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HABITAT STANDARDIZATION OF CPUE INDICES: RESEARCH NEEDS

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SUMMARY

Habitat standardization for billfish CPUE offers a potentially useful alternative to the statistical procedures used in the past. However, most of the assumptions of the current habitat-standardization methodology remain untested and some are not consistent with current knowledge about the behavior of billfish. This paper outlines research required to ensure the methods for habitat standardization produce robust estimates of CPUE.

RÉSUMÉ

La standardisation de l'habitat pour la CPUE des istiophoridés offre une alternative potentiellement utile aux procédures statistiques utilisées dans le passé. Toutefois, la plupart des hypothèses de l'actuelle méthodologie de standardisation de l'habitat n'ont toujours pas été testées et certaines ne concordent pas avec les connaissances actuelles en matière de comportement des istiophoridés. Le présent document décrit la recherche qui est nécessaire pour garantir que les méthodes de standardisation de l'habitat produisent des estimations robustes de CPUE.

RESUMEN

La estandarización del hábitat para la CPUE de marlines ofrece una alternativa potencial útil a los procedimientos estadísticos utilizados en el pasado. Sin embargo, la mayoría de los supuestos de la actual metodología de estandarización del hábitat no se ha comprobado todavía, y algunos no son coherentes con el actual conocimiento sobre la conducta de los marlines. Este documento recalca la necesidad de investigaciones que garanticen que los métodos de estandarización del hábitat producen estimaciones robustas de CPUE.

KEY WORDS

CPUE standardization, stock assessment, research needs, billfish

1. INTRODUCTION

Stock assessments routinely employ catch per unit effort (CPUE) indices of stock abundance to estimate stocks status. Such data are essential for fitting surplus production models, and were used in ICCAT assessments of Atlantic marlins at the Fourth Billfish Workshop in Miami (Anon. 2001). The early portions of the CPUE time series for both blue and white marlin rely on data from Japanese longliners. Through time, this fishery has undergone significant changes in gear configuration and areas fished (Uozumi and Nakano 1994, Yokawa and Uozumi 2001). These changes can result in variability in catchability that make the simple mean CPUE an unreliable index of stock abundance.

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Such trends are common attributes of many fisheries, and considerable effort is devoted to standardizing the CPUE time series to remove the influence of such effects from the time series. These standardizations have historically been accomplished through the application of formal statistical procedures such as the General Linear Model (GLM).

One of the features of the Japanese longline fishery is that the fishing depth has increased with time. 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 that stratifies catchability by depth. Hinton (2001) applied it to Pacific blue marlin with apparently good results. 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). One result was that the method could not explain some of the longline sets that actually caught blue marlin, particularly in the tropical area of the central and eastern Atlantic. Yokawa *et al.* (2001) speculated that the problem may have been caused by an inadequate model of vertical distribution of blue marlin, a lack of insight about fishing depths and/or the underwater movement of hooks. As a result, these authors concluded that it was premature to use the Hinton and Nakano method in stock assessments for Atlantic marlins, a view also supported by other studies (e.g., Venizelos *et al.* 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). The current paper is intended to stimulate discussion and planning for research to confirm the potential of habitat-based methods, and to define the data requirements for robust habitat-based standardization of CPUE.

