Atlantic Blue Marlin, *Makaira nigricans*, and White Marlin, *Tetrapterus albidus*, Bycatch of the Japanese Pelagic Longline Fishery, 1960–2000

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ABSTRACT—Since the late 1950's, a multi-national longline fishery has operated throughout the Atlantic Ocean to supply the growing global demand for tunas (Scombridae) and swordfish, Xiphias gladius. *Two species caught as bycatch include Atlantic blue marlin,* Makaira nigricans, *and white marlin,* Tetrapterus albidus, *referred to in this paper as "Atlantic marlin." Pelagic longlining has consistently been the principal source of adult mortality for both species, which are currently depleted and have been so for more than two decades. In this paper, we examined aspects of the Atlantic marlin bycatch of the Japanese pelagic longline fishery from 1960 to 2000. Temporal and spatial patterns in effort, target catch (species combined), marlin bycatch, marlin catch-per-unit-effort (nominal CPUE), and ratios of marlin bycatch to target catch (B:T ratios) were analyzed. An objective was to reveal changes, if any, in marlin bycatch associated with the fishery's target species "switch" (ca. 1980–87) from mostly surface-associated tunas to mostly the deeper-dwelling bigeye tuna,* Thunnus obesus. *The highest values of all variables examined occurred during the 1960's and then fell by the second half of that decade. Since 1970, mean levels of fishing effort, target fish catches, and blue marlin landings have increased significantly, while blue marlin CPUE and B:T ratios have remained relatively stable. Concurrently, white marlin landings, CPUE, and B:T ratios have all declined. While results suggest the fishery's target species change may have been a factor in lowering white marlin bycatch, the same cannot be said for blue marlin. Relative increases in blue marlin B:T ratios off the northeastern coast of South America and in the wider eastern Atlantic are cause for concern, as are continuing trends of CPUE decline for white marlin in this data set as well as others.*

Introduction

Four billfish species (Family Istiophoridae) range the Atlantic Ocean and adjacent waters of the Caribbean Sea and Gulf of Mexico: sailfish, *Istiophorus platypterus*; blue marlin, *Makaira nigricans*; white marlin, *Tetrapturus albidus*; and longbill spearfish, *Tetrapturus pfluegeri* (Robins and Ray, 1986). In addition to filling the role of apex predators in subtropical and tropical pelagic waters, the Atlantic marlins and sailfish also support recreational fisheries that have been valued in the billions of dollars (IGFA, 1996). Despite their ecological and economic importance, little is known about the basic biology and ecology of these species, especially their growth, reproduction, and movement within the vast, highly dynamic oceanic habitats that sustain them (Holland, 2003).

Most research on Atlantic billfishes has focused on issues of stock structure, population abundance, and fishing mortality as part of stock assessments that, since 1994, have been performed every 2–4 years under the auspices of the International Commission for the Conservation of Atlantic Tunas (ICCAT). Several lines of evidence suggest that Atlantic blue marlin and white marlin belong to single Atlantic-wide stocks (Ortiz et al., 2003; Graves and McDowell, 2003); in contrast, sailfish are managed as western and eastern Atlantic populations. Results of the most recent ICCAT stock assessments (ICCAT, 2002; Restrepo et al., 2003) indicated that: 1) the Atlantic blue marlin population is overfished, with its current biomass about 40% of the size required for maximum sustainable yields (MSY); and 2) the white marlin stock is even more depleted, with its current biomass only 12% of the level to support MSY.

For at least the last two decades, the principal source of mortality on adults of both Atlantic marlin species has been pelagic longline fishing (Uozumi, 2003). This method of fishing deploys a continuous mainline, of up to 60 mi in length, with regularly spaced branch lines which terminate with baited hooks (Bjordal and Lokkeborg, 1996; Sainsbury, 1996). For the most part, billfish are not targeted by longline fisheries; rather, they are caught incidentally as the bycatch of fleets that strive to supply the growing global demand for tunas (Scombridae) and swordfish, *Xiphias gladius* (Prince and Brown, 1991; Beerkircher et al., 2002). Therefore, understanding bycatch of longline fisheries is an important step in reducing uncertainties in stock assessments and projections, implementing appropriate management measures, and developing new techniques to reduce incidental marlin capture, injury, and mortality.

The main purpose of this paper was to identify and analyze temporal and spatial patterns in Atlantic marlin by-

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catch as reflected in the Japanese pelagic longlining database, which is the longest-running, most spatially-extensive of its kind (Myers and Worm, 2003). Historical trends in catch-per-unit-effort (CPUE) derived from this data source have been central components of billfish stock assessments, especially for gauging past and present fishing levels and removals relative to MSY (Jones et al., 1998; ICCAT, 2001, 2002; Restrepo et al., 2003; Uozumi, 2003). Our focus here was on variation in marlin bycatch within a 41-yr period (1960–2000) in the subtropical and tropical Atlantic Ocean between lat. 30°N and 30°S—where the bulk of Atlantic marlin catches occurs (Uozumi, 2003).

Of particular interest were quantitative changes that were consistent (or not) with the assertions first posed by Uozumi and Nakano (1994) and then repeated in several papers thereafter (e.g. Yokawa and Uozumi, 2001; Uozumi, 2003), that the relatively low Atlantic blue marlin CPUE's obtained by this fishery since the 1980's were not indicative of low population levels, but rather were artifacts of changes in fishing practices.

Specifically, Yokawa and Uozumi (2001) and Uozumi (2003) suggested that the operational switch from targeting mainly surface-associated albacore, *Thunnus alalunga*, and yellowfin tuna, *Thunnus albacares*, to targeting mainly the deeper-dwelling bigeye tuna, *Thunnus obesus*, has meant: 1) the gear only covered the lower limits of the blue marlin's depth distribution, and 2) shifting of fishing effort to focus on eastern Atlantic waters has amounted to movement away from preferred blue marlin habitats. Their implication, therefore, is that a drop in blue marlin catchability was the basis for any observed decline in blue marlin CPUE, and thus it should not be used, without adjustment, as an index of blue marlin abundance. It is unclear why the same argument was not made to explain the much greater declines in white marlin CPUE.

In this paper, we computed annual effort, target species catch, and marlin bycatch levels as well as CPUE and bycatch ratios (i.e. number of marlin caught per 100 target fishes, B:T ratio) for each Atlantic marlin species. More emphasis was placed on patterns of marlin B:T ratios than on CPUE precisely because the equivalency of effort units (Hilborn and Walters, 1992) over the time series has been questioned. Our objectives were to examine: 1) temporal variation in effort, target catch, and marlin bycatch before, during, and after the fishery's operational switch, 2) spatial changes in fishing effort, marlin CPUE, and marlin B:T ratios, 3) the extent to which marlin B:T ratios have been driven by concurrent changes in target and marlin catches, and 4) the theoretical interrelationships among bycatch and target species catchability and bycatch and target species abundance and how these ultimately affect B:T ratio levels.

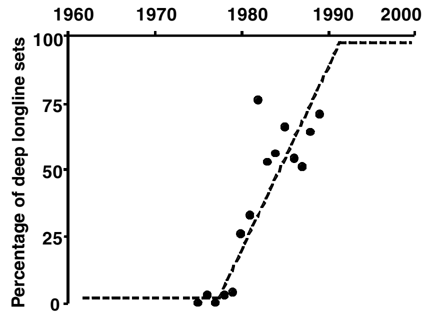

Figure 1.—Percentage of deep longline deployments made by the Japanese pelagic longline fishery in Atlantic waters. Based on data and depth definitions reported by Uozumi and Nakano (1994, Table 2) where a "deep longline" has a theoretical maximum hook depth ranging from 170 to 300 m. Dotted line in plot indicates general trend as described by Uozumi and Nakano (1994).

Materials and Methods

The data analyzed here were a subset of the pelagic Japanese longline (JLL) data series, provided on request by ICCAT. The JLL data series comprises historical (i.e. from 1956 forward) catch and effort information, aggregated on a monthly basis and at the geographic scale of 5° latitude by 5° longitude cell. Effort in the JLL is given as total number of longline hooks deployed and catch as numbers of boated and discarded tunas (several species), swordfish, and istiophorid billfishes. In this investigation, we focused on patterns of blue marlin and white marlin bycatch from 1960 to 2000 and within Atlantic waters between lat. 30°N and 30°S. The spatial focus was chosen because Japanese longline bycatch of marlins beyond these latitudes is relatively minor (Uozumi, 2003). Sailfish and longbill spearfish bycatch trends were not considered because, prior to the late 1990's, catches listed as sailfish actually included an unspecified proportion of longbill spearfish (Uozumi, 2003).

