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Use of Multibeam and Split-beam SONAR to Observe Changes in Fish School Biomass in Relation to Dolphin Abundance

By

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Dedication

To my grandfather, James Harley Osbun, who not only taught me what a strong work ethic is, but how to enjoy the little things.

1946-2007

Acknowledgments

I would like to thank my advisor, Dr. Rob Young for his time and patience. This research was a direction I never considered before, but your confidence assured me this would be a rewarding experience.

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Abstract

Annual migratory patterns produce a dramatic increase in the abundance of common bottlenose dolphins (*Tursiops truncatus*) each October and November in the coastal waters of northern South Carolina. Although this migratory dolphin peak is assumed to be associated with a seasonal increase in prey fishes, this relationship has never been verified. In this study, multibeam and split-beam echosounders were used to determine if demersal fish schools could be detected and quantified in a shallow soft-sediment environment, if they exhibit a migratory abundance peak in fall similar to dolphins, and if their patterns of spatial abundance are related to patterns of dolphin abundance. Concurrent fish and dolphin surveys were run during fall and winter, 2018-2019, along a 10 km long and 2 km wide section of coastal waters near North Inlet, South Carolina, using a multibeam (Kongsberg EM 3002) and split-beam (Simrad EK60) system. Concurrent bottom trawls identified Atlantic croaker (*Micropogonias undulatus*) as the predominant potential dolphin prey species, and estimates of mean length and weight were used to parameterize the detection of croaker schools using Echoview software, which provided estimates of fish school length, school depth, mean number of fish per unit area, and mean weight per unit area, enabling the calculation of estimated total croaker biomass along defined transects. Contrary to expectations, observed seasonal changes in fish school biomass did not coincide with the fall migratory peak of dolphins, nor was there a relationship between fish school biomass and dolphin abundance from survey transects (n-85, R^2<0.001). A Kongsberg M3 multibeam sonar was used to investigate subsurface dolphin foraging group behavior near Murrells Inlet, South Carolina, but foraging behavior was not able to be observed, in part due to low numbers of foraging dolphin groups. This study confirmed that a split-beam echosounder was able to successfully identify and quantify the biomass of demersal fish schools in a shallow, soft-sediment environment. The multibeam echosounder was not able to reliably distinguish demersal fish schools under these conditions, but alternative configurations warrant additional investigation of the use of multibeam echosounders to detect both demersal fish schools and subsurface dolphin behaviors in shallow coastal waters.

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Introduction

Each fall in the northern portion of the South Carolina coast, there is an increase in the local bottlenose dolphin (*Tursiops truncatus)* abundance by greater than an order of magnitude (Young and Peace, 1999, Silva et al., 2016). This region stretches from Little River to Winyah Bay and is better known in South Carolina as the Grand Strand. The increase in abundance is due to the migration patterns of the Southern Migratory Coastal Stock (SMC), which migrates south from Cape Hatteras, North Carolina, leaving in the fall and returning in the spring. During this time dolphins from the SMC stock have been identified through dorsal fin photo-identification as far south as central Florida, but there is little detail on how and where the members of the stock distribute throughout the majority of this period (Garrison et al., 2017a&b). Along the Grand Strand, dolphin abundance peaks in October and November, in this study referred to as the fall migratory peak (Young and Peace, 1999). During this peak, the transient SMC stock numerically overwhelms the resident South Carolina-Georgia Coastal (SCGC) Stock, which is not believed to seasonally migrate (Waring et al., 2011). The reasons behind the SMC stock migration and fall migratory peak are still unclear and warrant further investigation.

Photo-identification studies along the Grand Strand, have verified that some dolphins of the SMC stock remain in the area up to two weeks or more (Young, unpublished data). These dolphins are part of the migratory stock, as matches are not found between the fall migratory peak dolphins and the presumed SCGC dolphins seen during the rest of the year (Silva, 2016). This suggests that the stock may not be just passing through the Grand Strand but lingers in the area for a period of weeks, potentially taking advantage of a rich source of prey.

Prey Availability

Bottlenose dolphins forage on a wide range of prey species, including smaller-sized benthic and demersal fishes and, most prominently, members of the family Sciaenidae (Pate and Mcfee, 2012). Many of these fishes are soniferous (sound producing) and constitute >80% of the bottlenose dolphins' diet (Remage-Healey et al., 2006). Due to a high propensity to consume soniferous fishes, bottlenose dolphins are hypothesized to use passive listening to detect their prey's vocal emissions (Barros, 1993, Gannon et al., 2005). Gannon et al. (2005) studied this idea by playing a variety of fish sounds under water and observing changes in dolphin orientation in relation to the playback speaker. Dolphin orientation changed on average by 41° toward the speaker when fish sounds played. Additionally, dolphin echolocation increased significantly in response to the sounds.

Studies suggest that bottlenose dolphins preferentially prey upon soniferous fishes, and along the Grand Strand evidence shows an increase in soniferous fishes during the months of October and November. Soniferous fishes like Atlantic croaker (*Micropogonias undulates*) and spot (*Leiostomus xanthurus*) have seasonal migration patterns concurrent with the fall migratory peak of dolphins. Miglarese et al. (1982) studied the seasonal abundance of Atlantic croaker (*Micropogonias undulates*) in South Carolina estuaries and found that they leave the estuaries to spawn in coastal waters during October/November. Spot also spawn in autumn in the coastal waters of the southeastern US, and in southern North Carolina the October/November peak in coastal gillnets targeting spot were associated with increased bottlenose dolphin strandings bearing evidence of net entanglements (Friedlaender et al., 2001). Along the Grand

Strand, active recreational and pier fishing shows an increase in many sciaenid species during the fall as fishermen make their way to Murrells Inlet, SC for the local spot run (Burleson, 2019).

To further investigate the relationship between the fall dolphin migratory peak and potential prey resources along the Grand Strand, a quantitative assessment of local prey species is needed. Trawls are widely used to assess fish abundance and distribution, but they have limitations. Catch data from trawls are limited due to the species- and size-selectivity of the net. Bottom trawls target primarily demersal species, and small fishes may pass through the mesh while larger fishes may avoid the net, leaving an inaccurate representation of the entire fish community (Hightower et al., 2013). Trawling is also considered a destructive type of active fishing due to digging and furrowing of up to 6 cm of sediment (Petović et al., 2016). One way to minimize these issues is to implement a less intrusive method of recording fish abundance and distribution.

Echosounders have been used to monitor fish schools without disturbing the habitat being imaged. In their simplest form echosounders are a type of sound navigation and ranging (SONAR) used to determine the seafloor depth and detect aggregations of fish or biota in the water column, but these simple systems provided little quantitative information on fish schools (Simmonds and MacLennan, 2008). As technology has progressed, more sophisticated echosounders have been developed and used in fisheries, allowing the user to determine abundance and distribution of fish populations (Guillard et al., 2011).

Multibeam echosounders (MBES) and split-beam echosounders (SBS) are two types of SONAR that have been successfully used to asses fish schools. MBES use wide-angled beams to image a wide swath of the seafloor, as well as an image of the water column above the seafloor, allowing the user to image moving targets (Colbo et al., 2014). Raw data produced from the scans can be reconstructed into two-dimensional and three-dimensional images, providing measurements to quantify the overall area of a school (Trygonis and Kapelonis, 2018). Gerlotto et al. (2010) observed anchovy schools in the North Sea with MBES and identified fish school structures (spacing between fish or groups of fish) on a scale as small as 0.5 meters. This study provided evidence on the strength of MBES to image the structure of free-swimming fish schools. Split-beam echosounders have a small beam angle (e.g. Simrad EK60 has a 7° beam angle, Kongsberg, 2015), which provides a much narrower swath when compared to the MBES. In comparison, the swath of the MBES is up to 110 m per transducer (Kongsberg, 2004). One benefit of the MBES is the use of multiple frequencies to assess the environment. The SBS, on the other hand, is limited to a single frequency (Kongsberg, 2015). The limited frequency information in the SBS can be used to determine more precise school parameters (Weber et al., 2009), but the benefit of the MBES is the ability to ensonify the entire fish school. Matveev (2007) used a 120 -kHz SBS to explore changes in a stock of small fish (~15mm) and their biomass in a shallow channel of the Murray River, demonstrating that fish density was significantly higher at night. By combining both sets of SONAR the user can potentially use the precise estimates of fish size and spacing from the SBS to extrapolate over the entire extent of the fish school imaged by the MBES.

The implementation of MBES and SBS have focused on pelagic fish schools which can be imaged in the water column with little interference (noise) from the surface or seafloor. Studies with demersal fishes found on shallow, soft-sediment bottoms are less common, because high-frequency SONAR in a shallow environment can be difficult when trying to balance the power of a transmitted pulse (or ping) with the desired frequency to achieve optimal images (Simmonds and MacLennan, 2008). The difficulty lies in the relationship between frequency, resolution, and dissipation. High frequency SONARs provide better resolution, but a high frequency pulse loses strength faster, dissipating through the water and altering the interpretation of targets at greater distances. Shallow, soft-sediment habitats dominate the coastal waters along the Grand Strand (Ojeda et al., 2004) and are the primary setting where coastal bottlenose dolphins are known to forage.

