EXPERIMENT TO EVALUATE GEAR MODIFICATION ON RATES OF SEA TURTLE BYCATCH IN THE SWORDFISH LONGLINE FISHERY IN THE AZORES – PHASE 4

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BACKGROUND:

The problem of sea turtle bycatch in longline fisheries has been recognized worldwide (for review, see Balazs and Pooley 1994, Bolten et al. 1996, Williams et al. 1996, Long and Schroeder 2004). Bolten et al. (1994) and Ferreira et al. (2001) presented preliminary data on bycatch of loggerhead sea turtles (*Caretta caretta*) in the swordfish longline fishery in the Azores. The waters around the Azores are an important developmental habitat for the juvenile oceanic stage of the Atlantic loggerhead population (Bolten 2003). Using mtDNA sequence analyses, Bolten et al. (1998) determined that the source rookeries for this oceanic population are primarily in the southeastern USA. Therefore, the nesting populations of loggerheads in the southeast USA are the primary populations impacted by the swordfish longline fishery in the Azores. Bjorndal et al. (2000, 2003), using a length frequency model and skeletochronology, provided data on growth rates for this juvenile population and determined that the duration of the oceanic stage was 6.5 – 11.5 years depending upon the size at which the turtles departed the oceanic zone for the neritic zone (Figure 1).

A workshop (funded by the National Marine Fisheries Service, OPR) was held in Horta, Azores, Portugal, 2 – 4 September 1998, to review the impact of the swordfish longline fishery on sea turtles and to design an experiment to evaluate gear modification on longline bycatch rates of sea turtles (Bolten et al., 2000). This Workshop was attended by commercial longline fishermen from the Azores, fishery biologists from the Department of Oceanography and Fisheries at the University of the Azores, the Director of Fisheries from the Ministry of Agriculture and Fisheries in the Azores, and a representative of the Ministry of the Environment in the Azores. In addition, Jerry Wetherall (NMFS, Honolulu) participated and provided comparative information from other longline fisheries and ensured that the experimental design was statistically rigorous. Alan Bolten (ACCSTR, University of Florida), who has conducted sea turtle research in the Azores since 1989, convened the Workshop.

OBJECTIVE:

The objective of this project was to conduct an experiment to evaluate effects of gear modification on rates of sea turtle bycatch in the swordfish longline fishery in the Azores. Based

on results from Phases 1, 2 and 3 of this project (years 2000, 2001 and 2002), the primary variables evaluated in Phase 4 of the project (year 2003) was hook type and size: Circle hook 16/0 non-offset (Mustad # 39960), Circle hook 18/0 non-offset (Lindgren-Pitman), and Japanese tuna hook 3.6mm S/S (Ocean Producers International #OPI023). Although the primary objective was to evaluate the effect of hook type on rates of sea turtle bycatch, the effect of hook type on the location of hooking (e.g., mouth vs. esophagus) was also evaluated. The location of hooking has very important implications for the survival of the hooked turtles. Effect of hook type on rates of catch for target species was also evaluated.

METHODS:

A 24.5-meter commercial swordfish longline vessel (*Mizar*) from the Azores was contracted to conduct the experiment in the waters around the Azores. The experimental design consisted of the following components:

- 73 sets were conducted in Phase 4 between 2 September 2003 – 7 December 2003.
- Buoy lines were 6-24 meters long, depending on sea conditions.
- There were 4 branchlines between buoys and approximately 80 meters of mainline between each branchline.
- The branchlines were 16 meters long.
- Three hook types were tested in Phase 4: Circle hook 16/0 non-offset (Mustad # 39960), Circle hook 18/0 non-offset (Lindgren-Pitman), and Japanese tuna hook 3.6mm S/S (Ocean Producers International #OPI023).
- There were approximately 1500 hooks per set; the number varied depending upon sea conditions (total hooks deployed for the 73 sets of Phase 4 = 114,417 [mean = 1567 hooks per set]).
- For Phase 4A (first 27 sets) the three hook types were individually alternated along the set (that is, A, B, C, A, B, C, A, B…). Since there were 4 hooks between the buoys, the relationship between the hook type and hook position on the gear varied. After 27 sets, the Japanese tuna hook 3.6mm S/S (Ocean Producers International #OPI023) was discontinued because of the high rate of turtle catch and high proportion of turtles that were caught in the throat.
- For Phase 4B (sets 28 through 73) only two hook types were evaluated in the experiment: Circle hook 16/0 non-offset (Mustad # 39960) and Circle hook 18/0 non-offset (Lindgren-Pitman). These two hooks were alternated throughout the set with a total of 4 hooks between the buoys; the relationship between hook type and hook position relative to the buoys was constant and equal.

- The bait was squid for all sets.

The experiment was conducted during the primary months of the swordfish fishery in the Azores. This time period was treated as one season with no seasonal effect.

Data collected for all turtles caught during the experiment included the following: species, body size (curved carapace length), status (dead, active, sluggish), manner of capture (entangled in line or caught on hook), type of hook, position of hook in the turtle, and position of hook between the buoys. Turtles were tagged with standard flipper tags before release. Small skin samples were collected from all turtles for genetic analyses to monitor source rookeries impacted by this fishery.

Data collected on the fish species caught included the following: species, body size, hook type, and position between the buoys. Water temperature, sea conditions, wave direction, wind direction and speed, and water depth were also collected for each set.

