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HABITAT PREFERENCES OF ISTIOPHORID BILLFISHES IN THE WESTERN NORTH ATLANTIC: APPLICABILITY OF ARCHIVAL TAG DATA TO HABITAT-BASED STOCK ASSESSMENT METHODOLOGIES

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SUMMARY

The Japanese pelagic longline fishery, which has a broad temporal and spatial coverage in the Atlantic Ocean, provides an important time series used in assessments of istiophorid billfishes. Past assessments of Atlantic blue marlin and white marlin by the ICCAT SCRS indicate a pronounced decrease in stock abundance of both species over the past fifty years. The current biomass of the white marlin is estimated to be 15% of that necessary for maximum sustainable yield (B_{MSY}), while blue marlin are estimated to be at 0.4 B_{MSY}. Over the past fifty years Japanese pelagic longline fishing operations have moved from shallow longline sets targeting yellowfin tuna to deeper longline sets targeting swordfish and bigeye tuna. As billfish are known to spend the majority of their time in surface waters, it was expected that billfish catch rates would be reduced for deeper set longlines. Coupled with the historical decrease in abundance of the stocks, the reduction of catch rates of deeper sets in recent years should be more pronounced. However, in some instances, billfish catch rates of deeper set longlines in recent years have exceeded those of shallow set longlines during times of higher billfish abundance. Such findings are enigmatic, and there are several possible explanations for the observed results (none of which are mutually exclusive): (1) the assessments may not be correct (billfish abundance may not be as low as it is currently estimated to be); (2) deep set longline hooks may fish at shallower depths than estimated; (3) the majority of billfish may be taken as deep set longlines are deployed and retrieved (a longer time for the bait to be moving through the water column); or (4) billfish may preferentially feed at depth.

In this paper we provide detailed time-at-depth information for two blue marlin released alive from pelagic longline gear with pop-up archival satellite tags (PSATs) programmed to release from the animals after 30 days. Both blue marlin made several dives each day. The fish moved quickly to depth, and the times at depth were greater than those spent in descent or ascent. The depth of dives was greater during daylight hours. These data are suggestive of feeding excursions to deeper waters, movements for which these fish are well adapted with large eyes and a brain (eye) heating organ. If billfish undertake specific feeding movements to depth, then one would expect increased catch rates for deeply set longline gear. Researchers have recently attempted to standardize catch rates of billfish on pelagic longline for the time fish spend at depth (habitat-based models). However, if feeding motivation is not the same for an animal at all depths, then such standardizations will significantly bias catch rates and lead to errors in assessment.

RÉSUMÉ

La pêcherie palangrière pélagique japonaise, qui dispose d'une large couverture spatio-temporelle dans l'océan Atlantique, fournit une série temporelle primordiale dans les évaluations des istiophoridés. Les évaluations antérieures sur le makaire bleu et le makaire blanc de l'Atlantique réalisées par le SCRS de l'ICCAT indiquent une baisse marquée de l'abondance du stock des deux espèces au cours de ces 50 dernières années. La biomasse actuelle du makaire blanc est estimée être à 15% de celle qui est nécessaire pour atteindre la

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production maximale équilibrée (B_{PME}), tandis que le makaire bleu est estimé être à 0,4 B_{PME}. Ces 50 dernières années, la pêche à la palangre pélagique du Japon s'est modifiée, les opérations à la palangre ciblant le germon en eaux peu profondes cédant la place aux opérations à la palangre ciblant l'espadon et le thon obèse en eaux profondes. Comme les istiophoridés sont connus pour passer la plupart de leur temps dans les eaux de surface, on s'attendait à une diminution des taux de capture des istiophoridés capturés à la palangre de profondeur. Conjointement avec la baisse historique de l'abondance des stocks, la réduction des taux de capture des opérations en profondeur ces dernières années devrait être plus prononcée. Toutefois, dans certains cas, les taux de capture des istiophoridés à la palangre de profondeur ont dépassé ceux réalisés à la palangre en eaux peu profondes à des époques de plus grande abondance des istiophoridés. Ces constatations posent une énigme et il existe plusieurs explications éventuelles pour les résultats observés (aucun d'entre eux n'étant mutuellement exclusif) : (1) les évaluations ne sont peut-être pas correctes (l'abondance des istiophoridés n'est peut-être pas aussi faible qu'elle est actuellement estimée) ; (2) il se peut que les hameçons des palangres mouillés en eaux profondes pêchent à des profondeurs moins grandes qu'on ne l'estime ; (3) la majorité des istiophoridés peuvent être capturés lors du mouillage et du relevage des palangres en eaux profondes (l'appât dispose d'une période plus longue pour se déplacer à travers la colonne d'eau) ; ou (4) les istiophoridés s'alimentent peut-être de préférence en profondeur.