In addition to their utility in imaging and assessing fish schools, MBES has also been used to examine predator-prey dynamics between fish and dolphins. Benoit-Bird and Au (2009) used MBES to look at the interactions between spinner dolphins (*Stenella longirostris*) and their prey off the coast of Oahu, HI. Differences in target strength (acoustic scattering) between the spinner dolphins and their prey were used to observe behaviors of the dolphins underwater. The difference in target strength between dolphins and fishes is attributed to density variation due to the lungs of the dolphin compared to the swimbladder of a fish (Au, 1996). Benoit-Bird and Au (2009) used this information to calculate prey density and found that dolphin group sizes were predictably related to prey density. Along the Grand Strand foraging behaviors seen by dolphins are noticeable when they occur at the surface (e.g. repeated fluke-in/out dives in one location, feeding circles, lunge feeds, fish kicks, fish tosses, etc.) (Smith et al., 2013), but once dolphins dive below the water foraging behaviors can no longer be observed in the turbid waters. This limitation hinders the knowledge and understanding of subsurface dolphin behaviors and how these behaviors may change during seasonal migrations from both the SMC stock and prey species.

Objectives and Hypotheses

The primary objective of this study was to examine the utility of MBES and SBS to identify temporal changes in fish school biomass in the near-shore-coastal habitat along the Grand Strand and to determine if changes in fish abundance coincide with changes in bottlenose dolphin abundance. The secondary objective is to explore using the MBES to assess bottlenose dolphin subsurface foraging behavior. Specifically, I hypothesized that:

1. By using a MBES and SBS parameters of each fish school identified in the SONAR images will enable the calculation of fish school biomass.
2. There will be an increase in fish school biomass during the months of October and November in association with the fall migratory peak of bottlenose dolphins.
3. Changes in fish school biomass will correspond with dolphin abundance during survey tracks.
4. During the fall migratory peak, subsurface dolphin foraging behavior on fish schools can be observed and described using a MBES.

Materials and Methods

Study Area

This study took place along the coast of northern South Carolina, between Winyah Bay and Murrells Inlet (Figure 1). This coastal region contains large riverine estuaries, brackish water sounds, and salt marshes along the intertidal zone. Winyah Bay is a partially-mixed-riverine estuary that drains the third-largest watershed on the US east coast (Mallin et al., 2000). The sandy beaches along this coast are subdivided by several natural inlets leading to salt marsh estuaries. Many of these inlets define the north and south boundaries of barrier islands. The coast has a tidal range toward the upper end of the microtidal category (~1.7 m), with high wave energy and a sediment starved continental margin, often categorized as a high-energy shelf (Ojeda et al., 2004). The inshore shelf along this coastline has a shallow slope, with an average depth of approximately 10 m at a distance of 2 km from shore, and a mix of low relief live/hard bottom and sandy bottom habitats.

Concurrent Fish and Dolphin Surveys

Changes in near-coastal fish biomass and in the distribution of bottlenose dolphins were simultaneously investigated from October 2018 through February 2019 aboard Coastal Carolina University’s 15.2 m R/V Coastal Explorer. Fish biomass was assessed using simultaneous MBES and SBS SONAR in-situ surveys, with periodic bottom trawls to verify species composition, and the distribution and abundance of dolphins was determined from concurrent visual surveys. Three separate survey periods were established during the months of October, November, and January/February to capture broad seasonal changes during fall and winter. An additional planned survey in early September was cancelled due to Hurricane Florence. Within each monthly period, three single day surveys were conducted within a two-week time span: October 17 to 23, November 16 to 27, and January 31 to February 5. Each survey was conducted in nearshore waters along a 10 km stretch of coastline divided into 10 1-km wide subsections and centered roughly on North Inlet, SC (Figure 2). Surveys included 10 replicate shore-normal 2.0 km transects, each with a randomly selected position within a subsection and generally running from 0.5 to 2.5 km from shore, with variations due to nearshore depth limitations. Water depths ranged from approximately 3 m near-shore to 12 m offshore.

For the SONAR fish surveys, the MBES (300 kHz, Kongsberg EM 3002) was mounted off the bow of the boat and the SBS (120 kHz, Simrad EK60) was mounted off the starboard aft corner. The EM 3002 is a high-resolution MBES with 200° of dynamically focused beams and an electronic pitch and roll compensation system (Kongsberg, 2004). Sound velocity measurements from an Applied Microsystems Smart SV&P accounted for refraction errors throughout the water column. The EK60 is a SBS with a 7° acoustic cone used to detect the size and spacing of individual fish. The information gathered from the EK60, in combination with the wide-swath view of the fish aggregation from the EM 3002, was intended to enable the extrapolation of the precise measurements from the SBS to the entire school imaged by the MBES. Both units gathered data simultaneously and continuously at a relatively consistent speed of 5 knots along the survey track. Surveys were discontinued if the Beaufort Sea State reached 4 or higher, as frequent whitecaps inhibit dolphin sightings and choppy conditions can also reduce the quality of the SONAR data.

The species composition of the demersal fish assemblage was determined from periodic otter trawls conducted during each survey. Each survey also included traditional data collection techniques to assess fish species, dolphin abundance, and environmental parameters. The trawl had a 6.1 m opening, 1.9 cm mesh, and 60.96 cm x 31.75 cm doors and was deployed and retrieved by hand three times during each survey. Trawling locations were selected from the nearshore, shore-parallel sections of the survey track

(Figure 2). These inshore sections were selected because the trawl performed better in waters less than 7 m deep. Trawling sites during each survey were chosen in an opportunistic manner to take advantage of the longer stretches of transit between transect lines, which varied each survey depending on the randomly selected transect locations. Fishes captured by the trawl were counted by species and both total and standard length (mm) were recorded for each individual. Surface water temperature and salinity was determined for a water sample collected during each trawl using a YSI 650 MDS.

Visual dolphin surveys were conducted during the SONAR surveys along each shore-normal transect line (Figure 2). Each dolphin survey utilized two observers stationed on the elevated bridge of the boat, scanning for dolphins with their naked eyes. Each observer scanned one side of the boat, from 0° (straight ahead) to ±100° degrees. When dolphins were identified at the surface, the number of dolphins present and their distance from the boat when directly abeam was estimated. If calves were present, the number of adults & calves were counted separately.

Dolphin Foraging Surveys

Dolphin subsurface foraging behavior was investigated on November 11 and 12, 2019, near Murrells Inlet, SC (Figure 3), aboard a 7.2 m Privateer using the Kongsberg M3 SONAR (500 kHz transducer). The Kongsberg M3 unit was used for these surveys due to of its maneuverability and wide range of functions for imaging the water column, including an easily adjustable head for oblique angles needed to observe potential dolphin foraging behavior. The Murrells Inlet survey area was chosen due to its easy access to coastal waters and the historical observations of large foraging dolphin groups during the fall migratory peak. During the two survey days, shore-parallel transects were repeatedly run within 1.5 km of shore, searching for multi-dolphin groups engaged in potential foraging behavior. As dolphin groups were located and approached, the procedures of Silva et al. (2016) were followed for behavioral observations, including identification of dolphin group location, behavior, and group size and composition. Foraging behavior for this study was defined as a group of dolphins engaged in various behaviors noted by Smith et al. (2013), including repeated fluke-in/out dives in one location, surface lunges and chases, or fish tosses. The Kongsberg M3 was mounted on the port aft side of the boat and if potential foraging behavior was observed the transducer was angled between 30-40° forward and 30-45° to the right of the boat to image dolphins in a side view. The Range function, which allows the user to specify the maximum theoretical vertical depth and horizontal distance covered by the Kongsberg M3 beams (Kongsberg, 2017), was alternated between 40 and 50 m in an attempt to find the best suitable distance to view dolphins foraging in shallow waters (4.4 to 5.6 m). The boat slowly maneuvered around the outside of the dispersed foraging group, attempting to capture images of foraging dolphins in the water column for 10 to 50 minutes. Imaging of each foraging bout lasted between 10 and 50 minutes depending on the size and activity of the group.

Echoview Data Processing

SONAR data files were sorted by survey date and uploaded into Echoview (version 10). The data from both the MBES and SBS were cleaned by removing surface noise down to one meter below the surface using the surface line tool. Bottom noise was removed using the “Best Bottom Candidate” command. When necessary, the surface & bottom exclusion lines were manually adjusted if the bottom line laid over a school or formed spikes due to noise. The data were processed to reduce noise throughout the water column using the command “Impulse Noise Removal,” which removes noise caused by other SONARs (i.e. the MBES).

