Satellite observed Sea-surface Temperatures and Yellowfin Tuna Catch and Effort in the Gulf of Mexico

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Abstract.– A substantial longline fishery has recently developed in the Gulf of Mexico. Tuna are believed to aggregate in regions of sea-surface temperature change (frontal zones), and this behavior may significantly bias the catch and effort statistics critical for managing the fishery. We report the results of an effort to relate the sea-surface thermal structure evident in satellite imagery to yellowfin tuna *Thunnus albacares* catch and effort, with the goal of providing fishery managers an assessment of how the yellowfin tuna catch-per-unit-of-effort (CPUE) is affected by the presence/absence of temperature variability. We examined over 6000 longline set records and 109 satellite sea-surface temperature (SST) images, and compared the CPUE with sea-surface temperature statistics computed from image data in the corresponding area of the longline set. We found no discernable relationship between image SST statistics and CPUE, and conclude that catch statistics in the northwestern Gulf of Mexico are not biased by yellowfin tuna aggregating in regions of SST variability.

Manuscript accepted 25 February 1991.
Fishery Bulletin, U.S. 89:429–439 (1991).

Satellite sensors that detect ocean color or temperature have repeatedly confirmed that the ocean environment is highly structured, with the juxtaposition of different water masses forming frontal zones where important parameters such as salinity, temperature, and nutrient concentration can change rapidly over short horizontal distances. In turn, phytoplankton, zooplankton, and nekton abundances may also change significantly in these regions, either in response to favorable nutrient/food conditions or by accumulating in converging currents. Because the surface water mass boundaries are sometimes discernable in satellite imagery, the locations of associated phytoplankton, zooplankton, and pelagic fish assemblages can sometimes be determined from such imagery (Thomas and Emery 1988, Klimley and Butler 1988).

Large and commercially important pelagic fishes, such as tuna, are thought to respond to increased food concentrations or other favorable conditions by aggregating in these frontal regions (Alverson 1961, Beardsley 1969, Laurs et al. 1984, Maul et al. 1984, Fiedler and Bernard 1987, Klimley and Butler 1988). Fishermen have long believed that fishing near thermal or color fronts would increase fishing success, and sometimes refer to presumably favorable waters as "tuna water" (Alverson 1961). The fisherman's ability to locate such frontal zones is usually limited by the field of coverage available from his vessels for sampling temperature (or color) or that of a spotter pilot's ability to detect color boundaries. Because satellite sensors can now detect ocean temperature or color over large geographic areas, pilot projects to use satellite imagery as a fisheries aid have been undertaken on both the east and west U.S. coasts (Breaker 1981, Montgomery 1981, Wittenberg-Fay 1986, Cornillon 1986).

Efforts to provide sea-surface temperature (SST) charts as fisheries aids have been accompanied by scientific investigations to evaluate the possible relationships between SST, ocean color, and fishing success. Laurs et al. (1984) used thermal and ocean color imagery from the Coastal Zone Color Scanner to relate albacore *Thunnus alalunga* catch to oceanographic features in the eastern Pacific, and concluded that albacore catch was clearly associated with oceanic color and thermal fronts apparent in the imagery. They also observed that shoreward intrusions of oceanic water were coincident with notable albacore aggregations. Laurs et al. (1984) based their conclusions on a visual analysis of catch rates superimposed on images, and did not present any statistical analyses, such as relating catches to distances from frontal regions. Fiedler and Bernard (1987) analyzed satellite imagery and stomach contents data taken from albacore and skipjack *Katsuwonus pelamis* and demonstrated that these fish were opportunistically feeding on prey items associated with frontal regions off the California coast.

Maul et al. (1984) utilized satellite imagery to compare SST with Atlantic bluefin tuna *Thunnus thynnus thynnus* catches reported by the Japanese longline fishery that operated in the Gulf of Mexico during 1979 and 1980. The 1980 catch was substantially higher than that of 1979, and Maul et al. (1984) attributed the increased catch to the shift of fishing activities closer to the frontal zone associated with the Loop Current edge. They stated that 85% of the 1980 catch was taken within 100km of the Loop Current. In contrast to the Laurs et al. (1984) study, much of the Maul et al. (1984) analyses were quantitative, rather than qualitative, since the distances from the locations of bluefin catches to the edge of the Loop Current were analyzed.

Herron et al. (1989) continued efforts to quantify the relationship between fish catches and temperature structures in the Gulf of Mexico by analyzing 20 sea-surface temperature (SST) images acquired concurrently with trawl catches of the demersal butterfish *Peprilus burti*. They calculated statistically significant regressions relating butterfish trawl catches to SST gradients computed from satellite imagery.

In their study of tuna catch in the Gulf of Mexico, Maul et al. (1984) concentrated on bluefin catches relative to the edge of the Loop Current. In addition to the Loop front, there are numerous other coastal and oceanic regions of rapid temperature change that are potentially important aggregators of tuna. For example, Huh et al. (1978) described extensive coastal and shelf thermal patterns in the northeastern Gulf of Mexico that were present during 1976–77. Although extensive cloud cover and regions of near-isothermal SST values occur in the Gulf of Mexico during the summer months (Huh et al. 1978), considerable variation in SST is evident in satellite imagery collected during the fall through spring months. Figure 1 is an image of Gulf of Mexico SST patterns on 21 March 1988, and demonstrates the intricate thermal patterns that can be present in the northern Gulf of Mexico.

