............................................................................ 13

   2.2 Tracking schools – Centroid & Cross-Correlation (COR)......................... 14

   2.3 Schools’ speeds and heading........................................................................... 18

3 Schools Frequency Analysis..................................................................................... 20

   3.1 School #1 frequency response.................................................................... 21

   3.2 School #2 frequency response.................................................................... 22

   3.3 School #3 frequency response.................................................................... 23

   3.4 School #4 frequency response.................................................................... 24

   3.5 School #5 frequency response.................................................................... 25

   3.6 Schools species estimation........................................................................... 25

4 Schools tracking ....................................................................................................... 26

   4.1 School #1 track............................................................................................ 26

   4.2 School #2 track............................................................................................ 28

   4.3 School #3 track............................................................................................ 29

   4.4 School #4 track............................................................................................ 30
List of Figures

Figure 1 - Love model for Cod target strength by modeling its swimbladder, red dots indicate OAWRS ping frequencies of 850,955,1125,1335,1465,1600Hz............................................................. 14

Figure 2 - School #1 tracks with one ping spacing at March 7 23:52:39 to March 8 02:18:29. Shows 2 tracks: 1) red - track calculated by cross-correlating between every ping; 2) blue - track calculated by tracking the centroid in each ping, every ping................................................................. 18

Figure 3 - Frequency response for school #1 in Lofoten region, at times Mar 08 - 00:15:09, 01:06:49, 01:34:19 ............................................................................................................. 21

Figure 4 - Frequency response for school #2 in Lofoten region, at times Mar 08 - 00:15:09, 01:06:49, 01:34:19 ................................................................................................................................................ 22

Figure 5 - Frequency response for school #3 in Lofoten region, at times Mar 08 - 00:15:09, 01:06:49, 01:34:19 ................................................................................................................................................ 23

Figure 6 - Frequency response for school #4 in Lofoten region, at times Mar 05 - 17:50:49, 19:09:09 ................................................................................................................................................ 24

Figure 7 - Frequency response for school #5 in Lofoten region, at times Mar 05 - 17:50:49, 19:09:09 ................................................................................................................................................ 25

Figure 8 - School #1 tracks on a five ping average SPL map at start time with six ping spacing at March 7 23:52:39 to March 8 02:18:29. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping............................................................................................................. 27

Figure 9 - School #2 tracks on a 5 ping average SPL map at start time with six ping spacing at March 7 23:52:39 to March 8 02:05:09. Shows 2 tracks: 1) red - track calculated by cross-
correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping .................................................. 28

Figure 10 - School #3 tracks on a 5 ping average SPL map at start time with six ping spacing at March 7 23:50:59 to March 8 02:23:29. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping .................................................................................................................. 29

Figure 11 - School #4 tracks on a 5 ping average SPL map at start time with six ping spacing at March 5 17:53:19-19:43:19. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping.. 30

Figure 12 - School #4 tracks on a 5-ping average SPL map at time March 5 17:58:19. First ping that COR track accumulate an offset from the centroid track .................................................. 31

Figure 13 - School #4 tracks on a 5 ping average SPL map at time March 5 18:03:19. Second ping that COR track accumulate an offset from the centroid track .................................................. 32

Figure 14 - School #5 tracks on a 5 ping average SPL map at start time with six ping spacing at March 5 17:49:59-19:24:59. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping.. 33

Figure 15 - School #5 tracks on a 5 ping average SPL map at time March 5 17:59:59. Emergence of second school causes the centroid to move rapidly while the cross-correlation path hardly changes since the correlation is maximized at the first school position .................................................. 34

Figure 16 - School #5 tracks on a 5-ping average SPL map at time March 5 18:20:49. In this ping the two schools that moved together merge and keep moving throughout the track .................. 35

Figure 17 - school #1 speeds calculated throughout the track: 1) blue – speed calculated along the track and using the positions of the centroid track; 2) red – speed calculated using the track and

8
positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.

Figure 18 – school #2 speeds calculated throughout the track: 1) blue – speed calculated along the track and using the positions of the centroid track; 2) red – speed calculated using the track and positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.

Figure 19 – school #3 speeds calculated throughout the track: 1) blue – speed calculated along the track and using the positions of the centroid track; 2) red – speed calculated using the track and positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.

