# A Pilot Study to Determine the Movements of Buoy Line Used in the Crab Pot Fishery to Assess Bottlenose Dolphin Entanglement

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# A Pilot Study to Determine the Movements of Buoy Line Used in the Crab Pot Fishery to Assess Bottlenose Dolphin Entanglement

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# Abstract

A pilot study on the characteristics of crab pot buoy line movements to assess bottlenose dolphin entanglement was conducted from 19 September to 30 September 2005 in the Charleston Harbor, Charleston, South Carolina. The objectives of this study were to determine: 1) the movements of the buoy line in the water at various tidal stages, current strengths, lengths of line, and water depth, 2) if lead-core rope was a better alternative to nylon rope, 3) and if the manner of deployment of the gear affected the suspension of the line in the water and on the bottom. Diamond braided nylon (#10) rope of varying length (20 ft. – 80 ft.) were used during 31 trials and stiffened (polypropylene lead-core) rope was used in four trials. Observations of the buoy line movements were captured with an Atlantis underwater camera attached to a Digital DPC-1000 video recorder. Results from this study showed that: 1) the method used for deployment was important in keeping the buoy line from arcing or coiling, 2) little to no arcing occurred in water current velocities of >0.20 m/s, 3) rope lengths of ≥50 ft. deployed in <10 ft. of water produced waving in the water column and arcing on the bottom, 4) slack tide was a period of increased risk of entanglement for bottlenose dolphins, and 5) poly lead-core rope was not a good alternative to nylon rope unless in deep water with strong water current velocities. This pilot study produced questions that can be used for future studies on the characteristics of buoy line movements in the crab pot fishery as it relates to bottlenose dolphin entanglements.

# Introduction

Entanglement in fishing gear is a continuing threat to coastal bottlenose dolphins (*Tursiops truncatus*) throughout the world. While net fisheries pose a significant risk to bottlenose dolphins (Read, 1994), bottom fixed-gear, such as trap/pot gear, are known to pose similar risks for entanglement. Between 1992 and 2006, eight bottlenose dolphins were found dead entangled in crab pot buoy lines in South Carolina. An additional eight bottlenose dolphins stranded dead in South Carolina without gear attached but with rope wounds indicative of entanglement in crab pot buoy lines. Further, eight bottlenose dolphins in South Carolina have been successfully disentangled from crab pot buoy lines since 1996, five of these since 2003 (Figure 1).

A recent study investigating the effect of the Atlantic blue crab fishery on bottlenose dolphin mortality in South Carolina (Burdett and McFee, 2004) found that this fishery is a significant source of mortality for bottlenose dolphins. However, the manner in which dolphins became entangled in the line connecting the buoy (hereafter referred to as the "buoy line") to the crab pot was not known. Noke and Odell (2002) have documented crab pot tipping behavior in the Indian River Lagoon, Florida as a potential risk to entanglement as dolphins manipulate the pots to extract the bait. Similarly, bottlenose dolphins along the Georgia coastline have been observed tipping crab pots to retrieve bait (Davis, 2003). This behavior does not appear to occur in South Carolina based on interviews with South Carolina crab pot fishers and direct observation (Burdett, 2003). Unlike entanglements in Georgia and Florida where rope wounds can be found at the base of the flukes, body, and head, dolphins entangled in crab pot buoy lines in South Carolina show wounds and gear limited almost exclusively to the base of the flukes

(McFee and Hopkins-Murphy, 2002). It is possible that the mechanism of entanglement in crab pot lines in South Carolina may be purely accidental, caused by some behavior near crab pots, due to curious play, or factors due to properties of the gear itself.

Interviews with fishers conducted during Burdett's (2003) study revealed that the length of line placed between the buoy and crab pot varies anywhere between 30-80 feet (ft.), often in water depths less than 20 ft. Many of the crab fishers interviewed stated that the long lines allowed the crab pot to stay on the bottom without rolling in strong currents. This practice has the potential to create "looping" of the line in the water column, especially at low tide, thereby exposing dolphins to line that could be accidentally wrapped around appendages. Documentation of how buoy line lengths move at varied water depths, current strengths, and tidal cycles, with varied line length, would allow managers to understand the mechanism of dolphin entanglement. This documentation could then lead to suggestions for gear modification to lessen entanglement threats.

The objectives of this study were to determine: 1) the movements of the buoy line in the water column at various tidal stages, current strengths, lengths of line, and water depth, 2) if lead-core rope produced less waving in the water column or arcing off the bottom than nylon rope, 3) and if the manner of deployment of the gear affected buoy line movements. Conclusions from this study will enable us to provide the Atlantic Bottlenose Dolphin Take Reduction Team (ABDTRT) and the National Marine Fisheries Service (NMFS) with recommendations for mitigating crab pot fishery activities that adversely affect marine mammals.

# Methods

The original plan was to deploy two commercial crab pots (21.5 in. x 24 in., hexagonal mesh braced with zinc and 5/8 in. rebar; Beaufort Marine, Beaufort, South Carolina) outfitted with two different lengths of buoy line in a shallow water (<10 ft.) location. After viewing buoy line movements with an underwater camera (AUW525C Atlantis Underwater Viewing System, J.J. Communications, Inc., Englewood, New Jersey; Figure 2) in shallow water, the pots were to be moved to a deep water (~20 ft.) location to observe the buoy line movements. However, after the first day it was apparent that observing buoy line movements in deep water would not be possible in strong currents with the pole-mounted camera. In shallow water, the recording method was modified such that the camera was manually carried by a swimmer along the length of buoy line in order to view line movements. This recording method proved ineffective in deep water, therefore, the project was limited to shallow water after the second day.

Three different methods of crab pot deployment were used to determine if the manner in which crab pots were placed in the water affected the buoy line movements. In Method 1, the boat was idled while the crab pot was lowered into the water, keeping the buoy line as straight and uncoiled as possible. In Method 2 (most commonly used by commercial fishers), the buoy line was coiled on the bottom of the boat and the boat was moved in a semi-circle, allowing the buoy line to come out of the boat on its own. In Method 3, the boat was idled, and the rope thrown out, paying no attention to keeping the rope straight and uncoiled (see Table 1 for deployment schedule).

The study began September 19 and lasted until September 30, 2005. Data were collected on nine of the ten week days; no data were collected on September 28 due to inclement weather. The first week of the study centered around high tides (within one hour prior to high tide) and started one day after a full moon when tidal heights for the month were greatest. A generalized example of the deployment schedule follows. Three crab pots were outfitted with varying lengths (e.g., 20 ft., 30 ft., and 40 ft.) of #10 diamond braided, nylon rope (The Fishnet Co., Jonesville, Louisiana). A 17 ft. Boston Whaler with a 50hp Evinrude engine was used to carry the pots to a shallow water (<10 ft.) location (such as Crab Bank [CB]) in the Charleston Harbor, South Carolina (SC) (Figure 3). The 20 ft. and the 30 ft. buoy line configurations were first deployed from the boat a short distance apart. Buoy line movements were stored on a Digital DPC-1000 video recorder (J.J. Communications, Englewood, New Jersey) using an underwater camera that was attached to a 10 ft. expandable pole and lowered into the water. Water depth and camera start and end times were recorded. Waypoints of pot and buoy locations were collected at the beginning and end of the trials. Once sufficient (i.e., clear view of the line was captured) video was captured at the shallow water site, the 30 ft. and 40 ft. rope configurations were set in a deep water site (~20 ft.) (e.g., near the bank of James Island [JID]; Figure 3). This process was repeated at each site, while buoy line length was increased in 10 ft. increments until pots at each location were viewed with 80 ft. of line. An expandable (up to 15 ft.) flow probe (Forestry Suppliers, Inc., Jackson, Mississippi) was used starting on September 23, 2005 to record current velocity [meters per second (m/s)] at each crab pot location. The flow probe did not arrive in time to use at the beginning of the study because of shipping complications.