A U.S.-based fishery for bluefin and yellowfin tuna *Thunnus albacares* has rapidly developed in the Gulf of Mexico. Although Japanese longline vessels harvested considerable numbers of yellowfin tuna during 1963–81 (Wilson 1988), domestic landings prior to 1983 were relatively low and primarily the result of bycatch from swordfish *Xiphias gladius* fishermen. By 1986, however, Louisiana landings had leaped to 24 million pounds (Adams 1987). In the same year, 3.4 million pounds of yellowfin tuna were landed in the west coast of Florida, with the majority landed in the panhandle region. These fishermen frequently rely on ocean-surface temperature to judge where to set their lines. The conventional wisdom is to set lines when a temperature change of a "couple degrees" is detected.

At the present state of knowledge, assessment and management of the tuna resource must depend on catch statistics to indicate changes in overall stock size. Catch-per-unit-of-effort (CPUE) can be elevated if fishermen locate tuna that may have aggregated at fronts or regions of rapid temperature change; alternatively, the CPUE may be depressed by the absence of fronts or the fisherman's inability to locate them. In either case, the data used for assessment and management decisions could be biased to an unknown extent by the possible concentrating effect of frontal boundaries. This research was intended to explore possible relationships between the Gulf of Mexico SST structure observable in satellite imagery and the yellowfin tuna catch and effort, and to determine whether regions of temperature change yield increased fishing success.

Methods

There were three primary components to the research: (1) Acquisition, validation and summarization of the seasonal and spatial patterns in the longline fishery catch and effort data; (2) development of a satellite image database and description of the seasonal and spatial patterns in SST; and (3) investigation of any associations between the two data sets.

Data on longline sets were acquired from longline logbook records compiled by the National Marine Fisheries Service (NMFS). Data were from domestic fishery longline sets in the Gulf of Mexico and western Atlantic spanning September 1986–December 1987. These records included date, location of set, length of longline in miles, number of hooks fished, and number of fish caught. Catch records without valid latitude and longitude coordinates were deleted, as were records outside the Gulf of Mexico (east of 80°30′W longitude and south of 6°N latitude). Data such as time of day and duration of set, bait used, sizes of fish caught, or whether the reported geographic coordinates represented the location of the beginning or end of the set, were not available for our analyses. The total number

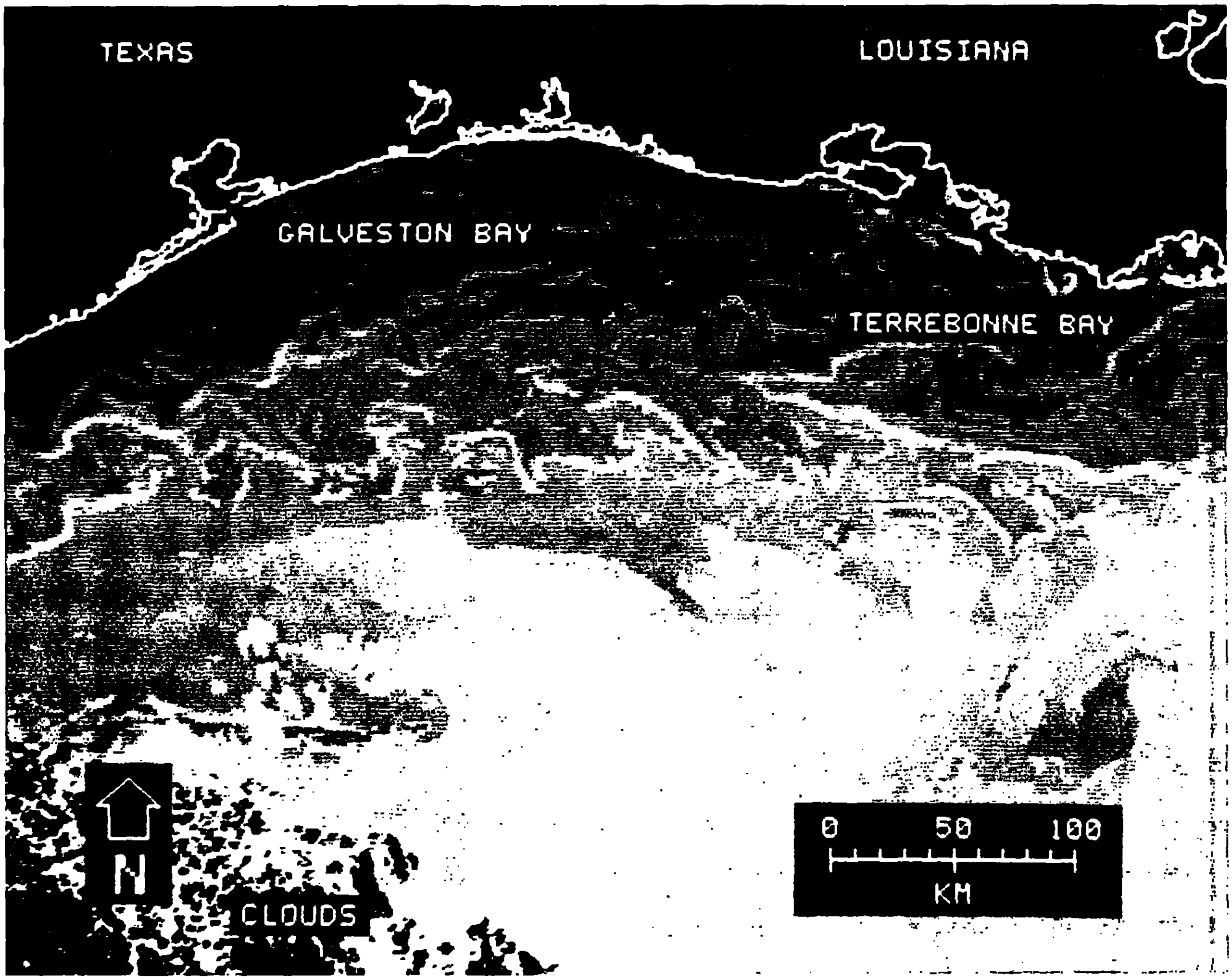

Figure 1
Enhanced satellite sea-surface temperature image of the northern Gulf of Mexico acquired by the NOAA-9 satellite on 21 March 1988.

