Relationship between sea turtle stranding rates and shrimp fishing intensities in the northwestern Gulf of Mexico: 1986–1989 versus 1990–1993

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Abstract.—This paper tested the null hypothesis that the statistical relationship between monthly sea turtle (species combined) stranding rates (strandings per 100 km of accessible shoreline) and monthly shrimp fishing intensities (days fished per 100 km^2) in the northwestern Gulf of Mexico was the same in 1990–93 as in 1986–89. The expectation was that regulations requiring use of turtle excluder devices (TED's) in shrimp trawls during 1990–93 would reduce the incidental catch of sea turtles and thereby diminish or eliminate the statistical relationship between stranding rates and fishing intensities. Significant positive correlations were detected between the log-transformed stranding rates and fishing intensities for shrimping landward of the 20-fathom (36.6-m) contour in 1990–93. The null hypothesis was not rejected; therefore TED regulations did not result in diminishing or eliminating the statistical relationship between sea turtle stranding rates and shrimp fishing intensities in the northwestern Gulf. Various hypotheses were suggested as possible explanations.

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Endangered Species Act amendments of 1988 mandated an independent review of scientific and technical information pertaining to conservation of sea turtles and the causes and significance of turtle mortality, including that caused by commercial trawling (National Research Council, 1990). Incidental capture of sea turtles in shrimp trawls was identified as the most important human-associated source of mortality in juvenile, subadult, and breeding sea turtles in coastal waters. It was concluded that shrimping could be compatible with sea turtle conservation if adequately controlled, especially through mandatory use of turtle excluder devices (TED's) at most places and times of year. Federal regulations requiring use of TED's by offshore (seaward of the COLREG's demarcation line [the boundary used by the U.S. Coast Guard to distinguish inshore from offshore waters]) shrimp trawlers longer than 25 ft were published in 1987 (Federal Register, vol. 52, no. 124, p. 24247–24262, 28 June 1987). These regulations did not require TED's in "try nets" (small trawls towed and retrieved intermittently during shrimping operations to sample abundance of shrimp), and TED's were used only sporadically in the northwestern

Gulf until 1990 (McDonald, 1990; Henwood et al., 1992; Crouse, 1993b; Weber et al.[1]; Crouse et al.[2]). Therefore, 1986–89 can be considered pre-TED years, for the most part. In contrast, 1990–93 were years during which TED regulations were in effect.

Caillouet et al. (1991) examined the statistical relationship between monthly sea turtle stranding rates (species combined) and monthly shrimp fishing intensities in the northwestern Gulf of Mexico during 1986–89. They detected significant statistical relationships between stranding rates and fishing intensities in some offshore depth intervals within 0 to 15 fathoms (fm) (27.4 m) in two geographic zones of the northwestern Gulf: the upper coast defined as shrimp statistical subareas 17–18, and the lower coast defined as subareas 19–21 (Fig. 1; see Kutkuhn, 1962).

In this paper, we used the approach of Caillouet et al. (1991) to determine whether or not the statistical relationships they detected between monthly sea turtle stranding rates and monthly shrimp fishing intensities during 1986–89 continued to exist after TED regulations had been promulgated. We tested the null hypothesis that the statistical relationship between monthly sea turtle stranding rates and fishing intensities in two geographic zones of the northwestern Gulf was the same in 1990–93 as in 1986–89. The expectation was that regulations requiring use of TED's in shrimp trawls during 1990–93 would reduce the incidental catch of sea turtles and thereby diminish or eliminate the statistical relationship between sea turtle stranding rates and fishing intensities.