Dans le présent document, nous fournissons une information détaillée du temps en profondeur pour deux makaires bleus remis à l'eau vivants d'une palangre pélagique et auxquels on a apposé des marques-archives pop-up par satellite (PSAT) programmées pour se détacher des poissons au bout de 30 jours. Les deux makaires bleus ont fait plusieurs plongées tous les jours. Les poissons se sont déplacés rapidement vers le fond, et le temps passé en profondeur a été supérieur à la durée de la descente ou de l'ascension. La profondeur des plongées était plus grande durant les heures diurnes. Ces données suggèrent des excursions trophiques en eaux plus profondes, déplacements pour lesquels ces poissons sont bien adaptés grâce à leurs yeux de grande dimension et à un organe de réchauffement placé dans le cerveau (œil). Si les istiophoridés réalisent des déplacements trophiques spécifiques vers les eaux profondes, on s'attendrait à constater une hausse des taux de capture des palangres mouillées en eaux profondes. Les chercheurs ont récemment tenté de standardiser les taux de capture des istiophoridés capturés à la palangre pélagique pour calculer le temps que le poisson passe en profondeur (modèles basés sur l'habitat). Toutefois, si la motivation trophique d'un poisson varie en fonction de la profondeur, ces standardisations vont considérablement fausser les taux de capture et engendrer des erreurs dans l'évaluation.

RESUMEN

La pesquería japonesa pelágica de palangre, que tiene una amplia cobertura temporal y espacial en el océano Atlántico, proporciona una importante serie temporal en la evaluación de istiofóridos. Las pasadas evaluaciones de la aguja azul y aguja blanca del Atlántico realizadas por el SCRS de ICCAT indicaban un pronunciado descenso en la abundancia del stock para ambas especies en los últimos cincuenta años. Se estima que la biomasa actual de la aguja blanca se sitúa en un 15% de la necesaria para permitir el rendimiento máximo sostenible (B_{RMS}); se estima que la aguja azul se halla en 0,4 B_{RMS}. En los últimos cincuenta años las operaciones de pesca japonesas con palangre pelágico han pasado de operaciones de fondeo de palangre superficiales que tenían como objetivo el rabil a operaciones de palangre más profundos dirigidas al pez espada y el patudo. Como se sabe que los marlines pasan la mayoría de su tiempo en aguas superficiales, se esperaba que las tasas de captura de marlines se reducirían en las operaciones de palangre más profundas.

Junto con el descenso histórico de la abundancia de los stocks, la reducción de las tasas de captura de las operaciones de fondeo de palangre en profundidades mayores de los últimos años debería ser más pronunciada. Sin embargo, en algunos casos, las tasas de captura de los marlines de las operaciones de palangre a mayor profundidad de los últimos años han superado a las operaciones de palangre superficiales durante los tiempos de mayor abundancia de marlines. Dichos hallazgos son un enigma, y existen varias explicaciones posibles para los resultados observados (explicaciones que no se excluyen entre sí en ningún caso): (1) las *evaluaciones pueden no ser correctas (la abundancia de marlines podría no situarse en niveles tan bajos como los estimados actualmente); (2) los anzuelos de palangre fondeados en aguas profundas pueden pescar en profundidades más superficiales que las estimadas; (3) la mayoría de los marlines pueden capturarse cuando el palangre de profundidad se despliega o recoge (lo que supone un período de tiempo más largo durante el cual el cebo se mueve a través de la columna de agua); o (4) los marlines pueden alimentarse preferentemente en aguas profundas. En este documento proporcionamos información detallada sobre profundidad en el tiempo para dos agujas azules liberadas vivas del arte de palangre pelágico con marcas archivo "pop up" (PSATs) programadas para desprenderse del animal al cabo de 30 días. Ambas agujas azules realizaron varias inmersiones al día. Los peces se desplazaron rápidamente a aguas profundas y el tiempo pasado en aguas profundas superó al que pasaron en el descenso o ascenso. La profundidad de las inmersiones fue superior durante las horas de luz del día. Estos datos sugieren excursiones tróficas a aguas más profundas, movimientos para los cuales están adaptados estos peces con grandes ojos y un órgano generador de calor en el cerebro (ojo). Si los marlines emprenden movimientos de alimentación específicos a aguas profundas, sería de esperar que las tasas de captura se incrementaran con artes de palangre de profundidad. Recientemente, los investigadores han intentado estandarizar las tasas de capturas de los marlines en el palangre pelágico considerando el tiempo que los peces pasan en aguas profundas (modelos basados en el hábitat). Sin embargo, si la motivación alimentaria no es la misma para un animal en todos lo niveles de profundidad, entonces dicha estandarización produciría un sesgo importante en las tasas de captura y conduciría a errores en la evaluación.*

