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DISTRIBUTION, ABUNDANCE, GROWTH, MORTALITY, AND SPAWNING DATES OF YELLOWFIN TUNA, Thunnus albacares, LARVAE AROUND THE MISSISSIPPI RIVER DISCHARGE PLUME

C. B. Grimes, K. L. Lang
Southeast Fisheries Center, Panama City Laboratory, 3500 Delwood Beach Road, Panama City, Florida 32407, U.S.A.

SUMMARY

During September (2-10), 1987, the NOAA ship *Oregon II* occupied 81 stations located 4-6 km apart along 25 km long transects of the Mississippi River discharge plume. Neuston (1x2 m; 0.947 mm mesh) and surface Tucker trawl (1x1 m; 0.222 mm mesh) samples yielded 978 larvae provisionally identified as yellowfin tuna.

Because yellowfin tuna are difficult to distinguish from blackfin tuna, *T. atlanticus*, we attempted to rigorously verify the identity of 910 of these larvae using pigmentation and vertebrae count (including clearing and staining) characters, and also unsuccessfully attempted to develop new diagnostic characters using a reference collection of larvae from the Pacific Ocean where blackfin tuna do not occur. Pigmentation and vertebrae count characters yielded equivocal results so we relied solely upon pigmentation characters, and determined that 209 of the 910 larvae provisionally identified as yellowfin tuna were incorrectly identified.

Distribution and abundance about the discharge plume showed a distinct pattern. Most larvae were found along the Gulf of Mexico shelf water side of the frontal zone (31-32 ppt), i.e., where shelf and plume water mix. No larvae were collected in plume waters and very few in full salinity of Gulf of Mexico shelf waters.

We used sagittal otolith microstructure to determine ages of the larvae (n=316) ranging from 2.57-7.48 mm SL; ages ranged from 2-14 days. Absolute growth (SL/observed age in days) ranged from 0.5 mm/d to 1.38 mm/d. A least squares linear model best described the relationship between standard length and age, and suggested a population growth rate (slope) of 0.47 mm/d. Larvae in Gulf of Mexico shelf waters just outside of the front grow significantly faster than larvae in frontal waters. Daily mortality rates were estimated from a catch-curve analysis.

Our results, along with other published and unpublished findings, suggest that considerable reproduction of yellowfin tuna occurs in the Gulf of Mexico at least from mid-summer into September, and that a significant proportion of that spawning may occur near the Mississippi River discharge plume. Abundance, growth and mortality were elevated in Gulf of Mexico shelf waters just outside of the frontal region.

RESUME

Au mois de septembre (2-10) 1987, le navire de la NOAA "Oregon II" a suivi 81 stations situées à 4-6 km les unes des autres sur une ligne de 25 km recoupant transversalement le courant de décharge du Mississippi. Des échantillons recueillis avec des filets Neuston (1x2 m, maille de 0,947 mm) et Tucker de surface (1x1, maille de 0,222 mm) ont donné 978 larves identifiées de façon provisoire comme étant des albacores.

Du fait qu'il est difficile de distinguer les albacores des thons à nageoires noires *(Thunnus atlanticus)*, nous avons tenté de vérifier soigneusement l'identité de 910 de ces larves en utilisant des caractéristiques de pigmentation et de comptage des vertèbres (y compris les décolorations et les taches); nous avons également tenté sans succès d'élaborer de nouvelles caractéristiques pour le diagnostic à partir d'une collection de référence de larves du Pacifique où le thon à nageoires noires n'est pas présent. Les caractéristiques de pigmentation et de comptage des vertèbres ont donné des résultats équivoques, si bien que nous n'avons compté que sur les caractéristiques de pigmentation, et en avons conclu que 209 des 910 larves identifiées provisoirement comme étant des albacores l'avaient été de façon erronée.

La distribution et l'abondance dans la zone de panache montrent un mode distinct. La plupart des larves ont été trouvées le long du bord extérieur de la zone frontale du plateau du golfe du Mexique (31-32 ppt), c'est-à-dire là où se rencontrent les eaux du plateau et celles du courant de décharge. Aucune larve n'a été trouvée dans les eaux de la zone de panache, et très peu dans les secteurs totalement salés du plateau du golfe du Mexique.

Nous avons utilisé la microstructure des saggitae de l'otolithe pour déterminer l'âge des larves (n = 316) mesurant de 2,57 à 7,48 de LS; les âges allaient de 2 à 14 jours. La croissance absolue (LS/âge observé en jours) allait de 0,5 à 1,38 mm/jour. Un modèle linéaire des moindres carrés est celui qui illustre le mieux le rapport entre la taille standard et l'âge, et suggère un taux de croissance de la population de 0,47 mm/jour. Les larves des eaux du plateau du golfe du Mexique juste en-dehors du front se développent bien plus vite que les larves des eaux frontales. Le taux de mortalité journalier a été estimé en analysant la courbe de capture.

Nos résultats, ainsi que d'autres résultats, publiés ou inédits, suggèrent qu'il se produit une reproduction considérable d'albacore dans le golfe du Mexique, du moins du milieu de l'été à septembre, et qu'un pourcentage significatif de cette ponte aurait lieu à proximité de la zone de panache du Mississippi. L'abondance, la croissance et la mortalité étaient élevés dans les eaux du plateau du golfe du Mexique juste en-dehors de la zone frontale.

RESUMEN

En el mes de septiembre de 1987 (2 al 10) el barco "Oregón 2" del NOAA estudió 81 estaciones separadas entre sí por una distancia entre 4 y 6 km, a lo largo de una línea de 25 km que corta en transversal el penacho de desagüe del río Mississippi. En muestras recogidas con arrastre Neuston (1x2 m; malla de 0.947 mm) y Tucker de superficie (1x1; malla de 0.222 mm) se obtuvieron 978 larvas que, provisionalmente, se clasificaron como rabil.

Al ser difícil distinguir el rabil del atún aleta negra, *T. atlanticus*, se intentó identificar con toda exactitud 910 de estas larvas por su pigmentación y contando vértebras (incluyendo la coloración y las manchas); también se intentó sin éxito, hallar nuevos caracteres de diagnóstico usando como referencia larvas recogidas en el Pacífico, donde no hay *T. atlanticus*. La pigmentación y el conteo de vértebras dieron resultados poco fiables, por lo que se confió tan solo en los caracteres de pigmentación, hallándose que 209 de las 910 larvas clasificadas provisionalmente como rabil, no lo eran.

