An analysis of the possible utility of time–area closures to minimize billfish bycatch by U.S. pelagic longlines

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Abstract.–This study examined the relative rates of billfish bycatch and target species catch by areas (1°, 2°, and 5° latitude and longitude) and months in the catch data reported in mandatory log books kept by U.S. pelagic-longline fishermen in order to identify potential time–area strata that could reduce billfish bycatch. The 1986–91 mean percentages identified month–area strata with high percentages of sailfish and marlin bycatch and marlin only bycatch. The analyses indicated that the elimination of effort in cells selected according to percentages of billfish in the catch could have reduced the 1986–91 billfish bycatch by 50% and the target species from 13.9 to 19.2%, depending on the spatial resolution employed. The corresponding analysis of marlin only indicated a 50% reduction in marlin bycatch could have been attained and a 16.4–20.7% reduction in the target species catch. The time–area closures identified in the 1986–91 logbook data were applied to the data for 1992–95 and provided a test of the spatial and temporal stabilities of these results. For the evaluation of sailfish and marlin combined, the reductions in both billfish bycatch and target species catches averaged less than the predicted values, but in all cases billfish were selectively protected. For the evaluation of marlin only, the reduction of sailfish bycatch was less than the predicted amount and the reduction of the target species was slightly greater than the predicted value. The agreement between the predicted level of protection for billfish or marlin and the mean value for the 1992–95 test period increased with increasing size of the grid. At the 5°cell size, the mean reduction was 22.8% for the targeted species and 48.6% for marlin (compared with predicted values of 20.7 and 50% respectively). These results suggest that time and area restrictions on fishing could significantly reduce the bycatch of billfishes in the pelagic-longline fisheries without equivalent reductions in the catch of target species.

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The U.S. Fisheries Management Plan for Atlantic Billfishes (sailfish, blue and white marlin, and spearfish) reserves billfish stocks for recreational use; their commercial harvest by U.S. fishermen has been prohibited since the plan became effective in 1988 (SAFMC, 1988). The most recent stock assessment for billfishes found that, over the Atlantic as a whole, blue and white marlin stocks are seriously overfished (Anonymous, 1996). Their stocks were at about 21 and 24%, respectively, of the biomass needed to support maximum sustainable yield (MSY) at the beginning of 1996 (Anonymous, 1996). Fishing-induced mortality was estimated to be 3.19 times higher than that which would produce MSY for blue marlin, and 1.88 times higher than that which would produce MSY for white marlin. Most of the fishing mortality on these species is the result of bycatch in the pelagic-longline fisheries that target other species, particularly tuna and swordfish.

Many authors have promoted the concept of marine reserves (also called marine protected areas or MPAs) as management tools to enhance conservation of fishery resources (Bohnsack, 1994; Shackell and Wilson, 1995; Hutchings, 1995, 1996; Allison et al., 1998; Lauck et al., 1998). Closed areas have been used in many parts of the world to control bycatch mortality (Alverson et al., 1994). Hutchings (1996) noted that MPAs might have considerable merit in reducing bycatch when assessed against the effectiveness of other forms of regulatory control such as bycatch limitations and catch quotas. Often, however, the concept of marine reserves is restricted to closures of particular habitats or portions of habitats. Kenchington (1990) noted that such marine reserves would be of little use for species such as billfish that have both pelagic larvae and highly pelagic adults. Among other options for reducing bycatch, Alverson et al. (1994) observed that time–area control of fishing activity offers an opportunity to reduce unwanted bycatch. The main objective of employing time–area strategies is to take advantage of variation in the degree of co-occurrence between target and bycatch species (Murawski, 1992). The effectiveness of such controls obviously depends on the degree of overlap between the bycatch and the targeted species (Adlerstein and Trumble, 1992).

Cramer (1996) used logbook data on U.S. large pelagic fish (data that have been mandatory since October 1986) in order to evaluate the spatial distribution of the catch of undersized swordfish by the longline fishery in strata of 1° latitude and longitude by season and area. Her study evaluated the implications of removing time–area strata with high swordfish discard rates on the total catch of the longline fishery. The present study uses the same data set to evaluate the degree of overlap between billfish bycatch and target species catch for the U.S. pelagic longline fishery and develops a method for selecting candidate time–area cells whose closure would selectively enhance billfish survival and minimize impacts on the target species catch.

Methods

The longline catch data were inspected 1) to determine the species composition of the catch to identify the set of species which, taken together, constitute the primary targets of the fishery, and 2) to identify possible trends in the reporting of billfish bycatch. The reported bycatch of billfish declined markedly in 1992 compared with earlier years. Consequently, the data were partitioned into two periods: 1986–91 and 1992–95. Data from the first period were used to characterize the spatial and temporal distributions of the catch. Data from the second period were used to test temporal stability of the results of analyses of the first period.

The billfish bycatch and the combined billfish (sailfish, spearfish, and blue and white marlin) bycatch as well as the target species catch for each longline set of each reported trip were summed into cells of 1°, 2°, and 5° latitude and longitude and month over the period 1986–91. The analysis was also repeated and only blue and white marlin bycatch was considered along with the target catch. Separate cumulative frequency distributions of the percentage of billfish or marlin bycatch in the combined billfish and target species catches by number by cell were constructed for each level of spatial resolution. These frequency distributions were used to estimate the percent reduction in billfish bycatch and target species catch that would have occurred if the effort in time–area cells with billfish or marlin bycatch rates above an arbitrary threshold had been completely eliminated during the 1986–91 fishery. The distribution of the minimum number of cells producing any specific reduction in billfish or marlin catches with the least impact on target species catch could then be determined from these data.

