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Variations in the age and growth of yellowfin tuna larvae, *Thunnus albacares,* collected about the Mississippi River plume

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Synopsis

Eight hundred and one yellowfin tuna larvae ranging from 2.57–7.48 mm SL were collected near the Mississippi River discharge plume in the Gulf of Mexico during July and September, 1987. Larvae were most abundant at intermediate salinities (i.e. frontal waters) where chlorophyll *a* and macrozooplankton displacement values were also highest. Using sagittal otolith microstructure, we estimated larval ages ranging from 3–14 d. These ages were used to back calculate spawning dates from 13–24 July and 22–31 August. Mean absolute individual growth rate (length age^{-1}) was 0.47 mm d^{-1}, with the least squares linear regression SL = 1.67 + 0.47 AGE ($r^2 = 0.60$, Pr > F = 0.0001) representing the best growth curve. Highest growth occurred at intermediate salinities near 31‰, and temperatures near 29° C. There was significant temporal variation in growth, with larvae collected in July growing slower than those from September (0.37 and 0.48 mm d^{-1}, respectively). The pooled instantaneous daily mortality rate (Z) of the larvae was estimated to be 0.33 d^{-1} (0.16 d^{-1} in July and 0.41 d^{-1} in September). These results show that significant spawning of yellowfin tuna may occur in the northern Gulf of Mexico in the vicinity of the Mississippi River discharge plume, and suggest that larval growth and survival may be enhanced in the plume frontal waters.

Introduction

Yellowfin tuna, *Thunnus albacares,* are large, epipelagic members of the family Scombridae. They are common in the Gulf of Mexico beyond the 910 meter isobath (Springer 1957) and support one of the most valuable commercial fisheries in the Gulf. Ex-vessel values increased from less than US $ 500 000 in 1981 (Fee 1987) to US $ 29 000 000 in 1988 (E. Snell personal communication). Factors affecting stock size of this species such as growth, mortality (fishing and natural) and recruitment are, therefore, of major concern.

There is little published information on the reproduction or early life history of yellowfin tuna. Some reproductive development in June was reported for fish from Puerto Rico, but none for fish from the Bahamas (Erdman[1]). Spawning reportedly occurs in the spring and summer in Cuban waters (Gorbunova & Salabarria 1967 – cited in Fritzsche 1978). Histological examination of fish from the U.S. Atlantic coast and Gulf of Mexico revealed no evidence of spawning activity from August to Feb-

[1] Erdman, D.S. 1968. Spawning seasons of some game fishes around Puerto Rico. International Oceanographic Foundation, Twelfth Annual International Game Fish Conference, 17–18 Nov. 1967. 19 pp.

ruary (Goldberg & Herring-Dyal[2]). Historical collections of early life stages of yellowfin tuna have also suggested little spawning in the Gulf of Mexico; fewer than 50 larvae and young juveniles have been collected (Klawe & Shimada 1959, Finucane et al.[3], Kelley et al.[4]).

Ages and growth rates have been established for adult yellowfin tuna using scales (Yabuta et al. 1960, Yang et al. 1969), vertebrae (Aikawa & Kato 1938), fin rays (Draganik & Pelczarski 1984), and changes in length (Moore 1951, Diaz 1963, Le Guen & Sakagawa 1973). Sagittal otoliths have been used to age yellowfin tuna from 40 to 110 cm FL and daily increments have been validated for juveniles and adults during a mark-recapture experiment of tetracycline injected fish (Wild & Foreman 1980). Daily growth increments have also been counted on otoliths from juvenile and adult yellowfin tuna ranging in size from 3 to 80 cm FL and up to two years old (Uchiyama & Struhsaker 1981). However, ages and growth rates have not been determined for larvae and early juvenile yellowfin tuna.

A key environmental/oceanographic feature that may influence the distribution, abundance, growth and recruitment of fish larvae in the northern Gulf of Mexico is the Mississippi River plume. The volume of water discharged from the Mississippi River averages 18 300 m^3 sec^{-1} (Gunter 1979). When this drainage enters the Gulf, it forms a shallow plume of low salinity water that lies on top of the warmer, but more saline outer continental shelf or oceanic water, and can project up to 100 km offshore (Riley 1937). The river plume mixes with the outer shelf or oceanic waters along its seaward edge creating a 6–8 km wide frontal zone or region. Nested within the frontal zone are small scale (5–50 m) turbidity fronts that form, relax, and reform with frequencies roughly approximating tidal cycles (Grimes & Finucane 1991). Hydrodynamic conditions (primarily horizontal density gradients) at turbidity fronts can produce surface convergence rates of up to 1.0 m sec^{-1} (Govoni & Grimes 1992). Phytoplankton biomass (Grimes & Finucane 1991, Lohrenz et al. 1990), microzooplankton (Dagg & Whitledge 1991) and fish larvae (Govoni et al. 1989, Grimes & Finucane 1991) can be concentrated in the frontal zone. Simulations using an advection-diffusion model, suggest that physical convergence at turbidity fronts can account for observed concentrations of fish larvae in the frontal zone (Govoni & Grimes 1992).

While physical convergence might influence the spatial distribution of phytoplankton and zooplankton in the frontal zone, biological processes are at work as well. The mixing of plume water with the clear, more oligotrophic shelf water creates a favorable environment for phytoplankton growth as organisms rapidly utilize river-associated nutrients as turbidity (light limitation) decreases (Lohrenz et al. 1990). Growth and grazing rates of microzooplankton can also be higher in the plume front (Dagg & Ortner unpublished data). The Mississippi River plume frontal zone can, therefore, at times be very productive and may offer an enhanced feeding environment for fish larvae.