Because the deep water site (JID) proved impracticable for viewing with either the pole-mounted camera or hand-carried camera, research focused on the shallow water site (CB) and different deployment methods (see Table 1 for deployment schedule). During this first week of experimentation, two deployment days were open due to elimination of the deep water site. These two days (September 22 and 23) were used to experiment with a 5/16 in. polypropylene lead core sinking rope (Blue Ocean Tackle, Inc., Hesperia, California). Experimental trials with the lead core rope to explore potential buoy line movement differences from the standard nylon rope were conducted at Crab Bank and in a shallow area near James Island (JIS), characterized by increased current strength.

The process of using varied lengths of buoy lines at 10 ft. increments between 20 ft. and 80 ft. was repeated the second week, but at low tide (within one hour prior). Similar to the first week, two days (September 29 and 30) were used to experiment with the lead core rope and to observe the buoy line movements at mid-ebb (approximately 3 hours after high tide) and mid-flood (approximately 3 hours prior to high tide). A third location was chosen near Plum Island (PI) where water currents were observed to be stronger in shallow water. Crab pots were deployed using methods 2 and 3 at this location on September 30.

## Results

### Rope behavior

A summary of the results of the buoy line movements at varied lengths from 20 ft. – 80 ft. can be found in Tables 2 and 3. The buoy line movements observed in the water column was described in four ways: 1) straight slope (SS) in which the buoy line started from the buoy descending through the water column at a slight angle to the bottom

(Figure 4); 2) waving slope (WS), in which the buoy line was waving or undulating in the water column as it sloped to the bottom (Figure 5); 3) vibrating (V), in which the buoy line was vibrating as it sloped to the bottom; and 4) coiling (C), in which the buoy line may have looped somewhere along the line of descent to the bottom. Descriptions were not mutually exclusive. For instance, the buoy line may have had a straight slope with a small coil or loop on the descent to the bottom (*i.e.*, SS/C). Similarly, four criteria were used to describe the amount of arcing or looping off the bottom as the buoy line ran along the bottom to the crab pot: 1) none (N), in which the buoy line stayed on the bottom all the way to the crab pot; 2) low (L), in which the buoy line bounced slightly up and down off the bottom (usually seen with strong currents); 3) moderate (M), in which the buoy line arced off the bottom; and 4) severe (S), in which multiple coils or loops (nesting) arced off the bottom (Figure 6).

### Methods of deployment

Method 1 was used in 12 trials with #10 diamond braided nylon rope. A straight slope (SS) was observed on eight (67.0%) of the trials and a waving slope (WS) was observed on four (33.0%) of the trials. Of the 10 trials where the buoy line could be observed along the bottom, six (60.0%) produced no looping or arcing (N) off the bottom to the crab pot and four (40.0%) trials produced moderate looping or arcing (M) off the bottom.

Method 1 was used in two trials with 5/16 in. poly lead core rope. A straight slope (SS) was observed on one trial while a straight slope with a coil (SS/C) was observed in the other trial. On the bottom, one trial produced moderate to severe arcing (M-S) off the bottom and the other trial produced severe arcing (S) off the bottom.

Method 2 was used in 13 trials with #10 diamond braided nylon rope. A straight slope (SS) was observed on seven (53.8%) trials, a straight slope with a coil (SS/C) observed in two (15.4%) trials, a straight slope with vibration (SS/V) on one (7.7%) trial, a waving slope (WS) was observed in two (15.4%) trials, and a waving slope with a coil (WS/C) in one (7.7%) trial. On the bottom, seven (53.8%) trials produced no arcing or looping (N) of the buoy line, two (15.4%) trials produced a low (L) degree of arcing, and four (30.8%) produced moderate (M) arcing.

Method 2 was used in two trials with 5/16 in. poly lead core rope. A straight slope (SS) was observed in one trial and a waving slope (WS) was observed in the other. On the bottom, one trial produced no arcing or looping (N) off the bottom in strong current while the other trial produced severe arcing (S) in slow current.

Method 3 was used in six trials with #10 diamond braided nylon rope. A straight slope (SS) was observed in four (66.7%) trials and a waving slope (WS) was observed in two (33.3%) trials. On the bottom, one (16.7%) trial produced no arcing or looping (N), one (16.7%) trial produced moderate (M) arcing, and four (66.7%) trials produced severe (S) arcing or looping off the ground. A summary of the buoy line movements can be found in Table 2.

## Water current velocity

Water current velocity data were recorded during 19 trials using the nylon rope and two trials using the lead-core rope. Water current velocity for both sites ranged from 0.05 m/s – 0.37 m/s. At Crab Bank water current velocity ranged from 0.05 m/s – 0.10 m/s at low tide and 0.20 m/s on a flood tide. At the James Island (JIS) location, water current velocity ranged from 0.24 m/s – 0.35 m/s on a mid-ebb tide and 0.37 m/s on a high tide. At Plum Island, water current velocity ranged from 0.24 m/s – 0.35 m/s on a mid-ebb tide and 0.28 m/s at low tide. No measurements were collected at high tide at Plum Island. Fourteen trials were conducted with water current velocities ≤0.20 m/s and seven trails were conducted with water current velocities >0.20 m/s (Table 4).

**Nylon buoy lines**

*20 ft. #10 diamond nylon rope*

This line showed no waving or coiling at 8.6 ft. during a high tide, with a straight slope of line extending 13 ft. before reaching the bottom and then running straight to the crab pot. It reacted similarly at low tide in water depths of 2.8 ft. and 5.0 ft. in low velocity currents (.05 m/s and .10 m/s, respectively) using method 2 at low tide. The line was not used in deep water (~20ft.) as it would have barely reached bottom.

*30 ft. #10 diamond nylon rope*

This line was used twice for each deployment method, totaling six trials. In the one deep water (21.3 ft.) trial at high tide, the buoy was pulled underwater posing a navigational hazard, but the buoy line had a straight slope to the crab pot. The other trial at high tide occurred in shallow water (7.7 ft.) and the line followed a straight slope before reaching the bottom and running to the crab pot. Both of these trials used method 1.

The next two trials were conducted at low tide with varied current velocity using method 2. The first of these two trials was conducted in 4.9 ft. of water with low current velocity (0.09 m/s). While the line was straight and sloping to the bottom, it arced off the bottom approximately one foot short of the crab pot. This arcing did not occur in the second trial where the water was shallower (3.8 ft.) with a stronger current velocity (0.28 m/s).

The final two trials were conducted using method 3. The first of these was conducted at mid-ebb tide at a depth of 5.1 ft. and a current velocity of 0.24 m/s. The buoy line was a straight slope to the bottom where it ran to the crab pot. The second of these trials was conducted on a mid-flood tide in 4.1 ft. of water with a slightly lower current velocity (0.20 m/s). The rope in this trial sloped to the bottom for 8.0 ft. and then severely coiled ("nested") within inches of the crab pot.

### *40 ft. #10 diamond nylon rope*

This rope was used twice for each method, totaling six trials. The first trial was performed with method 1 at high tide in deep water (21.4 ft.). The buoy itself was ¾ submerged but the buoy line followed a straight slope to the crab pot.  The second trial, also using method 1, was conducted at high tide in shallow water (9.0 ft.) with a straight slope 12.0 ft. to the bottom and then ran along the bottom straight to the crab pot.

