Assessing Movements of Three Buoy Line Types Using DSTmilli Loggers: Implications for Entanglements of Bottlenose Dolphins in the Crab Pot Fishery

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Assessing Movements of Three Buoy Line Types Using DSTmilli Loggers: Implications for Entanglements of Bottlenose Dolphins in the Crab Pot Fishery

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Abstract

A study was conducted in October 2006 in the Charleston, South Carolina area to test the movements of three different buoy line types to determine which produced a preferred profile that could reduce the risk of dolphin entanglement. Tests on diamond-braided nylon commonly used in the crab pot fishery were compared with stiffened line of Esterpro and calf types in both shallow and deep water environments using DSTmilli data loggers. Loggers were placed at intervals along the lines to record depth, and thus movements, over a 24 hour period. Three observers viewed video animations and charts created for each of the six trial days from the collected logger data and provided their opinions on the most desirable line type that fit set criteria. A quantitative analysis (ANCOVA) of the data was conducted taking into consideration daily tidal fluctuations and logger movements. Loggers tracking the tides had an r^2 value approaching 1.00 and produced little movement other than with the tides. Conversely, r^2 values approaching 0.00 were less affected by tidal movement and influenced by currents that cause more erratic movement. Results from this study showed that stiffened line, in particular the medium lay Esterpro type, produced the more desirable profiles that could reduce risk of dolphin entanglement. Combining the observer’s results with the ANCOVA results, Esterpro was chosen nearly 60% of the time as opposed to the nylon line which was only chosen 10% of the time. ANCOVA results showed that the stiffened lines performed better in both the shallow and deep water environments, while the nylon line only performed better during one trial in a deep water set, most probably due to the increased current velocities experienced that day.

Introduction

The bottlenose dolphin (*Tursiops truncatus*) is a coastal delphinid that inhabits near-shore and estuarine environments. As such, they have the great potential to interact with human activities. In the southeastern United States, fishery interaction is the leading cause of anthropogenic mortality of bottlenose dolphins (Waring *et al.*, 2006). In South Carolina, the commercial crab pot fishery is the leading source of fishery-related mortality for bottlenose dolphins (Burdett and McFee, 2004; McFee *et al.*, 2006).

While information exists on fishery entanglements of bottlenose dolphins in South Carolina, the mechanism of how and why they become entangled is unknown. Bottlenose dolphins in the Indian River Lagoon, Florida, and in parts of Georgia have been documented to steal the bait of crab pots using a strategy called pot tipping behavior (Nokes and Odell, 2002; Haymans, 2005, respectively). This behavior could explain some of the entanglements in these areas. In both of these areas, modifications to gear were made to prevent dolphins from tipping the pot over and stealing the bait. However, this behavior has not been documented in South Carolina and interviews with crab fishers in South Carolina revealed that no loss of bait occurred by dolphins (Burdett and McFee, 2004).

In 2005, the National Ocean Service's Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) in Charleston, South Carolina conducted a pilot study on the movements of buoy lines used in the crab pot fishery to determine where and when bottlenose dolphins may be more susceptible to entanglement (McFee *et al.*, 2006). This study took into consideration the length of buoy line, tidal stage, water depth, and water current velocity. The current study expanded the pilot study to observe movements of three different buoy line types with varying degree of stiffness. A similar study exposing captive manatees to varying degrees of stiffened rope to determine whether stiffened rope produced less entanglements than standard nylon ropes commonly used in the crab pot fishery was conducted at Sea World in San Diego, CA (Bowles *et al.*, 2003). Captive or wild dolphins were not used for the current study. Rather, the main objectives were to determine which buoy line type would pose the least threat of entanglement to bottlenose dolphins based on specific criteria to assess movements using DSTmilli data loggers and to assess movements of each buoy line type under similar conditions of tidal cycle, water depth, and water current velocities. Results of this study will provide recommendations to the National Marine Fisheries Service and the Atlantic Bottlenose Dolphin Take Reduction Team to aid in the reduction of mortality of bottlenose dolphins in the crab pot fishery.

Methods

Study Site

Deployments of buoy lines were tested in two locations of the Stono River Estuary (SRE) southeast of Charleston, South Carolina (Figure 1). These locations were chosen based on known fisher effort and dolphin sightings in this area. A shallow water (<4.7 m) site was chosen at the first turn of Abbapoola Creek near the Stono River and a deep water (~9 m) site was chosen on the northeast bank of the Stono River across from the mouth of Abbapoola Creek. Both locations are part of a well-mixed C-type estuary (Day *et al.*, 1989).

Outfitting Gear

Three rope types (buoy lines) were chosen based on their kilotex value (k-value), which is a measure of rope stiffness provided by the manufacturer. The lower the k-value, the stiffer the rope. The three buoy line types used were: diamond-braided (#8) nylon (k-value 39, The Fishnet Co., Jonesville, LA), Esterpro™ (#8 medium lay) polysteel filaments/polyester (k-value 34; Polysteel Atlantic Ltd., Nova Scotia, Canada), and polypropylene with wire core (#8.75) calf (k-value 31; Willard Rope Co., Rockdale, TX) (Figure 2). Soaking or "curing" of the lines was not done prior to deployment. This was in part done so that the lines were exposed to the same conditions over time and to determine if performance of the lines changed over the study period.

Each line was cut to 15.24 m (50 ft) and, starting at approximately 5 cm from the buoy end, marked every 1.2 m (4 ft) with a permanent ink marker. DSTmilli data loggers (Star-Oddi, Reykjavik, Iceland) were secured to each line at the marked intervals with small, 10.16 cm nylon cable ties (Gardner Bender, Charlotte, North Carolina). The ends of the cable ties were cut off near the loggers (Figure 3). In addition to the 12 loggers secured at each of the marks, a 13th logger was placed on top of the crab pot to monitor any rolling of the pot. Each logger weighed less than 5 g in water and was 38.4 mm x 12.5 mm. The loggers recorded depth (m) and temperature (◦C) every 20 s for approximately 24 h with a reported accuracy of +/- 0.4% of the selected depth range of 20 m and +/- 0.1◦C for temperature.

One end of each line was tied to each yellow football-shaped buoy and the other end tied to the base of the crab pot. Four crab pots, supplied by the crab fisher, were used for each deployment. One line of each type was attached to three crab pots and a fourth line was used as a replicate of one of the lines for each deployment alternating a different line type as a replicate in successive deployments (see Table 1 for deployment schedule).

An Argonaut XR 1.5 MHz Autonomous Multi-Cell current velocity meter (SonTek/YSI, Inc., San Diego, California) system was attached to plywood sheeting and weighted on the bottom with PVC pipe filled with sand. Two ropes attached to a buoy were placed at opposite ends of the plywood to allow for deployment (Figure 4). Prior to deploying the Argonaut, the unit was set to record data hourly in the multi-cell mode of either three cells (shallow water) or seven cells (deep water). The first cell begins 0.50 m above the unit from the bottom and terminates as close to the surface as possible when the Dynamic Boundary Adjustment setting is turned on. For the shallow water deployments, each cell was 0.75 m and, for the deep water deployments, each cell was 1.00 m. The unit was set with a sampling interval of 3600 s, with an averaging interval of 45 s. The Wave Spectra option was turned on to capture wave action.

Deployment

Shallow water deployments were made in Abbapoola Creek on October 9, 12, and 16, during 2006. Line types used for each day can be found in Table 1. Each crab pot was deployed by the crab fisher in the same manner with the line coiled on the bottom of the boat and the pot placed in the water. The fisher would move the boat in a circle to allow the line to come out of the boat. An observer made sure that loggers did not catch on any coiled line before entering the water. Waypoints of locations of the pots and buoys were collected using a Garmin GPS map76S (Garmin, Olathe, Kansas). The four crab pots were placed in a row, sufficiently spaced as to not interfere with one another. The Argonaut was placed between the 2nd and 3rd crab pot (Figure 5). While the Argonaut recorded water current velocity and direction hourly, the position of it between the pots probably did not accurately account for the velocities at all buoys. To partially compensate for velocity data at all buoys, an expandable flow probe (Forestry Suppliers, Inc., Jackson, Mississippi) was used to record water current velocity at each end of the row of pots and at the Argonaut in the morning immediately after deployment and then again later in the day. The lines were allowed to soak for approximately 24 h and then removed.

Deep water deployments were made in the Stono River on October 19, 23, and 26, during 2006. The procedure described above for shallow water deployment was also used for the deep water deployments.

Data Analysis

Once buoy lines were retrieved, the data loggers were removed from the lines and each logger's data were downloaded into a Dell Latitude D610 computer (Dell, Inc., http://www.dell.com/). Each logger was independently placed in the communication box and data were transferred into Sea Star software (Star Oddi, Reykjavik, Iceland). Data from each logger were re-converted to display desired units of measure (meters for depth and degree Celsius for temperature). The data were then transferred to Microsoft Excel spreadsheets and charts were created for each data logger showing time on the x-axis and depth on the y-axis. The 13 logger profiles from each chart were then compiled into one chart to depict a particular buoy line (see Appendix 1). This was done for each line representing each day of deployment. The buoy line profiles generated from these charts were then analyzed by three observers without knowledge of the buoy line types. A qualitative analysis was made by each observer to determine which buoy line fit set criteria the best. These criteria were: 1) degree of arcing of the line (determined by adjacent logger profiles that crossed each other), 2) erratic movement (determined by degree of a “zig-zag” appearance of the logger profiles), 3) sudden ascent or descent of loggers, 4) arcing off the bottom (see 1 above), and 5) relative amount of time it took the line to ascend from the bottom or descend to the bottom. Each observer then provided opinions on what buoy lines would be their first and second choices.

Data from each logger were also analyzed using Matlab to animate the buoy lines. A set of Matlab scripts was used to extract raw data from the supplied Excel Spreadsheets and produce movies illustrating temporal behavior of the lines being studied. Data for each experiment are distributed across several files. A line configuration spreadsheet gives the mapping of loggers to lines and line positions in each of the experiments. Logger spreadsheets provide depth data collected in each of those experiments. The data extraction script (process.m) reads the line configuration spreadsheet and identifies loggers used throughout the series of experiments. Each logger spreadsheet is read and the usable data extracted. Depth data are retained without processing and time codes in DD/MM/YY HH:MM:SS format are converted to a Matlab-defined numeric value representing time. The data from all loggers are stored in a Matlab cell array and saved prior to constructing the movies. Next, animations are created using the visualization script (showlines.m). The line configuration and previously generated cell array are passed to this function. The script finds a common time range for the loggers used in a single experiment and interpolates the depth time series for each experiment to align the measurements from all loggers to a common time scale. The sampling intervals of both the raw and visualized time series are 20 seconds. Using the Matlab animation functions, an AVI-formatted animation is created. For each frame, the depths for each logger are plotted and a title giving the date and time of the aligned sample is displayed as the graph title. Each frame of the resulting animation corresponds to 20 seconds of real time (one sampling interval). Played at the standard rate of 15 frames per second gives a time-scale factor of 300 to 1. The X-coordinate is taken to be the logger position along the line and the animation can not be taken to illustrate the orientation of the line in the water as more than one orientation may produce the same depth readings. The Matlab scripts are supplied as part of this report (Appendix 2).

The same three observers of the charts reviewed the animations separately without knowledge of the buoy line types (Figures 6a and 6b). The criteria used to determine best buoy line type were: 1) erratic logger movements, 2) arcing of the line (determined by adjacent loggers that may be above or below each other), 3) arcing off the bottom (see 2 above), 4) amount of curve in the line (e.g., a line that went straight from the buoy to the bottom was preferable to one that curved to the bottom), and 5) relative amount of time it took the line to ascend from the bottom or descend to the bottom. Each observer then provided opinions on what buoy lines would be their first and second choices.

To determine how close in agreement the reviewers were in their analyses of both the charts and animations, a series of Kappa tests were performed with proportions of agreement tests run independently of Kappa. This test is widely used to measure inter-observer variability and is preferred because it accounts for chance (Landis and Koch 1977). Sample category size was determined to be too small to achieve reliable Kappa scores, therefore, proportion of agreement scores averaged among the three observers were used to evaluate the degree of agreement.

To examine the influence of tidal depth on each line type, an Analysis of Co-Variance (ANCOVA) was then performed for each day at each logger position (PROC GLM). The data from each individual excel file were imported into SAS (v9.1.3 for Windows) using the Data Step and the SAS Macro Language Facility. An individual SAS dataset was created from each excel file. The datasets were then merged into a single all-inclusive master SAS dataset with a total of 1,313,736 observations. Since actual measured tidal depths for Abbapoola Creek were not available, tidal depths (m) were obtained from the nearby Charleston Harbor tide gauge. Measured tidal data were downloaded from NOAA's Center for Operational Oceanographic Products and Services (http://tidesonline.nos.noaa.gov/) for the deployment dates. The nearest recording tide gauge was the Charleston Harbor tide gauge (#8665530 -- 32° 46.9' N, 79° 55.5' W). Since the tidal data were recorded every 6 minutes and the DSTmilli loggers recorded every 20 seconds, an interpolation procedure was used to estimate tidal depth every 20 seconds. Using the SAS procedure PROC EXPAND [factor=(18,1) method=spline], tidal data were interpolated to every 20 seconds using a spline interpolation method. The tidal data were then merged into the master SAS dataset with the logger data. Obvious erroneous data were excluded for malfunctioning data loggers. Logger depth data points > 5m at the shallow water site and > 9.5m at the deep site were excluded from the analysis since these values exceeded the maximum depths at the sites. Values greater than those mentioned are indicative of a malfunctioning logger.

For the ANCOVA, the dependent variable was logger depth and the independent variable was tidal depth. The class variable was line type. Contrast statements were used to compare significant differences between slopes (of different line types) using the interaction term of the model. The analyses were performed by day and logger position. Additionally, individual simple linear regressions were performed to obtain individual r^2 values for each individual logger regressed against tidal depth.

Environmental Data

Tidal data were obtained from http://tidesonline.nos.noaa.gov for the Stono River, Abbapoola Creek entrance (32.6766N and -80.0066W). Climatological data (eg., wind speed and direction, ambient temperature) were obtained from http://www.weather.gov/climate. Average water temperatures were collected by averaging the hourly water temperatures collected by each individual logger. Observations of sea state or swell were classified into one of four categories at the time of deployment and the time of retrieval. These categories were: 1) 0-0.5 m, 2) 0.5 m-1.2 m, 3) 1.2 m–1.8 m, and 4) >1.8 m.

Results

Chart Analysis

Over 4,000 data points per logger per trial were plotted on charts. Four charts representing four buoy line types were created for each day resulting in 24 total charts for the study period. Results from the qualitative analysis showed that the Esterpro line was chosen as the most desirable profile on each day (9/9=100%) in the shallow water trials (Table 2). For the deep water trials, one observer chose the Esterpro line type as the most desirable profile for each day, a second observer chose Esterpro on two days and the calf line type on one day, and a third observer chose the nylon line type on two days and the calf line on one day. Combining both shallow and deep water trials, the Esterpro buoy line was chosen on 14 occasions (77.8%), and the calf and nylon buoy lines on two occasions each. The averaged percentage of agreement score was 0.67 for the chart analysis.

Animation Analysis

Results from the qualitative analysis (Table 3) in shallow water showed that the calf buoy line was chosen on five occasions (55.5%) and the Esterpro buoy line chosen on four occasions (44.4%). In deep water, the calf buoy line was chosen on five occasions (55.5%), the Esterpro buoy line on three occasions (33.3%), and the nylon buoy line on one occasion (11.1%). Combining both shallow and deep water trials, the calf buoy line was chosen on 10 occasions (55.5%), the Esterpro buoy line on seven occasions (38.9%), and the nylon buoy line on one occasion (5.6%). The averaged percentage of agreement score for the animation analysis was 0.67.

ANCOVA

We would expect that loggers that simply changed in depth due to changes in tidal height would have a high r^2 value. This was demonstrated by loggers that were resting on the bottom or the loggers that were attached to the pot (Figure 7). If all loggers on a particular line were simply tracking the tidal movements, they all would have r^2 values approaching 1.00. The logger near the surface would be expected to have an r^2 value approaching 0.00 because its depth is not changing drastically with the tidal movements (Figure 8). However, the loggers in the water column are moving presumably under the influence of currents. As a result, for the shallow water trails, loggers approximately mid-way in the water column (loggers 2 and 3) were compared for each buoy line on each day. Similarly, loggers 8 and 9 were compared for each buoy line on each day.

Results of the ANCOVA on loggers 2 and 3 for shallow water and loggers 8 and 9 for deep water are shown in Table 4 with corresponding r^2 values and p-values. In Trial 1, logger 4 was used instead of logger 3 because loggers in position 3 on two of the buoy lines failed to work. The Esterpro buoy line was chosen for Trial 1 based on significantly higher r^2 values than the other two buoy lines. In Trial 2, logger 4 was used because one of the loggers in position 3 failed to work. For the same reasons, the calf buoy line was chosen for Trial 2. In Trial 3, either the Esterpro or calf buoy lines could have been chosen because the Esterpro buoy line had a significantly higher r^2 value for logger 2 than the other buoy lines and there was no significant difference ($p=0.29$) between the two for logger 3 on each line. The Esterpro buoy line was chosen for Trial 4 based on significantly higher r^2 values of loggers in positions 8 and 9 than the other two buoy lines. Even though these values were low, the logger at position 10 on the Esterpro buoy line was significantly greater ($p<.00001$) than either of the other two buoy lines. In Trial 5, either the Esterpro or nylon buoy lines could have been chosen as their loggers at positions 8 and 9 were not significantly different ($p=0.55$ and $p=0.32$, respectively). The nylon buoy line was chosen in Trial 6 with both logger positions 8 and 9 significantly greater than the other two buoy lines.