Plots were generated to examine annual variation as well as average decadal patterns in: 1) fishing effort (number of longline hooks deployed), 2) target fish catch (i.e. number of tunas and swordfish combined), 3) blue marlin and white marlin bycatch (in numbers), 4) nominal CPUE for each marlin species (e.g. number of marlin caught per 1,000 hooks), and 5) species-specific marlin B:T ratios (number of marlin per 100 target fishes). Marlin bycatch ratios were calculated as $100^*B_{x,t}/T_t$, where B_x is the total number of marlin of species x captured in year t, and T_t is the total number of target fishes (i.e. tunas and swordfish combined) captured in that same year.

"Decadal" variation in fishing effort, target catch, marlin bycatch, and ratios thereof was evaluated by comparing mean levels before (1960's and 1970's), during (1980's) and after (1990–2000) the Japanese longline fishery's switch from mainly shallow- to deep-fishing configurations (Fig. 1) and its concurrent shift to concentrate on eastern Atlantic waters. Decades were chosen as the unit of time based on the relatively long life span of both marlin species (Wilson, 1984; Hill et al., 1989). Our decadal comparisons (note that 1990–2000 is 11 years, not ten) were made using analysis of variance (ANOVA) models, followed by t-tests, with time period as the independent variable, and fishing effort, target catch, marlin bycatch, marlin CPUE, and marlin B:T ratio as dependent variables.

Following Sokal and Rohlf (1981), problems of non-normality and heterogeneity of variance were minimized via data transformation prior to statistical analyses: fishing effort, target catch, and marlin bycatch values were $\log_e$-transformed, and marlin CPUE and B:T ratio were arcsine-transformed. When comparing means, the Bonferroni method (Sokal and Rohlf, 1987) was used such that "experiment-wise" error rate was held at the P<0.1 level. Also examined at the decadal scale were spatial changes in the distribution and intensity of fishing effort, marlin CPUE, and marlin B:T ratios. This was achieved by computing, for each 5° by 5° cell, decadal averages (from annual totals) and generating maps using the geographical information system software ArcMap.[1]

The "evolution" of the marlin bycatch (a measure of the fishery's inefficiency) over the 41-year time period was examined by plotting what are termed here as marlin "bycatch time trajectories." Specifically, each year's position in an x-y plot was graphed, where the absolute number of target fishes constituted the x-coordinate and the absolute number of a given marlin captured constituted the y-coordinate. In other words, construction of our marlin bycatch time trajectories amounted to plotting the numerator of a given annual B:T ratio against its denominator. Likewise, the mean decadal position (i.e. with vertical and horizontal error bars) of the fishery in this bycatch-target "space" was also graphed. Finally, we also explored, mostly from a theoretical standpoint, how B:T ratio values vary with relative changes in the catchability and abundance of both target and bycatch species.

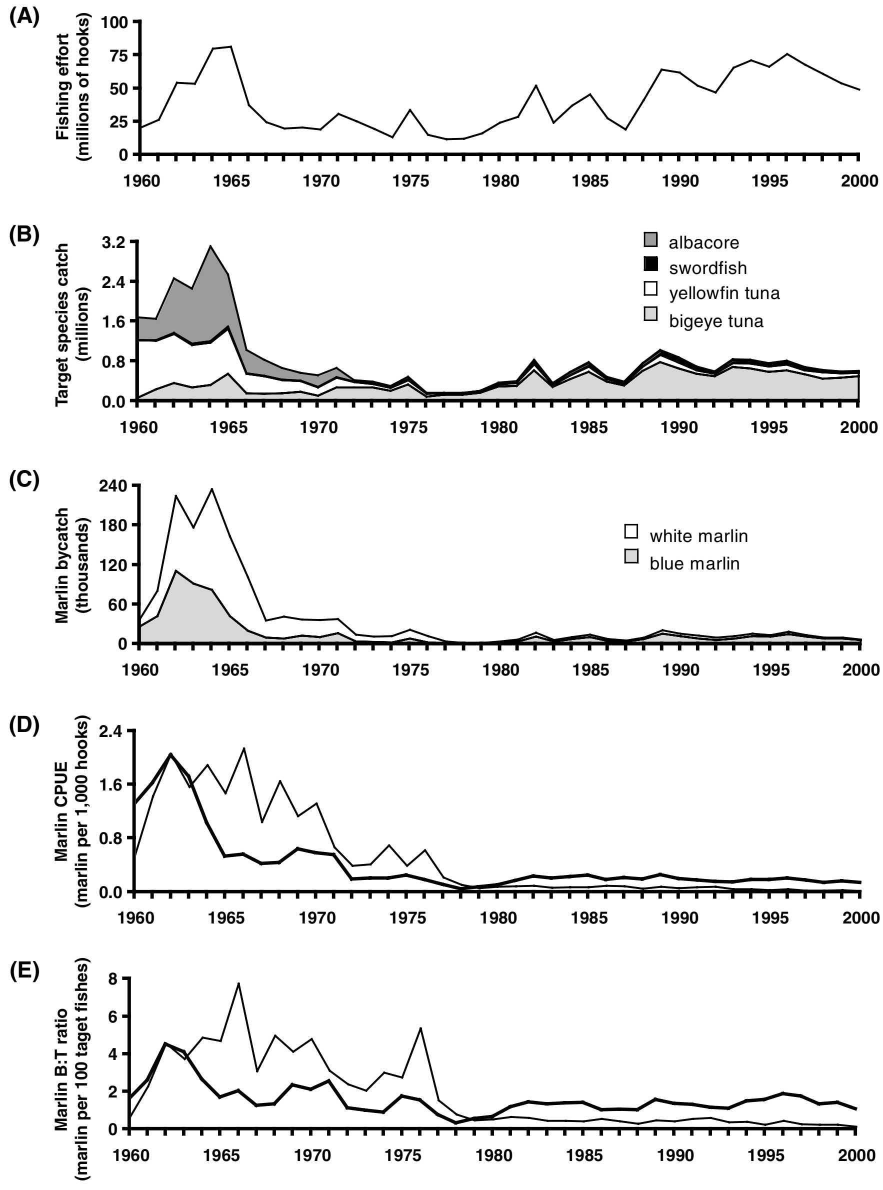

Figure 2.—Historical patterns in (A) fishing effort, (B) target species catch, (C) marlin bycatch, (D) marlin CPUE, and (E) marlin B:T ratios. Panels (B)–(C) are stacked area graphs. Bold and light lines on panels (D) and (E) pertain to blue marlin and white marlin, respectively.

Results

Annual Variation

Shown in Figure 2A–E, from 1960 through 2000, are annual patterns of fishing effort, numbers of target fishes caught, marlin bycatch numbers, marlin CPUE values, and marlin B:T ratios. Fishing effort peaked in 1965 at 82 million hooks, generally declined through 1970 and then gradually increased toward peak levels over the next 25 years (Fig. 2A). Concurrently, the relative proportion of individual target species and their combined numbers changed considerably (Fig. 2B). Highest target species landings were in 1964, when about 3.1 million individual target fishes were harvested with albacore, yellowfin tuna, bigeye tuna, and swordfish constituting 61, 27, 10, and 0.95% of the total target catch, respectively. By 1976, target fish catches had declined to a historical low of about 177,000 individuals, with bigeye tuna alone constituting about half of the catch. From 1976 forward, numbers of target fishes generally increased such that 2000 landings were over 600,000 individuals, with bigeye tuna accounting for 82% of the catch.

Atlantic marlin bycatches (Fig. 2C) generally tracked target fish catches, with the highest numbers of each marlin spe-

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

cies caught per annum in the early to mid 1960's, then dropping to low levels by the late 1970's. Thereafter, blue marlin bycatch levels increased slightly and remained stable, whereas white marlin continued a slow, but steady decline through to the end of the time series. Annual variation in blue marlin and white marlin CPUE levels are shown in Figure 2D. For blue marlin, the highest annual CPUE occurred in 1962, after which CPUE declined over 45-fold to a historical low in 1978 of 0.044 blue marlin per 1,000 hooks. Four years later, blue marlin CPUE had increased about five-fold and then remained somewhat level through the end of the time-series. For white marlin, the highest CPUE values occurred up until 1970, but these were followed by a rapid, consistent decline through to the end of the time-series with the historical low occurring in the most recent year examined (i.e. 2000).