RESULTS:

- During Phase 1 of the experiment in year 2000, 237 turtles were captured in 93 sets (232 loggerheads, 4 leatherbacks, and 1 green turtle). Catch rate was calculated as 2.5 turtles per set (1.7 turtles per 1000 hooks). The number of loggerheads caught by each hook type is presented in Table 1. The loggerhead catch per 1000 hooks for each hook type is presented in Table 2. All 4 leatherbacks were caught entangled in the line, 2 on lines with straight J hooks and 2 on lines with offset J hooks. The green turtle was caught entangled on a line with a circle hook (16/0).

- During Phase 1, there was no significant difference among the 3 hook types in the number of loggerheads caught (exact binomial tests, $p > 0.05$), although the lower number of turtles caught on the offset J hook approached significance ($p = 0.0509$).

- During Phase 2 of the experiment in year 2001, 45 turtles were captured in 60 sets (44 loggerheads and 1 leatherback). Catch rate was calculated as 0.75 turtles per set (0.51 turtles per 1000 hooks). The number of loggerheads caught by each hook type is presented in Table 1. The loggerhead catch per 1000 hooks for each hook type is presented in Table 2. The leatherback was caught entangled on a line with an 18/0 circle hook.

- During Phase 2, there was no significant difference among the 3 hook types in the number of loggerheads caught (exact binomial tests, $p > 0.05$), although the higher number of turtles caught on the 16/0 circle hook approached significance ($p = 0.0539$).

- During Phase 3 of the experiment in year 2002, 21 turtles were captured in 48 sets (18 loggerheads and 3 leatherback). Catch rate was calculated as 0.44 turtles per set (0.28 turtles per 1000 hooks). The number of loggerheads caught by each hook type is presented in Table 1. The loggerhead catch per 1000 hooks for each hook type is presented in Table 2. Two

leatherbacks were entangled on lines and one leatherback was hooked in the mouth with a 16/0 circle hook.

- During Phase 3, there was no significant difference among the 3 hook types in the number of loggerheads caught (exact binomial tests, $p > 0.05$).

- During Phase 4 of the experiment in year 2003, 148 turtles were captured in 73 sets (143 loggerheads and 5 leatherback). Catch rate was calculated as 2.03 turtles per set (1.29 turtles per 1000 hooks). The number of loggerheads caught by each hook type is presented in Table 1. The loggerhead catch per 1000 hooks for each hook type is presented in Table 2. Two leatherbacks were entangled on lines around the front flipper (one on the 18/0 circle hook and one on the Japanese tuna hook); one leatherback was hooked in the mouth with a 16/0 circle hook; and two other leatherbacks were caught but were not able to be assessed as to hook type or location of hooking or entanglement.

- During Phase 4A (sets 1 – 27), the Japanese tuna hook caught significantly more turtles comparing among all 3 hook types (Friedman rank sum test with set as blocking variable and hook type as treatment variable, Friedman chi-square = 19.38, df = 2, $p = 0.0001$).

- During Phase 4 (combining Phases 4A and 4B), fewer turtles were caught with the 18/0 circle hook compared with the 16/0 circle hook for the 73 sets (Friedman chi-square = 4.8, df = 1, $p = 0.03$).

- During Phase 4, there was no significant difference between the 16/0 circle hook vs. the 18/0 circle hook in the location of the hooks in the turtles (Chi square = 0.02, df = 1, $p = 0.88$). However, there was a significant difference between the Japanese tuna hook vs the circle hooks (16/0 and 18/0 combined) in the location of the hooks in the turtles (Chi square = 20.1, df = 1, $p < 0.0001$, Table 3).

- During Phase 4A, there was no significant difference in the size distribution of the loggerhead turtles caught on the 16/0 circle hook vs. the 18/0 circle hook (Kolmogorov-Smirnov test, ks = 0.220, $p = 0.7$). However, during Phase 4A, the size distribution of the loggerhead turtles caught on the Japanese tuna hook (mean = 53.8 cm CCL) was significantly different from the size distribution of loggerheads caught on the circle hooks (16/0 and 18/0 combined; mean = 57.7 cm CCL; Kolmogorov-Smirnov test, ks = 0.289, $p = 0.03$). During Phase 4 (combining Phases 4A and 4B), there was no significant difference in size distribution of the loggerhead turtles caught on the 16/0 circle hook vs. the 18/0 circle hook (Kolmogorov-Smirnov test, ks = 0.144, $p = 0.81$).

- Not all sets caught turtles; turtles were not uniformly distributed but were clustered within the fishing area. The frequency distributions of turtles caught among sets for Phases 1, 2, 3, and 4 are presented in Figure 2 and show a similar pattern among years.

- The size distribution of loggerheads caught during Phases 1, 2, 3, and 4 is significantly different (mean = 52.7 cm CCL) than the overall size distribution of loggerheads (left hand curve Figure 3, mean = 34.5 cm CCL) in Azorean waters (Kolmogorov-Smirnov test, ks =

0.6618, $p < 0.0001$). Size distribution of loggerheads caught during Phase 4 (mean = 56.1 cm CCL) is significantly different than those caught during Phases 1, 2, and 3 (mean = 51.0 cm CCL, Kolmogorov-Smirnov test, ks = 0.445, $p < 0.0001$).