2. PROBLEM EVALUATION

The Hinton-Nakano model adjusts the effort component of CPUE to account for the proportion of the effort that occurs within the fish's presumed habitat. The habitat is first stratified by depth, then the effort exerted by each hook is weighted by the proportion of time the fish spends at the hook's average depth to compute an effective effort. CPUE is then computed as the catch divided by effective effort. Hooks that fish below the fish's presumed habitat do not contribute to the effective effort, and computations for some gear configurations in some areas can lead to estimates of no effective effort for the sets. This situation can lead to difficulties accounting for observations of catches in such sets because computed CPUE is infinite (catch/0). This was the case for blue marlin taken by the Japanese longline fishery in the tropical East and Central Atlantic, and these observations had to be omitted from further analyses (Yokawa et al. 2001). The CPUE estimates arising from positive catches in areas with very low (but positive) calculated effective effort are even more problematical. These can lead to very high CPUE estimates that can substantially elevate mean CPUE estimated for the fishery as a whole in a given year. In an earlier paper, the senior author used a computer simulation to evaluate the habitat approach by fishing a simulated blue marlin population in a spatiotemporally stratified representation of the Atlantic Ocean with simulated longline gears that changed configuration with time (Goodyear 2001). The method gave good results if there was accurate and precise knowledge of the distribution of the population, the distribution of the gear with respect to the population, and factors that may affect the fish's propensity to take bait. However, error in the assumptions used in the analyses often produced misleading results, and if the data used to construct the effective efforts were not precisely accurate, the predicted trends in CPUE were often wildly inaccurate (Goodyear 2001).

The potential for such error is evident from the paucity of information supporting the original formulation of the Hinton-Nakano method. The vertical distribution of blue marlin was modeled as a function of the proportion of time fish spend in temperature strata relative to the temperature near the surface. This assumption was justified by Hinton and Nakano (1996) based on a comparative analysis

of limited acoustic telemetry data for another species, striped marlin (*Tetrapturus audax*) from two locations in the Pacific (Brill *et al.* 1993). The relationship was parameterized for blue marlin using acoustic telemetry from only 9 blue marlin caught at the surface with sportfishing gear off Hawaii during two studies in 1988 and 1989 (Holland *et al.*, 1990; Block *et al.* 1992a,b). Strasburg (1970) noted that the species composition of food items in blue marlin stomachs was different for blue marlin caught on longlines compared to those caught while trolling surface baits, suggesting that the behavior of the species as a whole cannot be accurately extrapolated from animals caught from one gear. Similarly, the extrapolation of the observations from the Pacific to the Atlantic Ocean may not be warranted because of different oceanographic features in the two basins. For example, the Atlantic does not exhibit the decline in dissolved oxygen with depth that can restrict the vertical habitat in the Pacific (Lowe i 2000, Venizelos *et al.* 2001). Also, given that species evolve to differentially partition the available habitat, the extrapolation of presumed behaviors from one species to another (as in Hinton and Nakano 1996, Yokawa and Takeuchi 2001) is questionable.

In the Hinton-Nakano method the probabilities of catch at depth used to weight effort are assumed to be proportional to time the fish spend at depth which is proxied with water temperature relative to the surface mixed layer. Specifically, as applied to Atlantic blue marlin 75.9% were assumed to be in the upper mixed layer, 13.8% in the next cooler 1° C interval (-1° C), 5.8% in the -2° C interval, 2.1% in the -3° C interval, 1.2% in the -4° C interval, 0.5% in the -5° C interval, and so on with the entire distribution contained within the range 0° C to -8° C. This is not a problem (assuming this distribution is invariant and correct) if a fish's propensity to take a bait it encounters is the same at all depths. However, Maksimov (1970) estimated that 60.4 percent of blue marlin captured from longlines in the Atlantic struck longline hooks at depths of 130-170m, 25.4 percent at depths of 90-130m, and 13.2 percent took hooks at depths of 50-90m. Similarly, Gonzalez and Gaertner (1990) reported that CPUE for sailfish and white marlin was highest for hooks at calculated depths of 105-125 meters and attributed the observation to the location of the thermocline at approximately 100-200 m in the study area (Caribbean Sea). If these fish were actively feeding in the thermocline, which may span 10 or more °C, then the probability of them taking a bait once it was encountered would not appear to be constant across depths or temperatures. The importance of this consideration is obvious from the numbers. For instance (again assuming the Hinton-Nakano distribution is correct), for the probability of a fish to be caught from the mixed zone to be equal to that at 5° C below the mixed zone, its propensity to take a bait in the -5° C layer would have to be 0.759/0.005 or about 150 times more likely in the -5° C layer. Recent data from pop-up archival satellite tags placed on two blue marlin show rapid dives that suggest feeding excursions to depths much greater than the median (Graves et. al. 2002). Ignoring such an effect could introduce strong biases in the time series of CPUE.

