Evaluation of a Pound Net Leader Designed to Reduce Sea Turtle Bycatch

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Introduction

Pound nets are passive, stationary fish harvest devices with three primary components: leader, heart, and pound (Reid, 1955) (Fig. 1). Often suspended from anchored poles, the leader is a wall of mesh webbing that extends from the sea floor to approximately the sea surface and may run several hundred meters in length. Located at the deep end of the leader is the heart, funnel, and pound in which the fish are trapped.

The offshore pound net fishery in the southern portion of Chesapeake Bay had been documented to incidentally take threatened and endangered Kemp's ridley, *Lepidochelys kempii*, and loggerhead, *Caretta caretta*, sea turtles (Lutcavage and Musick, 1985; Bellmund et al., 1987; Mansfield et al.[1]). Sea turtles that become entangled or impinged in the leader cannot reach the surface to breathe and may drown. In 2004, NMFS mandated that all offshore pound net leaders in the main-stem portion of Virginia's Chesapeake Bay be removed from 6 May to 15 July effectively shutting down this portion of the fishery during this period.

In response to this closure, NMFS research staff, pound net fishermen, and Virginia Aquarium and Marine Science Center staff met on 27 Oct. 2003, and discussed potential experimental leader designs that could potentially reduce or eliminate sea turtle bycatch while maintaining target catch. The group settled on an experimental leader design that replaced the top two-thirds of the mesh leader with vertical ropes to potentially allow sea turtles to pass between vertical ropes without becoming entangled. The design was based in part on a leader modification historically used by pound net fishermen which used twine "stringers" at the top of the leader in place of mesh to allow surface debris to pass through the leader without causing damage. In addition, the experimental leader adopted a smaller mesh than typically used to further reduce the likelihood of a turtle becoming entangled in the mesh portion of the leader.

The objectives of this research were to:

1) Determine if the experimental pound net leader significantly reduces sea turtle interactions when compared to a control leader, and
2) Determine if there is a significant catch performance difference between pound nets set with the control and experimental leaders.

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[1]Mansfield, K. L., J. A. Musick, and R. A. Pemberton. 2001. Characterization of the Chesapeake Bay pound net and whelk pot fisheries and their potential interactions with marine sea turtle species. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Woods Hole, Mass. Contr. 43EANFO30131, 66 p.

ABSTRACT—Offshore pound net leaders in the southern portion of Chesapeake Bay in Virginia waters were documented to incidentally take protected loggerhead, Caretta caretta, *and Kemp's ridley,* Lepidochelys kempii, *sea turtles. Because of these losses, NOAA's National Marine Fisheries Service (NMFS) in 2004 closed the area to offshore pound net leaders annually from 6 May to 15 July and initiated a study of an experimental leader design that replaced the top two-thirds of the traditional mesh panel leader with vertical ropes (0.95 cm) spaced 61 cm apart. This experimental leader was tested on four pound net sites on the eastern shore of Chesapeake Bay in 2004 and 2005. During the 2 trial periods, 21 loggerhead and Kemp's ridley sea turtles were found interacting with the control leader and 1 leatherback turtle,* Dermochelys coriacea, *was found interacting with the experimental leader. Results of a negative binomial regression analysis comparing the two leader designs found the experimental leader significantly reduced sea turtle interactions (p=0.03).*

Finfish were sampled from the pound nets in the study to assess finfish catch performance differences between the two leader designs. Although the conclusions from this element of the experiment are not robust, paired t-test and Wilcoxon signed rank test results determined no significant harvest weight difference between the two leaders. Kolmogorov-Smirnov tests did not reveal any substantive size selectivity differences between the two leaders.

Methods and Material

Background

The control leader was constructed of 29 cm mesh made from 2.5 mm (#42) nylon twine (Fig. 2). For the experimental leader, the top two-thirds of the traditional mesh leader was replaced with vertical ropes spaced every 61 cm (Fig. 2). The experimental leader for the first field trial had 0.95 cm polypropylene vertical ropes. The second field trial used a 0.79 cm hard-lay rope. Hard-lay rope is stiffer than standard rope. The