Fish schools throughout the SONAR data were detected using the Fish Detection command in Echoview. In order for Echoview to detect fish schools and determine desired parameters, such as density weight (mean biomass of fish per area surveyed), mean depth of fish school, and corrected length of fish school along the transect axis, settings must be adjusted to account for specific species. The trawls were used to determine a focal species for the detection which established length and weight parameters. These parameters were needed for the calculation of target strength (TS), which is required for fish school detection. The trawl data were also used to narrow down the fish schools being detected. The trawl with the most fish was used to identify the transects that took place before and after that specific trawl. Then by referring back to the raw data and using the measure tool in Echoview, school height, school length, and distance between multiple fish schools found in the transects were determined and the averages were used to adjust parameters in the properties window of Fish Detection. Echoview used this information and outlined each school, providing measurements of the fish school parameters listed and defined in Table 1.

Data from the two dolphin foraging survey days were separated by event (dolphin group) and uploaded into Echoview (version 10). The “Maximum Intensity” command was used to alter the view of the raw data into a horizontal landscape. To eliminate noise from the bottom a bottom line was applied using “Best Bottom Candidate,” editing the line to lay smooth against the seafloor. The recorded timing of observed foraging bouts was used to find strong TS signals in the echogram, and these signals were visually reviewed for evidence of foraging behavior or other behaviors visually identified during the surveys.

Data Analyses

Because the SBS was mounted off the starboard aft side, only data from the starboard swath of the MBES were processed. The Echoview output variables (Table 1) for the SBS and MBES SONAR systems were utilized to calculate an average fish school biomass over each transect.

The biomass estimation in Echoview requires information on the target strength (TS) and weight (kg) of the species being detected. Methods from Krahforst (2010) were followed to calculate these parameters. Weight (kg) was calculated using a length-weight relationship length (mm) represented by average total length. Target strength (dB) was calculated using an equation from Love (1971), where fish length (L, ft):

$$TS(dB) = 19.1 * Log_{10}\big(L(ft)\big) + 0.9 * Log_{10}\big(\lambda(ft)\big) - 34.2 \qquad \text{(Equation 1)}$$

In this equation λ is the wavelength of the transducer, which was calculated using the wavelength equation, where v (m/s) is sound speed and f (Hz) is frequency:

$$\lambda = {}^{\mathrm{v}\,(^{\mathrm{m}}/_{\mathrm{s}})}\big/_{\mathrm{f}\,(\mathrm{Hz})} \qquad \text{(Equation 2)}$$

For each fish school along a transect detected by Echoview, biomass of the school was calculated using density weight (kg/m^2), the corrected length (m) of the school along the transect line, and the average depth (m) which the school was found, which were each pulled from the exported Echoview data files. One half the width of the surveyed swath was determined by multiplying the average water depth by the tangent of one half the beam angle (the beam angle was 7° for the SBS or 72° for the MBES). This value was then doubled to represent the entire swath width and multiplied by the corrected length to calculate the area (m^2) of the seafloor surveyed. The area surveyed was then multiplied by density weight (kg/m^2) to get the overall biomass (kg).

Differences in corrected length, mean depth, and density weight were compared between SBS and MBES SONAR systems using a two-sample t-test, assuming equal variance in Microsoft Excel (version 16.39). These variables were compared to verify if schools detected by SBS and MBES systems were significantly different. Significance was assessed at a $p \leq 0.05$. Differences in estimated fish biomass were also compared between the SBS and MBES SONAR systems using a two-sample t-test, assuming equal variance in Microsoft Excel (version 16.39) (Hypothesis 1). Significance was assessed at a $p \leq 0.05$.

The total fish school biomass from each transect and the estimated dolphin count during each transect, over the entire survey period, were compared using a linear regression to determine if a relationship existed. Change in fish biomass over the entire survey period was analyzed as a time series to determine if any patterns exist during the months surveyed. The linear regression and times series were analyzed in Rstudio Team (2020, Wickham, 2016).

Results

Concurrent Fish and Dolphin Surveys

Eight of the nine planned survey days were complete surveys, yielding 85 shore-normal fish and dolphin survey transects for analysis. Survey 5 (November 17, 2018) was discontinued after completing only five transects and no trawls due to increasing sea state. Salinity was stable across all surveys, between 34.0 and 34.5, and surface water temperature declined from a mean of 19.9 ºC in October to a mean of 10.7 ºC in January/February (Table 2).

The trawl catch was analyzed in order to identify a target species, mean weight, and target strength to parameterize Echoview. Twenty-one species of fish were caught, from a total of 24 trawls (Table 4). Bay Anchovy (*Anchoa mitchilli*) had the highest species count followed by small (<60 mm) young-of-year Silver Seatrout (*Cynoscion nothus*), but these small fishes were unlikely to be major prey species for dolphins. Based on known dolphin prey species in South Carolina (Pate and McFee, 2012) and observed fish sizes, the captured species most likely to be targeted by dolphins were Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*) and start drum (*Stellifer lanceolatus*), all soniferous fishes of the family Sciaenidae. Of these, Atlantic croaker were present in substantially higher quantities over the entire survey period, except in one trawl during January where spot was the dominant species. Therefore, Atlantic croaker were selected as the target species for Echoview analyses of fish schools.

A length-weight equation for Atlantic croaker caught between Cape Hetteras, NC and Cape Canaveral, Florida (SEAMAP-SA, unpublished data) was used to estimate the mean weight of Atlantic croaker in acoustically observed fish schools:

$$Weight(g) = 5E - 6 \times (TL(mm))^{3.126451} \qquad \text{(Equation 3)}$$

The mean total length (TL) of Atlantic croaker captured in the trawl was 163.04 ±1.65 mm, yielding a target weight of 41.26 g, which was converted to kg to input into

Echoview. A single mean length was used for these calculations because Atlantic croaker length did not significantly differ between trawls from each survey month (ANOVA, df= 2, *F*= 2.22, *p*= 0.12). Target strength (TS) for Atlantic croaker was therefore set at -38.75 dB based on the TS Equation (Equation 1). The Fish Detection command was adjusted with parameters set at: school length = 0.20 m, school height = 1.50 m, max vertical linking distance = 3.0 m, and maximum horizontal linking distance = 1.0 m. These values were obtained from measurements of 14 schools imaged immediately before or after the bottom trawl that yielded the highest abundance of fish during the study.

Based on these parameters, Echoview identified a total of 499 fish schools over the 9 survey days (85 transects) from the SBS and 1131 schools from the MBES. The number of schools per transect ranged from 0 to 195 for the SBS and 0 to 256 for the MBES. The SBS data identified 12 transects (14.1 %) with no Atlantic croaker schools, and the MBES identified 2 transects (2.4 %) with no Atlantic croaker schools.

Given these discrepancies, differences between the outputs from the two SONARS were further investigated. Average corrected school length (m) (SBS= 225.26, MBES= 14.57), school depth (m) (SBS= 4.78, MBES= 3.49), and density weight (kg/m^2) (SBS= 7.04, MBES= 113.2) were all significantly different (n-85) between the SBS and MBES (n=85, t-test, t= 1.97, *p*<0.0001). This could mean schools detected by the MBES were on average shorter in length than schools detected by the SBS, schools detected by the MBES were broken into smaller schools or that the SBS had little difficulty detecting schools close to the seafloor where the MBES could have struggled finding schools at a deeper average depth.

Echograms from each SONAR were also visually compared to identify potential differences in the fish schools they were imaging. The SBS generally showed more fish/fish schools along the seafloor, where the MBES may have only seen one small grouping and detected smaller pelagic schools (example Figure 7). As seen in Figure 8, the noise found in the MBES echogram may have blocked the identification of demersal fish schools, while the SBS consistently distinguished between the seafloor and fish schools. SBS have been commonly used in studies to asses fish densities in various environments (Matveev, 2007, Simmonds and MacLennan, 2008, Hashim et al, 2017), with this knowledge and based on the discrepancies in Echoview data and echogram images, fish biomass calculations proceeded using only the SBS data.

Changes in fish school biomass were observed over each surveyed month (Figure 4). The average total fish school biomass (kg) decreased from October to November and then showed a large and unexpected increase in January/February. A more fine-scale examination of biomass estimates from each individual transect (Figure 5) support this general trend, and with the possible exception of one transect in November, the monthly averages do not appear to be biased by a single outlier transect.

Dolphin sightings occurred in four of the nine survey days, with 16 sightings in total (Table 3). The mean number of dolphins seen in these 16 transects was 5.38 with a range of 1-25 adult dolphins. Calves were sighted in two transects. Total fish school biomass (kg) and dolphin count were compared between each transect over the entire survey period (Figure 6). The data are scattered with a near horizontal line of best fit, indicating no relationship between school biomass and dolphin count (linear regression,

$R^2 = 6.82 \times 10^{-5}$, $p = 0.9402$). These data does not agree with the hypothesis that changes in fish biomass coincide with dolphin abundance throughout the transects.

