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AN ANALYSIS OF PACIFIC STRIPED MARLIN (*TETRAPTURUS AUDAX*) HORIZONTAL MOVEMENT PATTERNS USING POP-UP SATELLITE ARCHIVAL TAGS

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ABSTRACT

Previous studies reached inconsistent conclusions when using morphometrics, molecular markers, conventional tags, or spatial analyses of catch per unit effort rates in attempts to characterize movement patterns and stock structure of Pacific striped marlin (*Tetrapturus audax* Philippi, 1887). A better understanding of the movement patterns of this species is important, since striped marlin are the only istiophorid for which there are targeted commercial fisheries. To this end, 248 pop-up satellite tags were placed on striped marlin at regions of high seasonal abundance in the Pacific Ocean. Fish were caught on rod-and-reel, tagged, and released off Mexico (Baja California), Ecuador (Galápagos Islands and Salinas), New Zealand, and eastern Australia. Small numbers of striped marlin were also opportunistically tagged in other regions of the Pacific. The longest days-at-liberty for fish tagged at each region ranged between 4 and 9 mo, with the mean days-at-liberty ranging from 2 to 3 mo. Within the time frame of this study, striped marlin exhibited a degree of regional site fidelity with little to no mixing between fish tagged at different regions. One notable track extended over 2000 km away from New Zealand before circling around New Caledonia and returning to within 400 km of the origin 8 mo later. It is likely that marlin stocks can be managed and assessed on a region by region basis and continued tagging and genetic studies will allow these regions to be better defined.

Istiophorid billfishes, in general, have very little commercial value and are most often taken as bycatch in fisheries targeting other species. That is not the case, however, for striped marlin (*Tetrapturus audax* Philippi, 1887) where directed fisheries developed in the early 1960s to satisfy a demand for Japanese fish sausage (Kume and Joseph, 1969). Striped marlin are presently harvested for the sashimi and frozen filet markets while also forming the basis of important recreational fisheries in the United States (California and Hawaii), Mexico, Ecuador, New Zealand, East Africa, and Australia. The combined impact of both commercial and recreational fisheries raises striped marlin above all other istiophorids in economic value and are thus the most studied of the group.

Striped marlin are found in more temperate waters than other istiophorids (Ueyanagi and Wares, 1975) with a strong preference for waters 20–25 °C (Howard and Ueyanagi, 1965). Regions that produce the highest longline catch rates have been mapped to illustrate a horseshoe-shaped distribution that is continuous along the continents of the eastern Pacific with two branches stretching west, across the Pacific, primarily between 20°–30° above and below the equator (Nakamura, 1974; Squire and Suzuki, 1990).

There has been no consensus regarding the degree of Pacific striped marlin stock structure and reviewing the literature provides conflicting views. Suggestions that northern and southern hemisphere stocks are separate have come from a variety of sources: differences in morphometric and meristic characters (Kamimura and Honma, 1958); spatially and temporally distinct spawning grounds (Kamimura and

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Honma, 1958); the lack of striped marlin contaminated by the 1954 nuclear testing at Bikini Atoll (northern hemisphere) in the south Pacific (Nakamura, 1969), and a zone of low hook rates in the equatorial Pacific. In contrast, Kume and Joseph (1969) suggested striped marlin slowly move south as they get larger and cited long range movement of some tagged individuals as evidence that northeastern and southeastern Pacific fish are likely a single population. Furthermore, distinction between southeastern and southwestern striped marlin stocks has also been proposed (Morrow, 1957).

Molecular studies have also searched for stock structure of Pacific striped marlin. When analyzing the same suite of samples collected off Mexico, Hawaii, Ecuador, and eastern Australia, both allozyme (Morgan, 1992) and mitochondrial DNA (Graves and McDowell, 1994) studies found slight between-sample differences. A more recent study (comparing samples from Japan, Taiwan, Australia, Hawaii, California, Mexico, and Ecuador) failed to find stock structure using mitochondrial DNA but a comparison of microsatellite DNA lumped Taiwan, Japan, Hawaii, and California into a single group that is distinct from Australia, Ecuador, and Mexico (McDowell and Graves, in press).

Studying fish movement can ultimately lead to the ability to define fish stocks. Previous studies have attempted to describe striped marlin movement patterns throughout the Pacific by plotting changes in longline catch per unit effort (CPUE) over spatial and temporal scales (Furukawa et al., 1958; Koga, 1967; Kume and Joseph, 1969; Squire and Suzuki, 1990), but these studies are inconsistent when compared. Conventional tagging programs can provide insight into movement patterns and to this end over 12,000 tags have been placed on striped marlin. The overall return rate of these tags has been < 1% with over 90% of recoveries occurring in < 1 yr (Squire and Suzuki, 1990; Ortiz et al., 2003; Bromhead et al., 2004). With a record distance of 6713 km in 141 d, conventional tagging has demonstrated that striped marlin are capable of traversing long distances over short time intervals. Based upon the observation that < 8% of striped marlin tag recoveries resulted in a horizontal displacement of over 1000 km, Bromhead et al. (2004) concluded that striped marlin demonstrate some level of regional site fidelity whereas Ortiz et al. (2003) came to the opposite conclusion. Ortiz et al. (2003) also stated that the striped marlin tag data did not support seasonal movement patterns while Bromhead et al. (2004) concluded that this species does have seasonal movement patterns. Anecdotal information from the northeastern Pacific does, in fact, appear to support some level of regional site fidelity and seasonal movement. For example, striped marlin tagged off southern California have been recovered off southern Baja California, Mexico; fish tagged off Mexico have been recaptured in California and one California tagged marlin was recaptured off California a year later (Squire, 1987).

The inconsistent and conflicting results that are apparent when reviewing the striped marlin literature relevant to horizontal movement patterns and stock structure underscores the need for further work in this area. The advent of electronic tagging technology presented an opportunity to collect new fishery independent data to address the spatial movement patterns throughout the Pacific. Because of the very low rate of return of conventional tags placed on striped marlin, pop-up satellite archival tags (PSAT) were chosen over surgically implanted archival tags since PSATs do not require the fish to be recaptured. Here we present data collected from 248 PSATs deployed on striped marlin in the Pacific.