KEY WORDS

Gear selectivity, feeding behavior, habitat, longlining, fishing effort, standardized catch rates, Makaira nigricans, Tetrapturus albidus, billfish.

1. INTRODUCTION

Recent assessments of Atlantic blue marlin and white marlin by the Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) demonstrate a significant decrease in the abundance of both species over the past fifty years (ICCAT 2001). Both blue marlin and white marlin experienced large decreases in abundance in the 1960s and 1970s, and relatively smaller, but steady declines since that time. Current biomass of the white marlin is estimated to be 15% of the biomass that would result in maximum sustainable yield (B_{MSY}), while blue marlin are estimated to be at 0.4 B_{MSY}. In response to the overfished condition of these stocks, ICCAT has adopted management actions to reduce fishing mortality, including significant reductions in billfish landings and the release of all live billfish.

Stock assessments of Atlantic billfishes are based on time series of catch-per-effort data of various fisheries that interact with these species. If fishing practices change over time within a fishery it may be necessary to standardize CPUEs throughout the time series for comparison, a process that can be problematic. For Atlantic billfishes, the Japanese pelagic longline time series has been a major element of all recent stock assessments. However, over the fifty-year history of this time series, there have been major changes in the target species and the depth at which the gear is deployed (Yokawa and Uozumi 2001). Originally, Japanese longlines were fished relatively shallow for yellowfin tuna, with hook depths ranging from 15 to 20 m (Yamaguchi 1986). During the 1970s, the Japanese longline fishery developed gear that fished more deeply in the water column in an effort to target bigeye tuna (Suzuki and Kume 1982). This deep longline gear was introduced into the Atlantic in the early 1980s and is now the predominant longline gear employed for bigeye tuna. Typically, hooks are set at depths ranging from 170 to 300 m (Uozumi and Nakano 1994).

The change in depth of longline deployments in the Japanese longline fishery could affect catchability of billfish. Studies employing acoustic and satellite tag technology have demonstrated that blue marlin and striped marlin spend the majority of their time in the waters of the upper mixed layer (Holland *et al.* 1990; Block *et al.* 1992a, b; Brill *et al.* 1993; and Graves *et al.* 2002), a behavior that is probably common to all istiophorids. If one assumes that a billfish's inclination to feed is independent of depth, and since billfish spend the majority of their time near the surface, one would expect lower catch rates of these species on deeply set longlines. To account for this Hinton and Nakano (1996) developed a model that incorporates habitat information to standardize catchability by depth. The general effect of this model is to decrease the effective fishing effort of deeply set longlines, which in turn, increases catch per effort values for those sets.

When one takes into account the observation that there has been a substantial decrease in billfish abundance over the past fifty years, it is expected that billfish catch rates would be even more depressed on the deep longline sets which have occurred in recent years, relative to those on shallow longline sets in the past. This is not always the case. In some instances, catch rates of billfish on deeply set longlines in recent years have exceeded those of shallow set longlines in earlier years. These differences become more pronounced when standardized with the habitat-based model (Goodyear *et al.* 2002).