Dolphin Foraging Surveys

During the two dolphin foraging survey days, six dolphin groups were investigated, ranging in group size from 4 to 40. Only one group, with a group size of 40, was engaged in potential foraging behaviors based on periodic fluke out dives signifying a rapid return to the bottom, although the frequency of these dives was inconsistent, and no surface activities indicated feeding near the surface. The other groups were either traveling or milling. Sonar data were only analyzed for the one event with potential foraging. The raw data were edited and reviewed, but no dolphin foraging behavior was confirmed. The echograms that contained the period of time which the dolphin group was followed only contained 5-7 potential dolphin pings with a large return noticed in the water column. Due to the limited number of pings, none of which imaged consecutive movements, interpretation of dolphin foraging behavior was not possible.

Discussion

In this study two types of SONAR systems (SBS and MBES) were used to identify and characterize fish schools along the Grand Strand, SC. Based on Atlantic croaker as a target species, changes in fish school biomass were successfully quantified using the SBS. However, the method of combining SBS and MBES data did not work as expected and only the SBS captured reliable images of demersal fish schools in the shallow, soft sediment environment. The calculated fish school biomass did not peak as anticipated during the fall months and the fish biomass per transect did not correlate with bottlenose dolphin abundance per transect. Efforts to image dolphin foraging behavior using MBES were unsuccessful, but the ideal conditions of a large and active foraging group were not encountered.

Concurrent Fish and Dolphin Surveys

The purpose of narrowing down the fish detection to Atlantic croaker was to focus the analysis in Echoview on just one dominant species rather than all possible species collected from the sites. Atlantic croaker were selected as the target species for the SONAR analysis due to their frequent occurrence in the trawls (79%) and high abundance relative to other likely dolphin prey captured species. Atlantic croaker are a dermersal soniferous fish which belongs to the family Sciaenidae, a family often foraged upon by bottlenose dolphins (Pate and McFee, 2012). Pate and McFee (2012) reviewed the stomach contents of bottlenose dolphins and found that Sciaenids were present in 76% of dolphin stomachs and represented 61% of the total prey items consumed. With this assumption it is likely that schools outside of Atlantic croaker were detected, but with the addition of parameterizing fish schools and a target strength specifically to detect Atlantic croaker the occurrence should be limited. Due to the potential of detecting other schools the calculation of fish school biomass was a max estimate.

Once the species was determined and analyses were performed, discrepancies between the two sets of echograms (SBS and MBES) made it clear that the two SONAR systems were not comparable. These discrepancies could potentially be associated with the different operating frequencies used. The MBES runs at a higher frequency (300 kHz) than the SBS (120 kHz) which can lead to discrepancies in the schools that can be observed and detected. High frequencies, while better for resolution, lead to an increased rate of absorption, meaning that the ping sent out will dissipate faster so targets at a greater distance will have a weaker or altered detection signal (Simmonds and MacLennan, 2008). With different frequencies that also means the two systems have different wavelengths. This affects the study because a high frequency SONAR like the MBES used can detect fish as small as 5mm, where a SBS may only detect fish as small as 12.5 mm. This also leads to a difference in target threshold detection. The MBES could be detecting higher amounts of schools because small schools above the detection threshold for the MBES may fall below the detection threshold of the SBS (Misund and Coetzee, 2000). Gurshin (2012) encountered issues in density estimations using both a SBS and MBES, where the SONARs showed differences between known density measurements being imaged. Throughout the study MBES and SBS showed sensitivity toward different fish school structures, MBES had issues with densely packed schools and SBS had issues with non-uniform school structure.

Total fish school biomass unexpectedly peaked in the winter months, rather than during the fall migratory peak for dolphins in October and November. Bearden (1964) studied Atlantic croaker migration in North Carolina and found that during the months of October and November Atlantic croaker would migrate offshore in search of warmer bottom waters. However, the exact timing and duration of this migration is undoubtedly influenced by annual variability as well as longer term changes in climate. Given these variations and the limited number of observations from this study (3 days per month), it is possible that a fall peak in fish abundance occurred but went unwitnessed. The winter peak of fish school biomass has large variability, which could also indicate that the increase of biomass detected is more relatable to the biomass calculated during the month of October. Agreeing with the results means that dolphins would be passing the chance of higher fish school biomass in the winter along the Grand Strand, but this migration further south could mean an even greater biomass increase in deeper southern waters.

Contrary to our hypothesis, total fish school biomass (kg) per transects did not share a relationship with dolphin counts per each transect. The anticipated result was a correlation between dolphin count and total fish school biomass but taking into consideration the previous results of low biomass in the fall months the lack of relationship is to be expected. Studies have researched the seasonal migration of dolphins (Taylor et al., 2016), and their potential correlation with the movements of prey species (Bills and Keith, 2012). Dolphins forage from a wide area along the Grand Strand and in this study the survey transects were separated by 1-km increments on average. Over this small spatial scale, it could be difficult to discern any relationship between fish biomass and dolphin behavior, because the heterogeneity of fish schools along sandy bottoms is temporally fluid and not place-based, and wide-ranging dolphins may not be responding to prey distribution at all times, as they are often engaged in behaviors other than foraging.

Surveys originally planned for the month of September 2018 were cancelled due to hurricane Florence, which prevented any preliminary surveys meant to gather data on the fish school biomass and dolphin abundance before the start of the fall migratory peak. Studies have shown that dolphin sightings following a hurricane can significantly drop. Fazioli and Mintzer (2020) determined a 0.80 dolphin/km encounter drop after Hurricane Harvey in relation to a drop-in salinity, on average 14 ppt decrease. Studies observing demersal fish school movements found significant effects from storm events, with the time of recovery varying dramatically (Bacheler et al., 2019). The first survey took place a month after Hurricane Florence and salinity was not depressed, so it is unclear whether any lasting impacts from the storm were still impacting the dolphin or fish populations.

Dolphin Foraging Surveys

The objective of the dolphin foraging surveys was to identify and follow groups of dolphins exhibiting active foraging behavior and capture foraging images with the Kongsberg M3. Throughout the two survey days only one group of dolphins showed behavior associated with foraging. When looking through the echogram there was a potential sighting of strong target strength, shown as large objects in the water column, thought to be from dolphins (Figure 9). The pings in which this was seen were limited, which could mean dolphin movement was happening quickly or the orientation of the Kongsberg M3 was not suited for the dolphin movements. One complication is that if dolphins forage in shallow waters (2-3 meters), the behaviors might be too close to the surface for the SONAR unit to image. Benoit-Bird et al. (2004) found that when dolphins were seen foraging at the surface they were always detected by the SONAR. If dolphins were noted as milling or traveling, they were never detected by SONAR, because of their position in the water. In this study, it is likely that the low number of dolphin foraging groups prevented the time needed to observe and identify foraging behaviors.

Conclusions

In conclusion, this study successfully implemented the Simrad EK60 SBS to image and measure various fish school parameters which were used to calculate the fish school biomass of potential dolphin prey, but it did not identify a relationship between patterns in prey fish abundance and the fall migratory peak of bottlenose dolphins. Attempts to implement a MBES did not work as expected and although it was not able to calculate fish school biomass, there is still potential for further investigations with this technology. The findings from the dolphin subsurface foraging surveys were not definitive and may improve with repeated attempts on large groups of highly active, foraging dolphins. The results of this study verify the utility of using SBS to assess demersal fish schools in shallow, sandy environments. Future studies can benefit from preliminary surveys to determine optimal frequencies and transducer angles in varying environments, and more frequent surveys over a longer time span will allow for more definitive conclusions regarding the short-term variability and long-term seasonal changes in fish communities.

The outcomes of this study verify the utility of using SBS to assess demersal fish schools in shallow, sandy environments. Future research can benefit from preliminary surveys to determine optimal frequencies and transducer angles for equipment in varying environments, and an increased number of surveys over a longer time scale could further clarify the relationship between changes in fish and bottlenose dolphin abundance.