Materials and Methods

Pop-up satellite archival tags (PSATs), manufactured by both Wildlife Computers (WC) and Microwave Telemetry (MT), were used to study the movements of striped marlin. Striped marlin were captured with rod-and-reel during seasons of peak abundance off Baja California, Mexico, the Galápagos Islands, and Salinas, Ecuador, the northern tip of New Zealand, the southeast coast of Australia, and the United States (southern California and Hawaii); a small number of fish were also opportunistically tagged off Costa Rica and Panama. Each fish was brought alongside the fishing vessel and tagged by inserting a nylon tag head through the dorsal midline just beneath the tallest bony rays of the dorsal fin. As the program evolved, many methods of tag rigging were attempted, but the majority of tags were rigged with an umbrella style dart (described in Domeier et al., 2005) and 300 lb Sufix Superior monofilament (Yao I Fabric Co., LTD, Taiwan). Until 2005, a pressure release device (RD1500, supplied by Wildlife Computers) was incorporated into the leader of WC tags to allow for separation of the leader in the event the tag approached depths in excess of 1500 m (tag is lost to crushing at approximately 2000 m). The use of the RD1500 was discontinued in 2005 after a recaptured striped marlin revealed the device was cutting through the leader. Beginning in 2005, all tags were rigged with 250 lb nylon coated braided stainless steel leader (Sevenstrand, Pure Fishing, Huntington Beach, CA).

Tags that remained on the fish for fewer than 21 d were not used for analyzing movement patterns unless they traveled a minimum distance of 500 km. Tracks for each fish were computed using the PSAT Tracker algorithm, which in very simple terms, uses light-based geolocation estimates for longitude and then matches sea surface temperatures recorded from the tag with that measured from satellites to determine latitude (Domeier et al., 2005). Longitude estimates were derived using light-based geolocation algorithms either supplied by the tag manufacturer (in the case of Wildlife Computer tags) or calculated by the manufacturer (in the case of Microwave Telemetry tags). A new version of the PSAT Tracker algorithm was used that allowed the tag manufacturer's light based latitude estimates to be weighted during the SST matching process. For future reference, the algorithm's user-defined variables used to create striped marlin tracks were set as follow: MSD1 = 50; MSD2 = 50; Velocity = 5.0; Depth = 6.0; Time = 2.0; TempC = 0.1; SelectPts = 12; CandidatePts = 30, Temp = Ave; Res = Ultra; Bracket Width = 60.0; LonMax = 12; Sun box checked; DistFact = 50; SkipFact = 1.50; MfgFact = 50; and activated "sun box." Two of these variables relate to the tag manufacturers' light based solution for latitude and were not described in Domeier et al. (2005). The first is the "MfgFact" which is a variable (0–100) that changes the degree to which the manufacturer's light based solution is weighted and the second is the "sun box," which when activated, only weights the light based latitude during the non-equinox periods.

Daily position estimates for each fish were pooled to conduct fixed kernel method spatial analyses for each region when a minimum of ten fish tracks were available. Although PSAT Tracker was used to generate plots of the fixed kernel density estimates, the actual calculations were based upon Worton (1989), a method that relies on a least squares cross-validation for the estimation of an optimal smoothing parameter (h). To compensate for tagging site bias, the first 2 wks of position estimates for each track were not used for spatial analyses. Seasonal kernel analyses were calculated by pooling inter-year data and breaking the data into quarters when data were available ($n > 100$ per quarter). Solstice and equinox dates were used as the break points between seasons and data were presented for winter, spring, summer and fall, however, it is important to note that these seasons represent different months of the year in the northern and southern hemisphere.

Results

A total of 248 PSATs (87 Microwave Telemetry and 160 Wildlife Computer) were deployed on striped marlin between the years 2000 and 2005 (Table 1). Since each fish remained in the water during the tagging process, it was not possible to get precise measures of size, however, visual estimates of weight were recorded (Table 2). All fish tagged were greater than the published minimum size of maturity (29 kg; Hanamoto, 1977), with the exception of Hawaii, where all were juveniles. Striped marlin tagged in New Zealand and Australia tended to be larger than fish tagged in other regions (Table 2). After applying the 21 d/500 km filter to the tagging data, 125 sets of tag data remained for a total of 10,676 d of data. The longest days-at-liberty (DAL) was 259 with a mean of 85 d. Using the PSAT Tracker program, 4773 position estimates were calculated for the total data set (Fig. 1). The longest straight line distance (SLD) traveled for any striped marlin was 5970 km (mean SLD: 1040 km) while the longest measured track distance (TD) was 10,500 km. Sample sizes and tag statistics by region were not equal (Table 3) with nearly twice as many fish tracked off Baja California (46) compared to the next highest sample size from New Zealand (26).

Regional Results

California, U.S.A., and Baja California, Mexico.—Forty-six out of 127 tag sets, originating off Baja California between 2001 and 2005, qualified for spatial analyses; 2749 position estimates spanned all months of the calendar year (Fig. 1; Table 3). Thirty-seven of these tag sets originated from fish that were tagged during the fall months off the Pacific coast near Bahia Magdalena (360 km northwest of Cabo San Lucas); of the remaining tracks, eight originated (May and June) in the Sea of Cortez off La Paz and one near Guadalupe Island (370 km southeast of San Diego) in August. Fifteen of 20 marlin tagged off the coast of southern California between 2003 and 2005 qualified for analyses; fish were tagged in the late summer/early fall and tracks spanned early September through early March, encompassing 600 estimated positions (Fig. 1; Table 3) that were contained within a 1600 km radius.