- For Phases 1, 2, 3, and 4 combined, there was a significant difference among the hook types in the location of the hooks in the turtles (Table 3). J style hooks had a significantly higher rate of throat capture compared with circle hooks (Chi-square = 75.6, df = 1, $p < 0.0001$); 60% of the loggerheads ingesting J style hooks were hooked in the throat compared with 13% of the loggerheads ingesting circle hooks. Japanese tuna hooks had a significantly higher rate of throat capture compared with circle hooks (Chi-square = 38.8, df = 1, $p < 0.0001$); 52% of the loggerheads ingesting Japanese tuna hooks were hooked in the throat compared with 13% of the loggerheads ingesting circle hooks. Because sea turtles hooked in the throat are assumed to have higher mortality than those hooked in the mouth, the differences between circle hooks and both J style hooks and Japanese tuna hooks have important implications for sea turtle mortality.

- The effect of hook position along the mainline on loggerhead bycatch was not significant during Phase 1, 2, 3, or 4 (exact binomial tests, $p > 0.05$; Table 4).

- The rate of turtles caught increased significantly as the hour of day of line retrieval increased ($r^2 = 0.86$, $p < 0.001$; Figures 4 and 5). The rate of fish caught remained constant as hour of day of line retrieval increased ($p = 0.7$).

- The number of swordfish caught and the catch per 1000 hooks are presented in Tables 5 and 6, respectively.

- The number of blue sharks caught and the catch per 1000 hooks are presented in Tables 7 and 8, respectively.

- Further analyses of the blue shark catch data were conducted because of the concern with potential increases of shark catch rates with circle hooks. Note that data can only be compared within a year and not among years because in Phases 2, 3, and 4 blue sharks were targeted because of market demand. In Phase 1, there was no significant difference in the number of blue sharks caught on the non-offset J hook compared with the 16/0 circle hook (Friedman rank sum test with set as blocking variable and hook type as treatment variable, $p = 0.26$), but the offset J hook caught significantly fewer blue sharks (Friedman rank sum test, $p < 0.001$). In Phase 2, there was no significant difference in the number of blue sharks caught between the 16/0 and 18/0 circle hooks (Friedman rank sum test, $p = 0.43$), but unlike the results from Phase 1, the non-offset J hook caught significantly fewer blue sharks than the circle hooks (Friedman rank sum test, $p < 0.001$). In Phase 3, there was a significant difference in the number of blue sharks caught among the 3 hook types (Friedman rank sum test, $p = 0.0001$). In Phase 4A, there was a significant difference in the number of blue sharks caught among the 3 hook types (Friedman rank sum test, $p = 0.0008$). In Phase 4A and 4B combined, there was no significant difference in the number of blue sharks caught between the 16/0 and 18/0 circle hooks (Friedman rank sum test, $p = 0.81$).

CONCLUSIONS:

- Experiments can be conducted successfully in the Azores with the commercial fleet, and the results can be exported to other regions and ocean basins.

- High turtle bycatch rate in the waters around the Azores allows for a rigorous experimental design and statistical analyses.

- The size ranges of turtles caught in the longline fishery in the waters around the Azores are the size/age classes that recruit to the neritic foraging grounds of the western Atlantic. High mortality in these age classes as a result of longline bycatch will result in reduced recruitment to the western Atlantic nesting beaches and may be contributing to the apparent, recent population decline seen at these nesting beaches.

- Use of circle hooks significantly decreased the rate of throat hooking in loggerhead turtles. This result has important implications for reduced sea turtle mortality.

- Results from Phases 1 and 2 are not consistent with respect to blue shark catch on J hooks compared to circle hooks. The possible increase of blue shark catch with circle hooks compared with J style hooks needs further investigation, not only for blue sharks, but also for other shark species including threatened and endangered shark populations so that they are not further jeopardized through increased bycatch rates. In Phases 2 and 4, there was no difference in the number of blue sharks caught on 16/0 circle hooks vs. 18/0 circle hooks.

- Hour of day of longline retrieval had a significant effect on the rate of loggerhead turtles caught. Therefore, retrieval of the longline earlier in the day would reduce the interaction with loggerhead turtles.

- Turtles are not uniformly distributed throughout the fishing area. Therefore, when turtles are caught during fishing, fishing vessels could move to another location to reduce the probability of catching turtles.

- Gear modification has excellent potential to reduce sea turtle interaction and bycatch.

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LITERATURE CITED:

Balazs, G.H. and S.G. Pooley (editors). 1994. Research plan to assess marine turtle hooking mortality: results of an expert workshop held in Honolulu, Hawaii, November 16-18, 1993. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-201. 166 pages.

Bjorndal, K.A., A.B. Bolten, T. Dellinger, C. Delgado, and H.R. Martins. 2003. Compensatory growth in oceanic loggerhead sea turtles: response to a stochastic environment. Ecology 84:1237-1249.

Bjorndal, K. A., A. B. Bolten, B. Koike, B. A. Schroeder, D. J. Shaver, W. G. Teas, and W. N. Witzell. 2001. Somatic growth function for immature loggerhead sea turtles in southeastern U.S. waters. Fishery Bulletin 99:240-246.

Bjorndal, K. A., A. B. Bolten, and H. R. Martins. 2000. Somatic growth model of juvenile loggerhead sea turtles *Caretta caretta*: duration of pelagic stage. Marine Ecology Progress Series 202:265-272.