of sets available for analysis was 6618. The median longline length deployed was 24 miles, although some sets were recorded as over 70 miles long. The median number of hooks per set was 576, and the median number of hooks per mile of set was 24. Yellowfin tuna CPUE was computed by combining the number of fish kept with the number discarded, and tabulating CPUE as the total number of fish caught per 1000 hooks per set.

The satellite image database was developed from a total of 109 Advanced Very High Resolution Radiometer (AVHRR) images of the Gulf of Mexico obtained from archives maintained by the National Environmental Satellite Data Information Service (NESDIS) and NMFS. The imagery was acquired by the NOAA-9 and NOAA-10 satellites. In selecting images for analysis, an effort was made to exclude those containing significant cloud cover. This selection was made either by NMFS personnel while compiling their image archive, or by us during examination of images in the NESDIS archives. Although a total of ten images acquired during August–September 1987 were obtained from NMFS and included in the analysis, we did not obtain additional summertime imagery for the study, since SST in the Gulf is nearly isothermal during that time of year (Huh et al. 1978; see also summer month editions of the Oceanographic Monthly Summary). Consequently, the image database, and subsequent statistics, are biased with respect to the summer months and periods when significant cloud cover was present in the Gulf.

The National Oceanic and Atmospheric Administration (NOAA) satellites record image data in four or five bands: two in the reflected solar region of the spectrum and two or three in the emitted thermal region. The spatial resolution of the sensors is 1.1 km at nadir, increasing to about 5.5 km at the edges of the 2580 km-wide scan. The AVHRR data were processed into sea-surface temperature (SST) images using a TeraScan* computer system operated by the School of GeoSciences at Louisiana State University. The TeraScan system consists of a computer, color image display device, and other custom hardware and software designed to process AVHRR digital imagery. The images were digitally cut to fit a master image that encompassed the entire Gulf of Mexico (latitude 17°45.30′N to 30°44.70′N and longitude 81°0.33′W to 97°59.67′W).

Daytime images were calibrated and converted to SST using the multichannel SST algorithm (MCSST) described by McClain et al. (1985). Radiometric noise in channel 3 caused some difficulties in deriving SST from nighttime images. Spatial filtering techniques (Schowengerdt 1983) performed on the channel 3 image prior to computing the SST had little or no effect on the noise and often resulted in significant degradation of the information content in the completed image. Although image restoration techniques such as filtering in the frequency domain appear to have been successful in minimizing noise in channel 3 (Warren 1989), they were not a practical consideration for this project because of the large number of images to be processed and computer software limitations. Thus, channel 3 data were removed from each nighttime image file prior to processing data into SST. Since the nighttime processing technique was an untested modification of the MCSST algorithm, a linear regression analysis was used to compare the satellite-derived SST data with *in situ* Gulf of Mexico SST data obtained from NOAA weather buoys. Residuals were plotted by the date and time of image acquisition, satellite number, and buoy locations to look for potential bias in SST values that may have been related to the processing technique.

Since atmospheric effects can significantly reduce the reliability of satellite-derived SST measurements, particularly as the viewing angle increases from nadir, a threshold was defined to identify image data acquired at a satellite zenith angle of greater than 53 degrees. These pixels were digitally masked and therefore excluded from further processing.

The SST images were coregistered to an equidistant cylindrical projection (Snyder 1987) using least-squares transformation equations and the nearest-neighbor resampling technique (Lillesand and Kiefer 1979). They were then reformatted for additional processing with version 8.0 of the Science and Technology Laboratory Applications Software (ELAS) (Beverly and Penton 1989). ELAS was installed on a MicroVAX 3600 computer and a MicroVAX 3500 workstation and provided advanced spatial processing utilities required during the second phase of the analysis. A processing protocol was developed using sequential ELAS commands and VAX software utilities to analyze the SST images and transfer selected data and tabulations to the Statistical Analysis System** for statistical analysis and plotting. A binary mask constructed from the World Data Bank II digital coastline file (Gorney 1977a,b) was used in each processing stream to exclude land pixels from the analyses. This protocol was used for all subsequent processing during the study. The initial analysis of each SST image consisted of Gulf-wide tabulations of temperature frequencies and cloud pixels.

The magnitude of surface temperature gradients (MSTG) was derived from each SST image using Sobel operators and simple image arithmetic (Gonzales and Wintz 1977). Sobel operators use the 3 × 3 moving window technique to extract vertical (north-south) and horizontal (east-west) temperature gradients from digital images. The MSTG was computed by summing the absolute value of the horizontal and vertical gradient information (Gonzales and Wintz 1977). The result of this operation is that each pixel location is assigned a numerical value that indicates how greatly SST at that location differs from that of surrounding pixels. This gradient value is independent of the direction of temperature change. An additional masking operation was performed on each MSTG image to exclude contaminated pixels adjacent to the land and cloud masks that were created as an artifact of the moving window technique.