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Table 1. List of variables and definitions provided by the Echoview export analysis. Variables marked with an asterisk were used in analyses. (Echoview, version 10)

Region ID	ID number of the region being analyzed.
Sv Mean	Mean volume backscattering strength (dB re 1 m^-1).
Height Mean	Mean height of the domain which was analyzed (m).
Depth Mean*	Mean depth of the domain which was analyzed (m).
Ping S	Number of the first ping in the domain which was analyzed.
Ping E	Number of the last ping in the domain which was analyzed.
Dist M	Distance (measured by GPS) from the first ping in the analyzed variable to the middle ping in the domain which was analyzed.
Lat M	Latitude (in decimal degrees) of the middle ping in the domain which was analyzed.
Lon M	Longitude (in decimal degrees) of the middle of ping in the domain which was analyzed.
Corrected Length*	Length (the horizontal dimension in the plane of the echogram) of a school represented by a region on an echogram (m), corrected for known beam geometry.
Corrected Thickness	Thickness (the vertical dimension in the plane of the echogram) of a school represented by a region on an echogram (m), corrected for known beam geometry.
Density Number	Number of fish per unit area for the domain which was analyzed (fish/nmi^2).
Density Weight*	Weight of fish per unit area for the domain which was analyzed (kg/nmi^2).
Range Mean	Mean linear distance from the center of transducer face along the beam axis of the domain which was analyzed (m).
Thickness Mean	Mean measure of the extent of an object, along the beam axis of the domain which was analyzed (m).
Corrected Perimeter	Length of the perimeter (in the plane of the echogram of a school represented by a region on an echogram (m), corrected for known beam geometry.
Corrected Area	Cross sectional area (in the plane of the echogram) of a school represented by a region on an echogram (m^2), corrected for known beam geometry.
Image Compactness	Measure of the shape of a school represented by a region on an echogram (no units), ratio between perimeter and area.
Corrected Mean Amplitude	Linear mean Sv of a school represented by a region on an echogram corrected for known beam geometry.
Corrected MVBS	Corrected mean amplitude in the dB domain (dB re 1m^2/m^3).
Coefficient of Variation	Reports the coefficient of variation of the Sv sample values in a school (%). Statistic used to measure the dispersion of the distribution for a set of data.
Vertical Roughness Coefficient	Measure of the variation of Sv with a range in a school represented by a region on an echogram (dB re 1m^2/m^3). Statistic used to measure the dispersion of acoustic energy within the school in the vertical direction.
3D School Area	Estimated surface area of a school represented by a region on an echogram, assuming it is cylindrical (m^2).
3D School Volume	Estimated volume of a school represented by a region on an echogram, assuming it is cylindrical (m^3).
ABC	Area backscattering coefficient for the domain which was analyzed (m^2 m^-2).
Area Backscattering Strength	Logarithmic representation of ABC (m^2nmi^-2).
Center of Mass	Center of “mass” (m) of the domain.
Inertia	Spread as the sum of squared distances from the center of mass, weighted by the sv at each distance and normalized by the total sb of the domain.
Proportion Occupied	Proportion of the water column with Sv above a threshold.
Equivalent Area	The area (m) that would be occupied if all the samples had the mean Sv of the domain.
Aggregation Index	Reciprocal of the equivalent area for the samples of the domain which was analyzed (m^-1).

Table 2. Mean temperature and salinity measurements collected from each SONAR fish survey day, collected during trawls from October 17, 2018 to February 5, 2019.

Date	Survey	Mean Temperature (ºC)	Mean Salinity (ppt)
10-17-2018	1	19.4	34.21
10-20-2018	2	20.6	34.42
10-23-2018	3	19.7	34.09
11-16-2018	4	16	34.22
11-17-2018	5	*NA*	*NA*
11-27-2018	6	14.85	34.34
01-31-2019	7	9.75	34.04
02-01-2019	8	10.3	34.31
02-05-2019	9	12	34.53

Table 3. Summary of dolphin sightings, broken down by survey and transect, during the concurrent fish and dolphin surveys, October 17, 2018 to February 5, 2019.

Date	Survey	Transect	Events	Dolphins	Calves
10-20-2018	2	9	1	25	0
11-16-2018	4	4	1	2	0
11-16-2018	4	5	1	12	1
11-16-2018	4	6	1	1	0
11-16-2018	4	9	1	4	0
11-16-2018	6	3	1	3	0
11-16-2018	6	5	1	1	0
11-16-2018	6	6	1	6	0
11-16-2018	6	8	1	3	0
02-05-2019	9	3	1	1	1
02-05-2019	9	4	1	3	0
02-05-2019	9	5	1	5	0
02-05-2019	9	6	1	4	0
02-05-2019	9	8	1	8	0
02-05-2019	9	9	1	4	0
02-05-2019	9	10	1	4	0

Table 4. Summary of the fish catch from otter trawl collections during fish surveys, October 17, 2018 to February 5, 2019. Mean TL= mean total length, expressed in (mm) ±1 SE calculated from trawls within each month. Each month included three survey days, each with three trawl collections, except for November, which only had trawls on two of the three survey days (again, each with three trawl collections).

		October Surveys		November Surveys		January/February Surveys	
Species	Total Count	Mean count per survey	Mean TL per survey (mm)	Mean count per survey	Mean TL per survey (mm)	Mean count per survey	Mean TL per survey (mm)
Anchoa mitchilli (Bay Anchovy)	129	0.375	<60	1	<60	13.33	<60
Cynoscion nothus (Silver Sea Trout)	74	0.5	103 ±46	11.67	<60		
Micropogonias Undulates (Atlantic croaker)	55	3.11	165.59 ±3.68	2.83	164.76 ±2.35	1.11	156.4 ±3.75
Larimus fasciatus (Banded Drum)	30			4.83	<60	0.11	<60
Chloroscombrus chrysurus (Atlantic Bumper)	19	2.13	<60	0.22	<60		
Leiostomus xanthurus (Spot)	19			0.11	179	2	115.39 ±2.4
Stellifer lanceolatus (Star Drum)	18	2	127.71 ±7.5	0.33	135.5 ±20.5		
Trinectes maculatus (Hogchoker)	18	0.11	94	2.83	<60		
Selene vomer (Lookdown)	14	0.33	71 ±14.57	1.83	<60		
Anchoa hepsetus (Striped Anchovy)	11	1.22	98				
Selene setapinnis (Moonfish)	7	0.875	<60				
Lagodon rhomboides (Pinfish)	6	0.625	117.44	0.167	114		
Menticirrhus americanus (Southern Kingfish)	4			0.5	191.33 ±8.33	0.11	160
Pogonias cromis (Black Drum)	3						
Prionotus carolinus (Sea Robin)	3			0.5	157 ±2.52		
Cynoscion regalis (Weakfish)	2	0.25	225	0.33	<60	0.11	<60
Chilomycterus schoepfi (Striped Burrfish)	2			0.33	<60		
Trichiurus lepturus (Atlantic Cutlassfish)	1	0.125	<60				
Peprilus paru (Harvest Fish)	1	0.125	72				
Chaetodipterus faber (Spade Fish)	1	0.125	122				
Paralichthys dentatus (Summer Flounder)	1					0.11	<60

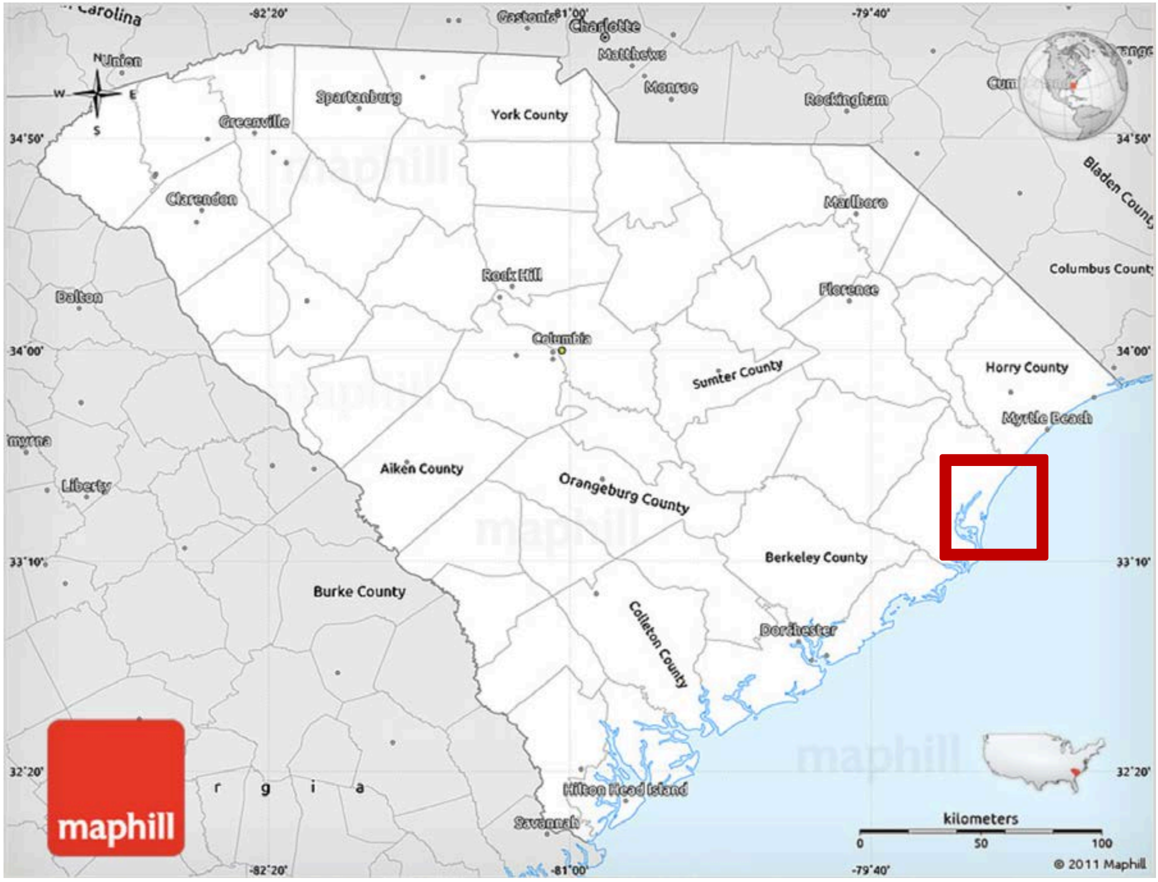


Figure 1. Map of South Carolina with the red square indicating the survey site off the coast between Winyah Bay and North Intel, SC. (Maphill)