La distribución y la abundancia alrededor del penacho de desagüe mostraban una pauta muy clara. La mayor parte de las larvas se encontraron a lo largo del borde exterior de la plataforma continental del golfo de México, en aguas de la zona frontal (31-32 ppt), es decir, allí donde se mezclan las aguas de la plataforma y del penacho. No se recogieron larvas en aguas del penacho y muy pocas en las aguas totalmente salinas de la plataforma del golfo.

Se usó la microestructura sagital del otolito para hallar la edad de las larvas (n=316) en un rango de 2.57-7.48 mm SL; la edad estaba entre 2 y 14 días. El crecimiento absoluto (SL/edad observada en días) estaba entre 0.5 mm/d y 1.38 mm/día. La relación entre la longitud estandar y la edad quedaba bien determinada por el modelo lineal de mínimos cuadrados, sugiriendo una tasa de crecimiento de la población de 0.47 mm/día. Las larvas de la plataforma del golfo de México, justo después del frente, crecen mucho más rápido que las larvas en las aguas frontales. Por medio del análisis de la curva de captura se estimaron las tasas de mortalidad diaria.

Los resultados obtenidos, junto con otros hallazgos, tanto publicados como inéditos, sugieren que existe una gran actividad de reproducción del rabil en el golfo de México, al menos desde mediados de verano hasta septiembre, y que gran parte del desove podría tener lugar cerca del penacho del río Mississippi. La abundancia, el crecimiento y la mortalidad eran altos en aguas de la plataforma del golfo de México, justo al exterior de la zona frontal.

INTRODUCTION

Yellowfin tuna, *Thunnus albacares*, are large, epipelagic members of the family Scombridae. They are found in tropical and subtropical seas worldwide, but are absent from the Mediterranean Sea (Collette and Nauen, 1983). They are migratory, like all tunas, but are considered the least so of the group. They can reach sizes of just over 200 cm FL and 175 kg, with lengths up to 150 cm common (Collette and Nauen, 1983). In the Gulf of Mexico the average size of yellowfin tuna is about 45 kg (Fee, 1987). Springer (1957) reported that they were common in the Gulf of Mexico beyond the 500 fm curve.

Yellowfin tuna are a commercially important species and the fishery continues to expand and increase in value. Worldwide total landings increased from 604,000 MT in 1983 to 823,000 MT in 1987 (FAO, 1987). A vital U.S. longline fishery has developed in the Gulf of Mexico since 1981 with landings increasing from 12.3 MT in 1981 to 2,900 MT in 1986 (Fee, 1987) and to 8,000 MT in 1988 (Snell, personal communication). Prior to 1981, stocks of yellowfin tuna were thought to be depleted in the Gulf of Mexico by foreign longline fishing (primarily by Japan) (Fee, 1987). The continued demand for fresh yellowfin tuna has supported the expansion of this fishery into one of the most valuable in the Gulf. Values have increased from less than $500,000 in 1981 to nearly $9,000,000 in 1986 (Fee, 1987) and to $29,000,000 in 1988 (Snell, 1990). The management of this important species is therefore of major concern.

There is little published information on the reproduction or early life history of yellowfin tuna in the Atlantic Ocean, and particularly in the Gulf of Mexico. Erdman (1968) reported reproductive development from fish from Puerto Rico, but none from fish from the Bahamas. Goldberg and Herring-Dyal (1981) found no evidence of spawning activity in fish from the Gulf of Mexico or U.S. Atlantic coast. Spawning reportedly occurs in the spring and summer in Cuban waters (Gorbunova and Salabarria, 1967 cited in Fritzche, 1978). There is also evidence of multiple spawnings per female (Nair et al., 1970).

Information on the distribution and abundance of yellowfin tuna larvae is also limited, but studies indicate that some spawning occurs year round in the tropical Atlantic, while it is restricted to summer at higher and lower latitudes (Richards, 1969; Ueyanagi, 1971; Richards and Simmons, 1971). A few early life stages have been reported from the Gulf of Mexico, i.e., five juveniles by Klawe and Shimada (1959) off northwest Florida, two larvae by Finucane et al. (1978) off Texas and about thirty larvae by Richards (unpublished SEAMAP data) throughout the Gulf.

Although there has been considerable interest in aging adult yellowfin tuna, little effort has been expended to provide daily ages of larvae that could be used to back-calculate spawning dates. Wild and Foreman (1980) validated daily growth increment deposition and aged juveniles, and Wild (1986) used daily otolith ages to estimate spawning dates, both for Pacific fish.

The purpose of this report is to describe the distribution and abundance, age, growth, mortality, and spawning dates of yellowfin tuna larvae about the Mississippi River discharge plume during September 1987.

METHODS

Larvae were collected on a research cruise to the Mississippi River plume by the R/V Oregon II September 2-10, 1987. We sampled stations 4-6 km apart along 25 km transects of plume and Gulf of Mexico shelf waters. Ichthyoplankton were collected using Tucker trawls (1 X 1 m; 0.333 mm mesh) and neuston nets (1 X 2 m; 0.947 mm mesh). Samples were preserved in 95% ethanol for 24 hours after which samples were drained and fresh preservative added. CTD casts were made at each station to collect hydrographic data. Sea surface temperature and turbidity were also sensed remotely using NOAA-9 AVHRR imagery.

Surface water samples (3.0 l) were collected at each station for determination of chlorophyll a. Each sample received 1 ml of a 1% $MgCo_3$ solution, was vacuum filtered through 2.5 cm GF/C filters which were frozen in aluminum foil and returned to the laboratory for pigment extraction (using acetone) and flourometric chlorophyll a determination (Strickland and Parsons, 1972).

Plankton samples were returned to the laboratory for sorting, enumeration and identification of ichthyoplankton to most precise taxonomic level possible. After all ichthyoplankton were removed macrozooplankton displacement volume was determined using a graduated cylinder partially filled with water.