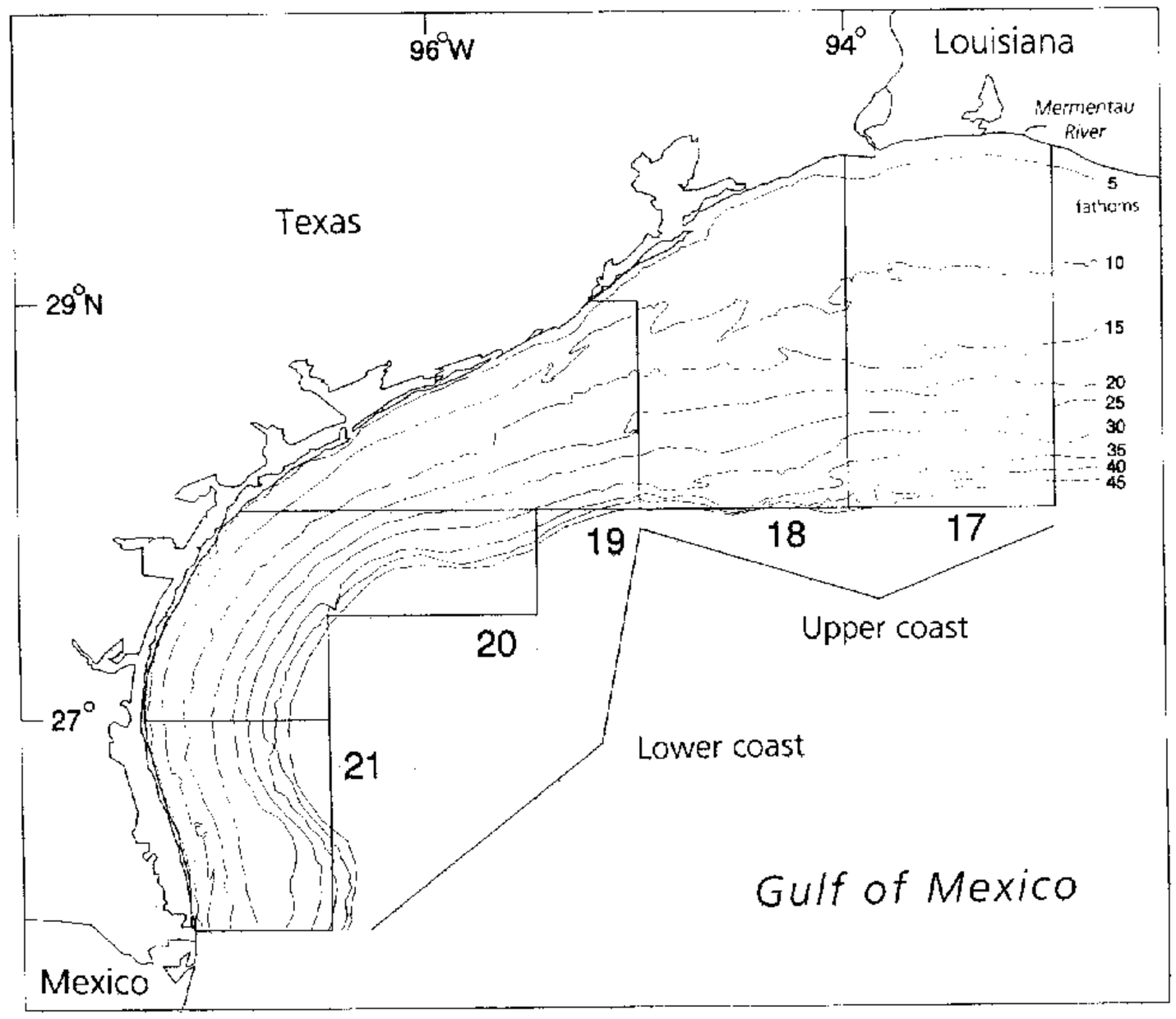

Figure 1

Boundaries of the upper coast (shrimp statistical subareas 17–18) and lower coast (subareas 19–21), and ten depth intervals of the northwestern Gulf of Mexico (see Kutkuhn, 1962; Patella, 1975).

Materials and methods

A data set (subareas 17–21) containing 2,445 sea turtle records was obtained from the Sea Turtle Stranding and Salvage Network (STSSN) headquarters, National Marine Fisheries Service (NMFS) Miami Laboratory, Miami, Florida. It contained records not only of sea turtle strandings but also of turtles caught or entangled in commercial and recreational fishing gears.

Stranded sea turtles, whether live or dead, exhibit no known external or internal signs of capture in shrimp trawls. To our knowledge, only mark-recapture studies have provided direct evidence that some tagged sea turtles captured incidentally in shrimp trawls have become stranded (e.g. Manzella et al., 1988; Fontaine et al., 1989). When examination of stranded sea turtles provides evidence of other causes of death, then capture in shrimp trawls may be ruled out; however, the remaining strandings still lack definite explanation. Strandings that had no explanation were the focus of our analyses.

Prior to our analyses, we deleted 890 records (419 from 1986 to 1989 and 471 from 1990 to 1993) based on codes in data fields named LAT, LONG, NOTE1, NOTE2,... NOTE6, HEADSTART, and TYPEREP (Table 1). The following categories of records were deleted:

[1] Weber, M., D. Crouse, R. Irvin, and S. Indicello. 1995. Delay and denial: a political history of sea turtles and shrimp fishing, 46 p. Center for Marine Conservation, 1725 DeSales St. NW. No. 500, Washington, D.C., 20036.

[2] Crouse, D. T., M. Donnelly, M. J. Bean, A. Clark, W. R. Irvin, and C. E. Williams. 1992. The TED experience: claims and reality, 17 p. A report by the Center for Marine Conservation, Environmental Defense Fund, and National Wildlife Federation. Center for Marine Conservation, 1725 DeSales St. NW, No. 500, Washington, D.C., 20036

Table 1

Frequencies of codes in data fields NOTE1–NOTE6, HEADSTART, TYPEREP, LONG and LAT of records deleted from the STSSN data for shrimp statistical subareas 17–21 and years 1986–93 prior to correlation analyses.[1]

Field	Code	Description	Frequency
NOTE1–NOTE6			
	01	Caught on hook and line	77
	02	Found in dredge hopper	0
	06	Power plant entrapment	3
	08	Cold stun related	69
	11	Entangled in fishing line	13
	13	Entangled in fishing net	4
	15	Found trapped in sunken wreckage	0
	18	Apparent propeller wounds, probably boat strike	53
	22	Caught in shrimp trawl	19
	24	Hook in mouth	17
	28	Entangled in debris, entangled on reef	0
	29	Rope tied to flipper(s) or neck, or both, or to body	13
	36	Emaciated	8
	40	NMFS Galveston Laboratory head-start	261
	41	Nature of wounds suggests entanglement in gill net, net of unknown type, trap line of unknown type, or line of unknown type	2
	43	Nature of wounds suggests bang stick	0
	44	Skull or head only	7
	45	Florida Department of Natural Resources head-start	2
	46	Butchered	6
	48	Entangled in a nonfishing gear medium	17
	51	Caught in a set net	0
	54	Blow to skull	1
	55	Live, adult turtle found flipped on beach	2
	56	Entangled in crab or lobster trap line	0
	58	Caught on trot line	1
	59	Caught in gill net	3
	60	Caught in fish trap	0
	61	Caught in fishing net of unknown type	0
	62	Miami Seaquarium head-start	0
	63	Caught in trawl not targeting shrimp	0
	64	Caught in cast net	0
	65	Catch method unknown	2
	68	Caught in drift net	0
	70	Posthatchling young of the year	165
	73	Nesting female, butchered apparently for eggs	0
	76	Stingray barb embedded in flesh or carapace	0
	80	Nature of wounds suggests crab or lobster trap line entanglement	0
	81	Living tag or apparent living tag noted	42
	82	Spear gun wounds	0
	83	Guts or part(s) only, probable butchering	0
	84	Apparent natural mortality in adult female on a nesting beach	0
	87	Guts or part(s) only, cause unknown	4
	88	Possible boat collision, but not from propeller	1
	90	Constriction wounds or marks on flippers or neck	6
	93	Caught in pound net	0
	95	Monofilament or steel line protruding from mouth or cloaca	1
	96	Probable dredge kill	1
	99	Additional tags applied this capture	0
	AE	Hook in flipper or other soft body part, but not in mouth	7
	AF	Monofilament line found in digestive tract upon necropsy or X-ray	2
	AG	Turtle has tag; number was not recorded	1
	AH	Caught in try net	1
	AI	Fishing hook(s) found in digestive tract upon necropsy or X-ray	9
	AJ	Binary coded internal tag verified	1
	AN	Caught in seine net	1
	AO	Caught in abandoned gear	1
	AP	Entangled in rope (not deliberately tied)	5
	AR	Apparent gaff or hook wounds	0
	AV	Caught on long-line	0
	AX	Found trapped in jetty rocks	2
	AZ	Hatchling found in stomach of predator	1
	BB	TED test turtle (captive-reared)	0
HEADSTART			
	H	Head-started Kemp's ridleys or greens	261
	T	Loggerheads captive-reared for TED certification trials	2
TYPEREP			
	I	Incidental catch or capture	109
LONG		East of longitude 93°07'30"W	8
LAT		South of latitude 26°00'00"N	17

[1] The frequencies in this table represent the number of records bearing a particular code, among the 890 records that were deleted. Therefore, the frequencies do not sum to the total records deleted. Zero frequency indicates that no records containing the code were found among the 2,445 records examined, but it was not known, a priori, that these codes were not represented in the data set.