There are several possible explanations, none of which are mutually exclusive, as to why catch rates on deep set longlines are not always considerably reduced relative to those on shallow set longlines: (1) The assessments of Atlantic billfishes may not be correct, and current abundance is not as low as it is estimated to be. (2) Deep set longline hooks may fish at shallower depths than predicted by current longline gear models. (3) The majority of billfish may be not be caught when the longline gear is at depth, but when the gear is deployed and retrieved (in which case there would not be a major difference between shallow and deep longline sets). (4) Finally, billfish may preferentially feed at depth, in which case standardizing catch rates by total time at particular depth or temperature strata would be an inappropriate correction.

In this paper we report on the detailed temperature and depth data of two blue marlin caught on pelagic longline gear in the western North Atlantic Ocean during 2001. Both fish were equipped with pop-up satellite archival tags (PSATs) programmed to release after 32 days. Analysis of temperature and depth records of these individuals indicates several dives to depths below 100 m on a daily basis, vertical excursions that may well be related to feeding.

2. MATERIALS AND METHODS

Two 30-day archival PSATs (PAT model tags from Wildlife Computers, Redmond, Washington, USA) were deployed on blue marlin during normal longline operations from commercial swordfish fishing vessels in waters off North Carolina and the east coast of Florida. Detailed descriptions of the PSATs and tag deployment are presented in Kerstetter (2002). Prior to release, individual weights of tagged fish were visually estimated, and hooking location, physical condition, and the approximate position of the fish on the length of the longline recorded. Fish were released after tagging by cutting the gangion near the hook, but leaving the hook in place. No resuscitation or other post-capture care was provided to either fish.

The PSATs measured ambient pressure and temperature readings at 2-minute intervals and stored the information as the percent of time that the tag was within each of twelve pre-set temperature and pressure bins. Tags were programmed to release from the fish after 32 days. After release from the fish the tags floated to the surface and transmitted data through passing ARGOS system satellites to researchers at the laboratory via the Internet. The point of the first satellite data transmission was used as the end proxy for determining minimum straight-line distance.

3. RESULTS

Two blue marlin were caught during normal pelagic longline fishing operations in the western North Atlantic Ocean and tagged with PSATs. The fish with tag 16122-01 was estimated to weight 180 Kg and was caught on a hook that was in the water (soak time) for six hours. The blue marlin with tag 24519-01 was estimated to weight 160 Kg, and was caught on a hook that had a soak time of about 35 hours (the extended soak time resulted from a parting of the main line). Both fish were hooked in the mouth and in good condition when released.

The PSATs released from the fish and began transmitting data on the expected dates. Both tagged fish moved significant distances from the tagging location, although movement patterns differed. The first blue marlin (tag 16122-01) moved approximately 750 nm northeast toward the central north Atlantic, while the second (tag 24519-01) traveled over 1,200 nm toward the southern edge of the Grand Banks.

The vast majority of time for these two fish was spent within the upper five meters of the water column (65.4% for tag 16122-01 and 81.5% for tag 24519-01) **(Figure 1)**. This pattern is strongly supported by the accompanying temperature data **(Figure 2)**. Note that the apparent preference toward warmer water in tag 24519-01 is likely due to the presence of warmer surface water temperatures off Florida rather than a behavioral difference.

While the majority of time of both blue marlin was spent near the surface, they did make occasional dives to depths below 150 m (tag 16122-01 to 192 m, and tag 24519-01 to 268 m). Examination of time at depth **(Figure 1)** suggests that movement between the surface and depths was relatively rapid, and that both individuals were spending a significant amount of time at depths in excess of 50 m. Examination of maximum depth values by hour of day demonstrates greater vertical movements during daylight hours **(Figure 3)**.

4. DISCUSSION

The PSATs provided a detailed record of habitat preference of two blue marlin released from pelagic longline gear in the western North Atlantic Ocean. Both individuals demonstrated a preference for water less than 100 meters in depth, with a large portion of their time spent within 50 meters of the surface. These data are consistent with reports of previous acoustic tracking of blue marlin in the Pacific (Block *et al.*, 1992a, 1992b), as well as the PSAT tagging of blue marlin taken on recreational gear off Bermuda (Graves *et al.*, 2002).

The PSAT data indicate that both blue marlin frequently dive to depths of 150 m, with some dives extending beyond 250 m. There was also evidence of a diurnal periodicity to the diving behavior, with both fish making their deepest dives during daylight hours. Holland *et al.* (1990) and Block *et al.* (1992a) used acoustic tags to study movements of five and six blue marlin, respectively, off the island of Hawaii. Although similar short-term duration diving behavior (to depths of 100 m or more) was noted for some fish, both studies noted considerable variation in diving patterns among individuals. These included differences in the frequency, depth and diel periodicity of the dives. Block *et al.* (1992a) observed two blue marlin diving to greater depths during daylight hours, and four that dove to greater depths and with a greater frequency at night.