All California tagged marlin moved south into Mexican waters with the longest track traveling 3200 km in a southerly direction while the remaining tracks tended to remain within 500 km of the Baja Peninsula. Striped marlin tagged offshore of Bahia Magdelana, Mexico, generally remained within 750 km of the southern tip of the peninsula. For Mexican fish, the farthest distance traveled from the tip of Baja California in a southerly direction was 1850 km and the farthest in a northerly direction was 1250 km. Twelve marlin tagged off Bahia Magdalena, Mexico, provided 5–9

Table 1. Location, number, and month of striped marlin PSAT deployments.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Australia		2	9	11	2							
New Zealand		20	1	7	6							
Mexico					1	10		1		1	63	54
California								1	13	3		
Ecuador		20	13									
Panama	1					2						
Costa Rica		1										
Hawaii		4	2									

Table 2. Regional size (kg) statistics for PSAT tagged striped marlin.

	Mean	St Error	Min	Max
Australia	94.34	4.24	45.45	130.00
New Zealand	112.28	4.18	54.55	159.09
Mexico	54.98	0.76	40.91	81.82
California	61.23	2.37	40.91	79.55
Ecuador	65.84	3.03	40.91	100.00
Panama	94.70	7.57	79.55	102.27
Costa Rica	81.82	0.00	81.82	81.82
Hawaii	31.06	4.22	22.73	36.36

mo tracks (Fig. 2). The range of SLD between tagging and pop-up locations for these relatively long-term tags was 169–867 km, with a mean of 500 km (± 235 km). None of these fish moved continuously away from the Baja Peninsula. One moved north on the Pacific side to 30°N in the late summer before turning back to the south. Two moved as far south as 15°N before turning back towards the Baja Peninsula. A fixed kernel density contour plot of just these longer term tags produced a 50% contour that remained within 200 km of the southern Baja Peninsula (not pictured). Two tags deployed off southern California produced 6-mo tracks with SLDs over 1400 km as they moved to waters off the Baja Peninsula (Fig. 2).

The 50% fixed kernel density contour for striped marlin tagged off southern California is a discontinuous band that runs along the coast of California and Baja California, Mexico, remaining within 500 km of land with the exception of one small islet 800 km southwest of the tip of Baja California (Fig. 3). For fish tagged off Baja California, the 50% fixed kernel density contour encircles the tip of the peninsula out to a radius of 400 km with a moderate sized discontinuous islet located near the Revillagigedo Islands (Fig. 4). Data allowed for fall and winter spatial analyses

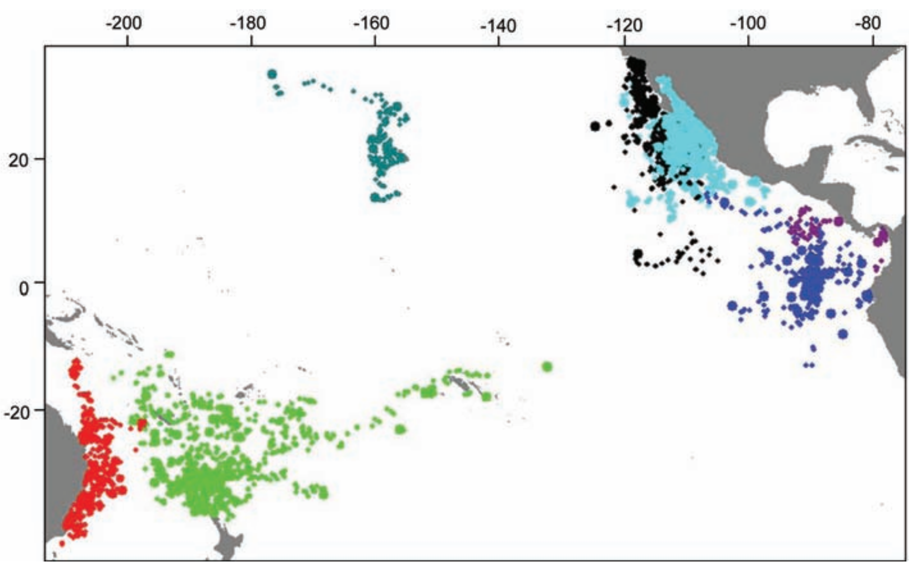

Figure 1. Position estimates for all tagged striped marlin. Different colors represent positions for fish tagged in a particular region (red = Australia; light green = New Zealand; teal = Hawaii; black = California; light blue = Mexico; dark blue = Ecuador; and purple = Costa Rica and Panama).

Table 3. Summary PAT tag statistics for tags with a minimum 21 days-at-liberty (DAL) or 500 km straight line distance (SLD). Track distance (TD) refers to the length of the track produced by PSAT Tracker. *Only one fish tagged off Costa Rica.

Region	Filtered tracks	Number positions	Mean DAL	Longest DAL	Mean SLD km	Longest SLD	Mean TD km	Longest TD km
Mexico	46	2,749	98	259	608	1,859	3,441	10,504
New Zealand	26	1,131	100	226	1,613	5,971	3,811	7,006
Ecuador	20	483	61	134	668	2,262	3,214	3,961
California	15	600	80	153	1,162	3,200	3,244	5,954
Australia	12	542	65	134	921	2,437	3,052	6,490
Hawaii	5	192	65	122	943	2,464	2,815	5,643
Costa Rica*	1	34	62	62	459	459	2,589	2,589

for California tagged fish (Fig. 5A–B) and year round seasonal analyses for Mexican tagged fish (Fig. 6A–D). California tagged fish showed southerly movement in the fall and winter while Mexican tagged fish showed very little seasonal northward movement on the Pacific side of the Baja Peninsula but movement into the northern portion of the Gulf of California occurred in the spring quarter before retreating to the south by the fall. There was considerable movement of marlin in and out of the Gulf of California (Figs. 1, 2). Of fish tagged on the Pacific side of Baja California, seven of the nine tracks > 6 mo moved into the Sea of Cortez for a portion of their track while 11 of 18 fish tracked more than 3 mo entered the Sea of Cortez for at least a portion of their track. Four out of five fish tagged in the Sea of Cortez and tracked for more