- turtles that occurred south of subarea 21 (south of latitude 26°00'00"N), because they had been assigned erroneously to subarea 21 (Fig. 1);
- turtles that occurred along the coastline of subarea 17, east of longitude 93°07'30"W, which is near the mouth of the Mermentau River (Fig. 1), because access to it by the STSSN was limited by logistics (Caillouet et al., 1991);
- turtles reported as caught or entangled, either intentionally or incidentally, in commercial (including shrimp trawls) or recreational fishing gears;
- head-started turtles (identified by tags; see

Fontaine et al., 1993), because their temporal-spatial distribution was determined in part by when and where they were released (Manzella et al., 1988; Caillouet et al., 1995);
- small, pelagic-stage turtles, because they were not considered vulnerable to incidental capture in trawls;
- strandings for which likely or possible causes had been assigned.

In some cases, particular codes that defined records to be deleted did not occur among the 2,445 records examined (i.e. they had zero frequency, Table 1), but this was not known a priori. The 1,555 records (937 from 1986–89 and 618 from 1990–93) retained for analysis represented strandings of wild sea turtles for which no known or likely cause of mortality had been assigned. As a consequence of more stringent deletion criteria, our re-analyses for 1986–89 were based on 111 fewer sea turtle records than were the analyses of Caillouet et al. (1991).

For each year, monthly sea turtle strandings (species combined, including those identified to species as well as those not identified to species) were summed over subareas within the upper and lower coasts. This produced 96 observations of monthly sea turtle strandings (2 geographic zones × 4 years × 12 months). Each observation was standardized to S, the monthly number of strandings per 100 km of accessible shoreline bordering the Gulf, which was a measure of sea turtle stranding rate.

A set of offshore, monthly shrimp fishing effort (days fished) data for subareas 17–21 during 1986–93 was obtained from the NMFS Galveston Laboratory (Patella[3]). It was not possible to partition shrimp fishing effort within subarea 17 into portions east and west of longitude 93°07'30"W; therefore the eastern boundary of subarea 17 (Fig. 1) marked the eastern boundary of the upper coast in regard to fishing effort. The total fishing effort at depths seaward of 30 fm (54.9 m) represented less than 8% of the total fishing effort in 1986–89 and 1990–93 on the upper and lower coasts (Table 2), but we included depth intervals seaward of 30 fm for comparison with shallower intervals. For 1986–89 and 1990–93, monthly fishing effort was summed over subareas within the upper and lower coasts, by depth interval (0–5, 5–10, ... >45 fathoms; see Kutkuhn, 1962; Patella, 1975). This produced 960 observations of monthly fishing effort (2 geographic zones × 10 depth intervals × 4 years × 12 months). Each observation was standardized to E, the monthly fishing effort per 100 km^2, which was a measure of fishing intensity.

[3] Patella, F. 1994. Galveston Laboratory, Southeast Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 4700 Ave. U, Galveston, TX 77551-5997. Personal commun.

Table 2

Percentage of shrimp fishing effort (days fished), total shrimp fishing effort, total catch (pounds of shrimp tails), and pounds caught per unit fishing effort on the upper and lower coasts of the northwestern Gulf of Mexico in 1986–89 and 1990–93, by depth interval.[1]

Depth interval		1986–89		1990–93	
(fm)	(m)	Upper Coast[2]	Lower Coast[3]	Upper Coast[2]	Lower Coast[3]
0–5	0.0–9.1	28.3	5.1	21.4	3.3
5–10	9.1–18.3	27.1	13.2	33.9	11.5
10–15	18.3–27.4	16.2	20.4	6.2	23.5
15–20	27.4–36.6	9.8	25.5	24.9	22.9
20–25	36.6–45.7	6.6	17.9	4.8	16.8
25–30	45.7–54.9	5.7	10.0	6.8	14.8
30–35	54.9–64.0	4.4	5.5	1.4	5.6
35–40	64.0–73.2	1.6	1.9	0.4	1.3
40–45	73.2–82.3	0.3	0.4	0.2	0.3
>45	>82.3	0.1	0.1	0.1	0.0
Total fishing effort		150,229	225,427	144,734	210,710
Total pounds caught		75,346,306	103,309,240	65,789,423	108,365,720
Pounds per unit fishing effort		502	458	455	514

[1] Based on data provided by Frank Patella (see Footnote 3 in the text).
[2] Shrimp statistical subareas 17 and 18 (Fig. 1; see Kutkuhn, 1962).
[3] Shrimp statistical subareas 19–21 (Fig. 1; see Kutkuhn, 1962).

Because some observations of S and E were equal to 0 and the data required logarithmic transformation to assure bivariate normality for correlation analyses, 1 was added to all observations of S and E. Tables 3 and 4 show that $\ln(S + 1)$ and $\ln(E + 1)$ had lower coefficients of skewness and kurtosis (both approaching zero) than did S and E, indicating that the log-transformed variables approached normality, whereas the nontransformed variables were not normally distributed.

Forty product-moment correlations (2 periods × 2 geographic zones × 10 depth intervals) between the paired variables $\ln(S + 1)$ and $\ln(E + 1)$ were calculated, each based on 48 observations (12 months × 4 yr) within a depth interval. These correlations were not statistically independent of each other, because each was based on one set of 48 observations of $\ln(S + 1)$ correlated with each of ten sets of 48 observations of $\ln(E + 1)$. Significant, positive correlations detected between $\ln(S + 1)$ and $\ln(E + 1)$ were tested for homogeneity by using chi-square. Finally, 140 product-moment correlations (2 periods × 2 geographic zones × 35 correlations) between pairs of $\ln(E + 1)$ for the ten depth intervals were calculated, each based on 48 observations. These correlations were statistically independent of each other.