Year-to-year changes in the numbers of each marlin species caught per 100 target fishes (i.e. B:T ratios) are shown in Figure 2E. Blue marlin B:T ratios followed the same general pattern as corresponding CPUE values, except that the rate of decline from 1962 to 1978 was less severe (a three-fold reduction). From 1982 forward, blue marlin B:T ratios remained somewhat level, ranging from 1.0 to 1.9. Similarly, annual variation in white marlin B:T ratios resembled that of white marlin CPUE. Relatively high B:T ratio values (i.e. from 2.1 to 7.8) persisted from 1962 through 1976. This was followed by a rapid decline from 1976 to 1978, and then a more gradual decline from 0.82 in 1978 to 0.14 in 2000.

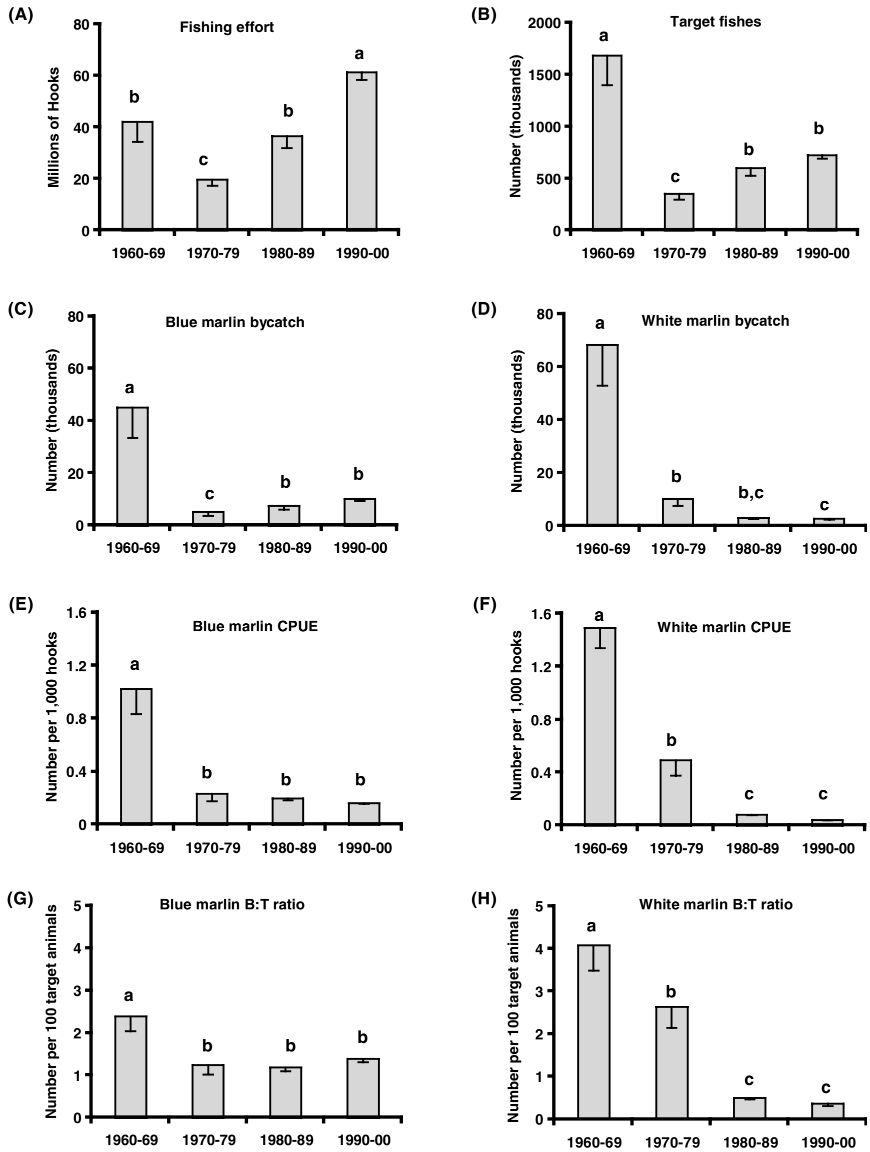

Figure 3.—Comparison of mean effort, target catch, marlin bycatch, and ratios thereof during the 1960's, 1970's, 1980's, and the 1990–2000 time periods. Statistical testing conducted after ln-transformation; ratios after arcsine-transformation. Bars sharing the same lowercase letter are not statistically different. Lines within bars indicate 1 standard error.

Temporal Comparisons

Figure 3 depicts results of the "decadal" analyses performed to examine for consistency with the assertion of Uozumi (2003). Mean annual fishing effort (i.e. average number of hooks deployed) initially dropped from over 40 million hooks in the 1960's to about 20 million hooks in the 1970's after which it increased steadily to almost 60 million hooks by the 1990–2000 time period (Fig. 3A). Concurrently, the catch of target fishes followed a similar pattern with a large drop from the 1960's to the 1970's followed by a statistically significant increase through the 1990–2000 time period (Fig. 3B). For both marlin species, mean bycatch levels dropped sharply from the 1960's to the 1970's, but then displayed very different patterns thereafter (Fig. 3C, D).

Whereas average bycatch of blue marlin increased two-fold from the 1970's to the 1990–2000 period, white marlin bycatch decreased by about two-thirds from the 1970's to the 1980's and remained at this level thereafter. Likewise, patterns of mean CPUE and B:T ratios also varied according to species. Highest mean levels for both species were during the 1960's, but in the case of blue marlin, no significant differences in mean CPUE or B:T ratio were detected from the 1970's forward (Fig. 3E, G).

Conversely, mean CPUE and B:T ratio values of white marlin followed the same general pattern of their landings—an 80% or greater reduction occurring from the 1970's to the 1980's followed by a statistically equivalent mean in the 1990–2000 time period (Fig. 3F, H).

Spatial Patterns

The distribution and intensity of Japanese longlining fishing effort within Atlantic subtropical and tropical waters has expanded and contracted over the 41-year time series of data (Fig. 4). During the 1960's, fishing effort was distributed throughout the study area, with areas of high intensity throughout. This was followed by a decade of much-reduced fishing effort between lat. 30°N and S, especially in middle Atlantic waters, with the heaviest fishing occurring in the Gulf of Mexico and in two distinct areas off the northwestern and the southwestern African continent. The ensuing 1980's was a period of renewed spatial expansion in the study area with the highest fishing intensity again occurring in the eastern Atlantic Ocean, but more so in equatorial waters. Finally, the pattern of fishing effort during the 1990–2000 time period was much the same as that of the previous decade, with the intensity of fishing generally increasing in eastern Atlantic waters. It was also during this latest time period that the fishery vacated or greatly reduced effort in areas of the Gulf of Mexico, the Caribbean Sea, and east of the island chains of the Bahamas and Lesser Antilles.

The spatial distribution and magnitude of marlin CPUE values by decade are presented in Figure 5. Clearly, the 1960's was a period of high CPUE values for both species, especially in western Atlantic waters and for white marlin in particular. The pattern of greater blue marlin and white marlin CPUE values in the western Atlantic persisted in the 1970's, but with large reductions in magnitude, particularly in middle Atlantic waters. In general, the spatial pattern in blue marlin CPUE values was similar in the ensuing two time periods, but with an overall tendency for reduction. In contrast, for white marlin, there was a continual, ubiquitous decline throughout