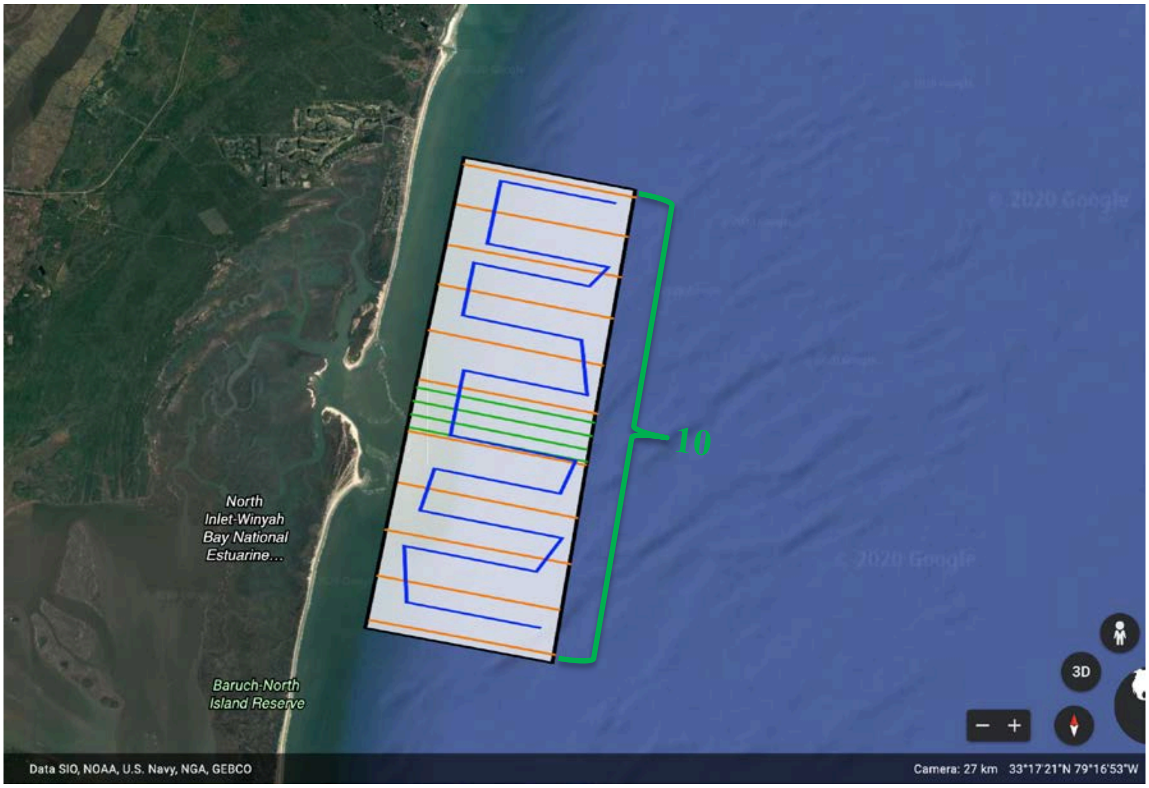


Figure 2. Map of SONAR fish survey site area (black rectangle) relative to the coast and North Inlet, SC. The orange lines define one-kilometer subsections of the 10 km length (green bracket), and the green lines illustrate the four potential transect positions within each subsection from which a shore-normal transect would be randomly selected. The blue line shows an example of a complete survey track, including 10 shore-normal transects, each two km in length, and connecting transits (roughly north-south) between transect lines. (Google Earth V 9.3.113.2, 2020)

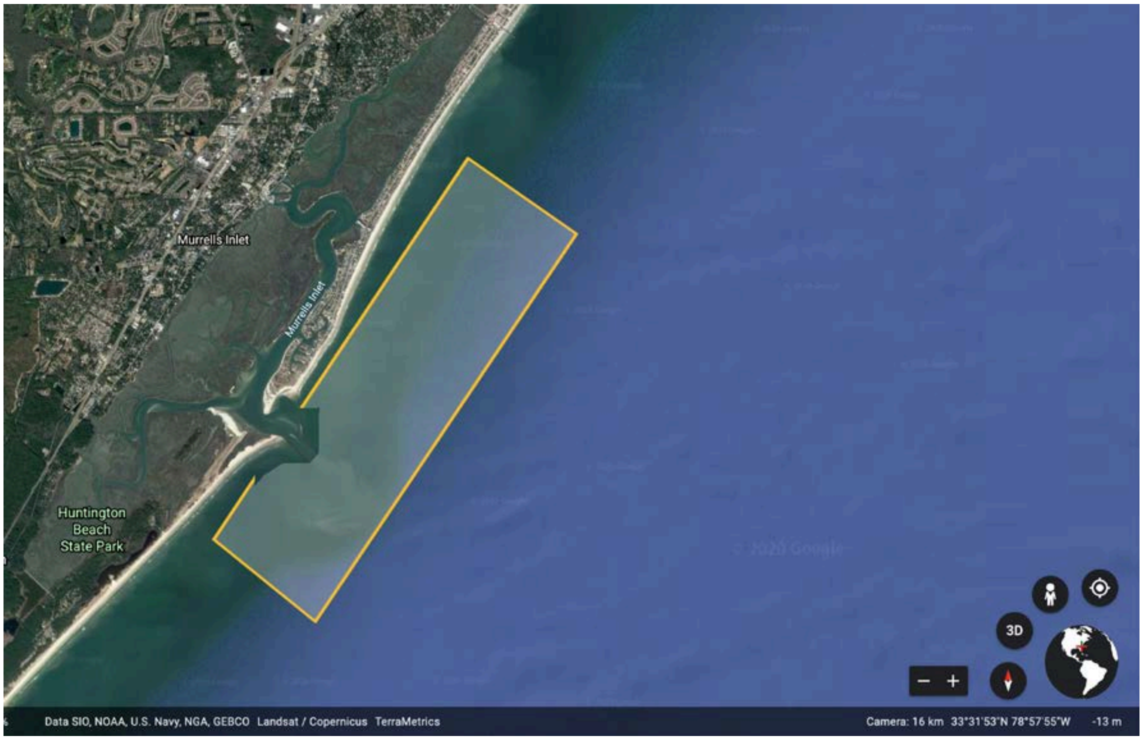


Figure 3. Map of dolphin foraging survey area relative to the coast and Murrells Inlet, SC. The boat would randomly search within this area to locate dolphins foraging groups for potential MBES imaging. (Google Earth V 9.3.113.2, 2020)

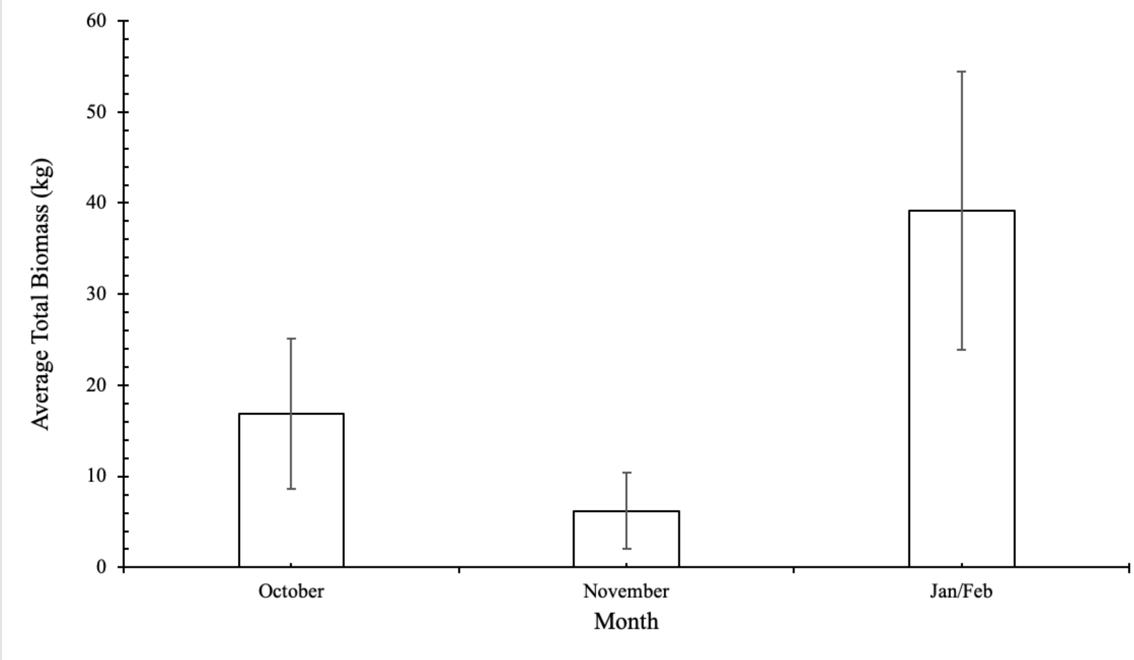


Figure 4. The average total fish biomass (kg) per transect line detected during each survey month, collected from three survey days each month. Errors bars represent one standard error.