The duration, periodicity, and diurnal patterning of the blue marlin dives are suggestive of temporary feeding movements to depth. Current PSAT technology does not allow one to record actual feeding events, but two additional lines of evidence, anatomical investigations and gut content analyses, support the hypothesis that blue marlin make short term vertical excursions for the purpose of feeding. Blue marlin, like other istiophorids, have specialized muscle tissue located beneath the brain that generates heat. The eye/brain heater organ allows the brain and eyes to remain at elevated temperatures while the rest of the fish's body mass remains at ambient temperature (Block 1986). Such heating should maintain visual acuity in the billfish's large eye, facilitating feeding as it moves to colder waters at depth. In addition, recent research on the visual acuity of blue marlin indicates that this species has evolved eyesight capabilities adapted for low light conditions (Kerstin Fritsches, personal communication[2]). Therefore, anatomically, Atlantic blue marlin appear to be well adapted for feeding in cooler waters well below the surface.

There have been numerous anecdotal comments regarding gut contents of billfishes, and several researchers have noted the presence of deep-water fishes in the gut contents of blue marlin (Baker, 1966; Erdman, 1962; Harvey, 1989). Strasburg (1970) observed differences in the diet composition of Pacific blue marlin caught by commercial longline and recreational fishing gear, suggesting feeding differences between individuals found on surface and at depth. Nevertheless, even shore based stomach content analyses of blue marlin in the Pacific Ocean have found deep-water fishes such as squirrelfish (*Holocentrus laeteoguttatus*), gempylids (*Trichyuris* spp.), and bigeye tuna, while studies of blue marlin in the Atlantic Ocean have reported swordfish, bigeye tuna, and bioluminescent "swallower" fish (*Pseudoscopelus* spp.) (Krumholtz and de Sylva, 1958; Erdman, 1962). It is worth noting that many of the deeper living prey fishes found in blue marlin stomachs are known to exhibit diurnal vertical movements, a pattern that corresponds with those of blue marlin dives.

Blue marlin are reported to spend the vast majority of their time in the upper 10 meters of the water column. In this environment they are known to prey upon many species of epipelagic fishes including various scombrids and dolphinfish (*Coryphaena hippurus*), and a large recreational fishery exploits this behavior. However, the available data lend strong support to the hypothesis that blue marlin also make frequent excursions to depth for the purpose of feeding. If this is the case, then the assumption that feeding intensity of blue marlin is independent of depth is not correct. Consequently, any standardization of catch rates that incorporates time at depth without considering different feeding motivations at depth will result in biased catch rates.

We recognize that our observations of blue marlin habitat utilization are based on only two individuals released in the western North Atlantic Ocean during the late summer. The resulting data, however, do provide limited insight into habitat utilization capabilities of this species in the Atlantic Ocean. Additional habitat utilization information is available from a few other studies employing PSATs or acoustic tags to investigate of habitat utilization by blue marlin, primarily in the Pacific Ocean. Overall, these studies are limited in locations and seasons, and it is not know if blue marlin exhibit similar patterns of habitat utilization and behavior over the species range which spans a variety of oceanographic conditions. Clearly, some differences are evident between fish released off Hawaii (Holland *et al.* 1990; Block *et al.* 1992a) and those of this study. Variations in habitat preference and diving behavior have also been noted among bluefin tuna from various locations in the North Pacific (Kitigawa *et al.* 2002). In addition, the generality of our observations on blue marlin to other species of billfishes is not known. However, until further information is available on habitat preference and feeding behavior of all istiophorids, it would be prudent to carefully consider any assumption inherent in models used to standardize catch rates.