The third trial was conducted at low tide in 4.5 ft. of water with a low current velocity (0.09 m/s) using method 2. The buoy line followed a straight slope 8.0 ft. to the bottom and then ran along the bottom in a half circle to the crab pot (as it had been deployed). Over a 12 minute time period, the line on the bottom started to straighten out and some of the line began to arc a few inches off the bottom. The fourth trial used method 2 in 4.1 ft. of water at mid-ebb tide with a current velocity of 0.08 m/s. The line followed a waving slope 10.0 ft. to the bottom. Once the line reached the bottom, it ran along the bottom for approximately 20.0 ft. before lifting off the bottom approximately 8.0 ft. from the crab pot, went over the top of the crab pot (Figure 7), and then down to where it was tied to the bottom of the crab pot. Wave action was causing the line in the water column to wave and the line on the bottom to rise momentarily.

The fifth trial used method 3 in 5.5 ft. of water at mid-ebb tide with a current velocity of 0.24 m/s. The buoy line followed a straight slope 13.0 ft. to the bottom and ran along the bottom before it arced approximately two ft. off the bottom just before connecting to the crab pot. The last trial used method 3 on a mid-flood tide in 4.1 ft. of water with a current velocity of 0.20 m/s. The buoy line followed a straight slope 9.0 ft. to the ground and then severely coiled (“nested”) on the bottom with some loops rising close to the crab pot.

### *50 ft. #10 diamond nylon rope*

Five trials were made with this length of rope. The first trial used method 1 in 8.7 ft. of water at high tide. The buoy line followed a straight slope 13.0 ft. to the bottom and then “zig-zagged” along the bottom. The line looped approximately six in. off the bottom just prior to reaching the crab pot. The second trial used method 1 in 22.2 ft. of water at a high tide. The buoy line followed a straight slope that was taut to the crab pot.

The third trial used method 2 at low tide in 3.5 ft. of water with a current velocity of 0.05 m/s. The buoy line waved in the water column with a small loop observed approximately 3.0 ft. from the buoy. The line “zig-zagged” along the bottom, arced approximately 6-12 in. off the bottom just before the crab pot and then rose above the crab pot before connecting to the bottom of the crab pot on the far side.

The fourth trial used method 3 in 5.9 ft. of water at mid-ebb tide with a current velocity of 0.24 m/s. The buoy line followed a straight slope 15.0 ft. to the bottom where the line ran straight to the crab pot. The final trial used method 3 on a mid-flood tide in 4.1 ft. of water with a current velocity of 0.20 m/s. The buoy line waved in the water column 8.0 ft. to the bottom and then ran behind the crab pot where it was severely coiled ("nested") with some loops coming off the bottom. The crab pot was almost directly beneath the buoy.

### *60 ft. #10 diamond nylon rope*

Three trials were conducted with this rope. The first trial used method 1 at high tide in 22.7 ft. of water. The buoy line followed a straight slope running directly to the crab pot. The second trial used method 1 at high tide in 9.2 ft. of water. The buoy line waved in the water column 15.0 ft. to the bottom before it "zig-zagged" along the bottom with some coiling occurring (but not off the bottom) before reaching the crab pot. The third trial used method 2 at low tide in 3.7 ft. of water with a current velocity of 0.05 m/s. The buoy line followed a straight slope with coiling in the water column 6.0 ft. before reaching the bottom. The line arced less than six in. off the bottom before running along the bottom to the crab pot.

### *70 ft. #10 diamond nylon rope*

Five trials were conducted with this length of rope. The first trial used method 1 at high tide in 9.2 ft. of water. The buoy line waved extensively in the water column 13.0 ft. before reaching the bottom. On the bottom, the line "zig-zagged" with some looping coming off the bottom. As the tide began to shift, the line began to wave even more and arced approximately two ft. off the bottom before reaching the crab pot. The second trial used method 1 at high tide in 8.5 ft. of water. The line moved similar to the line in the first trial. This trial was used to compare with the same length of lead-core rope. The buoy in this trial took less time to move to its new location as the tide was shifting than the lead-core rope and began to straighten out.

The third trial used method 2 at a high tide in 8.7 ft. of water with a current velocity of 0.37 m/s. The buoy line followed a straight slope but was also vibrating 25.0 ft. to the bottom and then ran straight to the crab pot. The fourth trial used method 2 at low tide in 3.7 ft. of water with a current velocity of 0.09 m/s. The buoy line followed a straight slope with a coil for 7.0 ft. before reaching the bottom. The line then ran in a semi-circle on the bottom until arcing approximately 6-12 in. off the bottom before reaching the crab pot. The last trial used method 2 at mid-ebb tide in 4.1 ft. of water with a current velocity of 0.35 m/s. The buoy line waved in the water column 8.0 ft. to the bottom where it bounced up and down as it ran straight to the crab pot.

### *80 ft. #10 diamond nylon rope*

Three trials were used with this length of rope. The first trial used method 1 at high tide in 8.7 ft. of water. The buoy line waved in the water column 13.0 ft. before reaching the bottom, then “zig-zagged” along the bottom before arcing approximately two ft. off the bottom just before reaching the crab pot. The second trial used method 2 near low tide in 2.8 ft. of water with a current velocity of 0.06 m/s. The buoy line followed a straight slope 7.0 ft. to the bottom and then ran straight to the crab pot. The last trial used method 3 at low tide in 2.4 ft. of water with a current velocity of 0.07 m/s. The buoy line arced off the buoy for approximately 5.0 ft. before severely coiling (“nesting”) and looping off the bottom 27.0 ft. from the crab pot. Approximately 47.0 ft. of line was contained in the nest. The remaining 27.0 ft. ran straight on the bottom to the crab pot because of the way this rope was initially deployed.

## Lead-core buoy lines

Four trials using 60 ft. (*n*=2), 70 ft. (*n*=1), and 80 ft. (*n*=1) of 5/16 in. poly lead-core rope were conducted. The first trial of 60 ft. used method 1 at high tide in 8.9 ft. of water. The buoy line followed a straight slope 11.0 ft. to the bottom, with a small, approximately one in. diameter coil in the line approximately one foot from the buoy. The line ran straight along the bottom until it approached the crab pot, where the line rose off the bottom, made an approximately one foot diameter loop and continued up through the water column approximately two ft. before curving back down to the crab pot.

The second trial of 60 ft. used method 2 at high tide in 8.7 ft. of water with a current velocity of 0.37 m/s. The buoy line followed a straight slope 20.0 ft. to the bottom and ran straight to the crab pot.

The third trial used 70 ft. of rope and method 1 at high tide in 8.4 ft. of water. This buoy line behaved similarly to the first trial with the 60 ft. of rope. The buoy line followed a straight slope 11.0 ft. to the bottom where it gathered and twisted as it ran to the crab pot. Just before reaching the crab pot the line rose off the bottom approximately six in. and made a one foot diameter loop in the water column. Just past the loop, the line continued to rise in the water column for approximately two ft. before descending to the crab pot. During the change in tide the buoy took a much longer time to move to its new position than the 70 ft. of nylon rope mentioned above.

The last trial used 80 ft. of rope and method 2 at mid-ebb tide in 4.0 ft. of water with a current velocity of 0.06 m/s. The buoy line waved in the water column 11.0 ft. to the bottom. The line stayed approximately six in. off the bottom as it looped and crossed itself (Figure 8) before continuing on in a semi-circle. As it continued in its circle, the line came off the bottom in multiple places and kinked along the entire course to the crab pot.