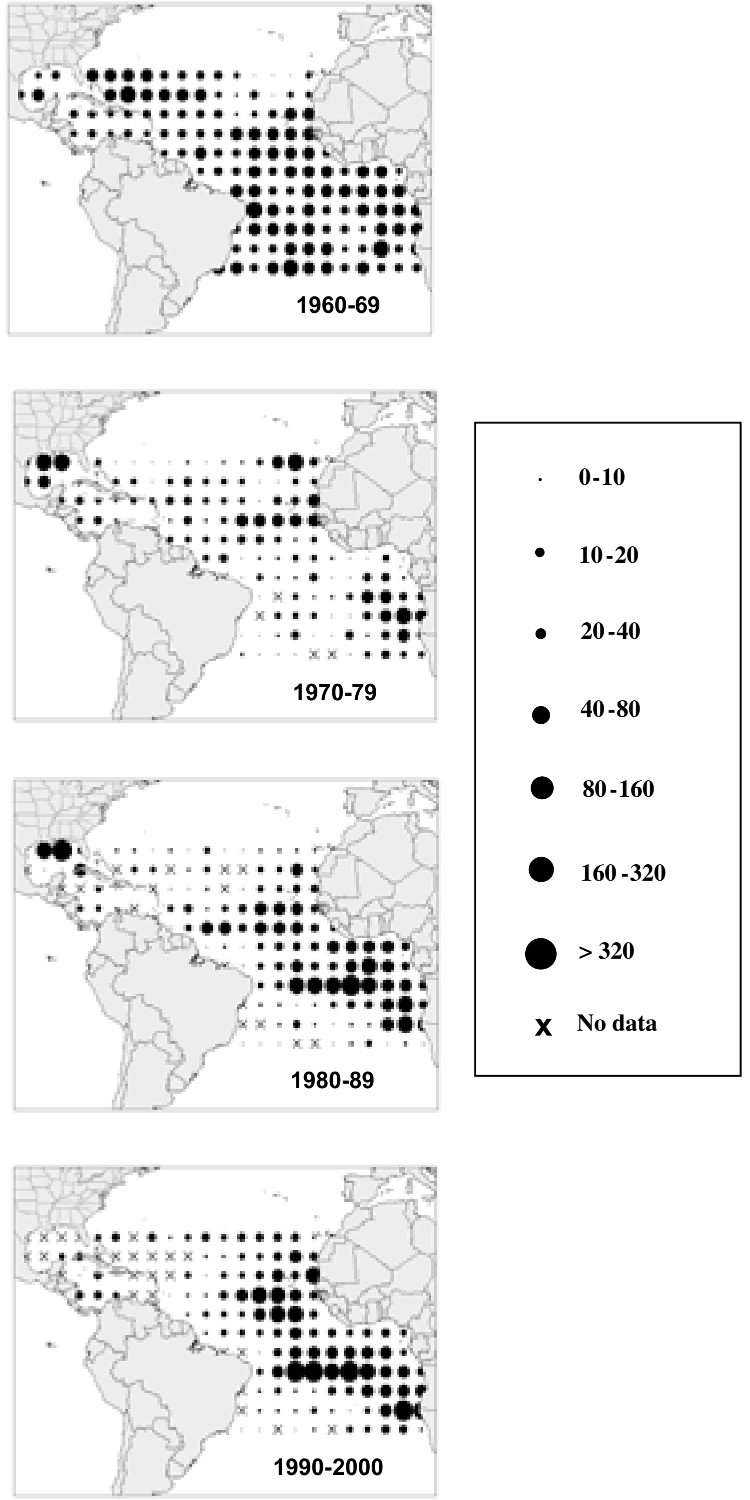

Figure 4.—Spatial distribution and intensity of Japanese longlining fishing effort in the Atlantic Ocean between lat. 30° N and S. Depicted is the average number of hooks deployed in each 5° × 5° cell per time period.

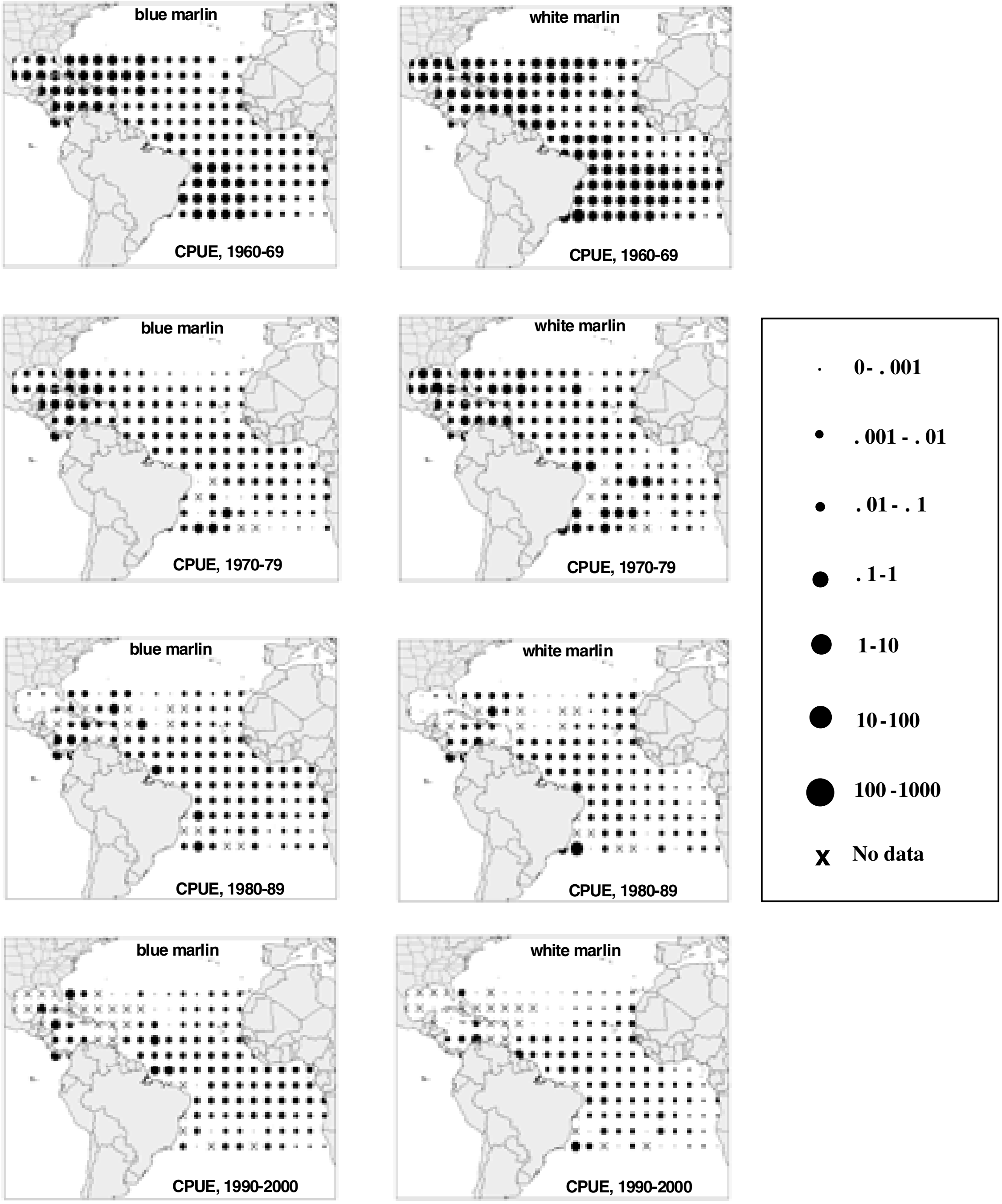

Figure 5.—Average marlin catch-per-unit-effort (number of marlin caught per 1,000 hooks) in the Atlantic Ocean between lat. 30°N and S.

the study area. Corresponding historical maps of marlin B:T ratios (Fig. 6) share many similarities with CPUE maps. The spatial pattern of marlin B:T ratios during the 1960's indicates generally high values throughout the domain for both species with a tendency for the highest values to occur in the western Atlantic. As with marlin CPUE, the magnitude of B:T ratio values are much reduced during the 1970's, especially in certain eastern and middle Atlantic areas. Again, the two marlin species respond differently after the 1970's with respect to B:T ratio. During the 1980's and the 1990–2000 time period, blue marlin B:T ratio maps indicate either minor change or increases in fished areas of