After initial sorting and identification it was necessary to verify the identification of all larvae provisionally identified as yellowfin tuna because they are hard to distinguish from other *Thunnus* larvae, especially blackfin tuna, *Thunnus atlanticus,* (Richards et al., 1990). Identifications were verified using morphology and pigmentation patterns according to Richards and Potthoff (1974). Because a critical pigment spot located on the ventral midline of blackfin tuna is sometimes lacking, and is always absent on yellowfin tuna (Richards et al., 1990), we cleared and stained all larvae provisionally identified as yellowfin tuna with alcian blue (Potthoff, 1984) to facilitate making vertebrae counts to distinguish these two similar species.

After verification of identity larvae were measured (0.1 mm SL) using an ocular micrometer and sagittal otoliths were removed. The otoliths which are crystalline and thus birefringent, were easily located and removed when viewed in a dark field between crossed polaroids. Otolith removal was done on a glass slide where they were mounted whole using a polymer medium (FLO-TEXX). No further preparation of otoliths was necessary before aging. Otoliths were thin enough that only optical sectioning, i.e., manipulating the focal plane of the microscope, was necessary to make precise ring counts. Sagittae were viewed (oil immersion and transmitted light at 1000X) and their radii measured using an image analysis system consisting of a compound microscope equipped with an MOS video camera, a microcomputer with a digitizing module, a video monitor and software for displaying, manipulating and measuring images (Pisces Microcomputer, Inc.). Ring counts were made twice by the same reader, and if ring counts differed by more than one ring another count was made. If the third count disagreed by more than one with either of the first two the otolith was rejected.

Age and size data were used to derive a general growth model for yellowfin tuna, while age data were also used to back-calculate spawning dates for each larva and estimate total instantaneous daily mortality rate. Mortality rate was estimated using a larval catch curve approach ($\log_e$ frequency on age) similar to the methods described by Essig and Cole (1986). Spawning dates were estimated for each larva by subtracting its age (days) from the collection date.

RESULTS

During September 1987 R/V Oregon II occupied 81 stations; one neuston and one surface Tucker trawl sample from each station were processed for this study.

Study Area

The plume was very dynamic, continuously moving, responding to the many environmental factors (e.g., wind, tides, river flow, etc.) that influence its configuration. Many strong turbidity fronts formed, relaxed, then reformed at frequencies roughly approximating tidal cycles. Frontal lifetime seemed to be relatively short, i.e., about 3 to 4 h and both formation and dissipation occurred quite rapidly, i.e., within 15 to 30 min. An AVHRR image in the visible channel (indicating turbidity), with our September sampling transects superimposed, clearly shows the position of the discharge plume, and indicates that we sampled Mississippi River discharge plume, Gulf of Mexico Shelf and frontal water (a mixture of the other two) (Fig. 1). These more or less distinct water masses are more clearly indicated on a hydrographic section of a sampling transect directly off Southwest Pass where yellowfin tuna larvae were collected (Fig. 2). Cooler plume water rested atop warmer but more saline Gulf of Mexico shelf water. The turbidity front was observed at about station 45 while the salinity contours approach the surface between station 45 to beyond the next most seaward station (44), a distance of about 6-8 km. This illustrates that the frontal region is a mixing zone of plume and Gulf of Mexico Shelf water about 6-8 km wide; turbidity fronts, 50-100 m scale, are imbedded within the frontal zone.

Identification

Resolving of the problem of distinguishing yellowfin tuna, *Thunnus albacares*, larvae from there congener blackfin tuna, *T. atlanticus*, proved difficult. According to Richards and Potthoff (1974) the pigmentation difference between yellowfin and blackfin tuna is a small pigment spot located on the ventral midline of blackfin tuna larvae, and this pigment spot may be absent in some cases (Richards et al., 1990). Therefore we decided to use the remaining morphological difference between the two species, the number of pre-caudal versus caudal vertebrae, to distinguish the two species. We cleared and stained larvae to facilitate making vertebrae counts, thereby circumventing relying on the presence of the pigment spot, but this was not conclusive either. Many larvae less than 5.0 mm SL lacked adequate vertebrae calcification to accept staining. We therefore unsuccessfully attempted to locate additional morphological characters (e.g., opercular spines, orbit diameter, interdigitation of fins, etc.) that would allow discrimination of yellowfin and blackfin larvae using a reference collection of yellowfin tuna larvae from the Pacific Ocean (off Japan) where blackfin tuna do not occur.

When we attempted to distinguish yellowfin and blackfin larvae greater than 5.0 mm SL using vertebrae counts an additional problem was encountered. Yellowfin and blackfin tuna larvae have the same total number of vertebrae, but they differ by one in the number of caudal and pre-caudal elements. Failure to correctly recognize the first caudal vertebra, i.e., first vertebra with a closed haemal arch, would result in vertebral counts that would fail to separate the two species. Our vertebral counts yielded identifications that were inconsistent with those based on the pigmentation character, i.e., larvae with ventral pigment spots had vertebral counts of yellowfin tuna larvae. Therefore we decided that identification would be based entirely on pigmentation. From the September collection of 978 larvae provisionally identified as yellowfin tuna, 910 were available for this study. Using the pigmentation character 149 were determined to be blackfin tuna, 34 were determined to be other *Thunnus* species and 24 larvae could not be distinguished from blackfin tuna because the pigment spot, although present, was not located near the origin of the caudal fin on the ventral midline. An additional 19 larvae were too damaged by collection to be accurately measured.

Distribution and Abundance

The distribution and abundance of yellowfin tuna larvae about the Mississippi River discharge plume showed a distinct pattern. Catch rates (neuston and Tucker trawl catch per tow) plotted on surface salinity for all transects were highest between 31 and $32^{0/00}$, i.e., along the Gulf of Mexico shelf water side of the frontal region (Fig. 3). No larvae were collected in plume waters and only a few in full salinity Gulf of Mexico shelf waters. The distribution of macrozooplankton displacement volumes and surface chlorophyll a values with salinity corresponded to the larval distribution, suggesting that highest primary and secondary production co-occurred with highest concentrations of larvae (Fig. 3).

Within the range of surface temperatures where larvae were caught (28.5-29.4 C), catches increased with temperature, and peaked at 29.4 C (Fig. 4).

