TEMPERATURE-DEPTH HABITAT UTILIZATION OF BLUE MARLIN MONITORED WITH PSAT TAGS IN THE CONTEXT OF SIMULATION MODELING OF PELAGIC LONGLINE CPUE

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SUMMARY

We evaluated data from electronic popup satellite archival tags (PSATs) collected via Argos transmissions as well as high resolution data from recovered tags to characterize the depth distributions of blue marlin in relation, ultimately, to their exposure to hooks fished from longline gear. Our tagged fish spent most of their time in the near surface waters (<5m), but periodically dived into and sometimes below the thermocline, presumably in search of prey. The actual depths explored varied greatly because the depth of the thermocline varied by area and season. The intent of the analysis was to provide a link between fish depths and oceanographic features for use in simulations of longline CPUE. We computed the fractions of time spent by each fish within each degree of water temperature relative to the temperature of the surface mixed layer. Where possible, frequency distributions were determined for periods of darkness, twilight, and full daylight. Results were highly variable within the time series for individual fish, and among fish. In order to preserve this stochastic property we recommend that the simulations draw randomly from the observed frequency distributions to simulate interactions between fish and hooks on simulated longline sets.

RÉSUMÉ

Nous avons évalué les données des marques-archives pop-up reliées par satellite (PSAT) recueillies au moyen des transmissions Argos ainsi que les données de haute résolution provenant de marques récupérées afin de caractériser les distributions en profondeur du makaire bleu par rapport, en dernier lieu, à son exposition aux hameçons palangriers. Notre poisson porteur d'une marque a passé la plupart de son temps dans les eaux proches de la surface (<5m), mais il a périodiquement plongé dans la thermocline et parfois en-deçà, probablement à la recherche d'une proie. Les profondeurs réelles explorées ont grandement varié étant donné que la profondeur de la thermocline a varié en fonction de la zone et de la saison. Le but de l'analyse était de fournir un lien entre les profondeurs du poisson et les caractéristiques océanographiques aux fins de son utilisation dans les simulations de la CPUE palangrière. Nous avons calculé les fractions de temps passées par chaque poisson à l'intérieur de chaque degré de température de l'eau par rapport à la température de la couche mixte de surface. Si possible, les distributions des fréquences ont été déterminées pour des périodes d'obscurité, de crépuscule et de jour complet. Les résultats ont fortement varié à l'intérieur de la série temporelle pour le même poisson et entre différents poissons. Afin de préserver cette propriété stochastique, nous recommandons que les simulations soient réalisées aléatoirement à partir des distributions de fréquence observées afin de simuler les interactions entre les poissons et les hameçons lors d'opérations palangrières simulées.

RESUMEN

Hemos evaluado los datos de marcas archivo pop-up vía satélite (PSAT) recogidos a través de transmisiones Argos, así como datos de alta resolución de marcas recuperadas para describir las distribuciones en profundidad de la aguja azul, en relación con su exposición a los anzuelos del palangre. Nuestro pez marcado pasó la mayor parte del tiempo cerca de aguas superficiales (<5m), pero se sumergió periódicamente en la termoclina y a veces por debajo de ella, presumiblemente en busca de presas. Las profundidades reales exploradas variaban en

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gran medida debido a que la profundidad de la termoclina variaba según las zonas y temporadas. La finalidad del análisis era proporcionar un vínculo entre las profundidades de los peces y los rasgos oceanográficos para poder utilizarlo en las simulaciones de la CPUE de palangre. Calculamos las fracciones de tiempo que pasó cada pez dentro de cada grado de temperatura del agua relativo a la temperatura de la capa de mezcla superficial. Cuando fue posible, se determinaron distribuciones de frecuencia para periodos de oscuridad, crepúsculo y plena luz del día. Los resultados fueron muy variables dentro de las series temporales para un mismo pez y entre diferentes peces. Con el fin de conservar esta propiedad estocástica, recomendamos que las simulaciones se tracen aleatoriamente partiendo de las distribuciones de frecuencia observadas para simular interacciones entre los peces y los anzuelos en calados de palangre simulados.

KEYWORDS

Blue marlin; Habitat; Behavior; Thermocline;Spatial variation; Longlines; Simulation

1. Introduction

The amount of time a fish spends at depth is thought to be important in the evaluation and prediction of billfish catchability on pelagic longline gear. It is clear from observed catch patterns that set depth influences species selectivity of longline sets (e.g. Boggs 1992, Hanamoto 1997, Nakano *et al.* 1997, Yang and Gong 1987). Hinton and Nakano (1996) introduced a model for incorporating habitat information into the standardization process which stratifies catchability by depth. The method offers a means to directly account for changes in fishing patterns that have occurred in the Japanese longline fishery in the Atlantic (Takeuchi 2001, Yokawa and Uozumi. 2001, Yokawa *et al.* 2001), and it was applied to Atlantic blue marlin (Yokawa *et al.* 2001) in preparation for the Fourth Billfish Workshop (Anon. 2001). The Workshop concluded that the assumptions used in the application of this method need further testing and recommended additional study of the relationships between marlin distribution and fishing depth, feeding behavior, the actual under-water movement of hooks, and the hooking time and depth of fish (Anon. 2001). These recommendations were reinforced by an ICCAT Methods Working Group review of the same issue (Anon. 2004). Anon (2004) also recommended longline catch per unit effort (CPUE) simulations to test CPUE standardization methods. Such simulations require information on the distribution of animals within their habitats. This paper presents an evaluation of blue marlin vertical habitat utilization based on data collected by popup satellite archival tags (PSATs) placed on 52 blue marlin.