# Discussion

### Methods of deployment

The methods of deployment of the crab pot gear in relation to the nylon rope movements were variable depending on the length of buoy line, current velocity, tidal stage, and water depth. A similar finding was described by Lyman et al. (2005) while observing ground lines in the Atlantic offshore lobster fishery. Arcs off the ground in the lobster fishery were dependent on the way the gear was configured and how it was deployed in relation to these environmental conditions (McKiernan, 2002; Lyman et al., 2005). In our study, lengths of nylon rope exceeding 40 ft. in length tended to arc in depths of less than five ft. Such arcing could potentially increase the risk of bottlenose dolphin entanglement, regardless of the deployment method used. Likewise, nylon rope exceeding 50 ft. in length showed effects of arcing in water depths between five ft. and 10 ft.

In water depths of less than 10 ft., deployment methods 1 and 2 resulted in buoy line movements that posed the least risk of entanglement to dolphins. Arcing off the ground or waving of the nylon rope in the water column was not observed until the buoy line length exceeded 40 ft. Noke and Odell (2002) noted that buoy lines in excess of 20 ft. could increase the risk of dolphin entanglements in a shallow water system. Our data suggests that buoy line lengths greater than 40 ft. could increase the risk of entanglement in a shallow water system.

Method 3 posed the greatest risk of entanglement to dolphins, even though the nylon rope rarely waved or coiled in the water column. This was the only method that resulted in severe coiling, arcing, and nesting of the line off the bottom in two-thirds of the trials. The one trial using this method that did not result in any coiling in the water column or arcing off the bottom, occurred in water with a current velocity ≥ 0.20 m/s. The stronger current velocity essentially allowed the line to uncoil fully and be pulled taut.

### Length of buoy line

When questioned about the length of buoy line used during fishing operations, crab fishers responded that excessive line lengths were used to keep pots from rolling in strong currents (Burdett, 2003). Movement or rolling of pots was not observed at any time during this study. Excessive buoy line lengths were noted with commercial crab pots near Crab Bank in 2005 during a photo-identification study of bottlenose dolphins conducted by NOS/CCEHBR staff (T. Speakman, pers. comm., 2005). In this observation, the buoy line was clearly visible waving in the water column.

In this study, longer buoy line lengths (>40 ft.) in a shallow water system (<10 ft.) showed the greatest potential of risk for dolphin entanglement, especially with slow water current velocities and at slack tide. In fact, the only times ropes >40 ft. displayed straight slopes and no coiling or arcing were when either methods 1 or 2 were used or during times of strong water current velocities. Even then, some trials with buoy lines of 40, 50, 70 and 80 ft. showed coiling and/or arcing (see Table 2).

### Tidal stage effects on nylon rope movements

Tidal stage had an appreciable effect on the nylon rope since it influenced both depth and current velocity. In trials performed during a mid-ebb or mid-flood tide, current velocities were stronger than those recorded at high or low tide. Deploying crab pots using method 1 or 2 during an ebb or flood tide could potentially reduce the risk of the line arcing off the bottom and coiling. Any coiling or arcing off the bottom of the line appears to be exacerbated at slack tide. This was observed in trials using 70 ft. nylon (two trials) and 70 ft. lead core (one trial) ropes in 8.4 ft.- 9.2 ft. of water. In all trials, a moderate arcing off the bottom increased to severe arcing (up to two ft. off the bottom) and wavering of the line in the water column at slack tide. This buoy line movement was also noted by McKiernan (2002) in the lobster fishery where the groundline reached maximum heights at slack tide. As the tide began to shift, the arcing and wavering decreased as the buoy was repositioned by the current. For the nylon rope, this repositioning took approximately nine minutes. For the lead core rope, the potential for exposure was greater as repositioning took approximately 15 minutes. Slack tide appears to be a time of increased risk for entanglement than other tidal stages, and is exacerbated when using lead-core rope. However, exposure to this time period is minimal on a daily basis.

### Effect of water current velocity on buoy line movements

Water current velocity strongly influenced the buoy line movements. In general, the stronger the current, the less chance for coiling and/or arcing of the line in the water column and on the bottom. Of the 14 trials conducted with water current velocity ≤0.20 m/s, only four showed no arcing on the bottom (see Table 4). Two of these four trials were conducted with 20 ft. of line where coiling and/or arcing was the least likely to occur regardless of the method used to deploy the crab pot. Conversely, of the seven trails conducted with water current velocities >0.20 m/s, only two showed low to moderate arcing. Of these two trials, one used method 3 and 40 ft. of line and the other used method 2 with excessive length of line (70 ft.). The other five trials showed no coiling of the rope in the water column or arcing on the bottom. It appeared therefore, that regardless of the deployment method, crab pots set in water with a current velocity exceeding 0.20 m/s had little to no effect on coiling or arcing of the line.

## Nylon versus poly lead-core rope

While the sinking, nylon ropes varied in their degree of coiling and arcing, they still did not produce the amount of coiling or arcing as the stiffened (lead-core) rope. The lead-core rope only appeared to be advantageous in strong current velocities. During slack tide and low current velocities, however, the lead-core rope increased the amount of time dolphins could be exposed to waving buoy lines in the water column. The nylon buoy lines waved in the water column due to wave action, and moderate arcs off the bottom occurred frequently with longer lines. These arcs occasionally leveled out when the tide began to shift, but lines were observed to arc over the pot once the lines repositioned themselves with the tidal flow. The exposure time for dolphins to waving buoy lines was shorter with the nylon buoy lines at slack tide as the buoy and line repositioned relatively more quickly.

The advantage of lead-core or similar stiffened line may be in contact by the dolphin with the line. In a study of captive manatees, the use of stiffened (e.g., calf) line significantly reduced the number of entanglements in introduced crab pot apparatus' (Bowles et al., 2003). In the one trial where a manatee was entangled in stiffened line, the animal was able to free itself as the line did not tighten or kink on the body (Bowles et al., 2003). Varying water current strength was not mentioned in this study. Similar types of studies have not been conducted on bottlenose dolphins in captivity, therefore, the ability of dolphins to free themselves from contact with stiffened line is only speculative.

## Dolphin behavior around crab pots and entanglement

The reasons for bottlenose dolphin entanglement in crab pot buoy lines are poorly understood in South Carolina. In studies conducted in Florida (Noke and Odell, 2002) and Georgia (Davis, 2003), crab pot tipping behavior was observed as a way for the animals to extract the bait from the bait wells. This behavior does not seem to occur in South Carolina (Burdett and McFee, 2004). Therefore, some other behavior may contribute to the high rate of mortality in this fishery, such as accidental contact with or curious reactions to gear.

Dolphins were not observed in close proximity to crab pots during this pilot study of limited duration (nine field days). However, during photo-identification studies of bottlenose dolphins near Charleston, dolphins have been observed manipulating crab pot lines on two separate occasions (T. Speakman, pers. comm., 2005). The first interaction occurred on 24 August 2004 in Nowell Creek off the Wando River (32.90041N and -79.89016W) on a flood tide in approximately 34 ft. of water and involved a single dolphin. The dolphin was observed diving near a crab pot buoy and apparently "tugging" on the line beneath the surface as evidenced by the buoy disappearing below the surface for a few seconds. Shortly afterward, the dolphin surfaced near the buoy. The second interaction occurred on 19 September 2005 in the Charleston Harbor, west of the James Island Yacht Club (32.75628N and -79.92075W) in close proximity to where some trials for this study were conducted, and to where a bottlenose dolphin was successfully disentangled from a crab pot buoy line on 25 September 2004. This observation occurred on a flood tide in approximately 5 ft. of water and involved two "medium-sized" dolphins. The two animals were apparently "tugging" on the crab pot buoy line, causing the buoy to disappear for several seconds. After spending a couple of minutes at the first buoy, they proceeded to travel approximately 160 ft. to another crab pot buoy and repeat the previous behavior.