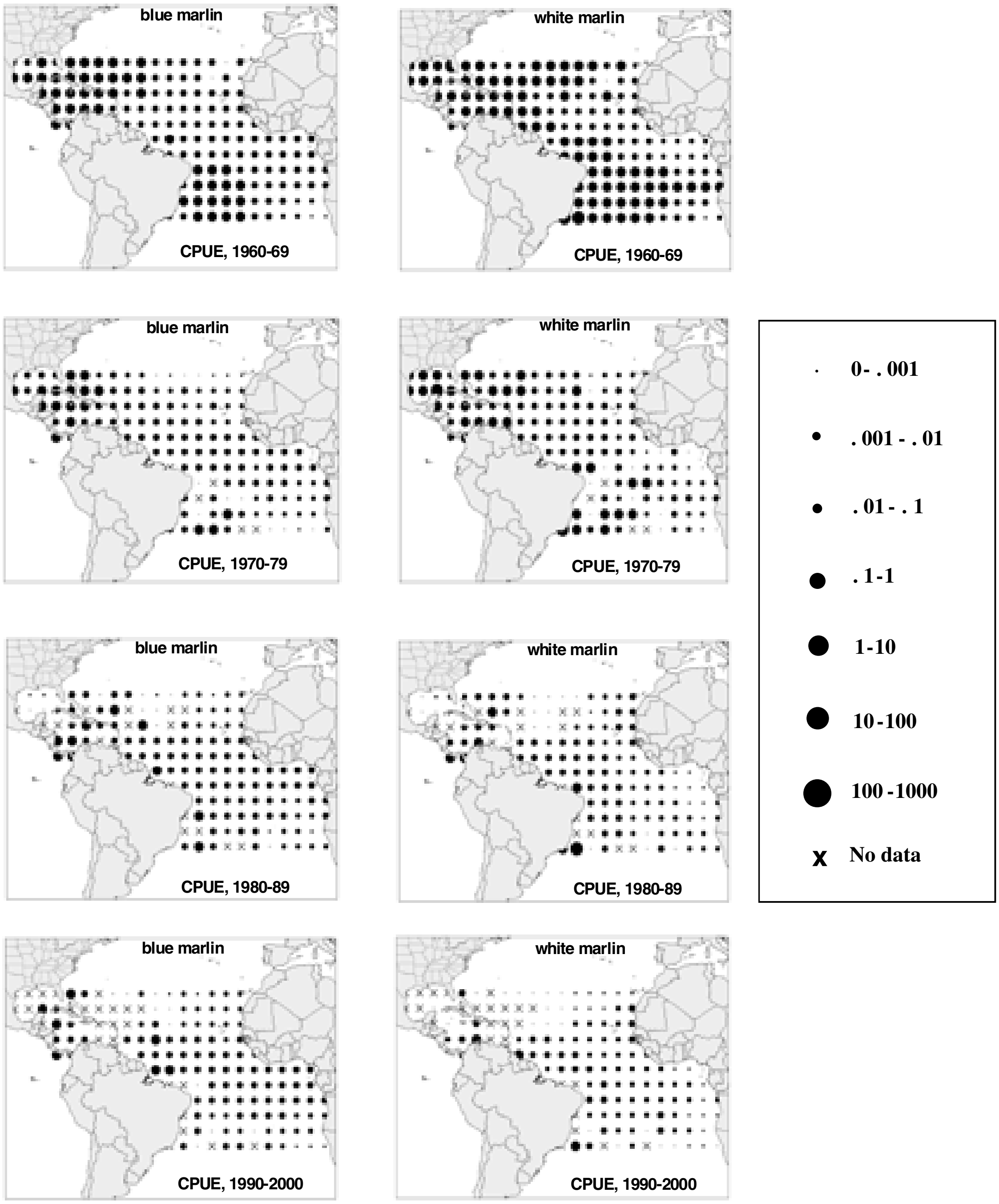

Figure 6.—Average marlin B:T ratio values (number of marlin caught per 100 target fishes) in the Atlantic Ocean between lat. 30°N and S.

the Caribbean Sea, off Brazil, and off the southern African coast. Concurrently, white marlin B:T ratio maps indicate severe reduction in values throughout the entire study area, especially by the 1990–2000 time period. These results imply that shifts in fishing grounds have had lesser effects on white marlin B:T ratios relative to other changes, such as those of gear configuration.

Bycatch Time Trajectories

A major limitation of using B:T ratios alone is that the magnitude of the numerator (B) and the denominator (T) are hidden; we dealt with this with our bycatch time trajectory graphs whereby numbers of both marlin species were plotted against numbers of target fishes (Fig. 7). This data presentation allows the "tracking" (from one year to the next) of the fishery's efficiency (strictly, inefficiency) at catching marlins over the 41-year time period. The bycatch time trajectory of blue marlin and white marlin are broadly similar in that it is during the 1960's that the highest bycatch and target catch values (as well as the greatest inter-annual changes) occur for both species. Likewise, during the 1970's, for both marlin species, the fishery "moves" towards the origin with the lowest bycatch and target catch numbers occurring at the end of this decade. However, after the 1970's, the bycatch trajectories for blue marlin and white marlin diverge. Whereas blue marlin numbers increase as target catch numbers increase during the ensuing 21 years, white marlin numbers remain consistently low. Figures 7E and 7F emphasize this difference by showing the average coordinates (± 1 standard error) in marlin bycatch—target catch "space" during the 1970's, 1980's, and the 1990–2000 time periods.

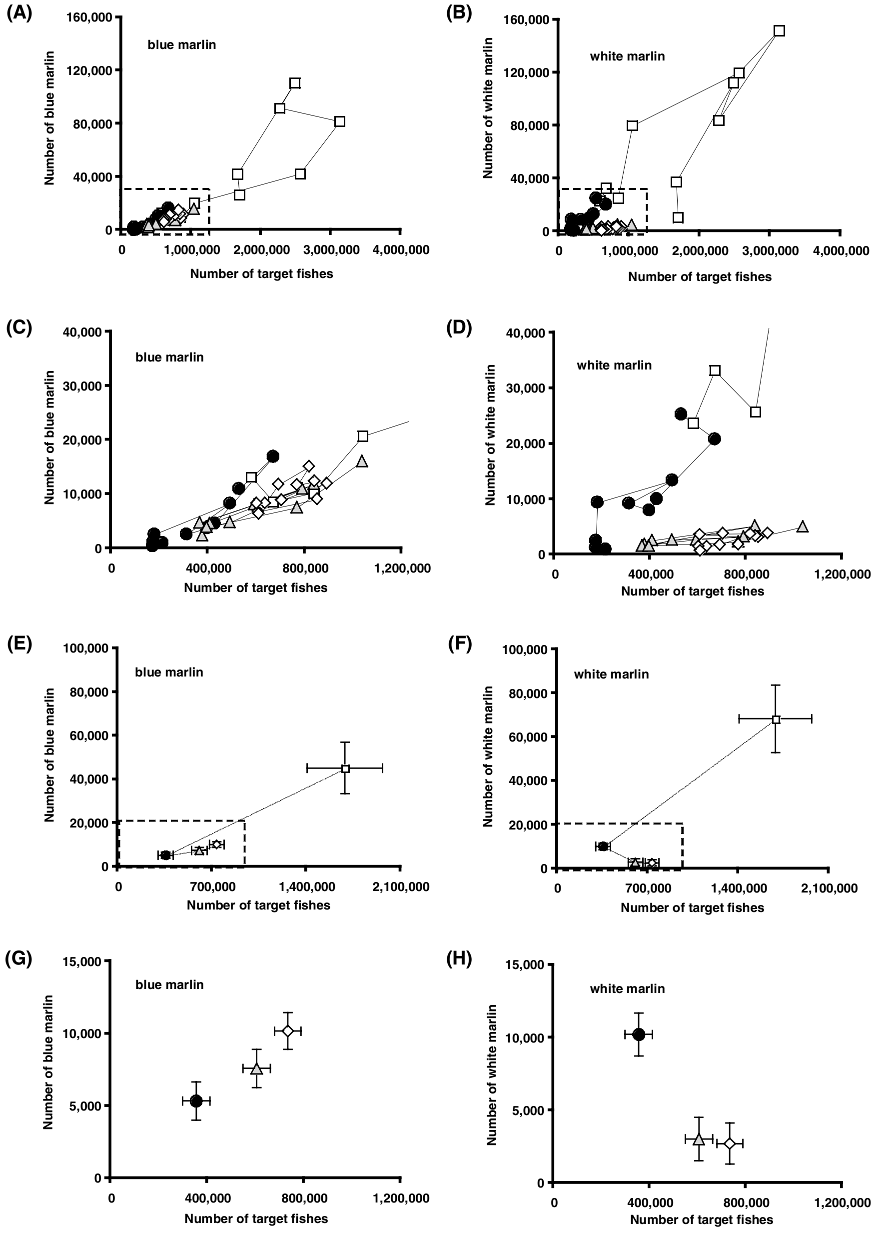

Figure 7.—Marlin bycatch time trajectories. Squares, dots, triangles, and diamonds, respectively, indicate years of the 1960's, 1970's, 1980's, 1990's, and 2000. Panels E–H show decadal mean values (± 1 S.E.). Note that plots in panels C and D are expanded views of areas defined by dotted lines in panels A and B. Likewise, plots in panels G and H are expanded views of areas defined by dotted lines in panels E and F.