As an example, the distribution of cells that, if they had been eliminated from the 1986–91 U.S. fishery, would have reduced the billfish and marlin bycatches by 50%, were plotted for examination. Although the reporting rate declined after 1991, the temporal and spatial relative distributions of billfish in the total longline catch would be unaffected, so long as the change in the reporting rate was random. Consequently, the temporal stability of the reduction in billfish and marlin bycatch for the time–area cells identified with the 1986–91 data was evaluated by using data from 1992 to 1995. This was done by calculating the percent reduction in the total billfish and marlin bycatch that would have occurred each year if the time–area cells identified in the 1986–91 data had been closed. This analysis assumed that the displaced effort would not shift elsewhere.

Results

The catch by species in the data file from U.S. pelagic longline logbooks from 1986 through 1995 is presented in Table 1. Inspection of these data indicates that the predominant target species of this fishery included swordfish, yellowfin tuna, bigeye tuna, albacore, and dolphin fish. Together they constituted 90% of the nonbillfish harvest that was reported in these logbooks. For this analysis, billfish bycatch is the combined catch of sailfish, spearfish, and blue and white marlin, and marlin bycatch is the combined catch of blue and white marlin. Inspection of the data in Table 1 indicates a sharp drop in the numbers of billfish caught after 1991. This is possibly a consequence of a change in reporting trends following the U.S. billfish management plan's prohibition of the sale of billfish, or the restrictions on landing undersized swordfish imposed in mid-1991, rather than a consequence of a true reduction in the bycatches of billfish by the U.S. pelagic-longline fleet. Although no observer data are available before 1992, this conclusion is supported by data collected by observers on longline vessels that indicate billfish bycatch rates after 1992 were much higher than those reported in the logbooks (Cramer[1]). For this reason, the longline logbook data were grouped into two periods: 1986–91 and 1992–95. Data from 1986 through 1991 were used to characterize the distribution of billfish and target species catches, and data from 1992 through 1995 were used to test the spatial and temporal stability of the patterns observed in the 1986–91 data.

The percentage of billfish in the combined billfish bycatch and target species catch for each month–area cell in strata of 1°, 2°, and 5° was estimated, and the results were sorted to obtain cumulative frequency distributions of the billfish bycatch percentages for each spatial resolution. At the same time, the cumulative catches of billfish and target species were compiled for each observation in the cumulative frequency distributions of percentage of billfish in the catch in each time–area cell. The results of this procedure are presented in Figure 1 and Table 2. Note

[1] Cramer, J. 1996. Pelagic longline billfish bycatch. International Commission for the Conservation of Atlantic Tunas (ICCAT) working document SCRS/96/97.

Table 1

Catch in number (not including billfish discards) by species reported in the logbook data for U.S. pelagic longlines for 1986–95.

Species	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Total
Swordfish	16,510	113,665	161,980	171,344	129,147	86,586	67,004	64,724	63,913	72,520	947,393
Bluefin tuna	58	484	422	717	599	540	1010	342	335	266	4773
Albacore	1181	2085	2984	3986	8220	9873	14,137	13,636	18,795	21,810	96,707
Bigeye tuna	3162	15,919	15,249	19,764	16,947	18,250	15,239	21,446	22,859	25,363	174,198
Yellowfin tuna	9241	59,665	67,569	83,844	68,711	70,433	94,510	68,360	73,337	85,135	680,805
Blackfin tuna	64	560	808	1450	1090	1525	3178	2797	3096	2363	16,931
Skipjack tuna	0	0	0	0	0	1384	2165	1374	232	279	5434
Bonito	0	0	0	0	0	0	0	238	1030	497	1765
Other tuna	0	0	0	0	0	0	1695	613	337	451	3096
Blue marlin	115	815	387	65	82	55	3	64	62	23	1671
Sailfish	4	55	147	53	66	22	5	34	56	87	529
Spearfish	4	52	47	2	15	2	8	30	19	14	193
White marlin	217	998	468	97	48	62	13	36	27	20	1986
Greater amberjack	0	0	0	0	0	0	112	836	1278	234	2460
Banded rudderfish	0	0	0	0	0	0	3	13	29	86	131
Dolphin fish	972	7861	10,768	29,899	31,899	32,576	25,351	26,142	29,617	72,321	267,406
King mackerel	1	11	35	119	11	67	118	4602	7176	1929	14,069
Wahoo	40	1346	2629	3157	3560	3736	6506	4393	3442	5477	34,286
Oilfish	0	0	0	0	0	0	0	37	5073	5102	10,212
Blue shark	944	1482	581	980	633	753	2050	1513	864	373	10,173
Mako shark	486	4055	4877	6946	4380	3475	414	338	371	187	25,529
Shortfin mako shark	0	0	0	0	0	0	3944	3738	3982	3747	15,411
Oceanic whitetip shark	0	0	0	0	0	0	319	226	166	205	916
Porbeagle shark	0	0	0	0	0	0	41	675	1591	509	2816
Bigeye thresher shark	0	0	0	0	0	0	200	304	626	472	1602
Other pelagic shark	0	0	0	0	0	0	0	0	0	8	8
Thresher shark	32	674	632	488	280	194	113	139	95	181	2828
Dusky shark	0	0	0	0	0	0	3365	7305	2826	2830	16,326
Bignose shark	0	0	0	0	0	0	70	254	124	123	571
Blacktip shark	0	0	0	0	0	0	3527	5965	6042	3954	19,488
Hammerhead shark	57	129	535	979	500	262	360	562	508	349	4241
Scalloped hammerhead shark	0	0	0	0	0	0	292	267	646	375	1580
Smooth hammerhead shark	0	0	0	0	0	0	627	452	484	231	1794
Night shark	0	0	0	0	0	0	478	455	379	421	1733
Silky shark	0	0	0	0	0	0	1685	1244	2134	2765	7828
Spinner shark	0	0	0	0	0	0	925	255	234	209	1623
Tiger shark	27	104	1051	183	98	108	165	173	477	202	2588
Other sharks	842	5740	4380	5424	9750	4620	3242	4242	1092	1376	40,708
White shark	20	137	1723	1222	537	95	104	163	16	2	4019
Sandbar shark	0	0	0	0	0	0	0	0	2020	14,192	16,212
Other	0	0	0	0	0	0	0	0	90	2515	2605

that the initial slope of the relation between the billfish percent reduction and target species percent reduction is much lower than 1.0 for each of the spatial resolutions examined. This finding suggests that the temporal and spatial distributions of billfish bycatch and target species are somewhat different and that it should be possible to selectively reduce the longline billfish bycatch in relation to target species catch. The data from Table 2 indicate that a 10% reduction in the 1986–91 billfish bycatch could have

Table 2

Estimated reduction in billfish bycatch and target species catch by elimination of time–area cells where the billfish percentage of catch is greater than or equal to the specified threshold value based on 1986–1991 catch rates in the U.S. pelagic-longline fishery. These estimates assume that the displaced effort will not be redirected elsewhere.

