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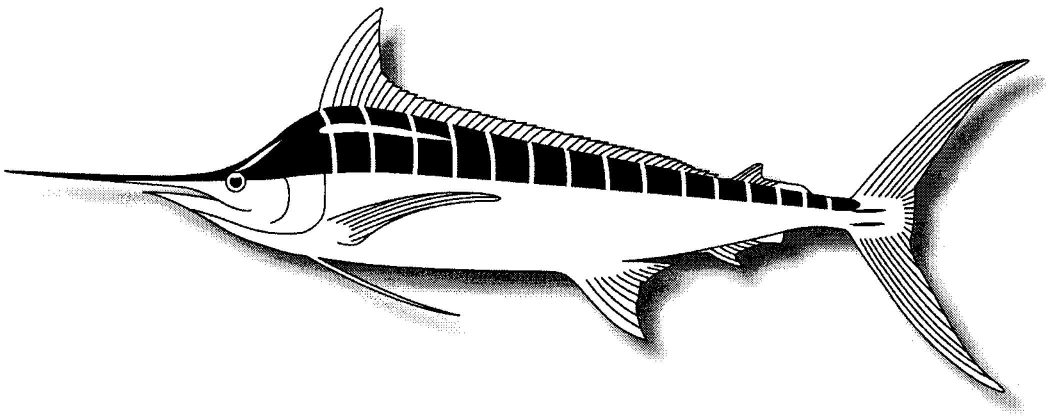

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A two boat study of the relationship between swordfish catch rates and fine- and broad-scale physical and environmental variables off eastern Australia*

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(* This report is an excerpt from a document that also includes the analysis of yellowfin and bigeye catches from the same study and can be obtained from the first author)

Abstract

The relationship between oceanographic and environmental variables and catches of broadbill swordfish was examined between May 1997 and March 1999 off the east coast of Australia between 25 and 36 degrees South. The use of an underway sampler on two longliners which recorded surface temperature, salinity and fluorescence enabled the examination of the association between these variables with the point of capture of individual fish as well as more commonly used variables such as moon phase and time of year. Using a combination of generalized linear and generalized additive models we examined two separate models – one incorporating the entire study area (Model 1) and one restricted to the northern area of the fishery (Model 2) – for the swordfish. In Model 1, the factors area, fluorescence, nearness to front, year and moon were significantly correlated to broadbill swordfish catch rates. In Model 2, salinity, nearness to front, moon and (month:year) were the main correlates of catch rate.

Introduction

Broadbill swordfish (*Xiphias gladius*) support a growing domestic longline fishery off the east coast of Australia with annual catches reaching 2,000 t per annum (Australian Fisheries Management Authority data base). To catch these fish longliners commonly use a suite of environmental indicators to position their lines. These may include proximity to temperature fronts, the presence of seamounts, the colour of the water or the presence of birds. With the development of remote sensing, sea surface temperature maps are routinely used to target particular water masses by the longline industry. Other factors, including moon phase, weather conditions and the local colour of the water, all contribute to whether a particular area is fished or not. Of these, water colour is consistently used as a way of identifying "good" or "bad" fishing waters. However, it is at best a subjective interpretation relying on each fisher's view of the water in which they work. For example, those that fish in the more productive southern waters have quite a different view of what constitutes clear, blue, green or other descriptions of a particular water mass than does someone from more tropical oligotrophic waters. As this knowledge is gained over years of experience it is difficult to quantify and even more difficult to test the relative importance of each factor in relation to the fishes' distribution. With the increasing realization that such factors are needed for more accurate stock assessments recent studies in the northern hemisphere have begun to tease out which of these factors are important. There is growing evidence that significant correlations do exist between pelagic fish abundance and a number of environmental variables (e.g. Laurs et al 1984, Fiedler and Barnard 1987, Power and Nelson May 1991 and Swartzman et al 1995).

More recently, there have been efforts to identify the factors affecting the distribution and abundance of larger pelagic species such as swordfish. Podesta et al (1993) found that very high catch per unit effort of swordfish in the western North Atlantic occurred more frequently in the vicinity of temperature fronts than would be expected by chance. However, they noted that the high variability in catch rates they encountered could not all be explained by these fronts and suggested that other, unmeasured, factors were likely to influence catch rate. In that paper they also commented on the lack of physical and biological data collected contemporaneously with fish captures. Bigelow et al (1999) identified a number of mesoscale factors that influenced catch rate of swordfish in the Hawaii-based swordfish fishery. These variables in order were latitude, time, longitude, lunar index, number of lightsticks, two measures of SST, wind velocity and bathymetry. Bigelow et al's study had no access to contemporaneous measures of salinity or fluorescence.