Discussion

The Japanese longlining data set examined here has been invaluable in numerous single-species stock assessments (see ICCAT, 2002) for assessment results on bluefin tuna, yellowfin tuna, albacore tuna, bigeye tuna, white marlin, blue marlin, and sailfish) and, most recently, as a means of quantifying changes in pelagic predatory fish communities in the global ocean (Myers and Worm, 2003). As the primary index of the relative abundance of one or more target or bycatch species, catch-per-unit-effort, and historical changes therein, has received the most scrutiny in previous analyses. By comparison, little attention has been placed on ratios of bycatch to target species (B:T ratios) and how these have varied over time and space (though see Goodyear, 1999). Similarly, debate over what CPUE trajectories imply about marlin stocks (see Goodyear, 2003) and Uozumi (2003) for contrasting points of view) has deflected attention away from trends in absolute quantities of marlin bycatch, which, in the case of blue marlin, have increased significantly since the purported operational switch.

Evident from our analyses was that it was during the 1960's that the highest values of all variables examined occurred. Fishing effort, target catch, marlin bycatch, marlin CPUE's, and marlin B:T ratios all peaked in the early or mid 1960's and, overall, then fell during the second half of that decade. Since 1970, mean levels of fishing effort, target fish catches, and blue marlin bycatch have increased significantly while blue marlin CPUE and B:T ratios have remained relatively stable. Concurrently, white marlin landings, CPUE, and B:T ratios have all declined drastically. All the above occurred as fishing grounds were shifted to focus on eastern Atlantic waters and gear was deployed to allow for deeper fishing to better target bigeye tuna. Presumably, an underlying reason for increased targeting of bigeye tuna was economic. In the Tokyo sashimi market, albacore, yellowfin, and bigeye tuna had similar values during the 1960's, whereas by the early 1990's, bigeye tuna commanded over triple the prices of each of the other species (Fonteneau, 1998).

Implicit in calculation of B:T ratios over time is that any change in catchability for the target species is known. Catchability for an individual species can change due to fishing operations or advances in technology but are often relatively minor and assumed constant in many stock assessments. Of more concern for this case is that the relative proportion of species in the target catch can change over time, implying a change in overall catchability if the catchability of each species is different. Given the similar order of magnitude for catches of the different target species at their respective peaks, we do not think this is a problem for our analyses of the Atlantic marlin B:T ratios. However, we note that almost all of the change in target species composition occurred during the 1960's and have remained relatively constant since 1970, with bigeye tuna as the dominant target species.

Uozumi and Nakano (1994) and Uozumi (2003) have not contested that Atlantic blue marlin and white marlin stocks were larger during the 1960's than at any point since. However, they have attributed low blue marlin CPUE levels obtained since the mid 1980's to changes in fishing practices and fishing grounds rather than to low or declining population levels. Whereas our white marlin bycatch, CPUE, B:T ratio, and bycatch time trajectory results could be construed as being consistent with this scenario, the same cannot be said of blue marlin. We contend that if the fishery's effective effort had indeed shifted away from primary blue marlin habitat, this would be reflected in lower average B:T ratios for this species. For the most part, this has not transpired, and whatever the operational changes that have, or have not, occurred, it appears that this fishery is no less efficient at capturing blue marlin. Consequently, because on average JLL fishing effort has about doubled from the 1970's to the 1990–2000 time period, so too has the blue marlin bycatch of this fishery.

Two interrelated assumptions form the basis of the fishing operation change argument of Uozumi and Nakano (1994) and Uozumi (2003): 1) that blue marlin are restricted to the shallowest strata of the water column, and 2) that longline fishing gear configured to fish deeply, usually does so. Electronic tagging and experimental longline fishing studies indicate greater utilization by both Atlantic marlin species of shallow vs. deep waters (Yang and Gong, 1988; Block, 1990); however, multiple daily excursions to depths of >200 m by blue marlin are not uncommon. This frequent deep-diving behavior, especially if associated with foraging (Graves et al., 2002; Kerstetter, 2003), may be the reason for the relative stability of blue marlin CPUE values and B:T ratios from 1970 forward. While the fishery may never have been fishing "deep enough" to reduce blue marlin bycatch, it is possible that some reduction in white marlin bycatch has occurred, although the magnitude of this reduction is unclear. The work of Yang and Gong (1988), Block (1990), and Horodysky et al. (2003) support the notion that white marlin inhabit, and presumably feed within, shallower depth strata than blue marlin; this may be a consequence of white marlin possessing lesser quantities of brain-eye heater tissue as compared to blue marlin (Block, 1990). That said, we are unconvinced that fishing depth changes have been a major contributor to the post-1979 patterns of CPUE and B:T ratio decline for white marlin. This is because other independent data sources, which are not complicated by major fishing operation changes, also point to drastic declines in white marlin population levels (ICCAT, 1994, 1998, 2001, 2003a). Therefore, we suspect that any reduction in white marlin catchability resulting from the JLL fishing deeper in the water column has not had a substantial effect on white marlin stock abundance, especially given that fisheries of nations other than Japan have combined to inflict most of the fishing mortality on this species in recent years.

Direct testing of the second (implicit) assumption behind the Uozumi (2003) contention (i.e. that a longline gear rigged to fish deeply, actually does) can be achieved via the attachment of electronic time-depth recorders (TDR's) in close proximity to baited longline hooks. Conversion of a longline from shallow- to deep-fishing typically entails increasing the distance between floats and/or extending the length of branch lines. While these measures can increase the maximum depths at which hooks settle, oceanographic conditions, gear deployment and retrieval velocity, hooked fish, and numerous other factors tend to conspire to make actual hook depths shallower than predicted from gear geometry (i.e. from catenary curves). This is readily apparent in experimental longline studies using TDR's such as that of Boggs (1992) who found that his gear averaged between 54% and 68% of predicted depths. Similar studies by Yanno and Abe (1998), Berkeley and Edwards (1998), and Mizuno et al. (1999) tend to corroborate this finding. Furthermore, as pointed out by Goodyear et al. (2003), all gear, regardless of configuration, must spend some time in the shallowest depth strata. Therefore, the estimated depth of capture of fish hooked when baits are either sinking during gear deployment or rising during gear retrieval will tend to be over- rather than underestimated. To better resolve the behavior of pelagic fish and the behavior of longline gear, Goodyear et al. (2003) and ICCAT (2003b) recommended further studies that combine TDR's and hook timers (electronic devices that record strike time) as well as the use of electronic archival tags. The use of archival tags holds great promise for quantifying habitat use and behavior of bycatch and target species as these devices can be programmed to record minute-by-minute measurements of the depths and temperatures experienced by their bearers along with estimates of geolocation for periods of months to years (Arnold and Dewar, 2001).

Analyses of B:T ratios (alone) shed no light on stock abundance or the population status of these species—nor can they. Unlike CPUE, the B:T ratio is a measure of a fishery's efficiency to harvest desirable species over undesirable ones. Among the potential benefits of using B:T ratios are that they are simple to compute, economically relevant and, therefore, readily grasped by fishers, managers, and the public. Also, the mapping of marlin B:T ratios has been shown to have utility for identifying potential time-area closure locations (Goodyear, 1999). In this study, relative increases in blue marlin B:T ratios off the northeastern coast of South America and in the entire eastern Atlantic are cause for concern as are continuing trends of CPUE decline (well after the target switch) for white marlin in this data set as well as others (ICCAT, 2001, 2003a).

Unfortunately, the magnitude of marlin B:T ratios observed in this study are not easily compared with those of other fisheries because (matched) bycatch and target species quantities are rarely reported on a species-specific basis and, when ratios are calculated, they are often computed using fish weights (Alverson et al., 1994; Hoey, 1995; Gaertner et al., 2002; Romanov, 2002). For the purpose of comparison, we computed mean marlin B:T ratios using data contained in the U.S. pelagic longline logbook database (Cramer, 1996). By our calculation, blue marlin and white marlin B:T ratios for this fishery for the period 1992–2000 (and in the same spatial domain) have been 1.8 and 1.3, respectively; recall that corresponding values were 1.4 and 0.4 for the Japanese fishery. No doubt the apparently large discrepancy between white marlin B:T ratio values obtained for the U.S. vs. the JLL fishery is due to a combination of fishing technique differences and higher abundances of this species in the western Atlantic waters compared to the region as a whole.