All Analyses

Table 5 shows the results from all three analyses. When combining these results, the Esterpro buoy line was chosen 57.1% of the time, the calf buoy line 32.1%, and the nylon buoy line 10.7% of the time. For shallow water trials, Esterpro buoy line was chosen 69.0% of the time, calf buoy line 31.0% of the time, and the nylon buoy line on zero occasions (0.0%). For deep water trials, Esterpro was chosen 45.2% of the time, the calf buoy line 33.3% of the time, and the nylon buoy line was chosen 21.4% of the time.

Environmental Conditions

The tidal heights (Mean Lower Low Water) at high tide ranged from a low of 4.8 ft (1.46 m) on October 26, 2006 to a high of 7.2 ft (2.19 m) on October 9, 2006. Tidal data are presented in Table 6. Average water temperatures were lowest (18.5˚C) on October 26, 2006 and highest (23.1˚C) on October 12, 2006. Average wind speed was lowest (2.9 mph [4.7 kph]) on October 26, 2006 and highest (10.5 mph [16.9 kph]) on October 23, 2006. Swell was less than 0.5 m on every day. All climatological data are presented in Table 7.

Average water velocity data for the entire water column are presented in Table 8. Incorrect settings caused the system to malfunction on the first day of deployment, therefore, no velocity data were available for Trial 1 (October 9, 2006). Likewise, data were not recorded after 0400 h during Trial 4 (October 20, 2006) for unknown reasons. Generally, average water velocity was greater in the deep water environment (Trials 4-6) than the shallow water environment (Trials 2 and 3). An ANOVA was run to show that velocities were significantly different between Trials ($p=0.006$). Water current velocities were significantly different between Trials 4 and 5 ($p=0.001$) and Trials 4 and 6 ($p=0.0034$) using a Tukey-Kramer least squares means adjustment for multiple comparisons. Average water velocity data using the multi-cell option of the Argonaut XR are presented in Table 9 (shallow water) and Table 10 (deep water). Average water velocity generally appeared to increase from the bottom of the water column to the surface in all the deep water trials (Cell 1 to Cell 7). This pattern was similar with the shallow water trials, except for a slight deviation in Trial 2. However, this pattern within each one hour recording period was highly variable making the assessment of the effects of velocity on the line movements difficult. This variability, and the fact that one hour elapsed between velocity recordings, precluded further statistical analyses of how velocity affected each buoy line were not conducted.

Discussion

Reducing the amount of vertical line in the water column would potentially reduce the risk of entanglement of bottlenose dolphins, but very few studies (Hopkins and Hoggard, 2006; Salvador *et al.* 2006) have investigated this potential. Recently, a crab pot trawl design linking multiple pots by ground-lines to a single vertical line has been proposed for offshore fishers (pers. comm., D. Hilton, NMFS/SER, St. Petersburg, Florida). This design has the potential to reduce the number of lines in the water column for each fisher. Most gear studies to reduce entanglement have focused on lines that break away with a weak link in the line (Hopkins and Hoggard, 2006; Salvador *et al.*, 2006), acoustic deterrents (Cox *et al.*, 2001; Barlow and Cameron, 2003), and galvanic timed releases (Hopkins and Hoggard, 2006). Rather than require commercial fishers in the crab pot fishery to replace existing lines with lines that have attached devices which may impede retrieval of gear and be less cost effective, the use of a line that hangs more vertical in the water column and exhibits reduced erratic movements may be as beneficial in reducing entanglement as attaching devices that may be expensive and face reluctance for use by the fishers.

While there were inconsistencies in the results both within the qualitative analyses and between qualitative and quantitative analyses, a general pattern could still be observed. The results showed that overall, the Esterpro buoy line was preferred nearly 60% of the time. When this buoy line was not preferred, the calf buoy line was chosen most of the time and the nylon buoy line was chosen approximately 10% of the time. Therefore, a case could be made for the use of a more stiffened buoy line like the Esterpro line as opposed to the more commonly used nylon line used in the crab pot fishery to potentially reduce the occurrence of bottlenose dolphin entanglements.

Observer agreement in the shallow water trials (Trials 1-3) was high for both the chart and animation analyses, with the Esterpro buoy line chosen the majority of the time. There appeared to be less agreement in the deep water trials and results varied between the chart and animation analyses. All observers felt it was easier to distinguish patterns and movements of the buoy lines while viewing the charts rather than the animations. However, all observers noted that the nylon buoy line tended to come off the bottom faster as the tide was flooding and take more time to fall to the bottom on ebbing tides. This would create more line in the water for an extended period of time. While the animations provided the opportunity to observe wide deviations in individual logger movement (see Figures 6a and 6b), subtle changes could easily be missed due to the speed of the animations. Slowing the animations down may have resulted in a different interpretation of the lines.

Changes in logger movements were more readily observable in the shallow water environment because less line was in the water column and the current velocities were slower. In the deep water trials, the buoy lines were subjected to generally greater water current velocities, causing lines to nearly overlap each other (see Figure 6b). The observer therefore, had to concentrate more on the loggers near the bottom to observe changes. As such, a quantitative analysis of the data needed to be performed.

Results from the ANCOVA provided a quantitative assessment of the buoy line movements as they related to tidal movement. The results from the ANCOVA show that the Esterpro buoy line more closely tracked the tidal movements on most occasions. The exceptions being, on Trial 2 (shallow water) and Trial 6 (deep water), when the calf and nylon buoy lines were preferred, respectively. In Trial 3, there was no significant difference between the calf and Esterpro buoy lines. These data suggest that stiffened line (either the Esterpro or calf) exhibits more stability and less movement than the nylon buoy line.

Interestingly, the ANCOVA analysis determined that the nylon buoy line was preferred in Trial 6 and showed no significant difference with the Esterpro buoy line in Trial 5. Both of these trials occurred in deep water. It was initially thought that this change may have been the result of an observed decrease in average water temperature (22˚C to 18.5˚C). However, the 3.5˚C change was probably not significant enough to cause an appreciable change in the nylon buoy line properties (pers. comm., S. Parolla, New England Ropes, Fall River, Massachusetts, 2007). A more plausible cause for the change is the increased water current velocities experienced during Trials 5 and 6. A new moon occurred on October 22, 2006 which would account for water current velocities being significantly greater than the previous shallow water trial. In the McFee et al. (2006) study, stronger current velocities had little to no effect on arcing of the lines. Buoy lines exposed to strong current tend to become taut and run almost directly to the pot as observed in the video animations and depicted in Figure 6b. Lyman *et al.* (2005) also noted that arcing of the lines was dependent on the speed and direction of the currents.

In a study conducted by Hopkins and Hoggard (2006), buoy lines made of polyester were compared to buoy lines made of nylon in an examination of breakaway buoy strengths. For this study, a manufactured hook system dragged behind a boat was used to simulate an entanglement. The authors noted that the nylon line was more susceptible to wrapping around the hook creating more force needed to break the line than the stiffer polyester line. Nylon rope has a tendency to absorb water causing it to shrink and expand, making it more pliable with reduced strength (pers. comm., S. Parolla, New England Ropes, Fall River, Massachusetts, 2007). The Esterpro line used in our study is made of an inner core of polysteel filaments wrapped by high tensity polyester. As a result, the polyester will not absorb water and the properties of the rope shouldn't change (pers. comm., S. Parolla, New England Ropes, Fall River, Massachusetts, 2007).

For large whales, entanglements in vertical line gear have been documented in ground-lines (lines that are in contact with the bottom) that run between pots (McKiernan *et al.*, 2002; Johnson *et al.*, 2005; Lyman *et al.*, 2005). Floating line is typically used for these ground-lines to reduce chaffing in the lobster fishery. Lyman *et al.* (2005) noted that using mini-loggers, similar to what was used in the present study, showed that these ground-lines between pots actually arced off the bottom with arc height varying with tidal currents. The concern in the Lyman *et al.* (2005) study was that whales were becoming entangled in this arc between the pots. Buoy lines in the blue crab fishery only have a single line running from the buoy to the pot in most instances. Arcing of the line off the bottom was not readily observed in the present study, but the video animations provided some information of the calf buoy line arcing off the bottom. This is similar to what was seen in a study incorporating lead line (McFee *et al.*, 2006). Too stiff of a line may cause arcing off the bottom.

Our concern was generally confined to the line in the water column since dolphins have been observed manipulating buoy lines causing the buoy to disappear below the surface momentarily. These observations were made during photo-identification research conducted by CCEHBR staff in the Charleston area in 2004 and 2005 (McFee et al., 2006) and as recent as August 2007 (pers. comm., T. Speakman, NOS/CCEHBR, Charleston, South Carolina, 2007). Other evidence from entangled dolphins points to entanglement in the vertical line. In at least four cases of dolphin entanglement, all dolphins were reported entangled between 0.6 m and 1.5 m from the buoy in water depths of nearly 6 m in every case (W. McFee, unpublished data). While curious dolphin behavior towards fishing gear may increase the risk of entanglement (Wells and Scott, 1994; Mann *et al.*, 1995; Wells *et al.*, 1998; Noke and Odell, 2002), other behaviors in close proximity to the buoy lines, such as sexual activity, feeding strategies, or crab pot tipping behavior (Noke and Odell, 2002; Davis, 2003) may contribute to entanglement. Crab pot tipping behavior, where the dolphin turns the pot upside down to retrieve bait from the bait well, has not been observed nor believed to be a problem in South Carolina (Burdett and McFee, 2004). As such, future studies elucidating the behaviors exhibited around crab pot buoy lines should be promoted as well as the use of passive acoustics to detect the amount of time dolphins actually spend around crab pots. Marine mammal stranding network personnel should also be diligent in recording the location on the buoy line where the dolphin is entangled, the total length of the buoy line, and the water depth in which the dolphin was entangled (if known).

Conclusions

This study provides some evidence that a stiffened buoy line (as opposed to nylon) may reduce the risk of entanglement of bottlenose dolphins in the crab pot fishery by creating less line in the water column and reducing erratic movement that has the potential to create arcs in the line. This was especially observed in the shallow water environment (<4.5 m) in depth where the Esterpro buoy line was chosen nearly 70% of the time. In deep water (< 9 m) in depth, the stiffened lines still produced the most desirable profiles on most occasions but results suggest that the nylon buoy line may still be as desirable as the stiffened line. This may be due, in part, to stronger water current velocities and/or the length of line used which kept all buoy lines in a similar configuration.

Stiffened line has also been demonstrated to reduce the risk of entanglement in a study of captive manatees (Bowles *et al.*, 2003). The pliable nature of nylon line in water may lend itself to become more easily wrapped around appendages when the animal comes into physical contact with the line, resulting in entanglement. The stiffened line used in the Bowles *et al.* (2003) did not show this pliable nature and thus, upon contact with the stiffened line, did not wrap around the appendage. Similar tests on bottlenose dolphins in captivity have not been conducted to determine if the same results would be obtained, but should be explored.

The use of stiffened buoy line in the blue crab pot fishery warrants attention as a possible mitigation strategy to help reduce the entanglements of bottlenose dolphins in this fishery. While the authors do not advocate the specific brand of stiffened lines used in this study, the use of a medium-lay, sinking, stiffened line similar to the Esterpro line should be further investigated as a potential alternative to nylon line used in the blue crab pot fishery. Considerations such as ease of handling, chaffing, durability, and cost need to be investigated before recommendations can be made. For instance, the Esterpro and nylon lines used in this study were considerably cheaper ($71 and $88 per 1200 ft, respectively) than the calf line ($98 per 150 ft). Studies such as this one, provide the foundation for future studies to build on to more effectively mitigate entanglements of bottlenose dolphins in fisheries.

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Table 1. Deployment schedule with location and buoy line types used. AC refers to Abbapoola Creek and SR refers to the Stono River.

Date	Trial #	Location	Water	Line Type A	Line Type B	Line Type C	Line Type D
10/9/2006	1	AC	shallow	Nylon	Esterpro	Nylon	Calf
10/12/2006	2	AC	shallow	Esterpro	Nylon	Calf	Esterpro
10/16/2006	3	AC	shallow	Calf	Esterpro	Nylon	Calf
10/19/2006	4	SR	deep	Nylon	Esterpro	Nylon	Calf
10/23/2006	5	SR	deep	Esterpro	Calf	Nylon	Esterpro
10/26/2006	6	SR	deep	Calf	Esterpro	Calf	Nylon

Table 2. Results of chart analysis from 3 observers. Each observer chose the line type which best fit set criteria of a preferred line profile.

	Observer 1	Observer 2	Observer 3
Trial 1	esterpro	esterpro	esterpro
Trial 2	esterpro	esterpro	esterpro
Trial 3	esterpro	esterpro	esterpro
Trial 4	esterpro	esterpro	nylon
Trial 5	esterpro	esterpro	nylon
Trial 6	esterpro	calf	calf

Table 3. Results of animation analysis from 3 observers. Each observer chose the line type which best fit set criteria of a preferred line profile.

	Observer 1	Observer 2	Observer 3
Trial 1	calf	calf	esterpro
Trial 2	esterpro	esterpro	esterpro
Trial 3	calf	calf	calf
Trial 4	calf	calf	calf
Trial 5	esterpro	nylon	esterpro
Trial 6	esterpro	calf	calf

Table 4. R^2 values from ANCOVA (NA = not applicable for that line type). Values highlighted in red for a particular logger position are not significantly different.

	Logger position	Nylon	Esterpro	Calf	Nylon	Esterpro	Calf
Trial 1	2	0.16	0.41	0.16	0.04	NA	NA
	4	0.55	0.83	0.62	0.54	NA	NA
Trial 2	2	0.11	0.03	0.76	NA	0.003	NA
	4	0.83	0.83	0.95	NA	0.74	NA
Trial 3	2	0.01	0.45	0.39	NA	NA	0.04
	3	0.7	0.78	0.84	NA	NA	0.66
Trial 4	8	0.02	0.12	0.00	0.01	NA	NA
	9	0.11	0.23	0.06	0.01	NA	NA
Trial 5	8	0.16	0.22	0.06	NA	0.10	NA
	9	0.28	0.39	0.18	NA	0.15	NA
Trial 6	8	0.24	0.07	0.01	NA	NA	0.04
	9	0.38	0.13	0.05	NA	NA	0.17

Table 5. Results from observers from the animations (video) and charts combined with ANCOVA results.

	Video	Video	Video	Chart	Chart	Chart	ANCOVA
Trial 1	calf	calf	esterpro	esterpro	esterpro	esterpro	esterpro
Trial 2	esterpro	esterpro	esterpro	esterpro	esterpro	esterpro	calf
Trial 3	calf	calf	calf	esterpro	esterpro	esterpro	calf/esterpro
Trial 4	calf	calf	calf	esterpro	esterpro	nylon	esterpro
Trial 5	esterpro	nylon	esterpro	esterpro	esterpro	nylon	esterpro/nylon
Trial 6	esterpro	calf	calf	esterpro	calf	calf	nylon

Table 6. Tidal data for the study period. L refers to low tide and H refers to high tide. Height is in feet.

Date	Tide	Time	Height
10/9/2006	L	3:56 AM	-0.5
10/9/2006	H	10:29 AM	7.2
10/9/2006	L	4:40 PM	0.0
10/9/2006	H	10:55 PM	6.0
10/10/2006	L	4:45 AM	-0.2
10/12/2006	H	12:42 AM	5.3
10/12/2006	L	6:29 AM	0.5
10/12/2006	H	1:14 PM	6.3
10/12/2006	L	7:27 PM	1.0
10/13/2006	H	1:41 AM	5.0
10/13/2006	L	7:26 AM	0.8
10/16/2006	H	4:41 AM	5.0
10/16/2006	L	10:29 AM	1.0
10/16/2006	H	5:04 PM	5.6
10/16/2006	L	11:14 PM	1.1
10/17/2006	H	5:33 AM	5.3
10/19/2006	L	12:38 AM	0.9
10/19/2006	H	7:05 AM	5.8
10/19/2006	L	12:58 PM	0.8
10/19/2006	H	7:14 PM	5.7
10/20/2006	L	1:14 AM	0.7
10/20/2006	H	7:46 AM	6.0
10/23/2006	L	2:54 AM	0.6
10/23/2006	H	9:35 AM	6.2
10/23/2006	L	3:38 PM	0.8
10/23/2006	H	9:39 PM	5.3
10/24/2006	L	3:28 AM	0.7
10/26/2006	L	4:43 AM	0.8
10/26/2006	H	11:22 AM	6.0
10/26/2006	L	5:43 PM	1.0
10/26/2006	H	11:31 PM	4.8
10/27/2006	L	5:28 AM	0.8

Table 7. Climatological data for the study period. Wtempave refers to average water temperature in degrees Celsius, Atempave refers to average ambient temperature in degrees Celsius, Windave refers to average wind speed in miles per hour (kilometers per hour), and Winddirect refers to wind direction.