	1° cells		2° cells		5°cells	
Billfish reduction (%)	Threshold (%)	Target reduction (%)	Threshold (%)	Target reduction (%)	Threshold (%)	Target reduction (%)
5	18.46	0.34	14.23	0.49	9.64	0.94
10	14.32	1.01	9.99	1.51	8.77	2.33
15	12.06	1.90	9.44	2.73	7.94	3.88
20	10.07	2.97	8.52	4.08	7.58	5.52
25	8.81	4.25	7.17	5.62	7.34	7.21
30	7.52	5.74	5.86	7.54	6.10	9.19
35	6.78	7.45	5.47	9.70	5.70	11.38
40	6.16	9.37	4.87	12.13	5.52	13.68
45	5.49	11.49	4.61	14.77	4.86	16.29
50	4.95	13.87	4.32	17.57	4.36	19.17
55	4.37	16.59	4.10	20.53	4.21	22.28
60	4.03	19.59	3.79	23.72	3.95	25.51
65	3.61	22.85	3.51	27.16	3.57	29.11
70	3.30	26.53	3.21	30.92	3.11	33.13
75	2.94	30.62	2.95	35.01	2.76	37.67
80	2.56	35.30	2.48	39.73	2.46	42.92
85	2.17	40.73	2.19	45.21	2.07	48.85
90	1.74	47.38	1.70	52.09	1.73	55.91
95	1.20	56.08	1.15	61.54	1.26	65.08

been attained with only a 1 to 2.3% reduction in the catch of target species, depending on the spatial resolution employed. This reduction would have been achieved by eliminating the effort in months and areas where the reported billfish bycatch exceeded the threshold percentage of billfish in the combined catch in Table 2. Similarly, a 50% reduction in the 1986–91 billfish bycatch would have been achieved by eliminating the effort in cells where the reported billfish bycatch exceeded the table values with corresponding reductions of 13.9 to 19.2% in the harvest of target species. A 95% reduction in the 1986–91 billfish bycatch would have been achieved by eliminating all effort in cells with reported catches of more than 1.2, 1.15, or 1.26% billfish for 1°, 2°, or 5° cells, and there would have been a concomitant reduction in target species catch of 56.1, 61.5, or 65.1%, respectively.

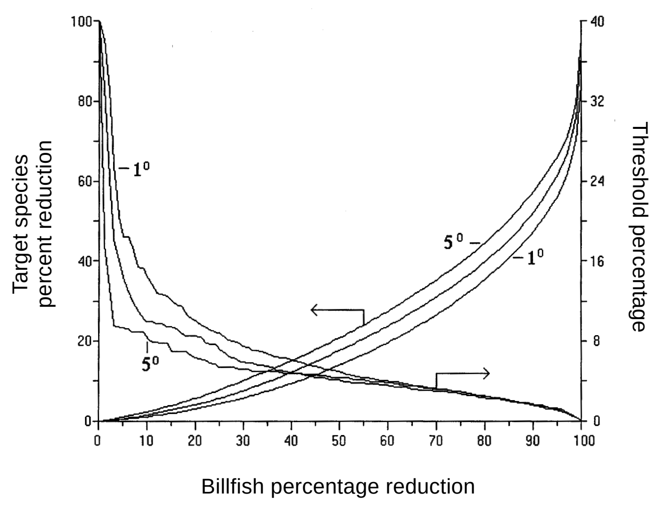

Figure 1

Percent reduction in target species and marlin bycatch associated with the removal of effort in time–area cells above the indicated threshold percentage of all billfish in the catch for cell sizes of 1°, 2°, and 5° of latitude and longitude.

The same type of analysis was conducted with only blue and white marlin as the billfish species of concern. The results are presented in Figure 2 and Table 3. As with billfish combined, the initial slope of the relation between the percent catch of marlin bycatch and of target species is much less than 1.0. This result also indicates that the combined marlin bycatch can be reduced by the elimination of select time–area strata and that the catch of target species would not be proportionately affected. The data from Table 3 indicate that a 10%

Table 3

Estimated reduction in blue and white marlin bycatch and target species catch by elimination of time–area cells where the marlin percentage of catch is greater than or equal to the specified threshold value based on 1986–91 catch rates in the U.S. pelagic-longline fishery. These estimates assume that the displaced effort will not be redirected elsewhere.