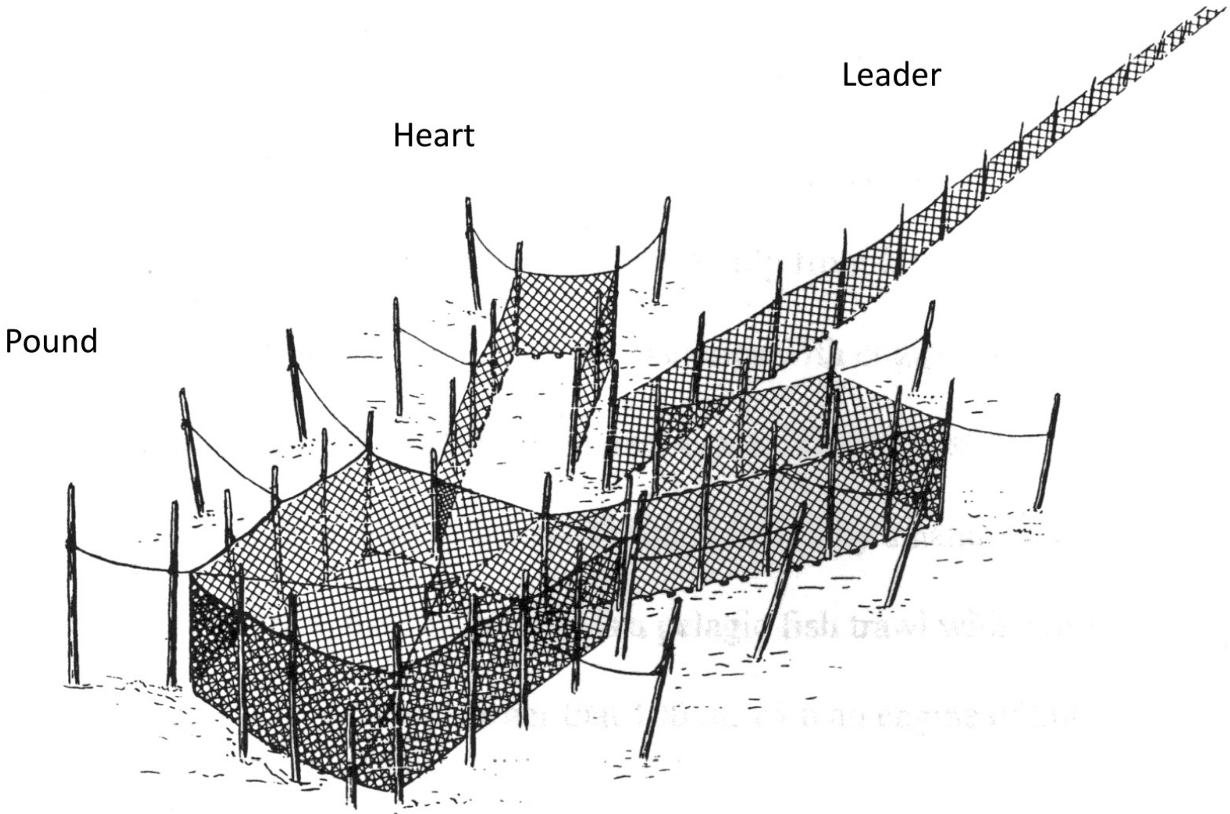

Figure 1.—Pound net diagram.

increased line stiffness was introduced to reduce the likelihood of sea turtle entanglement. The bottom third of the experimental leader was constructed of 20 cm mesh made from 2.5 mm (#42) nylon twine.

The leaders start between 283 m and 366 m from shore in depths ranging from 1.2 m to 5.7 m, vary in length between 229 m and 335 m, and end in depths ranging from 3.7 and 9.0 m. The funnels into the pound started at the sea floor and came within 2–5 m of the surface.

The experimental leaders were tested during two field-trial periods: 17 May 2004 through 28 June 2004; and 5 May 2005 through 29 June 2005. These periods were based on the seasonal arrival of sea turtles in the study area. The four pound net sites were located south of Kiptopeke State Park, Va., on the bay side of the Cape Charles peninsula. All four nets were separated by about 1 km and were oriented perpendicular to the shoreline. Net 1 was the northernmost net and Net 4 was the southernmost net (Fig. 3). The bathymetry in this part of the bay is relatively uniform with little vertical structure. The four pound net sites were chosen based on previously observed sea turtle and pound net leader interactions in this part of the bay.

Experimental Design

The control and experimental leaders were compared using an alternate design with scheduled leader switches to reduce spatial bias and increase the precision of the treatment comparison (Ott et al., 2001). When nets 1 and 3 had an experimental leader, nets 2 and 4 would have control leaders. In 2004, experimental leaders were placed on nets 1 and 3 and control leaders on nets 2 and 4 for the first half of the study, and were to be switched for the second half. In 2005, once turtles were first observed in the Chesapeake Bay region, the remaining study period was split into thirds, with leader switches to occur at the conclusion of the first and second thirds of the study.

Leader Monitoring

Two vessels were used to monitor the pound net leaders: one equipped with sonar technology; the second responsible for visual monitoring, target investigation, and sea turtle handling. Weather and sea state permitting, all four leaders were acoustically and visually surveyed twice a day at the latter part of a high and low tidal cycle.

The sonar vessel was equipped with a 900 kHz side-scan sonar fish, which was towed at approximately 1.5 m/sec and 10 m away from and parallel to the leader. Real-time data were displayed and recorded by a PC monitor and analyzed by a sonar technician. Each leader was insonified three times within each tidal cycle. Sea state permitting, both the flood and ebb sides of the leader were scanned.

At the conclusion of three scans, potential turtle targets identified by the sonar technician were investigated by a diver on the second research vessel and any turtles were retrieved. If a turtle interacting with the leader was encountered, meaning a turtle was in physical contact with the leader, the nature of the interaction was documented by the diver or technician. The turtle was removed from the leader and brought on board. The health status of the turtle was assessed and rehabilitation protocol was initiated by the research technician. In addition to sonar monitoring, each leader was visually scanned three times within each tidal cycle at a speed of 0.7–1.5 m/sec and a distance of 3–6 m from the leader.

Finfish Catch Sampling

If any of the four pound nets in the study were harvested, a research technician accompanied the fishermen to obtain a sample directly from the catch. Random samples were taken directly from the pound, intercepted as the catch was brailed into the retaining vessel, or taken after the catch had been placed in the boat. About 25 kg were removed from the catch as a representative sample. Once the harvest was complete, the total weight was estimated. Estimation was done by the research technician until 1 June 2004 of the first field trial, at which point this method was altered due to the potentially high estimation variation between research technicians. Thereafter, the vessel captain estimated the total catch weight.

Exact weights were obtained when possible, but this was usually not possible because the fishermen often harvest more than one net each trip, mixing the catches. If the entire catch was not removed from the pound due to high volume, the captain was asked to estimate the weight of fish that was left in the net. The catch left in the net was assumed to have the same species composition as the catch removed from the pound, to not influence more fish from entering the pound, and to not escape. These assumptions were made to ensure that data obtained from the next harvest were adjusted according to the catch that was left in the net.

The sample was sorted by species. Total weight of each species and total length of each fish was recorded. The species weight data were expanded to the total weight estimate to characterize the catch.

Four fish species were selected for the catch comparison analysis: Atlantic thread herring, *Opisthonema oglinum*, and butterfish, *Peprilus triacanthus*, both pelagic species; and Atlantic croaker, *Micropogonias undulatus*, and weakfish, *Cynoscion regalis*, both demersal species (Hildebrand and Schraeder, 1928; Murdy et al., 1997; Collette and Klein-MacPhee, 2002). These species were selected because they were the most consistent and dominant species represented in the catch.