The assumption that the vertical distribution of billfish is solely a function of temperature relative to the surface is questionable and doesn't seem to hold for other species. For example, Kitagawa *et al.* (2002) found that the vertical distribution of bluefin tuna in the East China Sea was markedly different than those migrating into the Sea of Japan, and concluded the difference was the result of the vertical distribution of prey. Deepwater species have been noted in stomachs of both blue marlin (e.g. Erdman 1962; Strasburg 1970; Koga *et al.* 1972; Harvey 1989) and striped marlin (Baker 1966). Such observations lead Harvey (1989) to conclude that blue marlin sometimes feed in relatively deep water, and Strasburg (1970) to conclude that it is probable that blue marlin regularly forage at depths up to 600m. Preliminary research findings on the visual acuity of blue marlin (Kristin Fritsches, personal communication, University of Queensland, Brisbane, Australia) indicates that the eye sight of this species has evolved low light capabilities and thus it would be prepared anatomically to feed at depth. Other physiological adaptations, such as the eye-brain heater organ (Block and Finnerty 1994), also support this deep water hypothesis. Such behavior would seriously compromise the utility of habitat-standardized CPUE using the Hinton-Nakano methodology. Specifically, it would tend to bias the Hinton-Nakano habitat-standardized CPUE estimates downward for the shallowest sets that don't reach the thermocline. For deeper sets with some hooks in the thermocline, the bias would be upward. This problem could be investigated by simultaneously determining the distribution of billfish catches with respect to actual depth of hooks and the distributions of the fish themselves. Brill and Lutcavage

(2001), however, note that the heart limits the depth at which tunas and billfishes can swim because of water temperature affecting heart function. It may therefore also be possible to develop theoretical physiological models that define maximum temperature/depth ranges for different species/sizes of billfish.

Additionally, the studies used to establish the percentages of blue marlin by depth (Holland *et al.*, 1990; Block *et al.* 1992a,b) were of short duration only (= 5 days), which may not have been sufficient time for these 9 animals to recover from the capture-release process and return to "normal" movement patterns. The additional detail possible from longer-term archival tags may provide more accurate habitat information, and although several projects now appear to be in preparation for this purpose, few of these tag data have yet been analyzed specifically for habitat preference (Kerstetter *et al.*, submitted). Moreover, the possibility that blue marlin have a distinct bimodal depth preference, spending 60-70 % of their time in surface waters but also spending significant time 25-40% below the surface mixed layer (100-200 meters) to feed when surface food is scarce (Kerstetter et al. submitted) should be considered in future work. Such a bimodal depth preference for this species could help explain perceived inconsistencies, such as the higher Japanese longline CPUE for blue marlin found by Matsumoto et al. (2001) on deep deployments of JLL gear from the recent part of this time series, compared to the historical shallow water deployments. The implications of such behavior on habitat-standardized CPUE estimates can be evaluated using computer simulation, but resolution of the question will require substantial detailed data from the fishery.

Bait movement is widely thought to be an important stimulus to get billfish to take a bait. This possibility is ignored in the Hinton-Nakano method, and quantifying the relationship in a way that allows it to be included in habitat standardization is beyond current data. For example, Boggs (1992) observed that 32% of striped marlin were caught on moving hooks (at deployment or during retrieval) and 68% were taken on settled hooks. Since hooks were moving for only about 1 hour of the 7-12 hour sets, these results suggest that striped marlin had a much greater propensity to take moving rather than settled baits. Okazaki *et al.* (1997) report even shorter periods for the sinking and rising of hooks. Scott *et al.* (2000) found that billfish (blue marlin, white marlin and sailfish) catch rates on longlines baited with live fish averaged 1.7 and 1.9 times greater than on those using dead bait based on Gulf of Mexico observer and logbook data, respectively. One explanation of this result is that the movement of live fish attracted the billfish. In another study, Okazaki *et al.* (1997) showed that a hooked fish alters the geometry of the line holding neighboring hooks, therefore generating bait movement. Park (1976) looked at longline shape following setting and concluded that billfishes and sharks were more often caught in entangled longline gear than tuna, suggesting that billfish either influence gear geometry or that gear geometry influences the catchability of billfish.