	1° cells		2° cells		5°cells	
Marlin reduction (%)	Threshold (%)	Target reduction (%)	Threshold (%)	Target reduction (%)	Threshold (%)	Target reduction (%)
5	18.15	0.38	11.54	0.53	7.32	1.11
10	10.16	1.14	7.06	1.71	6.22	2.79
15	7.71	2.34	5.19	3.50	5.49	4.76
20	6.17	3.79	4.79	5.37	5.21	6.33
25	5.77	5.10	4.24	7.44	4.83	8.62
30	4.97	6.80	4.02	8.99	4.65	10.81
35	4.54	8.57	3.87	11.59	4.16	13.63
40	4.15	10.95	3.64	14.14	4.02	15.70
45	3.78	13.60	3.44	16.55	3.86	17.72
50	3.46	16.37	3.23	19.55	3.58	20.74
55	3.24	19.50	3.12	22.44	3.12	23.66
60	3.00	22.03	2.87	25.95	2.84	27.44
65	2.76	25.04	2.67	29.47	2.68	30.54
70	2.39	28.50	2.39	32.87	2.47	34.89
75	2.14	32.94	2.10	36.53	2.20	38.76
80	1.86	37.90	1.85	41.40	2.01	44.08
85	1.56	43.97	1.67	46.43	1.78	49.78
90	1.21	50.49	1.23	53.72	1.49	56.75
95	0.73	59.39	0.84	63.06	1.07	66.45

reduction in the 1986–91 marlin bycatch could have been attained with only a 1.1 to 2.8% reduction in the catch of target species, depending on the spatial resolution employed. This would result by eliminating the effort in months and areas where the reported billfish bycatch exceeded the threshold percentage of billfish in the combined catch indicated in Table 3. Similarly, a 50% reduction in the 1986–91 marlin bycatch would have been obtained by eliminating the effort in cells where the reported billfish bycatch exceeded the table values with corresponding reductions of 16.4 to 20.7% in the harvest of target species. A 95% reduction in the 1986–91 marlin bycatch would have been achieved by eliminating all effort in cells that reported catches of more than 0.73, 0.84, or 1.07% marlin for 1°, 2°, or 5° cells, and there would have a concomitant reduction in target species catch of 59.4, 63.1, or 66.5% respectively.

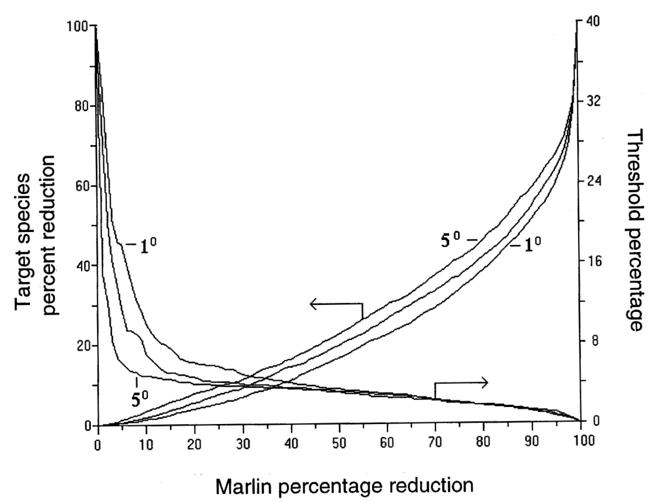

Figure 2

Percent reduction in target species and blue and white marlin bycatch associated with the removal of effort in time–area cells above the indicated threshold percentage of marlin in the catch for cell sizes of 1°, 2°, and 5° of latitude and longitude.

Obviously, the temporal and spatial distribution of the cells that would be eliminated with the current method for any particular threshold selected is of considerable interest. Figure 3 presents the distribution of cells by area and month that correspond to a threshold selection that would have eliminated 50% of the billfish bycatch from the 1986–91 U.S. pelagic-longline fishery as reported in the log books. Areas where fishing effort was expended within 5° cells are stippled or diagonally