Results

Ten significant positive correlations (i.e. correlation coefficients, r, greater than 0 at $P < 0.05$) were detected between the $\ln(S + 1)$ and $\ln(E + 1)$, half of them in 1986–89 (Fig. 2) and the other half in 1990–93 (Fig. 3). These ten correlations involved $\ln(E + 1)$ for some of the depth intervals between 0 and 20 fm

Table 3

Descriptive statistics for S, E, $\ln(S + 1)$, and $\ln(E + 1)$ for the upper and lower coasts of the northwestern Gulf of Mexico during 1986–89.

	S		E		$\ln(S + 1)$		$\ln(E + 1)$	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
n	48	48	480	480	48	48	480	480
Mean	3.98	2.72	9.02	12.51	1.09	1.10	1.57	2.01
Variance	40.62	8.87	340.25	283.53	0.91	0.39	1.32	1.39
Skewness coefficient	2.67	2.27	5.33	4.75	0.72	0.69	0.39	–0.27
Kurtosis coefficient	7.72	5.56	35.50	38.77	–0.27	0.31	–0.25	–0.77
Minimum	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Maximum	30.7	14.4	170.0	197.4	3.46	2.74	5.14	5.29

Table 4

Descriptive statistics for S, E, $\ln(S + 1)$, and $\ln(E + 1)$ for the upper and lower coasts of the northwestern Gulf of Mexico during 1990–93.

	S		E		$\ln(S + 1)$		$\ln(E + 1)$	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
n	48	48	480	480	48	48	480	480
Mean	2.86	1.67	8.06	11.05	1.12	0.84	1.31	1.76
Variance	8.07	2.72	356.92	201.81	0.48	0.26	1.44	1.63
Skewness coefficient	1.47	1.92	5.24	1.76	0.20	0.69	0.81	0.05
Kurtosis coefficient	1.87	4.18	35.38	2.95	–0.80	0.02	–0.03	–1.24
Minimum	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Maximum	11.3	8.1	195.4	77.0	2.51	2.21	5.28	4.36

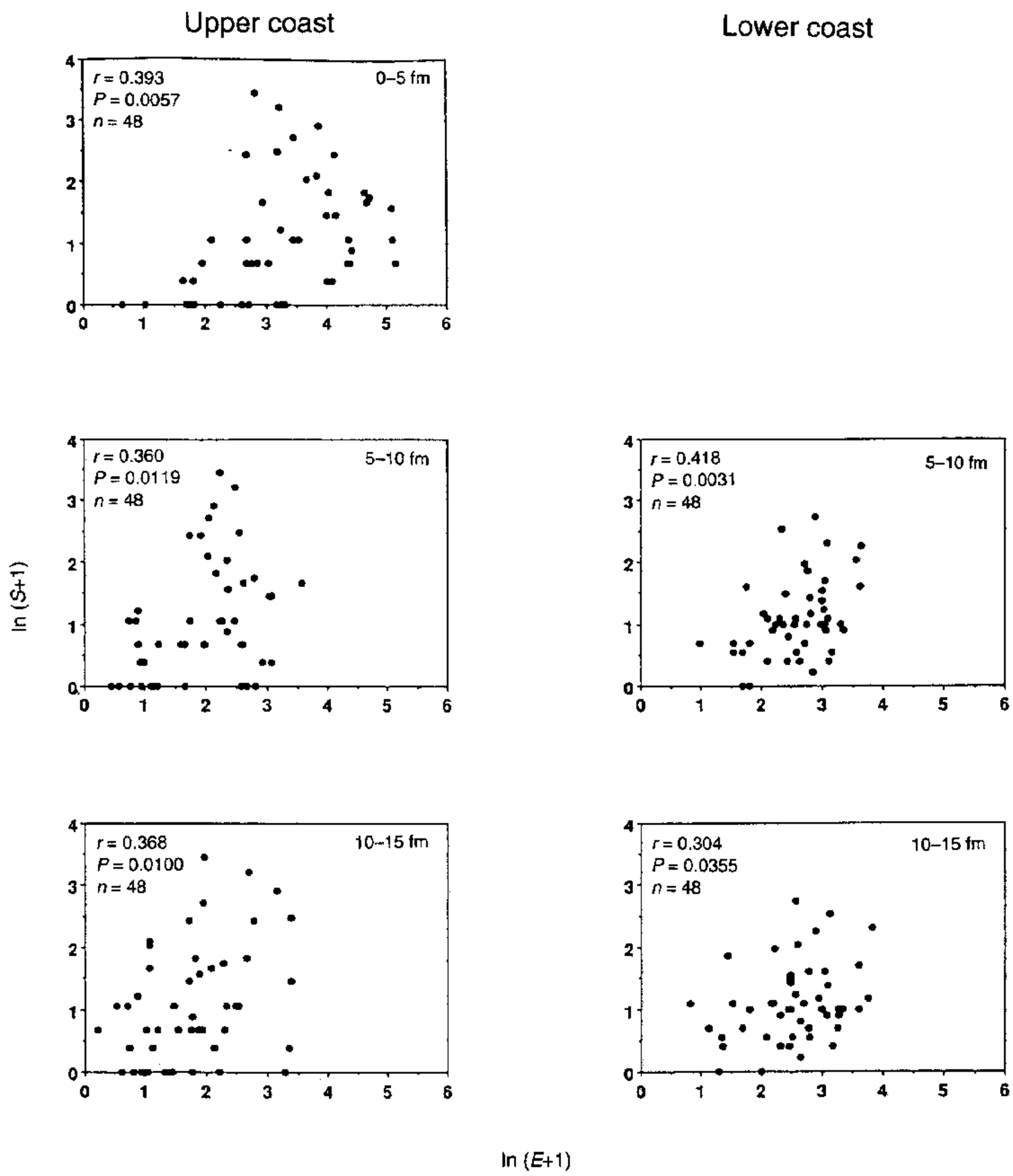

Figure 2

Scatter plots for significant (P<0.05), positive correlations between ln(S + 1) and ln(E + 1) on the upper coast (shrimp statistical subareas 17–18) and lower coast (subareas 19–21) of the northwestern Gulf of Mexico during 1986–89.