Bolten, A.B. 2003. Active swimmers – passive drifters: the oceanic juvenile stage of loggerheads in the Atlantic system. Pages 63-78 in A.B. Bolten and B.E. Witherington (editors), Loggerhead Sea Turtles. Smithsonian Institution Press, Washington, D.C.

Bolten, A.B., K.A. Bjorndal, H.R. Martins, T. Dellinger, M.J. Biscoito, S.E. Encalada, and B.W. Bowen. 1998. Transatlantic developmental migrations of loggerhead sea turtles demonstrated by mtDNA sequence analysis. Ecological Applications 8:1-7.

Bolten, A.B., K.A. Bjorndal, and H.R. Martins. 1994. Life history model for the loggerhead sea turtle (*Caretta caretta*) population in the Atlantic: Potential impacts of a longline fishery. Pages 48-54 in G.H. Balazs and S.G. Pooley (eds.), Research Plan to Assess Marine Turtle Hooking Mortality: Results of an Expert Workshop Held in Honolulu, Hawaii, November 16-18, 1993. NOAA Technical Memorandum NMFS-SWFSC-201.

Bolten, A.B., H.R. Martins, and K.A. Bjorndal (editors). 2000. Workshop to design an experiment to determine the effects of longline gear modification on sea turtle bycatch rates, 2-4 September 1998, Horta, Azores, Portugal. NOAA Technical Memorandum NMFS-OPR-19. 50 pages.

Bolten, A.B., J.A. Wetherall, G.H. Balazs, and S.G. Pooley (compilers). 1996. Status of marine turtles in the Pacific Ocean relevant to incidental take in the Hawaii-based pelagic longline fishery. NOAA Technical Memorandum. NOAA-TM-NMFS-SWFSC-230. 167 pages.

Ferreira, R.L., H.R. Martins, A.A. da Silva, and A.B. Bolten. 2001. Impact of swordfish fisheries on sea turtles in the Azores. Arquipélago 18A:75-79.

Long, K.J. and B.A. Schroeder (editors). 2004. Proceedings of the international technical expert workshop on marine turtle bycatch in longline fisheries. NOAA Technical Memorandum. NMFS-F/OPR-26. 189 pages.

Williams, P., P.J. Anninos, P.T. Plotkin, and K.L. Salvini (compilers). 1996. Pelagic longline fishery-sea turtle interactions: Proceedings of an industry, academic and government experts, and stakeholders workshop held in Silver Spring, Maryland, 24-25 May 1994. NOAA Technical Memorandum. NMFS-OPR-7. 77 pages.

Table 1: The effect of hook type on the numbers of loggerhead turtles caught. For Phases 1, 2, and 3, there was no significant difference among the 3 hook types within each year in the number of loggerheads caught (exact binomial tests, $p > 0.05$). For Phase 4A, the Japanese tuna hook caught significantly more turtles comparing among all 3 hook types (Friedman rank sum test with set as blocking variable and hook type as treatment variable, Friedman chi-square = 19.38, df = 2, $p = 0.0001$). Fewer turtles were caught with the 18/0 circle hook compared with the 16/0 circle hook for the 73 sets of Phases 4A and 4B combined (Friedman chi-square = 4.8, df = 1, $p = 0.029$).

Hook Type	**Phase 1 (year 2000) 93 sets 138,121 hooks**	**Phase 2 (year 2001) 60 sets 88,150 hooks**	**Phase 3 (year 2002) 48 sets 75,511 hooks**	**Phase 4A (year 2003) 27 sets 40,838 hooks**	**Phase 4B (year 2003) 46 sets 73,579 hooks**
Straight J 9/0 (Mustad #76800)	84	14	---	---	---
Offset J 9/0 (Mustad #76801)	63	---	---	---	---
Circle 16/0 (Mustad #39960)	85	21	8	26	23
Circle 18/0 (Mustad #39960)	---	9	---	---	---
Circle 16/0 offset (Mustad #39966)	---	---	6	---	---
Circle 18/0 offset (Lindgren-Pitman)	---	---	4	---	---
Circle 18/0 (Lindgren-Pitman)	---	---	---	16	15
Japanese tuna hook 3.6mm (OPI023)	---	---	---	62	---
Total	232	44	18	104	38

Table 2: The CPUE of loggerheads per 1000 hooks for each hook type.

Hook Type	Phase 1 (year 2000)	Phase 2 (year 2001)	Phase 3 (year 2002)	Phase 4A (year 2003)	Phase 4B (year 2003)
Straight J 9/0 (Mustad #76800)	1.82	0.48	---	---	---
Offset J 9/0 (Mustad #76801)	1.37	---	---	---	---
Circle 16/0 (Mustad #39960)	1.85	0.71	0.32	1.91	0.63
Circle 18/0 (Mustad #39960)	---	0.31	---	---	---
Circle 16/0 offset (Mustad #39966)	---	---	0.24	---	---
Circle 18/0 offset (Lindgren-Pitman)	---	---	0.16	---	---
Circle 18/0 (Lindgren-Pitman)	---	---	---	1.18	0.41
Japanese tuna hook 3.6mm (OPI023)	---	---	---	4.55	---

Table 3: The effect of hook type on the location of the hook in the captured loggerhead turtles; data for Phases 1, 2, 3, 4 are combined. J style hooks (rows 1 and 2) had a significantly higher rate of throat capture compared with circle hooks (rows 3, 4, 5, 6, and 7) (Chi-square = 75.6, df = 1, $p < 0.0001$); 60% of the loggerheads ingesting J style hooks were hooked in the throat compared with 13% of the loggerheads ingesting circle hooks. Japanese tuna hooks (row 8) had a significantly higher rate of throat capture compared with circle hooks (rows 3, 4, 5, 6, and 7) (Chi-square = 38.8, df = 1, $p < 0.0001$); 52% of the loggerheads ingesting Japanese tuna hooks were hooked in the throat compared with 13% of the loggerheads ingesting circle hooks.