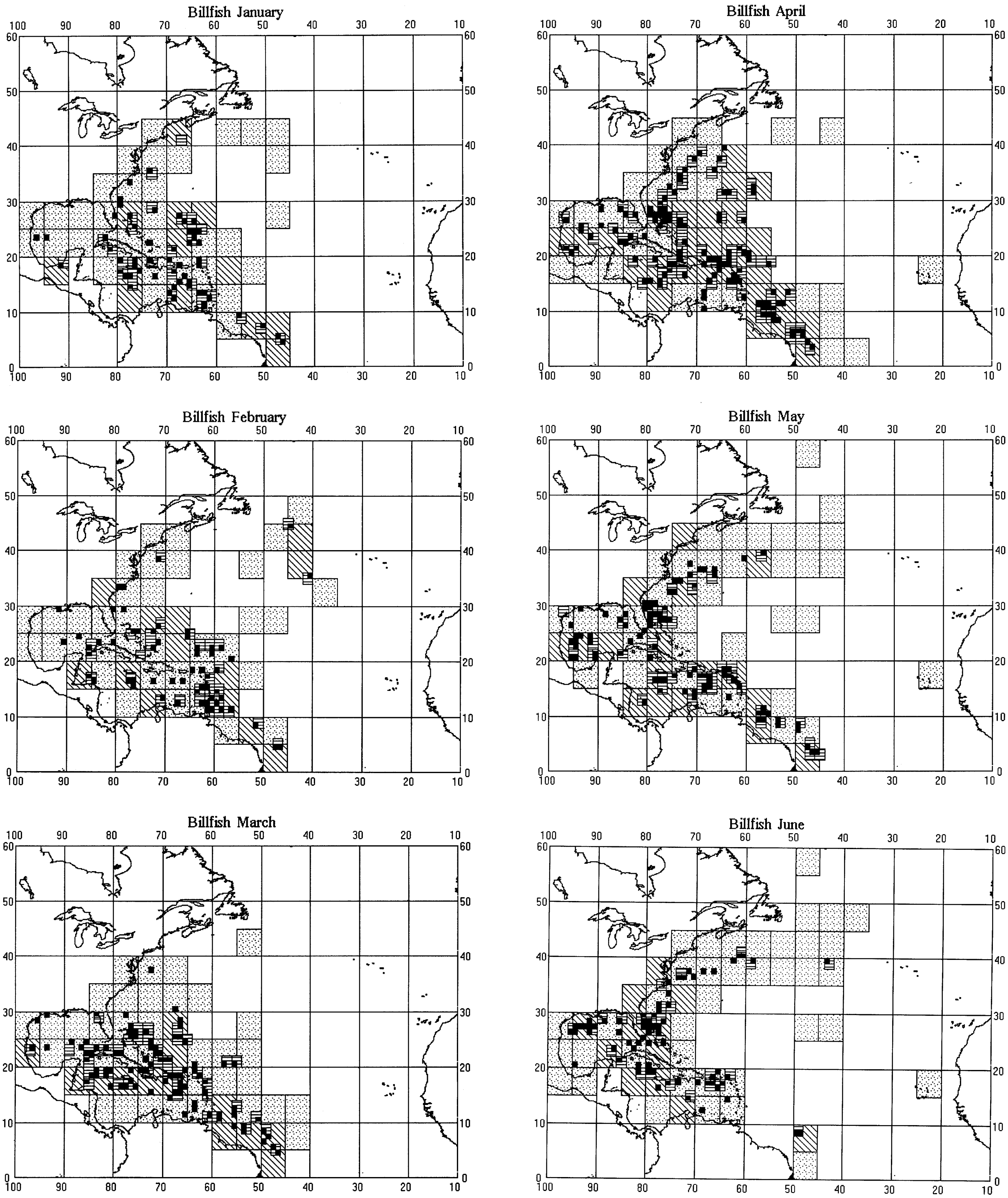

Figure 3

Distribution of 1986–91 U.S. pelagic-longline fishing effort by month and area fished (stippled or diagonally shaded cells of 5° cell or smaller. Month–area cells where billfish bycatch percentages were greater than the 50% threshold levels for 1° (filled), 2° (horizontal shading) and 5° (diagonal shading) cells. Elimination of the effort in these cells would have reduced the combined billfish bycatch by 50% and reduced the target species catch by 13.9, 17.6, and 19.2% respectively.

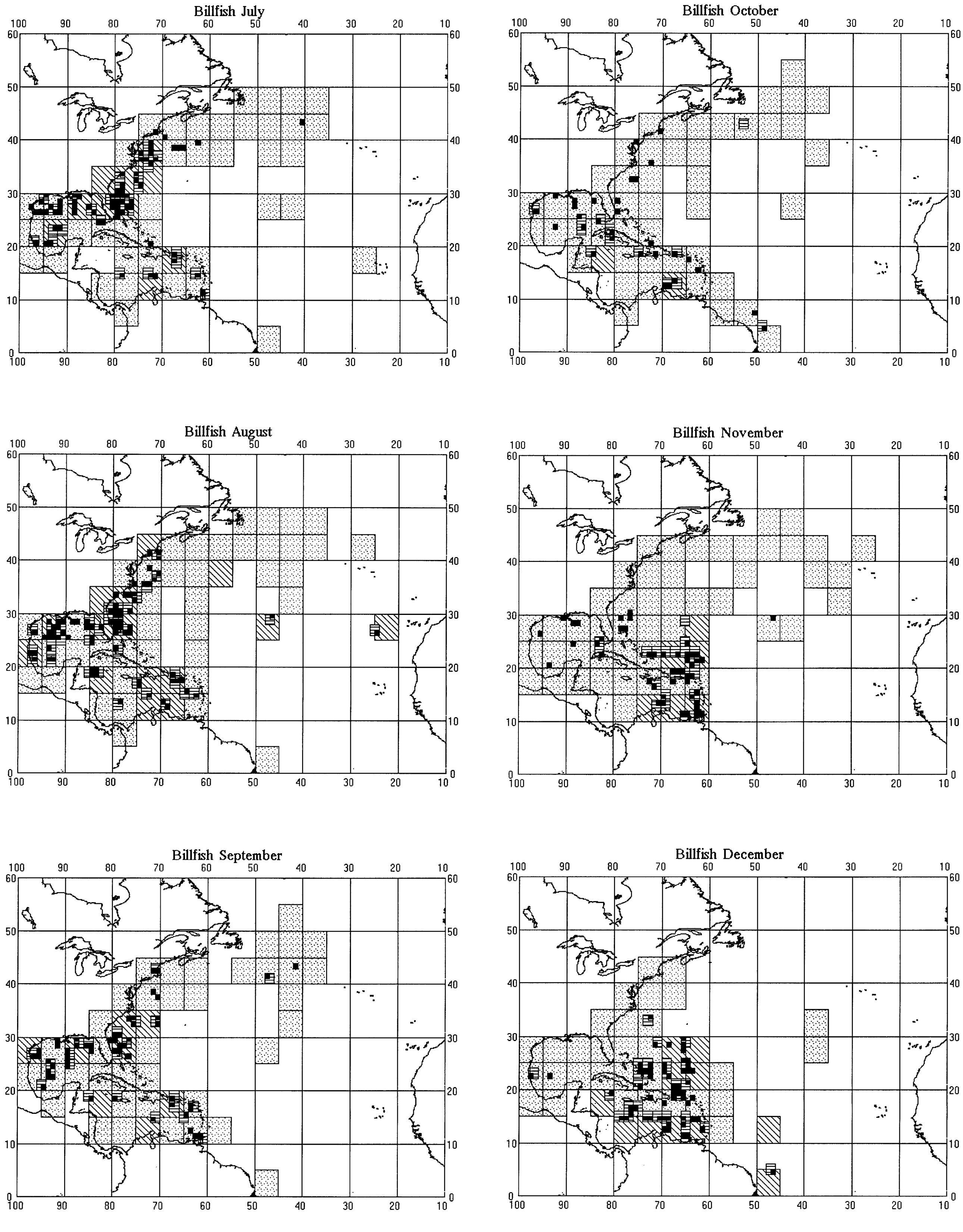

Figure 3 (continued)

shaded. The diagonally shaded 5° cells indicate where the billfish proportion of the catch within the 5° area exceeded the 4.36% threshold required to obtain a 50% reduction in the 1986–91 billfish bycatch indicated in Table 2. The horizontally shaded 2° cells indicate those cells where the billfish proportion exceeded the threshold for the 2° spatial resolution, and the filled 1° cells indicate those cells where the billfish proportion exceeded the 1° threshold. Inspection of these plots indicates a temporal pattern in the distribution of fishing effort—from southern waters in the winter to northern and eastern waters during the summer and fall. Also the minimum number of cells that would have to have been eliminated from the 1986–91 fishery to reduce the billfish bycatch by 50% occur during the months of September through November. There is also a tendency for the affected cells to move north from the southernmost regions fished in November and December to the entire U.S. coastline by July and August.

