NOTES

ANALYSIS OF SEA TURTLE CAPTURES AND MORTALITIES DURING COMMERCIAL SHRIMP TRAWLING

Five species of sea turtles occur in coastal United States waters of the southern North Atlantic and the Gulf of Mexico and are listed and protected under the Endangered Species Act (1973). These are the Kemp's ridley turtle, *Lepidochelys kempi*; hawksbill turtle, *Eretmochelys imbricata*; leatherback turtle, *Dermochelys coriacea*; green turtle, *Chelonia mydas*; and loggerhead turtle, *Caretta caretta*. Each of these species are captured by commercial shrimp trawlers, and these incidental captures have been identified as a source of sea turtle mortalities (Hopkins and Richardson 1984).

Several prior studies have attempted to quantify turtle catch rates and mortalities by trawlers through interviews with vessel captains (Anonymous 1976,[1] 1977[2]; Cox and Mauerman 1976; Rabalais and Rabalais 1980) and through direct observations by observers during commercial shrimp trawling (Hillestad et al. 1978; Ulrich 1978[3]; Roithmayr and Henwood 1982[4]). While these studies provide estimates of capture and mortality rates, more specific information is required to effectively protect the stocks. In particular, managers need to know when and where turtle captures occur, which species are impacted, at what depths the majority of captures occur, and how many turtles are captured and killed.

This report provides a preliminary analysis of existing data collected by fisheries observers during commercial U.S. shrimp trawling. Data from three National Marine Fisheries Service (NMFS) observer projects were used for analysis of turtle catch per unit effort (CPUE) and mortality rates. A brief description of the projects follow:

1) The sea turtle incidental catch and mortality project was instituted to provide information on the incidental capture and associated mortality of sea turtles off the southeastern United States. Trained fishery observers were placed aboard commercial shrimp vessels operating on the major grounds in the Gulf of Mexico and southern North Atlantic from 1979 through 1981.
2) The goal of the excluder trawl project was to design an apparatus for use with existing shrimping gear which would effectively prevent the incidental capture of sea turtles. Initial design and testing of prototype models were conducted during 1977, and field trials were continued through 1984. Fishery observers aboard cooperative and chartered shrimp trawlers began data collection in 1978. Data collection procedures were similar to those of the incidental catch project except that data records were maintained for each net. In this manner, the performance of excluder nets could be compared with that of standard trawls.
3) The objectives of the shrimp fleet discards project were to estimate the magnitude and species composition of incidental fish captures by the Gulf shrimp fleet. Data were collected through contractual arrangements with state agencies from 1973 through 1978. These agencies placed observers on commercial vessels to obtain at-sea sampling off their respective coasts. Data records similar to those of the other two projects were completed for each tow.

In estimating turtle CPUE and mortalities by species, we restricted our analyses to loggerhead, Kemp's ridley, and green turtles. Leatherback and hawksbill turtles were also captured in shrimp trawls, but the infrequency of captures made predictions of CPUE for these species imprecise. In predictions of CPUE for all species combined, these capture records were included.

Data Analyses

For estimations of turtle CPUE and mortalities, the three observer projects were merged. For each data set, effort (E) was standardized to re-

[1]Anonymous. 1976. Incidental capture of sea turtles by shrimp fishermen in Florida. Preliminary report of the Florida West Coast Survey, University of Florida Marine Advisory Program, 3 p.
[2]Anonymous. 1977. Alabama shrimp fishermen interviews for 1977-1978. Marine Resources Office, Alabama Cooperative Extension Service, 1 p.
[3]Ulrich, G. F. 1978. Incidental catch of loggerhead turtles by South Carolina commercial fisheries. Report of the National Marine Fisheries Service, Contract No. 03-7-042-35151, 33 p.
[4]Roithmayr, C., and T. Henwood. 1982. Incidental catch and mortality report. Final report to Southeast Fisheries Center, National Marine Fisheries Service, NOAA, 75 Virginia Beach Drive, Miami, FL 33149, 20 p.

flect hours towed with a single, 30.5 m headrope length net using the formula

$$E = (\text{nets} * \text{length} = 30.5 \text{ m}) * (\text{min} = 60)$$

where nets = number of nets towed,
length = headrope length of a net (meters),
min = minutes fished.