Because longlines are set over such large distances, sometimes as much as 100 km although usually ~ 50 km, environmental data can only be linked to some arbitrary position, such as the start of the set. Regional characteristics such as lunar phase or wind speed should not vary noticeably within the study area but there is little data that can be attached to individual fish at point of capture. For example, temperature, salinity and measures of ocean productivity such as fluorescence can change significantly over the course of a set. Thus, as Bigelow et al (1999) pointed out, it may be that the scale of measurements available for comparisons of catch rates with environmental variables are not appropriate to determine whether relationships exist or not. As such, valuable information, which may give us insight into a species' behaviour, may be lost.

Oceanography of the area

The fishery covers a diverse oceanography ranging from the tropical oligotrophic waters of the Coral Sea in the north to a mixture of tropical and subantarctic waters in the south. Linking much of the waters of the fishery is the East Australia Current, which has its origin as an offshoot of the Coral Sea and extends as far south as the east coast of Tasmania. The strength of this current is determined by both seasonal and interannual factors. In the Australian summer the East Australia Current is at its strongest and pushes as far south as the southern tip of Tasmania where it finally dissipates into the waters of the subtropical convergence (Clementson et al in press). In the winter it retreats northward as the winter westerlies drive subantarctic waters northward. Interannual variations can be even more pronounced. El Nino years produce relatively weak currents as the equatorial waters feeding the western Pacific are at their weakest. In contrast La nina years appear to be characterised by higher temperatures along the eastern seaboard and extend further southward.

Aims of the study

As part of a larger study to calibrate remotely sensed ocean colour on the east coast of Australia we aimed in this study to examine the relationship of catch rates of broadbill swordfish to environmental variables. Specifically, we ask whether there is a factor, or suite of factors (physical oceanographic as well as more regional variables such as lunar phase) associated with the observed catch rates of two longline vessels fitted with underway samplers.

Methods

Data collection

As part of the SEAWIFS ocean colour satellite project (Lyne and Parslow 1994) an underway sampler was developed with the purpose of calibrating the ocean colour imagery. The sampler measures three variables – temperature, salinity and fluorescence -- at the sea surface in relation to ship's position as measured by GPS and time of day. The sampler is connected to a computer that recorded the three variables at minute intervals at sea. Two of these samplers were fitted to two small longliners operating off the east coast of Australia between May 1997 and March 1999. At ~ two-monthly intervals CSIRO observers spent periods of up to a week on board these vessels. On these trips the observers recorded and identified all fish caught against the time at which they were caught. As time could be related directly to GPS position we were able to determine accurately the position of capture of individual fish. Size and biological details for all fish caught by the longlining operation were also recorded. In the laboratory observer data were matched with the underway files to link individual fish with all contemporaneous data collected. The observers also collected samples of chlorophyll and salinity to calibrate the sampler.

Oceanographic data
The oceanographic data for this study is based largely on surface characteristics of the main water masses of the region as determined by the underway sampler. We used that data in the following ways. Off Mooloolaba we used the steaming transect out to the fishing area for each fishing trip on which there was an observer to document changes in the surface characteristics (in this case surface temperature, salinity and fluorescence) of the water. This data set was not repeated for the southern zone as fishing was generally relatively close to the coast. To provide a seasonal comparison of the surface waters in which the longliners fished during the study we used a mean of the underway data from the first set of each fishing trip regardless of whether an observer was on board or not. The underway data was supported by satellite sea surface temperature imagery provided by the NOAA AVHRR satellite although cloudy conditions limited the usefulness of satellite imagery for periods of the study. Ocean colour satellite imagery from the SeaWifs (Sea-viewing Wide Field of View scanner) satellite was also cloud-affected so was not used in the statistical analyses but was used in the description of the study area.