Certainly, bait movement is viewed as an important determinant of the probability for successful catches by recreational billfish anglers. Given these observations, it seems rather likely that bait movement increases the catchability of billfish on longline hooks. Goodyear (2001) found that omitting this factor, assuming it is actually true, generally caused an upward bias in standardized CPUE that increased with time in situations where fishing depth increased with time. This was the result of fish biting baits with deep soaking depths while they were moving during deployment and retrieval. The effective effort was underestimated and CPUE was elevated as a result. Similar effects may accompany those sets affected by shear currents. One can envision longline baits being both elevated in the water mass and "trolled" as a result of shear.

Although densities of billfishes in the open ocean are very low, densities of targeted tunas on successful longline sets may not be that low, opening the possibility that there might be competition for bait between billfishes and other species. In demersal longlines, there is some evidence of changes in hooking rates due to competition between species, with the most aggressive species reducing the hooking rates of the less aggressive ones (Godoe *et al.* 1997). It is possible that similar effects occur in pelagic longlines. This could be tested by examining data on presence/absence of fish of different

species within neighboring hooks, provided that the exact position in the longline of each capture is recorded.

It could well be that the blue marlin caught on longlines configured to fish deep are taken mostly on a subset of longline sets where the catenary model of the depth distribution doesn't apply because of shear currents which both elevate the mainline and impart velocity to the baits relative to the surrounding water (Mizuno *et al.*, 1999). On average, the longlines configured to fish deeply will catch more of the species such as bigeye tuna that favor deeper water than shallowly deployed gear which never fishes in the deeper strata. However, such longlines (or parts thereof) may often fail to fish at the intended depths because the gear does not behave as expected. For the same reason, the longline catches of billfish may be derived from deployments that differ substantially from the average, so much so, that even the actual average depths of the hooks over all sets cannot reasonably predict catch rates. Models of gear geometry might also be improved with knowledge about the environment through which longline gear moves and knowledge on the way hooked fish alter this geometry. Both of these variables can be obtained by studies using temperature/depth probes.

These issues point to the possibly that the weakest link of the habitat-standardization lies in the adequacy of the gear model. Many authors have relied on depths calculated assuming a catenary curve where the estimated depth of catch is computed from the order of the branch line on the mainline (a common index of fishing depth). Boggs (1992) investigated the depth distribution and catch rates of longline hooks and found that realized set depths averaged only 54% and 68% of predicted depths for the two years of their study (1989 and 1990). Yanno and Abe (1998) also studied the depth distribution of longline hooks using time-depth recorders and found that setting depth was generally shallower than that calculated from a catenary curve, especially when the mainline and branch lines were of monofilament material. Sinking speed and the magnitude of vertical gear movement associated with hooked fish also varied according to the material composition of the main and branch lines. These authors concluded that the mainline depth cannot be predicted from gear configuration, specifically from the length of the float line, distance between floats, or setting speed. In a review of billfish hooking depth measured using time-depth recorders (TDR) attached to longline gear, Matsumoto et al. (2001) noted that catch by branch line did not coincide with the TDR results. The authors postulated that the difference might be due to the fact that some of the hooks do not reach the intended depth because of local oceanographic conditions such as the presence of shear currents, or that billfish are often caught on rising or sinking hooks. Berkeley and Edwards (1998) also reported extreme variability in hook depth among different sections of mainline on the same set, and among sets with the same gear configuration. They concluded that this variability was not the result of different gear configuration or deployment speed or technique Fbut reflected an unpredictable and largely unknown surface and subsurface water movement pattern (possibly modified by fish on the line). These observations indicate considerable uncertainty in the predictability of actual longline fishing depths. Knowledge about the extent of this problem, and the development of adequate models could be enhanced by extensive deployment of time-depth-temperature recorders on longline gear, across present and historical gear configurations and through analyses of local oceanographic conditions. Such experiments must address the effects of historical changes in the materials used in the construction of the longlines (Yamaguchi 1989) on the actual depth distribution of hooks. For example, Yanno and Abe (1998) noted the gear behavior differences between tar line ("black rope" in the study) and monofilament mainline.