Turtle CPUE ($\hat{R}$) and 95% confidence interval (C.I.) were calculated according to methods described in Snedecor and Cochran (1967) using the formulae

$$\hat{R} = \sum_{i=1}^{n} T_i \Big/ \sum_{i=1}^{n} E_i$$

$$95\% \text{ C.I. on } R = \hat{R} + 1.96\,(1/\bar{E})\sqrt{\sum_{i=1}^{n} (T_i - RE_i)^2/n(n-1)}$$

where R = CPUE (turtles/30.5 m net hour),
$\hat{R}$ = estimated CPUE,
T_i = number of individuals (turtles),
E_i = effort (30.5 m net hour),
n = sample size (number of tows).

The data were stratified by species, season, depth, and statistical zone (corresponding to those used by NMFS for reporting shrimp landings). For each zone, turtle CPUE, mean depth of capture, mean length of tow, and mortality were computed. In summarizing the data, the Gulf of Mexico was subdivided into eastern (NMFS statistical zones 1-7, corresponding to the Florida west coast excluding the panhandle), central (NMFS statistical zones 8-17, corresponding to the Florida panhandle through Louisiana), and western (NMFS statistical zones 18-21, corresponding to the Texas coast) areas. The southern North Atlantic area included the east coast of the United States from Florida to North Carolina, statistical zones 24-33. Part of zone 28, the Cape Canaveral ship channel and adjacent shrimping grounds (lat. 28°15′N to 28°30′N) was excluded to avoid positively biasing CPUE estimates. This habitat harbors large concentrations of turtles throughout the year, and high turtle catch rates (0.3643 ± 0.0045 turtles/hour)[5] do not reflect those occurring on the shrimping grounds outside the Canaveral area. Exclusion of these data is not expected to cause an underestimate of mortalities for the southern North Atlantic because commercial shrimping effort near Cape Canaveral is restricted to three or four vessels during most of the year.

Estimates of shrimp fishing effort for the offshore Gulf of Mexico shrimp fishery were obtained from the NMFS Galveston Laboratory (E. Klima[6]). The shrimp fishing effort was corrected for relative amounts of effort by single rigged, double rigged, and quad rigged vessels and then standardized to 30.5 m net hours. The Atlantic shrimp fishing effort was based on an effort estimate developed in 1983 (Anonymous 1983[7]). Because the data were being updated, more current Atlantic shrimp fishing effort data will be available at a later time.

Percent mortality of the total catch was estimated by a least squares linear regression using percent mortality as dependent upon minutes fished which yielded the relationship of $Y = 0.00165X - 0.03$. The average mortality over 30-min increments of tow length was calculated, and 10 unweighted means were regressed on minutes fished. Although this approach may violate the assumption of homogeneity in regression, it was assumed to be the most appropriate means of describing this relationship, since the dependence of mortality on tow time is strongly statistically significant ($r = 0.98$; $P < 0.001$). Percent mortality was multiplied by turtle captures ±95% upper and lower confidence bounds of turtle captures to estimate the number of turtles killed.

Results and Discussion

Turtle captures and mortality by statistical zone and season with associated trawling effort data were analyzed. While the total observer effort in the Gulf of Mexico (16,771 hours) was greater than the southern North Atlantic (9,943 hours), 482 turtles were captured in the southern North Atlantic and only 52 were captured in the

[5]Means ± the 95% confidence interval will be used throughout the paper.

[6]E. Klima, Southeast Fisheries Center Galveston Laboratory, National Marine Fisheries Service, NOAA, 4700 Avenue U, Galveston, TX 77550, pers. commun. Summer 1986.