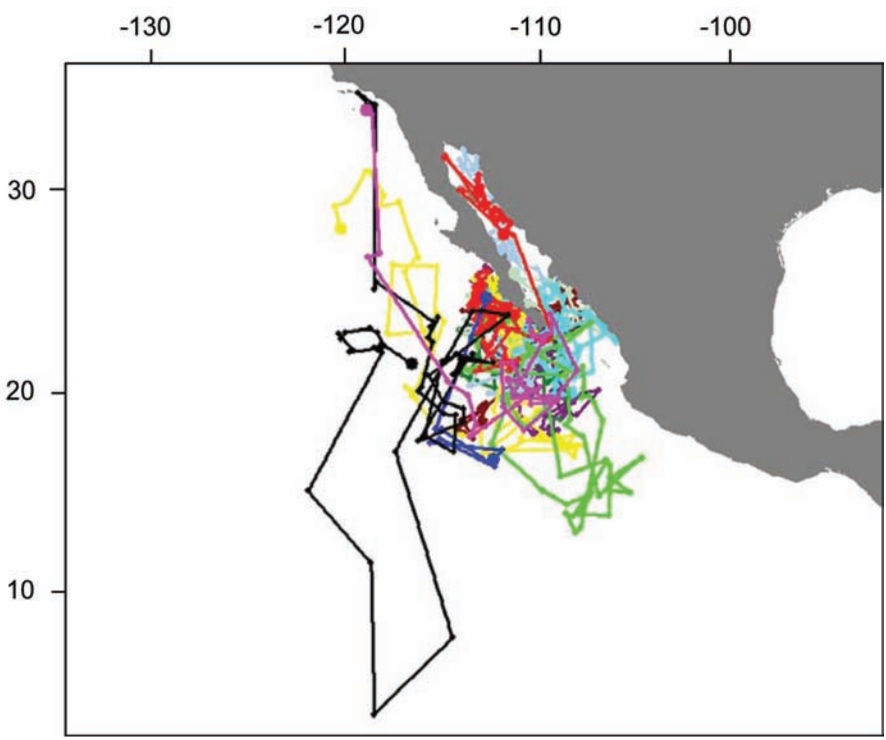

Figure 2. Five to nine month tracks for striped marlin tagged off Mexico and Baja California, Mexico (n = 14).

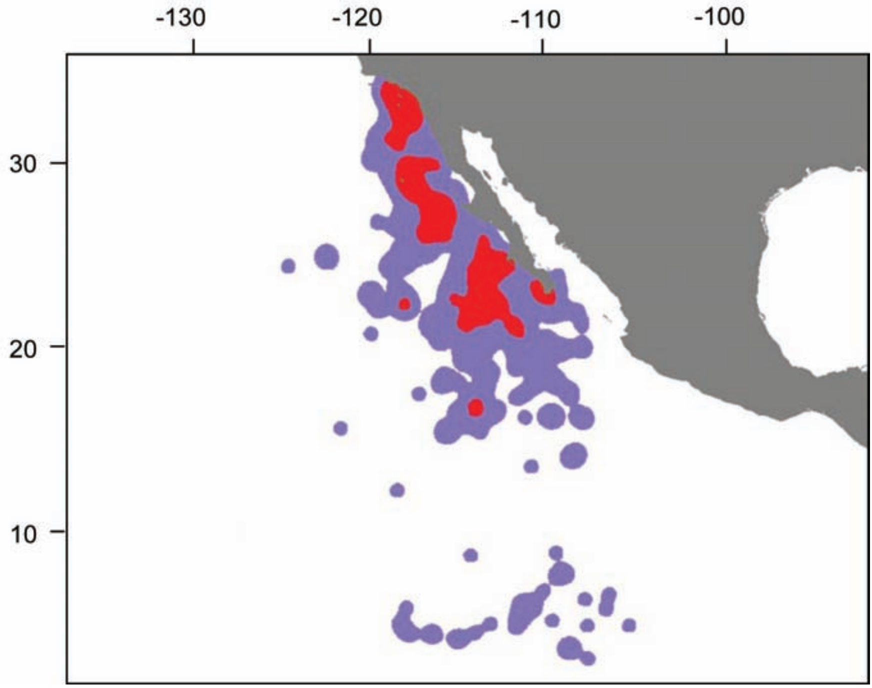

Figure 3. Fixed kernel density contour plot for striped marlin tagged off California (red: 50% contour; purple: 95% contour; points = 473; h = 0.43).

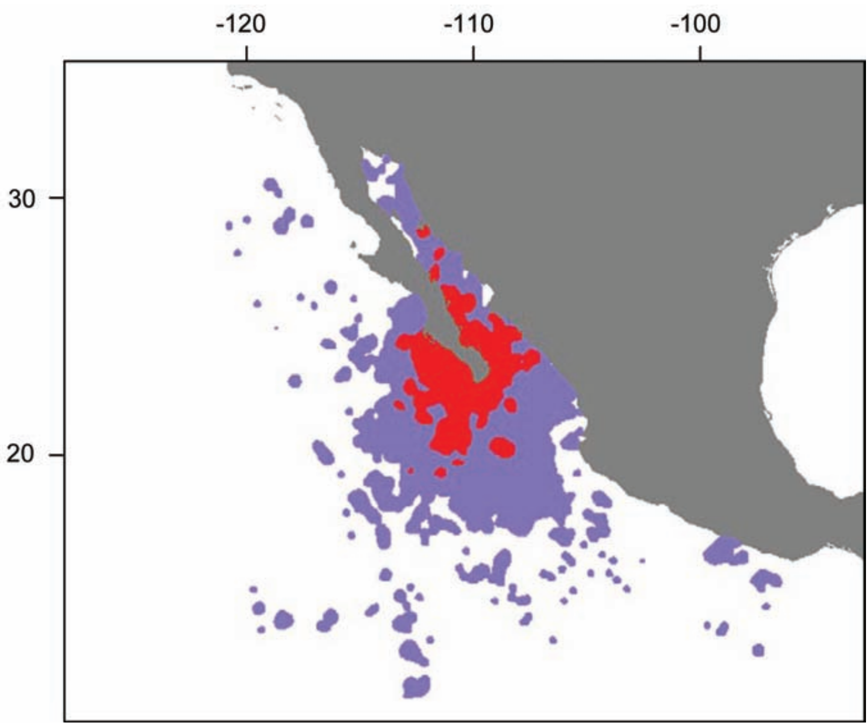

Figure 4. Fixed kernel density contour plot for striped marlin tagged off Mexico (red: 50% contour; purple: 95% contour; points = 2317; h = 0.16).