Figure 20 – school #4 speeds calculated throughout the track: 1) blue – speed calculated along the track and using the positions of the centroid track; 2) red – speed calculated using the track and positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.

Figure 21 – school #5 speeds calculated throughout the track: 1) blue – speed calculated along the track and using the positions of the centroid track; 2) red – speed calculated using the track and positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.
List of Tables

Table 1 - speeds reported for cod lab experiments [2]............................................................... 18

Table 2 – summation of quantitative results of schools’ tracks with reference to speed, heading, angle to ship, schools’ area and max cross-correlation coef............................................................... 42
1 Introduction

Conventional means of tracking and observing the migration patterns of fish shoals usually enable the study of one or just a few fish shoals. Rose [1] reports a three year experiment on the north-east newfoundland shelf studying the migration patterns and velocities of Atlantic cod using echosounders. When tracking fish shoals using echosounders, the ship must intersect the shoal and collect data directly above the shoal. Another method for tracking fish shoals is acoustic tagging. Comeau et al. [13] ran an experiment using acoustic tagging on multiple cod fish and deploying sixty-nine acoustic receivers that monitored the fish. This method monitors a larger area, but the observations are spatially highly undersampled.

The Ocean Acoustics Waveguide Remote Sensing system (OAWRS) allows for instantaneous mapping of underwater regions [3], enabling continuous observation and tracking of fish schools [3][6]. In the Nordic Seas Experiment conducted in 2014, the OAWRS system transmitted and received acoustic broadband signals, which propagated through the continental shelf in a waveguide. The OAWRS system then received the scattered signals and generated a map of features in the ocean, such as seafloor bathymetry and fish schools.

In the experiment four areas were mapped: 1) Alesund area on February 18-21; 2) Lofoten area near Rost on February 23; 3) Finnmark area from February 26 to March 4; 4) Lofoten area near Andenes at Mar 5-8. This paper focus on the data collected at the Lofoten area near Andenes Mar 5-8.

In this work, we analyzed small fish schools that were observed by the OAWRS system in the Lofoten area near Andenes, which is known to be a major spawning area for cod fish [4],[12].
Migration and behavior of large schools have been studied previously [6], however none of the analyses in this region have focused on small schools.

Cod speeds have been researched and measured previously [1], but either under lab conditions where the speed of a single fish was measured [2],[10] or for large schools with a time interval of days or hours [1], giving only an average speed over long time intervals. In the OAWRS system, the spacing between two consecutive pings is 50 seconds [3], which enables us to study the velocity of cod shoals at much smaller time increments. With the OAWRS system mapping tens of square kilometers in a single ping, we are able to observe an entire school at a specific moment and follow the evolution of the school over time. Furthermore, the large detection range of the OAWRS system allows us to observe and track multiple schools simultaneously. The increased areal coverage and spatial resolution of the OAWRS system enable us to study the speed, heading, area, and shape of small schools.

In this paper we analyze the frequency response of the schools studied and compare it to the Love model for cod swimbladder resonance [7]. We compare two methods for tracking the schools: 1) finding the centroid of the school in every ping and using it as a representation of the school’s position, 2) finding the maximum cross correlation coefficient between two pings to determine the shift in the position of the school. Using the tracks from the two methods, we calculate the schools’ speeds (centroid and cross correlation) along the track of the schools. We find that the speed of the schools match known cod speeds from the literature [1],[2],[10]. We also calculate the heading of the schools and find that all schools studied here are moving away from the shore.

In Chapter 2 we describe of calculation of frequency analysis, school tracking, and speed calculation. In Chapter 3 we show the frequency response analysis results: each school examined
seems to be most likely cod. Chapter 4 shows the school tracking results, where the paths of schools are determined using two methods of calculation (centroid and cross correlation). In Chapter 5 we show the speed of the schools over time. Chapter 6 includes a summary of the results and a discussion.

2 Method

2.1 Frequency response analysis

The OAWRS system basic operation is to send out acoustic pings and, using an array of acoustic receivers, record the Sound Pressure Level returned from any scatterers in the vicinity. The time interval between two consecutive pings was 50 seconds that allow considering the SPL mapping by the OAWRS to be instantaneous\cite{5}. With mapping large areas with magnitude of hundreds of squared kilometers, we are able to observe and study full size schools and track them over time. In the Nordic Seas experiments, the pings were of six different frequencies: 850,955,1125,1335,1465,1600Hz, where all pings consisted of 3 frequencies: 955,1335Hz and the third frequency alternated between the others with every ping.