2. Material and methods

PSATs are attached to the fish externally and log temperature, depth (pressure) and light intensity after the fish is released. Individuals can be monitored for weeks or months. The tags detach after a programmed interval and transmit summaries of the data through the ARGOS satellite system to a land station and then ultimately to the user via the Internet. This study used Wildlife Computers Inc.[4] (Redmond, WA) PAT model 2 and 3 tags. This tag allows the user to program pop-up date, sampling interval, criteria for premature release, bin demarcations for sampling temperature and pressure (depth), as well as transmission and memory priorities. These tags were programmed to sample depth (pressure), temperature and light once every 30 seconds or minute and the depth and temperature records were compiled into histograms at 6-hour intervals for most deployments. A few of the early deployments summarized histograms at 3-hour intervals. The temperature bins for most tags were for temperatures $\leq$12°C, each successive 2°C interval ending with 32°C, and >32°C. The depth bins for most tags included depths $\leq$-1 m, and successive intervals of 25 m to 250 m, and depths >250 m. The minimum and maximum temperatures and depths observed during each binning period were also retained in memory. The tags used in this study were programmed for deployment durations ranging from 7 to 90 days. A pressure-activated mechanical detachment device was also used which severs the 400 pound test monofilament tether at a depth of about 1,500 m (well before the rated 2000 m crush depth of the tag.) This feature helps prevents data loss in the event of fish mortality. Release locations were obtained from global positioning systems onboard the tagging vessels and popup locations were obtained directly from the ARGOS transmissions of each tag. Although PSATs transmit until their batteries are completely exhausted, all measurements taken during the deployment are

[4] References to commercial products do not imply endorsement by the National Marine Fisheries Service or the authors.

retained in the tag's non-volatile memory. This feature allows retention of all data in the tags memory in the event the tag is physically recovered.

All PSATs were rigged in a manner similar to those described by Block *et al.* (1998) and Graves *et al.* (2002). Billfish handling and tagging procedures and associated devices reviewed by Prince *et al.* (2002) were also used. The target area for tag placement was about 4 to 5 cm ventral to the dorsal midline, adjacent to the first several dorsal spines. An effort was made to insert the anchor through the dorsal midline, pterygiophores and connective tissue to a depth just short of exiting the opposite side of the fish. In addition, a conventional streamer tag (series PS) was placed in the fish well posterior of the PSAT using standard procedures (Prince *et al.* 2002). Two devices were used during tagging which tend to reduce stress in captured fish and aid in proper tag placement. The first was a "snooter" (a wire snare housed in a 1.5 m PVC tube, **Figure 1**), which secures to the upper bill and allows the tagger to maintain control of the fish with its head beneath the water during the tagging procedure (Prince *et al.* 2002). The second was small hook "gaff" (a long shaft 9/0 hook with point and barb removed, **Figure 2**) to manipulate the position of the fish relative to the tagging vessel. Captured fish were resuscitated from 3 to 15 minutes, depending on their apparent state of exhaustion, by moving the vessel ahead at two to three knots while maintaining control of the fish with the snooter.

We deployed 79 PSATs on blue marlin from recreational fishing vessels and commercial longliners during the period 2002-2004 **(Figure 3)**. Because of tag failures (i.e. non-transmitting tags) and a few fish deaths, our analyses are based on data from 52 tagged animals. Of these, 6 tags were physically recovered, which allowed extraction of high-resolution, archived data taken during the deployment (either once each 30-or 60-second interval) from these tags.

Our purpose was to associate aspects of blue marlin behavior to oceanographic features that would allow prediction of blue marlin habitat utilization for use in simulating longline catch per unit effort (CPUE). Previous analyses used the proportion of time spent within successively deeper layers of temperature relative to the surface mixed layer (e.g., Hinton and Nakano 1996, Takeuchi 2001, Yokawa and Uozumi 2001, Yokawa *et al.* 2001). Anon (2004) also recommended initial CPUE simulations use these oceanographic features, hence we adopted this approach for the current analysis. Anon (2004) also recommended including day-night fishing patterns in the CPUE simulations. Inspection of the archived, high-resolution data from recovered tags data indicated a clear day-night difference in behavior **(e.g., Figures 4 to 8)**. Accordingly we partitioned the data by day and night, and, where possible (archived, high resolution data), by twilight. In order to preserve the stochastic nature of animal behavior, we partitioned observations for each animal by their daily activity patterns to be commensurate with the duration of a longline set.

For the Argos-transmitted data, we compiled the proportions spent within successively deeper layers of temperature relative to the temperature of the surface mixed layer (termed Delta T) by each 6-hour period that could be clearly identified as daytime or night-time. For each time period, there are three types of summarized data transmitted via Argos satellites: (1) the proportion of time the fish spent within 12 user-defined depth bins (i.e. 25 m bin resolution in this study); (2) the proportion of time the fish spent within 12 user-defined temperature bins (i.e. 2.0^{o} C bin resolution in this study); and (3) minimum and maximum temperatures at depth minima and maxima visited by the fish, and at 6 additional depths between those points (PDT). We extracted the temperatures from the PDT data where the depth is $\leq$ 1 m, and calculated the daily average surface temperature (T_o) for each day. When there were no surface temperature observations (i.e. when fish did not surface for a day), we used previous and subsequent day's temperatures to linearly interpolate the surface temperature. Next, we generated 360 temperature (GT, 6 hrs, 1 temperature per minute) from the depth-temperature data, and PDT by taking the number of minutes at each depth bin and the range of temperatures for that depth bin from PDT. Then, for each depth bin, we used the probability density function derived from the high-resolution data to randomly generate the number of temperature values for each depth bin. A new temperature histogram was tabulated for the generated temperatures, and it was compared with the temperature histogram (T) of the data. The differences in numbers for each temperature bin were corrected by randomly eliminating the temperature values in positive bins, and randomly adding temperature values in negative bins. Finally, Delta Ts were calculated by subtracting the generated temperatures (GT) with the surface temperature (T), and the proportions of time spent at decreasing Delta T were tabulated at 1^{o} C bin resolution.