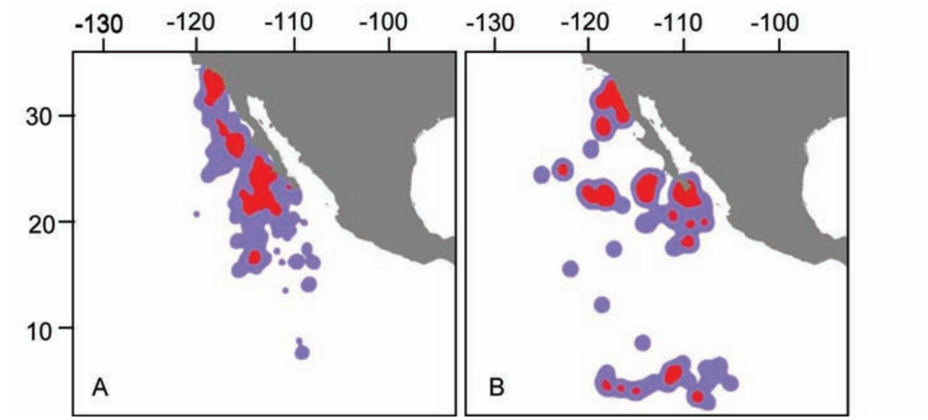

Figure 5. Seasonal fixed kernel density contour plots for striped marlin tagged off California (red: 50% contour; purple: 95% contour. (A) Fall quarter (points = 341; h = 0.44). (B) Winter quarter (points = 124; h = 0.48).

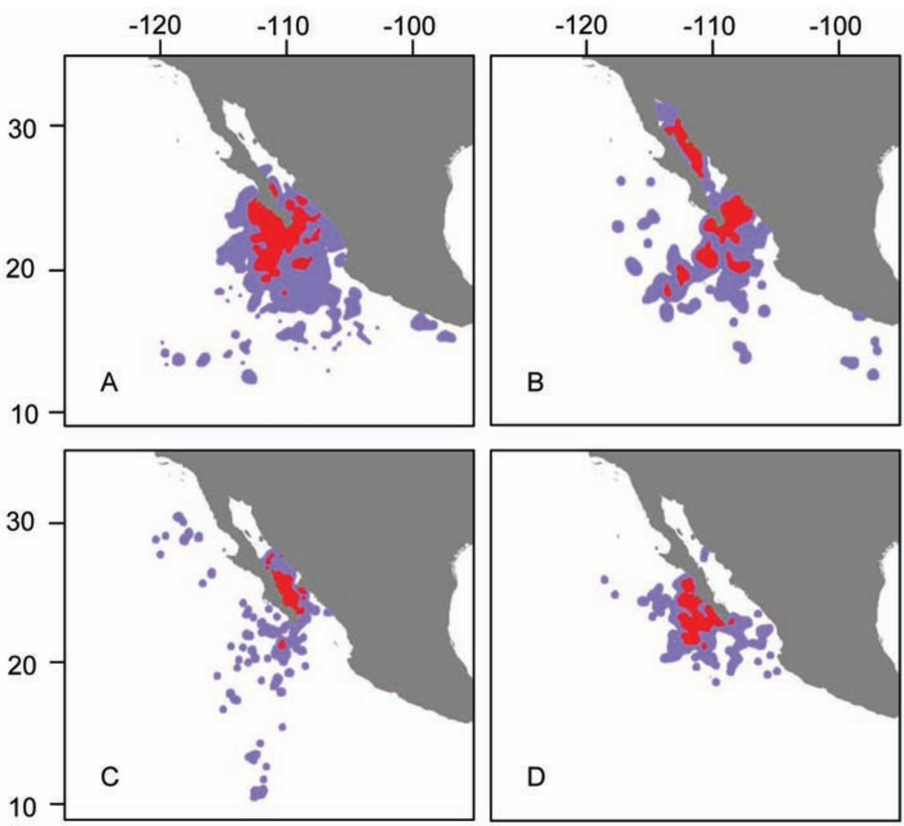

Figure 6. Seasonal fixed kernel density contour plots for stripped marlin tagged off Mexico (red: 50% contour; purple: 95% contour). (A) Winter quarter (points = 1206; h = 0.23). (B) Spring quarter (points = 439; h = 0.26). (C) Summer quarter (points = 367; h = 0.16). (D) Fall quarter (points = 310; h = 0.22).