The purpose of this paper is to describe the distribution, abundance and spawning dates of yellowfin tuna larvae about the Mississippi River plume and to make spatial and temporal comparisons of growth and mortality rates. The results may suggest what role the Mississippi River plume plays in the survival and recruitment of fish larvae in the Gulf of Mexico.

Materials and methods

Yellowfin tuna larvae were collected on two cruises (July and September, 1987) to the Mississippi River

[2] Goldberg, S.R. & H. Herring-Dyal. 1981. Histological gonad analyses of late summer-early winter collections of bigeye tuna, *Thunnus obesus*, and yellowfin tuna, *Thunnus albacares,* from the Northwest Atlantic and the Gulf of Mexico. U.S. Dept. Commer., NOAA Tech. Memo. NMFS. SWFC. 14. 9 pp.

[3] Finucane, J.H., L.A. Collins & L.E. Barger. 1978. Ichthyoplankton/mackerel eggs and larvae. Environmental studies of the south Texas outer continental shelf, 1977. NOAA final report to BLM under interagency agreement # AA550-1A7-21. September, 1978.

[4] Kelley, S., J.V. Gartner Jr., W.J. Richards & L. Ejsymont. 1990. SEAMAP 1986-ICHTHYOPLANKTON Larval distribution and abundance of Engraulidae, Carangidae, Clupeidae, Gobiidae, Lutjanidae, Serranidae, Coryphaenidae, Istiophoridae, Scombridae in the Gulf of Mexico. NOAA Tech. Memo. NMFS. SEFC. 245. 45 pp.

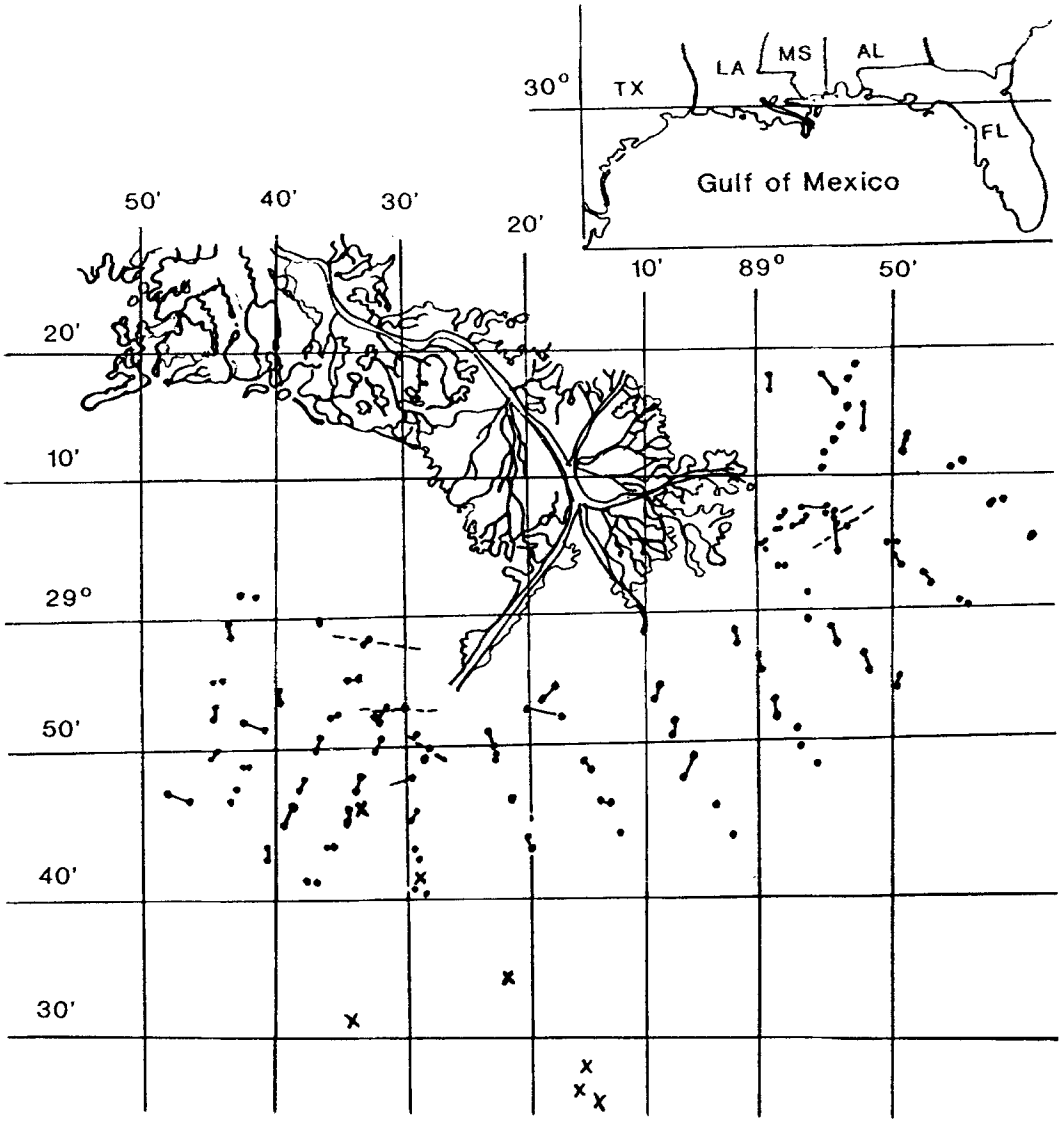

Fig. 1. Location of sampling stations about the Mississippi River delta during 1987 (x = July, • = September) with Gulf of Mexico inset for reference.

plume area (Fig. 1). Sampling in July was mostly fine scale (tens to hundreds of meters), i.e., collections were made on either side of visible turbidity fronts. Meso-scale (kilometers) sampling was conducted in September along transects that traversed mixed frontal waters and Gulf of Mexico shelf waters (Grimes & Finucane 1991).