Inspection of the high-resolution data from recovered tags revealed that most of the time spent in the surface mixed layer (Delta T bin = 0) was actually spent at the ocean surface (arbitrarily defined here as $\leq$ 5m). Time spent in this stratum was treated as a separate bin. The time periods for day, night, and twilight were determined from the light level data recorded by the tag. Daylight and darkness were easily separated. The change in light level at dusk and dawn were used to bound twilight based on the midpoint of the transition in light intensity.

Specifically, we quantified twilight as the two-hour period about dusk or dawn. Daily dawn/dusk data were pooled by day. The daily day-night-twilight patterns of time spent at the ocean surface and Delta T were then determined by pooling the archived, high-resolution observations for the appropriate periods. The mean delta T values were determined for each of the resulting distributions, and the Delta T- time distributions for each day-night (and twilight) compilation were sorted by increasing depth. The data were then tabulated for several percentiles of the observed frequency distributions.

3. Results and discussion

There were 996 sets of Delta T distributions for Argos night-time data **(Table 1)** and 898 sets for the daytime data **(Table 2)**. There is a clear day-night difference in the behavior of these animals, with animals spending more time below the surface mixed layer during the daytime. The high-resolution data from recovered tags yielded 404 daily estimates of time spent at the surface/Delta T for conditions of night-time and twilight, and 403 daily estimates for daytime conditions **(Tables 3 to 5)**. These data also indicate a trend of increasing use of cooler layers during the daytime than during darkness, with an intermediate behavior during periods of twilight.

Overall, our observations indicate large variability in habitat utilization as characterized by time spent at temperature relative to the surface mixed layer, both within and between individual animals. This is clearly indicated by the differences in depths explored in **Figures 4 to 8**. Each of these figures was constructed from data we retrieved from a recovered tag from a single blue marlin. Each figure represents the daily activity pattern during a single day of different weeks while the tag was attached (39 total monitoring days). Inspection of the Delta T fractions for the different percentiles in **Tables 1 to 5** also reveal the stochastic nature of the behavior with respect to Delta T. The distributions are not only highly variable, but even when sorted by mean Delta T, there is not a smooth progression of increasing use of cooler Delta T, with the increase in the mean. For example, the animals contributing to observations at the 90^{th} and 95^{th} percentiles of the distributions (sorted by mean), ventured into relatively colder/deeper water than those at the 97.5 and 99^{th} percentiles. These observations support the view that the behavior of blue marlin with respect to depth is more complex than can be captured by a model of Delta T alone.

We believe that the time spent at the ocean's surface is not generally associated with feeding behavior, but takes place when the fish are in a quiescent mode, particularly during nocturnal periods. Blue marlin appear to be daylight, sight feeders, that regularly descend into the water column to feed or possibly view forage above. The depths explored are likely a function of the distribution of the forage more so than the actual Delta T experienced by the marlin. The forage depth distribution is a function of both its species composition and oceanographic features. The thermocline is a principal feature of the tropical and subtropical environment influencing the pelagic habitat. It probably is a practical physical boundary for many forage species (from both directions). There is a strong association between Delta T and the temperature distribution within and above the thermocline. These factors would lead to strong, spatially local correlations between Delta T and habitat use that may not be very predictive across the entire spatial distribution of blue marlin. Certainly, the individual fish depicted in **Figures 4 to 8** exhibited fundamentally different behaviors during the period monitored.

Our blue marlin often made deep, short-duration dives that took them into relatively cold environments. The deepest dives observed are depicted in **Figure 9**. The mode is at 200-300m, but dives below 800m were observed. These correspond to a mode of minimum temperatures explored at 18 degrees C, and a minimum observed temperatures below 10 degrees C **(Figure 10)**. Clearly, blue marlin can penetrate these depths and temperatures as conditions require, if only briefly. Such excursions may be related to feeding or predator avoidance and are no doubt facilitated by their brain heater organ (Block 1986) that permits ocular and physical function at low temperatures (Block 1986; Block and Finnerty 1994; Fritsches *et al.* 2003; Fritsches *et al.* 2005). In either event, the view that this species' habitat does not include depths fished by deeply set pelagic longlines is not valid. Previous reports of blue marlin monitored via acoustic telemetry (Block *et al.* 1992a; Block *et al.* 1992b) were conducted over much shorter time periods (hours to days) than reported here (weeks and months). Resulting depth and temperature preferences from these studies conducted previously, indicated a more limited use of the water column.

Nonetheless, the correlations that must exist between Delta T, thermocline features, prey distributions and blue marlin habitat utilization make Delta T a potentially useful variable for simulating the depth distribution of the species from knowledge of the depth distributions of this oceanographic feature based on physical oceanography research and monitoring results. We feel that the mean behaviors over all Delta T are not locally predictive and recommend that simulations draw from the observed daily distributions. This procedure will preserve the stochastic nature of the observations, but will not ensure that the simulated depth distributions faithfully replicate

the true situation. Extrapolations of either the simulation results or any analysis thereof must be cognizant of these limitations.