Hook Type	External	Mouth	Throat	Total
Straight J 9/0 (Mustad #76800)	12	**34**	**51**	97
Offset J 9/0 (Mustad #76801)	14	**20**	**29**	63
Circle 16/0 (Mustad #39960)	17	**129**	**17**	163
Circle 18/0 (Mustad #39960)	3	**6**	**0**	9
Circle 16/0 offset (Mustad #39966)	2	**3**	**1**	6
Circle 18/0 offset (Lindgren-Pitman)	0	**2**	**2**	4
Circle 18/0 (Lindgren-Pitman)	5	**22**	**4**	31
Japanese tuna hook 3.6mm (OPI023)	0	**29**	**32**	61

Table 4: Effect of hook position between the buoys on loggerhead capture rates. For Phases 1 and 2, the position of the 8 hooks between each buoy were scored as: 1, 2, 3, 4, 4, 3, 2, 1; where position 1 was nearest the buoy. For Phases 3 and 4, the position of the 4 hooks between each buoy was scored as 1, 2, 2, 1, where position 1 was nearest the buoy. The effect of hook position was not significant (exact binomial tests, $p > 0.05$) in Phases 1, 2, 3, or 4.

Hook Position	Phase 1 Number of Loggerheads	Phase 2 Number of Loggerheads	Phase 3 Number of Loggerheads	Phase 4A Number of Loggerheads	Phase 4B Number of Loggerheads
1	65	10	10	51	17
2	50	12	8	51	21
3	53	13	---	---	---
4	55	5	---	---	---

Table 5: The numbers of swordfish caught by year and by hook type.

Hook Type	**Phase 1 (year 2000) 93 sets 138,121 hooks**	**Phase 2 (year 2001) 60 sets 88,150 hooks**	**Phase 3 (year 2002) 48 sets 75,511 hooks**	**Phase 4A (year 2003) 27 sets 40,838 hooks**	**Phase 4B (year 2003) 46 sets 73,579 hooks**
Straight J 9/0 (Mustad #76800)	382	203	---	---	
Offset J 9/0 (Mustad #76801)	341	---	---	---	
Circle 16/0 (Mustad #39960)	264	220	214	122	311
Circle 18/0 (Mustad #39960)	---	137	---	---	
Circle 16/0 offset (Mustad #39966)	---	---	172	---	
Circle 18/0 offset (Lindgren-Pitman)	---	---	205	---	
Circle 18/0 (Lindgren-Pitman)	---	---	---	90	286
Japanese tuna hook 3.6mm (OPI023)	---	---	---	138	---
Total	987	560	591	350	597

Table 6: Swordfish CPUE per 1000 hooks by year and by hook type.

Hook Type	Phase 1 (year 2000)	Phase 2 (year 2001)	Phase 3 (year 2002)	Phase 4A (year 2003)	Phase 4B (year 2003)
Straight J 9/0 (Mustad #76800)	8.30	6.91	---	---	---
Offset J 9/0 (Mustad #76801)	7.41	---	---	---	---
Circle 16/0 (Mustad #39960)	5.73	7.49	8.50	8.96	8.45
Circle 18/0 (Mustad #39960)	---	4.66	---	---	---
Circle 16/0 offset (Mustad #39966)	---	---	6.83	---	---
Circle 18/0 offset (Lindgren-Pitman)	---	---	8.14	---	---
Circle 18/0 (Lindgren-Pitman)	---	---	---	6.61	7.77
Japanese tuna hook 3.6mm (OPI023)	---	---	---	10.14	---

Table 7: The numbers of blue shark caught by year and by hook type.

Hook Type	**Phase 1 (year 2000) 93 sets 138,121 hooks**	**Phase 2 (year 2001) 60 sets 88,150 hooks**	**Phase 3 (year 2002) 48 sets 75,511 hooks**	**Phase 4A (year 2003) 27 sets 40,838 hooks**	**Phase 4B (year 2003) 46 sets 73,579 hooks**
Straight J 9/0 (Mustad #76800)	733	896	---	---	---
Offset J 9/0 (Mustad #76801)	600	---	---	---	---
Circle 16/0 (Mustad #39960)	796	1619	2403	497	1978
Circle 18/0 (Mustad #39960)	---	1476	---	---	---
Circle 16/0 offset (Mustad #39966)	---	---	1914	---	---
Circle 18/0 offset (Lindgren-Pitman)	---	---	2272	---	---
Circle 18/0 (Lindgren-Pitman)	---	---	---	479	1880
Japanese tuna hook 3.6mm (OPI023)	---	---	---	350	---
Total	2129	3991	6589	1326	3858

Table 8: **B**lue shark CPUE per 1000 hooks by year and by hook type.