In order to identify a certain aggregation of fish and try to match it to a certain species, we use the scattering strength of the school at the different frequencies and compared it to the Love model for cod (Figure 1).
Cod frequency response according to the Love model

Fish depth = 50.0-80.0 m, NBD = 65.0 m

Figure 1 - Love model for Cod target strength by modeling its swimbladder, red dots indicate OAWRS ping frequencies of 850, 955, 1125, 1335, 1465, 1600 Hz.

It is plain to see that the cod’s frequency response, in our frequencies of interest, is flat and around the -30 dB.

Scattering strength calculation for the schools investigated were done according to [6].

2.2 Tracking schools – Centroid & Cross-Correlation (COR)

Speed calculation of very large schools was investigated before and was found to be accurately done by means of optical flow, which enables to calculate the flow of mass (fish) inside the school [8], or by means of Doppler analysis [9]. However, for small-scale schools these methods do not apply. Since we are dealing with small size schools with well-defined contours, by a threshold that is easily determined, we can extract the contour itself, and calculate the school’s centroid and track that centroid over time.

We introduce two methods for tracking the schools:
a) Centroid tracking – calculating the centroid for each ping (frame)

b) Cross-correlation tracking – after cutting out the school from two pings, we cross correlate the two. The movement of the school is actually the shift in pixels represented by the maximum cross correlation coefficients.

Centroid

After marking the contour of the school we calculate the centroid of the contour by:

\[
C_x = \frac{\sum^{n-1}_i (x_i + x_{i+1})(x_i y_{i+1} - x_{i+1} y_i)}{6A}
\]

\[
C_y = \frac{\sum^{n-1}_i (y_i + y_{i+1})(y_i x_{i+1} - y_{i+1} x_i)}{6A}
\]

Where \(x_i, y_i\) are the contour coordinates and \(A\) is the contour polygon area. The centroid of the contour was saved in every ping and for this method of tracking represented the school position. Calculation of all other parameters for centroid method were done with reference to these coordinates in every frame.

Tracking by Cross-Correlation (COR) & cross correlation coef.

Although centroid tracking allows high accuracy with the position of the school and thus with the speed, it does not necessarily pin point the arrangement of the school with respect to the distribution of the SPL over the contour. For that reason, we used a method of cross correlation between pings to establish the point position of the school. For every ping, the school was identified and contoured in the same manner for the centroid tracking. By setting all other pixels to zero, we used normalized cross correlation (normxcorr2 function in MATLAB) to find the shift
in the position of the school from the last position recorded. The normalized cross correlation function follows the equation:

\[ y(u, v) = \frac{\sum_{x,y}[f(x,y) - \bar{f}][t(x-u,y-v) - \bar{t}]}{\left(\sum_{x,y}[f(x,y) - \bar{f}]^2\sum_{x,y}[t(x-u,y-v) - \bar{t}]^2\right)^{0.5}} \]

Where \( f(x, y) \) is the next ping, \( \bar{f} \) is the mean of the school (patch from previous ping that includes just the school and outside of the contour is 0), \( \bar{t} \) is the mean of the target frame in the area of the school patch.

Given the cross correlation coefficients, the shift of the school is determined by the coefficient with the maximum value. The shift calculated is added to last position calculated in the previous ping. Cross-correlation is important in order to establish whether the school is coherently migrating, which is applicable when the cross-correlation coefficient is bigger than roughly 0.5 [6].

**Time interval for tracking**

Tracking the schools was firstly done in every consecutive ping. As can be seen in Figure 2- School #1 tracks with one ping spacing at March 7 23:52:39 to March 8 02:18:29. Shows 2 tracks: 1) red - track calculated by cross-correlating between every ping; 2) blue - track calculated by tracking the centroid in each ping, every ping that resulted in an additive error which placed the position of the school, in the COR calculation, in a huge offset. The calculation of the additive error with every ping depends on the pixel resolution. Each pixel in the OAWRS image equals to a 30m × 30m patch. Considering that, we can get ±15m error in any direction with every ping. As shown in Figure 2 for school #1 we got a ~1.55km offset from the centroid position of the school, and the COR position resulted outside of the school itself.
Tracking the centroid in one ping spacing gave accurate results as it tracked the centroid of the school in every frame and there was no additive error – computation of the centroid is not restricted to pixilation. However, the track of the school is very noisy since the centroid of the school depends highly on range and angular resolution.