CTD casts were made at all stations on both cruises to collect hydrographic data. Plankton was collected with a 1 × 1 m Tucker trawl with 0.333 mm mesh during both cruises, as well as with a 1 × 2 m neuston net with 0.947 mm mesh during the September cruise. Tucker trawls were towed just below the surface at approximately 1 m sec^{-1} for 3 minutes, while the neuston net was towed at the surface at approximately 1 m sec^{-1} for 10 minutes. Samples were preserved in 95% ethanol for 24 hours, after which samples were drained and fresh preservative added.

Surface water samples were collected during

both cruises. During July, chlorophyll *a* and phaeopigment samples were taken from surface bottles of the CTD and analyses followed a modified fluorometric methodology (Strickland & Parsons 1972). Water collections were immediately filtered onto Watman GF/F glass fiber filters, homogenized by grinding in 90% acetone, and centrifuged. Fluorescence before and after acidification was measured on a Turner model 10[5] fluorometer, calibration factors applied, and chlorophyll *a* concentration determined. In September, surface water samples (approximately 3 l) were collected by bucket, vacuum filtered onto GF/C filters, and frozen in aluminum foil for later fluorometric determination of chlorophyll *a*.

In the laboratory, plankton samples were sorted and all ichthyoplankton removed and identified. Pigment was extracted from the September surface water samples using acetone, and fluorometric determinations of chlorophyll *a* were made according to Strickland & Parsons (1972). Macrozooplankton displacement volumes from the July samples followed the methodology of Yentsch & Hebard (1957), while the September displacement volumes were measured by immersing the drained plankton material in a partially filled graduated cylinder and noting the change in volume.

Yellowfin tuna larvae were identified based on pigmentation according to Richards & Potthoff (1974) and were measured to the nearest 0.1 mm standard length (SL) using an ocular micrometer. Otoliths were removed and mounted on a glass slide. Larvae were then cleared and stained with alcian blue (Potthoff 1984) to make vertebral counts in an attempt to reaffirm the identifications.

Sagittal otoliths were observed whole. No further preparation was necessary before aging. Daily growth increments were enumerated and otolith radii measured using oil immersion and transmitted light at 1000 X with an image analysis system (described in DeVries et al. 1990).

Growth was examined using two methods. To examine variation in growth with temperature and salinity, individual growth rates were determined by dividing length (SL at capture minus hatching length) by increment count. In addition, growth curves were fitted as least squares linear regressions of length on age.

Daily age data were used to calculate mortality rates and to back-calculate spawning dates. Instantaneous mortality rates were estimated using a catch curve approach, i.e., the slope of $\log_e$ frequency on age regressions, similar to that described by Essig & Cole (1986). No attempt was made to correct the mortality analysis for advection or diffusion of larvae. Also, larvae from neuston net and Tucker trawl samples were pooled for this analysis as the differential catchability with respect to size or age between the two gears was negligible.

Spawning dates were back-calculated by subtracting the age (d) of each larva from its date of collection. A correction of one day for hatching time was also subtracted as yellowfin tuna larvae have been shown to hatch in 1 to 1.5 days at 25° C (Harada et al. 1971).

Results

Collection

From 26–30 July, seven stations were occupied near turbidity fronts, and from 2–10 September 1987, 85 stations were sampled along transects that were approximately 25 km long with stations 4–6 km apart. A total of 801 yellowfin tuna larvae were collected (115 in July and 686 in September). Temperature and salinity cross sections were constructed from the CTD data for each transect for both cruises (Fig. 2) to allow more exact location of tuna larvae collections in relation to the hydrographic structure of the convergence fronts. The frontal zone was identified as that region along a transect where closely spaced isohalines approached the surface (e.g., between station 43 and 45 in Fig. 2).

Identification

Separation of small yellowfin tuna larvae, *Thunnus albacares,* from their congener blackfin tuna, *Thun-*

[5] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

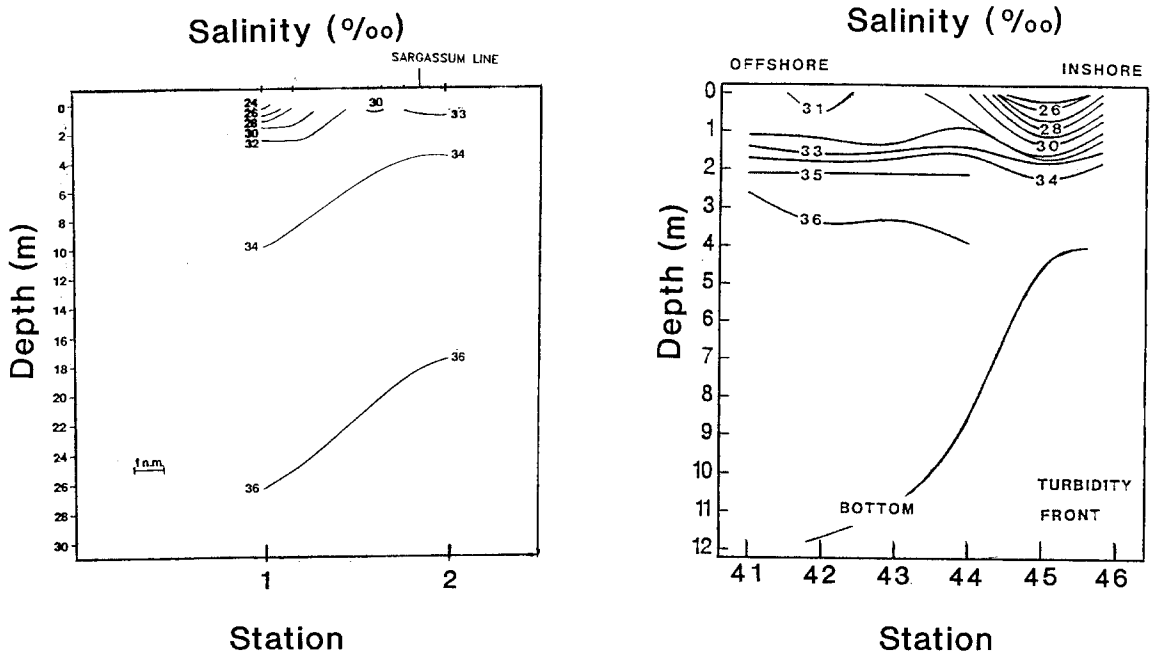

Fig. 2. Example of salinity cross sections of station locations from July (left) and September, 1987 cruises.