Future research should investigate factors that explain spatiotemporal variability in the Delta T proportions and/or other paradigms about the vertical habitat use of blue marlin. Absolute temperature, Delta T, actual depth (light concentration), prey and predator distributions and abundances are all likely to be important features of blue marlin habitat. One potentially useful tool for investigating the vertical habitat problem is the construction and analysis of "vertical habitat envelopes" as detailed by Luo *et al.* (in press). This quantitative framework integrates the depth and temperature preferences of PSAT-tagged fish in the form of temperature-depth matrices of utilization (time spent). The approach is conducive for comparative studies of animal behavior and for calculation (and visualization) of degrees of overlap, be it among individuals, species or fishing gear. Such light-depth or light-temperature envelopes might also be constructed and evaluated for pelagic longline species-interaction space.

Acknowledgements

The Billfish Foundation supported CPG's contribution to this study. D. Snodgrass, E. Orbesen, R. Nelson, B. Luckhurst, and G. Harvey assisted in deploying PSATs. We thank all participants in our Adopt A Billfish Program for sponsoring tags, providing tagging platforms, and transferring fish to our tagging vessels.

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Table 1. Fractions of time spent by blue marlin at temperature relative to the temperature of the surface mixed layer (Delta T) during hours of darkness based on Argos transmitted data from PSAT tags.

	Fraction of time at Delta T											
Delta T	*Percentile of Mean Delta T*											*Mean*
	0.010	*0.025*	*0.050*	*0.100*	*0.250*	*0.500*	*0.750*	*0.900*	*0.950*	*0.975*	*0.990*	
0	1.000	1.000	1.000	1.000	1.000	0.947	0.694	0.265	0.041	0.532	0.028	0.849
-1	-	-	-	-	-	0.049	0.251	0.514	0.473	0.050	0.338	0.079
-2	-	-	-	-	-	0.004	0.047	0.216	0.463	0.026	0.213	0.033
-3	-	-	-	-	-	-	0.006	0.006	0.024	0.064	0.140	0.018
-4	-	-	-	-	-	-	0.002	-	-	0.101	0.120	0.008
-5	-	-	-	-	-	-	-	-	-	0.163	0.079	0.005
-6	-	-	-	-	-	-	-	-	-	0.056	0.065	0.003
-7	-	-	-	-	-	-	-	-	-	0.006	0.019	0.002
-8	-	-	-	-	-	-	-	-	-	0.002	-	0.001
-9	-	-	-	-	-	-	-	-	-	-	-	0.001
-10	-	-	-	-	-	-	-	-	-	-	-	0.000
-11	-	-	-	-	-	-	-	-	-	-	-	0.000
-12	-	-	-	-	-	-	-	-	-	-	-	0.000
-13	-	-	-	-	-	-	-	-	-	-	-	-
-14	-	-	-	-	-	-	-	-	-	-	-	-
-15	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. Fractions of time spent by blue marlin at temperature relative to the temperature of the surface mixed layer (Delta T) during hours of daylight based on Argos transmitted data from PSAT tags.

	Fraction of time at Delta T											
Delta T	*Percentile of Mean Delta T*											*Mean*
	0.010	*0.025*	*0.050*	*0.100*	*0.250*	*0.500*	*0.750*	*0.900*	*0.950*	*0.975*	*0.990*	
0	1.000	1.000	1.000	1.000	0.960	0.372	0.455	0.335	0.000	0.210	0.017	0.583
-1	-	-	-	-	0.024	0.516	0.075	0.132	0.000	0.201	0.005	0.144
-2	-	-	-	-	0.016	0.098	0.025	0.018	0.000	0.016	0.001	0.069
-3	-	-	-	-	-	0.015	0.030	0.042	0.049	0.004	0.000	0.043
-4	-	-	-	-	-	-	0.154	0.043	0.368	0.028	0.005	0.031
-5	-	-	-	-	-	-	0.151	0.037	0.301	0.013	0.032	0.026
-6	-	-	-	-	-	-	0.041	0.031	0.184	0.016	0.114	0.022
-7	-	-	-	-	-	-	0.044	0.021	0.041	0.012	0.202	0.022
-8	-	-	-	-	-	-	0.021	0.046	0.000	0.028	0.214	0.019
-9	-	-	-	-	-	-	0.004	0.071	0.000	0.025	0.398	0.020
-10	-	-	-	-	-	-	-	0.170	0.003	0.223	0.013	0.012
-11	-	-	-	-	-	-	-	0.053	0.008	0.031	-	0.003
-12	-	-	-	-	-	-	-	0.002	0.027	0.087	-	0.003
-13	-	-	-	-	-	-	-	-	0.010	0.101	-	0.001
-14	-	-	-	-	-	-	-	-	0.007	0.006	-	0.001
-15	-	-	-	-	-	-	-	-	0.001	-	-	0.000

Table 3. Fractions of time spent by blue marlin in the upper 5m and at temperature relative to the temperature of the surface mixed layer (Delta T) during hours of darkness based on data retrieved from recovered PSAT tags.