Data analysis
We examined the relative effect of physical and environmental factors (defined in Table 1) on the catch rate of broadbill swordfish in the study area. Initially we produced scatter plots to visualize any potential relationships. We then applied generalised linear models (GLMs) and generalised additive models (GAMs) to investigate the relationships suggested by the plots using the S-Plus software package. We used the binomial distribution. Forward stepwise regressions were applied to the GLMs to determine the statistically significant terms in decreasing order of significance. GAMs were then fitted to the significant terms to determine the nature of the response to the variables. This procedure was followed as statistical inference from GAMs is relatively undeveloped compared with that for GLMs (Borchers et al 1997). The GAMs were necessary, however, as they allow "nonlinear effects of the covariates on the response to be estimated from the data" (Augustin et al 1998, see also Swartzman et al 1995). Once the significant main effects had been determined all two-way interactions were also tested for significance.

We assumed that each longline set was relatively stable horizontally on the basis that even if the line moved it moved in relation to the prevailing currents effectively staying with the same body of water. For this analysis we only used the underway data from the hauling period. We divided each haul into approximately equal segments composed of approximately 200 hooks. The catch data was standardised to the number of fish per 200 hooks.

The data was grouped in a number of ways before settling on two main comparisons. The first comparison used all 139 records from Areas 1 and 2 to determine which of the covariates was significantly correlated with fish abundance, the latter expressed as (the number of fish caught /number of hooks) X 100. Table 1 lists all the factors included as covariates. As the study area was effectively divided into two very different hydrographic regions – the "Mooloolaba" and "Bermagui" areas – a second analysis was run on the Mooloolaba data (Area 1) only, to examine more closely fine-scale effects in the region. The Bermagui data was not examined separately due to small sample sizes.

Results

We made 15 trips on the two fishing boats - 5 out of Bermagui and 10 out of Mooloolaba - during the course of the study. Surface oceanographic and environmental data was recorded on a further 37 trips when no observer was on board. From the combined data we have provided firstly a description of the waters during the course of the study (not reported here). Secondly, we have provided an analysis of the catches in terms of the physical oceanographic and environmental variables to determine the relationship, if any, between the two.

Biology

Catch composition
In all, 1,021 fish from 33 species were caught on observer-attended fishing trips out of Mooloolaba. Of these, broadbill swordfish (27.5% of total fish caught), followed by yellowfin (21.9% of total caught), bigeye (11.95%) and albacore (8.6%) made up ~70% of the catches. Nine species of shark totaled a further

9.7% of the catch. Off Bermagui a total of 297 fish from 23 species were caught on observer-attended trips. Of these 73% were yellowfin tuna, 7% were albacore and 1.6% were bigeye tuna. Approximately 5% of the total fish caught were sharks. Only three broadbill swordfish were caught on the trips out of Bermagui.

Catches in relation to environmental variables
Scatter plots between catch effort and the nine variables measured suggested a number of relationships. For broadbill swordfish, highest catch rates were made in waters with a temperature range between 23 and 26 ° C, salinities between 35.4 and 35.8 ppt, fluorescence values between 0 and 0.6 µg per litre. Catch rates were variable between years and months but were higher in moon phases 1 and 4. Most broadbill swordfish were caught north of 26 °S in all wind speeds but generally within 20 n.miles of the closest temperature front.

Model responses
Model 1. Area followed by month and fluorescence were significantly correlated with catch rate of swordfish. As few swordfish were caught in the study off Bermagui the significance of area in this case is not surprising. Time of year was the next most significant factor to correlate with catch rates, which were higher in the autumn and spring than at other times of the year. Finally, lower catch rates were correlated with increasing fluorescence.

Model 2. When the model was restricted to Mooloolaba we found that salinity followed by nearness to front, moon phase and year were significantly correlated with catch rate. The smoothing splines as determined by GAM showed that catches were initially correlated with lower salinities then increased again in waters with salinities greater than 35.6 ppt. Catches rose steadily to approximately 10 n.miles from the nearest front after which they declined. Catches were highest in the first quarter of the moon and in the first year of the study. Neither fluorescence nor temperature was significantly correlated with catch rate.