Another aspect of the Hinton and Nakano method as applied to Atlantic blue marlin that warrants investigation and testing is the spatial scale used in determining the average temperature at depth profile which is applied to judge the depths at which the fish are available for capture relative to the depths at which the gear is modeled to be fishing. While in large tropical oceanographic zones with little obvious water mass structure, applying the average temperature distribution across a large (say 5° latitude x 5° longitude) area may be adequate in regions not influenced by strong surface and subsurface currents, geographic stratification at scales smaller than $5^o x 5^o$ may be necessary to adequately capture water mass dynamics. This may be especially important in fisheries where water mass edges are the target of fishing effort, since these edges tend to have concentration effects on a

number of species, and appear not to be randomly distributed within individual $5^o x5^o$ grids. One effect of applying a large area average temperature distribution may, in fact, be evident in the analysis provided by Yokawa *et al.* (2001). One disturbing feature of the method applied is that a number of analytical strata exist for which the model estimates 0 effective effort occurred because all modeled hooks were deeper than the model predicted marlin would exist, even though substantial catch of marlin were recorded in the data. These 'residuals' indicate an obvious disagreement between the model and the data. In the analysis, these data were ignored, while in reality, the catches in fact occurred, leading to a bias in the catch rate patterns modeled by the method of Hinton and Nakano. While allowing for some probability of capture due to setting and/or hauling hooks through shallow depths (as in Yokawa and Takeuchi 2001) can eliminate cases of 0 effective effort, the feature of extreme catch per modeled hook would still persist and likely be viewed as inadequate model structure given the observed data rather than just as outliers to be ignored. Further evaluation of the degree to which these 'residuals' could be accounted for by finer-scale temperature a depth profile information should be performed.

3. RESEARCH NEEDS

It is perhaps noteworthy that, outside of a trial application with Pacific bigeye tuna (Bigelow *et al.* 2000), there has yet to be broad application of the Hinton-Nakano approach for other species assessments, even though longline catch per effort information is broadly applied in fitting assessment models. This is presumably because of the lack of data available to test assumptions about fish and fishing gear behavior that are critical to the method. Ultimately, the problem reduces to one of describing the actual probability distribution that a fish will take a bait it encounters (the fish model), and the actual distribution of the hooks on deployed gear (the gear model), both now and in the past. These models must also capture any important effects of variation in fish and gear behavior both within sets and within the physical strata selected for the analysis (e.g. 5° longitude-latitude square). If factors such as bait type or bait movement prove to be important, then these factors must also be integrated into both the fish and gear models. Other authors have highlighted the importance of understanding hooking behavior in order to interpret catch rates in longline gear (e.g., Loekkeborg 1989, Loekkeborg *et al.* 1993). Clearly, the determination of the utility of habitat standardization for billfishes awaits the outcome of future research. Some of the principal assumptions of the Hinton-Nakano method that must be tested before the method can be broadly sanctioned for use with billfishes or even generalized to other species include:

- The proportion of time a fish spends in each vertical stratum is solely a function of the difference between the temperature in that layer and the temperature of the surface mixed layer.

- The probability that a fish will take a bait in a vertical stratum is proportional to the proportion of total time it spends in that stratum (i.e., it is uninfluenced by where the fish is actually feeding).

- Fish behavior does not vary either spatially or temporally.
  o Observations of a few individuals caught at the surface are sufficient to characterize the whole population.
  o There is no difference by age, sex, time of year (e.g., spawning behavior), or size.

- The average depth of each hook on a longline set is predictable
  o Models accurately predict the depth distribution of hooks for all gear geometries
  o Hook depths for each gear configuration are not affected by local conditions.
  o Historical gears fished the same as recent gears with the same geometry.
  ▪ There have been no effects from changes in the materials used to construct the gear.
  ▪ There have been no temporal changes in fishing power of the vessels themselves.