Hook Type	Phase 1 (year 2000)	Phase 2 (year 2001)	Phase 3 (year 2002)	Phase 4A (year 2003)	Phase 4B (year 2003)
Straight J 9/0 (Mustad #76800)	15.92	30.49	---	---	---
Offset J 9/0 (Mustad #76801)	13.03	---	---	---	---
Circle 16/0 (Mustad #39960)	17.29	55.10	95.47	36.51	53.77
Circle 18/0 (Mustad #39960)	---	50.23	---	---	---
Circle 16/0 offset (Mustad #39966)	---	---	76.04	---	---
Circle 18/0 offset (Lindgren-Pitman)	---	---	90.26	---	---
Circle 18/0 (Lindgren-Pitman)	---	---	---	35.19	51.10
Japanese tuna hook 3.6mm (OPI023)	---	---	---	25.71	---

Figure 1: Size-frequency distributions of oceanic-stage loggerheads captured in waters around the Azores (left-hand curves, n = 1692) and neritic-stage loggerheads stranded in southeastern USA (right-hand curves, n = 1803) (modified from Bjorndal et al. 2000, 2001). Percentages were calculated for each population. Dashed lines are cubic smoothing splines (df = 15); vertical reference line is at the intersection of the two smooths at 53 cm CCL.

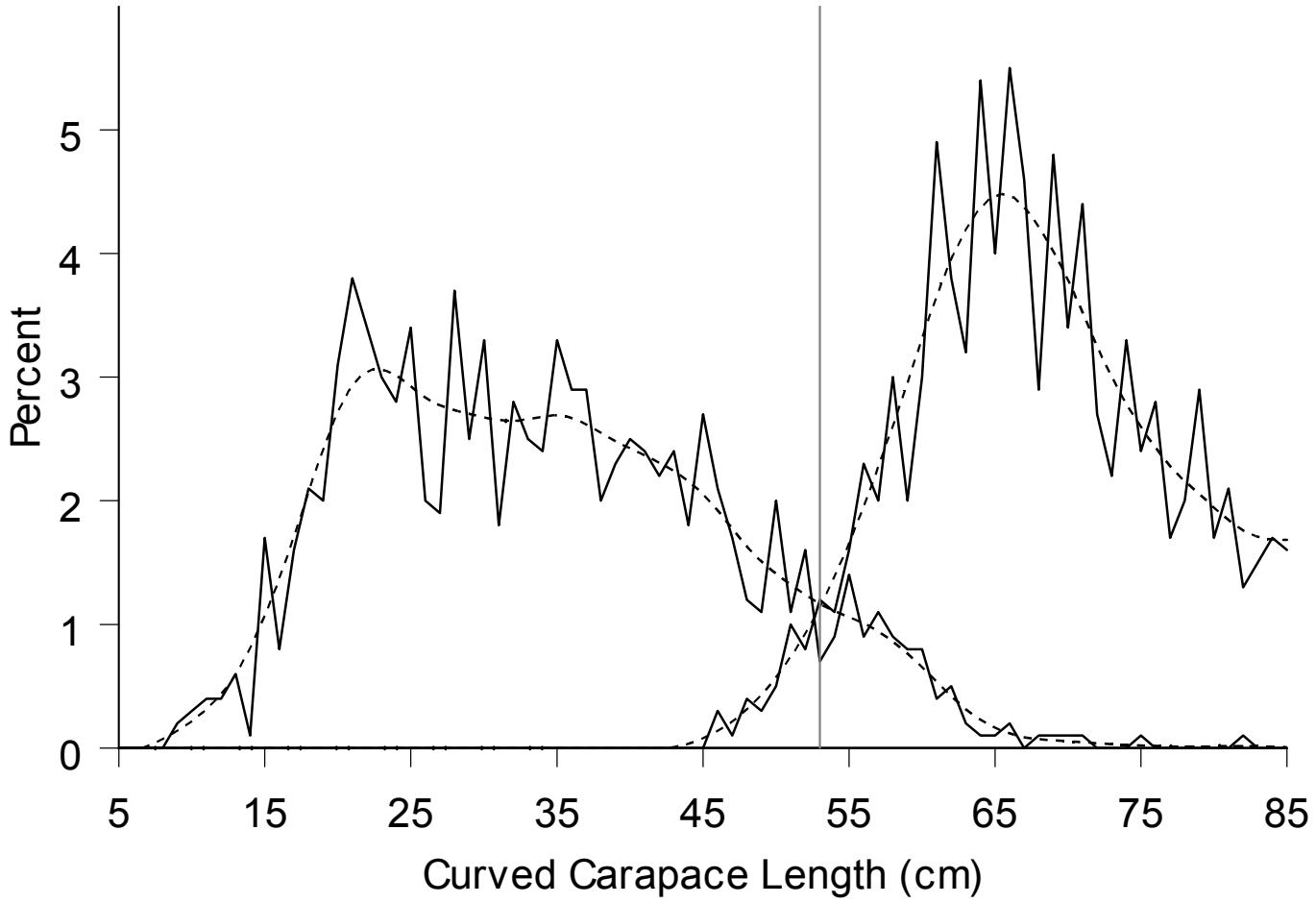

Figure 2: Frequency distributions of the number of turtles caught per set during Phase 1 (open circles), Phase 2 (solid circles), Phase 3 (open triangles), and Phase 4 (solid triangles).