(36.6 m), suggesting that sea turtle stranding rates increased as fishing intensities increased in these depth intervals. The null hypothesis of homogeneity among the ten correlations was not rejected (χ^2=9.5, P >0.05), showing that the correlations did not differ significantly from one another. Thus, the null hypothesis that the statistical relationship between monthly sea turtle stranding rates and shrimp fishing intensities in the northwestern Gulf was the same in 1990–93 as in 1986–89 could not be rejected.

Four significant negative correlations between ln(S + 1) and ln(E + 1) were also detected for depth intervals seaward of 20 fm. Two occurred on the upper coast, one in 1986–89 for ln(E + 1) in >45 fm (r=–0.358, P=0.0125), and one in 1990–93 for ln(E + 1) in the 35–40 fm depth interval (r=–0.334, P=0.0203). Two occurred on the lower coast in 1986–89, one for ln(E + 1) in the 20–25 fm depth interval (r=–0.431, P=0.0022), and the other in the 25–30 fm depth interval (r=–0.308, P=0.0332).

A temporal-spatial pattern in monthly fishing intensities was evident from the correlations involving the ln(E + 1) of the ten depth intervals (Tables 5–8). Significant correlations between the ln(E + 1) of adjacent depth intervals tended to be positive, showing that monthly fishing intensities in such depth intervals increased or decreased in synchrony. Conversely, monthly fishing intensities in widely separated depth intervals varied in opposite directions, as indicated by significant negative correla-

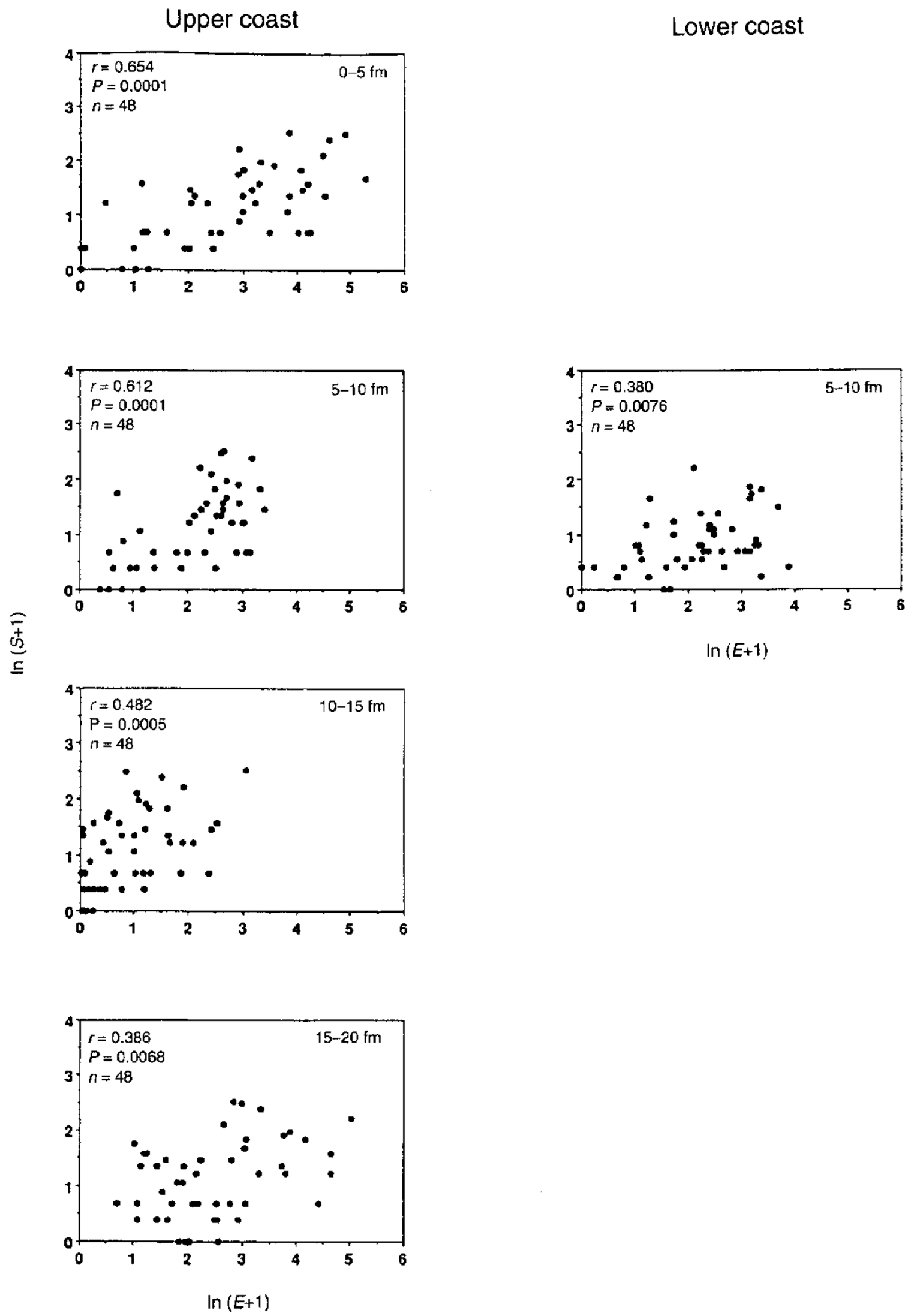

Figure 3

Scatter plots for significant ($P<0.05$), positive correlations between $\ln(S + 1)$ and $\ln(E + 1)$ on the upper coast (shrimp statistical subareas 17–18) and lower coast (subareas 19–21) of the northwestern Gulf of Mexico during 1990–93.

tions. Intermediate depth intervals represented a transition zone, as depicted by a general absence of significant correlations of $\ln(E + 1)$ between these depth intervals and either the shallower or deeper intervals.