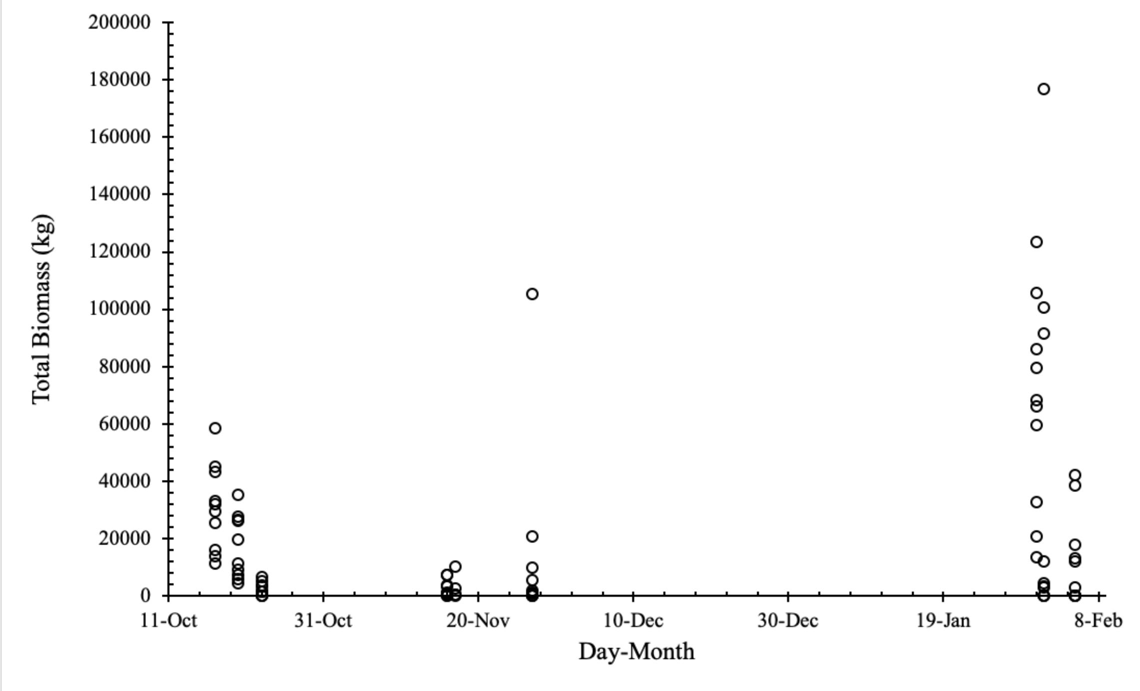


Figure 5. The total fish school biomass (kg) detected during each transect (open circle data points), over 9 survey days between October 2018 and February 2019. Ten transects were completed each survey day, except survey 5 (November 17, 2018) which only completed five. Dates are shown as Day-Month.

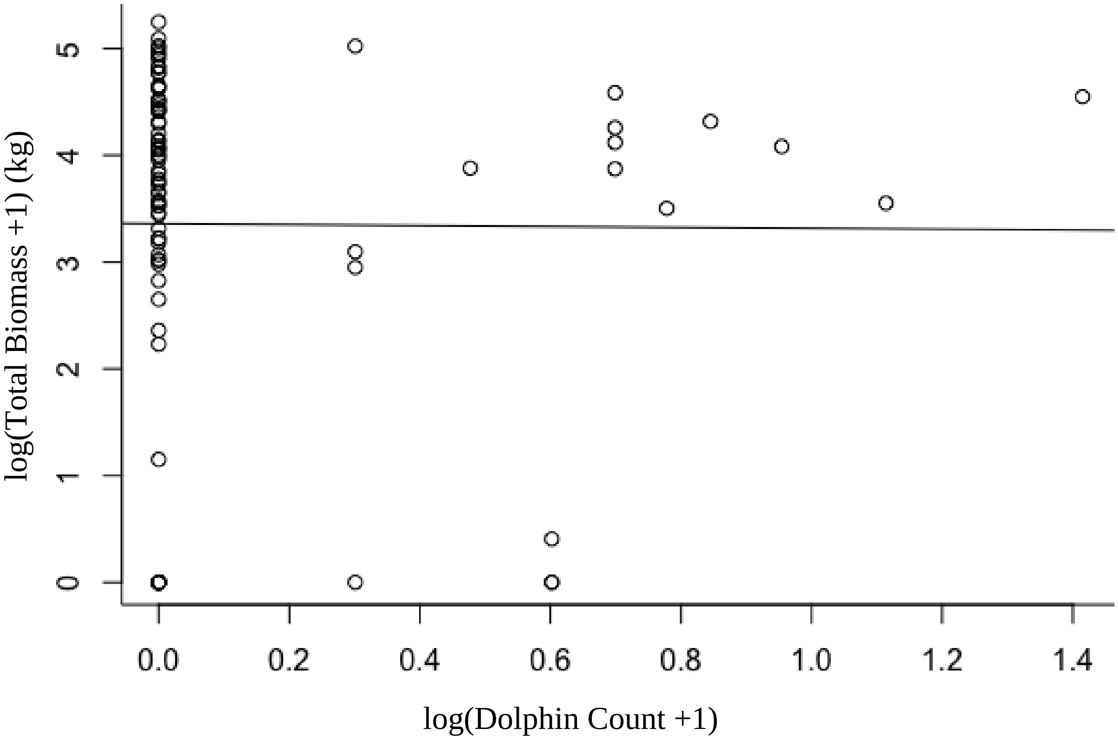


Figure 6. Linear regression showing no relation between the log transformed total fish school biomass (kg) per transect (+1 to eliminate zero values) versus log of dolphin count (n=85 transects). R^2 for the regression line = $6.82x10^{-05}$.