To reduce those errors while maintaining the track to represent the actual path that the school went through we used six ping spacing to find the track of the school. We found that it represented the actual track while eliminating most of the noisy movement and limiting the additive error for COR computation.
Figure 2: School #1 tracks with one ping spacing at March 7 23:52:39 to March 8 02:18:29. Shows 2 tracks: 1) red - track calculated by cross-correlating between every ping; 2) blue - track calculated by tracking the centroid in each ping, every ping

Note that the interval was six ping apart as long as the school was visible and distinct from background. Where other time intervals were employed they are annotated in the results.

2.3 Schools' speeds and heading

Cod speeds has been reported in a number of papers[1], [2], [10],[11]. For individual fish under lab experiments three different speeds were reported [2] and are detailed in Table 1.

<table>
<thead>
<tr>
<th>Speed range and endurance</th>
<th>Mean speed</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_{\text{crit}} = 0.4349-0.7119 ) (m/sec) Hours</td>
<td>(&lt; U_{\text{crit}} &gt; = 0.584 ) (m/sec)</td>
<td>Migration, routine swimming/foraging, spawning in moderate current fields</td>
</tr>
<tr>
<td>( U_{\text{burst}} = 0.9093-1.2284 ) (m/sec) Minutes</td>
<td>(&lt; U_{\text{burst}} &gt; = 1.033 ) (m/sec)</td>
<td>Trawl/predator avoidance, maneuvering through strong current fields</td>
</tr>
<tr>
<td>( U_{\text{spint}} = 0.9103-2.5829 ) (m/sec) Seconds</td>
<td>(&lt; U_{\text{spint}} &gt; = 1.451 ) (m/sec)</td>
<td>Predator avoidance; prey capture</td>
</tr>
</tbody>
</table>

Table 1 - speeds reported for cod lab experiments[2]

Another research led by Rose (1995) [1] observed cod schools over weeks and reported a daily mean speed of up to 0.28 m/sec. This measurement is calculated over the span of weeks and cannot reflect instantaneous speed that is calculated in this paper. However, it can be a reference of large schools movement. In the same research, Rose reported that the schools that were tracked kept the same heading of 198°, in each year. Rose attributed this to a “migration highway” which migrating cod would use partially due to thermal circumstances [1].
Once representing the school’s movement by the methods described in the previous chapter, speed and heading of the school was calculated for both types of tracks (centroid & COR). Speed was calculated as geometric distance between two positions on the track given by:

\[ U = \frac{\sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}}{\Delta t} \text{ (m/sec)} \]

This equation finds the average speed of the school where:

- \( U \) – Average speed between two pings \( i \) & \( i+1 \) (six pings apart as detailed in chapter 2.2)
- \( x_{i,i+1}, y_{i,i+1} \) – Coordinates of school’s position in the two pings calculated by centroid & COR methods
- \( \Delta t \) – Time interval between the two pings = number of pings \( X \) 50 seconds

We calculated the mean heading of the school to find correlations among the schools’ tracks. Heading of the school was calculated with respect to the north heading which is the positive y-axis and positive angle is counterclockwise of the y-axis. Heading calculation followed the equation:

\[ \text{heading} = \arctan \left( \frac{x_{i+1} - x_i}{y_{i+1} - y_i} \right) \text{ (°)} \]
3 Schools Frequency Analysis

The Lofoten region is a known area for spawning among cod fish [4],[12] and there we noticed a large amount of small cod schools, as of a few hundred square meters. The Lofoten region was investigated towards the end of the experiment dating March 5-8, while the small schools were mainly on March 5 and three were sighted on March 8. For confirmation as of the fish species to be cod, we present a frequency analysis for the schools investigated. In Figure 2 is the frequency response according to the Love model for cod [7]. It shows that at the frequency range that the OAWRS system operate we should get a flat frequency response.