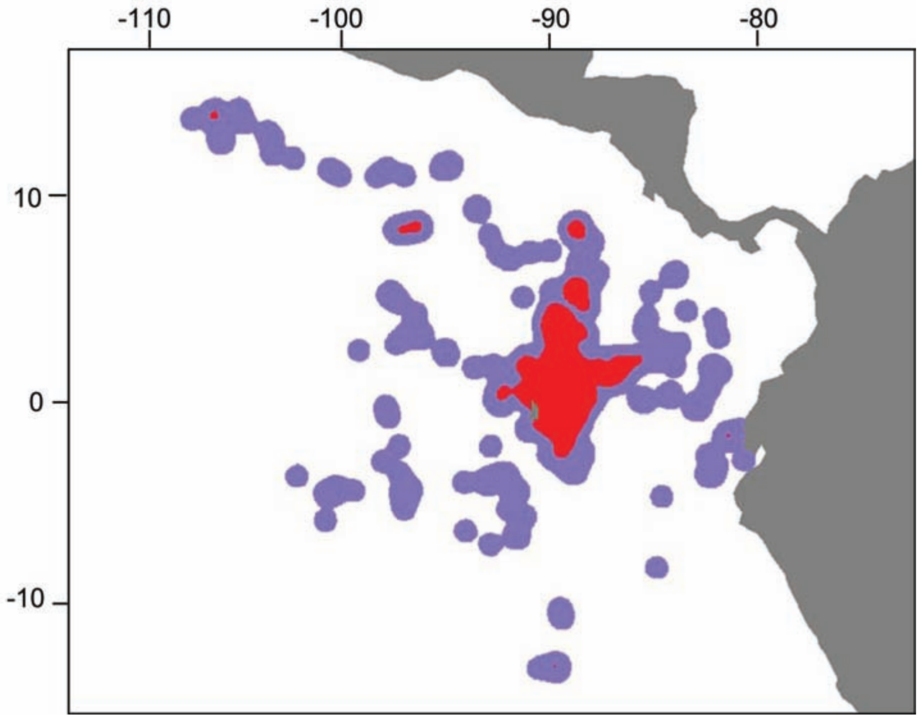

Figure 7. Fixed kernel density contour plot for striped marlin tagged off Ecuador (red: 50% contour; purple: 95% contour; points = 348; h = 0.34).

than 2 mo, exited the Sea of Cortez. Striped marlin tagged off southern California logged a single position point in the Sea of Cortez.

Ecuador.—Twenty out of 33 striped marlin tagged off Ecuador qualified for spatial analysis. All but two of these were tagged off the island of San Cristobal (Galápagos Islands) in February and March of 2005. The remaining two fish were tagged off Salinas in March of 2004. Fish tracks spanned the months of February through June. The two fish tagged off Salinas traveled to the vicinity of the Galápagos Islands while the Galápagos Islands tagged fish radiated in all directions from the tagging site, with the farthest position estimate being 2600 km northwest of the Galápagos (Fig. 1). Fifteen of 18 tracks originating in the Galápagos moved at least 400 km away from the islands with all but four reversing course and moving back towards the islands before the tags were prematurely shed. The relatively short average DAL provided only 483 calculated positions (Table 3) contained within a radius of 2000 km. The 50% fixed kernel density contour outlines a roughly circular region centered 200 km northeast of the Galápagos Islands with a maximum radius of 400 km (Fig. 7). Data were not sufficient for any seasonal analyses.

New Zealand.—Twenty-six out of 34 striped marlin tagged off northern New Zealand (NZ) and the Three Kings Islands (88 km northwest of the tip of NZ) qualified for horizontal movement analyses. These fish were tagged between February and May and produced tracks that spanned February through December. NZ tagged fish resulted in the longest average DAL (100 d) and the longest recorded SLD (5971 km) between tagging and pop-up positions (Table 3). In total, 1131 positions were estimated, contained within a radius of 3500 km (Fig. 1). After tagging, striped marlin

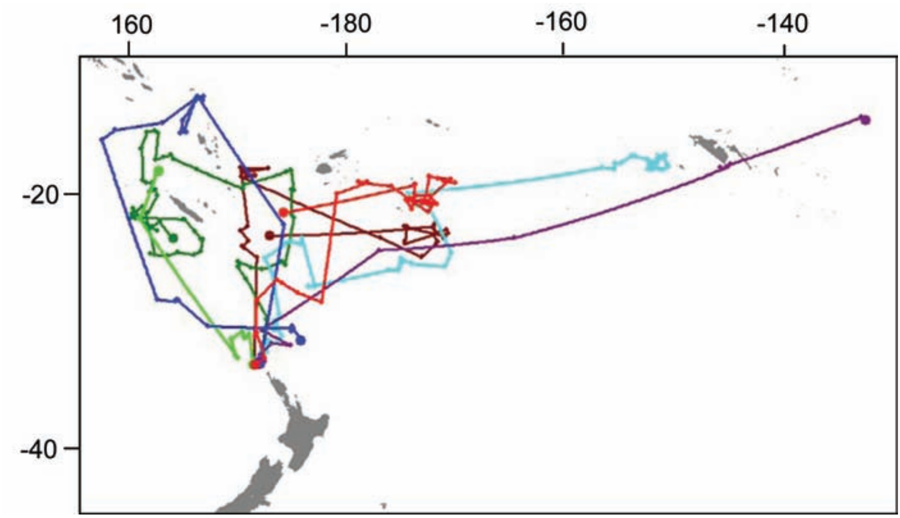

Figure 8. Five to nine month tracks for striped marlin tagged off New Zealand (n = 7).

moved away from NZ, spreading to points north along a band from 15–20°S latitude and 160 E–140°W longitude (Fig. 1). Westward movement was largely bounded by longitude 160°E with only a single position east of this line. Movement to the north extended to 10°S but only a single fish, logging seven positions, went north of 15°S. The longest distances traveled were to the west, with four fish logging 37 points west of 165°W; the farthest track reaching 132°W. Seven tracks were between 5 and 8 mo (Fig. 8). The range of SLD between tagging and pop-up locations for these relatively long-term tags was 493–5971 km, with a mean of 2501 km (± 704 km). The longest temporal track originates and ends in waters off northern NZ after a period of nearly 8 mo (blue track Fig. 8). Six of the other relatively long term tracks also showed some degree of movement back towards NZ, but the longest distance track (5971 km) did not exhibit any course reversal.

The 50% fixed kernel density contour for all positions is discontinuous with the largest segment extending 1000 km north and 967 km northwest of the northern tip of NZ; most of the smaller 50% contour segments are bound between 160°E and 170°W as far north as 20°S (Fig. 9A). Data were sufficient for for summer, fall and winter spatial analyses; the summer fixed kernel result shows the 50% contour to be in the offshore waters north of NZ while fall and winter 50% contours show fish spreading out along the 5800 km band of islands to the north and east (Fig. 9B–D).