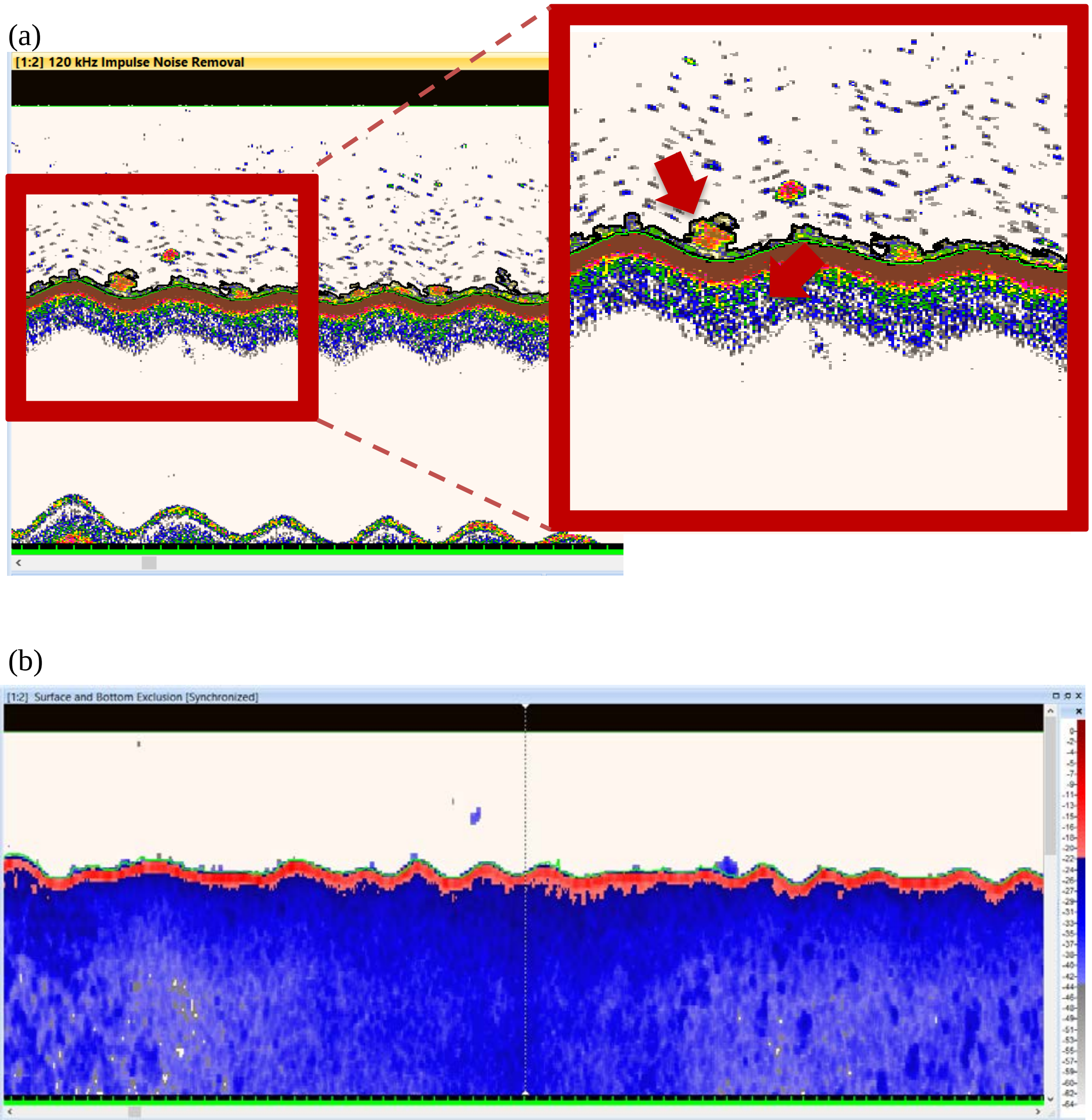


Figure 7. SONAR images taken during the SONAR fish surveys conducted along the Grand Strand in SC, with the SBS (a) and MBES (b) on October 23, 2018. The red arrows indicate the presence of fish schools by both SONARs. While only this short aggregation was observed by the MBES, the close-up inset of the SBS image indicates the detection of a continuing school of demersal fish along the bottom (outlined in black).

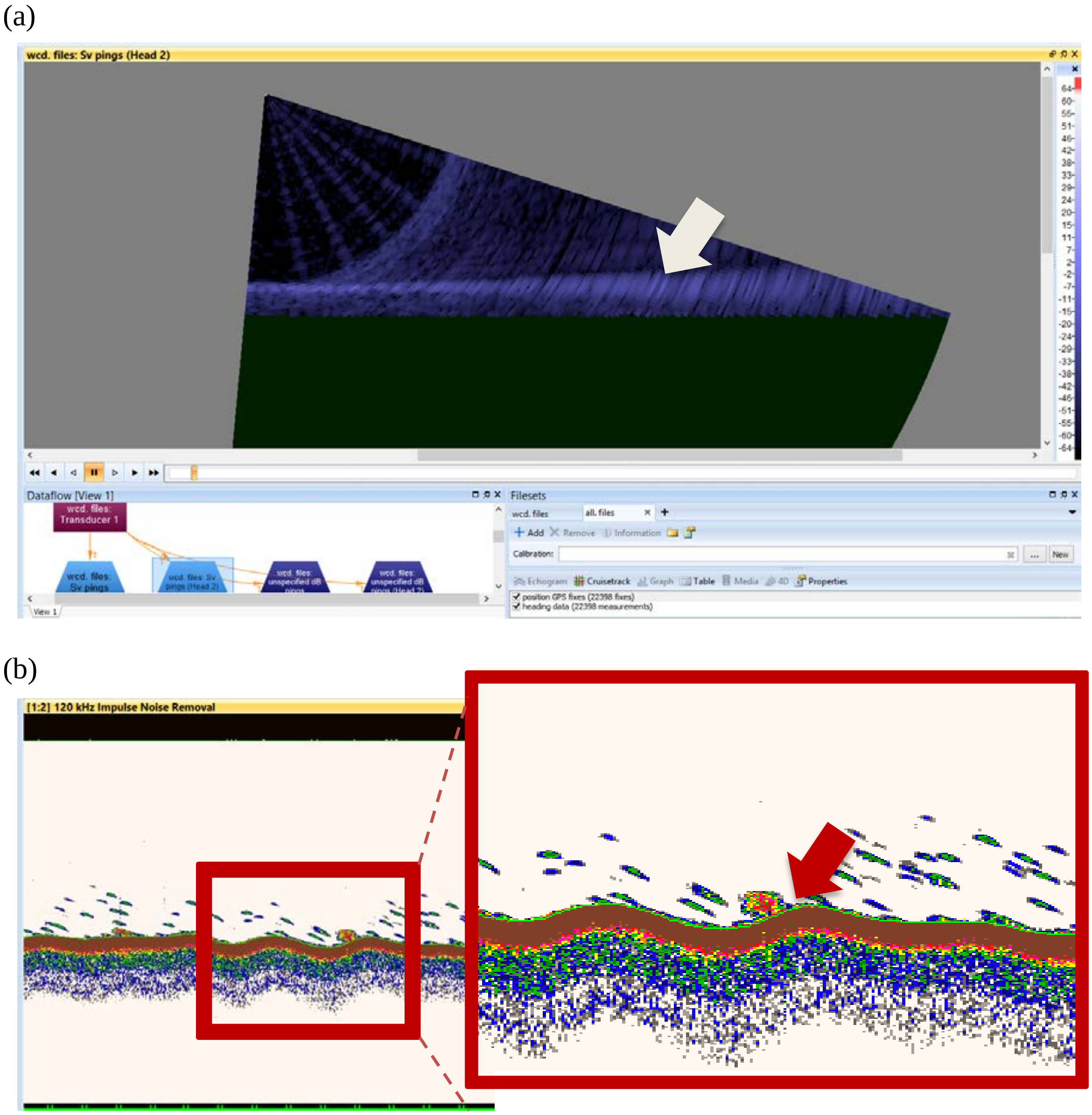
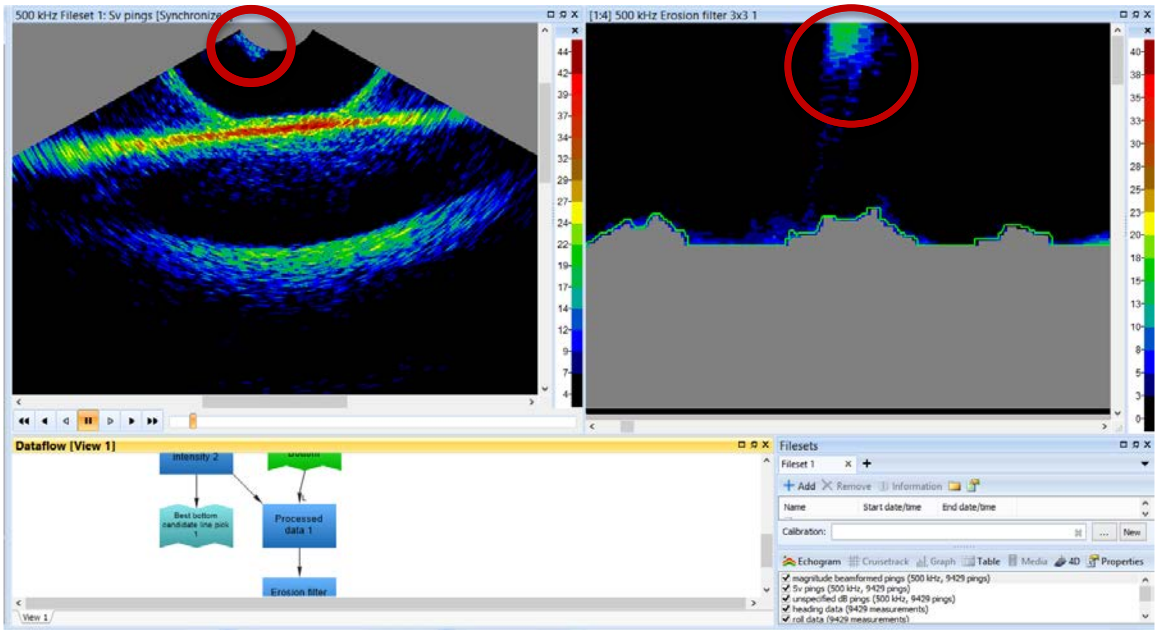


Figure 8. SONAR images from the SONAR fish surveys conducted along the Grand Strand in SC on February 5, 2019 showing where the bottom has been poorly delineated by the MBES, indicated by the white arrow (a) and clearly delineated by the SBS, indicated by the red arrow (b).



☑ magnitude beamformed pings (500 kHz, 9429 pings)
☑ Sv pings (500 kHz, 9429 pings)
☑ unspecified dB pings (500 kHz, 9429 pings)
☑ heading data (9429 measurements)
☑ roll data (9429 measurements)

Figure 9. SONAR images from the Dolphin Foraging surveys conducted off the coast of Murrells Inlet, SC, with the Kongsberg M3 Multibeam, on November 9, 2019. The red circle shows a strong target strength signal detected in the water column, likely from the large lungs of a dolphin. Successive images, however, were not detected, preventing an examination of trajectories or behavior.