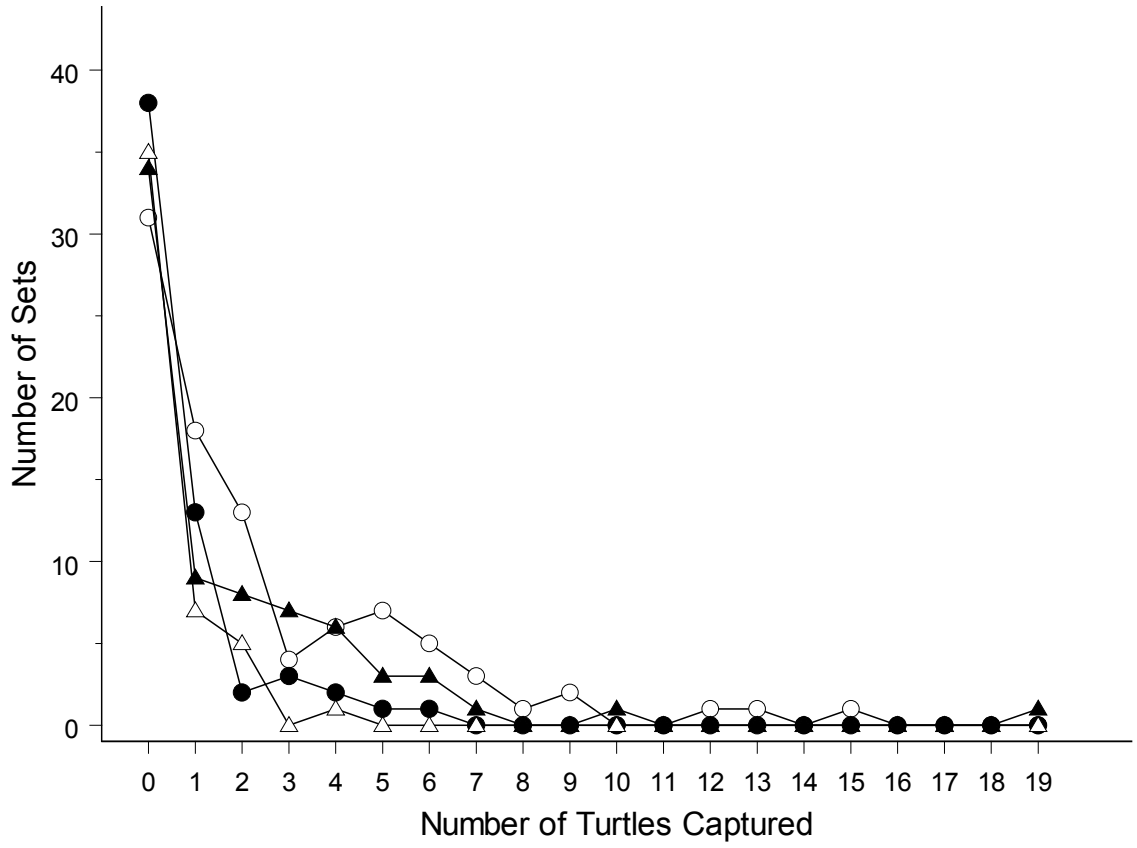

Figure 3: The size distribution of loggerhead turtles caught on the longline fishery in the waters around the Azores during Phases 1, 2, 3, and 4 of the experiment (histogram) compared with the overall size distribution of loggerheads in Azorean waters (left hand curve, see Figure 1). The size distribution of loggerheads caught during Phases 1, 2, 3, and 4 are significantly different (mean = 52.7 cm CCL) than the overall size distribution of loggerheads (left hand curve, mean = 34.5 cm CCL) in Azorean waters (Kolmogorov-Smirnov test, ks = 0.6618, $p < 0.0001$).