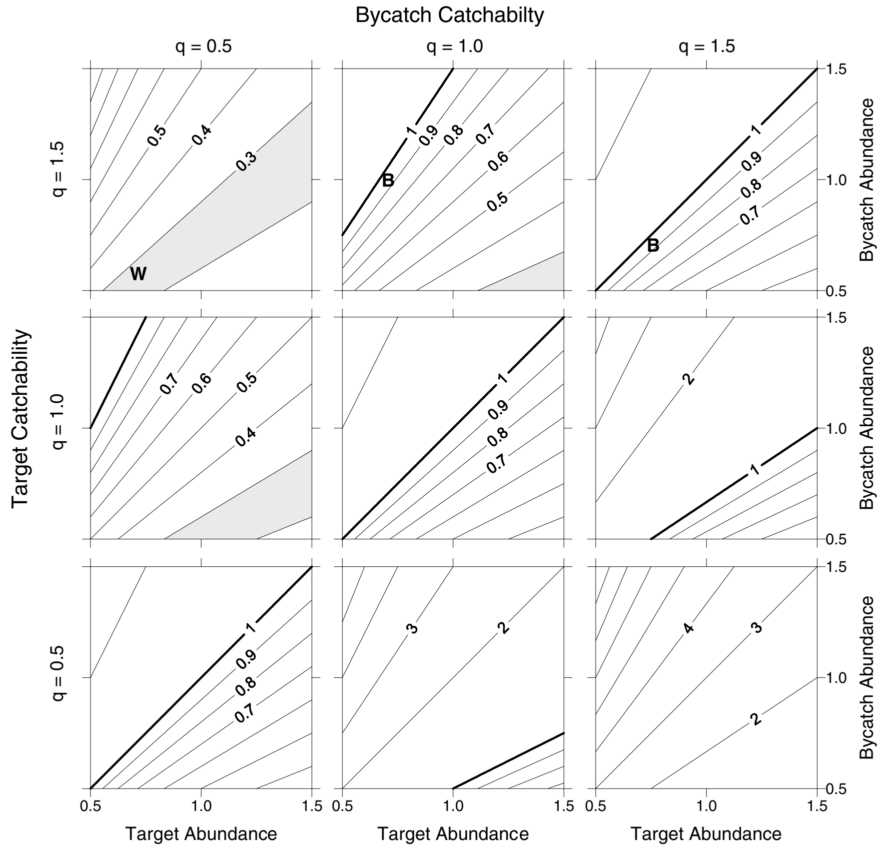

Figure 8.—B:T ratios for combinations of relative change in bycatch catchability (columns), target catchability (rows), target abundance (x-axis of plots), and bycatch abundance (y-axis of plots). Isopleths are shown in increments of 0.1 for values below 1.0 and in increments of 1.0 for values above 1.0. The thick line in each plot (if visible) denotes the no change in B:T ratio isopleth, roughly corresponding to the case of blue marlin. The shaded region in each plot (if visible) denotes the decline to 20–30% of original B:T ratio, roughly corresponding to the case of white marlin. The "W" and "B" in the top row of panels indicate likely position(s) of white marlin and blue marlin, respectively, during the 1990–2000 time period relative to the 1970's.

Whatever the cause, there is clearly room for testing new methods and approaches that further reduce the efficiency of all longline operations to capture unwanted species, including marlins. These include experimenting with different hook types (Prince et al., 2002) and baits (Broadhurst and Hazin, 2001), time-area closures (Goodyear, 1999), and perhaps novel bycatch avoidance devices, such as acoustic pingers (Barlow and Cameron, 2003).

An important feature of the B:T ratio is that it integrates changes in the quantity and location of effort. This can be seen by writing out the catch equation for both the bycatch and target species as C(x) = q(x)*f*N(x) where C=catch, q=catchability, f=effort, N=abundance, and x denotes either bycatch or target species. The B:T ratio is thus q(B)*N(B)/[q(T)*N(T)], and effort has been removed from the equation. Removal of effort as a variable is highly desirable in any case where the equivalency of effort units at the beginning vs. the end of a historical time series has been called into question (and when appropriate data for effort standardization are unavailable).

Figure 8 illustrates how changes in B:T ratio can be explained by combinations of the relative catchabilities and abundances of the bycatch and target species. Whereas changes in one variable can be offset by equivalent relevant changes in another variable, in our case, the situation is somewhat simplified because we are not entirely ignorant about q(T) and N(T) over the 41-year time period. For example, the abundance of the main target species (bigeye tuna) is known to have decreased (ICCAT, 2002), and it is reasonable to assume that target species catchability has increased (i.e. especially given that, over the time period in question, vessel sizes and ranges have tended to increase, sophisticated marine electronics have been increasingly used, and new fishing gear materials, hydraulic systems, and numerous other developments have been adopted).

Given the above, what possible combination of abundance and catchability changes could have led to the marlin B:T ratio patterns observed in this study? If we assume that a 25% target abundance decrease coincided with a 50% target catchability increase from the 1970's to the 1990–2000 time period, then the left side of the panels in the top row of Figure 8 are relevant. In the case of the relatively stable blue marlin B:T ratios, either both bycatch abundance and catchability remained about the same, or a decrease in blue marlin abundance was offset by an equivalent increase in its catchability (two positions labeled "B" in Figure 8).

If blue marlin catchability reduction is hypothesized, however, it must have been offset by a decrease in target abundance that exceeded the combined influence of blue marlin abundance decrease and target catchability increase. Otherwise, the blue marlin B:T ratio would not have remained relatively constant. In contrast, the white marlin pattern of B:T ratio decline over the same time period suggests that this species' abundance and its catchability decreased (area labeled "W" in Figure 8). In fact, given the knowledge about changes in target abundance and catchability, an assumption of no change in bycatch catchability would require an extreme depletion of white marlin (>70%) to achieve the observed B:T ratio. This demonstrates one utility of B:T ratios—hypotheses regarding changes in bycatch catchability can be directly examined relative to observed or assumed changes in target catchability and abundance.

In conclusion, several distinct temporal, spatial, and species-specific patterns are apparent in the Atlantic marlin bycatch of the Japanese pelagic longline fishery from 1960 to 2000. The fishery has contracted and expanded geographically, generally reflecting a shift eastward, and varied considerably in terms of fishing intensity. The most obvious pattern shared by the marlins is that both stocks suffered their greatest declines well before bigeye tuna became the primary target species of this fishery.

Differences between species, that possibly reflect operational fishing changes, become apparent when absolute bycatch quantities, CPUE values, and B:T ratio values are examined from 1970 forward. We found no patterns consistent with the contention of Uozumi (2003) that targeting bigeye tuna has resulted in reduced blue marlin bycatch or that suggests that some catchability adjustment is warranted to gain a better historical perspective of long term population changes for this species. Whereas the possibility exists that white marlin catchability may have decreased, any benefits to its stock appear to have been eclipsed by the general increase in fishing effort on a population that, even in the most recent decade, shows evidence of consistent decline.

Clearly, further work is required to establish whether the bycatch patterns evident in the Japanese pelagic longline fleet are consistent with those derived from other pelagic fishing fleets operating in the Atlantic Ocean. Especially where past or future fishing practice or gear changes are of interest, the consideration of spatial and temporal patterns in species-specific B:T ratios may be a useful, complementary approach.

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Literature Cited

Alverson, D. L., M. H. Freeburg, J. G. Pope, and S. A. Murawski. 1994. A global assessment of fisheries bycatch and discards. Food Agric. Organ., U.N., FAO Fish. Tech. Pap. 339, 233 p.

Arnold, G., and H. Dewar. 2001. Electronic tags in marine fisheries research. *In* J. R. Sibert, and J. L. Nielson (Editors), Electronic tagging and tracking in marine fisheries, p. 7–64. Kluwer Acad. Publ., Boston.

Barlow, J., and G. A. Cameron. 2003. Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. Mar. Mamm. Sci. 19: 265–283.

Beerkircher, L. B., C. J. Brown, and D. W. Lee. 2002. SEFSC pelagic observer program data summary for 1992-2000. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-486, 26 p.

Berkeley, S., and R. Edwards. 1998. Factors affecting billfish capture and survival in longline fisheries: potential application for reducing bycatch mortality. Int. Comm. Conserv. Atl. Tunas, Madrid, Coll. Vol. Sci. Pap. 48:255–262.

Bjordal, A., and S. Lokkeborg. 1996. Longlining. Fishing News Books, Blackwell Sci., Inc., Cambr., Mass., 156 p.