Depth or Delta T	*Fraction of time at Depth or Delta T*											
	Percentile of Mean Delta T											*Mean*
	0.010	*0.025*	*0.050*	*0.100*	*0.250*	*0.500*	*0.750*	*0.900*	*0.950*	*0.975*	*0.990*	
>5 m	1.000	1.000	1.000	1.000	0.998	0.991	0.914	0.358	0.525	0.641	0.584	0.911
0	-	-	-	-	0.002	0.003	0.045	0.362	0.053	0.038	0.070	0.037
-1	-	-	-	-	-	0.006	0.024	0.241	0.082	0.029	0.020	0.015
-2	-	-	-	-	-	0.001	0.016	0.038	0.148	0.022	0.021	0.015
-3	-	-	-	-	-	-	0.001	0.001	0.141	0.025	0.029	0.008
-4	-	-	-	-	-	-	-	-	0.029	0.042	0.043	0.005
-5	-	-	-	-	-	-	-	-	0.022	0.031	0.041	0.002
-6	-	-	-	-	-	-	-	-	-	0.067	0.044	0.003
-7	-	-	-	-	-	-	-	-	-	0.076	0.068	0.002
-8	-	-	-	-	-	-	-	-	-	0.029	0.079	0.001
-9	-	-	-	-	-	-	-	-	-	-	-	0.000
-10	-	-	-	-	-	-	-	-	-	-	-	-
-11	-	-	-	-	-	-	-	-	-	-	-	-
-12	-	-	-	-	-	-	-	-	-	-	-	-
-13	-	-	-	-	-	-	-	-	-	-	-	-
-14	-	-	-	-	-	-	-	-	-	-	-	-
-15	-	-	-	-	-	-	-	-	-	-	-	-

Table 4. Fractions of time spent by blue marlin in the upper 5m and at temperature relative to the temperature of the surface mixed layer (Delta T) during hours of twlight based on data retrieved from recovered PSAT tags.

Depth or Delta T	*Fraction of time at Depth or Delta T*											
	Percentile of Mean Delta T											*Mean*
	0.010	*0.025*	*0.050*	*0.100*	*0.250*	*0.500*	*0.750*	*0.900*	*0.950*	*0.975*	*0.990*	
>5 m	1.000	0.958	0.898	0.710	0.552	0.446	0.339	0.674	0.523	0.456	0.581	0.520
0	-	0.042	0.065	0.290	0.423	0.477	0.423	0.013	0.119	0.174	0.023	0.344
-1	-	-	0.020	-	0.004	0.073	0.238	0.044	0.179	0.066	0.017	0.079
-2	-	-	0.016	-	0.004	0.004	-	0.074	0.013	0.004	0.019	0.026
-3	-	-	-	-	0.004	-	-	0.111	0.019	0.100	0.025	0.012
-4	-	-	-	-	0.004	-	-	0.084	0.038	0.021	0.081	0.009
-5	-	-	-	-	0.008	-	-	-	0.040	0.042	0.058	0.003
-6	-	-	-	-	-	-	-	-	0.071	0.112	0.113	0.003
-7	-	-	-	-	-	-	-	-	-	0.025	0.029	0.002
-8	-	-	-	-	-	-	-	-	-	-	0.054	0.001
-9	-	-	-	-	-	-	-	-	-	-	-	0.000
-10	-	-	-	-	-	-	-	-	-	-	-	0.000
-11	-	-	-	-	-	-	-	-	-	-	-	0.000
-12	-	-	-	-	-	-	-	-	-	-	-	0.000
-13	-	-	-	-	-	-	-	-	-	-	-	0.000
-14	-	-	-	-	-	-	-	-	-	-	-	-
-15	-	-	-	-	-	-	-	-	-	-	-	-

Table 5. Fractions of time spent by blue marlin in the upper 5m and at temperature relative to the temperature of the surface mixed layer (Delta T) during hours of daytime based on data retrieved from recovered PSAT tags.

Depth or Delta T	*Fraction of time at depth or delta T*											
	Percentile of Mean Delta T											*Mean*
	0.010	*0.025*	*0.050*	*0.100*	*0.250*	*0.500*	*0.750*	*0.900*	*0.950*	*0.975*	*0.990*	
>5 m	*0.998*	*0.990*	*0.979*	*0.741*	*0.022*	*0.134*	*0.501*	*0.176*	*0.263*	*0.029*	*0.051*	*0.222*
0	0.002	0.010	0.008	0.172	0.977	0.562	0.053	0.617	0.394	0.054	0.102	0.478
-1	-	-	0.007	0.072	0.002	0.245	0.033	0.012	0.015	0.051	0.021	0.183
-2	-	-	0.006	0.012	0.000	0.049	0.170	0.011	0.015	0.227	0.052	0.058
-3	-	-	-	0.003	0.000	0.011	0.159	0.016	0.030	0.495	0.226	0.023
-4	-	-	-	-	-	-	0.078	0.016	0.029	0.145	0.127	0.010
-5	-	-	-	-	-	-	0.005	0.015	0.041	-	0.134	0.007
-6	-	-	-	-	-	-	-	0.019	0.082	-	0.280	0.006
-7	-	-	-	-	-	-	-	0.015	0.091	-	0.007	0.004
-8	-	-	-	-	-	-	-	0.014	0.006	-	-	0.003
-9	-	-	-	-	-	-	-	0.029	0.018	-	-	0.003
-10	-	-	-	-	-	-	-	0.023	0.010	-	-	0.003
-11	-	-	-	-	-	-	-	0.027	0.005	-	-	0.001
-12	-	-	-	-	-	-	-	0.012	0.000	-	-	0.000
-13	-	-	-	-	-	-	-	-	0.001	-	-	0.000
-14	-	-	-	-	-	-	-	-	0.001	-	-	0.000
-15	-	-	-	-	-	-	-	-	-	-	-	0.000



Figure 1. Use of a snooter to control an Atlantic blue marlin during the deployment of a PSAT tag promotes safety. Note that the head of the marlin is being maintained below the surface of the water during the tagging process.