Similar plots are presented for marlins in Figure 4, with the respective threshold percentages of marlin in the catch. As for billfishes combined, the number of cells above the threshold percentages is at a minimum in October but increases thereafter to a peak in April. The affected cells move north during the spring and summer from primarily southern latitudes in the winter. However, some cells in the Caribbean exceed the 50% thresholds of Table 3 in almost every month.

To test the temporal and spatial stability of the areas identified in Figures 3 and 4, I calculated the percent reductions in billfish and marlin bycatch and target species that would have occurred if those areas had been closed in each year from 1992 through 1995 for each level of spatial resolution considered (Tables 4 and 5). These estimates assumed that the time–area strata identified for closure would not be redirected elsewhere but did include strata fished in 1992–1995 that were not present in the 1986–91 base period. For billfish combined, billfish would have been selectively protected by closing the time–area cells identified from the 1986–91 data evaluation each year from 1992 through 1995 with all levels of spatial resolution examined. The agreement between predicted and 1992–95 observed values increased with increasing grid size (Table 4). Mean billfish reductions increased from 28.6% to 41.6% from 1° to 5° cells compared with the predicted levels of 50%. The mean reductions for targeted species were slightly less than the predicted values. The observed mean values were 12.8, 11.9, and 16.7%, compared with the predicted values of 13.9, 17.6, and 19.2% for the 1°, 2° and 5° cells, respectively. In general, the larger 5° grid produced results that were closest to the values predicted from the 1986–91 data set and showed the least year-to-year variability in the percent reduction of billfish bycatches.

For the analyses considering marlin species only, marlins would also have been selectively protected by closing the time–area cells identified from the 1986–91 data evaluation each year from 1992 through 1995 with all levels of spatial resolution examined. The agreement between predicted and 1992–95 observed values also increased with increasing grid size (Table 5) but were closer to the predicted values than for the evaluation of billfish combined. Mean marlin reductions increased from 35.7% to

Table 4

Evaluation of the temporal stability of the estimated percentage changes in billfish bycatches and target species catches using the time–area closures identified in the analyses of the 1986–91 longline data. The threshold levels were selected to reduce combined billfish bycatch by 50%, and the time–area cells that were excluded are those indicated in Figure 3. The estimated percentage reductions are based on the proportion of the annual total catch within the cells identified for closure and include areas fished in 1992–95 that had not been fished during the 1986–91 base period. The columns labeled "cells" are the percentages of the time–area strata fished during the year that would have been eliminated by closing the indicated cells.

	Predicted percentage reduction with billfish threshold model								
	1° cells			2° cells			5° cells		
Year	Billfish	Target	Cell	Billfish	Target	Cell	Billfish	Target	Cell
1992	24.5	11.7	15.7	25.8	10.7	14.1	42.2	15.7	20.3
1993	37.0	15.5	16.1	33.7	13.2	13.2	39.1	17.9	19.3
1994	32.1	13.6	19.1	35.5	12.7	14.7	44.5	17.8	20.7
1995	20.8	10.2	13.7	23.2	10.9	14.5	40.7	15.2	19.9
Mean	28.6	12.8	16.2	29.6	11.9	14.1	41.6	16.7	20.1

48.6% from 1° to 5° cells compared with the predicted levels of 50%. The mean reductions for targeted species were slightly greater than the predicted values. The observed mean values were 18.6, 20.1, and 22.8%, compared with the predicted values of 16.4, 19.6, and 20.7% for the 1°, 2° and 5° cells, respectively. As with billfish combined, the larger 5° grid produced results that were closest to the values predicted from the 1986–91 data set and showed the least year-to-year variability in the percent reduction of marlin catches. Overall, the result for marlin at the 5° resolution was in remarkable agreement with the values predicted from the evaluation of the 1986–91 data.

Discussion

This study was intended to consider pelagic longlines only. However, bottom-longline and pelagic-longline sets could not always be clearly distinguished in the database used for the analysis. Consequently, some of the effort and catch included in the analyses were likely from bottom-longline sets. Some additional refinement of the analyses might have been possible with additional attention to eliminating bottom-longline data. However, the total of the bottom-longline sets is thought to be only about 10% of the longline sets in the database (Cramer[2]), and all identified bottom-longline sets were eliminated from the analysis. Consequently, it is not likely that a complete elimination of the bottom-longline sets would have had an important effect on the basic pattern seen in the results of this study.

The International Commission for the Conservation of Atlantic Tunas (ICCAT) CPUE data files (task ii) indicate that billfish often accounted for 15% or more of the Japanese longline catch in the Gulf of Mexico and Caribbean before about 1977. However, the total harvest of billfish by the pelagic-longline fishery documented in the 1986–95 U.S. logbooks was never large in comparison with other species in their reported catch, and most were discarded even before the prohibition on harvest was promulgated by the U.S. Atlantic Billfish Plan. According to logbook records only 16.26% of the billfish caught during the period 1986–89 were retained. This figure dropped to 4.82% for the period 1992–95. Observer data for pelagic-longline trips indicate that the actual bycatch rates for billfish in this fishery are much higher than is currently being reported in logbooks (Cramer[1]). This phenomenon perhaps exists because billfish are not economically important components of the harvest, a phenomenon that was intensified by the U.S. Atlantic Billfish Plan which prohibited commercial harvest of billfishes after 1988. If so, it is likely that billfish were under-reported in the logbook data for the 1986–91 period used in the present analysis. The magnitude of the reporting rate is unknown for the 1986–91 period. However, unreported rates would not pose a problem for the analysis presented here if they were randomly distributed in time and space. This question could possibly be addressed in future analyses by using observer data from U.S. domestic pe-

[2] Cramer, J. 1996. Sustainable Fisheries Division, Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149.