nus atlanticus, proved difficult. The difference in pigmentation between the two species (blackfin tuna have a pigment spot near the ventral origin of the caudal fin which is absent in yellowfin tuna) may not always be definitive (Richards et al. 1990). Therefore, we attempted to use the other reported morphological difference, the number of precaudal versus caudal vertebrae (Richards[6]) to distinguish the two species. Larvae were cleared and stained with alcian blue (Potthoff 1984) to facilitate making vertebral counts. Yellowfin and blackfin tuna larvae have the same total number of vertebrae, and only differ by one in the number of precaudal and caudal elements. Therefore, failure to correctly identify the first caudal vertebra, i.e., the first vertebra with a closed hemal arch, can result in erroneous vertebral counts and equivocal identifications.

This staining procedure was also not always conclusive. Larvae less than 5.0 mm SL did not accept staining. Larvae greater than 5.0 mm SL accepted staining, however, the vertebral counts yielded identifications that were sometimes inconsistent with those based on pigmentation. That is, some larvae with ventral pigment spots had vertebral counts of yellowfin tuna.

Using a reference collection of wild caught yellowfin tuna larvae from the Pacific Ocean (off Japan) where blackfin tuna do not occur, we attempted to locate additional morphological characters (i.e., opercular spines, orbit diameter, and interdigitation of fins) that would allow discrimination of yellowfin and blackfin larvae. No differences were found, and because these samples were consistent with our yellowfin samples (lacking ventral pigmentation and having ambiguous vertebral counts), we decided to base identification entirely on pigmentation since it proved to be as useful and consistent as an identification aid as vertebral count.

Distribution and abundance

We used salinity as an indicator of station location in relation to the hydrographic structure of the Mississippi River plume. The highest catches of yellow-

[6] Richards, W.J. 1989. Preliminary guide to the identification of the early life history stages of scombrid fishes of the western central Atlantic. NOAA Tech. Memo. NMFS-SEFC-240. 101 pp.

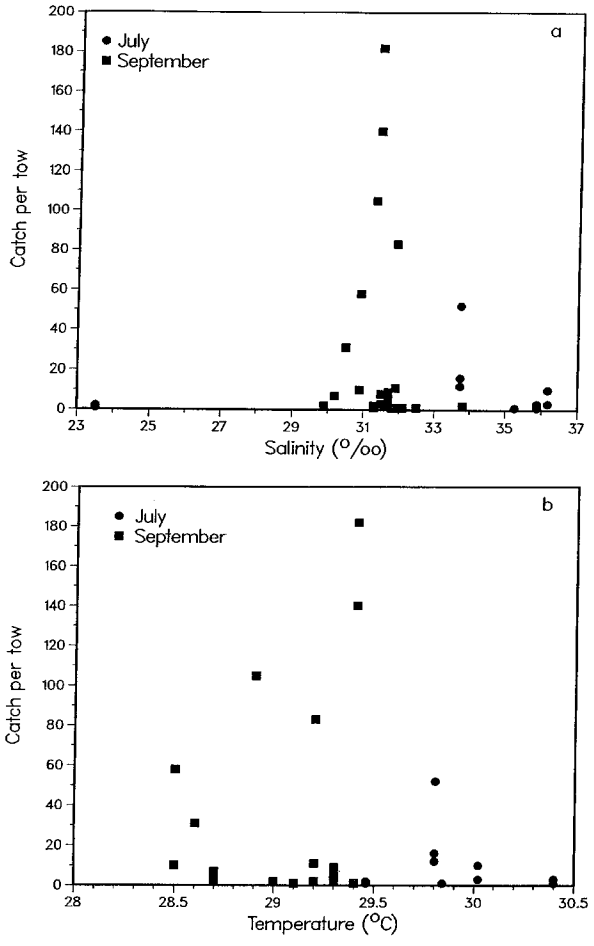

Fig. 3. Distribution of yellowfin tuna larvae shown as catch per tow of positive stations by a- salinity and b- temperature.

fin tuna larvae were made at intermediate salinities typical of the frontal zone (Fig. 3a). During July when yellowfin tuna larvae were collected at 5 of the 7 stations sampled, most larvae were collected at surface salinities near 34‰, although collections were made at salinities ranging from 23.5 to 36.2‰. During September when yellowfin larvae were collected at 19 of the 85 stations sampled (neuston net and Tucker trawl collections combined), the greatest numbers of larvae came from salinities near 31‰, although collections were made at salinities ranging from 29.9 to 33.8‰.

Yellowfin tuna larvae were collected within a rather narrow range of temperatures. During July, collections were made at temperatures ranging from 29.5 – 30.4° C with highest numbers of larvae taken at temperatures near 29.8° C. In September, yellowfin tuna larvae were collected at temperatures ranging from 28.5 – 29.4° C with highest numbers taken at 29.4° C (Fig. 3b).