The possible relationships among thermal features and yellowfin tuna CPUE was examined by computing summary statistics (e.g., mean, median, coefficient of variation) of the SST and MSTG data for circular regions of sea surface encompassing each longline set. Since the orientation and initial and final geographic coordinates of the sets were not available, we defined three concentric circular areas encompassing each reported location of a longline set. The recorded location of the set was the center of these circular areas, while the radii were specified as the length of the longline set, one-half the length of the set, and one-

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*TeraScan is a proprietary computer system marketed by SeaSpace, 3655 Nobel Drive, Suite 160, San Diego, CA 92122.

**The Statistical Analysis System is a proprietary computer software package marketed by the SAS Institute, Box 8000, Cary North Carolina 27511-8000.

quarter the length of the set. We assumed that these circular sampling areas represented the area fished by the gear and/or traversed by the fish during the set. The mean, median, and coefficient of variation of the SST and MSTG pixel values contained within the three concentric circular regions were computed for each set. These SST and MSTG statistics computed for the circular regions (polygons) encompassing the sets were then plotted against the corresponding yellowfin tuna CPUE at that same location. The potential bias due to spatial and temporal variation in cloud coverage was examined by classifying each circular polygon into one of three groups based on the percentage of cloud cover (25–49%, 50–74%, >74%) and comparing the results with CPUE and the statistics tabulated from the image data. Plots of CPUE versus the circular polygon statistics by month were also done to determine whether associations between SST variability and yellowfin tuna CPUE were present only at certain times of the year.

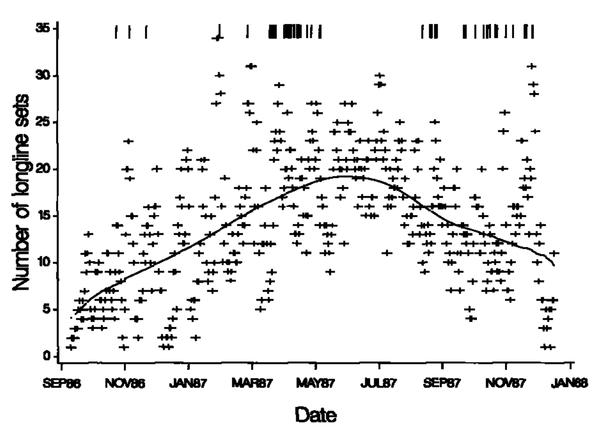

Figure 2

Number of longline sets reported each day in the Gulf of Mexico, September 1986–December 1987. Curve is fit using robust locally-weighted regression (Cleveland 1979). Vertical bars at the top margin of the plot are drawn at the corresponding dates of the satellite images used in the analyses.

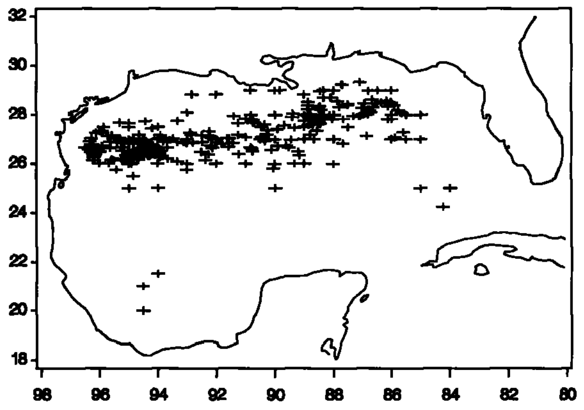

Figure 3

Geographic location of longline sets deployed in the Gulf of Mexico during March 1987.

Results

Yellowfin tuna database

The fishery data include only records for which geographic coordinates were available. In that respect, the results may be biased if longline sets records lacking geographic coordinates occurred in a given region, or had anomalously high or low yellowfin tuna catches.

The longline fishery operated nearly every day in the Gulf of Mexico from September 1986 to December 1987. Usually 10–20 sets were recorded each day, with very few days when no sets were reported (Fig. 2). The frequency of sets appeared to increase in late 1986 to midsummer 1987, followed by a decline in autumn (Figure 2 and subsequent figures include a curve, similar to a running mean, that was fit using Cleveland's (1979) technique of robust locally-weighted regression). Fishing effort during 1986–87 was heavily concentrated in the northwestern Gulf of Mexico, where extensive seasonal variation in SST was observed. Sets were mainly deployed between 26°N and 29°N latitude, and were fairly uniformly distributed west of the Mississippi River Delta between 88° and 96°W longitude (cf. Fig. 3).

Yellowfin tuna are apparently present and available to the longline fishery, at least in small numbers, throughout the year, since 79.2% of the sets caught one or more yellowfin tuna (Fig. 4). There was a noticeable decline in the daily percentage of sets catching at least one yellowfin tuna in the early months of 1987 (Fig. 4), but because the data set did not cover multiple years, it is uncertain whether this is an annual phenomenon.

The mean yellowfin CPUE for the entire data set (6618 sets) was 14.2 fish/1000 hooks with a standard deviation of 18.9. The median CPUE was 8.9 fish/1000 hooks. These CPUE figures are comparable to those reported by Polacheck (1989) for yellowfin tuna in the Pacific. The daily mean yellowfin CPUE may be elevated in the fall months and depressed during the late-winter and early-spring months (Fig. 5).