- The average of the catch rates at each depth in the distribution around a hook's average depth equals the catch rate at the average depth.

- The velocity of a bait relative to the water around it has no effect on the propensity of a fish to take that bait.

- Hook behavior is independent of gear geometry and water currents.
  o Shear currents do not effect the vertical distribution of hooks
  o Shear currents do not impart motion to the baits

- The catch rate of individual hooks is independent of catches on neighboring hooks.
  o There is no effect of a hooked fish on the depths of nearby hooks.
  o There is no effect of a hooked fish on bait movement of nearby hooks.

- Gear geometry is independent of catch rate
  o Average depths of hooks is the same regardless of total numbers of fish caught on a set
  o There are no gear saturation effects (e.g., high catches of other species does not influence the probability of catching a billfish

- Bait type is not important
  o Live or dead bait
  o Species (e.g., squid vs. mackerel)

- Other gear considerations are not important:
  o Presence or absence of lightsticks (also, color differences?)
  o Time of set and haulback (e.g., daylight vs. nighttime)
  o Use of lead weights on gangions

- Longline gear materials (i.e. cotton vs. monofilament) do not affect the depth distribution of long hooks or the catchability of the target and non-target species.

- There is a homogeneous physical environment within each 5º latitude-longitude stratum.
  o Temperature-depth distributions for each set is accurately represented everywhere in the stratum.
  o Effects of within stratum variations in shear currents can be accounted for
  o Temporal (seasonal) consistency within the water column (i.e., thermocline stability)

- Different species of the family Istiophoridae and Xiiphidae have the same vertical habitat use characteristics

- Habitat features between the Pacific, Indian, and Atlantic Oceans are sufficiently homogeneous that observations of species distributions in one area of one basin can be safely extrapolated.
  o Different dissolved oxygen profiles with depth between the major ocean bodies do not result in different depth distributions or other behaviors of billfish in the different basins.
  o Heterogeneous distributions of prey do not influence the local distribution of billfish.

4. RESEARCH POSSIBILITIES

Several technologies are available to develop data to test these assumptions. Time-depth recorders (TDRs) have been used to quantify the actual fishing depths of the gear, and hook timers have been used to determine the depths and times at which fish take baits. Other developing technologies, "hook

timers" for example (Boggs 1992), have also allowed increasing precision on the times and means by which billfishes are caught by longline gear. Recent developments with electronic archival tags allow much better characterization of habitat utilization, and other similar technologies could be brought to bear upon the problem. The data collected should develop information about the following topics:

- Fish behavior
o Actual distribution of fish with depth and temperature, including spatial and temporal variability
o Actual distribution of fish feeding
o Describe actual habitat preferences

- Gear-fish interactions
o Time-depth-temperature of hooks catching billfish
o Velocity of hooks catching billfish
o Influence of bait type and condition
o Positions of billfish regarding other neighboring fish caught in the longline
o Fighting time of fish, once hooked

- Gear time-depth data
o For baskets at different distances along mainline.
o At different number of hooks per basket
o At different levels of catch
    - For different target species
    - For different oceanographic conditions
o Sets at local current features vs. "average" conditions
o Present technology vs. historic gear material

- Hook movement
o Hook velocity at bite (i.e., moving or still)
o Data to predict hook velocity as a function of
    ▪ Number of hooks per basket,
    ▪ Use of a hook thrower and/or line setter
    ▪ Orientation of the set relative to local current features

If the future of CPUE standardization for billfishes and other species is to rely on habitat-based methods, it will be essential to establish an integrated and coordinated research program to develop the data necessary to test assumptions about fish and fishing gear behavior that are critical to the method. If successful, such a program will undoubtedly result in a better understanding of both the fish's habitat and refinements in our understanding of the dynamics of the fishing gear, and may lead to new and better methods for standardization of the catch and effort data required for stock assessments.

5. ACKNOWLEDGEMENTS

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