Date	Wtempave	Atempave	Windave	Winddirect	Swell (m)
10/9/2006	22.5	17.5	10.4(16.7)	20	0-0.5
10/12/2006	23.1	21.1	7(11.3)	310	0-0.5
10/16/2006	21.1	14.7	7.8(12.5)	100	0-0.5
10/19/2006	22.3	21.9	4.8(7.7)	200	0-0.5
10/23/2006	21.2	16.7	10.5(16.9)	280	0-0.5
10/26/2006	18.5	9.4	2.9(4.7)	150	0-0.5

Table 8. Average water current velocity in cm/s for each Trial. NC refers to data not collected. Data were collected on a hourly basis for each Trial. No data were collected for Trial 1 due to meter error.

Time	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
08 20 00	39.46	24.02	20.22	56.65	30.04
09 20 00	50.24	17.81	22.83	45.09	48.95
10 20 00	46.04	12.09	7.7	11.52	224.45
11 20 00	49.61	12	31.8	33.37	135.14
12 20 00	43.87	19.77	21.56	43.92	204.99
13 20 00	24.91	21.64	6.83	43.45	13.91
14 20 00	29.66	43.56	8.01	35.51	24.06
15 20 00	42.78	44.06	18.97	30.59	17.15
16 20 00	37.78	27.51	4.84	13.6	8.79
17 20 00	20.72	2.82	5.62	8.6	17.23
18 20 00	19.38	20.04	8.77	47.84	17.86
19 20 00	4.33	31.93	7.57	58.52	7.92
20 20 00	7.16	27.65	3.76	45.92	24.16
21 20 00	15.24	30.51	4.69	22.77	105.54
22 20 00	30.91	6.24	6.15	7.73	7.35
23 20 00	34.04	16.34	8.05	40.89	38.6
00 20 00	29.79	9.44	11.82	35.25	41.36
01 20 00	13.33	21.51	29.88	37.77	13.66
02 20 00	23.62	9.31	57.29	27.58	51.81
03 20 00	16.3	35.58	41.56	11.04	10.18
04 20 00	31.26	36.87	30.51	13.66	22.88
05 20 00	11.62	25.06	NC	52.7	34.25
06 20 00	19.06	7.34	NC	57.21	23.95
07 20 00	14.62	30.12	NC	59.16	15.5
08 20 00	14.07	26.84	NC	49.27	NC
Average	26.79	22.40	17.07	35.58	47.49

Table 9. Average multi-cell current velocity data for shallow water Trials 2 and 3. No data were collected for Trial 1 due to meter error. Units are in cm/s.

	Trial 2			Trial 3		
	Cell 1	Cell 2	Cell 3	Cell 1	Cell 2	Cell 3
08 20 00	35.8	31.7	5.1	24.4	22.3	20.7
09 20 00	49.6	44.6	32.6	20.2	10.2	15.5
10 20 00	48.8	41.1	54.7	9.5	16.4	10.2
11 20 00	47.9	54.9	55.8	11.4	10.4	5.9
12 20 00	52.3	41.4	65	16.7	22.4	10.2
13 20 00	33.6	18	50.6	21.6	21.1	30.5
14 20 00	26	28.4	16.2	41.4	27.1	26.5
15 20 00	42.8	31.2	32.9	44.9	34.5	39.7
16 20 00	42	34.4	48.1	30.4	18.1	20.4
17 20 00	15.9	9.7	6.5	10.6	4.1	6.2
18 20 00	20.9	6.7	10.5	18.7	21.4	28.4
19 20 00	0.6	10.9	1.9	26.6	39.1	28.9
20 20 00	10.1	21.8	13.7	27.6	33.2	33.8
21 20 00	19.7	26.7	10.7	27.1	25.7	15.6
22 20 00	31.6	27.1	25.6	6.9	17.7	7.7
23 20 00	35.9	37.5	42.3	15.4	11.8	4.2
00 20 00	24.7	28	31.4	9.4	5.5	13.6
01 20 00	11.2	18.9	17.1	22.3	18.4	10.1
02 20 00	29.8	7.2	25	11.6	4.9	21.5
03 20 00	16.3	26.6	28.5	32.9	16	26.3
04 20 00	29.3	24.6	21.4	38.9	24.5	24.1
05 20 00	9.9	12.5	8.3	21.6	21.1	6.9
06 20 00	17.4	4.8	9.4	3.9	12.5	14.2
07 20 00	13	4.1	8.1	31.7	40.3	38.7
08 20 00	17.7	14.3	9.2	21.1	44.2	29.2
Average	27.31	24.28	25.22	21.87	20.92	19.56

Table 10. Average multi-cell current velocity data for deep water Trials 4-6. Units are in cm/s.

	Trial 4							Trial 5							Trial 6						
Time	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
08 20 00	28.9	12.5	46.5	52.1	36.2	54.6	117	43.7	47.3	58.2	62.6	64.7	60.6	58.2	24.1	280.1	331.2	211.6	140.9	169.5	167.3
09 20 00	7.3	47.6	33.3	43.8	76.5	59.3	165.1	28.1	42.9	46.2	40.8	51.5	52.4	44.3	67.7	300	396.5	202.2	221.9	270.3	180.2
10 20 00	17.3	10.9	57.6	61.6	28.9	36.4	121	18.4	17.2	13.4	8.3	12.5	8.1	6.1	96.4	213.9	170.6	304.2	260.8	173.1	90
11 20 00	27.9	340.3	298.6	110.4	116.9	214.4	198.2	28.5	22.2	28.6	39.4	33.3	44.9	50	146.7	237.5	212.2	301.3	197.3	208.1	144.1
12 20 00	9.7	25.2	46.2	61.6	79.2	118.2	83.3	39.1	41	44.1	41.9	51.8	45.9	46.9	152.7	199.9	59.8	238.2	251.3	179.1	83.4
13 20 00	6.9	11.7	32.5	49.5	54.6	49.7	103	34.9	39.6	37	49.8	46.2	54	49.6	6	22.4	20.4	16.9	4.9	12.9	154
14 20 00	10.1	5	33.6	40.3	37.3	29.4	26.2	30.1	36.7	37.7	38.3	34.8	34.5	49.5	20.3	25.6	17.2	26.4	3.4	6.6	102.9
15 20 00	19.4	17.1	27.2	32.9	40.1	34.1	64.7	22.5	27.8	35	29	40.4	39.1	59.8	21.2	9.7	1.1	2.1	57.6	107	144.1
16 20 00	12.9	19.6	8.3	13.6	19.7	24.3	13.9	7.7	11.4	12.3	16.7	26	46.6	68.4	9.7	6	26.2	77.6	148.8	216.7	198.9
17 20 00	29.1	5.1	5.7	19.4	62.3	72.4	107.9	17.7	5.9	4.3	9.4	11.1	5.4	25	20.1	21.8	32	121.8	163.9	38.9	134.3
18 20 00	9.2	16.2	28.6	33.8	24.7	21.2	12.9	33.2	41.5	50.2	54.4	53.8	54.5	38.5	54.7	22.2	38.3	90.7	116.3	128.4	137.5
19 20 00	8	7.8	21.1	20.3	20.4	21.5	17.2	56.9	63	57	65.1	60.2	50.9	24.1	8.5	36	110.6	130.4	344	194.9	188.9
20 20 00	4.5	8.9	13.7	17.1	9.5	42.4	9.1	46.1	53.8	46.2	54.3	49	33.3	30.3	8.3	177.4	161	237.4	328.3	267.9	217.1
21 20 00	16.6	11.7	13.9	69.8	88.8	12	94.8	10.7	14	27.4	29.8	29.9	24.8	16.5	41.6	248.1	279.5	186.6	260.4	174.6	262.2
22 20 00	5.8	13.4	4.4	49.6	115.3	217.1	164.6	3.9	14.6	13.1	4.6	17.3	5.5	11	26.6	151.5	239.5	271.7	172.2	248.2	185.9
23 20 00	22.4	7.9	39.5	57.2	82.1	91.8	123	37.5	39.1	38	43.2	46.7	42	65.1	49.7	256.1	259.3	177.2	77.2	136.7	121.7
00 20 00	24.6	9.8	34.5	27.9	44.9	110.8	88.7	20.3	34.7	31.8	38	42.9	43.9	69	49.7	143.8	212	157.3	104.3	207.3	95.6
01 20 00	21.8	33.5	38.8	45.7	86.5	103.1	77	27.2	33.4	33.3	46	49.9	41.8	48.3	16.4	9.1	84.9	151.5	120.6	88.1	133
02 20 00	41.2	46.7	56.6	61.3	58.3	67.9	65.8	26.7	25.4	28.1	26.8	37.5	46.9	60.2	34.5	2.5	80.4	166.6	41.6	96.1	159.4
03 20 00	32.9	33	43.6	42.4	50.9	45.9	44.6	15.6	14.2	6.4	13	15.8	33.3	15.9	24.4	7.2	196.5	155.9	280.2	314.4	126
04 20 00	16.9	35.2	34	27.7	38.3	26.9	31.7	14.7	10.8	18.6	15.3	17.7	6.6	24.3	20.6	42.3	166.7	199.1	190.4	255.6	119.8
05 20 00	NC	NC	NC	NC	NC	NC	NC	34.8	49.4	50.7	61.6	56	59.5	40.6	36.9	71.6	202.7	313.9	201.8	30.8	263
06 20 00	NC	NC	NC	NC	NC	NC	NC	49.6	59.3	61.7	62.6	62.5	50.6	18.9	15.7	205.7	261.4	272.9	162.5	241.6	264.2
07 20 00	NC	NC	NC	NC	NC	NC	NC	47.6	59.3	58	63.4	62.6	60.8	50.4	9.4	233.3	298	180.4	190	245.1	206.5
08 20 00	NC	NC	NC	NC	NC	NC	NC	43.5	43.7	53	44	51.9	55.2	46.3	137.4	163.3	172.1	80.9	30.8	48.6	272.6
Average	17.78	34.24	43.72	44.67	55.78	69.21	82.37	29.56	33.93	35.61	38.33	41.04	40.04	40.69	43.97	123.5	161.2	171	162.9	162.4	166.1

Figure 1. Map of deployment locations in Abbapoola Creek (red dot) and the Stono River (black dot) near Charleston, South Carolina.

Figure 2. Buoy line types used in this study: diamond-braided (#8) nylon; Esterpro™ (#8 medium lay) polysteel filaments/polyester; polypropylene with wire core (#8.75) calf.

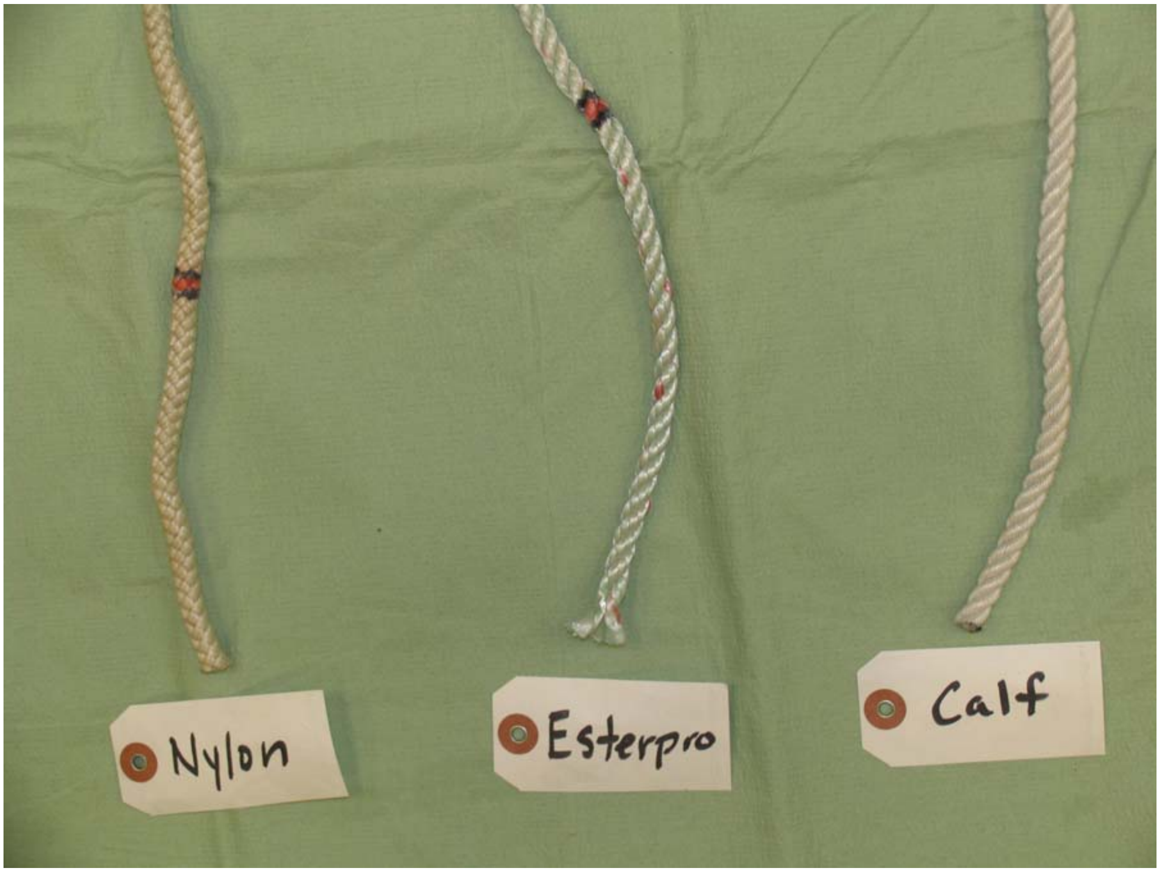


Figure 3. Example of attachment of DSTmilli logger with cable tie on Esterpro buoy line.

Figure 4. Configuration of Argonaut XR current velocity meter. The white cylinder on the right is the battery.

Figure 5. Example of a deployment configuration of the crab pots with the position of the Argonaut XR current velocity meter. This map was created for Trial 2 in Abbapoola Creek on October 12, 2006.

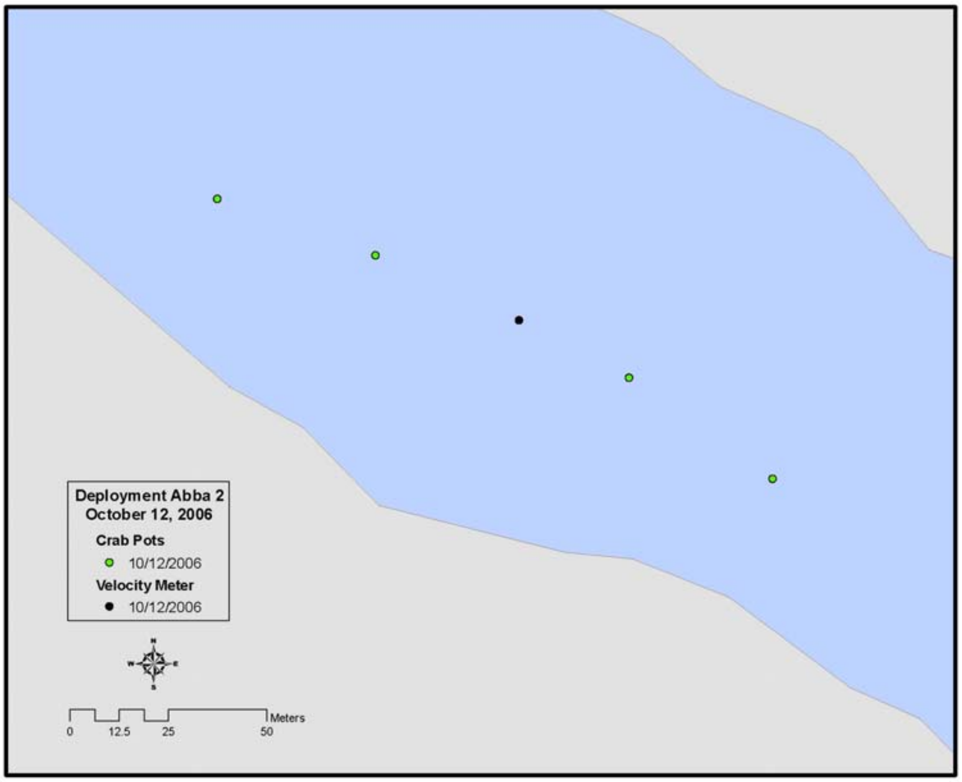
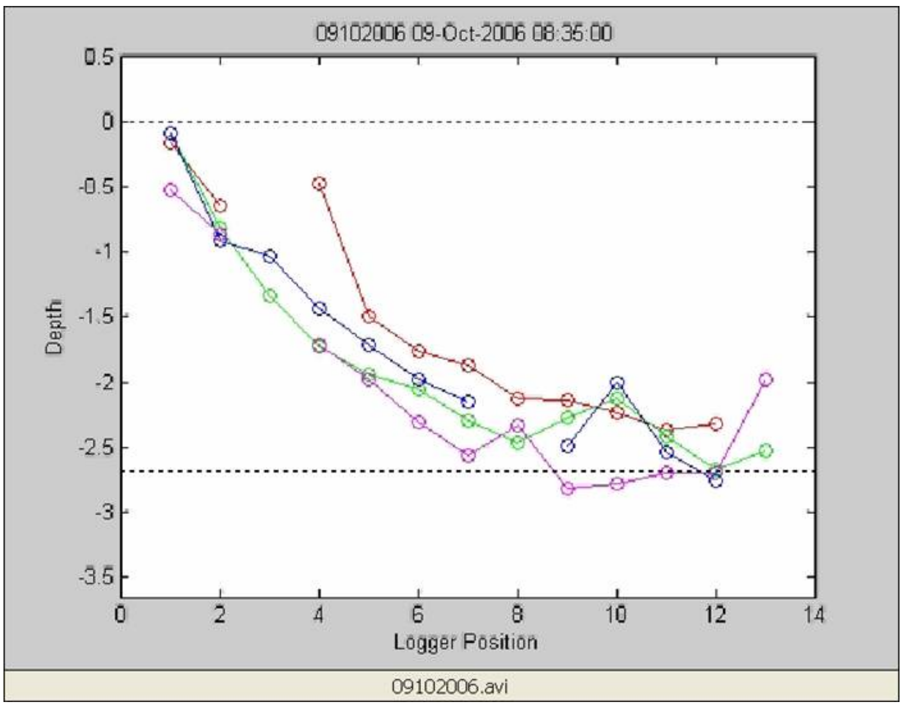


Figure 6. (a) – Screen capture of video animation of Trial 1 (shallow water) depicting the four buoy lines. Circles represent logger positions. The red buoy line is nylon, the blue buoy line is nylon, the green buoy line is Esterpro, and the pink buoy line is calf. (b) – Screen capture of video animation of Trial 6 (deep water). The red buoy line is calf, the blue buoy line is calf, the green buoy line is Esterpro, and the pink buoy line is nylon.