In 1986–89 and 1990–93, loggerhead sea turtles, *Caretta caretta,* and Kemp's ridley sea turtles, *Lepidochelys kempii,* occurred most frequently in the strandings, followed by green sea turtles, *Chelonia mydas,* and leatherback sea turtles, *Dermochelys coriacea* (Tables 9 and 10). Strandings of hawksbill sea turtles, *Eretmochelys imbricata,* were equal in number to those of leatherback turtles in 1986–89 (Table 9), but fewer in number than leatherback turtles in 1990–93 (Table 10). Monthly strandings

summed over 1986–89 were highest in April and May (Table 9). Monthly strandings summed over 1990–93 were highest in April and July (Table 10). The total number of strandings decreased from 939 in 1986–89 to 618 in 1990–93.

Discussion

Even though TED regulations were in effect during 1990–93, significant statistical associations continued to exist between sea turtle stranding rates and fishing intensities in some offshore depth intervals within 0 to 20 fm. The 1990–93 period differed somewhat from the 1986–89 period with regard to which depth intervals had significant positive correlations. In 1986–89, significant positive correlations between $\ln(S + 1)$ and $\ln(E + 1)$ were detected on the upper coast only for the 0–5, 5–10, and 10–15 fm depth intervals. However, in 1990–93 on the upper coast, not only were there significant positive correlations for the 0–5, 5–10, and 10–15 fm depth intervals, but also for the 15–20 fm depth interval. On the lower coast, in 1986–89, significant positive correlations occurred between $\ln(S + 1)$ and $\ln(E + 1)$ for the 5–10 and 10–15 fm depth interval, but in 1990–93 only the 5–10 fm depth interval had a significant positive correlation. In addition, the significant positive correlations we detected for the period 1986–89 were somewhat lower (though not significantly) than the comparable ones detected by Caillouet et al. (1991), no doubt the result of excluding 111 more records from the data set, than they did, before conducting our analyses.

Table 5

Correlation coefficients, r, measuring the associations between the $\ln(E + 1)$ of ten depth intervals on the upper coast during 1986–89.

Depth interval	Depth interval (fm) 0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45
5–10	0.723*[1]								
10–15	0.497*	0.678*							
15–20	0.548*	0.508*	0.679*						
20–25	0.312*	0.237	0.447*	0.695*					
25–30	0.165	0.000	0.304*	0.319*	0.645*				
30–35	–0.142	–0.472*	–0.281	–0.217	–0.168	0.510*			
35–40	–0.447*	–0.505*	–0.300*	–0.276	–0.115	0.256	0.433*		
40–45	–0.372*	–0.459*	–0.213	–0.267	0.010	0.148	0.365*	0.491*	
>45	–0.492*	–0.549*	–0.290*	–0.160	–0.025	–0.162	0.154	0.340*	0.588*

[1] An asterisk indicates that the correlation coefficient, r, was significantly different from zero at $P < 0.05$.

Table 6

Correlation coefficients, r, measuring the associations between the $\ln(E + 1)$ of ten depth intervals on the lower coast during 1986–89.

Depth interval	Depth interval (fm) 0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45
5–10	0.151								
10–15	0.175	0.379*[1]							
15–20	0.375*	0.147	0.585*						
20–25	0.271	0.108	0.102	0.718*					
25–30	–0.050	0.281	–0.087	0.260	0.629*				
30–35	–0.176	0.116	–0.316*	–0.200	0.138	0.600*			
35–40	–0.143	–0.016	–0.272	–0.445*	–0.387*	0.100	0.447*		
40–45	–0.162	–0.121	–0.251	–0.373*	–0.460*	–0.112	0.317*	0.662*	
>45	0.031	0.040	–0.132	–0.278	–0.393*	–0.053	0.168	0.460*	0.580*

[1] An asterisk indicates that the correlation coefficient, r, was significantly different from zero at $P < 0.05$.

The statistical relationship between stranding rates and fishing intensities persisted despite our using more stringent criteria than did Caillouet et al. (1991) to exclude from the analyses strandings to which possible causes had been assigned. In the absence of significant heterogeneity among the significant positive correlation coefficients, the null hypothesis could not be rejected. Therefore, there was no significant change in the degree of statistical association between sea turtle stranding rates and fishing intensities for some offshore depth intervals within 0 to 20 fm, despite TED regulations, nor was there a significant difference in the degree of this association between the upper and lower coasts.

In 1990–93, as in 1986–89, there was a significant positive correlation between $\ln(S + 1)$ and $\ln(E + 1)$ within 0–5 fm on the upper coast, but not on the lower coast. Depth increases more rapidly with distance from shore on the lower than on the upper coast (Fig. 1). In addition, shrimp move to deeper waters as they migrate southward along the Texas coast each year, accompanied by a corresponding concentration of the shrimping fleet in areas of shrimp abundance. A smaller percentage of fishing effort occurred in the 0–5 fm depth interval on the lower coast than on the upper coast (Table 2).

The significant negative correlations detected between $\ln(S + 1)$ and $\ln(E + 1)$ for some depth intervals seaward of 20 fm probably resulted from a tendency for fishing effort to be concentrated seasonally within certain depth intervals. The pattern of correlations involving fishing intensities in various

Table 7

Correlation coefficients, r, measuring the associations between the $\ln(E + 1)$ of ten depth intervals on the upper coast during 1990–93.

Depth interval	Depth interval (fm)								
	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45
5–10	0.594*[1]								
10–15	0.393*	0.453*							
15–20	0.299*	0.572*	0.528*						
20–25	0.095	0.165	0.153	0.295*					
25–30	–0.100	0.197	–0.048	0.038	0.629*				
30–35	–0.083	–0.135	–0.201	–0.086	0.289*	0.346*			
35–40	–0.416*	–0.314*	–0.390*	–0.255	0.005	0.209	0.109		
40–45	–0.232	–0.179	–0.433*	–0.136	–0.057	0.052	0.174	0.335*	
>45	–0.049	–0.092	0.225	0.001	0.109	0.238	0.117	0.011	–0.029

[1] An asterisk indicates that the correlation coefficient, r, was significantly different from zero at $P < 0.05$.

Table 8

Correlation coefficients, r, measuring the associations between the $\ln(E + 1)$ of ten depth intervals on the lower coast during 1990–93.