Discussion

Oceanographic influences
Off southern Queensland we detected both seasonal and interannual differences in the strength and extent of the southward flow of the southward component of the EAC. In this respect, although the waters in this study are significantly warmer, it is similar to the fluctuations we reported off southeastern Australia (eg. Young et al 1996). We know that these interseasonal and interannual changes can have impacts on the distribution and abundance of pelagic fauna in more southern waters of east coast Australia (Young et al 1993). This may also be the case in oceanic waters off southern Queensland. For example, there was a massive influx of South Equatorial Current water into the northern area of the fishery in the summer of 1998. Although the small sample size limits any conclusions, AFMA data for the period also showed a decline in catches relative to 1997. There are a number of factors, which could have led to this result (e.g. changes in fishing practice, increased fishing competition), but the significant change in the regional oceanography cannot be discounted. We have little idea of the changes the altered oceanographic conditions made on the food webs leading to pelagic fishes in the area. It is likely, however, the absence of any significant frontal structure in the area in which the boat worked would not have provided conditions suitable for the fish.

Catches in relation to sea surface variables
We identified six variables (Model 1 – area, month and fluorescence; Model 2 –salinity, fluorescence nearness to front, year and moon phase) that were correlated with catch rates of broadbill swordfish during the study period. Dealing with these in turn, relatively few swordfish were landed in Bermagui, thus area was, not surprisingly, the first variable to be distinguished. Whether this is a true indication of the distribution of the swordfish in the southern fishery is yet to be tested as lines were set relatively close to shore and not through the night. Japanese catches for the same latitude offshore show significant catches to 34 degrees South (Ward 1996). More interesting was the importance of time of year for catch rates. Catches peaked in autumn and spring, mirroring the pattern of catches by Japanese longliners in the same area (Ward 1996), and indicating the swordfish may be responding to peaks in productivity typical of these periods. Catches in February in both years of the study were significantly lower than other times of year;

also mirroring the Japanese catches (Ward 1996). This appears to be due, particularly in 1998, to the flood of warm nutrient-poor water down the coast at that time. One explanation for the low catches was that there was little in the way of suitable feed in the area at that time. Ocean colour imagery for the period shows the clearest water extending beyond the distance of the vessel with little evidence of frontal structure. In an apparent contradiction, however, the model also found that catches were highest when fluorescence was lowest but also those catches were higher near temperature fronts. This suggests that although the broadbill prefer clearer waters, proximity to fronts (source of concentrations of feed), as indicated previously (Sakagawa 1989, Podesta et al 1993), is more important. Year was also a significant factor. However, as only two years of data were analysed this result was probably related more to seasonal factors than anything longer term. Nevertheless, this is likely to be a major factor as the fishery develops given the interannual variability of the major water mass movements off eastern Australia. Moon phase affected catch rates significantly. In contrast to Japanese catches in the same area that found highest catches around the full moon (Ward 1996), our study showed highest catches just before the full moon. However, this is more than likely related to the concentration of fishing effort as the longliner tended to make two trips each month, one either side of the moon, thus missing at least part of the full moon period. Finally, salinity, previously inferred by Sakagawa (1989) as an important factor in the distribution of swordfish, was correlated with swordfish catch rates.

Summary

Because of the approach taken by this study there is no equivalent study with which we can compare our results. However, oceanic fronts, which have gradients in the concentration of temperature, salinity and Chlorophyll a, are known to be associated with concentrations of swordfish and tunas (eg. Laurs et al 1984, Podesta et al 1993, Bigelow et al 1999). Although various measures of sea surface temperature have been linked to concentrations of these fish (dealt with elsewhere in the main report), associations with salinity have only been inferred (Sakagawa 1989, Bigelow et al 1999). Similarly, although associations between tuna and ocean colour have been reported (eg. Fiedler and Barnard 1987), in situ measurements have not. Our data indicate therefore that direct measurement of fluorescence and salinity, together with an awareness of the position of the major fronts have the potential to increase our understanding of the distribution of these fish in oceanic waters off eastern Australia.

Limitations and future directions

As the sampling was restricted to only two boats spread over a distance of more than 10,000 square kilometers in at times a widely differing hydrography further effort is needed to decrease the variance associated with these results. Nevertheless, that significant values were computed for the same variables across the species examined indicates that the results do reflect actual patterns of distribution. We are presently continuing the field component of this work as a part of a recently funded project on the reproduction of broadbill swordfish (FRDC grant 1999/108). We aim to widen the hydrographic conditions to which we can attach catch rates for these species.

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