Australia.—Twenty-four striped marlin were tagged off the coast of southeast Australia (February through May) with only 12 resulting tracks qualifying for analyses (Table 3). Tag performance in Australia was relatively poor; the mean DAL was 65 d with the longest DAL being 134 d. Tracks spanned the months of early February through early August resulting in 542 total position estimates (Fig. 1) contained within a radius of 1250 km.

The net movement of Australian striped marlin was to the north as water cooled in the south; northward movement was largely restricted to latitudes below 22°S, with only a single fish (53 positions) moving north of this latitude. Eastward movement was limited with only five positions, from a single fish, east of 160°E. The 50% fixed kernel density contour for all positions is broken into clusters that hug the Australian

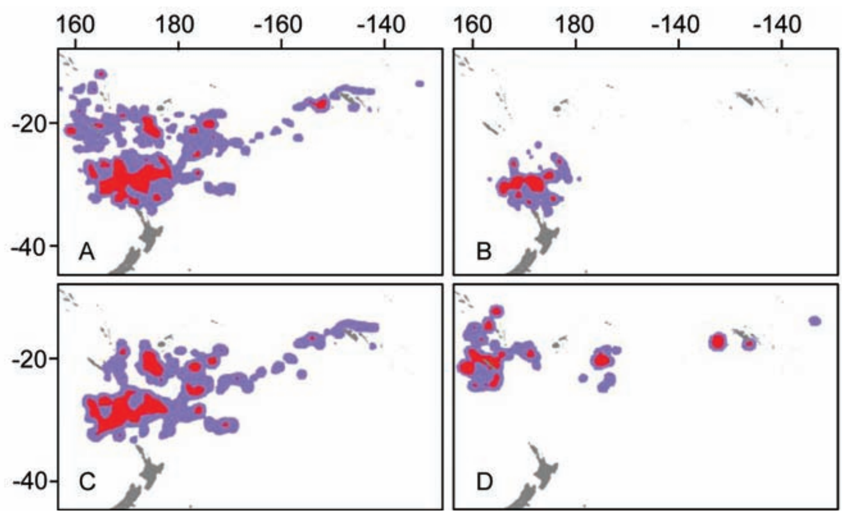

Figure 9. Fixed kernel density contour plot for striped marlin tagged off New Zealand (red: 50% contour; purple: 95% contour). (A) Analysis of total positions (points = 907; h = 0.39). (B) Summer quarter (points = 248; h = 0.41). (C) Fall quarter (points = 468; h = 0.52). (D) Winter quarter (points = 146; h = 0.49).

continental slope waters as well as the vicinity around Lord Howe Island (Fig. 10A). Data were sufficient for only a fall quarter analysis (Fig. 10B), which was nearly identical to the plot for total positions.

Hawaii.—Only six striped marlin were tagged off the Hawaiian Islands in February and March of 2005, five of which resulted in usable data (three tagged off Oahu and two tagged off Kona) spanning mid February through early July. The longest SLD was 2464 km with a mean of 943 km (Table 3). None of the Hawaiian tagged fish logged positions east of the Hawaiian Islands (Fig. 1). The three Oahu tagged fish moved south to approximately 15°N before two reversed course and returned to the vicinity of Hawaii; the third tag popped up 890 km south. The two Kona tagged fish exhibited more significant movement to the northwest (2464 km) and north (845 km). The longest track leading away from the islands followed the Musicians Seamounts in a

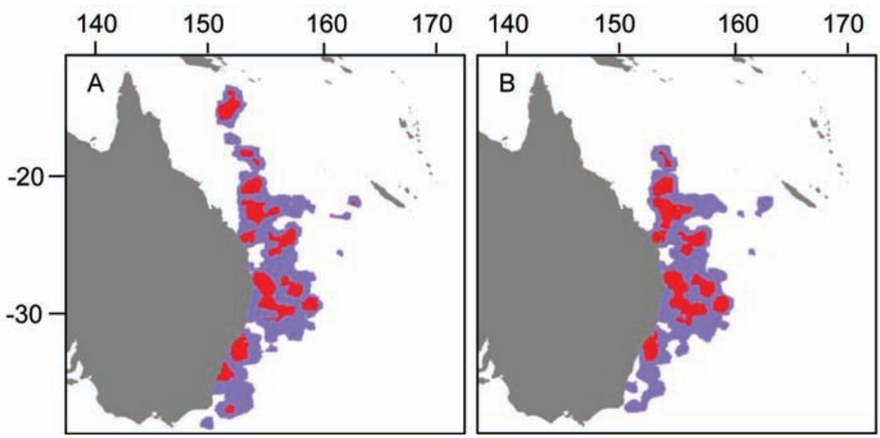

Figure 10. Fixed kernel density contour plot for striped marlin tagged off Australia (red: 50% contour; purple: 95% contour). (A) Analysis of total positions (points = 428; h = 0.26). (B) Fall quarter (points = 331, h = 0.29).

northward direction before crossing west to the Hess Rise. With the small number of fish and position data, no spatial analyses were performed. All position estimates were contained within a radius of 1450 km.

Costa Rica and Panama.—A single striped marlin was tagged off the coast of Costa Rica and three off Panama; only one tag from each of these locations resulted in meaningful data (Fig. 1; Table 3). The tag from the Costa Rica fish was recovered, providing an archival dataset spanning 62 d between February and April 2004. Movement was initially westward before reversing course and traveling back in the direction of the initial tagging location. The tag from the Panama striped marlin popped up very near the tagging location after 64 DAL. These tagging results are reported because striped marlin are relatively rare in nearshore waters between Mexico and Ecuador, however, a sample size of one did not justify fixed kernel spatial analysis.