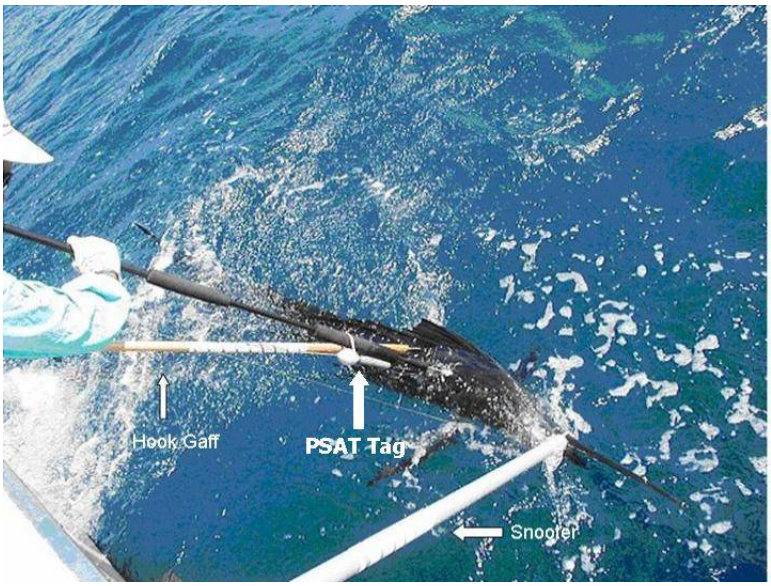


Figure 2. A small hook gaff (wooden pole) and a snooter (pvc pipe) are being used in tandem to control this Atlantic sailfish to insure safe and precise placement of a PSAT tag.

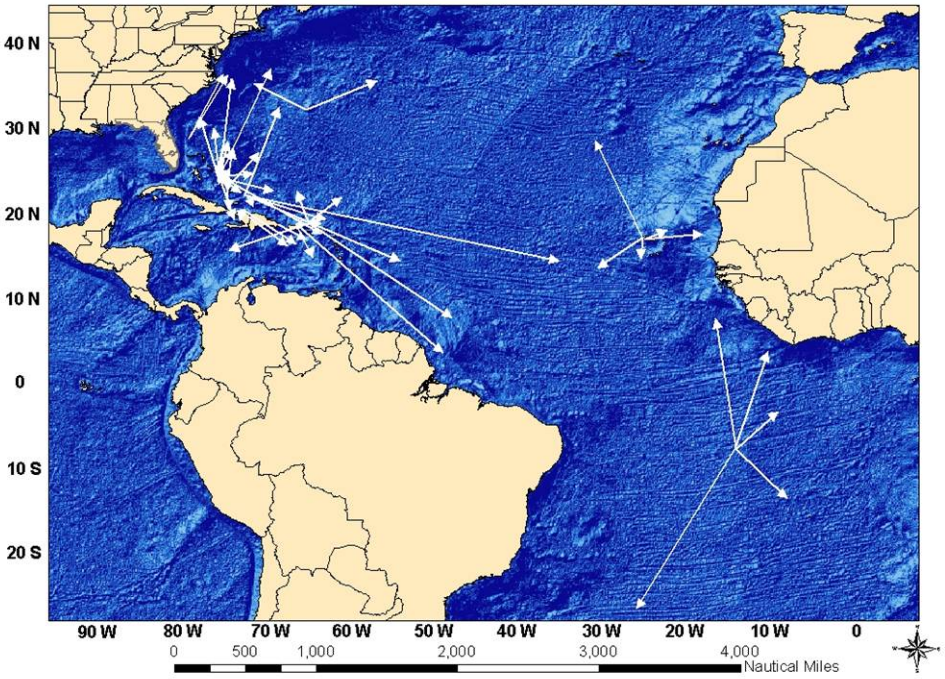


Figure 3. Tag and popoff locations of PSAT tags applied to blue marlin in this study.

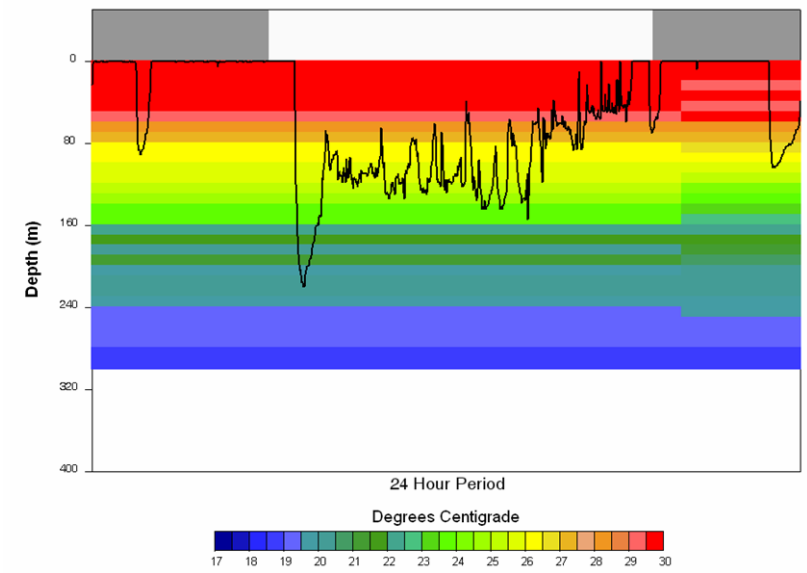


Figure 4. Excerpt from a time series (October 12-November 20, 2003) of temperature-depth measurements by a PSAT tag applied to a blue marlin and later recovered. The shaded/white area above the zero depth value on the y-axis denotes darkness and daylight periods respectively. Excerpt was taken from the first part of the time series on 10/17/03 and demonstrates typical day time diving activity in the first part of the track.