Sea Turtle Interaction Analysis

The Poisson distribution is often used to characterize rare, discrete data (Cameron and Trivedi, 1998). An assumption of Poisson regression is that the rate parameter is equal to the variance. If this assumption is violated, the data are either overdispersed (variance is greater than the mean) or underdispersed (variance is less than the mean). Overdispersion is the result of clustered or contagious data, indicative of social aggregations that often occur in nature, and will artificially inflate the significance level of Poisson regression (McCullagh and Nelder, 1989; Cameron and Trivedi, 1998).

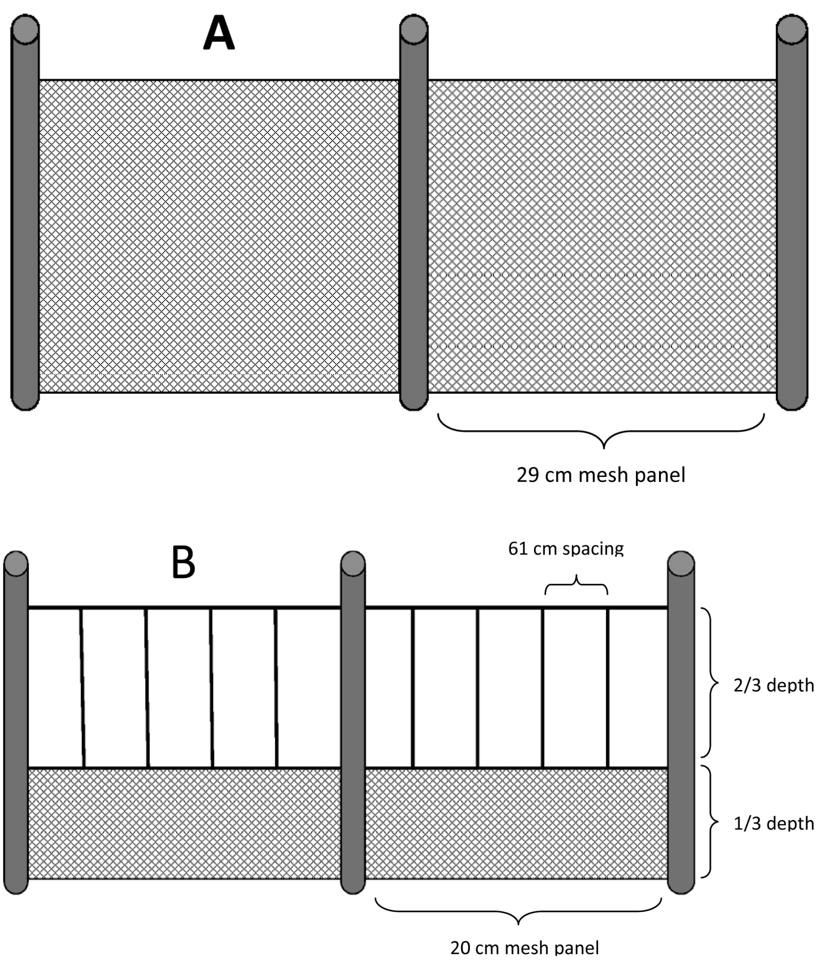

Figure 2.—Panel diagram of control pound net leader (A) and experimental pound net leader (B).

A likelihood ratio test, which compares the log-likelihood between two models, can be used to detect overdispersion. If overdispersion is present, negative binomial regression can be used in place of Poisson regression. Negative binomial regression incorporates aspects of the Poisson and gamma distributions that account for the waiting time between events. Consequently, negative binomial regression allows for inherent dependence or clustering in the stochastic process being measured, adjusting the conditional variance to provide an accurate characterization of the data (Cameron and Trivedi, 1998). The Wald Chi-Square test of significance was used to determine any significant difference between the control and experimental leaders.

The sample unit for this analysis was one calendar day, given sea turtles were present in the study area. This unit was chosen based on the monitoring schedule and was considered a reasonable unit by which to gauge the rate of sea turtle interactions. In cases when the leaders were not monitored due to sea state or inclement weather, the calendar day was still included in the analysis since turtles entangled in a leader will likely remain entangled until the tissue anchoring it has deteriorated (Bellmund et al., 1987). It is possible that impinged turtles would be missed in such cases.

Catch Comparison Analysis

Temporal variability in the bay's fish assemblage, which is substantial, has been well documented (Murdy et al., 1997; Jung and Houde, 2002). Due to high temporal and interannual variability, it was deemed not appropriate to assess leader catch performance using a before/after treatment comparison.

Due to individual net characteristics and localized geographic and environmental factors, spatial variability likely affects the catch as well. To quantify spatial variability, different net sites fitted with the same leader design during the same time period were compared. Total weight of each of the analyzed species for this comparison period was used to calculate catch efficiencies for each pound net site. For the purpose of this assessment, catch efficiency is the relative rate by which the individual pound nets harvested a given species. If spatial variation for a given species was moderate between nets, the sample data were scaled. If spatial variation for a given species was highly divergent between nets, the data from those nets were not used in the comparison. If the catch rate for a given net was within 100% of the catch rate of another net, it was considered moderate variation.

Once pound net catch efficiencies were incorporated into the sample data, paired samples from nets fitted with different leaders that had equal fishing effort and were harvested on the same day were used to assess the catch performance of the control and experimental leaders. The modification to the experimental leader between 2004 and 2005 was not expected to affect the capture of finfish so the data were pooled.

A Shapiro Wilk test of normality was performed on the error distribution of the paired data (p=0.05). If normally distributed, a one-tailed paired t-test was used to determine if the harvest weight of individual species was significantly different between the experimental and control leaders (p=0.05). In instances of non-normal data, the non-parametric one-tailed Wilcoxon signed rank test was used (p=0.05). A Kolmogorov-Smirnov two-sample test (K-S test) was conducted to investigate length frequency differences of the analyzed species between the experimental and control leaders (p=0.05).