While the age class of the dolphin involved in the first observation above was unknown, the second observation of two “medium-sized” dolphins would suggest juveniles or sub-adults were involved with the interaction. This curiosity of young animals towards fishing gear has been suggested as a behavior that increases the risk of entanglement for this age class (Wells and Scott, 1994; Mann et al., 1995; Fertl and Leatherwood, 1997; Wells et al., 1998; Noke and Odell, 2002). Analyses of bottlenose dolphin mortality caused by fisheries in South Carolina indicated that the majority of cases involved young animals, especially for males (McFee and Hopkins-Murphy, 2002; Burdett, 2003; McFee et al., 2006). While this curious or playful behavior may explain the large percentage of juvenile bottlenose dolphins involved with crab pot rope entanglements, it may not explain why some adults become entangled. Other behaviors that may distract dolphins from their surroundings, such as feeding or sexual activity, could contribute to entanglement.

## Conclusions

This pilot study provided possible explanations of the mechanism and risk of bottlenose dolphin entanglement in the crab pot fishery in South Carolina, and might be generalized to other regions in the United States with similar problems. These results may help managers explore options to modify crab pot fishery practices that will reduce the risk of bottlenose dolphin entanglement.

While it was obvious that methods 1 and 2 provided the least amount of coiling or arcing of the buoy line, environmental conditions (e.g., wave action, wind speed, current velocity, etc.) may be counter-productive and actually increase exposure of bottlenose dolphin to coiling or arcing buoy lines. These threats can be reduced if the fisher takes into consideration the following recommendations:

1. Reduce the length of buoy line deployed to less than 50 ft. in water depths less than 10 ft.
2. Deploy crab pots on an ebbing or flooding tide when water current velocities are stronger to allow the buoy line to lay along the bottom untangled and with reduced arcing. Regardless of deployment method, buoy lines from crab pots set in current velocities exceeding 0.20 m/s showed little tendency to arc off the bottom or wave in the water column.
3. Avoid deploying crab pots at slack tide when fouling is most likely to occur, increasing the risk of entanglement to bottlenose dolphins.

The use of stiffened rope, such as lead-core rope, needs further research. Trials using lead-core rope in this study showed that this rope was not advantageous in shallow water, and may reduce the waving in the water column and arcing off the bottom only in deep water and strong water current velocities. The potential to minimize the waving and arcing by experimenting with other stiffened rope, such as the calf rope used in the Bowles et al. (2003) study, should be explored.

Future research should also focus on the use of mini-loggers to record depth of the buoy line at defined increments along the line, over a longer period of time through multiple tidal cycles, as discussed by Lyman et al. (2005). Stranding networks should employ data recording protocols for crab pot entanglement events that include rope lengths of crab pot gear, water depth at which the entanglement occurred (if known), water current velocity (if available) at the entanglement location, and the distance between the entangled dolphin and crab pot buoy. The latter will aid in determining if the dolphin became entangled in the buoy line in the water column or from arcing on the bottom. All of these factors, added to the fisher recommendations, will hopefully reduce entanglement of bottlenose dolphins in the crab pot fishery.

## Acknowledgments

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**Table 1.** Dates of crab pot deployment with location (CB= Crab Bank, JI= James Island, PI= Plum Island), rope length (feet), rope type, tidal stage, and method of deployment.

| Date | Location | Line length (ft.) | Line type | Tidal stage | Method of deployment |
|---|---|---|---|---|---|
| 9/19/2005 | CB | 20 | #10 nylon | High | 1 |
| | CB | 30 | #10 nylon | High | 1 |
| | JI | 30 | #10 nylon | High | 1 |
| | JI | 40 | #10 nylon | High | 1 |
| 9/20/2005 | CB | 40 | #10 nylon | High | 1 |
| | CB | 50 | #10 nylon | High | 1 |
| | JI | 50 | #10 nylon | High | 1 |
| | JI | 60 | #10 nylon | High | 1 |
| 9/21/2005 | CB | 60 | #10 nylon | High | 1 |
| | CB | 70 | #10 nylon | High | 1 |
| | CB | 80 | #10 nylon | High | 1 |
| 9/22/2005 | CB | 60 | lead-core | High | 1 |
| | CB | 70 | lead-core | High | 1 |
| | CB | 70 | #10 nylon | High | 1 |
| 9/23/2005 | JI | 60 | lead-core | High | 2 |
| | JI | 70 | #10 nylon | High | 2 |
| 9/26/2005 | CB | 20 | #10 nylon | Low | 2 |
| | CB | 40 | #10 nylon | Low | 2 |
| | CB | 30 | #10 nylon | Low | 2 |
| 9/27/2005 | CB | 50 | #10 nylon | Low | 2 |
| | CB | 60 | #10 nylon | Low | 2 |
| | CB | 70 | #10 nylon | Low | 2 |
| 9/29/2005 | CB | 40 | #10 nylon | Midebb | 2 |
| | CB | 80 | lead-core | Midebb | 2 |
| | CB | 80 | #10 nylon | Near low | 2 |
| | CB | 80 | #10 nylon | Low | 2 |
| | CB | 20 | #10 nylon | Low | 2 |
| 9/30/2005 | PI | 70 | #10 nylon | Midebb | 2 |
| | PI | 30 | #10 nylon | Midebb | 2 |
| | PI | 40 | #10 nylon | Midebb | 3 |
| | PI | 30 | #10 nylon | Midebb | 3 |
| | PI | 50 | #10 nylon | Midebb | 3 |
| | CB | 30 | #10 nylon | Midflood | 3 |
| | CB | 40 | #10 nylon | Midflood | 3 |
| | CB | 50 | #10 nylon | Midflood | 3 |

**Table 2.** Movements of nylon rope with various environmental conditions. Location abbreviations are: CB= Crab Bank, JI= James Island, PI= Plum Island. (SS= straight slope; WS= waving slope; WS/C= waving slope with coil; SS/C= straight slope with coil; SS/V= straight slope with vibration; N= none; L= low; M= moderate; S= severe).