Age and Growth

Sagittal otoliths of yellowfin tuna larvae had visible, presumably daily, growth increments very similar to those described for other scombrids (Brothers et al., 1985; DeVries et al., 1990). Each increment was composed of one optically transparent and one less transparent layer. The first one or two increments often appeared diffuse, followed by 4-5 that were usually distinct. We could not directly establish that growth increments are deposited on a daily basis. However, we assumed, like Brothers et al. (1983) and DeVries et al. (1990) that the growth increments we counted were structurally homologous to increments proven to be deposited daily in a wide variety of species, particularly other scombrids (cited in Brothers et al., 1983).

Some evidence supporting the daily timing of increment deposition is provided by the fact that otolith radius directly opposite the rostrum was proportional to standard length. For example, for larvae collected in frontal waters (like all larvae) the relationship is best described by a third degree polynomial equation:

$$SL = 0.675 + 0.251(\text{radius}) - 0.004(\text{radius}^2) + 0.00002(\text{radius}^3),\ r^2 = 0.89,\ n = 47.$$

The otoliths of most larvae were readable, i.e., only seventeen were rejected. Larvae aged (316) ranged from 2.57-7.48 mm SL with modal SL about 2.3 mm (Fig. 5), and ages ranged from 3-14 days. Although the size ranges were similar, larvae collected at frontal water stations were somewhat larger (mode = 4.75 mm SL) than those collected in Gulf of Mexico shelf waters (mode = 4.25 mm SL) (Fig. 6). Similarly, larvae from frontal waters had an older age distribution (mode = 7 days) than Gulf of Mexico shelf larvae (mode = 6 days) (Fig. 7).

Growth rates were quite variable overall, and for the size range observed length increased linearly with age. Absolute growth (SL/observed age (days,d)) ranged from 0.5 mm $\cdot$ d^{-1} to 1.38 mm $\cdot$ d^{-1} (mode = 0.78 mm $\cdot$ d^{-1}) for all larvae (Fig. 8). A least squares linear model best described the relationship between standard length and age (Fig. 9). This model indicates a population growth rate of 0.47 mm $\cdot$ d^{-1}.

Yellowfin tuna larvae in Gulf of Mexico shelf waters just outside the front grew faster than larvae in frontal waters. Modal absolute growth rate in frontal waters was 0.725 mm $\cdot$ d^{-1} as compared to 0.825 mm $\cdot$ d^{-1} in Gulf of Mexico shelf waters (Fig. 10) ANCOVA of absolute growth rate with size (SL) as a covariate and water mass as the main effect showed that these growth differences were significant (Means = 0.77 and 0.70 mm $\cdot$ d^{-1} for shelf and frontal waters, respectively; Pr>F = 0.001). Size was included in the convariance model to compensate for differences in size ranges of fish from the two water masses, as well as changes in absolute growth with size.

Mortality

We calculated the least squares linear regression of $\log_e$ frequency on age of yellowfin tuna larvae to estimate the total instantaneous rate of daily mortality (slope). Mortality rates calculated for larvae in the Gulf of Mexico shelf waters were higher than frontal waters (0.43 vs. 0.27), and the rate for pooled samples was 0.33.

Spawning Dates

Age of each larva in days was subtracted from its collection date to produce an estimate of spawning date. Larvae were spawned from August 23 to September 1, 1987, with the most larvae being spawned on August 30 (Fig. 11).

DISCUSSION

Clearly, conclusive identification of yellowfin tuna larvae was fraught with problems. We used the best available taxonomic information and techniques to distinguish yellowfin tuna from its congener backfin tuna (Richards and Potthoff, 1974; Potthoff, 1984), and even attempted to discover new diagnostic morphological characters from a reference collection from the Pacific Ocean off Japan where blackfin tuna do not occur.

Pigmentation diagnostic characters were equivocal (Richards et al., 1990), so we resorted to clearing and staining to facilitate making precaudal and caudal vertebral counts, and discovered that distinctions of yellowfin from blackfin larvae based upon vertebral counts and pigmentation did not always agree. Thus, we decided to use pigmentation alone to discriminate between the two closely related species. In the final analysis, it does not seem possible to distinguish all yellowfin and blackfin tuna larvae, particularly those less 5 mm SL.

Yellowfin larvae, chlorophyll a and macrozooplankton were all concentrated just outside the frontal waters in Gulf of Mexico shelf waters. Govoni et al. (1989) showed that fish larvae in general were concentrated at the Mississippi River plume front. Govoni et al. (1989) and Govoni and Grimes (Unpublished MS) suggested that hydrodynamic convergence that occurs at turbidity fronts is capable of at least partially accounting for fish larvae concentrations. Grimes and Finucane (in press) also reported larval fish concentrations in frontal waters, and macrozooplankton and chlorophyll a as well, and suggested that higher primary and secondary production in frontal waters may create a resource rich environment that could also partly account for larvae concentrations.

Our growth rates for yellowfin tuna (0.47 mm · d^{-1}) are lower than those reported in the literature for some other scombrids, e.g., bluefin tuna, *Thunnus thynnus,* (1.39 mm · d^{-1}) (Brothers et al., 1983), skip-jack tuna, *Euthynnus pelamis,* (1.6 mm · d^{-1} up to 27 cm FL) and yellowfin tuna, *Thunnus albacares,* (1.4 mm · d^{-1} up to 642 cm FL) (Uchiyama and Struhsaker, 1981) and Atlantic mackerel, *Scomber scombrus,* (1.3 mm · d^{-1}) (calculated by Waltz, 1985 from Kendall and Gordon, 1981) and king and Spanish mackerel, *Scomberomorus cavalla* and *S. maculatus,* (0.82 and 1.31 mm · d^{-1}) (DeVries et al., 1990). These differences are expected since the size range of our larvae (2.57 - 7.48 mm SL) was generally smaller than those aged in the above studies, and absolute growth rate in fishes increases with size during the larval and juvenile stages.

Larvae in Gulf of Mexico shelf waters just outside frontal waters grew significantly faster than those in the frontal waters proper. DeVries et al. (1990) reported similar results for king mackerel larvae and juveniles which grew faster in the Mississippi plume area as compared to fish collected away from the plume. Grimes and Finucane (in press) have suggested that the resource rich plume environment may offer a food rich environment leading to enhanced growth and survival, and these findings for yellowfin tuna are consistent with that hypothesis. However, even though growth was faster in shelf waters outside frontal waters, the largest larvae were collected in frontal waters.