When possible, exact catch weights were compared with estimated catch weights to evaluate catch estimate accuracy and consistency.

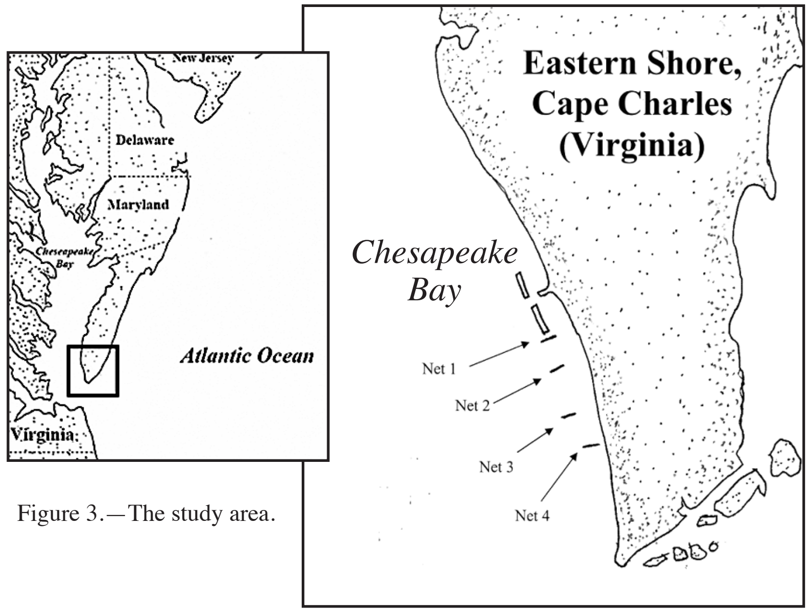

Figure 3.—The study area.

Environmental Data Collection

Environmental data were collected to investigate potential correlation between environmental conditions and sea turtle/pound net leader interactions. Three Onset Tidbit temperature loggers were used to record surface, midwater and bottom temperature trends during the trial periods. In 2004, an electromagnetic current meter was used to measure current speed at the midpoint of each leader for one entire flood and ebb tidal cycle. In 2005, an Aquadopp Profiler[2], which records current direction and magnitude, water pressure and water temperature throughout the water column, was placed at the shore-side end of the leader on Net 2 for the entire study. Before each leader was scanned,

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

sea state, tidal stage, wind direction, and Secchi depth readings were recorded. A Raytheon DE-719 recording fathometer was used in 2004 to create depth profiles for each leader in the study.

Results

Sea Turtle Interactions

Four strandings were already recorded by the Sea Turtle Stranding and Salvage Network (STSSN) by the start of the 2004 field trial indicating a high probability that turtles were present in the sample area. Between 17 May and 26 June 2004, 37 sea turtles were encountered in the study area. Seven were determined to have interacted with the leader while alive (Table 1). The remaining turtles, most of them dead and floating, either had no evidence of interacting with one of the leaders, were determined to have floated into the net already dead, or were found alive and swimming inside the pound. Six interactions occurred with the control leader; four loggerhead and two Kemp's ridleys. One interaction was a leatherback that became entangled by two wraps around the front left flipper in a vertical rope of an experimental leader.

Five of the interactions occurred within the first five days of the study; 17 May to 21 May 2004. The last two interactions occurred on 21 and 23 June. Four of the interactions occurred on the north side or ebb side of the leader, two on the south side, and one was undocumented. Two turtles were identified via sonar and five were found via visual inspection.

The likelihood ratio test identified overdispersion in the event data (p=0.046) so negative binomial regression was used to compare the interaction frequency. The Wald chi-square test found no significant difference (p=0.060) between the leader types.

In 2004, we had difficulty in getting the participating fishermen to follow the leader alternation schedule. As a result, over the course of the 41-day study, the experimental leader had 97 days of effort and the control leader had 71 days of effort.

Table 1.—Summary of 2004 sea turtle pound net leader interaction.

Date	Species	Net no.	Leader type	Side of leader	Depth of interaction (m)
17 May 04	Kemp's ridley	2	Control	North	1.2
17 May 04	Loggerhead	2	Control	Unknown	Unknown
18 May 04	Loggerhead	2	Control	North	1.2
19 May 04	Kemp's ridley	2	Control	North	1.2
21 May 04	Loggerhead	4	Control	North	Unknown
21 June 04	Loggerhead	1	Control	South	1
23 June 04	Leatherback	2	Experimental	South	1.2

Table 2.—2005 sea turtle pound net leader interaction summary.

Date	Species	Net no.	Leader type	Side of leader	Depth of interaction (m)
24 May 05	Loggerhead	1	Control	North	1.2
27 May 05	Kemp's ridley	1	Control	North	2.1
31 May 05	Loggerhead	1	Control	North	1.8
31 May 05	Loggerhead	1	Control	North	1.8
31 May 05	Kemp's ridley	1	Control	North	1.2
31 May 05	Loggerhead	1	Control	North	1.2
31 May 05	Loggerhead	1	Control	North	1.2
31 May 05	Loggerhead	1	Control	North	Unknown
31 May 05	Loggerhead	1	Control	North	Unknown
01 June 05	Kemp's ridley	3	Control	South	Unknown
01 June 05	Kemp's ridley	3	Control	North	2.7
01 June 05	Loggerhead	3	Control	North	1.2
02 June 05	Loggerhead	4	Control	North	1.2
02 June 05	Kemp's ridley	2	Control	North	1.2
04 June 05	Kemp's ridley	4	Control	North	1.2

The 2005 field period started on 6 May 2005, earlier than the 2004 study, so as to be present before the turtles arrived in the bay. The first sea turtle reported in the bay area by the STSSN was on 18 May 2005. Between 18 May and 4 June 2005, the period used in the sea turtle analysis, 20 sea turtles were encountered in the study area. Fifteen of these were found interacting with the leaders in the study; all were in control leaders (nine loggerhead, six Kemp's ridley) (Table 2). All 15 were determined to have interacted with the leader while alive. The remaining five turtles were found floating dead in the study area not interacting with a pound net.