Since cod are demersal species, their frequency response might be affected by their depth and therefore be influenced by seabed scattering as well. For that reason the frequency response analysis was conducted on three different times (pings) for us to get more samples. A Least Square linear fit was done using MATLAB to estimate the slope of the frequency response.
3.1 School #1 frequency response

Figure 3 - Frequency response for school #1 in Lofoten region, at times Mar 08 - 01:06:49, 01:34:19

Figure 3 depicts the frequency response of school #1 in two different pings over the night of March 7-8. We can see that the span of the response level is not larger than 3Db, which is fairly flat.
3.2 School #2 frequency response

Figure 4 depicts the frequency response of school #2 in three different pings over the night of March 7-8. We can see that level span of the response here is also about 3dB.

*Figure 4 - Frequency response for school #2 in Lofoten region, at times Mar 08 - 01:06:49, 01:34:19*
3.3 School #3 frequency response

Figure 5 depicts the frequency response of school #3 in three different pings over the night of March 7-8. In pings 01:06:49 and 01:34:19 the response span is about 2-3dB and consistent between the pings.

Figure 5 - Frequency response for school #3 in Lofoten region, at times Mar 08 - 01:06:49, 01:34:19
3.4 School #4 frequency response

Figure 6 depicts the frequency response of school #4 in two different pings over the March 5. In pings 18:45:49 & 19:09:09 we get a span of 2-3dB in the response levels which can be considered as a flat response.

![Frequency response in Lofoten region - shoal 4 Mar 05](image)

*Figure 6 - Frequency response for school #4 in Lofoten region, at times Mar 05 – 17:50:49, 19:09:09*
3.5 School #5 frequency response

Figure 6 depicts the frequency response of school #4 in two different pings over the March 5. We can see that ping 19:09:09 has a response level of a 1dB span which practically flat. Ping 18:45:49 shows a span of 4dB between frequencies which but with a fluctuating trend and not a linearly increasing trend.

3.6 Schools species estimation

As we are dealing with the Lofoten region, which is known to be a cod dominant spawning grounds[4][12], and the fact that the frequency response of the schools is mostly flat, as we expected by the model in Figure 1, it is most likely that these schools are cod.

In chapter 4 we track these schools over time and calculate their instantaneous speed and the mean speed over the track. We find correlation between the schools’ speeds and known cod speeds.
4 Schools tracking

In chapter 2.2 we describe the method of how the schools were tracked. In this chapter, we bring the tracking results for all the schools. We show that tracking the schools using the COR method manages to keep track with the centroid method, but still gets some

4.1 School #1 track

School #1 was tracked for 148 minutes starting at March 7 23:52:39 until March 8 02:18:29. Figure 8 shows the tracks calculated by cross-correlation and by Centroid.
Shoal #1 track from Mar 07 23:52:39 to Mar 08 02:18:29 (168 pings)

90
7658-
Cross-correlation track, 6 ping spacing

- Center Of Mass track, 6 ping spacing

85
7657

School

Feature #1

School

Range (km)

Figure 8 - School #1 tracks on a five ping average SPL map at start time with six ping spacing at March 7 23:52:39 to March 8 02:18:29. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping

The tracks mostly correlate to each other and the points along the tracks are inside the school’s contour in all pings investigated. Towards the end of the track we notice that the COR track has sidestep (Feature #1) and then returns to following the centroid track. Feature #1 seems to happen due to the ship turning at high rate and placing school #1 at the end fire. At the endfire, the school becomes elongated and it centroid stays very close but the cross-correlation peaks at another position inside the contour.
4.2 School #2 track

School #2 was tracked for 135 minutes starting at March 7 23:52:39 until March 8 02:05:09. Figure 9 shows the tracks calculated by cross-correlation and by Centroid.

Figure 9 - School #2 tracks on a 5 ping average SPL map at start time with six ping spacing at March 7 23:52:39 to March 8 02:05:09. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping.

Since the ship’s track coincided with the school’s track, at some time intervals it was impossible to distinguish the school from the saturated field. Those intervals are depicted in Figure 9.
4.3 School #3 track

School #3 was tracked for 153 minutes starting at March 7 23:50:59 until March 8 02:23:29. Figure 10 shows the tracks calculated by cross-correlation and by Centroid.