The daily instantaneous mortality rates we calculated (0.33 overall; 0.43 and 0.27 for Gulf of Mexico shelf and frontal waters) are consistent with those reported in the literature for other scombrids, e.g., 0.35-0.69 for *Scomber scombrus* (Sette, 1943; Kendall and Gordon, 1981; Ware and Lambert, 1985) and 0.83 for *Scomberomorus cavalla* (Grimes et al., 1990).

The co-occurrence of higher growth and mortality rates in Gulf of Mexico shelf waters just outside the front than in frontal waters proper, while the largest larvae were found in frontal waters deserves further discussion. As several authors have pointed out, the imposition of size-selective mortality will cause population growth to appear higher than true growth because the smallest (slowest growing) fish of a given age are removed leaving the faster growing fish from which to measure population growth (e.g., Ricker, 1975; Post and Prankevicius, 1987; Al-Hossaini et al., 1989; Pepin, 1989). If the higher mortality rate on larvae in shelf waters were size-selective, then higher growth in shelf waters may only be apparent. Thus, the growth findings for yellowfin tuna do not appear to be consistant with the hypothesis that concentrated food in frontal waters leads to superior growth and survival (Grimes and Finucane, in press). However, because of the possibility of size-selective mortality influencing apparent growth rates it will be necessary to determine the relative values of growth and mortality in the two water masses to evaluate the hypothesis, i.e., $\hat{S}_2 = \hat{S}_1^{m/g}$ where $4\hat{S}_2$ and $\hat{S}$, are survival in the two equal time periods and m and g are growth and mortality, respectively (Werner and Gilliam, 1984).

The number of larvae collected and the spawning dates we estimated (August 23 - September 1) suggest that there is considerable reproduction of yellowfin tuna in September in the Gulf of Mexico. That at least a significant portion of that spawning occurs near the discharge plume of the Mississippi River is indicated by our results, and by the fact that 411 yellowfin larvae were collected in the discharge plume in July 1987 (Shaw unpublished data). Because a few juveniles (26, 31 and 36 mm TL) were collected in August off northwest Florida-Alabama (Klawe and Schimada, 1959), two larvae (3.8 and 5.7 mm SL) in July off Texas (Finucane et al., 1978), about 30 larvae in two years of Gulf of Mexico-wide sampling during late summer 1982 and 1983 (Richards unpublished SEAMAP data), our collection and those of Shaw (unpublished data) spawning extends at least from July through September.

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Figure 1. NOAA-9 AVHRR satellite image in the visible channel showing the position of stations occupied September 2-10, 1987. Dots indicate stations along transects that cross the interface between plume water (indicated by light and medium shades) and Gulf of Mexico shelf water (indicated by darkest shades). North latitude and west longitude are indicated at the top and right margins.

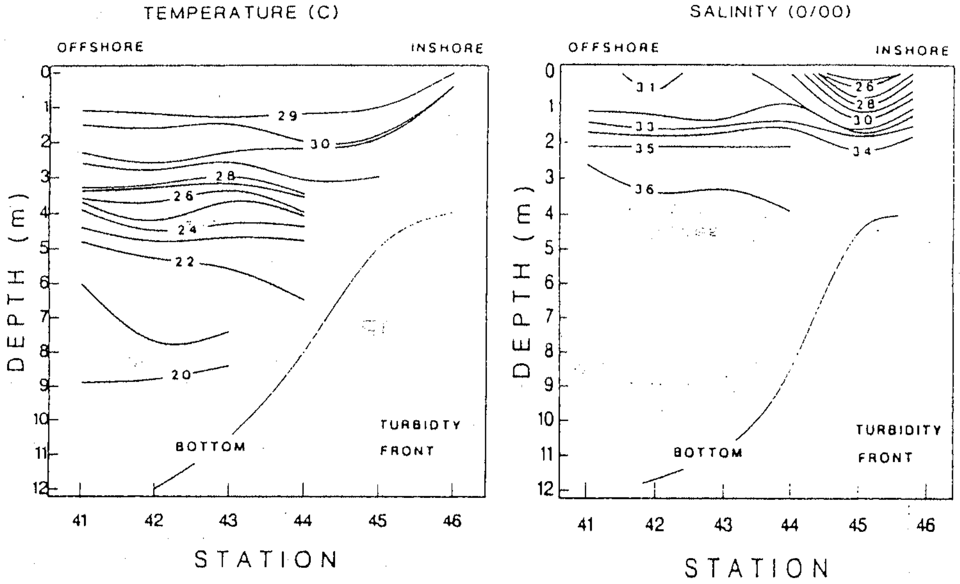

Figure 2. Hydrographic section along a sampling transect directly off Southwest Pass of the Mississippi River.