Depth interval	Depth interval (fm)								
	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45
5–10	0.550*[1]								
10–15	0.520*	0.838*							
15–20	0.433*	0.636*	0.667*						
20–25	0.238	0.320*	0.439*	0.796*					
25–30	0.130	0.287*	0.347*	0.604*	0.791*				
30–35	–0.305*	–0.234	–0.096	–0.053	0.082	0.389*			
35–40	–0.330*	–0.129	–0.002	–0.202	–0.129	0.196	0.731*		
40–45	–0.256	–0.210	–0.096	–0.231	–0.269	0.026	0.515*	0.668*	
>45	0.117	0.114	0.085	0.145	0.142	0.229	0.266	0.282	0.165

[1] An asterisk indicates that the correlation coefficient, r, was significantly different from zero at $P < 0.05$.

Table 9

Numbers of sea turtle strandings in the northwestern Gulf of Mexico by species and month, summed over years 1986–89.[1]

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Loggerhead (*Caretta caretta*)	9	9	42	144	94	30	41	34	26	24	17	19	489
Kemp's ridley (*Lepidochelys kempii*)	0	6	32	81	47	37	23	44	23	21	15	10	339
Green (*Chelonia mydas*)	0	0	5	7	6	6	1	1	0	3	1	3	33
Leatherback (*Dermochelys coriacea*)	0	0	0	6	4	3	0	1	0	1	3	0	18
Hawksbill (*Eretmochelys imbricata*)	0	1	2	0	1	3	1	1	3	2	2	2	18
Undetermined	0	0	6	6	2	5	8	3	4	4	0	2	40
Total	9	16	87	244	154	84	74	84	56	55	38	36	937

[1] After some records were deleted (see Table 1).

Table 10

Numbers of sea turtle strandings in the northwestern Gulf of Mexico by species and month, summed over years 1990–93.[1]

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Loggerhead (*Caretta caretta*)	8	11	27	50	16	8	48	30	22	15	16	31	282
Kemp's Ridley (*Lepidochelys kempii*)	5	2	18	38	20	17	44	34	38	22	22	11	271
Green (*Chelonia mydas*)	0	2	4	5	2	1	2	1	3	1	2	1	24
Leatherback (*Dermochelys coriacea*)	0	0	0	5	5	2	3	0	0	0	0	0	15
Hawksbill (*Eretmochelys imbricata*)	0	1	0	0	1	1	1	0	2	1	2	0	9
Undetermined	0	0	0	2	2	1	2	0	3	5	0	2	17
Total	13	16	49	100	46	30	100	65	68	44	42	45	618

[1] After some records were deleted (see Table 1).

depth intervals suggested that monthly fishing intensities in contiguous depth intervals increase or decrease in the same direction. This pattern also suggests that monthly fishing intensities are high in deeper waters when they are low in shallower waters, and vice versa, probably in association with the seasonal migrations of shrimp and the fishing fleet (Tables 5–8). Thus, when fishing intensities in depth intervals between 0 and 20 fm were positively associated with strandings, the fishing intensities seaward of 20 fm were low, producing inverse associations with stranding rates.

The pattern of correlations between the $\ln(E + 1)$ of the various depth intervals may have influenced the correlations between $\ln(S + 1)$ and $\ln(E + 1)$. Some of the significant positive correlations detected between $\ln(S + 1)$ and $\ln(E + 1)$ may have resulted from correspondences between stranding rates and fishing intensities, whereas others may have been coincidental. Our analyses determined only that there were significant positive correlations between $\ln(S + 1)$ and $\ln(E + 1)$, but they cannot prove there was a cause and effect relationship between fishing intensities and stranding rates. On the other hand, our results would be consistent with a cause and effect relationship. Although the positive correlations we detected were not significantly heterogeneous, they did tend to decrease in strength with depth, which may suggest a decreasing degree of statistical association between stranding rates and fishing intensities as depth increases. This tendency also could occur if sea turtles injured or killed in deeper waters were less likely to wash ashore than those injured or killed closer to the shoreline (Caillouet et al., 1991).

The significant positive correlations we detected between $\ln(S + 1)$ on $\ln(E + 1)$ were circumstantial evidence of a relation between sea turtle stranding rates and shrimp fishing intensities, but they did not demonstrate that shrimping caused the strandings. Nevertheless, they were consistent with previous findings that sea turtles are caught and killed incidentally in shrimping (National Research Council,

1990) and that some turtles incidentally caught during shrimping operations become stranded (Manzella et al., 1988; Fontaine et al., 1989). The surprising aspect of our findings comes from the expectation that TED regulations would lead to a reduction or elimination of the statistical association between sea turtle stranding rates and fishing intensities in the northwestern Gulf. To explain this continued statistical association, we offer the following hypotheses:

1 legal and properly installed TED's failed to eject all of the sea turtles caught incidentally in shrimp trawls;
2 sea turtles were captured and ejected repeatedly from trawls containing legal and properly installed TED's, and eventually succumbed to the stresses of repeated passage through such trawls;
3 sea turtles were captured incidentally in shrimpers' try nets that had no TED's;
4 violations of TED regulations resulted in incidental capture of sea turtles;
5 nonshrimping causes of sea turtle mortality were in synchrony with shrimping effort.

Legal and properly installed TED's may have failed to eject all of the sea turtles caught incidentally in shrimp trawls (hypothesis 1). Prior to June 1994, supporting floats were not required on bottom-opening hard TED's (Mitchell[4]). Tests by NMFS showed that use of such legal TED's without floats could result in sea turtle mortality (Mitchell[4]). Therefore, NMFS issued new rules to ensure sea turtle escape. Other NMFS studies have shown that sea turtles are sometimes caught in TED-equipped shrimp trawls (Renaud et al., 1990, 1991; Epperly et al., 1995). Each type of TED certified for use by the shrimp industry has been tested under an established scientific protocol (Federal Register, vol. 55, no. 195, p. 41882–41883, 9 October 1990). NMFS-certified TED's that were properly installed and "tuned" (adjusted) were required to be no less than 97% effective in ejecting incidentally captured sea turtles. The actual rate of ejection could vary below 97% under less than ideal shrimp trawling conditions.