Table 5

Evaluation of the temporal stability of the estimated percentage changes in marlin and target species catches using the time–area closures identified in the analyses of the 1986–91 longline data. The threshold levels were selected to reduce marlin catch by 50%, and the time–area cells that were excluded are those indicated in Figure 4. The estimated percentage reductions are based on the proportion of the annual total catch within the cells identified for closure and include areas fished in 1992–95 that had not been fished during the 1986–91 base period. The columns labeled "cells" are the percentages of the time–area strata fished during the year which would have been eliminated by closing the indicated cells.

	Predicted percentage reduction with marlin threshold model								
	1° cells			2° cells			5° cells		
Year	Marlin	Target	Cell	Marlin	Target	Cell	Marlin	Target	Cell
92	24.7	15.0	17.8	41.0	18.2	19.7	48.9	20.4	23.3
93	38.3	19.8	18.6	43.8	20.8	17.8	45.3	22.7	19.8
94	44.9	21.5	20.5	47.0	20.4	17.3	47.6	23.1	23.2
95	35.0	18.2	16.2	45.8	21.1	18.2	52.5	24.9	22.7
Mean	35.7	18.6	18.3	44.4	20.1	18.3	48.6	22.8	22.2

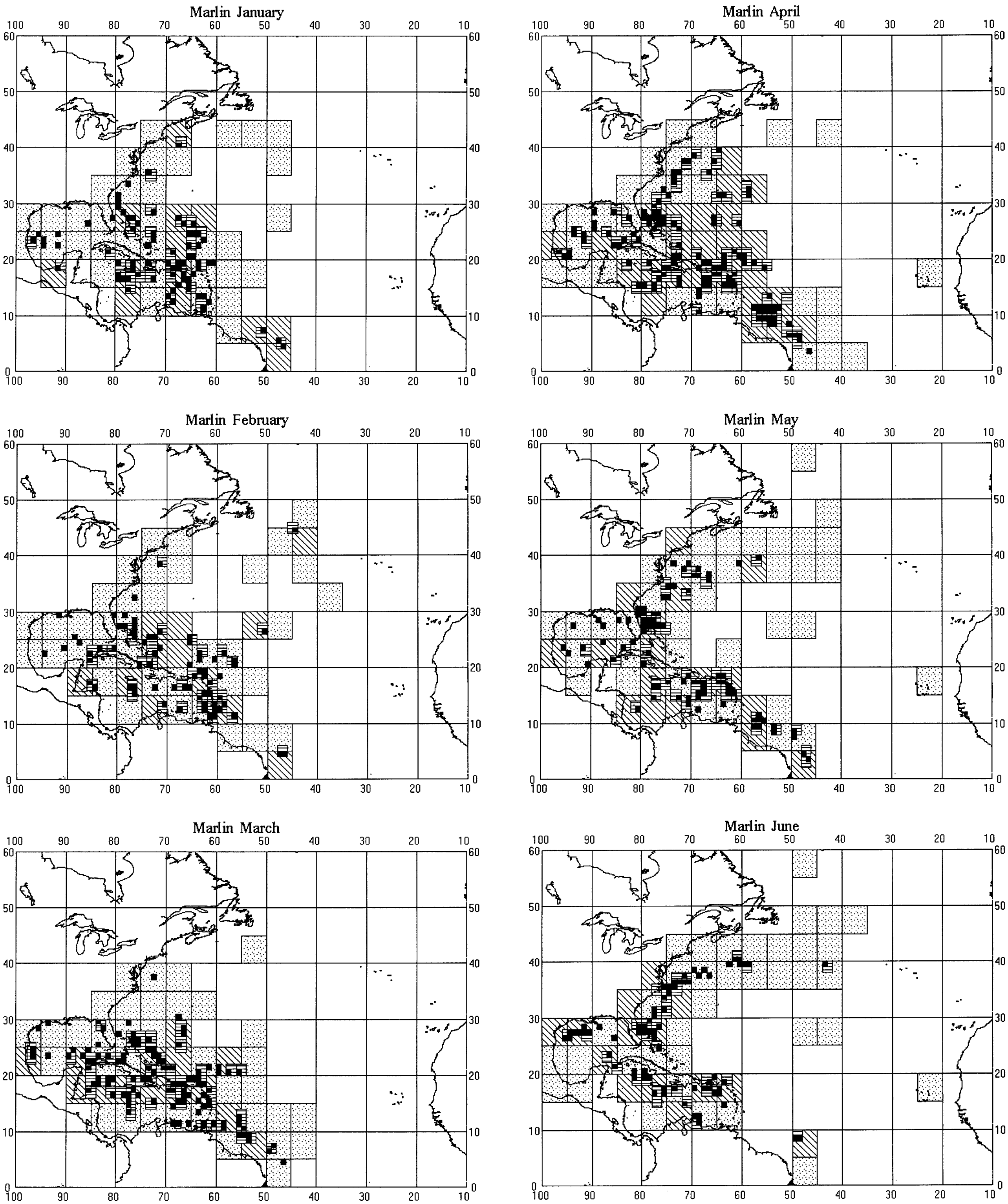

Figure 4

Distribution of 1986–91 U.S. pelagic-longline fishing effort by month and area fished (stippled or diagonally shaded cells of 5° cell or smaller. Month–area cells where marlin bycatch percentages were greater than the 50% threshold levels for 1° (filled), 2° (horizontal shading), and 5° (diagonal shading) cells. Elimination of the effort in these cells would have reduced the marlin bycatch by 50% and reduced the target species catch by 16.4, 19.6 and 20.7%, respectively.