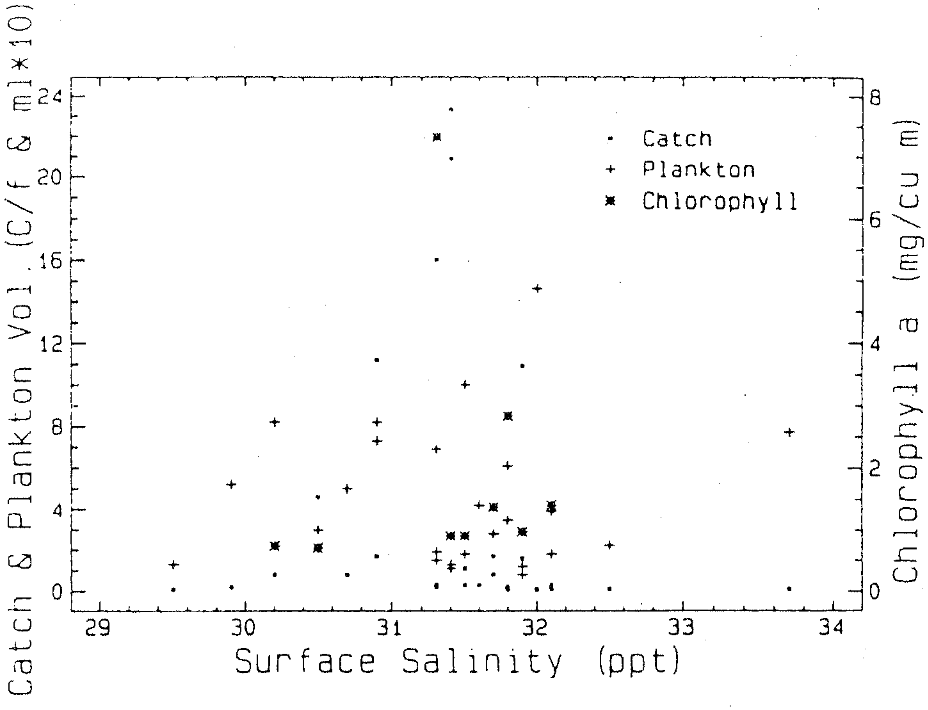

Figure 3. Neuston and Tucker trawl catch per tow of yellowfin tuna larvae, macrozooplankton displacement volume and chlorophyll a values for all stations plotted on surface salinity.

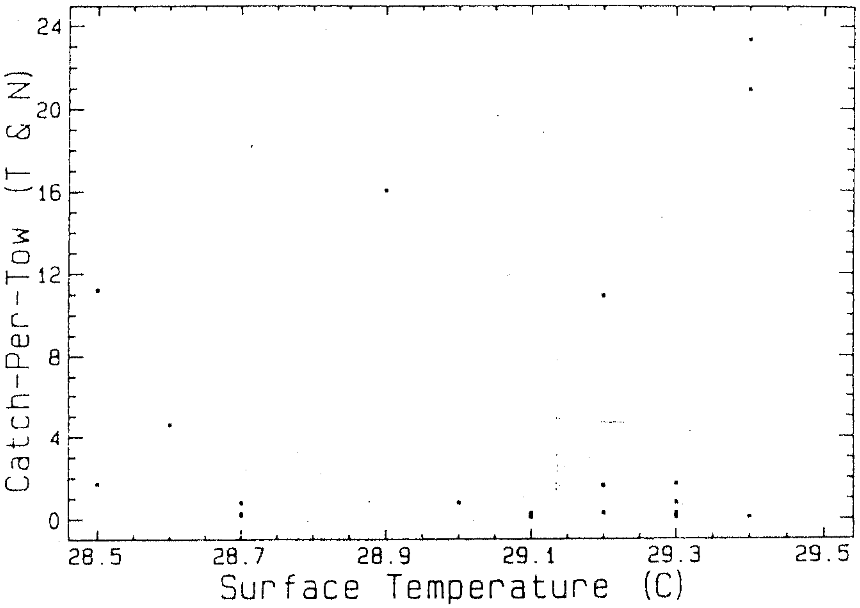

Figure 4. Neuston and Tucker trawl catches of yellowfin tuna plotted on sea surface temperature.

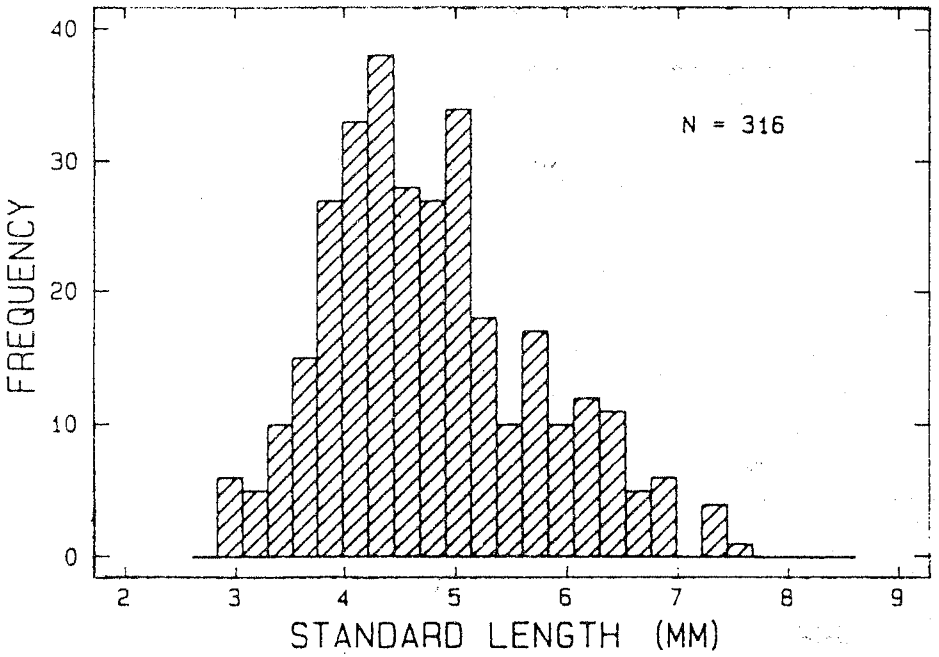

Figure 5. Standard-length frequency distribution of yellowfin tuna larvae that were aged.