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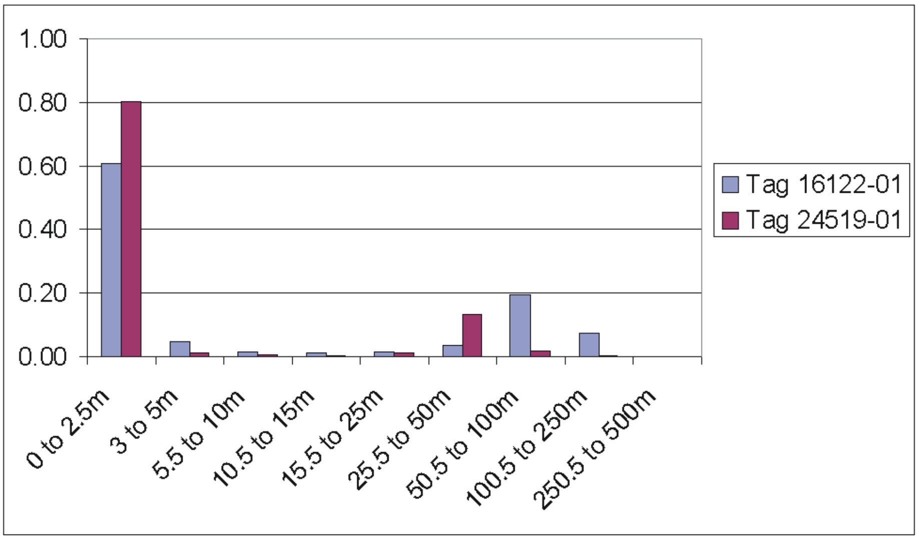

Figure 1. Fraction of total time at depth for two PSAT tags on Atlantic blue marlin.

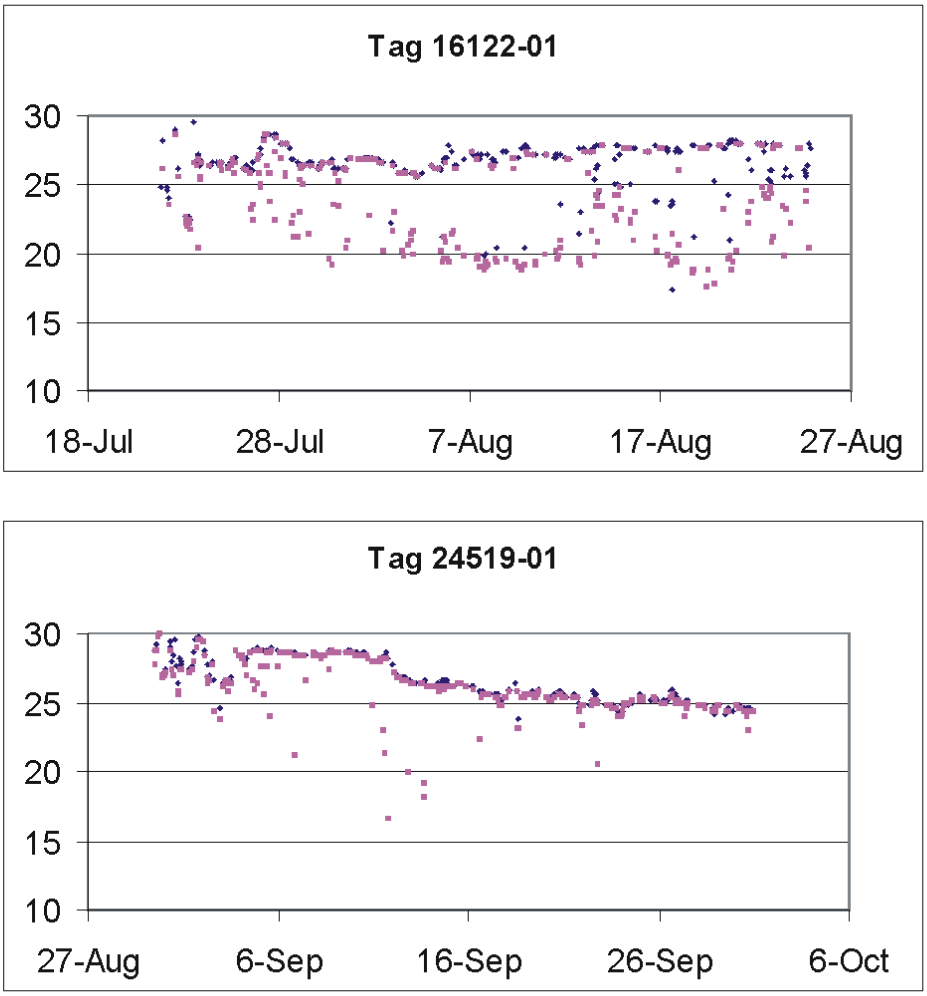

Figure 2. Minimum and maximum temperatures in degrees C for two PSAT tags deployed on Atlantic blue marlin.