There is no evidence that individual sea turtles were captured and ejected repeatedly from certified, properly installed TED's during commercial shrimp trawling operations (hypothesis 2). If they had been, they would have undergone repeated stress. To determine whether sea turtles are captured and ejected repeatedly from TED's during commercial trawling operations, underwater observations would be required and the sea turtles would have to be marked for repeated recognition. During TED certification trials conducted near Panama City, Florida, Kemp's ridley turtles, released into TED-equipped shrimp trawls and submerged for less than 8 min before ejection and surfacing, developed blood acidosis. The acidosis was, for the most part, metabolic (caused by accumulation of lactate) and to a lesser degree respiratory (caused by accumulation of CO_2)(Stabenau et al., 1991). The turtles released excess CO_2 when they hyperventilated after surfacing (Stabenau et al., 1991). Other research showed that at least 20 h were required for complete recovery from lactate acidosis in loggerhead sea turtles caught in shrimp trawls during sea turtle surveys in Port Canaveral Ship Channel, Florida (Lutz and Dunbar-Cooper, 1987). It is doubtful that a sea turtle in a state of severe blood acid-base disequilibrium, resulting from submergence and struggling to escape a shrimp trawl, would dive soon after release from a TED (Stabenau[5]). If it dived, the blood acidosis would be exacerbated. On the other hand, if the turtle remained at or near the surface it could take frequent breaths and recover from the acid-base disturbance. As standard practice, sea turtles submerged in shrimp trawls for less than 10 minutes during TED certification trials are allowed at least 48 h of recovery before being submerged in a second test (Fontaine[6]).

Sea turtles may have been captured incidentally in shrimpers' try nets (hypothesis 3) within which TED's were not required. Even though these small trawls are towed for relatively brief intervals, direct observations aboard shrimp trawlers have shown that sea turtles are caught incidentally in try nets (Renaud et al., 1990, 1991; Mitchell[4]).

Violations of TED regulations have been shown to result in incidental capture of sea turtles in shrimp trawls (hypothesis 4). For example, unprecedented numbers of sea turtles were stranded in Louisiana in 1993 and in Texas in 1994 and 1995, concomitant with concentrations of shrimp trawling. These stranding events were attributed, at least in part, to violations of TED regulations, including, but not limited to, various illegal alterations of TED's (Crouse, 1993a; Shaver, 1994, 1995; Steiner, 1994; Shrimp Trawling in the Southeastern United States Under the Sea Turtle Conservation Regulations, Endan-

[4] Mitchell, J. 1995. Pascagoula Laboratory, Southeast Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, P.O. Drawer 1207, Pascagoula, MS 39568-1207. Personal commun.

[5] Stabenau, E. 1994. Department of Physiology, School of Medicine, East Carolina University, Greenville, NC 27858-4354. Personal commun.

[6] Fontaine, C. 1995. Galveston Laboratory, Southeast Fish. Sci. Cent., Natl. Mar. Fish. Serv, NOAA, 4700 Ave. U, Galveston, TX 77551-5997. Personal commun.

gered Species Act, Section 7 Consultation, Biological Opinion, NMFS, 14 November 1994; Mitchell[4]). As a consequence, NMFS developed an Emergency Response Plan (Federal Register, vol. 60, no. 77, p. 19885–19886, 21 April 1995; Federal Register, vol. 60, no. 85, p. 21741–21745, 3 May 1995). This plan, a resurgence of sea turtle strandings along the Texas coast during the spring 1995 shrimping season (Shaver, 1995), and an ensuing ruling by Judge Samuel B. Kent (*Center for Marine Conservation vs. Brown*, C.V. No. G-94-660, U.S. District Court, Galveston, Texas) led to additional TED restrictions on shrimping seaward to 12 nautical miles.

There is little evidence to support hypothesis 5, that causes of strandings other than incidental capture of sea turtles in shrimp trawls were in synchrony with shrimping. It seems unlikely that a major nonshrimping cause of sea turtle mortality has escaped detection during the many years of study of factors causing sea turtle injury and mortality at sea (National Research Council, 1990; Kemp's Ridley Recovery Team[7]). Prior to our analyses, we deleted stranding records that represented known or likely causes (Table 1), even when some of these causes did not absolutely rule out incidental capture in shrimp trawls (Table 1). The records retained for analysis represented strandings for which no cause was known. Nevertheless, it is possible that causes other than shrimping contributed to the unexplained strandings that were retained for our analyses, because it is known that there are other minor causes of sea turtle mortality, some of which could have been in synchrony with shrimping.

The lower total number of strandings in the northwestern Gulf in 1990–93 as compared with 1986–89 (Tables 9 and 10) would be encouraging were it not for differences in STSSN coverage in 1990–93 and 1986–89. Schroeder (1989), Whistler (1989), and the National Research Council (1990) pointed out that temporal–spatial coverage of sea turtle strandings is rarely uniform because the STSSN depends for the most part on volunteers. During 1986–89, to supplement the efforts of volunteers, universities, and other agencies (Texas A&M University, the University of Texas, National Park Service, U.S. Fish and Wildlife Service, and Texas Parks and Wildlife Department), NMFS Galveston Laboratory personnel conducted systematic surveys at least once a month along accessible shorelines of beaches bordering the Gulf from the Mermentau River to the Rio Grande (Caillouet et al., 1991). During 1990–93, personnel at Galveston Laboratory focused their coverage only on subarea 18 during March–November; STSSN coverage in other areas of the northwestern Gulf in those years depended more on volunteers, universities, and other agencies than was the case in 1986–89. Therefore, the decrease in total number of strandings might have occurred because of a reduction in STSSN coverage, but the mandatory use of TED's and the decrease in total shrimp fishing effort, both on the upper and lower coasts (Table 2), cannot be ignored as possible contributing factors. The statistical association between stranding rates and fishing intensities persisted in 1990–93 despite the reduction in total strandings. It is essential that STSSN coverage of strandings be consistent, both spatially and temporally, to provide data sufficient to assess real trends in sea turtle strandings and to determine their relationship to natural as well as anthropogenic causes.

The statistical association between sea turtle stranding rates and shrimp fishing intensities in the northwestern Gulf is worthy of concern and further attention. Continued strandings of sea turtles demonstrate that the problem of sea turtle mortality at sea has not been solved (Henwood et al., 1992; Shaver, 1994, 1995). It is clear that further efforts will be necessary to solve this problem and thereby speed the recovery of sea turtle populations. Those efforts must include reduction or elimination of human-caused sea turtle mortality at sea (National Research Council, 1990; Henwood et al., 1992).

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