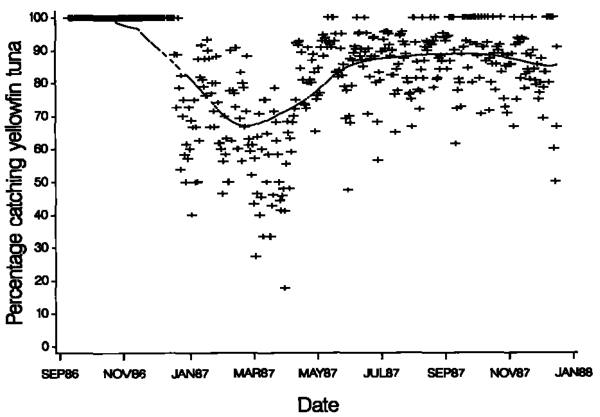

Figure 4

Daily percentage of longline sets that caught one or more yellowfin tuna in the Gulf of Mexico. Curve is fit using robust locally-weighted regression.

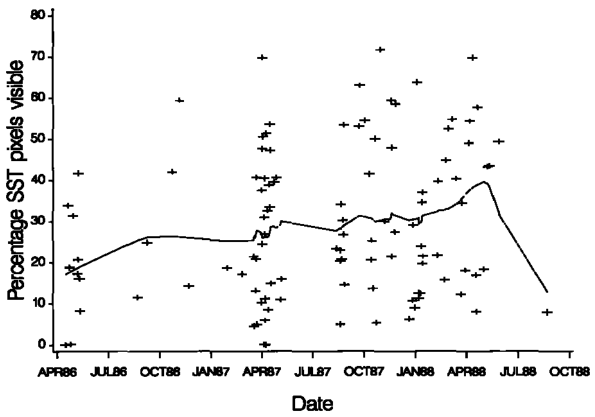

Figure 6

Percentage of cloud-free water pixels used to derive sea-surface temperatures from Advanced Very High Resolution Radiometer satellite images used in the study, 1986–88. Curve is fit using robust locally-weighted regression.

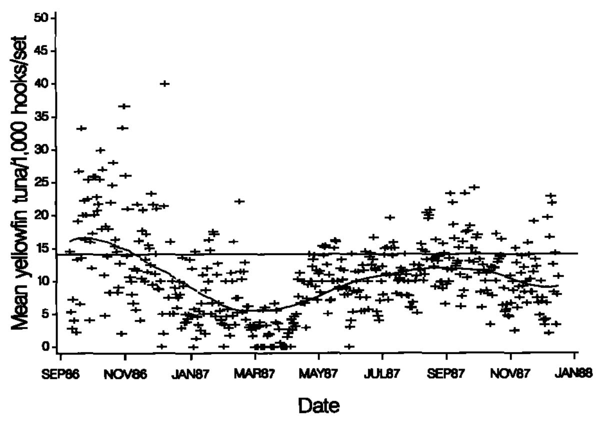

Figure 5

Daily mean yellowfin catch/1000 hooks in the Gulf of Mexico, 1986–87. Straight line is overall mean yellowfin CPUE. Curve is fit using robust locally-weighted regression.

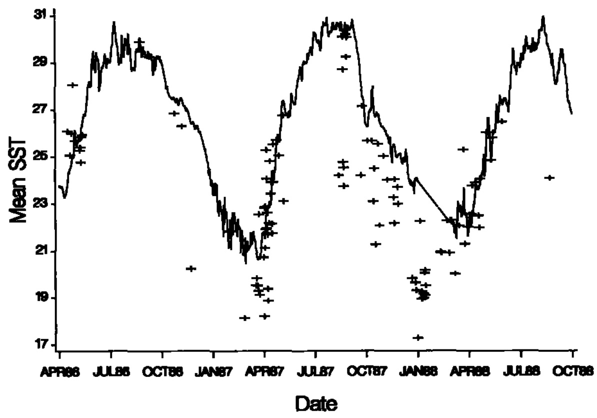

Figure 7

Mean satellite-derived sea-surface temperature (SST) for the Gulf of Mexico derived from Advanced Very High Resolution Radiometer imagery, 1986–88. Curve is daily mean surface temperature recorded at National Weather Service data buoy 42001, located at latitude 25.9°N, longitude 89°W.

Image database

The regression analysis of satellite-derived SST with the buoy SST data showed acceptable agreement between the two temperature values (r^2 0.902, n 206; Fig. 7). There was some tendency for SST from satellites to be lower than those from buoys at the higher temperature ranges, with the imagery acquired by NOAA-10 satellite accounting for most of the variation.

The geographic region in this study, excluding land, covered 1,512,272 ocean surface pixels. Cloud cover and/or the position of the satellite track reduced the number of pixels available for analysis in each image. Image coverage of the study region ranged from less than 1% to 70% of the available pixels, with no seasonal pattern to the coverage (recall that summertime images were generally excluded from the analyses) (Fig. 6). Figures 6 and 7 also portray the temporal coverage of the imagery used in our analyses. The mean image-wide derived SST and the daily mean surface temperature recorded at the National Weather Service data buoy 42001 (latitude 25.9°N, longitude 89°W) both follow the expected seasonal progression of SST (Fig. 7). Of note is the more rapid warming of SST in spring of 1987 compared with the spring of 1988. The SST coefficient of variation can be viewed as a broad index of how "structured" the sea-surface temperature is (Fig. 8). There was a clear seasonal trend to this statistic during 1986-87, indicating that considerable spatial variation in SST was present from the winter through early spring. The warming of SST during the spring months to more isothermal conditions, mentioned previously, is coincident with a decline in the SST coefficient of variation.