[7]Anonymous. 1983. Environmental assessment of a program to reduce the incidental take of sea turtles by the commercial shrimp fishery in the southeast United States. U.S. Department of Commerce, National Marine Fisheries Service, 9450 Koger Blvd., St. Petersburg, FL 33702.

Gulf of Mexico (Table 1). This indicates that per unit effort, 16 turtles were captured in the Atlantic for every one turtle captured in the Gulf.

An attempt was made to compare mean depth and duration of tow for turtle captures with the mean depth and duration of tow for all effort by area with and without turtle captures. The mean depth of fishing and mean length of tow were computed from effort data for each statistical zone and for tows in which loggerhead, Kemp's ridley, or green turtles were captured. In most cases (particularly the Gulf of Mexico) sample sizes were small, and no patterns or consistency were evident. We suggest that despite some apparent statistical differences which we attribute to small sample sizes, average depth and tow duration of turtle captures were probably not different from that of the effort.

Summary information on observer effort, CPUE, shrimping effort, estimated captures, and estimated mortality in the Gulf of Mexico and southern North Atlantic are presented for loggerhead, Kemp's ridley, and green turtles (Table 1). Estimated CPUE for all turtles in the Gulf of Mexico (zones 1-21) was 0.0031 ± 0.0008 turtles/net hour, and CPUE for the southern North Atlantic (zones 24-33) was 0.0487 ± 0.0041 turtles/net hour.

The calculation of estimated mortality used minutes fished as a means of estimating the percent of the turtles captured that are killed. Based on mean tow times from our effort data, the overall mortality rate for the Gulf of Mexico is 29%. The eastern Gulf mortality rate is 34%, the central Gulf rate is 22%, and the western Gulf rate is 38%. For the Atlantic coast, the rate is 21% reflecting the shorter average duration of trawl tows on this coast.

The mortality rates based on minutes fished do not distinguish among species. This is because of the small numbers of captures for species other than loggerhead turtles. If there are differences in the ability of the other turtle species to survive long periods of immersion and the stress involved in being captured in a trawl, the differences are not measurable from these data.

In using minutes fished to estimate mortality, the data did not conform to expected models over the range of our observations. In tows of <60-min duration, mortality rates were <1% suggesting that the logistic model might be most appropriate to describe the relationship. However, of logistic, 2d and 3d order polynomial and linear models, the best fit over the range of tow times observed in these studies was provided by the linear model. In tows of <60-min duration and in tows longer than 360 minutes, the linear model is probably inappropriate; mortality is negligible in very

TABLE 1.—Observer effort, turtle captures, CPUE, shrimping effort, estimated captures and estimated mortality of loggerhead, Kemp's ridley, and green turtles in the Gulf of Mexico and the southern North Atlantic.

Area	NMFS observer effort (net hours)	Number of turtles	CPUE + 95% C.I. on CPUE (turtles/net hour)	Annual shrimping effort (net hours)[1]	Estimated captures (turtles/yr)	Estimated mortality (turtles/yr)
Loggerhead turtles, *Caretta caretta*						
Atlantic	9,943	453	0.0456 ± 0.0039	704,376	32,120 ± 2,747	6,745 ± 577
Gulf of Mexico						
eastern	2,589	12	0.0046 ± 0.0026	611,530	2,813 ± 1,590	956 ± 541
central	6,353	14	0.0022 ± 0.0012	2,391,498	5,261 ± 2,870	1,157 ± 631
western	7,829	16	0.0020 ± 0.0010	1,312,670	2,625 ± 1,313	998 ± 499
overall	16,771	42	0.0025 ± 0.0008	4,315,698	10,789 ± 3,453	3,129 ± 1,001
Kemp's ridley turtles, *Lepidochelys kempi*						
Atlantic	9,943	18	0.0018 ± 0.0008	704,376	1,268 ± 564	266 ± 119
Gulf of Mexico						
eastern	2,589	0	0	611,530	[2]245 ± 245	83 ± 83
central	6,353	2	0.0003 ± 0.0004	2,391,498	717 ± 957	158 ± 210
western	7,829	4	0.0005 ± 0.0005	1,312,670	656 ± 656	249 ± 249
overall	16,771	6	0.0004 ± 0.0004	4,315,698	1,726 ± 1,726	501 ± 501
Green turtle, *Chelonia mydas*						
Atlantic	9,943	7	0.0007 ± 0.0003	704,376	493 ± 211	104 ± 44
Gulf of Mexico						
eastern	2,589	0	0	611,530	[2]61 ± 122	21 ± 41
central	6,353	2	0.0003 ± 0.0003	2,391,498	717 ± 717	158 ± 158
western	7,829	0	0	1,312,670	[2]131 ± 262	50 ± 100
overall	16,771	2	0.0001 ± 0.0002	4,315,698	432 ± 863	125 ± 250