(a)



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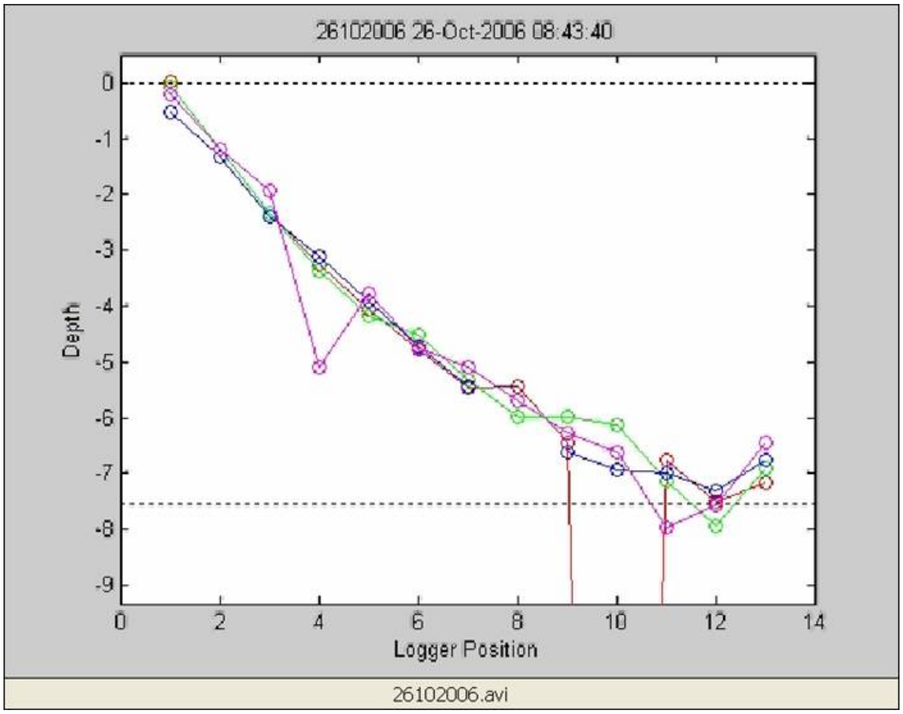
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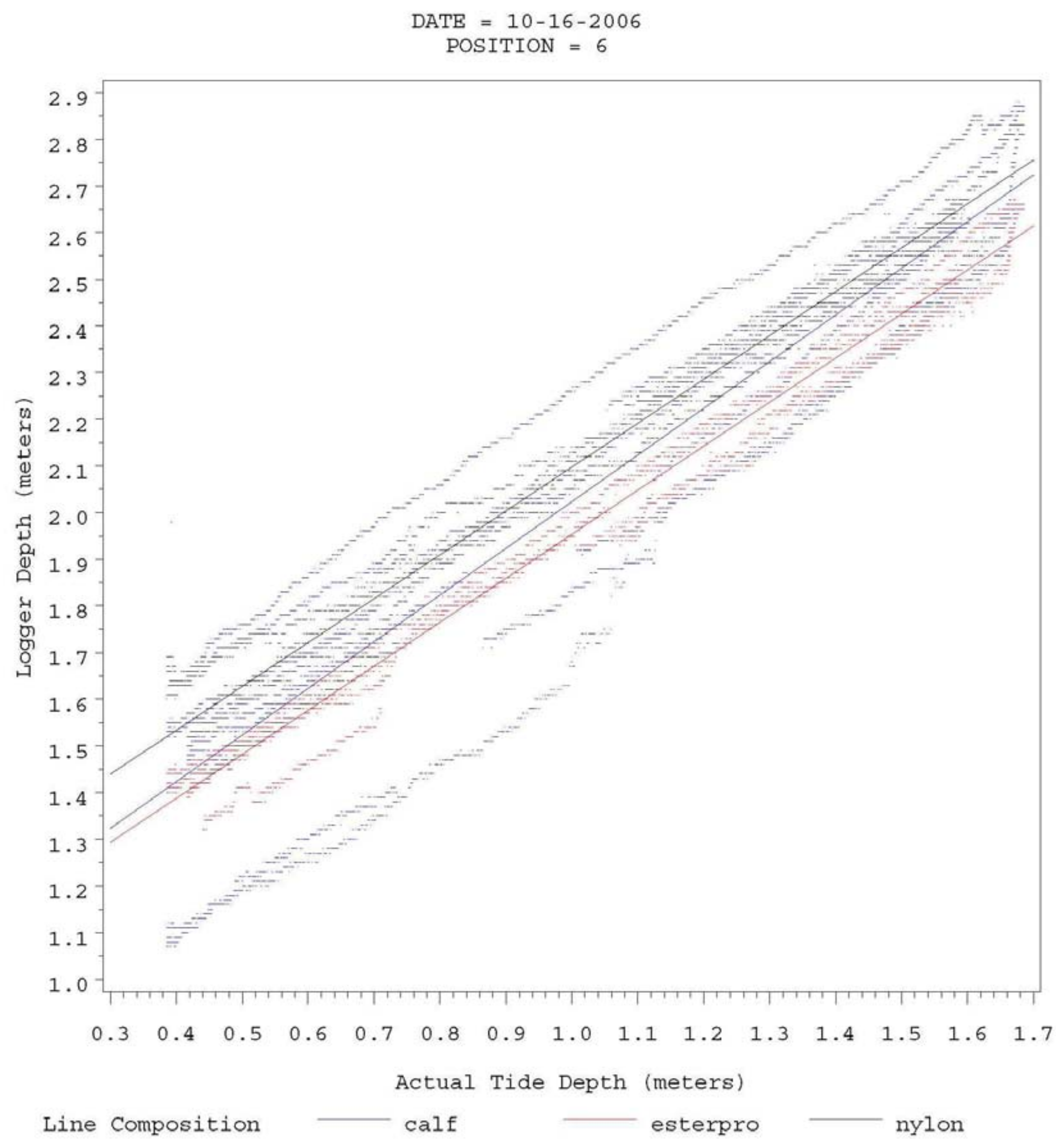
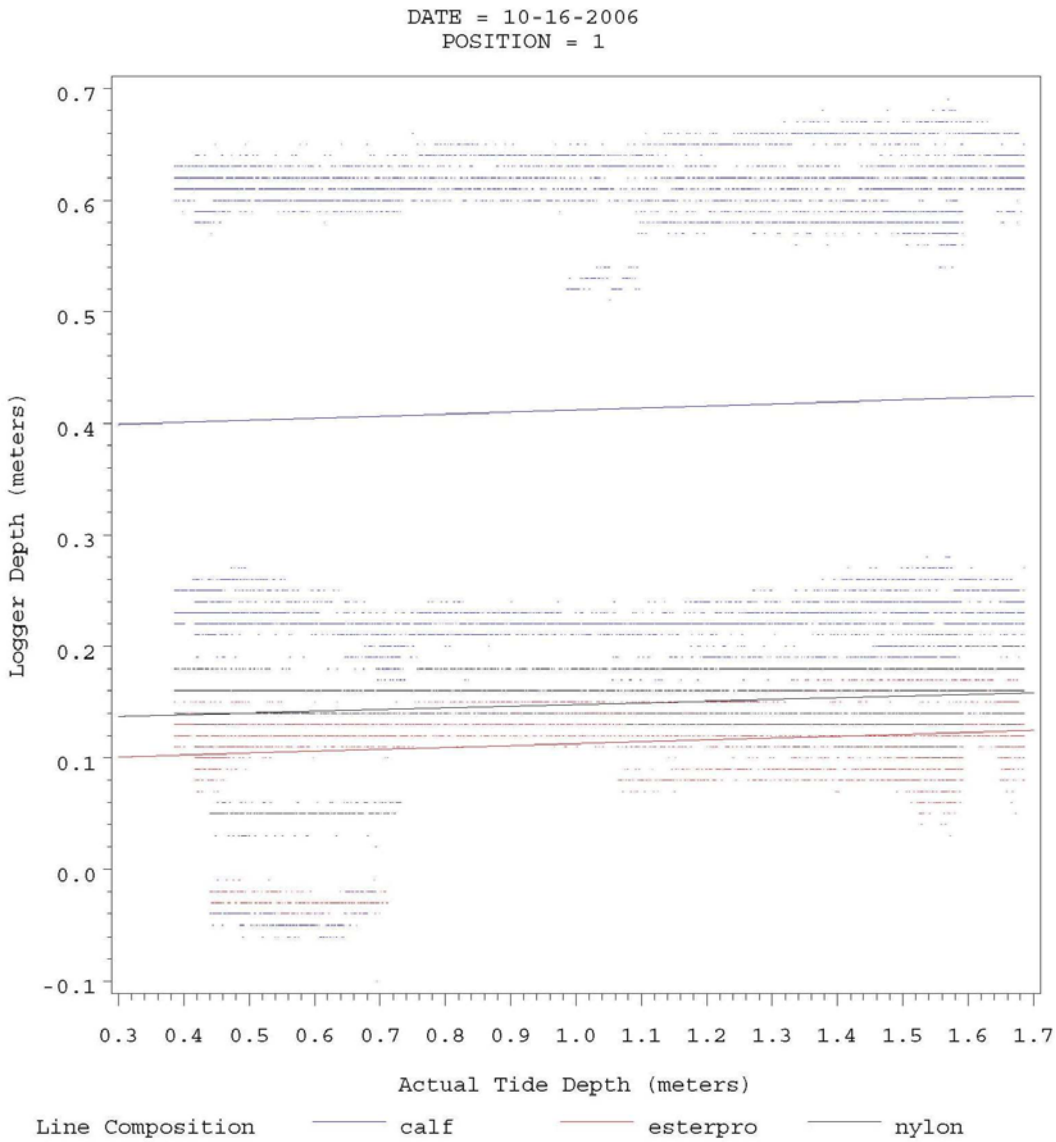
14
26102006.avi

Figure 7. Results of ANCOVA for DSTmilli loggers in position 6 on the four buoy lines during Trial 3. Note that because these loggers spent most of their time on the bottom, r^2 values approached 1.00.




```
Regression Equation:
DEPTH(linetype:calf) =  1.02305 + 1.00034*ACTUALTIDE
DEPTH(linetype:esterpro) =  1.010162 + 0.943232*ACTUALTIDE
DEPTH(linetype:nylon) =  1.157459 + 0.940074*ACTUALTIDE
  calf     RSQUARE = 0.8817414503
  esterpro RSQUARE = 0.9881455435
  nylon    RSQUARE = 0.9806555494
```

Figure 8. Results of ANCOVA for DSTmilli loggers in position 1 on three of the four buoy lines during Trial 3. The first logger for the fourth buoy line is not shown because of a malfunction. Note that because these loggers spent all of their time near the surface, r^2 values approached 0.00

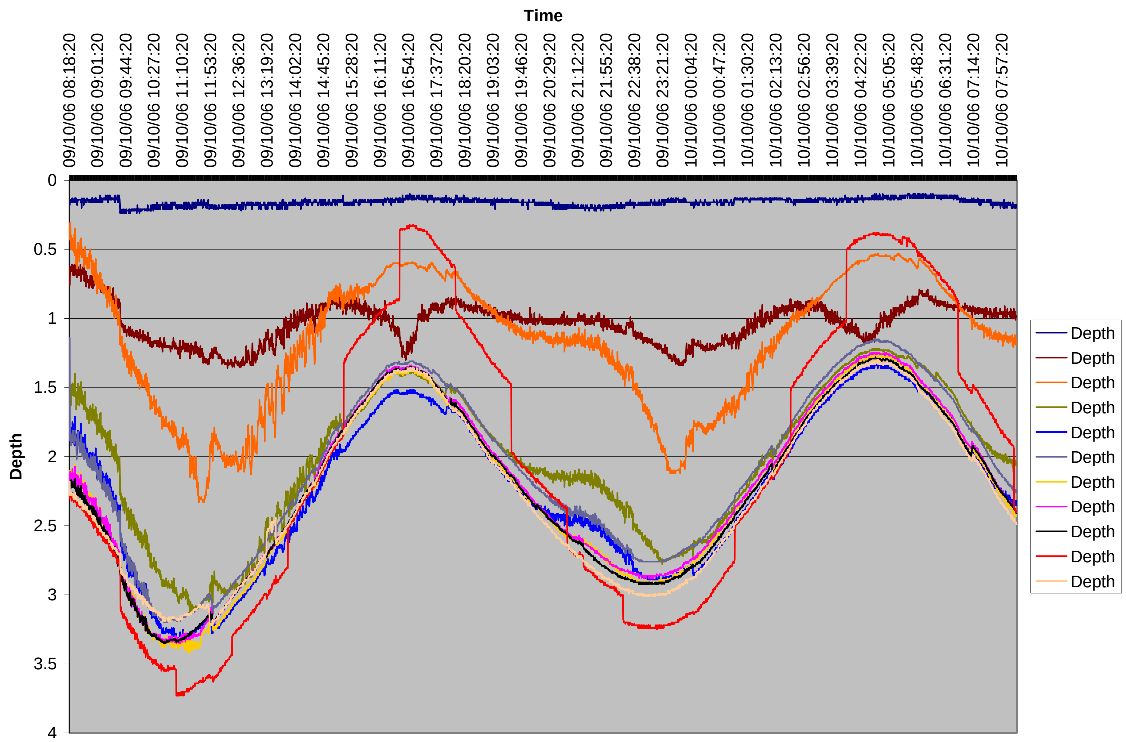



```
Regression Equation:
DEPTH(linetype:calf) =   0.393227 + 0.018473*ACTUALTIDE
DEPTH(linetype:esterpro) =   0.095723 + 0.016965*ACTUALTIDE
DEPTH(linetype:nylon) =   0.132663 + 0.015038*ACTUALTIDE
  calf      RSQUARE = 0.0016376837
  esterpro  RSQUARE = 0.0337965656
  nylon     RSQUARE = 0.0473830778
```