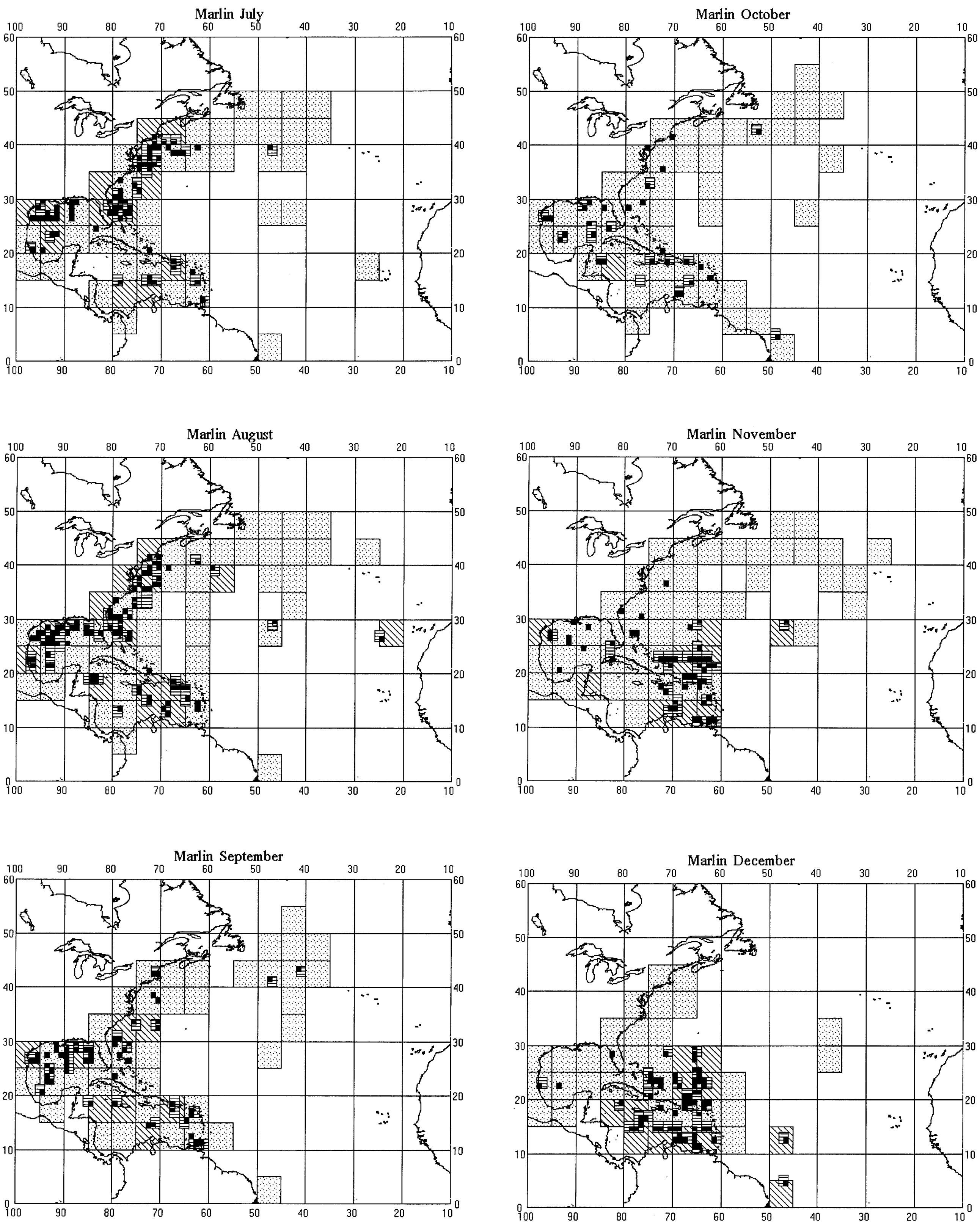

Figure 4 (continued)

lagic-longline vessels, although the amount of available data for the period is limited.

Although the study results demonstrate that time–area restrictions on the U.S. pelagic-longline fishery could substantially reduce the bycatch of billfish by this fishery, it is only a first step. As Murawski (1992) pointed out, any bycatch reduction plans involving time–area manipulation of the fishery should be economically viable and the proposed program must be effectively implemented and enforced. These issues were beyond the scope of the present study. An evaluation of the utility of time–area restrictions for reducing the mortality of billfish in the longline fishery must also consider aspects of the dynamics of the fishery itself. Among other considerations, the present analysis assumes that the effort eliminated by a time–area closure would not be redirected to some other time or area. The catch associated with a stratum removed by the selection of a particular threshold of percent billfish in the catch was simply removed from the total catch of both the billfish bycatch and target species. With no restriction on total effort, it seems more likely that the affected effort would be redirected into some other area, and the total billfish bycatch, although reduced, would not be reduced by the magnitude indicated in Tables 2 and 3 (and of course, neither would the target species). Analyses that consider the possible redirection of effort would need to include socioeconomic considerations about the nature and dynamics of the pelagic-longline fishery. Also catch limitations arising from the U.S. allocation of total allowable catches of the various target species by ICCAT could be integrated into the analysis. The focus of such an analysis would be to minimize the billfish bycatch by selecting fishing areas that would maximize the catch rates of target species in areas of minimal billfish bycatch. This could both promote efficient use of the target resources and the reduction of billfish bycatch. Similarly, other management objectives could be integrated into the time–area question.

Although, such extensions of the methods presented here should prove fruitful for the selection of actual management restrictions, the results of this study clearly indicate that the relative time and areal distributions of billfish and target species in the pelagic-longline catch are different. This difference can be exploited to reduce the billfish bycatch in this fishery with less than a proportional effect on the catch of targeted species. A next step toward identifying realistic management measures could be the characterization of reasonable, contiguous geographic areas where pelagic-longline closures would be both practical and of the greatest benefit to increased billfish survival. However, because U.S. vessels are a small part of the total Atlantic pelagic-longline fishery, greatest gains from this approach would necessarily involve participation of the pelagic-longline fleets from other countries.

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