[1]Gulf of Mexcio effort estimates provided by NMFS, Galveston Laboratories (E. Klima text footnote 5) and southern North Atlantic effort based on estimates from Anonymous 1983.
[2]Based on CPUE for the overall Gulf of Mexico.

short tows and never reaches 100% because turtles may be captured at any time during the tow and will survive if captured in the latter stages. Tows shorter than 1 hour and longer than 6 hours, however, are relatively uncommon in commercial shrimping operations.

In the southern North Atlantic, the CPUE for all turtles was strongly dependent on depth (Fig. 1). In depths >10 fathoms, turtle captures were rare, even though, based on aerial surveys (Fritts et al. 1983), turtles are distributed well offshore in waters considerably deeper than 10 fathoms. The strong depth dependency of CPUE may reflect the fact that the continental shelf is relatively narrow along the southeastern seaboard, and the fact that most shrimping occurs in waters <10 fathoms. In the Gulf of Mexico, CPUE appeared to be relatively constant over all depths (Fig. 1).

These estimates are conservative because only offshore (outside the barrier islands) effort and turtle captures were considered.

It should be emphasized that trawl related turtle mortalities are not confined to U.S. waters, but occur on a worldwide basis. The same turtle populations impacted in U.S. waters are also impacted in territorial waters of other countries. In the case of the Kemp's ridley which is believed to be equally distributed in United States and Mexican waters, Mexican trawlers may account for mortalities similar to those of U.S. trawlers. To effectively protect sea turtles, international cooperation is essential.

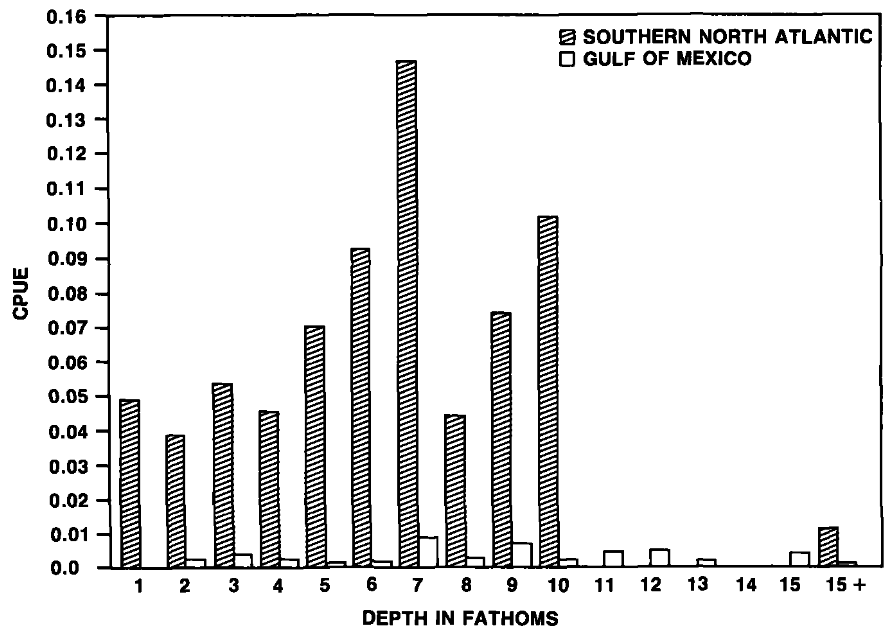

FIGURE 1.—Catch per unit effort (turtles/net hour) as a function of depth for captures in the southern North Atlantic and the Gulf of Mexico.