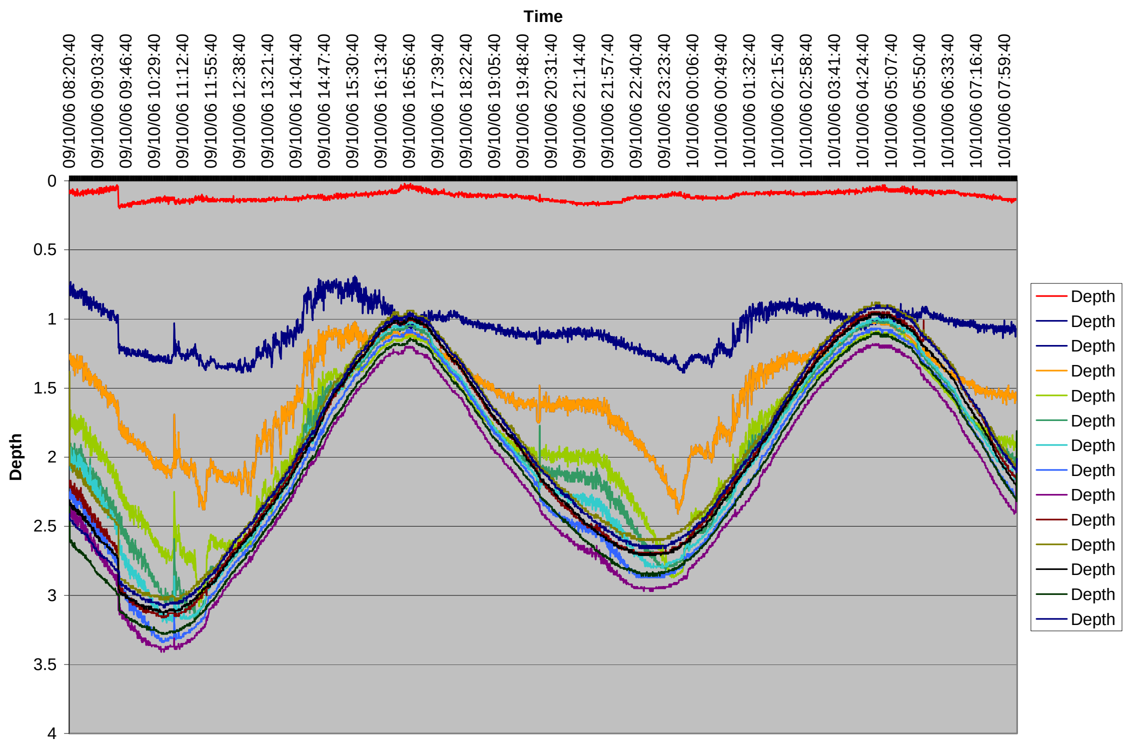
APPENDIX 1

Charts of data loggers for each buoy line type for each trial

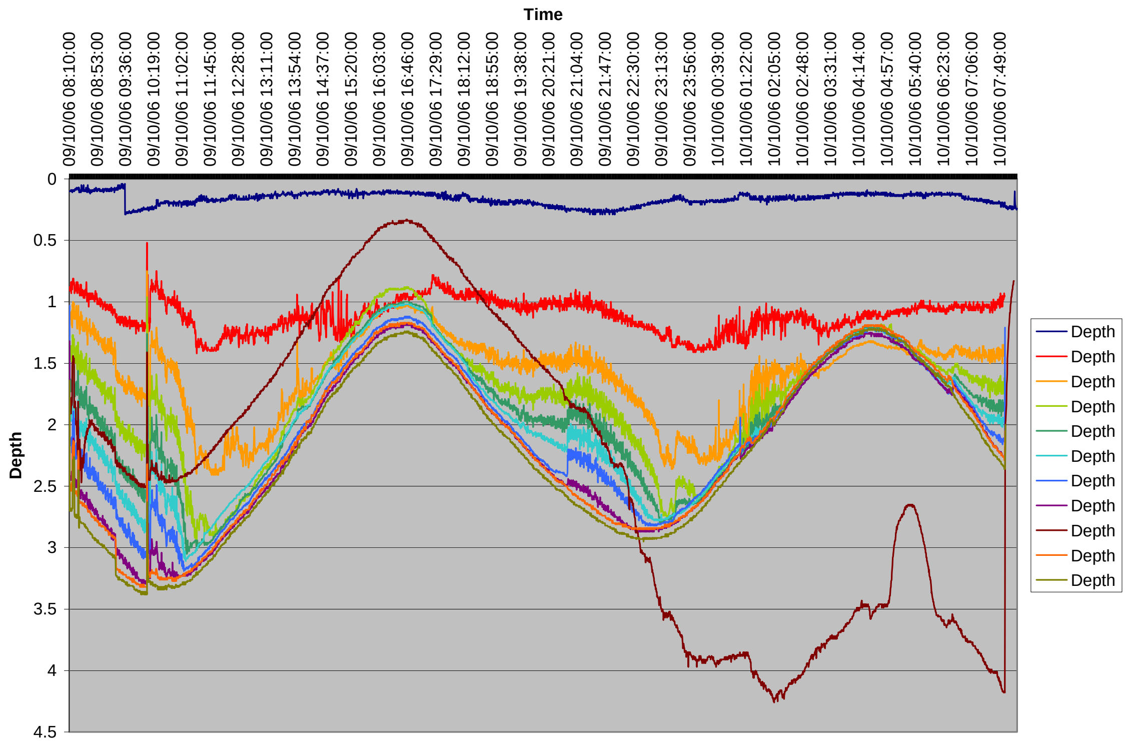
Line A (Nylon) Trial 1 (10/09/2006)



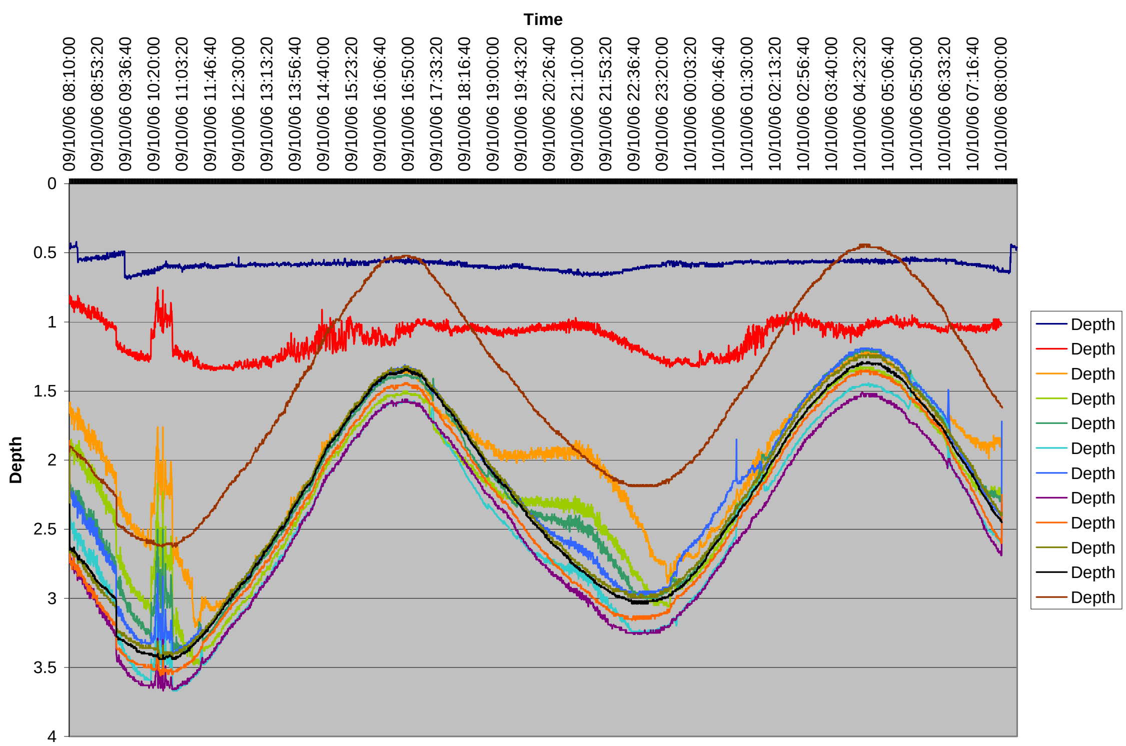
Line B (Esterpro) Trial 1 (10/09/2006)



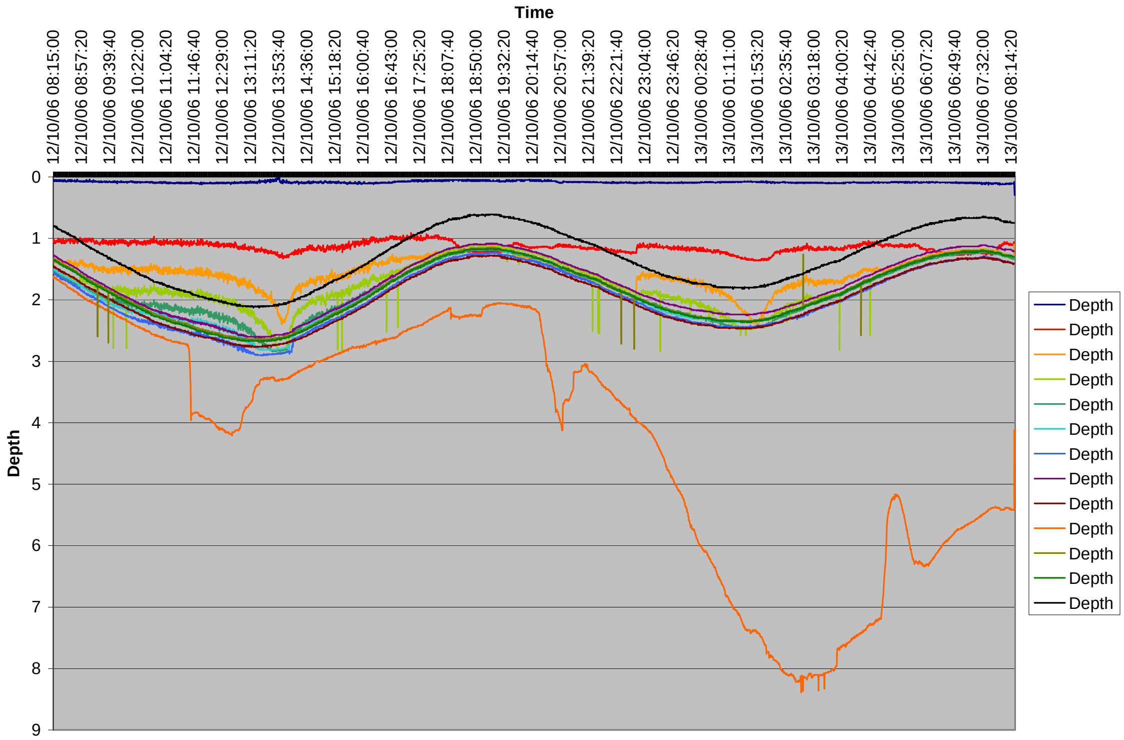
Line C (Nylon) Trial 1 (10/09/2006)



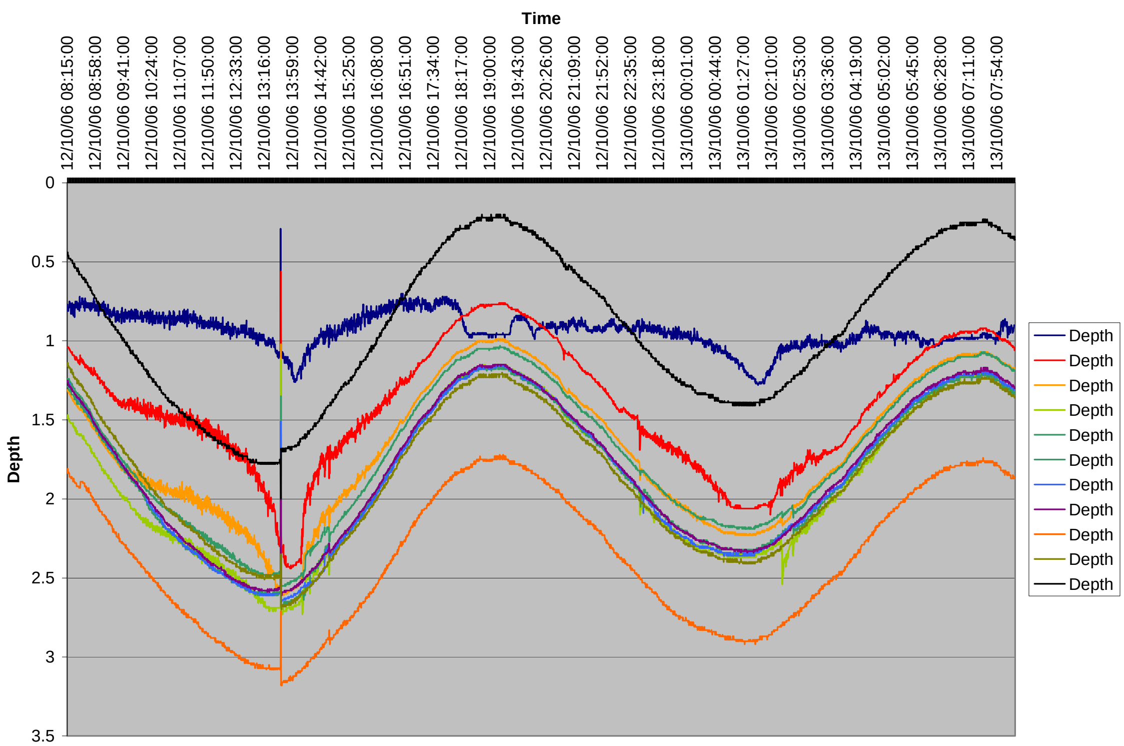
Line D (Calf) Trial 1 (10/09/2006)



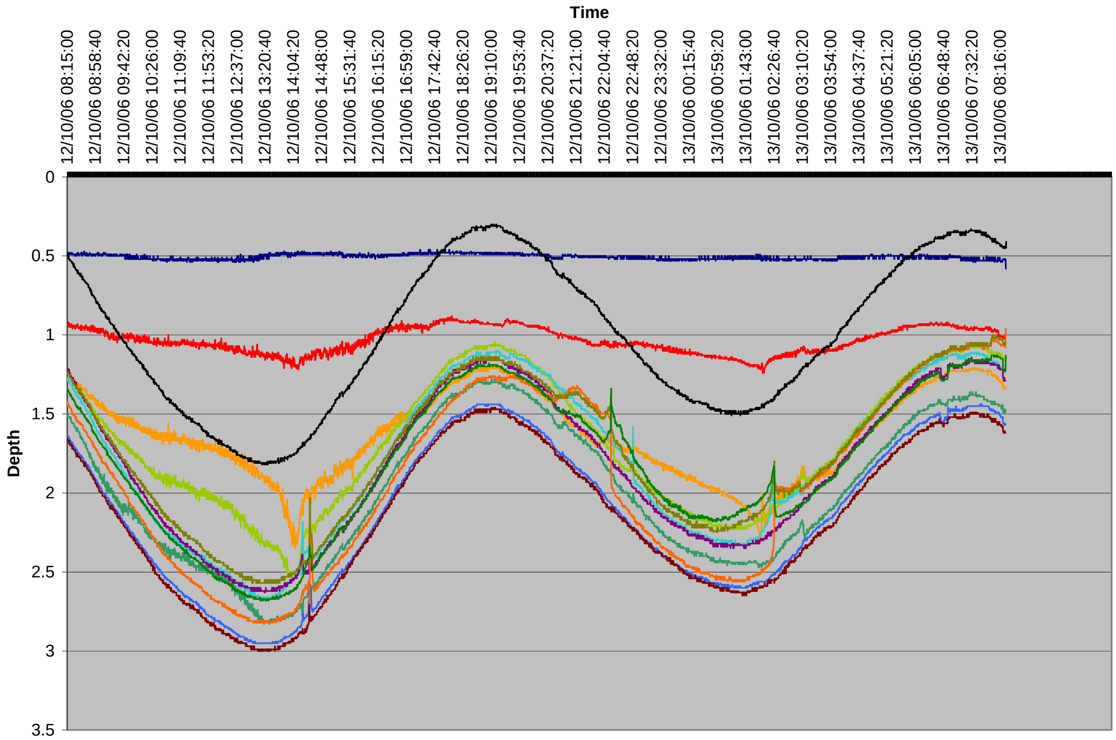
Line A (Esterpro) Trial 2 (10/12/2006)



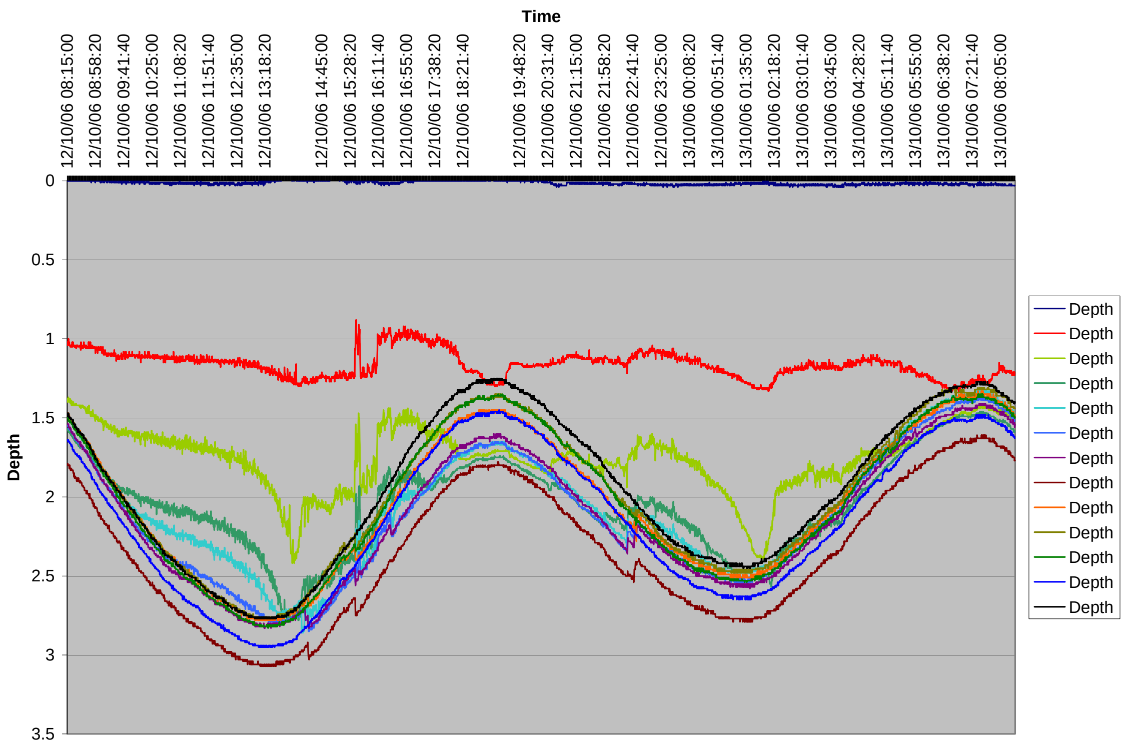
Line B (Nylon) Trial 2 (10/12/2006)