| Line length (ft.) | Location | Method of deployment | Depth (ft.) | Tidal stage | Wind direction/speed | Current velocity (m/s) | Line movement in water column | Arcing off bottom | Line to bottom (ft.) |
|---|---|---|---|---|---|---|---|---|---|
| 20 | CB | 1 | 8.6 | High | SE/9 | N/A | SS | N | 13 |
| | CB | 2 | 5.0 | Low | SE/<5 | 0.10 | SS | N | 11 |
| | CB | 2 | 2.8 | Low | SW/7 | 0.05 | SS | N | 6 |
| 30 | CB | 1 | 7.7 | High | SE/9 | N/A | SS | N | 13 |
| | JI | 1 | 21.3 | High | SE/9 | N/A | SS | U | unknown |
| | CB | 2 | 4.9 | Low | SE/<5 | 0.09 | SS | M | 9 |
| | PI | 2 | 3.8 | Low | NE/7 | 0.28 | SS | N | 9 |
| | PI | 2 | 5.1 | Midebb | NE/7 | 0.24 | SS | N | 10 |
| | CB | 3 | 4.1 | Midflood | N/10 | 0.20 | SS | S | 8 |
| 40 | JI | 1 | 21.4 | High | SE/9 | N/A | SS | U | unknown |
| | CB | 1 | 9.0 | High | NE/8 | N/A | SS | N | 12 |
| | CB | 2 | 4.5 | Low | SE/<5 | 0.09 | SS | M | 8 |
| | CB | 2 | 4.1 | Midebb | SW/7 | 0.08 | WS | L | 10 |
| | PI | 3 | 5.5 | Midebb | NE/7 | 0.24 | SS | M | 13 |
| | CB | 3 | 4.1 | Midflood | N/10 | 0.20 | SS | S | 9 |
| 50 | CB | 1 | 8.7 | High | NE/8 | N/A | SS | M | 13 |
| | JI | 1 | 22.2 | High | NE/8 | N/A | SS | N | unknown |
| | CB | 2 | 3.5 | Low | NE/0 | 0.05 | WS/C | M | 6 |
| | PI | 3 | 5.9 | Midebb | NE/7 | 0.24 | SS | N | 15 |
| | CB | 3 | 4.1 | Midflood | N/10 | 0.20 | WS | S | 8 |
| 60 | JI | 1 | 22.7 | High | NE/8 | N/A | SS | N | unknown |
| | CB | 1 | 9.2 | High | NE/10 | N/A | WS | N | 15 |
| | CB | 2 | 3.7 | Low | NE/<5 | 0.05 | SS/C | N | 6 |
| 70 | CB | 1 | 9.2 | High | NE/10 | N/A | WS | M | 13 |
| | CB | 1 | 8.5 | High | NE/5 | N/A | WS | M | 10 |
| | JI | 2 | 8.7 | High | NE/5 | 0.37 | SS/V | N | 25 |
| | CB | 2 | 3.7 | Low | NE/5 | 0.09 | SS/C | M | 7 |
| | PI | 2 | 4.1 | Midebb | NE/7 | 0.35 | WS | L | 8 |
| 80 | CB | 1 | 8.7 | High | NE/10 | N/A | WS | M | 13 |
| | CB | 2 | 2.8 | Near-Low | SW/7 | 0.06 | SS | N | 7 |
| | CB | 3 | 2.4 | Low | SW/7 | 0.07 | WS | S | 5 |

**Table 3.** Movements of lead core rope with various environmental conditions. Location abbreviations are: CB= Crab Bank, JI= James Island, PI= Plum Island. (SS= straight slope; WS= waving slope; SS/C= straight slope with coil; N= none; M-S= moderate to severe; S= severe).

| Line length (ft.) | Location | Method of deployment | Depth (ft.) | Tidal stage | Wind direction/speed | Current velocity (m/s) | Line movement in water column | Looping off bottom | Line to bottom (ft.) |
|---|---|---|---|---|---|---|---|---|---|
| 60 | CB | 1 | 8.9 | High | NE/5 | N/A | SS/C | M-S | 11 |
| 60 | JI | 2 | 8.7 | High | NE/5 | 0.37 | SS | N | 20 |
| 70 | CB | 1 | 8.4 | High | NE/5 | N/A | SS | S | 11 |
| 80 | CB | 2 | 4.0 | Midebb | SW/7 | 0.06 | WS | S | 11 |

**Table 4.** Line movements at water current velocities ≤0.20 m/s and >0.20 m/s. (SS= straight slope; WS= waving slope; WS/C= waving slope with coil; SS/C= straight slope with coil; SS/V= straight slope with vibration; N= none; L= low; M= moderate; S= severe).

| Water current velocity ≤0.20m/s | Line length (ft.) | Method of deployment | Tidal stage | Line behavior in water column | Arcing off bottom |
|---|---|---|---|---|---|
| | 20 | 2 | Low | SS | N |
| | 20 | 3 | Low | SS | N |
| | 30 | 2 | Low | SS | M |
| | 30 | 3 | Midflood | SS | S |
| | 40 | 2 | Low | SS | M |
| | 40 | 2 | Midebb | WS | L |
| | 40 | 3 | Midflood | SS | S |
| | 50 | 2 | Low | WS/C | M |
| | 50 | 3 | Midflood | WS | S |
| | 60 | 2 | Low | SS/C | N |
| | 70 | 2 | Low | SS/C | M |
| | 80 | 2 | Near-low | SS | N |
| | 80 | 3 | Low | WS | S |
| | 80 (lead core) | 2 | Midebb | WS | S |
| **Water current velocity >0.20m/s** | | | | | |
| | 30 | 2 | Low | SS | N |
| | 30 | 3 | Midebb | SS | N |
| | 40 | 3 | Midebb | SS | M |
| | 50 | 3 | Midebb | SS | N |
| | 70 | 2 | High | SS/V | N |
| | 70 | 2 | Midebb | WS | L |
| | 60 (lead core) | 2 | High | SS | N |

**Figure 1.** Map of confirmed bottlenose dolphin entanglements in the blue crab fishery, probable entanglements in the blue crab fishery, and disentanglements in South Carolina.

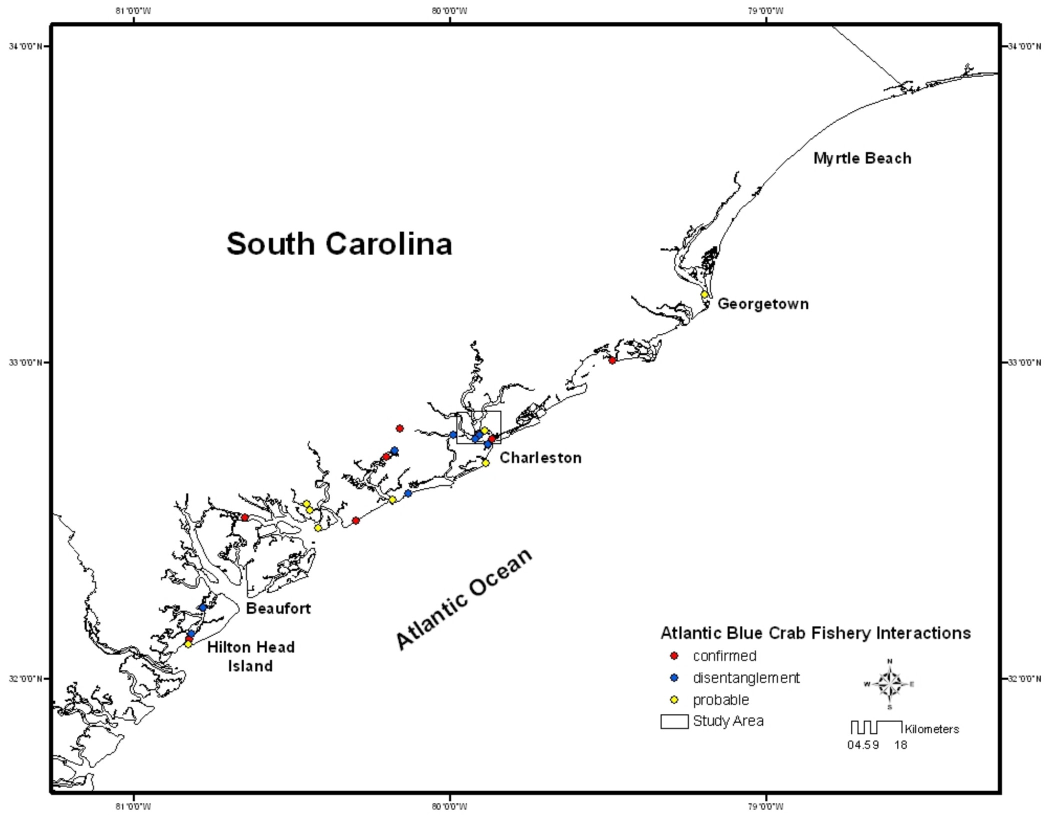

**Figure 2.** Atlantis Underwater Viewing System used to capture video of buoy line movements (A= on board monitor; B= underwater camera; C= DPC-1000 digital video recorder).