The magnitude of surface chlorophyll *a* values and macrozooplankton displacement volumes associated with collections of tuna larvae were also highest at intermediate salinities (Fig. 4a, b). Chlorophyll *a* values ranged from 0.1 to 20.0 mg m^{-3} in July with the highest value obtained at 23.5‰, and from 0.7 to 7.3 mg m^{-3} in September with the highest value obtained at 31.3‰. Macrozooplankton displacement volumes ranged from 0.02 to 0.34 ml m^{-3} in July with the highest values at 35.9 and 23.5‰.

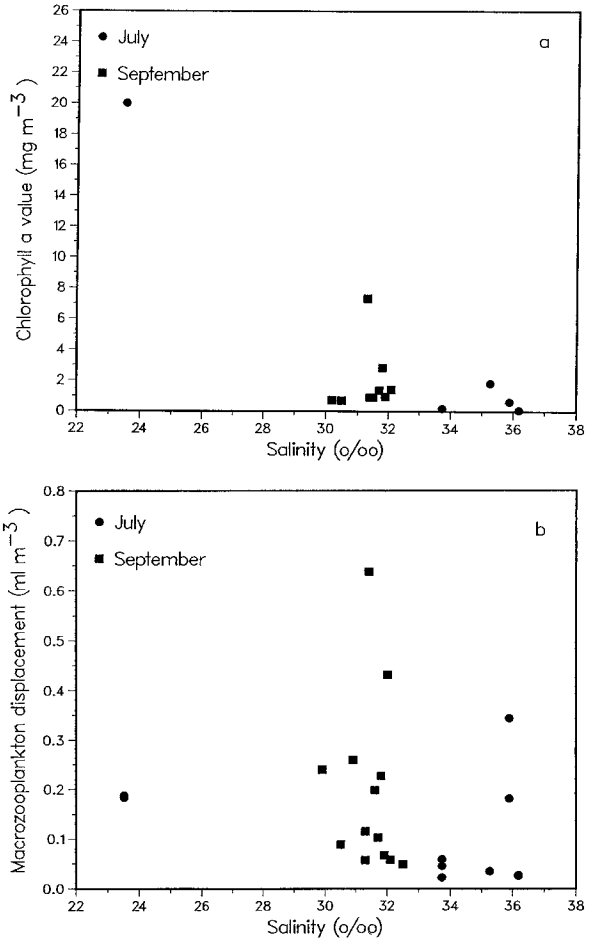

Fig. 4. a- Distribution of chlorophyll *a* values (mg m^{-3}) and b- macrozooplankton displacement volumes (ml m^{-3}) associated with positive collections of yellowfin tuna larvae by salinity.

September samples ranged from 0.05 to 0.64 ml m^{-3} with the highest value at 31.4‰.

Size and age

Size of larvae varied by collection. Larvae collected in July ranged from 2.6 to 8.7 mm SL (mean = 3.8 mm; mode = 4.3 mm). In September, the mean size of the Tucker trawl samples was 4.7 (range 2.9 – 7.5 mm SL; n = 426). Inclusion of the neuston net samples from the September cruise had little effect on this comparison as the mean size of the neuston net samples was 4.8 mm SL (range 3.7 – 7.0 mm; n = 241).

We determined ages of 768 larvae in this study (101 from July and 667 from September). Some otoliths (14 from July and 19 from September) were considered unreadable (a reliable count could not be made) and were discarded. Larvae collected in July ranged from 3 to 14 d (mean = 5.9 d; mode = 5 d), while those from September were 3 to 12 d (mean = 6.3 d; mode = 6 d). No correction for the time prior to increment deposition was required because larvae of the closely related species, skipjack tuna, *Euthynnus pelamis,* have been shown to deposit the first growth increment on their otoliths 1 day after hatching (Radtke 1983).

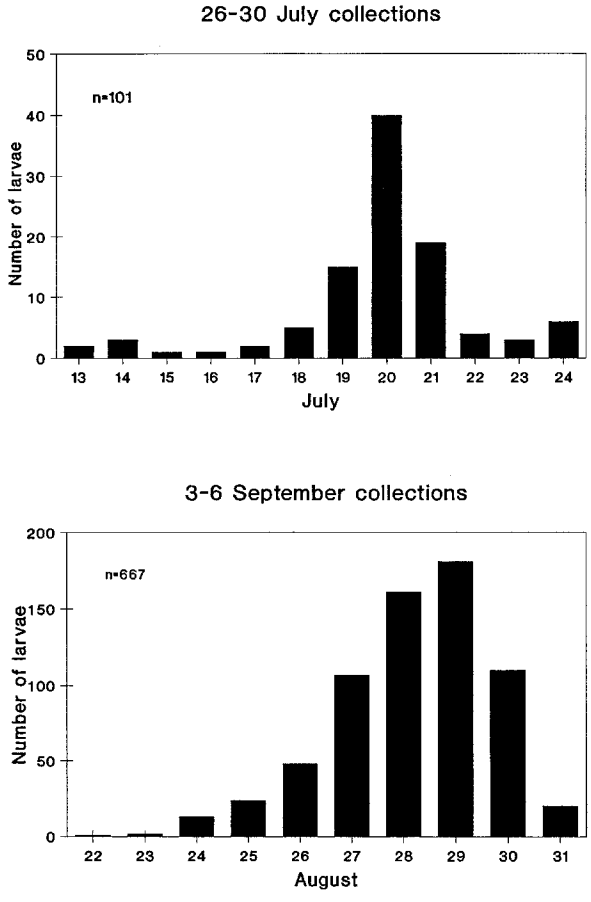

Fig. 5. Frequency histogram of back-calculated spawning dates of yellowfin tuna larvae by collection.