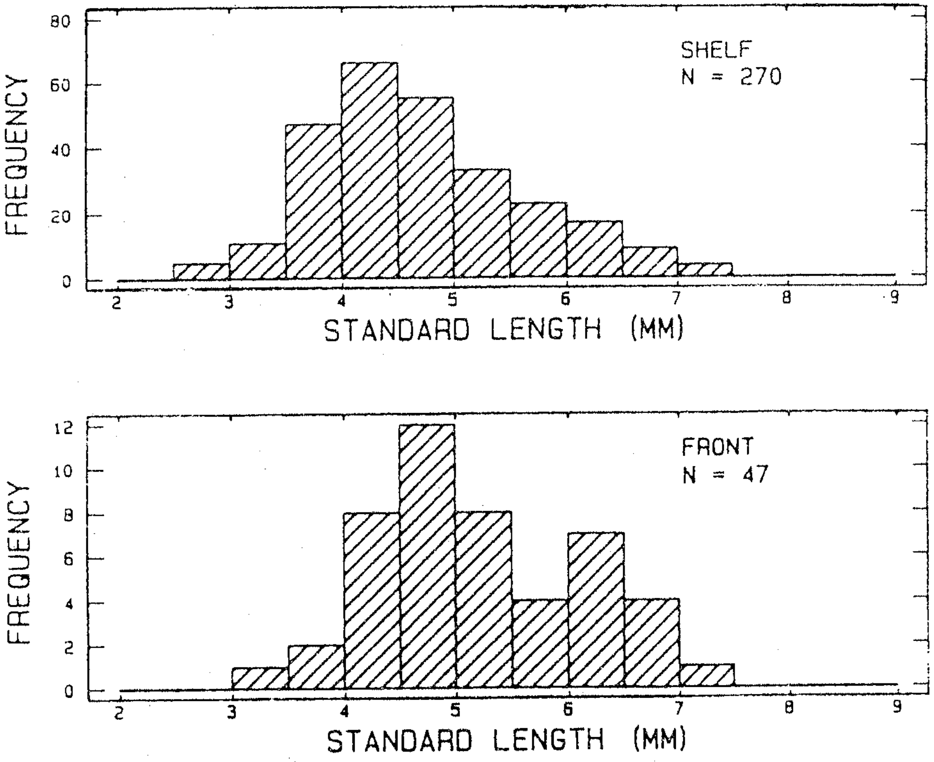

Figure 6. Standard-length frequency distribution of yellowfin tuna larvae collected in Gulf of Mexico shelf waters and frontal waters.

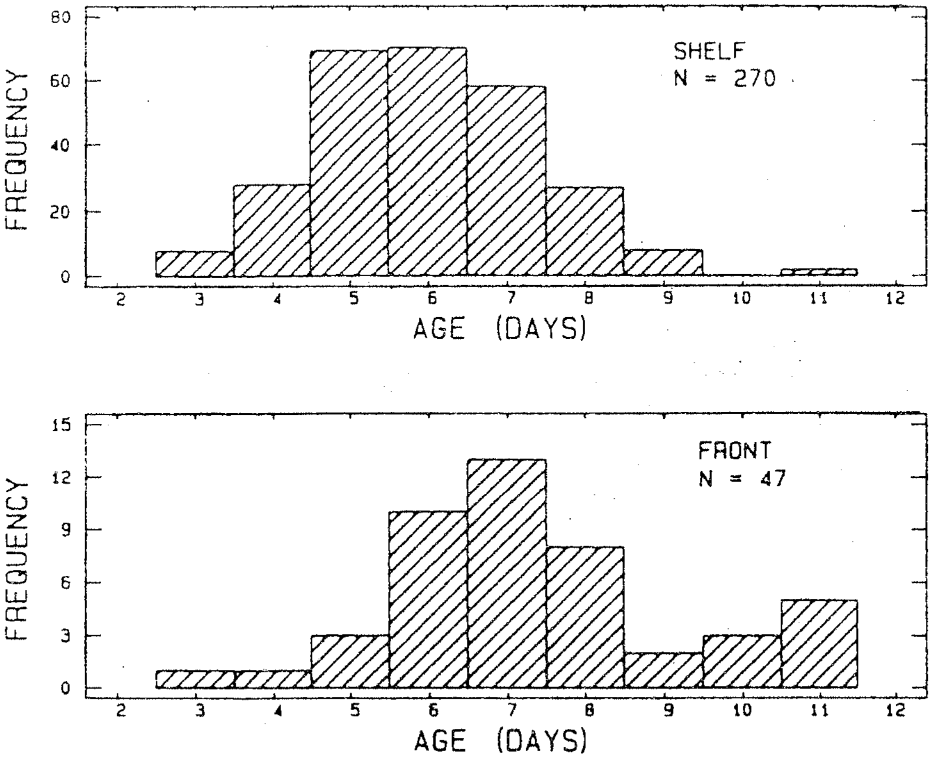

Figure 7. Age-frequency distribution of larvae collected in Gulf of Mexico shelf waters and frontal waters.

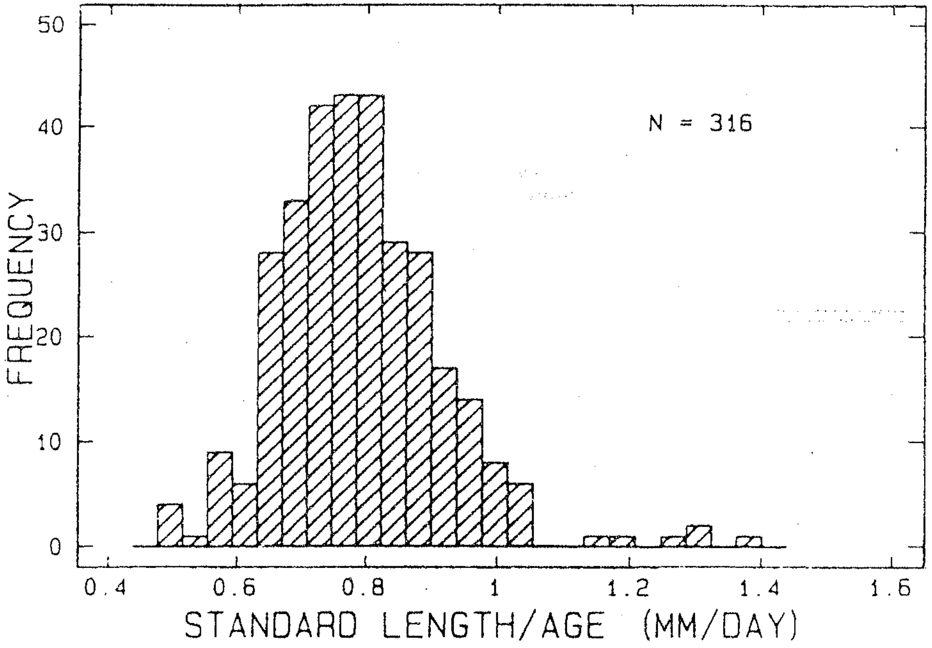

Figure 8. Frequency distribution of absolute growth of (SL/observed age) yellowfin tuna larvae collected around the Mississippi River discharge plume.