![Shoal track from Mar07 23:50:59 to Mar08 02:23:29 (175 pings)](image)

Figure 10 - School #3 tracks on a 5 ping average SPL map at start time with six ping spacing at March 7 23:50:59 to March 8 02:23:29. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping.
4.4 School #4 track

School #4 was tracked for 110 minutes starting at March 5 17:53:19-19:43:19. Figure 11 shows the tracks calculated by cross-correlation and by Centroid.

![Shoal 4 track from Mar05 17:53:19 to Mar05 19:43:19 (120 pings)](image)

*Figure 11 - School #4 tracks on a 5 ping average SPL map at start time with six ping spacing at March 5 17:53:19-19:43:19. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping*

We can see that most of the offset that the COR track is accumulated at the first two iterations of calculation. Figure 12 and Figure 13 show the evolution of the school in those two pings. This
offset can be attributed to the fact that the school area on the SPL map got larger over this time (17:53:19-17:58:19) and although the centroid of the school has not changed by much the correlation shift was much larger. In the following ping investigated (18:03:19 - Figure 13) we can see that the shift of both tracks was similar while keeping the offset gained in the previous ping.

Figure 12 - School #4 tracks on a 5-ping average SPL map at time March 5 17:58:19. First ping that COR track accumulate an offset from the centroid track.
In Figure 13 we can see that the school almost doubled its area and yet the shift in both tracks is similar. The enlargement of the school and its being elongated is due to the ship turning and placing the school near the end-fire of the array.

Figure 13 - School #4 tracks on a 5 ping average SPL map at time March 5 18:03:19. Second ping that COR track accumulate an offset from the centroid track.
4.5 School #5 track

School #5 was tracked for 95 minutes starting at March 5 17:49:59-19:24:59. Figure 14 shows the tracks calculated by cross-correlation and by Centroid.

Figure 14 - School #5 tracks on a 5 ping average SPL map at start time with six ping spacing at March 5 17:49:59-19:24:59. Shows 2 tracks: 1) red - track calculated by cross-correlating between every six ping; 2) blue - track calculated by tracking the centroid in each ping, every six ping

The centroid position, at the third ping investigated (17:59:59 – Figure 15), moves a large distance compared to the position of the COR track. As shown in Figure 15, the school doubled it size and
actually seems to comprise of two schools that are moving coherently and eventually merge. For that reason we contoured for our calculations the two schools as one starting of ping 17:59:59. Figure 16 shows the merge of the two schools while the offset remains between the two tracks.

Figure 16 shows the merge of the two schools while the offset remains between the two tracks.

**Figure 15 - School #5 tracks on a 5 ping average SPL map at time March 5 17:59:59. Emergence of second school causes the centroid to move rapidly while the cross-correlation path hardly changes since the correlation is maximized at the first school position.**
Figure 16 - School #5 tracks on a 5-ping average SPL map at time March 5 18:20:49. In this ping the two schools that moved together merge and keep moving throughout the track.

5 School speed calculations

For the tracks that were presented in chapter 3, we present here the calculated speeds for every school and track (centroid & COR). In chapter 5 we compare the speeds presented here with speeds that were measured for cod in laboratories and in open water. Calculation of the speeds is shown in chapter 2.
5.1 School #1 speeds

Figure 17 shows the speeds of the two tracks of school #1 throughout the track.

![Graph showing speed variations](image)

**Figure 17** - school #1 speeds calculated throughout the track: 1) blue - speed calculated along the track and using the positions of the centroid track; 2) red - speed calculated using the track and positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.

Indicated in Figure 17 is a very big speed difference between the COR and the centroid track. As explained in chapter 4.1 the big difference is due to the school getting to the endfire of the array in the interval of the two pings investigated (pings at times 01:25:59-01:30:59).
5.2 school #2 speed

Figure 18 shows the speeds of the two tracks of school #2 throughout the track.

![Graph showing school #2 speeds](image)

**Figure 18** – school #2 speeds calculated throughout the track: 1) blue – speed calculated along the track and using the positions of the centroid track; 2) red – speed calculated using the track and positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.
5.3 School #3 speeds

Figure 19 shows the speeds of the two tracks of school #3 throughout the track.