The number of interactions exceeded the takes authorized under the Endangered Species Act Section 10(a)(1)(A) permits issued for the purpose of this study. Consequently, all control leaders were removed on 4 June 2005 and replaced with experimental leaders. No sea turtles were found interacting with the four experimental leaders for the remainder of the study, which ended 29 June 2005.

All 15 events occurred between 24 May and 4 June. Fourteen interactions occurred on the north side of the leader; one occurred on the south side. Ten interactions occurred within 2 m of mean low water, two occurred within 3 m of mean low water and the depth of three interactions were undetermined.

Eleven of 15 events were identified during leader alternation. Seven turtles (six loggerhead, one Kemp's ridley) were entangled or impinged with the control leader on Net 1 during removal on 31 May 2005; three were alive and four were freshly dead. The next day, three turtles (one loggerhead, two Kemp's ridley) were found interacting with the control leader on Net 3 during removal; one turtle was alive and two were freshly dead. On 4 June 2005, a small, dead Kemp's ridley (29 cm) came up in the control leader on Net 4 as it was being removed.

Since no sea turtle/pound net leader interactions occurred in the 2005 experimental leader, the 2004 and 2005 data sets were combined. The likelihood ratio test indicated overdispersion (p<0.001). The negative binomial regression found the experimental leader significantly reduced sea turtle interactions (p=0.003).

Environmental Data

There was little evidence of strong stratification in the water column except for brief periods. These brief stratifica-

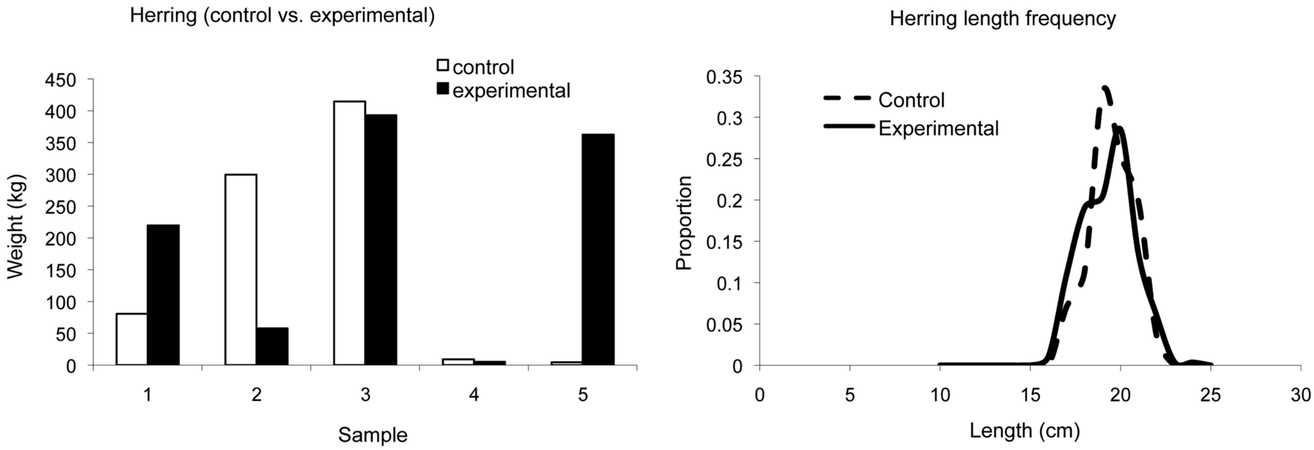

Figure 4.—Herring sample weights and length frequencies.

tion periods did not correlate with turtle interactions. The semi-diurnal periodicity indicates that tidal currents dominate other current forces. The maximum observed surface current was about 1 m/sec, however the mean maximum surface current was about 0.5 m/sec. Maximum surface flood (north) and ebb (south) currents are very similar in magnitude. Bottom current is about one half the magnitude of surface current. A complete presentation of the environmental data collected in 2004 and 2005 is provided by DeAlteris et al.[3,4]

Table 3.—Net catch efficiencies.

Species	Net 1	Net 2	Net 3	Net 4	Total (kg)
Herring	18%	21%	33%	28%	19,484
Butterfish	13%[1]	35%	49%	4%[1]	1,655
Croaker	44%	34%	28%	4%[1]	56,755
Weakfish	26%	37%	30%	7%[1]	38,368

[1] Highly divergent, not used in comparison.

Table 4.—Catch weight comparison.

Species	Mean CTL weight (kg)	Mean EXP weight (kg)	Paired samples	P (T<t)
Herring	162 (σ 185)	208 (σ 174)	5	0.33
Butterfish	22 (σ 27)	55 (σ 55)	6	0.22[1]
Croaker	3016 (σ 3982)	2597 (σ 6572)	8	0.40
Weakfish	484 (σ 649)	525 (σ 480)	10	0.42

[1] Wilcoxon signed rank test.

Catch Comparison

Spatial variation between the nets was assessed between 5 June and 29 June 2005, when all 4 nets were fitted with experimental leaders. During this period, Net 1 was harvested 12 times, Net 2 was harvested 12 times, Net 3 was harvested 13 times, and Net 4 was harvested 11 times. The total estimated harvest weight and catch efficiencies of all four species are detailed in Table 3. All 4 nets were used in the herring catch comparison, resulting in 11 paired samples. Due to the highly divergent butterfish catch rates, only nets 2 and 3 were used in the butterfish comparison, resulting in 6 paired samples. Due to the highly divergent croaker catch rate of Net 4, it was excluded from the croaker comparison, resulting in 10 paired samples. Due to the highly divergent weakfish catch efficiency of Net 4, it was excluded from the weakfish comparison, resulting in 10 paired samples.

The leader comparison samples were obtained during the entire study period in 2004 (5 May through 28 June 2004) and the portion of the 2005 study period in which the different leaders were in use (5 May through 3 June 2005). During these periods, 138 catch samples were taken.