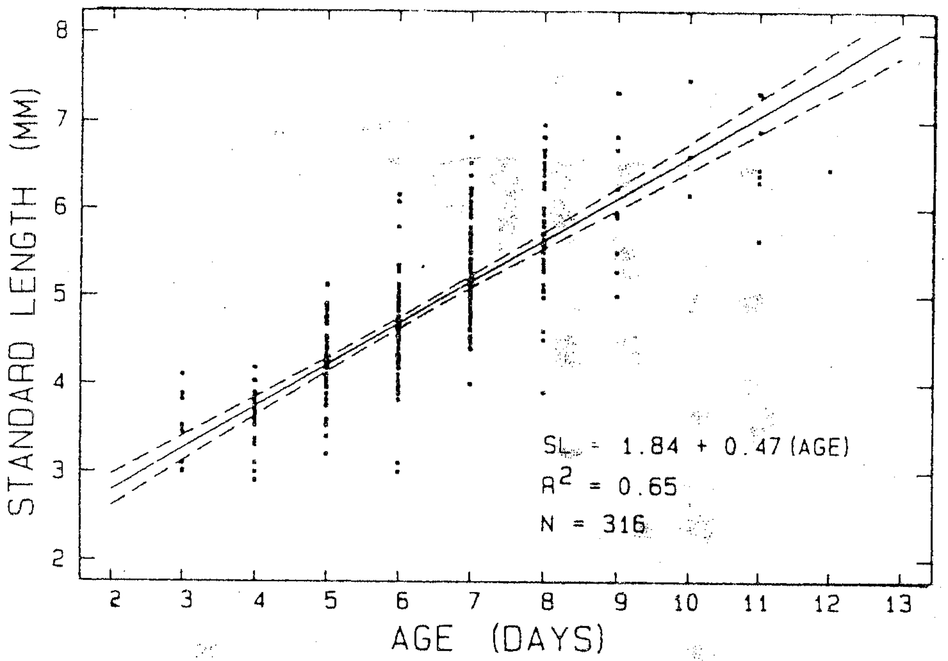

Figure 9. The least-squares linear regression of standard length on age of yellowfin tuna larvae collected around the Mississippi River discharge plume.

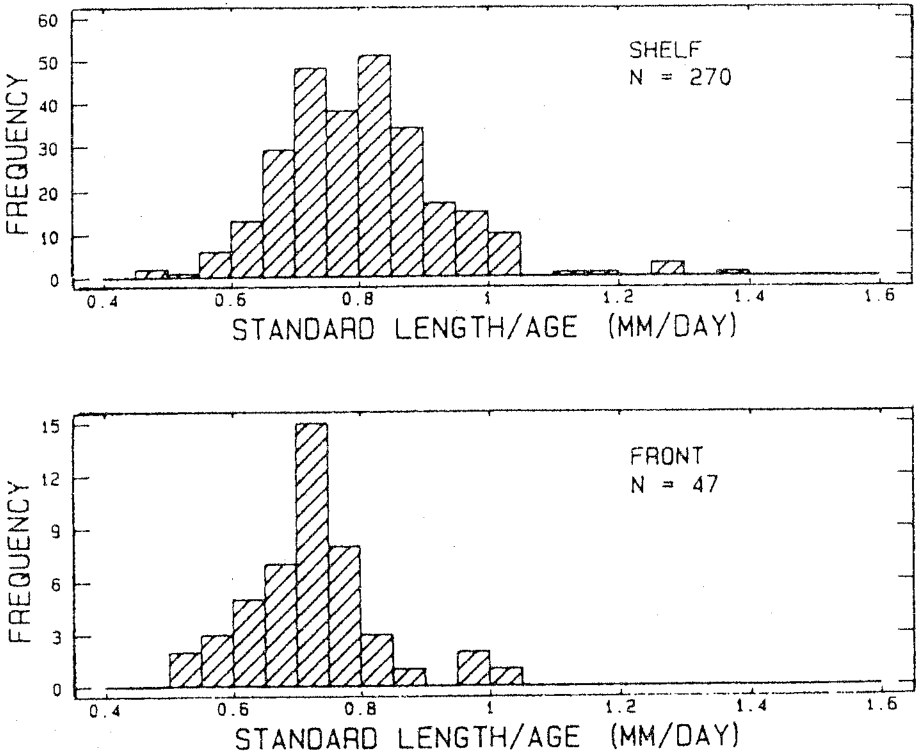

Figure 10. Frequency distribution of growth rates of yellowfin tuna larvae from Gulf of Mexico shelf waters and frontal waters.

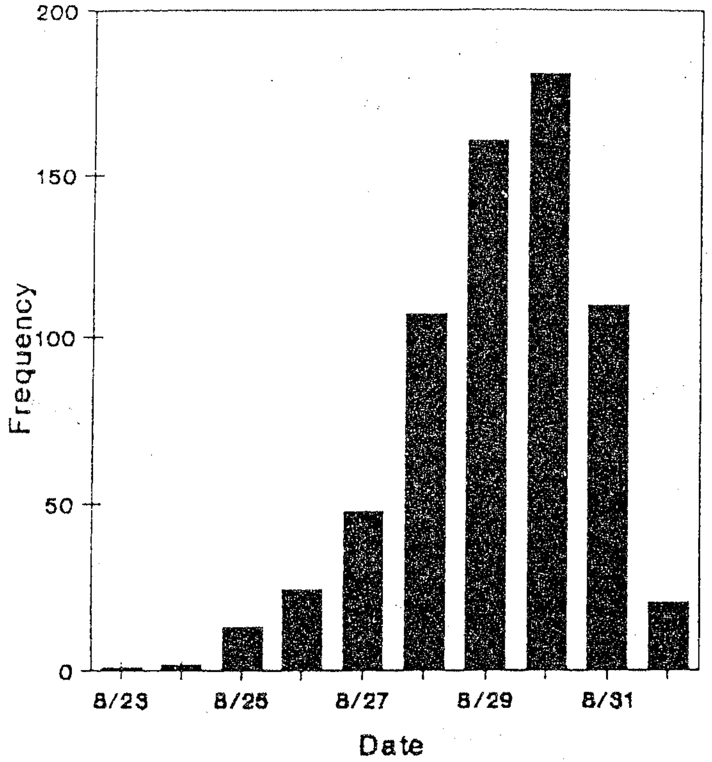

Figure 11. Estimated (back-calculated) spawning-date distribution for yellowfin tuna larvae collected around the Mississippi River discharge plume.