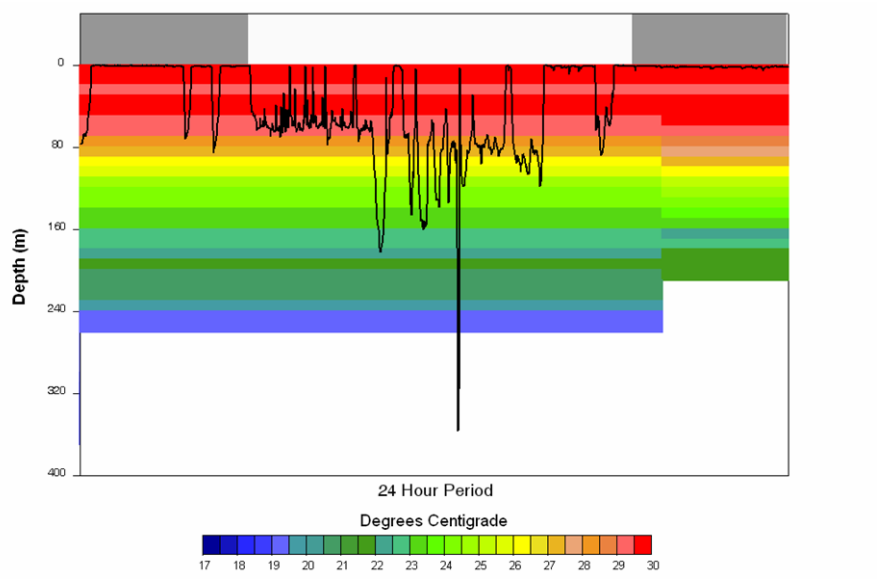


Figure 5. Excerpt from time series (October 12- 20, 2003) of temperature-depth measurements by a PSAT tag applied to a blue marlin and later recovered. The shaded/white area above the zero-depth value on the y-axis denotes darkness and daylight periods respectively. Except was taken from the early part of the time series on 10/24/03 and demonstrates the deepest dive (340 m) during the track.

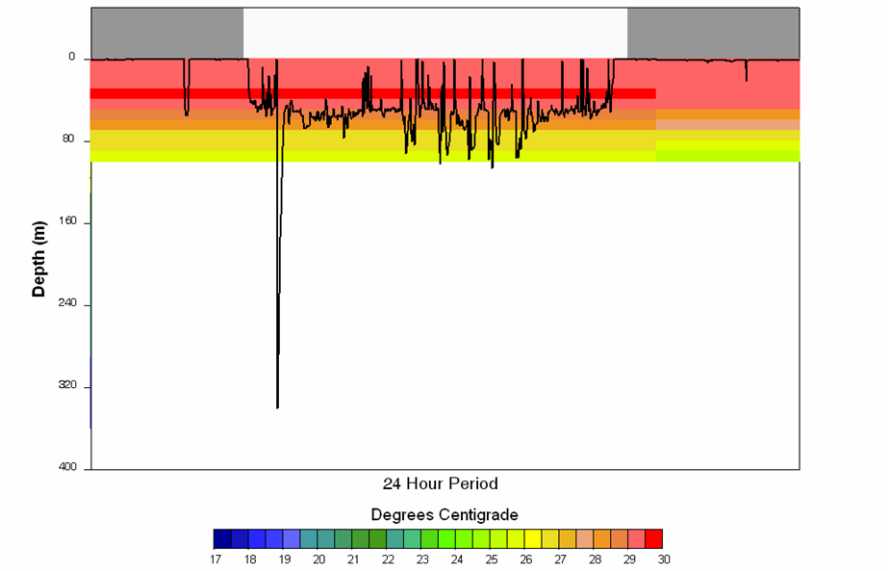


Figure 6. Excerpt from a time series (October 12-November 20, 2003) of temperature-depth measurements by a PSAT tag applied to a blue marlin and later recovered. The shaded/white area above the zero-depth value on the y-axis denotes darkness and daylight periods respectively. Excerpt was taken from the middle part of the time series on 10/29/03 and demonstrates typical daytime behavior with occasional deep dives.

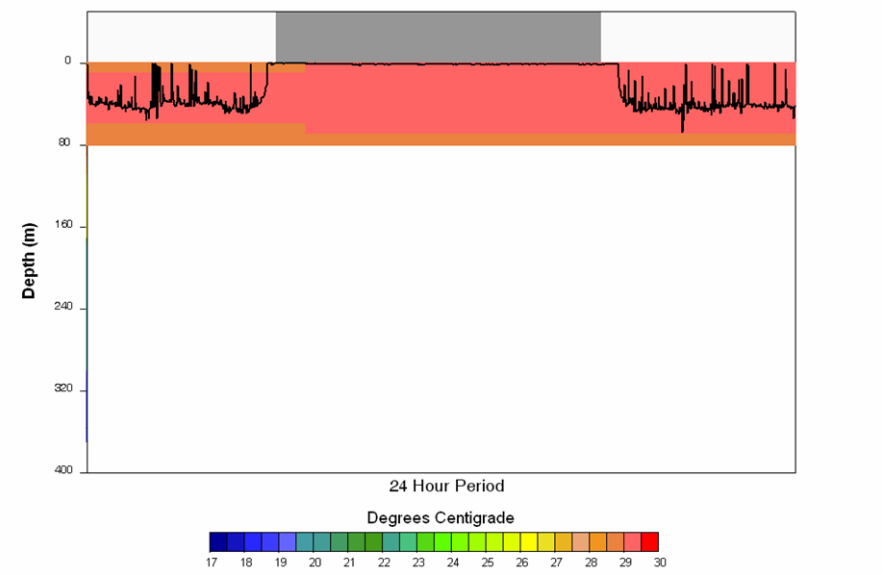


Figure 7. Excerpt from a time series (October 12-November 20, 2003) of temperature-depth measurements by a PSAT tag applied to a blue marlin and later recovered. The shaded/white area above the zero-depth value on the y-axis denotes darkness and daylight periods respectively. Excerpt was taken from later part of the time series on 11/17/03 and demonstrates quiescent (dormant) activity during nocturnal periods towards the end of the track.