Image and yellowfin tuna CPUE relationships

Regions of rapid sea-surface temperature change appear as lighter lines in the gradient image (Fig. 9). Superimposed on this image are the locations of longline sets (crosses), and the circular region encompassed by the length of the longline set. Plots of yellowfin tuna CPUE versus mean circular polygon SST, SST coefficient of variation, mean polygon gradient, and polygon gradient coefficient of variation, respectively, indicated no apparent relationship between CPUE and these statistics (Figs. 10–13, computed for polygons with radii equivalent to set length). This result was also true when examining plots of yellowfin tuna CPUE versus the polygon statistics partitioned by month and percentage cloud cover, and for polygon statistics computed using the more restricted regions encompassed by one half and one quarter of the set length.

Discussion

Although the results of other studies support the hypothesis that tuna are more abundant near thermal fronts (Laurs et al. 1984, Maul et al. 1984, Fiedler and Bernard 1987), we were unable to detect any relationship between yellowfin tuna CPUE and SST structure in the northwestern Gulf of Mexico during 1986–87. Our results therefore seem to contradict, at least for the northwestern Gulf of Mexico, the belief among longline fishermen that tuna and other oceanic fish aggregate in regions of rapid temperature change. The perception of increased fishing success near fronts has apparently been incorporated into the fishing strategy used by the longline fleet, since fishermen monitor SST and other environmental indicators to decide where to set the gear. However, our data represent the initial stages of this developing fishery, and the longliners may have employed this strategy in the absence of alternative information concerning where best to locate their gear.

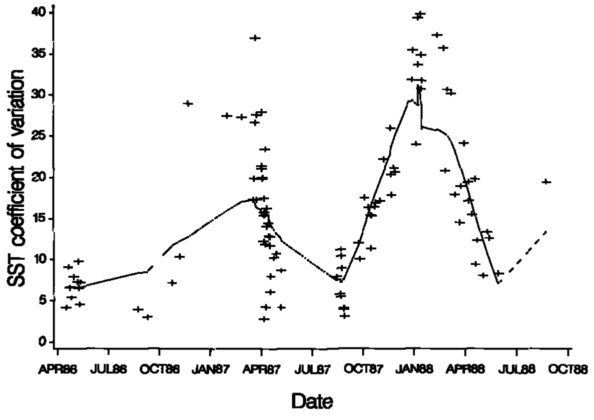

Figure 8

Coefficient of variation of sea-surface temperature (SST) for the entire Gulf of Mexico derived from Advanced Very High Resolution Radiometer imagery, 1986–88. Curve is fit using robust locally-weighted regression.

We nonetheless accept that under appropriate circumstances, oceanic fish orient to and aggregate at thermal features. Hence, there may be several explanations why we did not detect any associations. Only one set of geographic coordinates was recorded for each longline set, and it was not known whether the location represented the beginning, midpoint, or end of the set. By comparison, the positive albacore-front associations reported by Laurs et al. (1984) were obtained using data from trolling vessels. In that case, fishing effort could be located more precisely, both in terms of the fisherman's strategy and with respect to analyzing the resultant CPUE relative to SST patterns. Since longlines used by the Gulf fleet may exceed 50 miles in length, the uncertainty associated with the unknown orientation of the set could have masked a relationship between yellowfin tuna CPUE and the satellite-derived SST structure. Although the actual orientation of a set would be difficult to determine, given the effects of wind and currents during the time the gear was fished, information on the coordinates of each end of the longline during payout and haulback would provide some insight into the spatial orientation of the set, and in turn enable a more refined analysis of tuna-temperature associations. Finally, information on the times of payout and haulback would be valuable for refining estimates of fishing effort and selecting satellite images nearer the actual times of fish capture.

An alternative analytical approach would be to define specific fronts in the imagery, and examine CPUE versus distance from an identified front as the measure of the association between fish and front. This is the