Validation

We did not demonstrate the daily periodicity of increment deposition on the otoliths of yellowfin tuna larvae. However, daily increment formation has been validated and documented in juvenile and adult yellowfin tuna (7–110 cm FL; Wild & Foreman 1980, Uchiyama & Struhsuker 1981). In addition, the growth increments we observed were structurally homologous to those proven to be daily in larvae of the related species, southern bluefin tuna, *Thunnus maccoyii* (Jenkins & Davis 1990), and a variety of other scombrid species (cited in Brothers et al. 1983). We also established that the radius of otoliths of yellowfin tuna larvae is directly proportional to the standard length of the larvae (SL = 2.39 + (0.10)RADIUS, $r^2 = 0.69$, Pr > F = 0.0001), evidence that is consistent with the hypothesis that increments are deposited daily.

Spawning dates

The temporal distribution of back-calculated spawning dates (minus 1 d hatching time correction) indicates that spawning occurred at least from mid-July through September. Spawning dates for larvae collected from 26–30 July ranged from 13–24 July 1987 with most larvae being spawned on 20 July (Fig. 5). Larvae from the 3–6 September collection were spawned from 22–31 August 1987 with the modal back-calculated spawning date being 29 August. Neither spawning date frequency was corrected for mortality.

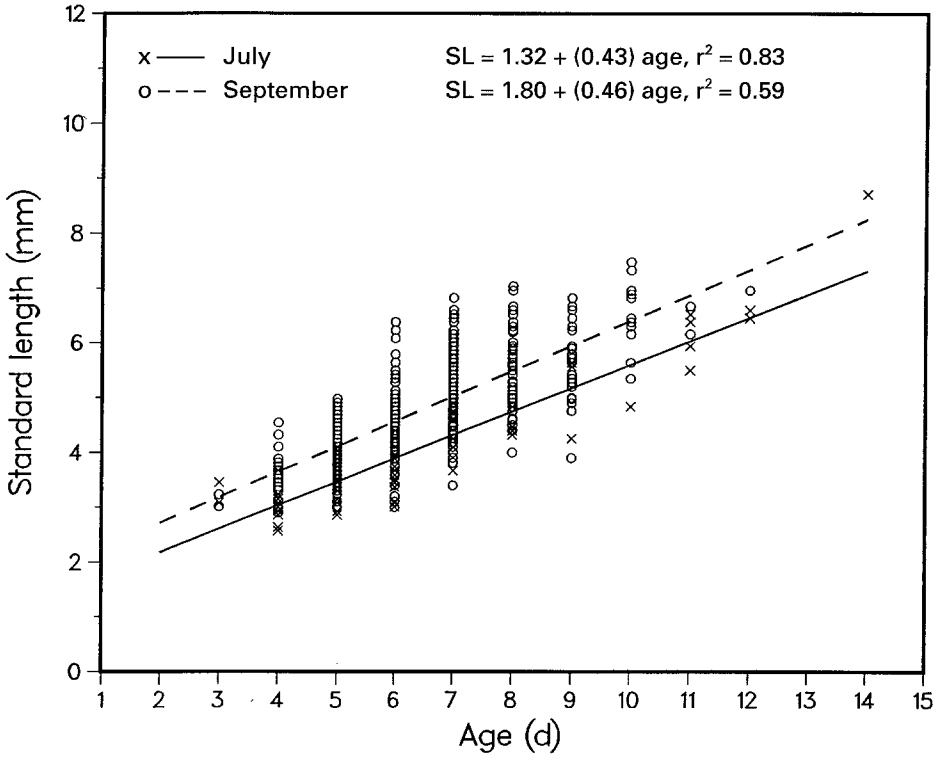

Fig. 6. Linear regressions of standard length on age for yellowfin tuna larvae by collection.

Growth

Individual growth of the yellowfin tuna larvae was calculated as SL age^{-1}, and general growth curves were described by standard length on age regressions. Individual growth rates of the larvae ranged from 0.22–0.79 mm d^{-1} with an overall mean of 0.47 mm d^{-1}. The mean growth rate of the July collection was 0.37 mm d^{-1}, while that of the September collection was 0.48 mm d^{-1}. The difference in growth by collection was highly significant (t test, Pr > t = 0.0001).

The growth of all yellowfin tuna combined (both collections) is represented by the equation SL = 1.67 + 0.47 (AGE), r^2 = 0.60, Pr > F = 0.0001. The growth curve for the July collection is SL = 1.32 + 0.43(AGE), r^2 = 0.83, Pr > F 0.0001, while the equation for the September larvae is SL = 1.80 + 0.46(AGE), r^2 = 0.59, Pr > F = 0.0001 (Fig. 6).

Salinity effect

When we examined the relationship between mean individual growth rates and salinity, lowest rates occurred at high salinities (indicative of Gulf of Mexico outer shelf or oceanic waters) and highest rates occurred at intermediate salinities (indicative of frontal waters; Fig. 7a). An analysis of covariance (Model: SL = Salinity (interval) with age as the covariate) indicated that salinity does have a significant effect on growth (r^2 = 0.64, Pr > F = 0.0001).

Temperature effect

Temperature also appears to have an effect on the growth of yellowfin tuna larvae. When data were pooled for both collections, highest mean growth rates occurred at intermediate temperatures (ca. 29.4° C; Fig. 7b). The temperatures where highest growth rates occurred (ca. 29.4° C) were the lowest temperatures of the July collection and the highest temperatures of the September collection. These data suggest that the optimum temperature for growth of yellowfin tuna larvae is between 29 and 29.5° C. The effect of temperature on growth was found to be significant (ANCOVA; Model: SL =