Block, B. A. 1990. Physiology and ecology of brain and eye heaters in billfishes. *In* R. H. Stroud (Editor), Planning the future of billfishes. Research and management in the 90's and beyond, p. 123–136. Proc. Second Int. Billfish Symp., Kailua-Kona, Hawaii, Aug. 1–5, 1988. Part 2: Contrib. pap. Mar. Rec. Fish. 13.

Boggs, C. H. 1992. Depth, capture time and hooked longevity of longline-caught pelagic fish: timing bites of fish with chips. Fish. Bull. 90:642–658.

Broadhurst, M. K., and F. H. V. Hazin. 2001. Influences of bait on catches of swordfish (*Xiphias gladius*) and other species in an artisanal sub-surface longline fishery off northeastern Brazil. Fish. Res. 53:169–179.

Cramer, J. 1996. Recent trends in the catch of undersized swordfish by the U.S. pelagic longline fishery. Mar. Fish. Rev. 58:24–32.

Fonteneau, A. 1998. A comparison of bigeye stocks and fisheries in the Atlantic, Indian and Pacific Oceans. *In* R. B Deriso, W. H. Bayliff, and N. J. Webb (Editors), Proceedings of the First World Meeting on Bigeye Tuna, p. 190–211. Inter-Am. Trop. Tuna Comm., Spec. Report 9.

Gaertner, D., F. Menard, C. Develter, J. Ariz, and A. Delgado de Molina. 2002. Bycatch of billfishes by the European tuna purse seine fishery in the Atlantic Ocean. Fish. Bull. 100:683–689.

Goodyear, C. P. 1999. An analysis of the possible utility of time-area closures to minimize billfish bycatch by U.S. pelagic longlines. Fish. Bull. 97:243–255.

__________. 2003. Mean hook depth—an unsuitable metric for computing effective effort for standardizing billfish longline CPUE. Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap. 55(2):669–687.

__________, D. Die, D.W. Kerstetter, D. B. Olsen, E. Prince, and G. P. Scott. 2003. Habitat standardization of CPUE indices: research needs. Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap. 55:613–623.

Graves, J. E., D. W. Kerstetter, B. E. Luckhurst, and E. D. Prince. 2002. Habitat preferences of istiophorid billfishes in the western north Atlantic: applicability of archival tag data to habitat-based stock assessment methodologies. Int. Comm. Conserv. Atl. Tunas SCRS/0/071, 10 p.

__________, and J. R. McDowell. 2003. Stock structure of the world's istiophorid billfishes: a genetic perspective. Mar. Fresh. Res. 54:287–298.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, N.Y., 570 p.

Hill, K. T., G. M. Cailliett, and R. L. Radtke. 1989. A comparative analysis of growth zones in four calcified structures of Pacific blue marlin, *Makaira nigricans*. Fish. Bull. 87:829–843.

Hoey, J. J. 1995. Bycatch in western Atlantic pelagic longline fisheries, *In* Solving bycatch: considerations for today and tomorrow. Alaska Sea Grant Coll. Program Rep. 96-03, 322 p.

Holland, K. N. 2003. A perspective on billfish biological research and recommendations for the future. Mar. Fresh. Res. 54:343–347.

Horodysky, A. Z., D. W. Kerstetter, and J. E. Graves. 2003. Habitat preferences and diving behavior of white marlin (*Tetrapturus albidus*) released from the recreational rod-and-reel and commercial pelagic longline fisheries in the western North Atlantic Ocean: implications for habitat-based stock assessment models. Int. Comm. Conserv. Atl. Tunas SCRS/2003/033, 13 p.

ICCAT. 1994. Report of the second ICCAT Billfish Workshop. Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap., XLI, 587 p.

________. 1998. Report of the third ICCAT Billfish Workshop. Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap., XLVII, 352 p.

________. 2001. Proceedings of the Fourth Billfish Workshop, Miami, Florida USA. Stock Assessment Analyses. Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap. 53:10–110.

________. 2002. Report for biennial period, 2000-2001. Int. Comm. Conserv. Atl. Tunas, Madrid, Spain. 2:Pt. II (2001), 204 p.

________. 2003a. Report of the 2002 ICCAT white marlin stock assessment meeting (Madrid, May 14-17, 2002). Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap. 55(2):350–452.

________. 2003b. Report of the 2003 Meeting of the ICCAT Working Group on Assessment Methods (Shimizu, Japan, 7–11 April, 2003). Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap., SCRS 2003/013.

IGFA. 1996. World record game fishes. Int. Game Fish Assoc., Pompano Beach, Fla., 352 p.

Jones, C. D., E. D. Prince, G. P. Scott, and M. I. Farber. 1998. Models of blue marlin and white marlin in the Atlantic Ocean: a case history. *In* F. Funk, T. J. Quinn II, J. Heifetz, J. N. Ianelli, J. E. Powers, J. F. Schweigert, P. J. Sullivan, and C.-I. Zhang (Editors), Fishery stock assessment models. Lowell Wakefield Fish. Symp., p. 99–119. Univ. Alaska Sea Grant Coll. Program Rep. 98-01.

Kerstetter, D. W., B. E. Luckhurst, E. D. Prince, and J. E. Graves. 2003. Use of pop-up satellite archival tags to demonstrate survival of blue marlin (*Makaira nigricans*) released from pelagic longline gear. Fish. Bull. 101:939–948.

Mizuno, K., M. Okazaki, H. Nakano, and H. Okamura. 1999. Estimating the underwater shape of tuna longlines with micro-bathythermographs. Inter-Am. Trop. Tuna Comm. Spec. Rep. I-ATTC, 10, 35 p.

Myers, R. A., and B. Worm. 2003. Rapid worldwide depletion of predatory fish communities. Nature 423:280–283.

Ortiz, M, E. D. Prince, J. E. Serafy, D. B. Holts, K. B. Davy, J. G. Pepperell, M. B. Lowry, and J. C. Holdsworth. 2003. A global overview of the major constituent-based billfish tagging programs and their results since 1954. Mar. Fresh. Res. 54:489–507.

Prince, E. D., and B. E. Brown. 1991. Coordination of the ICCAT enhanced research program for billfish. *In* Proceedings of the international symposium and workshop on creel and angler surveys in fisheries management, p. 13–18. Houston, Tex. Am. Fish Soc. Symp. 12.

__________, M. Ortiz, and A. Venizelos. 2002. A comparison of circle hook and "j" hook performance in recreational catch-and-release fisheries for billfish. Am. Fish. Soc. Symp. 30:66–79.

Restrepo, V., E. D. Prince, G. P. Scott, and Y. Uozumi. 2003. ICCAT stock assessments of Atlantic billfish. Mar. Fresh. Res. 54:361–367.

Robins, C. R., and G. C. Ray. 1986. A field guide to Atlantic coast fishes of North America. Peterson Field Guide Series. Houghton Mifflin, Boston, 354 p.

Romanov, E. V. 2002. Bycatch in the tuna purse-seine fisheries of the western Indian Ocean. Fish. Bull. 100:90–105.

Sainsbury, J. C. 1996. Commercial fishing methods: an introduction to vessels and gears. Fishing News Books, Blackwell Sci., Inc., Camb., Mass., 359 p.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. The principles and practice of statistics in biological research. W. H. Freeman and Co., N.Y., 859 p.

__________ and __________. 1987. Introduction to biostatistics. W. H. Freeman and Co., N.Y., 567 p.

Uozumi, Y. 2003. Historical perspective of global billfish stock assessment. Mar. Fresh. Res. 54:555–565.

Uozumi, Y., and H. Nakano. 1994. A historical review of Japanese longline fishery and billfish catches in the Atlantic Ocean. Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap. 17:471–486.

Wilson, C. A. 1984. Age and growth aspects of the life history of billfish. Ph.D. dissert., Dep. Biol., Univ. S. C., Columbia, 180 p.

Yang, W. S., and Y. Gong. 1988. The vertical distribution of tunas and billfishes and fishing efficiency between Korean regular and deep longlines in the Atlantic Ocean. Bull. Natl. Fish. Res. Dev. Agency [Pusan, Korea] 42:39–42.

Yanno, K., and O. Abe. 1998. Depth measurements of tuna longline by using time-depth recorder. Nippon Suisan Gakkaishi 64:178–188.

Yokawa, K. Y. and Y. Uozumi. 2001. Analysis of operation pattern of Japanese longliners in the tropical Atlantic and their blue marlin catch. Int. Comm. Conserv. Atl. Tunas, Madrid. Collect. Vol. Sci. Pap. ICCAT 53:318–336.