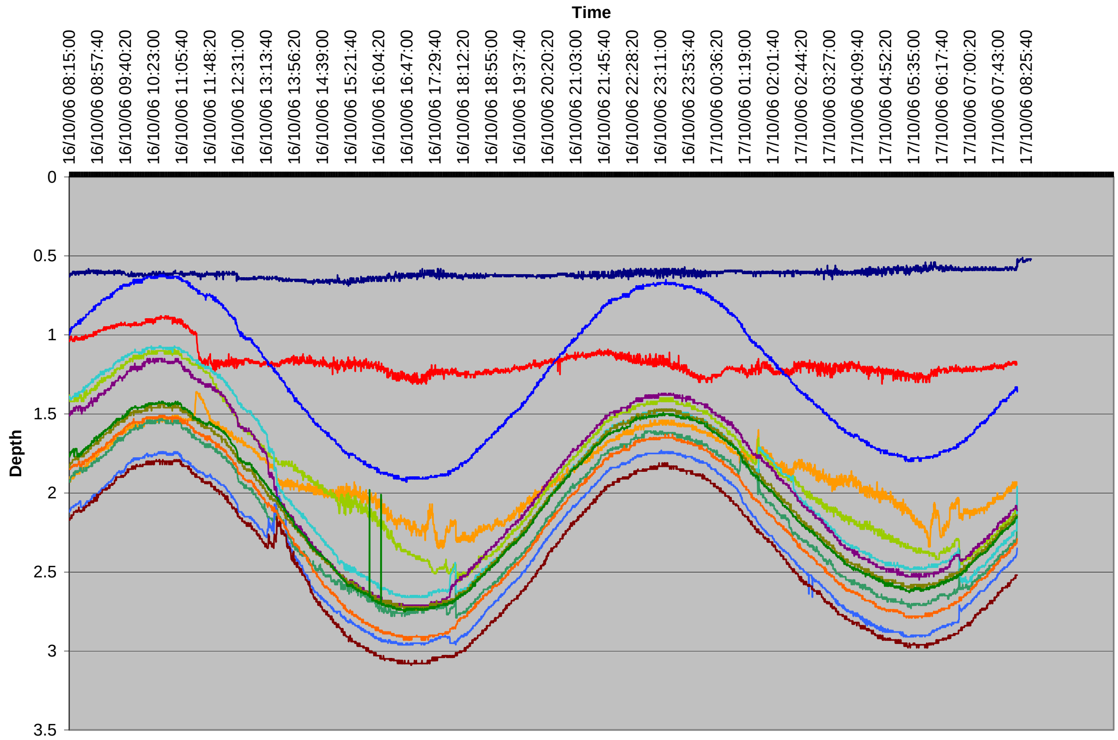
Line C (Calf) Trial 2 (10/12/2006)



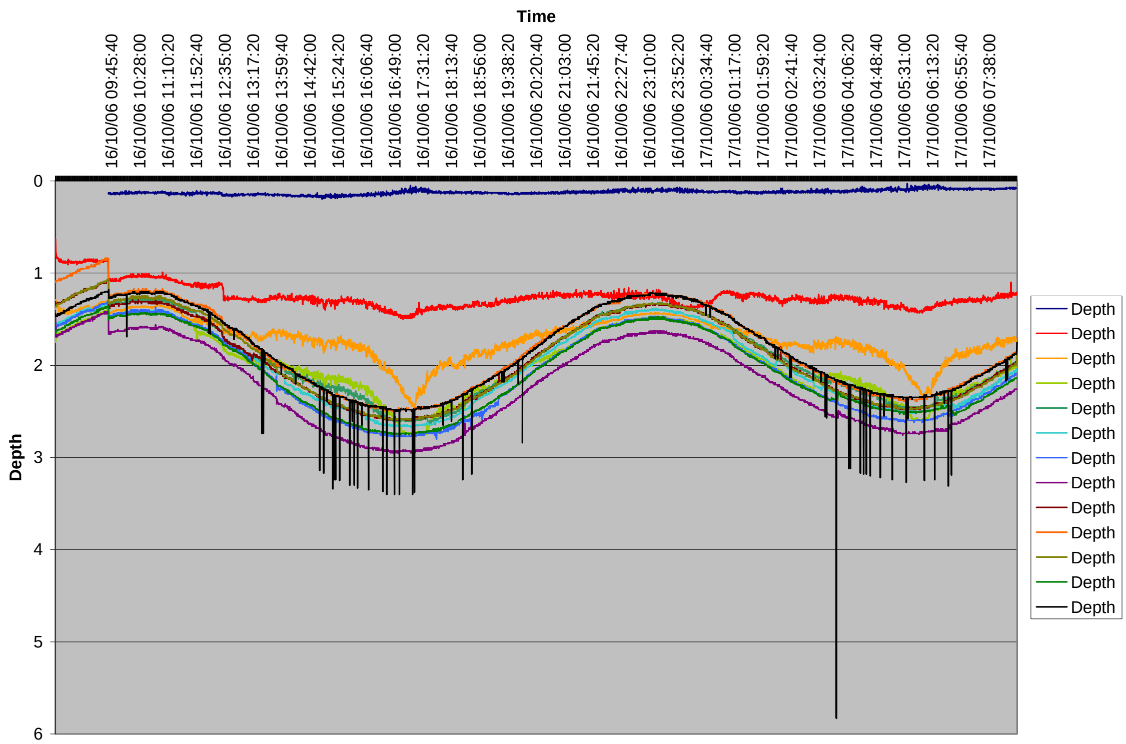
Line D (Esterpro) Trial 2 (10/12/2006)



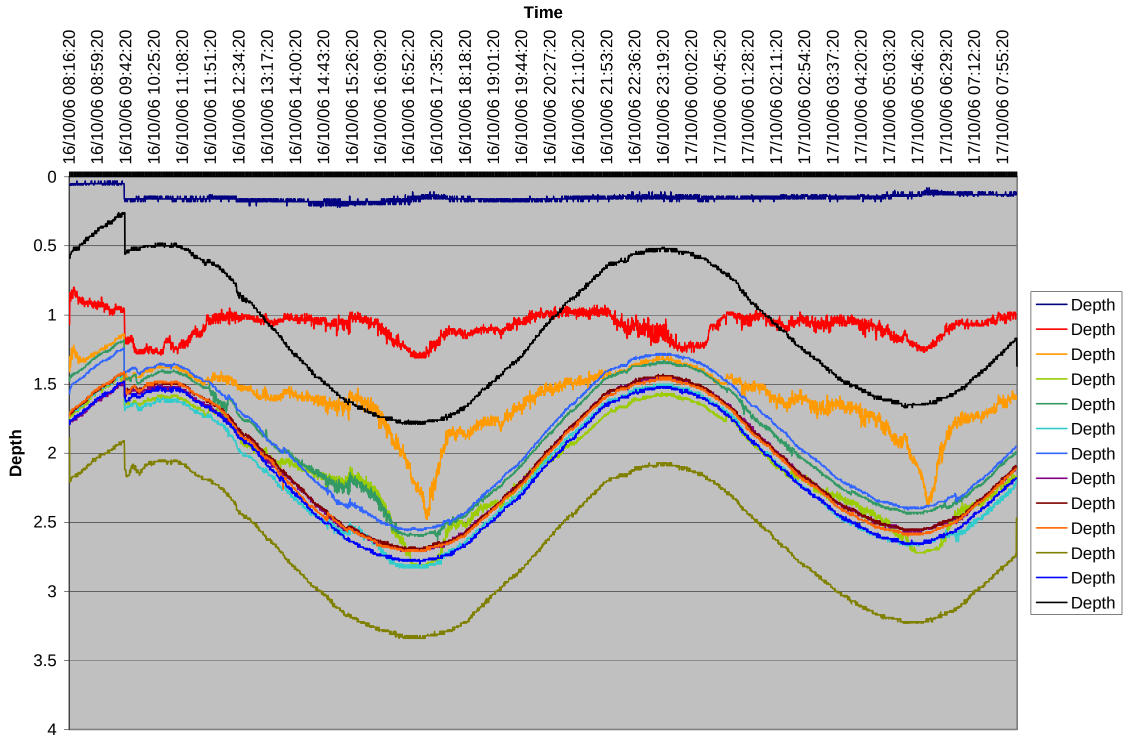
Line A (Calf) Trial 3 (10/16/2006)



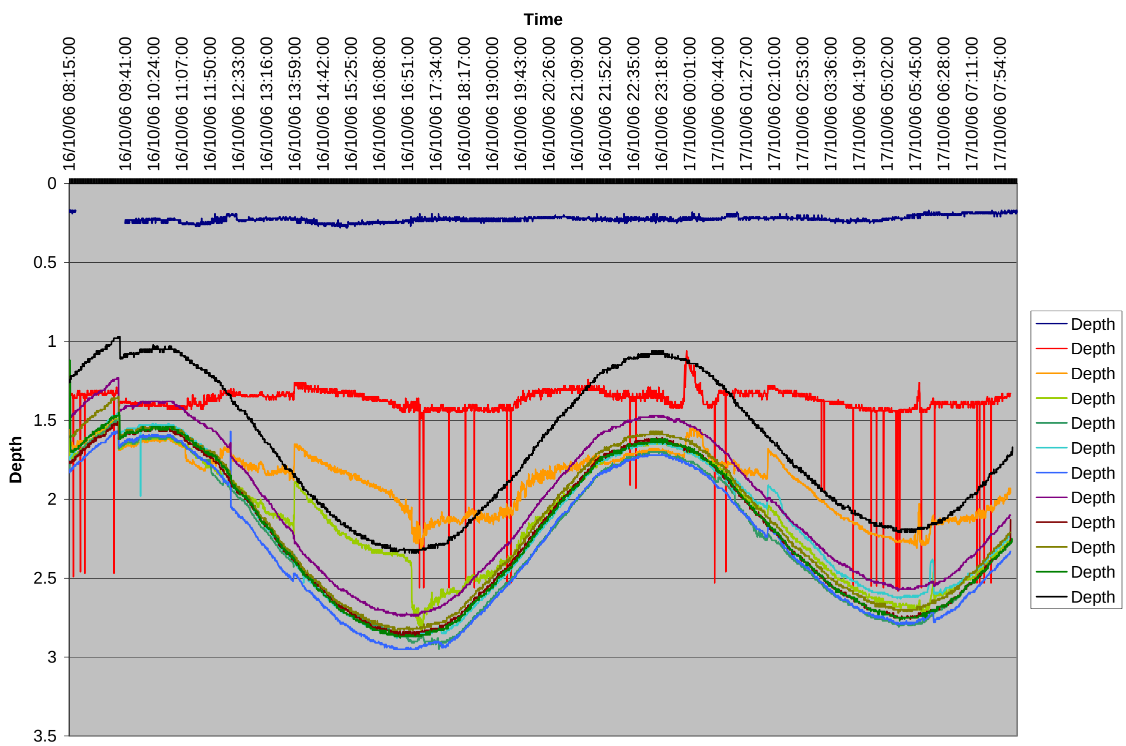
Line B (Esterpro) Trial 3 (10/16/2006)



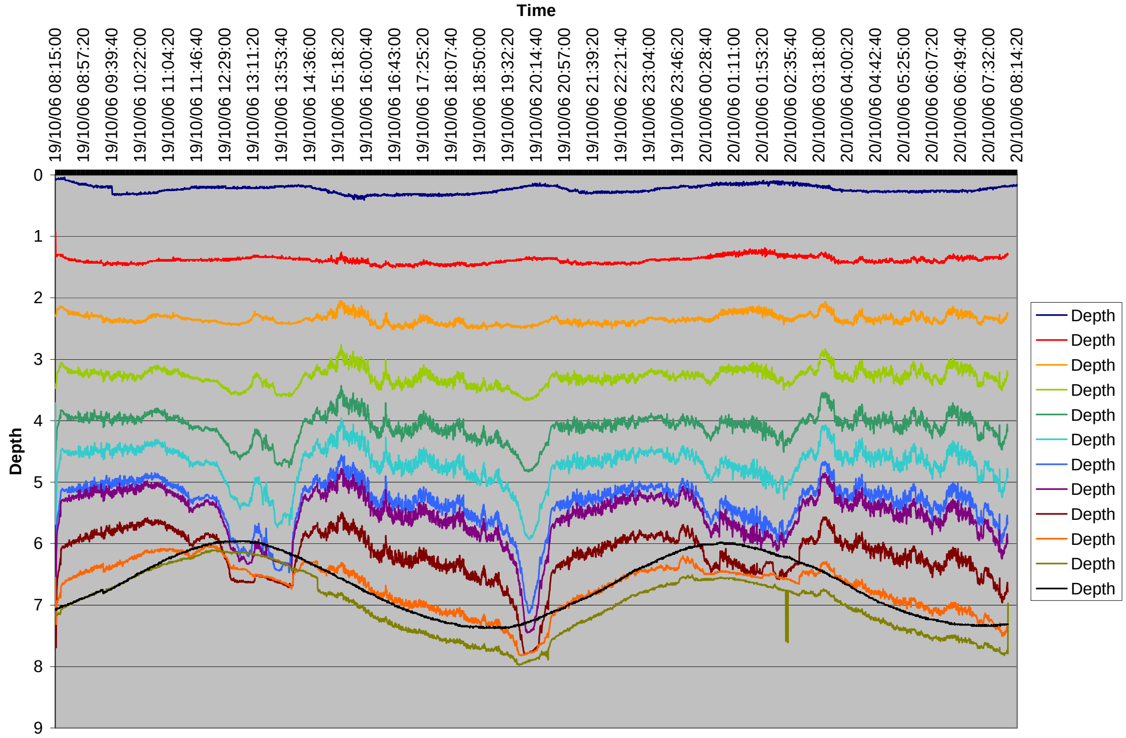
Line C (Nylon) Trial 3 (10/16/2006)



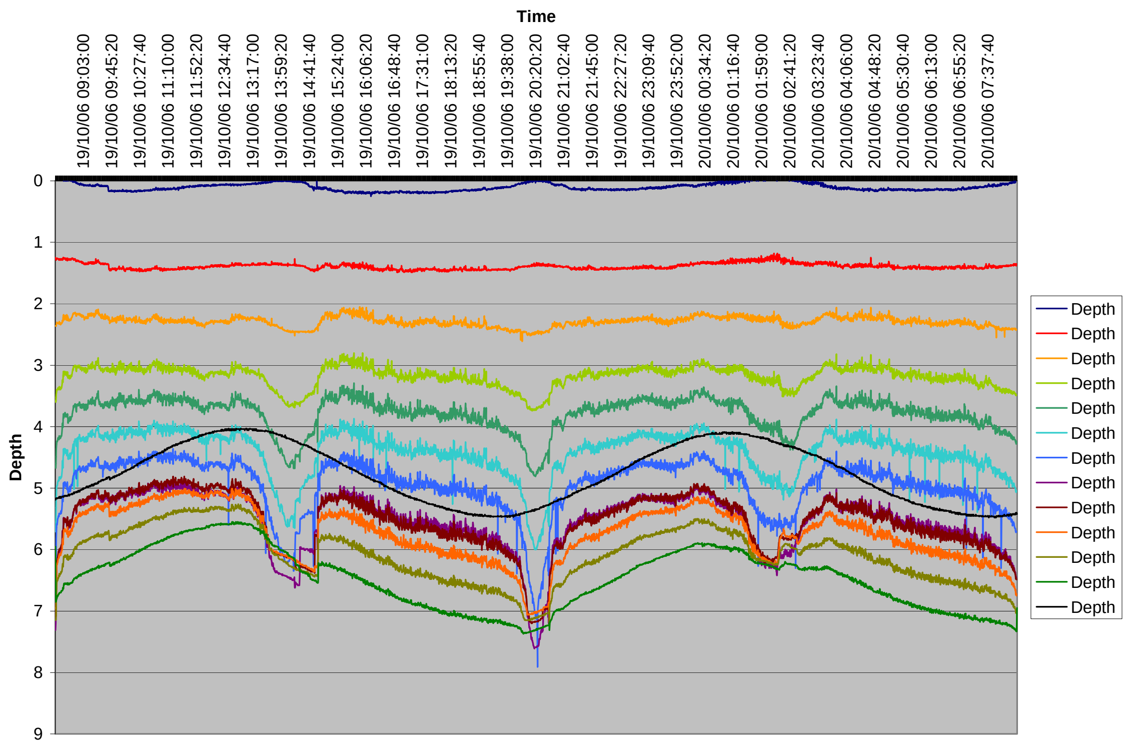
Line D (Calf) Trial 3 (10/16/2006)