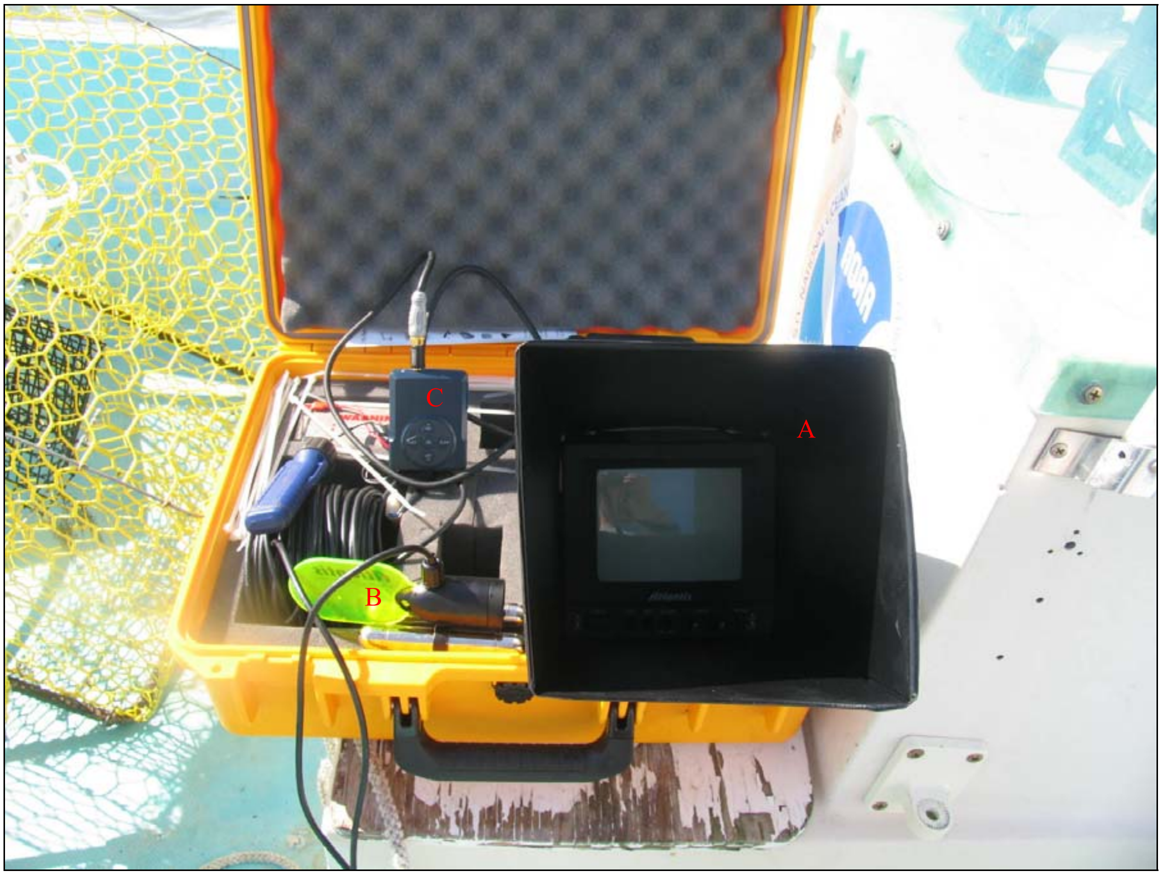

**Figure 3.** Map of study locations (CB= Crab Bank; JIS= James Island shallow; JID= James Island deep; PI= Plum Island) in Charleston, South Carolina.