Herring

Herring were present in 5 of the 11 paired samples. Nets with a control leader caught more than nets with an experimental leader in 3 of the 5 paired samples with fish present (Fig. 4). The Shapiro Wilk test indicated the error structure was normally distributed (p=0.92). The paired t-test found no significant difference between the two leader types (p=0.33) (Table 4). The K-S test did not find a significant difference between the two leader types (p=0.07) (Table 5).

Butterfish

Butterfish were present in each of the 6 paired samples. Nets with an experimental leader harvested more than nets

[3]DeAlteris, J., D. Chosid, R. Silva, and P. Politis. 2004. Evaluation of the performance in 2004 of an alternative leader design on the bycatch of sea turtles and the catch of finfish in Chesapeake Bay pound nets, offshore Kiptopeake, VA. Final Rep. submitted by DeAlteris Associates Inc. to NMFS Northeast Fisheries Science Center, Gloucester, Mass., 39 p.

[4]DeAlteris, J., R. Silva, E. Estey, K. Tesla, and T. Newcomb. 2005. Evaluation of the performance in 2005 of an alternative leader design on the bycatch of sea turtles and the catch of finfish in Chesapeake Bay pound nets, offshore Kiptopeake, VA. Final Rep. submitted by DeAlteris Associates Inc. to NMFS Northeast Fisheries Science Center, Gloucester, Mass., 33 p.

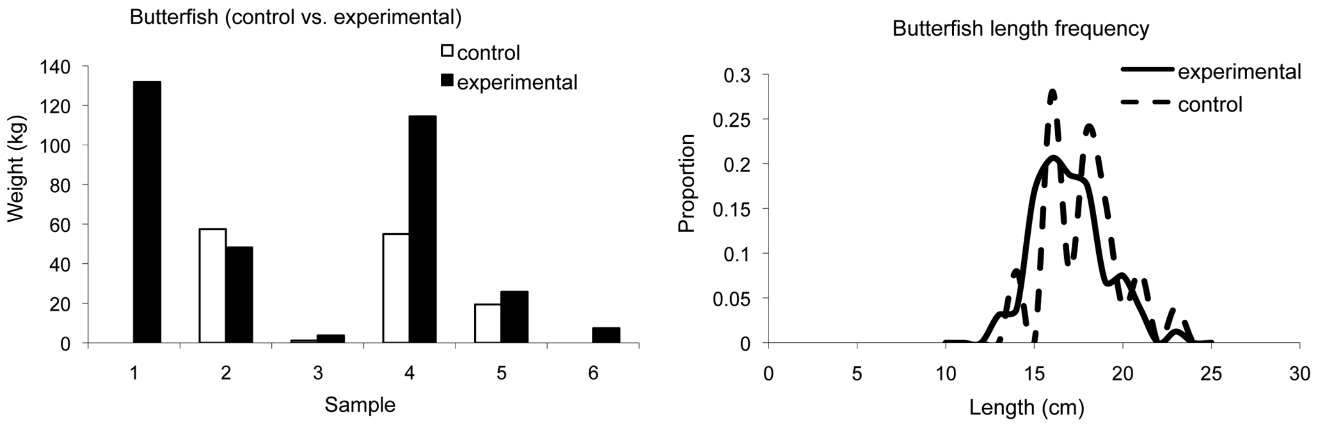

Figure 5.—Butterfish sample weights and length frequencies.

with a control leader in 5 of 6 paired samples with fish present (Fig. 5). The Shapiro Wilk test indicated the error structure was not normally distributed (p=0.04). The Wilcoxon signed rank test found no significant difference between the two leader types (p=0.22) (Table 4). The K-S test did not find a significant difference between the two leader types (p=0.08) (Table 5).

Table 5.—Length frequency comparison.

Species	Mean length CTL (cm)	Mean length EXP (cm)	P (T<t)
Herring	19.5 cm (19.3–19.7)[1]	19.4 cm (19.2–19.5)[1]	0.07
Butterfish	17.9 (17–18.8)[1]	16.9 (16.7–17.2)[1]	0.08
Croaker	26.3 (26–26.6)[1]	26.6 (25.9–27.4)[1]	<0.0001
Weakfish	25 (24.8–25.3)[1]	23.6 (23.4–23.8)[1]	<0.0001

[1] Ninety-five percent confidence interval.

Croaker

Croaker were present in 8 of 10 paired samples. Nets with an experimental leader caught more croaker than nets with a control leader in 4 of 7 paired samples with fish present (Fig. 6). The Shapiro Wilk test indicated the error structure was normally distributed (p=0.38). The paired t-test indicated no significant difference (p=0.40) between the two leader types (Table 4). The K-S test found a significant difference between the two leader types (p<0.001) (Table 5).

Weakfish

Weakfish were present in all 10 paired samples. Nets with an experimental leader caught more than nets with the control leader in 7 of the 10 paired samples (Fig. 7). The Shapiro Wilk test indicated the error structure was normally distributed (p=0.06). The paired t-test indicated no significant difference (p=0.42) between the two leader types (Table 4). The K-S test found a significant difference between the two leader types (p<0.001) (Table 5).

Exact Weight vs. Estimated Weight

Between the 2004 and 2005 field trials, exact weights were compared with the captain's weight estimate 14 times. All of these comparison samples were taken from estimates and weights provided by the owner of Net 1. On average, the captain's total catch estimate was 320 kg over the exact weight, with a standard deviation of 1,000 kg. The average exact harvest weight was 6,637 kg, with a range of 3,750 through 12,000 kg. Since there were no exact weights obtained from the second fisherman in the study, catch estimation variability between the fishermen could not be assessed.

Discussion

Sea Turtle Interactions

The regression analysis for the 2004 interaction data was not significant at a=0.05 (p=0.060). However, the p-value was very close to achieving the defined level of significance. In addition, these findings were constrained by the low number of observed interactions in 2004. When data from the 2004 and 2005 studies were pooled, the experimental leader significantly reduced sea turtle interactions (p=0.003).