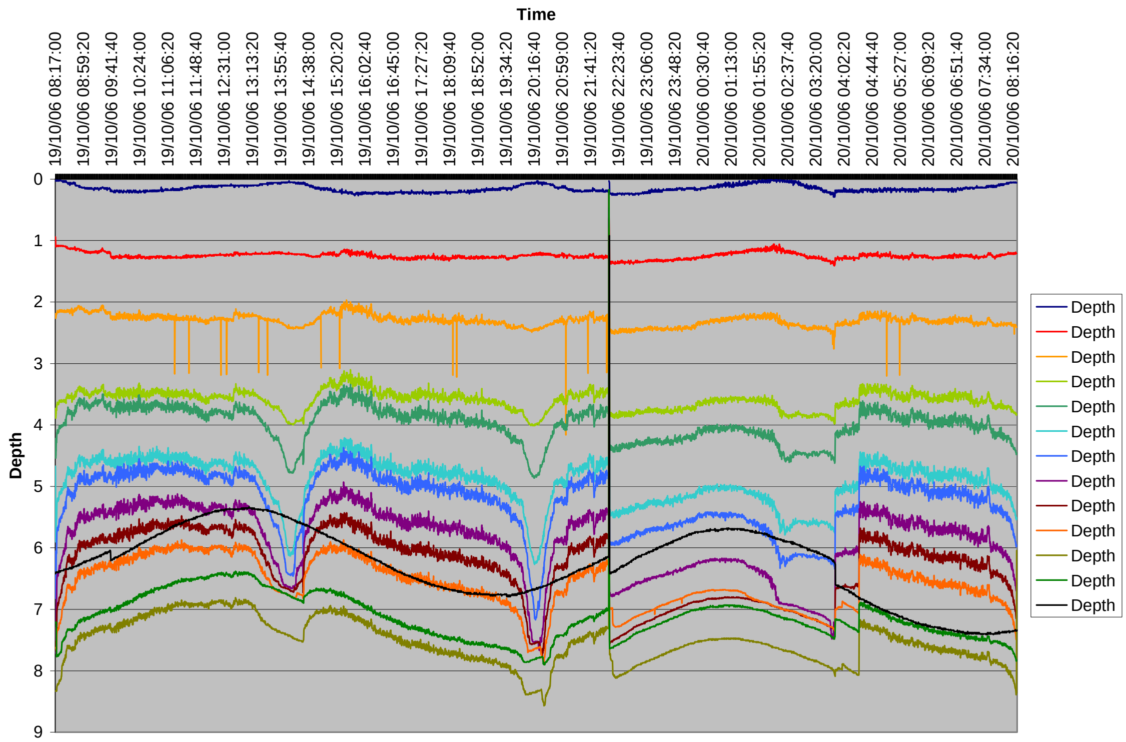
Line A (Nylon) Trial 4 (10/19/2006)



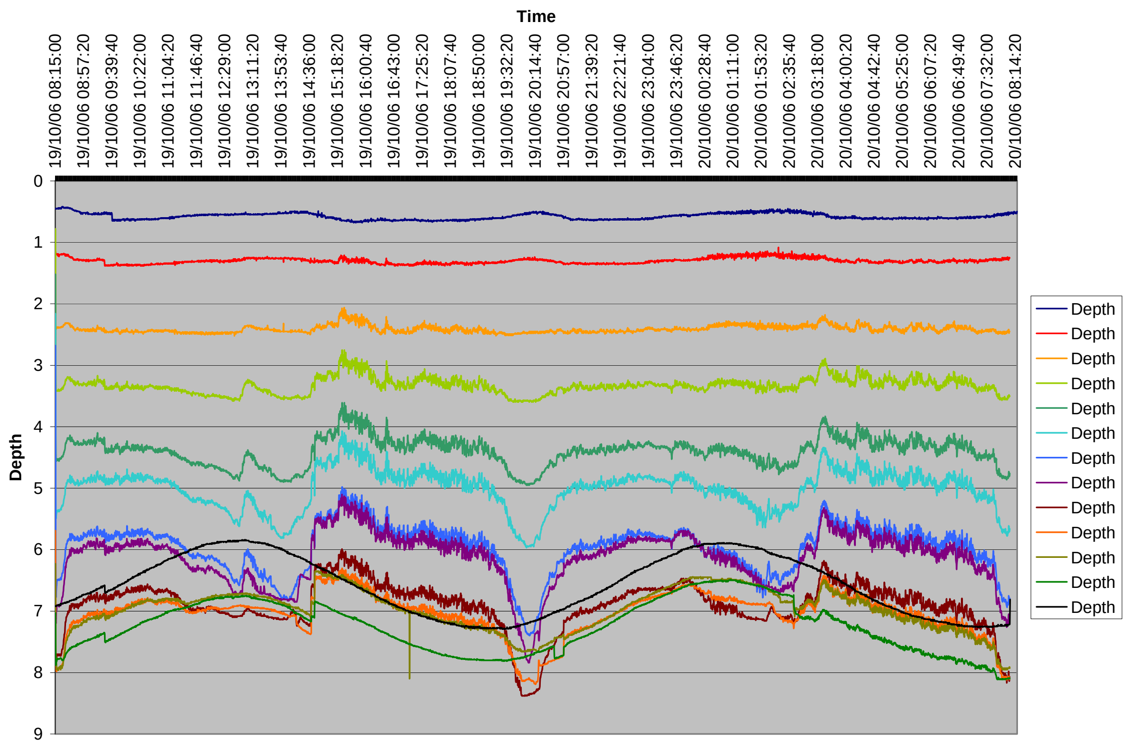
Line B (Esterpro) Trial 4 (10/19/2006)



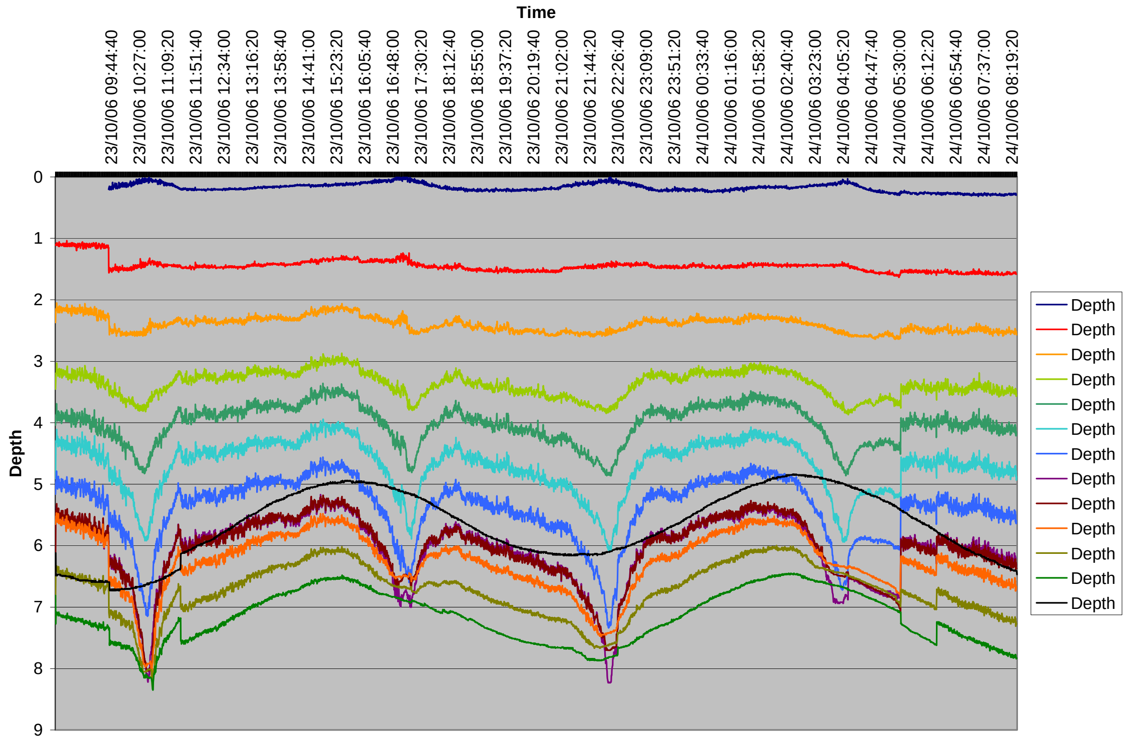
Line C (Nylon) Trial 4 (10/19/2006)



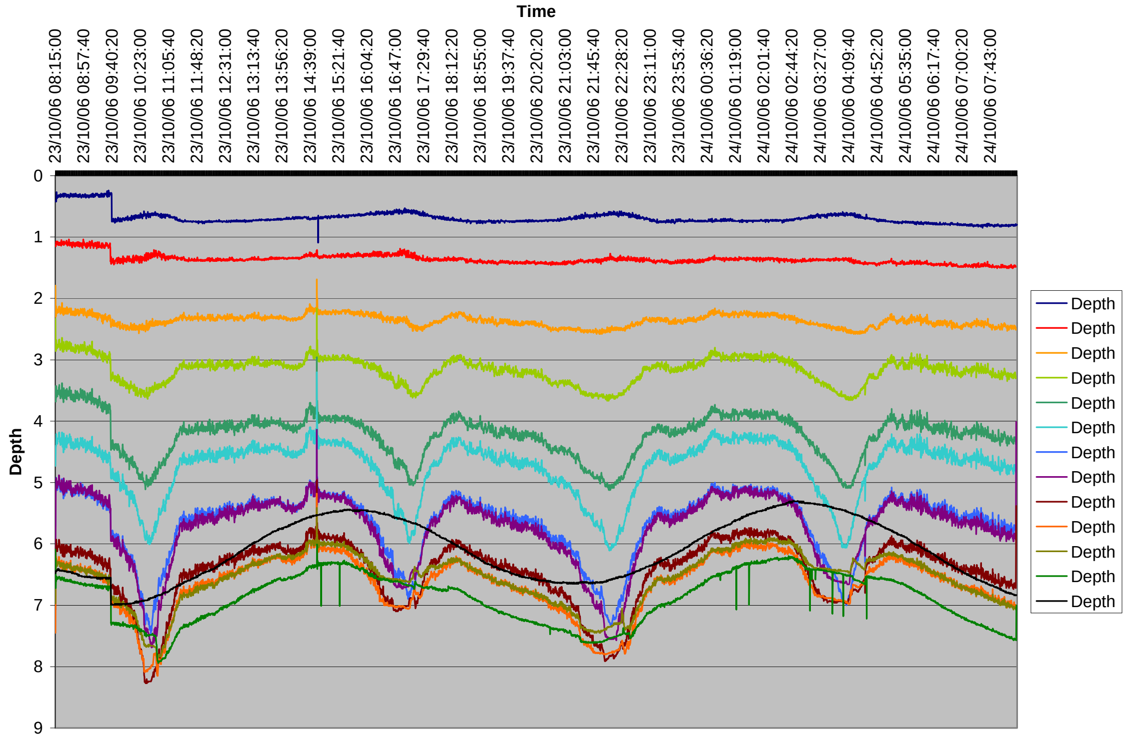
Line D (Calf) Trial 4 (10/19/2006)



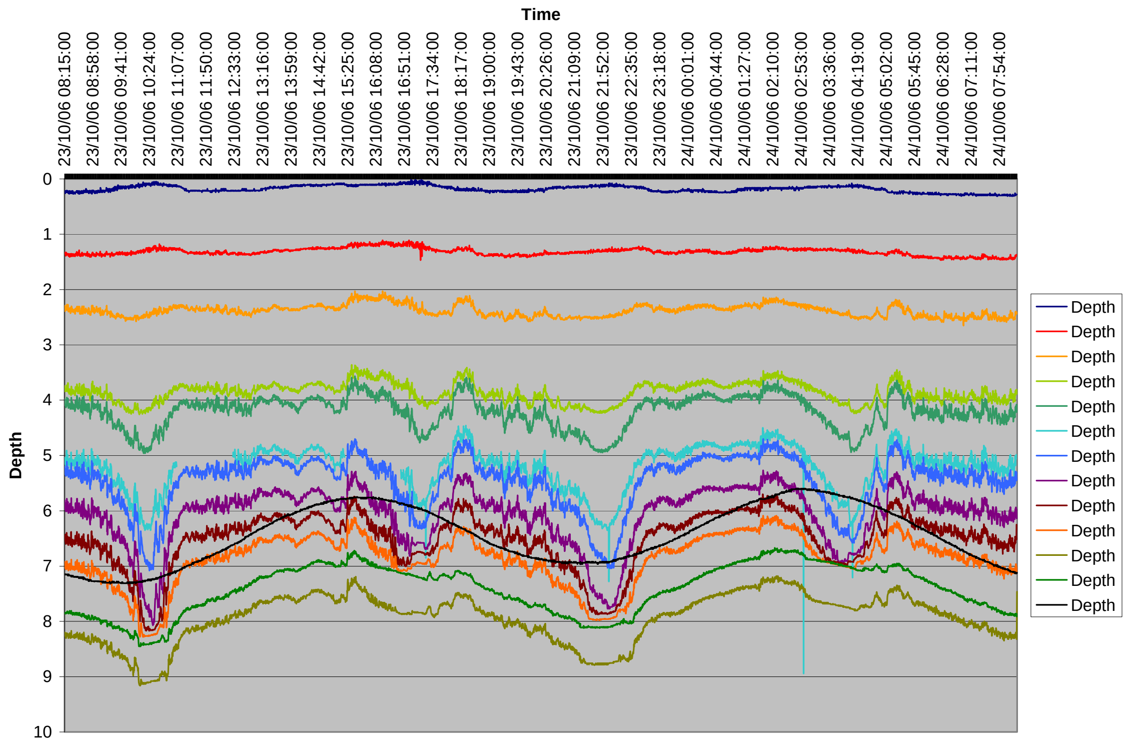
Line A (Esterpro) Trial 5 (10/23/2006)



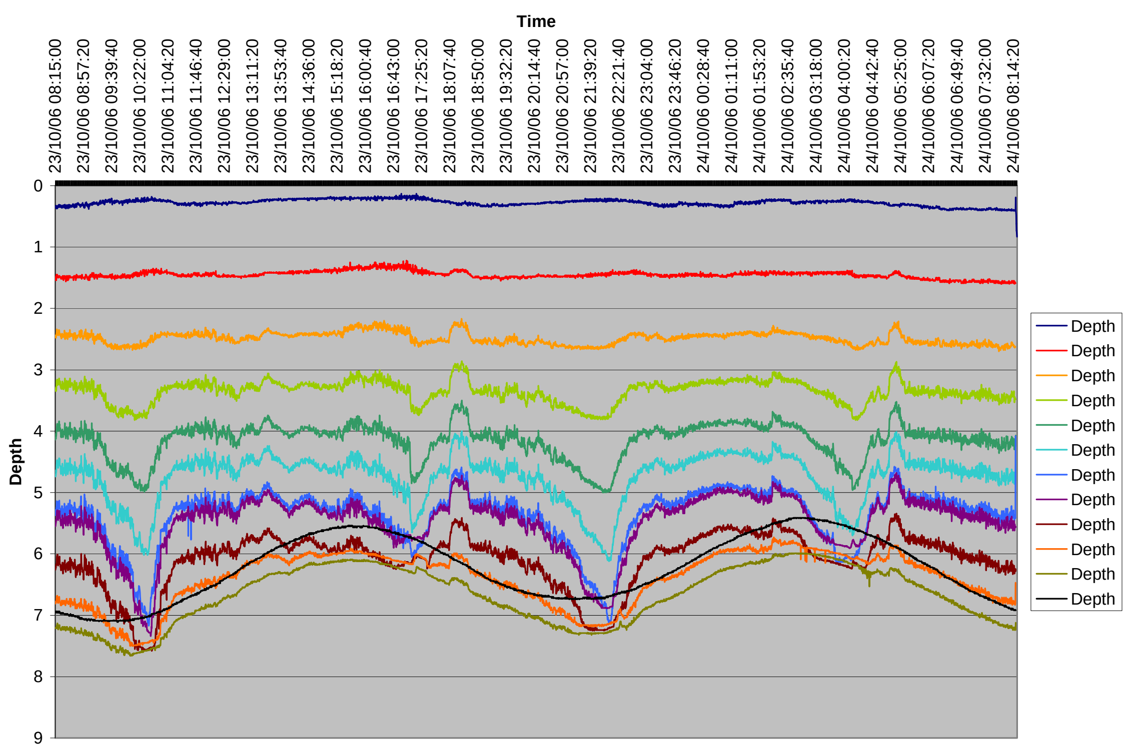
Line B (Calf) Trial 5 (10/23/2006)