![Graph showing speeds](image)

This graph illustrates the speeds of school #3 through the track. The blue line represents the speed calculated along the track and using the positions of the centroid track, while the red line indicates the speed calculated using the track and positions in the COR track. Dashed lines denote the mean speed of the speeds calculated according to colors.
5.4 School #4 speeds

Figure 20 shows the speeds of the two tracks of school #4 throughout the track.

Figure 20 – school #4 speeds calculated throughout the track: 1) blue – speed calculated along the track and using the positions of the centroid track; 2) red – speed calculated using the track and positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.
5.5 School #5 speeds

Figure 21 shows the speeds of the two tracks of school #5 throughout the track.

Figure 21 – school #5 speeds calculated throughout the track: 1) blue – speed calculated along the track and using the positions of the centroid track; 2) red – speed calculated using the track and positions in the COR track. Dashed lines are the mean speed of the speeds calculated according to colors.
6 Characterization of schools and discussion

Chapters 4-5 detail the results for the five schools that were tracked. Table 1 displays all the information derived from tracking the schools. The attributes that were derived are: mean speed of COR & centroid tracks, mean heading of tracks, mean value of the maximum of cross correlation coefficient throughout the tracking procedure.

Figures 8-16 show the tracks we calculated in both methods. We can see that tracks follow each other throughout the tracks, with some small offset between the two tracks in every frame. It is noticeable that the COR track is more susceptible to contour changes that happen frequently due to the ship turning and putting the schools at the endfire of the receiver array. And still, the position of the cross correlation for all the tracks stayed inside the contour of the school in every ping that was investigated, showing the applicability of this method.

The speeds that were calculated and brought in Table 2 comply with the speeds reported in various papers for cod fish [1],[2],[10],[11].

Heading of the schools was calculated and analyzed to find a correlation between the different trajectories of the schools. Table 2 shows the mean heading of the school for each of the tracking methods. All schools heading are in the range of northwest to east which is all towards offshore direction.

We can see that the schools’ areas are small comparing to other schools found in the area in the experiments [6], and the standard deviation of the area of each school can go over to 50% from the mean value. As stated earlier, this is mostly to the turning of the ship and the elongation of the school as a result.
The last column of Table 2 details the mean value of the maximum cross correlation coefficients throughout the tracks of the schools. We can see that the mean value of all the schools tracks were above 0.74 while in all the tracks the maximum value coefficients were roughly ≥0.5, which comply with the definition of coherently migrating fish [6].

<table>
<thead>
<tr>
<th>School #</th>
<th>Mean COR speed (m/sec) (STD)</th>
<th>Mean centroid speed (m/sec) (STD)</th>
<th>Mean heading of school COR (°)</th>
<th>Mean heading of school centroid (°)</th>
<th>Mean area of school (km²) (STD)</th>
<th>Mean cross-correlation coef. (min coef. Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3420 (0.1506)</td>
<td>0.3031 (0.1382)</td>
<td>43.0892</td>
<td>43.8359</td>
<td>0.0176 (0.0104)</td>
<td>0.7656 (0.5292)</td>
</tr>
<tr>
<td>2</td>
<td>0.2717 (0.1799)</td>
<td>0.2560 (0.1995)</td>
<td>91.6826</td>
<td>85.3356</td>
<td>0.0496 (0.02)</td>
<td>0.7463 (0.5072)</td>
</tr>
<tr>
<td>3</td>
<td>0.2470 (0.2408)</td>
<td>0.2547 (0.2243)</td>
<td>18.8289</td>
<td>21.9157</td>
<td>0.0178 (0.0116)</td>
<td>0.7501 (0.4985)</td>
</tr>
<tr>
<td>4</td>
<td>0.5001 (0.2289)</td>
<td>0.5156 (0.2340)</td>
<td>-18.0829</td>
<td>-33.7204</td>
<td>0.0319 (0.0176)</td>
<td>0.7888 (0.5979)</td>
</tr>
<tr>
<td>5</td>
<td>0.2940 (0.1594)</td>
<td>0.3268 (0.2087)</td>
<td>-8.2242</td>
<td>-4.7136</td>
<td>0.0149 (0.0075)</td>
<td>0.7861 (0.6562)</td>
</tr>
</tbody>
</table>

*Table 2 – summary of quantitative results of schools’ tracks with reference to speed, heading, angle to ship, schools’ area and max cross-correlation coef.*
Bibliography