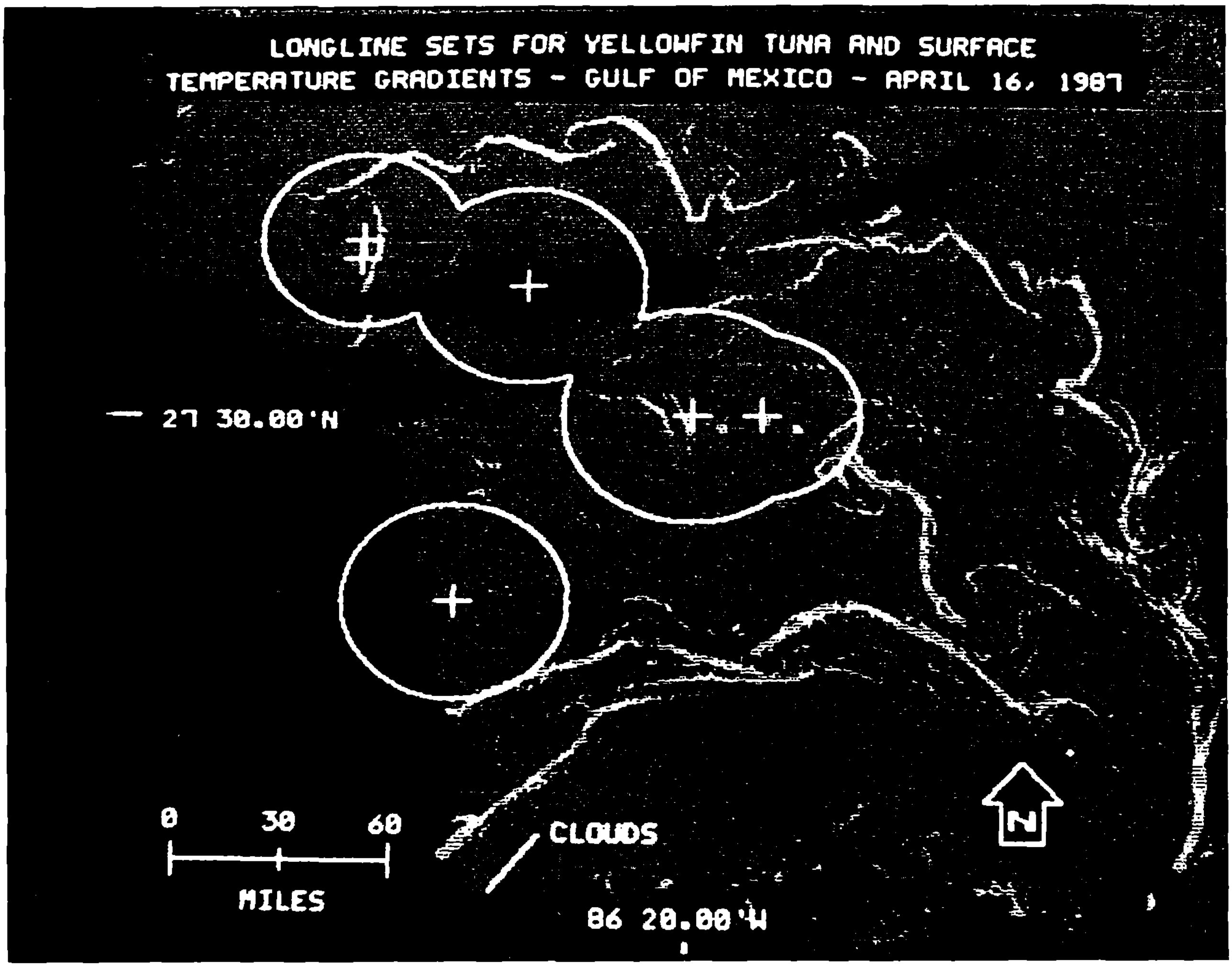

Figure 9
Example of sea-surface temperature (SST) gradient image. Lighter colors indicate higher gradient magnitude, as at frontal zones. Crosses indicate locations of longline sets, with circles encompassing length of sets.

approach used by Maul et al. (1984) and others, and may work well if the interest is in a dominant and clearly defined feature such as an edge of the Loop Current or the Gulf Stream. We did not use this approach for two reasons. First, the additional time and computational effort seemed unwarranted, based on the negative outcome of our gradient analyses. Secondly, such an approach would require us to define a "front" using an arbitrary criteria: we would necessarily have to define a given gradient magnitude, extending over a given distance, as comprising a suitable front. Then, because we would expect to define multiple fronts in the northwest Gulf of Mexico (cf. Fig. 1), defining distances to the fronts would be problematic. For example, in the case where a longline set was located 40km from one of the defined fronts, and 60km from another, it would be difficult to determine to which front the set should be related. Additionally, elevated catches near a front do not necessarily indicate fish were directly associated with that front; animals proximal to a front have not necessarily reacted to its existence. We believe our approach, which asks, "Are catches elevated when SST varies over some region encompassing those catch locations?", to be a more conservative and objective assessment of possible fish-SST associations. It is also one less likely to be inadvertently biased by preconceptions concerning fish-front associations.

There are also several possible biological explanations why we did not find a tuna-temperature relationship:

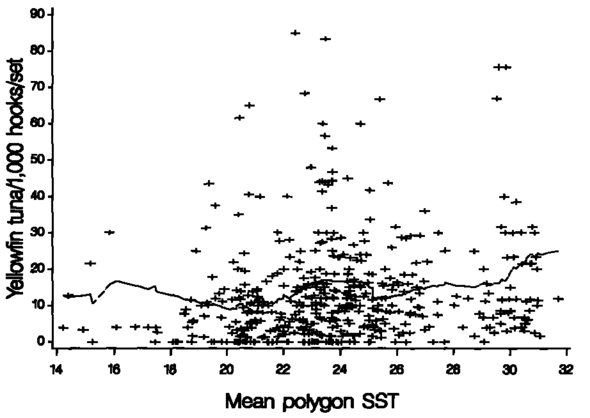

Figure 10

Yellowfin tuna CPUE versus corresponding satellite-derived sea-surface temperature (SST) in the circular region equivalent to longline set length. Curve is fit using robust locally-weighted regression.

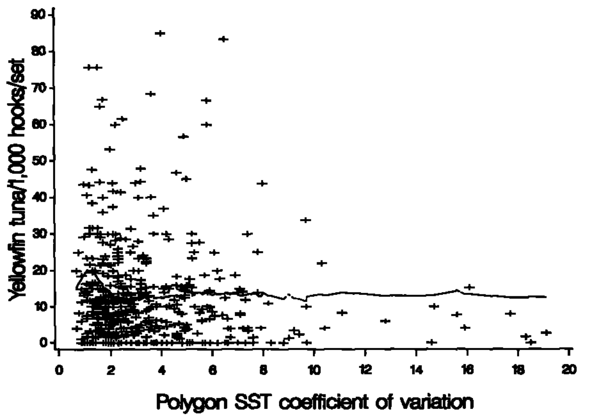

Figure 11

Yellowfin tuna CPUE versus corresponding satellite-derived sea-surface temperature (SST) coefficient of variation in the circular region equivalent to longline set length. Curve is fit of data using robust locally-weighted regression.