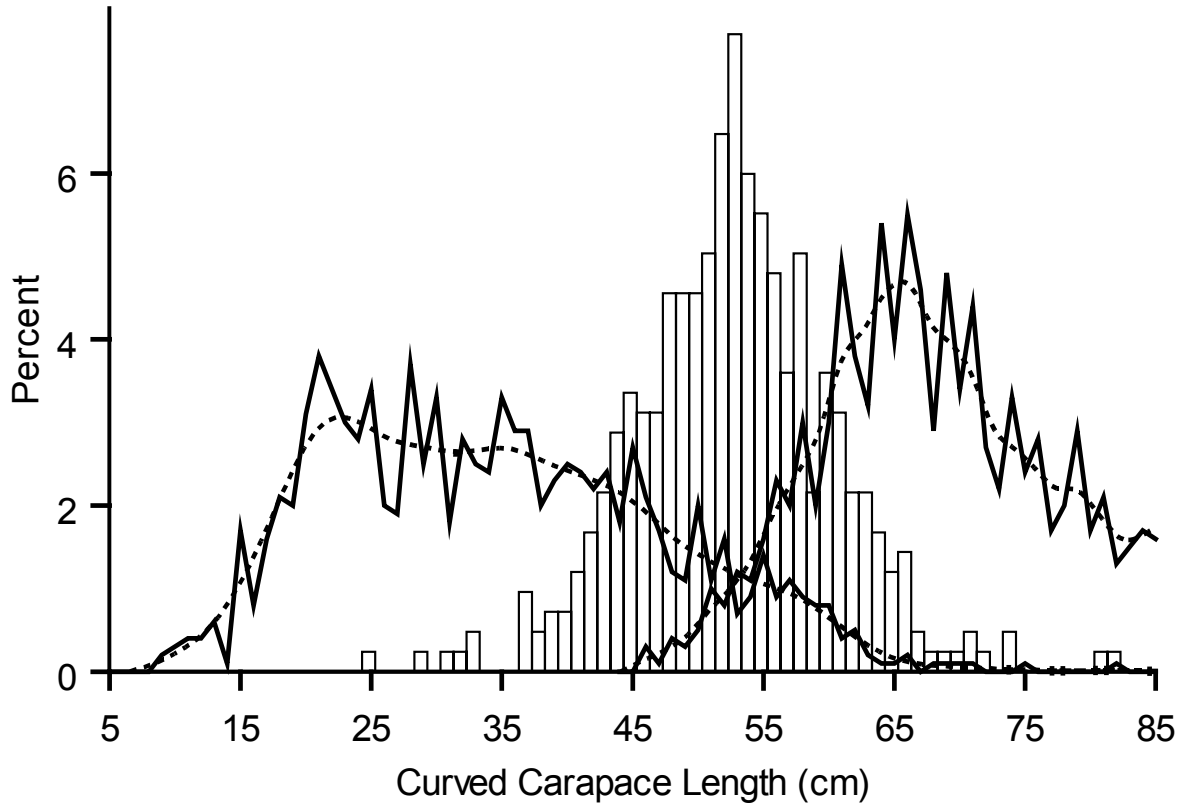

Figure 4: The relationship between both the rate of turtles caught and the rate of fish caught and the hour of day that the longline was retrieved during Phase 1 of the experiment in 2000. The rate of turtles caught increased as the hour of day increased (see Figure 5). The rate of fish caught remained constant as hour of day of line retrieval increased ($p = 0.7$).

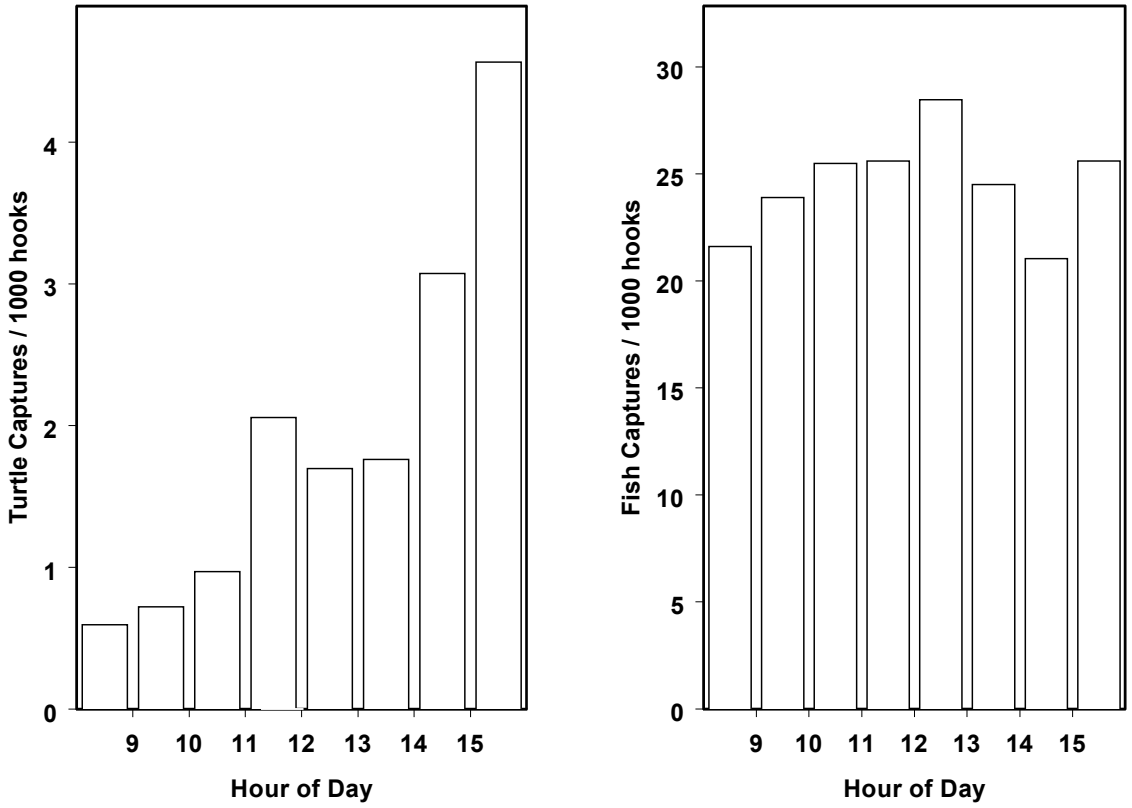

Figure 5: The relationship between the rate of turtles caught and the hour of day that the longline was retrieved during Phase 1 of the experiment in 2000. There was a significant effect in the rate of turtles caught as the hour of day of longline retrieval increased ($r^2 = 0.86$, $p < 0.001$).