In addition to the significant results of the negative binomial regression of the pooled data, other observations indicate the experimental leader worked as designed. When the control leaders were removed from the study area in 2005 due to take levels over those anticipated in the Section 10 research permit, they were replaced with experimental leaders for the remainder of the study, doubling the number of experimental leaders and therefore increasing the likelihood of a turtle interaction with an experimental leader. For 24 days no sea turtles were found interacting with any of the four experimental leaders. These observations were not considered in the regression analysis. Furthermore, assuming the 2005 leader design is less likely to entangle a turtle due to the stiffer vertical ropes, the level of significance for the pooled data is conservative.

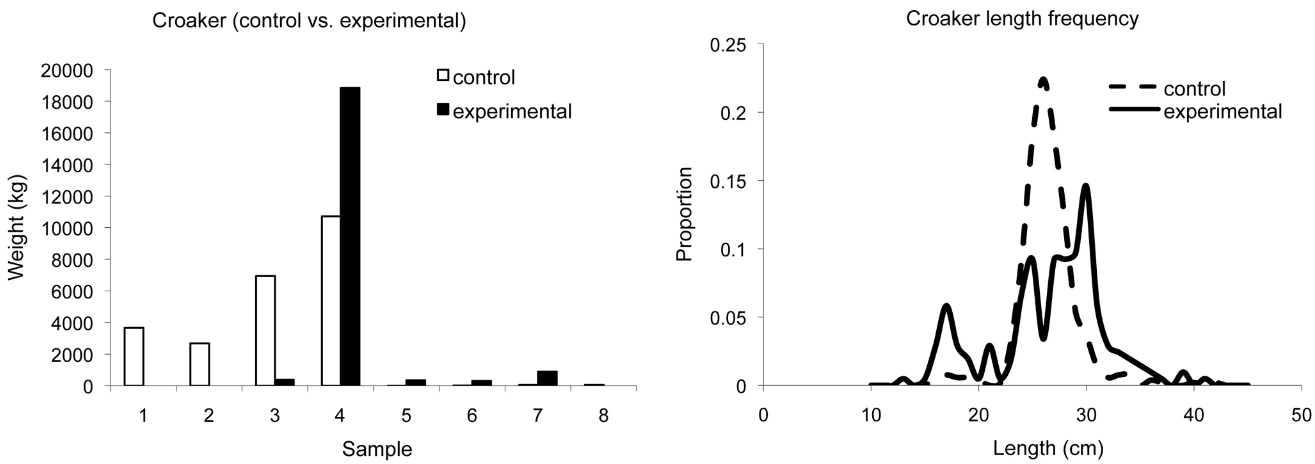

Figure 6.—Croaker sample weight and length frequencies.

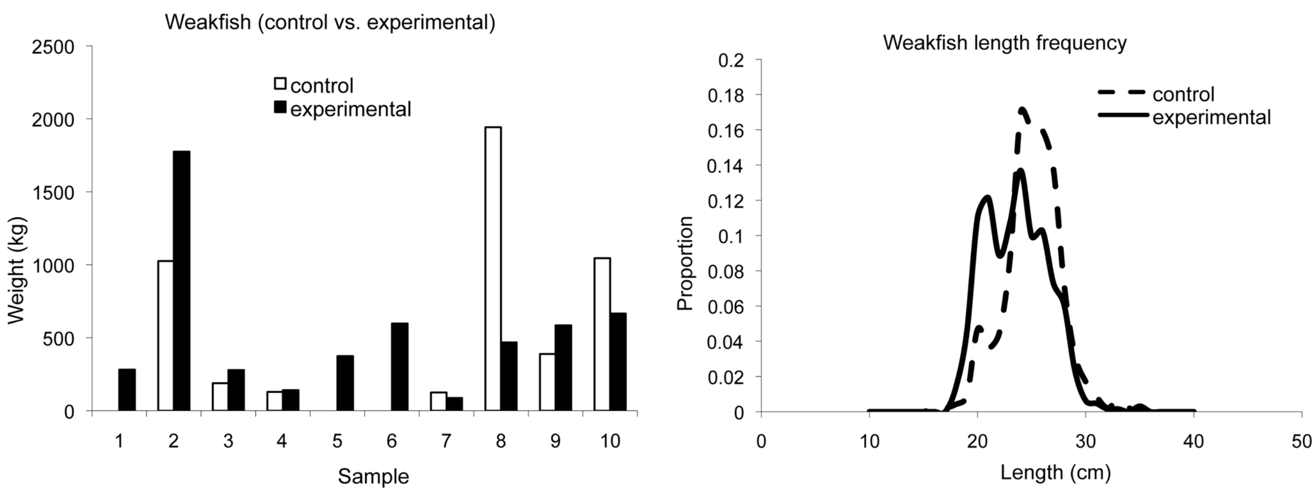

Figure 7.—Weakfish sample weights and length frequencies.

Spatial independence between the nets may have influenced the statistical analysis. Conspicuously, of the 22 observed interactions, 18 of 21 occurred on the north side or ebb side of the leaders (one was undocumented), even though the current meter demonstrated the flood and ebb currents to be very similar in magnitude (DeAlteris et al.[4]). There is a large breakwater made of scuttled concrete ships just north of Net 1, which has been implicated in creating a large scale disturbance that increases sea turtle and pound net leader interactions (Lutcavage and Musick, 1985). However, the other leaders in the study are a considerable distance from this structure, making it an unlikely cause of interactions on the north side of these leaders.

It has been demonstrated that sea turtles in the bay move in relation to tidal cycles and exhibit philopatry both within and between seasons (Byles, 1988), but these data may indicate a spatial movement pattern in this part of the bay where both loggerhead and Kemp's ridley turtles consistently move from north to south along the eastern shore during this time of year.