Conclusions

From our analyses, it is evident that significant numbers of sea turtles are captured by commercial trawlers in both the Gulf of Mexico and the southern North Atlantic, and that over 20% of these turtles are drowned in the trawl. We estimate that 9,874 loggerhead, 767 Kemp's ridley, and 229 green turtles may be killed annually.

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THE RELATIONSHIP BETWEEN LUNAR PHASE AND GULF BUTTERFISH, *PEPRILUS BURTI*, CATCH RATE

Through the joint efforts of Japan and the United States, a research program was conducted in fall 1984 and spring 1985 to identify squid resources in the northern Gulf of Mexico (Grace 1984, 1985). Although large concentrations of squid were not located, commercial quantities of gulf butterfish, *Peprilus burti*, were encountered. Maximum sustainable yield (MSY) estimates from the spring data indicated annual potential catches of 50,000 t with a projected ex-vessel value of $19 million (Gledhill[1]). Although gulf butterfish are sufficiently abundant to support a fishery, critical gaps of information on gulf butterfish distribution and location exist which are needed in order to harvest this resource efficiently. Preliminary data from the U.S.-Japan joint surveys indicated that gulf butterfish catch rates were greatest at bottom temperatures of 15°-19°C. Subsequent scientific and commercial efforts at targeting gulf butterfish based upon bottom temperature have produced catches ranging from few individuals to many tons. In a recent study, we found that fishing success for gulf butterfish was often high for several days followed by periods of low success (Allen et al. 1986). This phenomena parallels catch patterns encountered by east coast gulf butterfish fishermen (Amos[2]), who suggest that lunar phase affects catch rates. We analyzed the effect of lunar phase on catch rates. The purpose of this paper is to present evidence that bottom trawling success for gulf butterfish is related to lunar phase.

Methods

Gulf butterfish catches from the two U.S.-Japanese joint surveys and from an additional gulf butterfish survey conducted by SEAMAP (August 1985) were examined. Initially, catch rates per hour of individual trawls were calculated per calendar day. A lunar day value (1-29) was assigned to each calendar day of trawling during the three cruises. Lunar day 1 was assigned to the third calendar day proceeding the new moon on through day 29 falling on the third calendar day following the last quarter moon phase. Mean catch (kg/hour per lunar day) was then calculated and plotted. Catches from trawled stations outside of the depth range in which gulf butterfish were caught during each trip (i.e., < minimum depth or > maximum depth) were not included when calculating mean catch/hour per lunar day.

The effects of moon phase and trip on natural log catch rates ($\ln(x + 1)$, where x = kg/hour per individual trawl) of gulf butterfish were investigated, using the general linear model (GLM) procedures (SAS) Institute (1982). Type III sums of squares were used for the analysis due to unequal number of observations in each subclass. Each observation from each trip was assigned into a lunar phase period (1-4). Mean catch ($\ln(x + 1)$/hour) and number of trawls sampled during each trip and lunar phase are presented in Table 1. An

[1]Gledhill, C. T. 1985. A preliminary estimate of gulf butterfish (*Peprilus burti*) MSY and economic yield. Unpubl. manuscr., 66 p. Southeast Fisheries Center, Mississippi Laboratories, National Marine Fisheries Service, NOAA, Pascagoula, MS 39568-1207.

[2]Duncan Amos, Georgia Marine Extension Program, P.O. Box Z, Brunswick, GA 31523, pers. commun. July 1986.