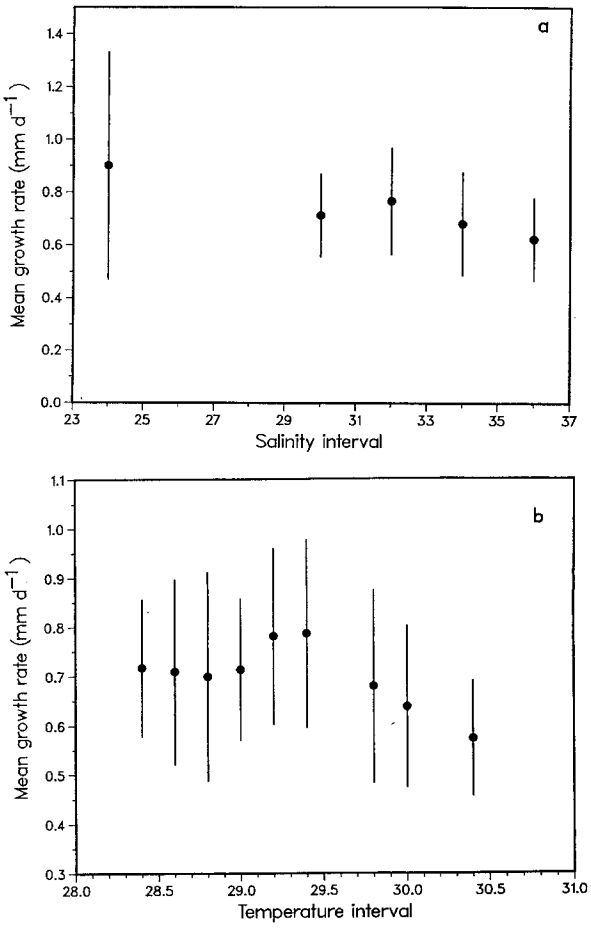

Fig. 7. Mean individual growth rates and 95% confidence intervals for yellowfin tuna larvae at a- 2‰ salinity intervals and b- 0.2° C temperature intervals.

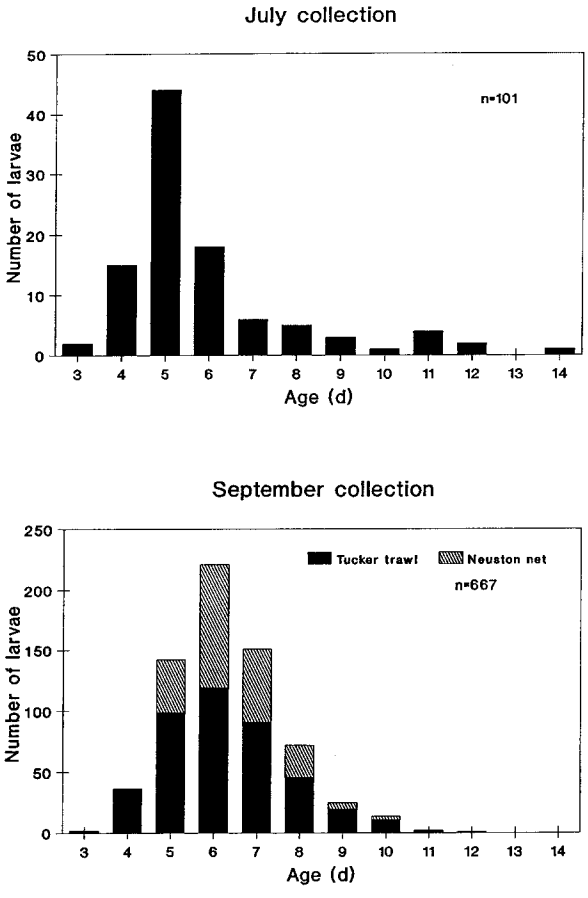

Fig. 8. Frequency histograms of ages of yellowfin tuna larvae by collection.

Temperature (interval) with age as the covariate; $r^2 = 0.62$, $Pr > F = 0.0001$).

Species effect

Because there was a possibility that some small (< 5 mm) blackfin tuna larvae were incorrectly identified as yellowfin tuna larvae (as discussed above), we compared growth rates of yellowfin tuna larvae to those of similarly-sized blackfin tuna larvae (Lang et al. unpublished data) to determine if misidentification could have influenced growth results. No significant differences in growth rates were found between the two species (ANCOVA, Model SL = Species with age as the covariate, $Pr > F = 0.2941$.

Mortality

Age frequency data (Fig. 8) were used to estimate instantaneous daily mortality rates as the slope of the least squares linear regression of $\log_e$ frequency (Z) on age. The mortality rate of all yellowfin tuna larvae was 0.33 d^{-1}; but, when examined by collection, larvae from July had a lower mortality rate than those from September ($Z = 0.16$ vs. 0.45 d^{-1}). Because gear selectivity could have confounded the seasonal comparison, we compared mortality estimates by gear type for the September cruise and found little difference (Tucker trawl $Z = 0.39$ d^{-1} and neuston net $Z = 0.42$ d^{-1}).

Discussion

Definitive identification of yellowfin tuna larvae, especially those below 5 mm SL, is difficult. We used current taxonomic information and techniques to distinguish yellowfin tuna from its congener blackfin tuna (Richards & Potthoff 1974; Potthoff 1984), consulted larval fish taxonomists (see acknowledgements), and investigated new diagnostic morphological characters from a reference collection of yellowfin tuna larvae from Japanese waters. Because identifications based on pigmentation could be made repeatedly and consistently, we decided to use that character to discriminate between the two closely related species. The possibility exists, however, that with such an unprecedented large number of larvae, we may not have been able to distinguish 100% of yellowfin from blackfin tuna larvae, particularly those less than 5 mm SL.

Very few yellow fin tuna larvae have been previously reported from the Gulf of Mexico. Three small juveniles (26, 31 and 36 mm TL) were collected in August around the 1830 m isobath between Pensacola, FL and Mobile, AL (Klawe & Shimada 1959). Two larvae (3.8 and 5.7 SL) were found off Texas in July as a result of extensive sampling from 1975 to 1977 (Finucane et al.[3]). Approximately 30 larvae were collected by the state-federal cooperative Southeast Area Monitoring and Assessment Program (SEAMAP) in 1982 and 1983 (W.J. Richards personal communication 1989). The relatively large number of larvae we collected and the estimated spawning dates 13–24 July and 22–31 August) suggest that there may be considerable yellowfin tuna spawning during the summer around the Mississippi River plume.