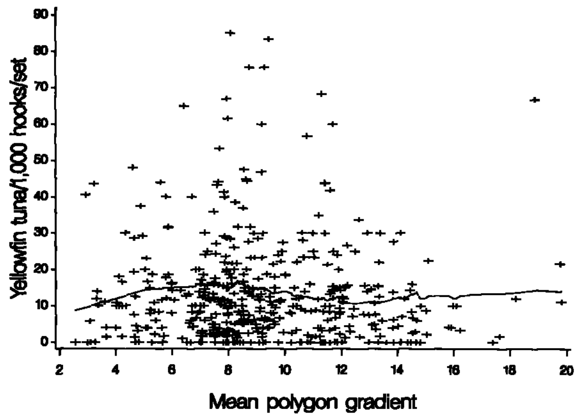

Figure 12

Yellowfin tuna CPUE versus corresponding satellite-derived sea-surface temperature (SST) gradient in the circular region equivalent to longline set length. Curve is fit of data using robust locally-weighted regression.

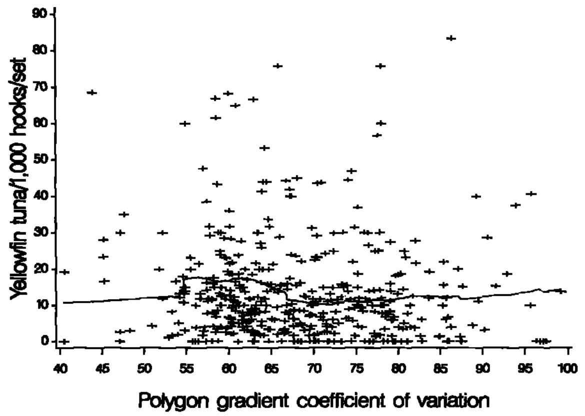

Figure 13

Yellowfin tuna CPUE versus corresponding satellite-derived sea-surface temperature (SST) gradient coefficients of variation in the circular region equivalent to longline set length. Curve is fit of data using robust locally-weighted regression.

(1) Tunas are renowned for their swimming ability, and telemetric studies have demonstrated that 70 cm skipjack tuna can readily traverse a distance of over 100 km/day (Dizon et al. 1978). Although yellowfin tuna in this study may have remained in the vicinity of a particular front for an extended period, it is also possible the yellowfin tuna were actively moving over a wide geographic area. (2) The particular longline set may have been targeting other species, and so hooks may have been set at a depth or time of day inappropriate for the capture of yellowfin, also masking any yellowfin CPUE-temperature relationships. (3) There is some evidence that yellowfin tuna aggregate at fronts during certain life-history stages. Beardsley (1969) compared numbers of yellowfin tuna caught by longlines, purse seines, and bait boats at a frontal zone in the eastern tropical Atlantic. He concluded that the smaller surface-schooling yellowfin taken in the purse seines were more abundant near the front, but that there was no apparent association between the front and the numbers of larger fish captured on longlines. Additional biological information such as length, sex, gonad

weight, maturity stage, and age is necessary to determine whether relationships exist between frontal occurrence and life-history stages of the species. Also, yellowfin tuna may aggregate at color fronts, and not thermal boundaries. This phenomenon was observed by Laurs et al. (1984) in albacore tuna.

Finally, the SST structure present in the northwest Gulf of Mexico is dynamic, and can change rapidly depending on local atmospheric conditions. Huh et al. (1978) provide a sequence of Gulf of Mexico images demonstrating how SST can change with time, and speculated that air-sea heat fluxes can rapidly alter the pattern of SST temperatures observable from satellites. The AVHRR detect only the immediate surface temperature (Schluessel et al. 1987), which may not be indicative of deeper water the yellowfin tuna may prefer. Consequently, the surface thermal patterns in the northwestern Gulf of Mexico may not persist long enough to either aggregate yellowfin tuna directly or set up other conditions, such as enhanced food availability, that would result in a detectable fish-temperature relationship.

In summary, the fisherman's belief that tuna aggregate in response to thermal patterns is a persuasive argument that such behavior occurs, and we initiated this research with that preconception. We are now uncertain whether such a phenomenon has global applicability, and consider from our results that this behavior does not reliably occur in the northwestern Gulf of Mexico. This may be due to the dynamic and non-persistent nature of the thermal patterns, or that those patterns do not generally occur in conjunction with other processes such as upwelling.

Acknowledgments

This research was supported by the National Marine Fisheries Service Marine Fisheries Initiative (MARFIN) program, contract number NA89WC-H-MF015. We wish to offer our sincerest thanks to Tom Leming and Rex Herron of the National Marine Fisheries Service (NMFS), who provided much of the imagery used in this study, to Joan Browder, also of NMFS, who provided the tuna catch data, and to Larry Rouse of the LSU Coastal Studies Institute, who assisted with satellite imagery. We thank Wendy Morrison, Floyd Stayner, and David Wilensky for assistance with computer details. We also wish to thank Robert Carney, LSU Coastal Ecology Institute, whose efforts provided the VAX computers essential to this study. Finally, we thank the editorial staff of the *Fishery Bulletin* for their considerable assistance with a difficult manuscript.

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