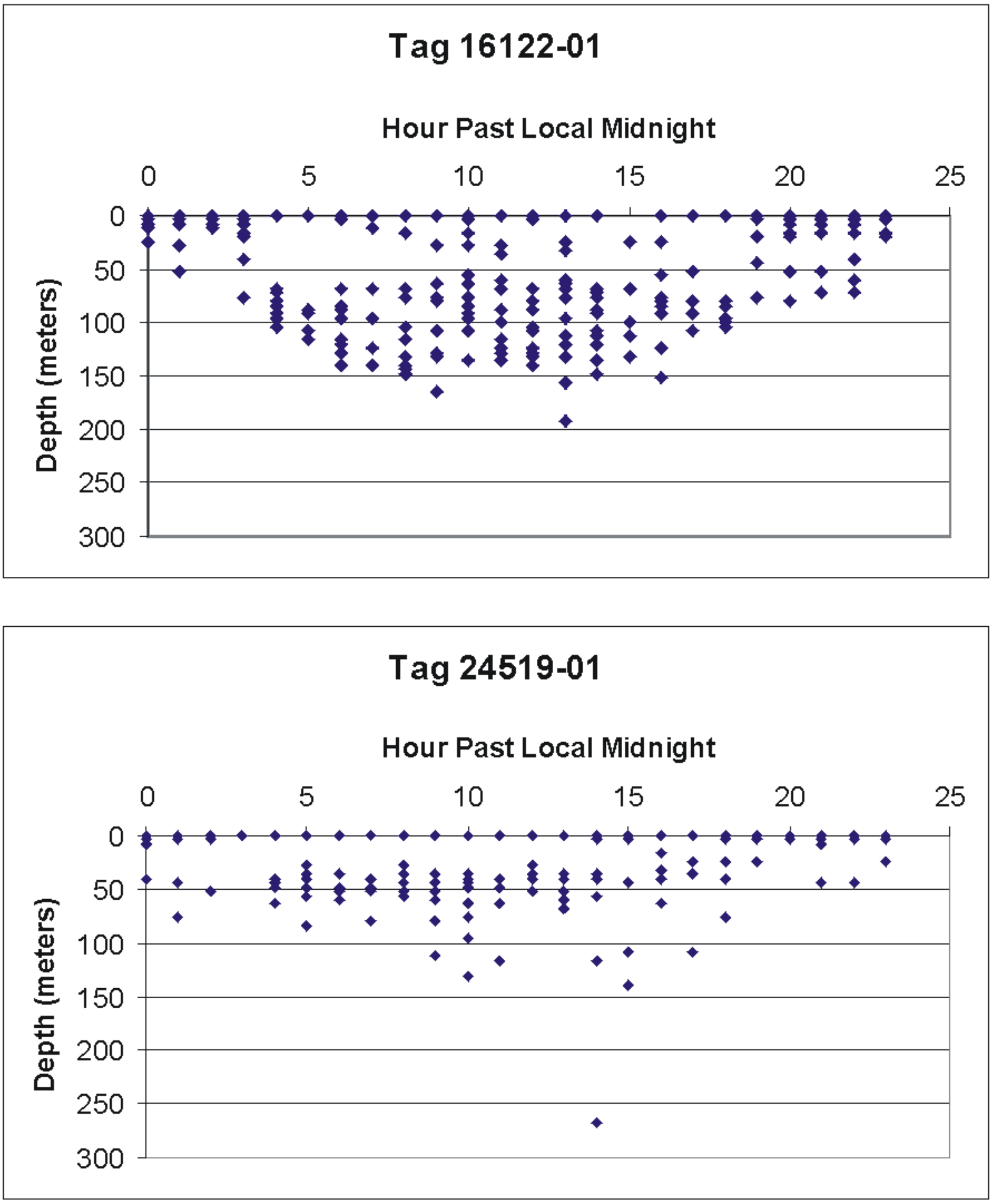

Figure 3. Maximum depths by hour for PSAT tags on two Atlantic blue marlin.