Discussion

Conventional tagging studies of striped marlin have not documented any trans-Pacific movements and only three trans-equatorial movements have been reported (Ortiz et al., 2003; Bromhead et al., 2004). PSAT tagging produced similar results in that no trans-Pacific migrations occurred within 9 mo maximum time at liberty, and no fish tagged outside of Ecuador moved across the equator. Fish tracked from each individual aggregation site resulted in position estimates that were contained within a radius of 2000 km or less, New Zealand being the exception (3500 km radius). This study provided evidence that striped marlin exhibit regional site fidelity over time spans up to 9 mo with some indication of seasonal movements indicated for fish tagged off Mexico and New Zealand. Furthermore, there was very little sharing of space between groups of fish tagged in different regions of the Pacific; the only examples coming from Ecuador and Mexico (one fish from Ecuador moved north) and between Australia and New Zealand (one fish from Australia crossed the Tasman Sea). Noteworthy tracks included a circuitous route extending over 2000 km away from New Zealand before circling around New Caledonia and returning to within 400 km of the origin 8 mo later; similarly relatively long term tracks beginning in Mexico extended far to the north and south before reversing course. All of the longest tracks (5–9 mo) off Mexico remained very near the Baja Peninsula (50% contour within 200 km) with none moving continuously away from Mexico.

The longest distance tracks were those that originated near the temperate extremes of the range for this species (e.g., New Zealand, southern California, southeastern Australia). In contrast, striped marlin tagged near the center of their geographic range, for a given region, demonstrated much less movement. Fish tagged off Mexico provide the best example with a mean straight-line-distance of 480 km for fish carrying tags for more than 5 mo; a much smaller value than the same calculation made from fish tagged off New Zealand (2500 km). One hypothesis that might explain this difference is that only a fraction of a regional population travels to the temperate edge of its range. This could be tested by tagging fish near the center of their range a month or two prior to the time fish are expected to appear in the more temperate regions. This sampling strategy would also minimize the impact of premature tag shedding.

Pop-up tag shedding was a serious problem for this study, resulting in a 50% success rate in recovering useful data and a low average DAL, nevertheless, this study illustrated that data collected through the use of these tags can surpass decades-long conventional tagging programs in just a few years. Until the recovery rate of archival tags placed on marlin can be expected to increase, or a dramatic improvement in PSAT performance is realized, multi-year tracks will remain out of reach. Of note is the fact that every tag remaining on striped marlin for 5 mo or more was manufactured by Microwave Telemetry. This despite the fact that the number of Wildlife Computer tags outnumbered Microwave Telemetry tags nearly two-to-one. It is likely that the use of the RD-1500 release device supplied by Wildlife Computers is responsible for the lack of long term tracks. This device was not used on Microwave Telemetry tags. Movement of the RD-1500 was not restrained for this study, likely exacerbating the impact of the sharp edges of this device on the monofilament tether.

Efficiently tagging striped marlin requires targeting fish while they are aggregated in regions that are accessible by recreational fishing vessels. Although the first 14 d of each track were discarded before spatial analyses, the fixed kernel density contour plots will tend to be biased towards the tagging sites. This can be seen during the fall months of the seasonal analyses for New Zealand and Mexico. Seasonal quarters following the quarter of tagging are more representative of striped marlin spatial habitat as the fish have dispersed from the aggregation site. In the case of Mexico, the summer quarter is primarily based on fish tagged in the spring in the Sea of Cortez since most of the tags placed on fish in the fall had been shed by summer. Although it can be argued that fish tagged in the summer quarter may not accurately be compared with those tagged in the fall, it is important to note that fall tagged fish showed movement into the Sea of Cortez in the spring.

Tagging off Hawaii and the Galápagos Islands did not provide enough data for any meaningful conclusions, but both of these areas could potentially be important for studying movement between regions. The Galápagos has supported historically high catch rates of striped marlin and its central location in the eastern Pacific could make it an important mixing zone for northern and southern hemisphere fish, should such mixing actually occur. Likewise, Hawaii's central location in the northern Pacific provides a important site to look for movement between the western and eastern Pacific. Hawaii's importance as a striped marlin study site is increased by the fact that genetic studies have grouped samples from Japan, Taiwan, Hawaii, and California (McDowell and Graves, in press).

The relationship between striped marlin found off California and Mexico remains confusing due to conflicting results between tagging and molecular studies. All fish tagged with PSATs off California in the summer and fall mingled with Mexican fish in the fall and winter. The finding that recent molecular results separate Californian fish from Mexican fish (McDowell and Graves, in press) can be explained if striped marlin from California have a discrete spawning ground from those that have been sampled off Mexico. Unfortunately, striped marlin arrive off California just after the spawning season and PSAT tags have not performed well enough to track these fish into the next spawning season. Since sampling for genetic studies has not been restricted to known spawning areas it would seem reasonable that sampling off Mexico in the fall and winter would eventually collect fish that had been in California; this has not happened, perhaps because fish traveling south from California are an extremely low percentage of the total striped marlin off Mexico. Conventional and PSAT tagging, combined, have shown fish to move back and forth between Mexico and California as well as Hawaii and Mexico/California (Ortiz et al., 2003; Bromhead et al., 2004); given these movement records it is difficult to explain the proposed genetic differentiation. Continued tagging in association with tissue sampling will hopefully resolve this issue. Tracking striped marlin from specific regions through their known spawning season would be most valuable.

Although data presented here are not enough to make definitive statements about striped marlin stock structure in the Pacific, the sum total of these results in conjunction with previous tagging and genetic studies suggest that some level of regional site fidelity for striped marlin exists in the Pacific. Multi-year tracks obtained from archival tagged Atlantic bluefin tuna (Block et al., 2005) have shown that pelagic fishes can show short term regional site fidelity in one area before making a long distance migration and exhibiting regional fidelity in a second area. It is likely that marlin stocks can be managed and assessed on a region by region basis and continued tagging and genetic studies will allow these regions to be better defined. Until much longer term tracking of striped marlin is possible, some level of uncertainty must be acknowledged.

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