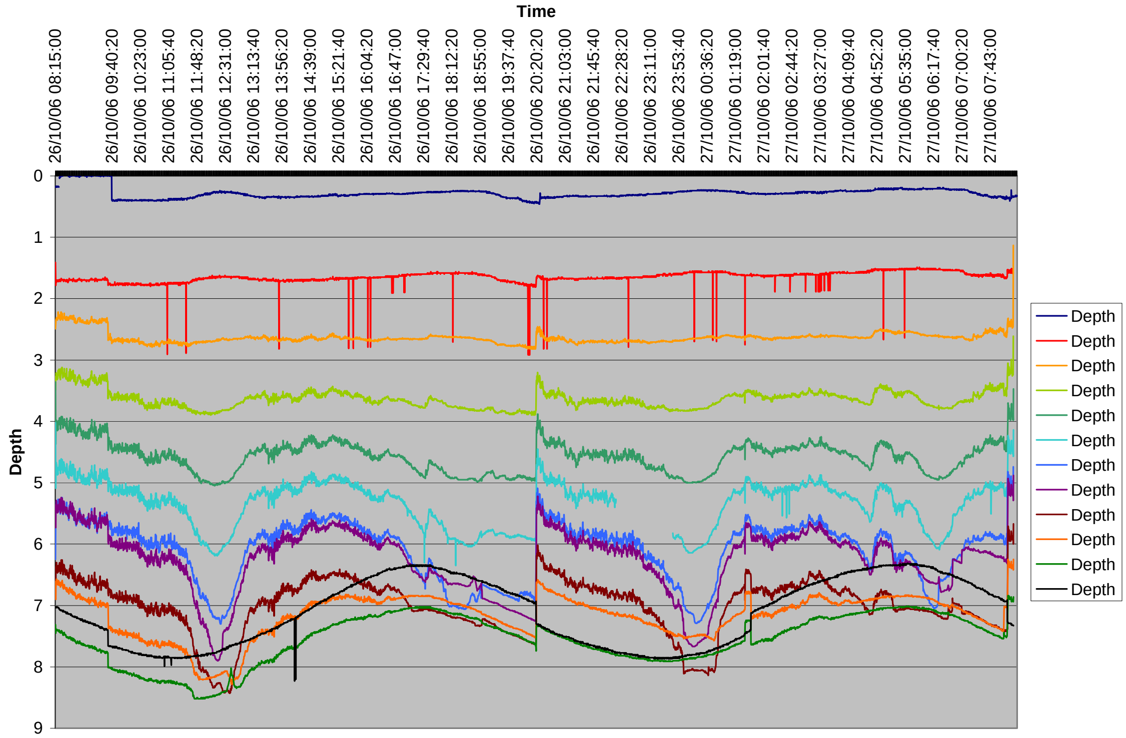
Line C (Nylon) Trial 5 (10/23/2006)



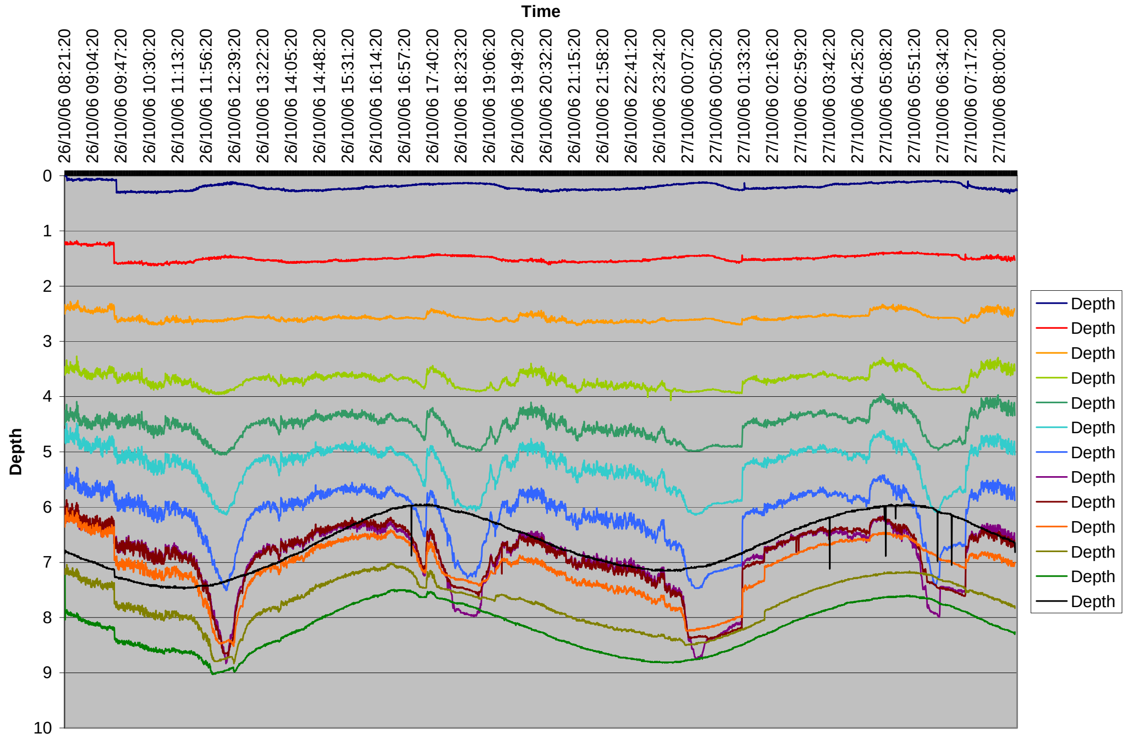
Line D (Esterpro) Trial 5 (10/23/2006)



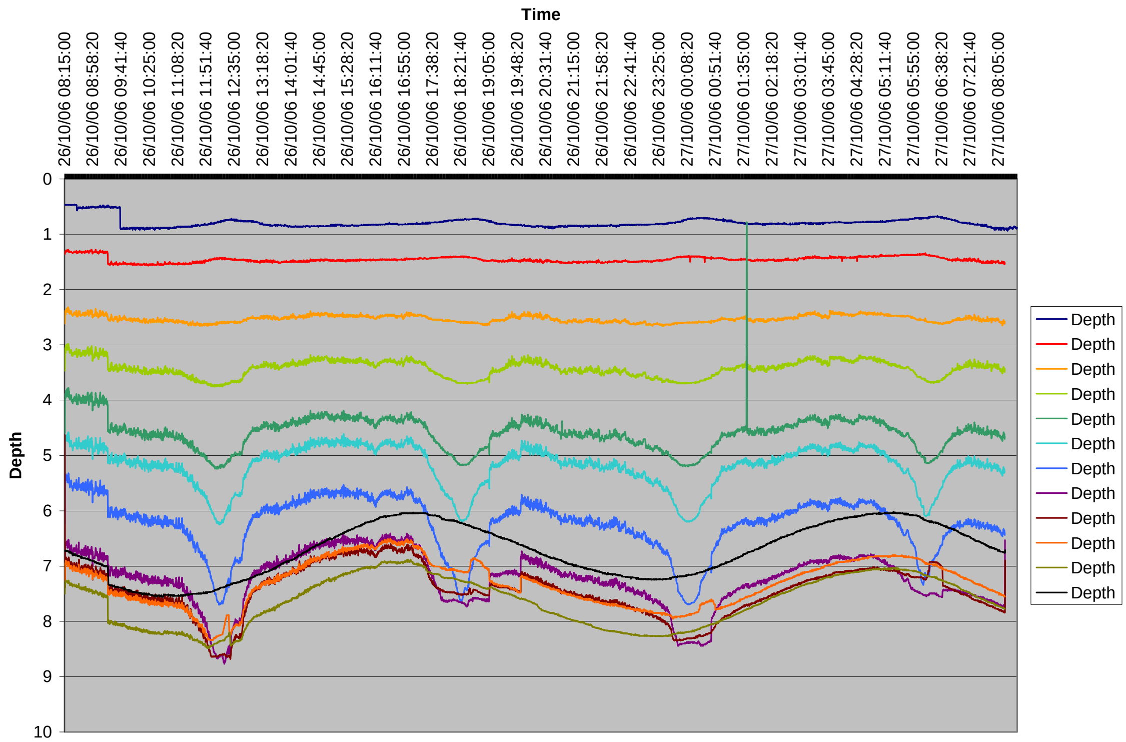
Line A (Calf) Trial 6 (10/26/2006)



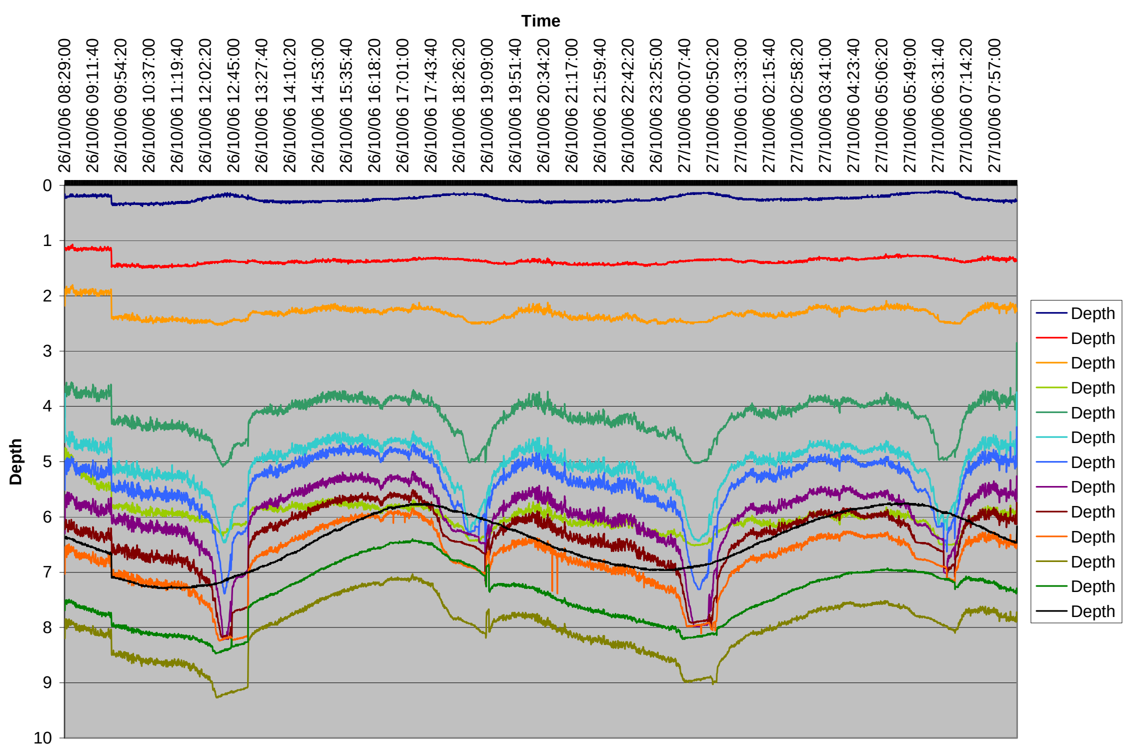
Line B (Esterpro) Trial 6 (10/26/2006)



Line C (Calf) Trial 6 (10/26/2006)



Line D (Nylon) Trial 6 (10/26/2006)



APPENDIX 2

Matlab scripts for video animations

```
function [lidlist,logdata] = process( dir )

fn = [dir 'lineconfiguration.xls'];
% Read the line configuration spreadsheet
[type, sheets] = xlsfinfo(fn);
% Process each sheet
for k=1:length(sheets)
% Read data from the line configuration sheet
num = xlsread(fn, sheets{k});
lids(k,:,:) = num(1:13,[1 4 7 10]);

end

% Find all of the loggers used in the experiment
lidlist = unique(lids);
for i=1:size(lidlist,1)
% Check to make sure the logger file is available
lfn = [dir 'Loggers\' sprintf('%4d.xls',lidlist(i))];
disp(lfn);
if fileattrib(lfn)
% Read the sheet info
[t,s] = xlsfinfo(lfn);
% Read each sheet
ssave = 1;
for j=1:length(s)
[n,t,r] = xlsread(lfn,s{j},'B15:D10000');
% Find the bounds of useful data in the sheet
klast = 0;
for k=size(r,1):-1:1
if ~isnan(r{k,1})
klast = k;
break;
end

if klast > 0
% Convert the time code column
tc = [];
depth = [];
for k=1:klast
tc(k) = datenum(r{k,1},'dd/mm/yy HH:MM:SS');
depth(k) = r{k,3};

end

% Save the time and depth data for this logger
logdata{i,ssave}=[tc' depth'];
```

```
function process( dir )

fn = [dir 'lineconfiguration.xls'];
% Read the line configuration spreadsheet
[type, sheets] = xlsfinfo(fn);
% Process each sheet
for k=1:length(sheets)
% Read data from the line configuration sheet
num = xlsread(fn, sheets{k});
lids(k,:,:) = num(1:13,[1 4 7 10]);
end
% Find all of the loggers used in the experiment
lidlist = unique(lids);
for i=8:size(lidlist,1)
% Check to make sure the logger file is available
lfn = [dir 'Loggers\' sprintf('%4d.xls',lidlist(i))];
disp(lfn);
if fileattrib(lfn)
% Read the sheet info
[t,s] = xlsfinfo(lfn);
% Read each sheet
for j=1:length(s)
[n,t,r] = xlsread(lfn,s{j},'B15:D10000');
% Find the bounds of useful data in the sheet
klast = 0;
for k=size(r,1):-1:1
if ~isnan(r{k,1})
klast = k;
break;
end
end
if klast > 0
% Convert the time code column
tc = [];
depth = [];
for k=1:klast
tc(k) = datenum(r{k,1},'dd/mm/yy HH:MM:SS');
depth(k) = r{k,3};
end
% Save the time and depth data for this logger
logdata{i,j}=[tc' depth'];

end
```

```
function showlines( lcfn, lidlist, logdata)

% Read the line configuration spreadsheet
[type, sheets] = xlsfinfo(lcfn);
% Process each sheet
for k=1:length(sheets)
% Read data from the line configuration sheet
num = xlsread(lcfn, sheets{k});
lids(:,:) = num(1:13,[1 4 7 10]);
times(:,:) = num(15:16,[2 5 8 11]);
% Find a common range for the experiment in this sheet
tmin = max(times(1,:))+ datenum(sheets{k},'ddmmyyyy') + 10*60/86400;
tmax = min(times(2,:))+ datenum(sheets{k},'ddmmyyyy') + 1 - 10*60/86400;
tdelta = 20/86400;
trange = tmin:tdelta:tmax;
depth = ones(length(trange),13,4)*NaN;
% For each line
for iline=1:4
% Find the data for each position in the line
for iposition=1:13
loggerindex = find(lidlist==lids(iposition,iline));
% Find the data for this experiment and logger
for ilogdata=1:7
if length(logdata{loggerindex,ilogdata}) > 0
t0 = min(logdata{loggerindex,ilogdata}(:,1));
t1 = max(logdata{loggerindex,ilogdata}(:,1));
if (tmin>t0) && (tmax<t1)
depth(:,iposition,iline) =
interp1(logdata{loggerindex,ilogdata}(:,1),logdata{loggerindex,ilogdata}(:,2),trange);
%disp([datestr(t0) ' ' datestr(t1) 'in range']);
else
%disp([datestr(t0) ' ' datestr(t1) ' not in range ' datestr(tmin) '...' datestr(tmax)]);
end
end
end
end
end

bottom = max(median(depth(:,12,:),3));
% Show line behavior over time
mov = avifile([sheets{k} '.avi'],'compression','Cinepak');
for i=1:length(trange)
bottomnow = -median(depth(i,12,:));
plot(1:13,-depth(i,:,1),'r-o');
hold on;
```

```
plot(1:13,-depth(i,:,2),'g-o');
plot(1:13,-depth(i,:,3),'b-o');
plot(1:13,-depth(i,:,4),'m-o');
title([sheets{k} ' ' datestr(trange(i))]);
axis([0 14 -bottom*1.1 0.5]);
xlabel('Logger Position');
ylabel('Depth');
lh = line([0 14],[0 0]);
set(lh,'LineStyle',':');
set(lh,'Color',[0 0 0]);
lh = line([0 14],[bottomnow bottomnow]);
set(lh,'LineStyle',':');
set(lh,'Color',[0 0 0]);
hold off;
drawnow;
F = getframe(gcf);
mov = addframe(mov,F);
end
mov = close(mov);
end
```

```
function showlines( lcfn, lidlist, logdata )

% Read the line configuration spreadsheet
[type, sheets] = xlsfinfo(lcfn);
% Process each sheet
for k=1:length(sheets)
% Read data from the line configuration sheet
num = xlsread(lcfn, sheets{k});
lids(:,:) = num(1:13,[1 4 7 10]);
times(:,:) = num(15:16,[2 5 8 11]);
% Find a common range for the experiment in this sheet
tmin = max(times(1,:))+ datenum(sheets{k},'ddmmyyyy') + 10*60/86400;
tmax = min(times(2,:))+ datenum(sheets{k},'ddmmyyyy') + 1 - 10*60/86400;
tdelta = 20/86400;
trange = tmin:tdelta:tmax;
depth = zeros(length(trange),13,4);
% For each line
for iline=1:4
% Find the data for each position in the line
for iposition=1:13
loggerindex = find(lidlist==lids(iposition,iline));
% Find the data for this experiment and logger
for ilogdata=1:7
if length(logdata{loggerindex,ilogdata}) > 0
t0 = min(logdata{loggerindex,ilogdata}(:,1));
t1 = max(logdata{loggerindex,ilogdata}(:,1));
if (tmin>t0) && (tmax<t1)
depth(:,iposition,iline) =
interp1(logdata{loggerindex,ilogdata}(:,1),logdata{loggerindex,ilogdata}(:,2),trange);
%disp([datestr(t0) ' ' datestr(t1) 'in range']);
else
%disp([datestr(t0) ' ' datestr(t1) ' not in range ' datestr(tmin) '...' datestr(tmax)]);
end
end
end
end
end
% Show line behavior over time
mov = avifile([sheets{k} '.avi'],'compression','None');
for i=1:length(trange)
plot(1:13,-depth(i,:,1),'r-o');
hold on;
plot(1:13,-depth(i,:,2),'g-o');
plot(1:13,-depth(i,:,3),'b-o');
plot(1:13,-depth(i,:,4),'m-o');
title([sheets{k} ' ' datestr(trange(i))]);
```

```
axis([0 14 -10 0]);
hold off;
drawnow;
F = getframe(gca);
mov = addframe(mov,F);
```

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Under Secretary of Commerce for Oceans and Atmospheres

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