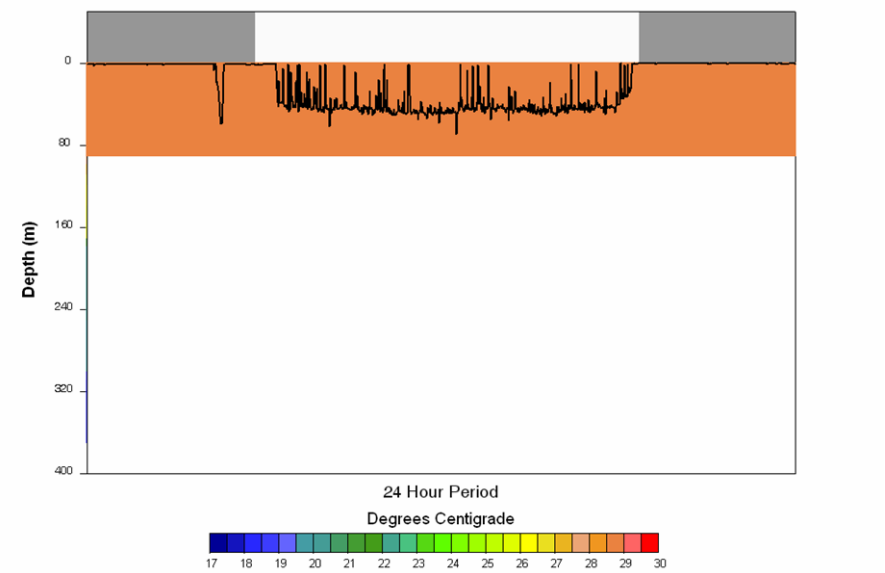


Figure 8. Excerpt from a time series (October 12-November 20, 2003) of temperature-depth measurements by a PSAT tag applied to a blue marlin and later recovered. The shaded/white area above the zero-depth value on the y-axis denotes darkness and daylight periods respectively. Excerpt was taken near the end of the time series on 11/19/03 and demonstrates restrictive daytime diving activity during the later part of the track.

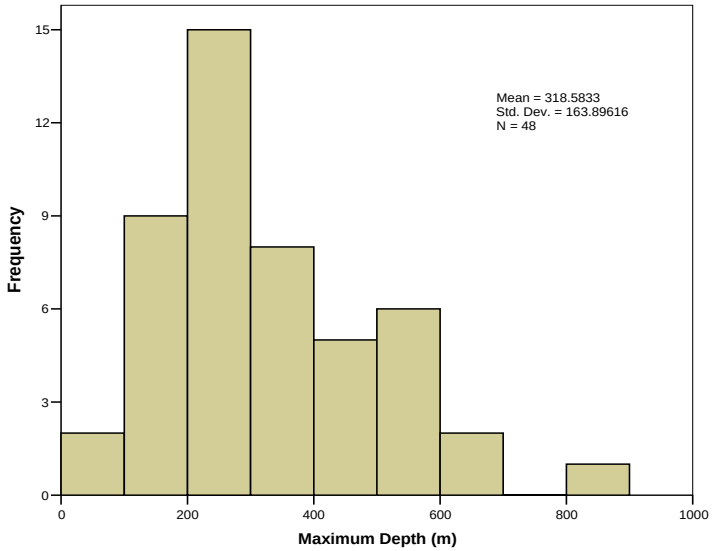


Figure 9. Maximum depths to which each tagged animal dived during its time at large.

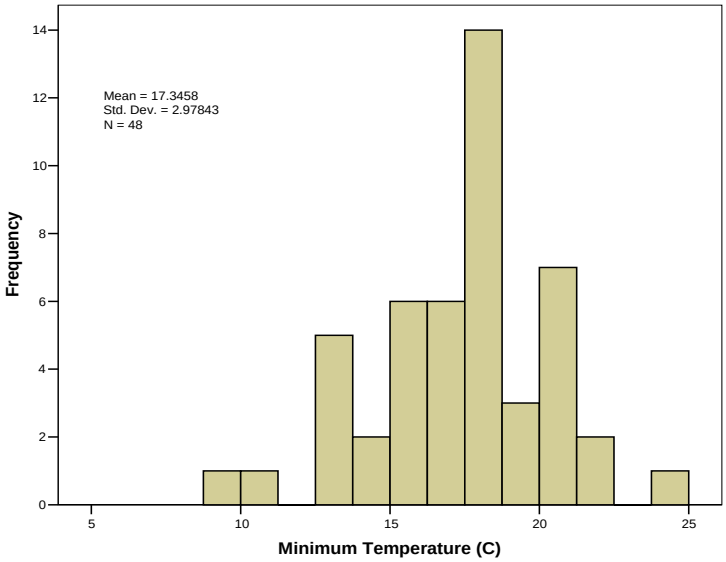


Figure 10. Minimum temperatures experienced by each tagged animal during its time at large.