Although larvae were collected at surface salinities ranging from 23.5 to 36.2‰, most were collected at intermediate salinities around 31–32‰, which occur within the frontal mixing zone between Mississippi River plume and Gulf of Mexico oceanic waters. Larvae were very rarely collected at salinities less than 30‰. The collection of three larvae at a salinity of 23.5‰ may have been due to a physical mixing event (i.e. the relaxation and dispersal of a previously observed convergence zone). This range of salinities for collections of tuna larvae was similar to other reported collections of 33.5 to 36.8‰ from the Gulf of Guinea (Richard & Simmons 1971).

Larvae were collected within a narrow range of sea surface temperatures (28.5 to 30.4° C). Yellowfin tuna larvae have only been reported from waters above 24° C (Richards 1969, Richards & Simmons 1971, Ueyanagi 1971). Our upper collection value of 30.4° C may be approaching a tolerance limit since the results of rearing experiments have shown no successful yellowfin tuna hatching at 30.6 to 32.9° C (Harada et al. 1980).

Highest values for both chlorophyll *a* and macrozooplankton displacement volumes usually co-occurred with tuna larvae at intermediate salinities (i.e., the frontal region). Chlorophyll *a* values may be an index of potential food for small zooplankton, and taken together with the zooplankton displacement volume, indicative of rich potential food resources for yellowfin tuna larvae. A high chlorophyll *a* value was associated with the only collection of yellowfin tuna larvae taken at low salinity (23.5‰).

Although we did not directly establish the validity of growth increments on yellowfin tuna otoliths, there is firm support in the literature that increments are deposited daily. The daily periodicity of increment formation has been established for larvae of the southern bluefin tuna, *Thunnus maccoyii* (Jenkins & Davis 1990) by marginal increment analysis, and for juvenile and adult yellowfin tuna by tetracycline marking (Wild & Foreman 1980, Uchiyama & Struhsaker 1981). Also, the uncorrected ages of the larvae in this study (3.2 mm at 3 days, 3.97 mm at 4 days, 5.1 mm at 7 days, 6.4 mm at 10 days and 9.03 mm at 14 days) agree well with ages and sizes of larvae produced in artificial rearing experiments in which larvae hatched at 2.7 mm and grew to 3.2 mm after one day, 3.7 at 3 days of age, 5.0 mm at 7 days, 6.3 mm at 10 days and 8.5 mm at 18 days of age (Harada et al. 1971).

The growth rates for yellowfin tuna larvae reported here (0.37 mm d^{-1} for July, 0.48 mm d^{-1} for September and 0.47 mm d^{-1} overall) are similar to those reported for southern bluefin tuna, *Thunnus maccoyii,* over a similar size range (0.32 mm d^{-1} – Jenkins & Davis 1990). Our observed growth rates, however, are lower than those reported for larger

scombrid individuals, e.g., bluefin tuna, *Thunnus thynnus* (1.39 mm d^{-1} – Brothers et al. 1983), skipjack 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 & Struhsaker 1981), Atlantic mackerel, *Scomber scombrus* (1.3 mm d^{-1} – calculated by Waltz[7] from Kendall & Gordon 1981) and king and Spanish mackerel, *Scomberomorous cavalla* and *S. maculatus* (0.82 and 1.31 mm d^{-1}, and up to 13 and 22 mm, respectively – DeVries et al. 1990). The slower growth found for yellowfin (and southern bluefin) tuna larvae is probably a reflection of their absolute growth rate which increases with size during larval and juvenile periods.

Analysis of the relationship between growth and salinity indicated that highest growth rates occurred at intermediate salinities (i.e., in frontal waters). Highest chlorophyll *a* values and macrozooplankton displacement volumes also occurred at intermediate salinities. Yellowfin tuna larvae may utilize this potential food resource to achieve higher growth even though Powell et al. (1990) were unable to document that spot larvae, *Leiostomus xanthurus,* associated with the Mississippi River plume fronts had a consistent nutritional advantage in growth (probably due to the dynamic nature of the front).

Detection of a significant relationship between sea surface temperature and growth suggested an optimum temperature for tuna larvae growth at approximately 29.0–29.5° C. This temperature range is within that producing the best hatching results for Harada et al. (1980), i.e., 26.4 to 30.1° C.

The overall mortality rate obtained here for yellowfin tuna larvae ($Z = 0.33\ d^{-1}$) is lower than those reported for southern bluefin tuna larvae ($Z = 0.66\ d^{-1}$; Jenkins et al. 1991). Some difference in results would be expected due to the use of different methodology (i.e., cohort specific sampling) in their study. Also, density dependent growth (which leads to prolonged stage duration and increased susceptibility to mortality) was indicated for the southern bluefin tuna larvae due to competition for food (Jenkins et al. 1991). The potential for food resources associated with the Mississippi River plume front, however, may be limiting density dependent mortality by supporting higher densities of larvae as proposed by Powell et al. (1990).

The difference in mortality rates between the July and September collections may be a result of distributional differences. All of the larvae in July were collected within meters of visible convergence fronts whereas the September collections were taken from a large scale distribution of stations. If the effect of the Mississippi River plume is to enhance the survival of tuna larvae, as indicated by this study, that effect may be more pronounced nearer the plume front.

[7] Waltz, W. 1985. Evaluation of a technique for estimating age of young-of-the-year king (*Scomberomorous cavalla*) and Spanish mackerel (*Scomberomorous maculatus*). S.C. Wildl. Mar. Res. Dep. MARMAP Rep. for contract number 6-35147.

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