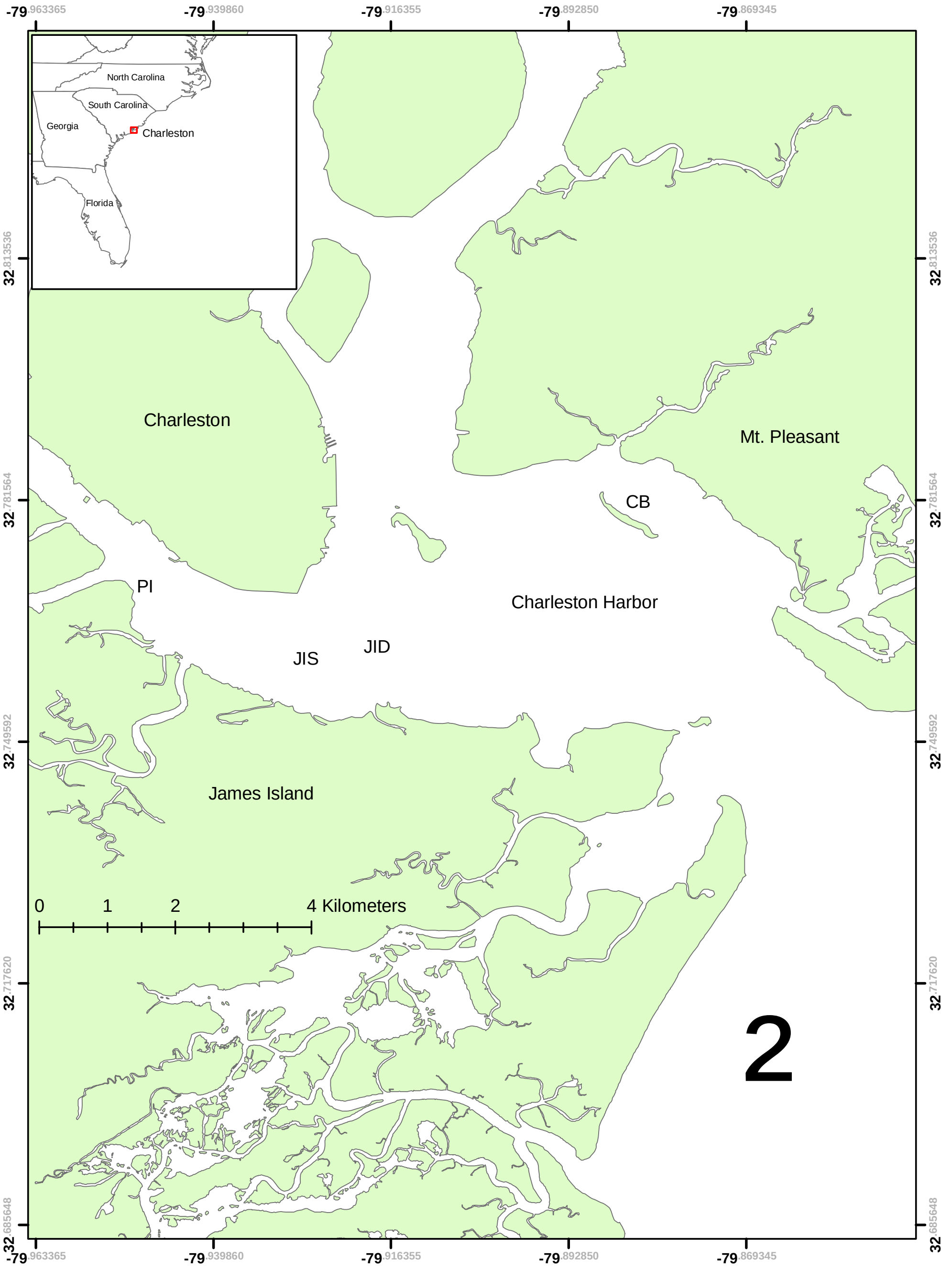

**Figure 4.** Example of a straight slope (SS) line in the water column**.**

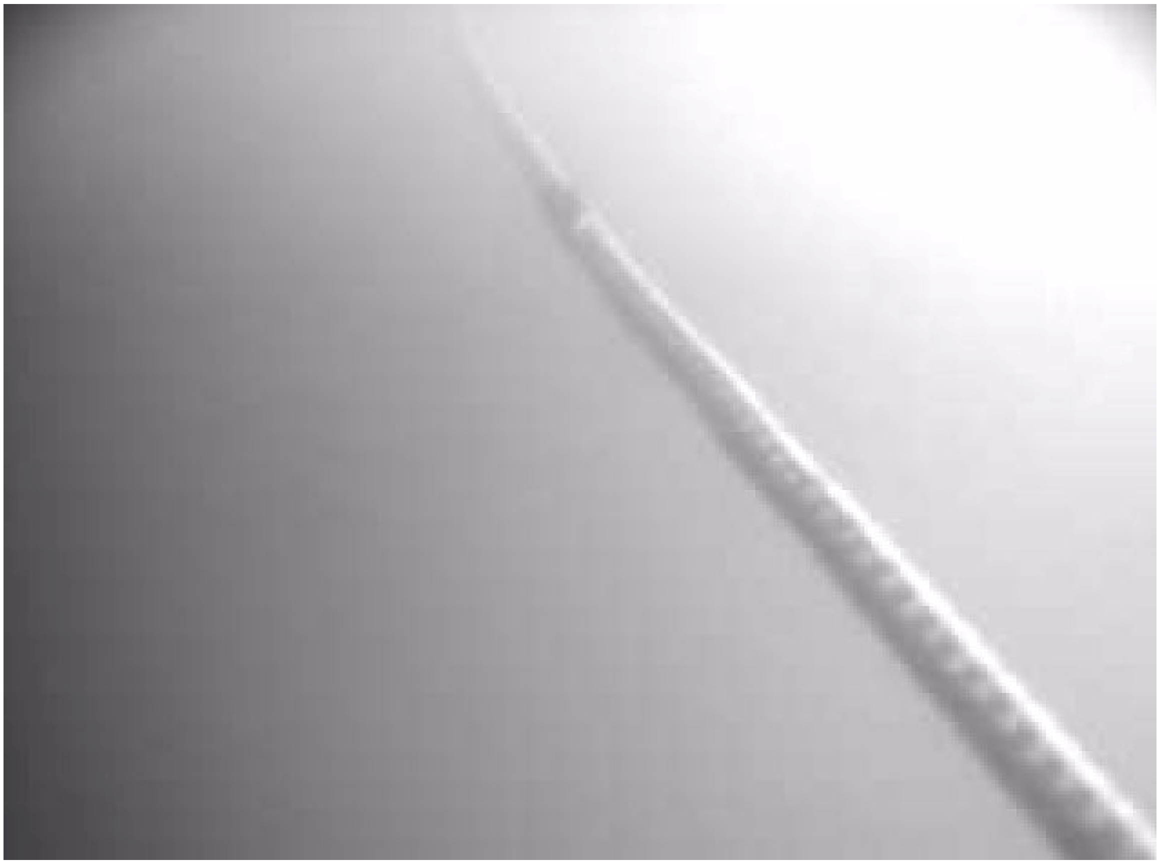

**Figure 5.** Example of a waving slope (WS) line in the water column.

**Figure 6.** Example of "nesting" line on the bottom.

**Figure 7.** View of 40 feet #10 diamond braided nylon rope ascending from the bottom and going over the top of the crab pot.

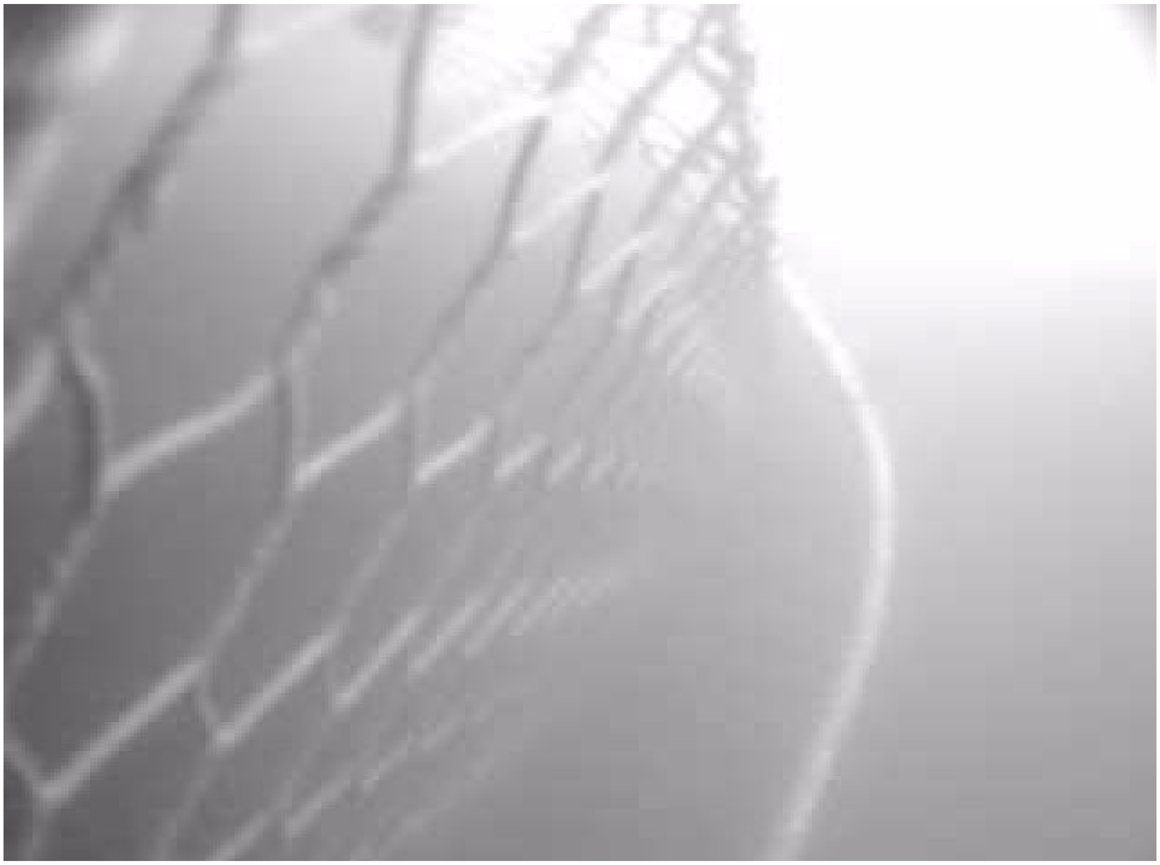

**Figure 8.** View of 80 feet poly lead core rope ascending off the bottom and crossing.

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