Ten interactions occurred in Net 1, six in Net 2, three in Net 3, and three in Net 4. If sea turtles have an increased likelihood of encountering the northernmost leader in the study first, whether it is an experimental leader or control leader, the assumption of spatial independence inherent in the negative binomial regression is violated. The issue of spatial independence would be mitigated by the leader rotation schedule if the event data were temporally uniform over the course of the study period. However, the overdispersed data indicate clustering, demonstrating the events were not temporally independent. Therefore, leader location during periods of increased interactions may have influenced the regression analysis.

A test was performed to further investigate the potential influence of spatial independence. All Net 1 control leader observations and associated sea turtle interactions were removed from the analysis while all Net 1 experimental leader observations were retained in the analysis, removing the possibility of a turtle encountering a control leader on Net 1. The negative binomial regression analysis on the modified data sets for 2004 and 2004–05 combined found the experimental leader still significantly reduced sea turtle interactions (2004 p=0.048; 2004–05 p=0.007).

Another indication that leader type, and not leader location, was the primary cause of interaction occurred in 2005. When the leaders were lifted on 31 May 2005 and 1 June 2005 for rotation, sea turtles were found interacting with both control leaders (nets 1 and 3). On 2 June, the day after the leaders were rotated, turtles were found in the control leaders now on nets 2 and 4. Based on these analyses and observations, it is concluded that the potential issue of spatial independence did not significantly influence the results of the negative binomial regression, and the initial conclusion that the experimental leader significantly reduced sea turtle interactions was appropriate.

Leader Monitoring Effectiveness

Questions were raised about the effectiveness of the sonar monitoring when turtles came up in the leader as they were being switched in 2005. All of the turtles that came up in the leaders were either alive or freshly dead, indicating they had likely been in the leader less than 6 hours (Lutcavage and Lutz, 1996). These interactions would have occurred well after the last sonar scans of the previous day, which was 18 hours prior. No sonar passes were made on Net 1 before the leader was removed; therefore, it is impossible to relate these events to the effectiveness of sonar.

Approximately half of the leader of Net 3 was insonified once before it was pulled. One priority target, which was likely the third turtle that was pulled out of that leader, was identified but not verified since the leader was being pulled. However, the sonar vessel conducted three scans according to protocol on Net 4 on 4 May 2005, prior to the leader being removed with a dead turtle entangled in it. This turtle was not identified as a target by the sonar technician, and it was postulated that sonar may have missed other small turtles interacting with the pound net gear.

A previous study found that sonar was effective at identifying dead turtles that were larger than 35 cm curved carapace length (CCL) interacting with pound net leaders (Mansfield et al.[5]). The 4 May sea turtle found in Net 4 was the smallest sea turtle encountered during both study periods (29 cm CCL), whether interacting with a leader or not, and was the only sea turtle smaller than 35 cm CCL. It should also be noted that sonar often identified blue crabs, *Callinectes sapidus*; horseshoe crabs, *Limulus polyphemus*; and other small targets. Therefore, we believe that sonar is effective and a reliable means of detecting sea turtles in pound net leaders.

Catch Comparison

The experimental leader created speculation as to whether it would successfully herd pelagic fishes, in addition to demersal fishes. Results from the paired t-test and Wilcoxon signed rank test found that leader type did not significantly affect harvest weight for the analyzed species when compared to the traditional leader design. It is likely that visual stimuli and low frequency noise generated by the vertical ropes caused schooling pelagic fishes to turn and avoid the ropes rather than pass between them (Wardle, 1986; Misund, 1994). The K-S test results indicate there were no substantive length selectivity differences between the two leader types. In instances where the K-S test were significant (croaker and weakfish, both demersal species), either the experimental leader resulted in the harvest of smaller fish (weakfish), or the mean size difference was minimal (croaker, 0.3 cm) and not biologically significant.

There are several factors that reduce the strength of the statistical tests. Although 138 samples were obtained over the course of the two seasons, the uncoordinated harvest of the pound nets resulted in only up to 11 paired samples to compare the catch performance of the two leader designs, which was further reduced due to the absence of the assessed species in some of these samples. Sources of variability may have influenced the results of the statistical tests as well. Although spatial variation between the nets was accounted for by scaling the sample data, this assumes the catch efficiencies calculated in 2005 during a 25-day period were representative of both study periods and were the same for both leader types.

Another source of error was exposed in the difference between the captain's harvest weight estimate and the exact harvest weight. Although the captain's estimates were generally accurate and consistent, it is a source of variability that could not be accounted for in the catch comparison analysis. Since no exact weights were obtained from nets 2, 3, and 4, the accuracy of the captain's estimates for these nets could not be evaluated, and it is assumed they were consistent.

A research technician estimated the harvest weights for the paired samples obtained on 26 May and 27 May 2004. It was not possible to assess the accuracy of these estimates, and it is assumed that they were consistent. Due to the relatively small sample size, coupled with the sources of error that could not be fully accounted for, it is not appropriate to state there is no statistical difference in catch performance between the two leaders. However, the data indicates the catch from pound nets fitted with the experimental leader was at least comparable to the catch from nets fitted with the control leader. Additionally, the fishermen involved in the study were satisfied with the catch performance of the experimental leaders.

Conclusions

Based on the statistical analyses and qualitative observations, the experimental leader achieved the two primary

[5]Mansfield, K. L., E. E. Seney, and J. A. Musick. 2002. An evaluation of sea turtle abundances, mortalities, and fisheries interactions in the Chesapeake Bay, Virginia. Final Rep., U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Gloucester, Mass. Contr. 43-EA-NF-110773, 102 p.

objectives of this study: Significantly reducing sea turtle bycatch while not significantly affecting the capture of finfish. Additional pound net sites, a higher allowable sea turtle take, and a coordinated harvest schedule would have greatly increased the strength of these conclusions. The reduction in sea turtle mortality attributed to the experimental leader provided sufficient evidence to resource managers to allow restricted offshore pound net fishermen to use the experimental pound net leader between 6 May and 15 July. This regulation was implemented on 23 June 2006 (71 FR 36024).

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