

Abstract—Patterns of distribution and growth were examined for young-of-the-year (YOY) greater amberjack (*Seriola dumerili*) associated with pelagic *Sargassum* in the NW Gulf of Mexico. *Seriola dumerili* were collected off Galveston, Texas, from May to July over a two-year period (2000 and 2001) in both inshore (<15 nautical miles [nmi]) and offshore zones (15–70 nmi). Relative abundance of YOY *S. dumerili* (32–210 mm standard length) from purse-seine collections peaked in May and June, and abundance was highest in the offshore zone. Ages of *S. dumerili* ranged from 39 to 150 days and hatching-date analysis indicated that the majority of spawning events occurred from February to April. Average daily growth rates of YOY *S. dumerili* for 2000 and 2001 were 1.65 mm/d and 2.00 mm/d, respectively. Intra-annual differences in growth were observed; the late-season (April) cohort experienced the fastest growth in both years. In addition, growth was significantly higher for *S. dumerili* collected from the offshore zone. Mortality was approximated by using catch-curve analysis, and the predicted instantaneous mortality rate (Z) of YOY *S. dumerili* was 0.0045 (0.45%/d).

Distribution, age, and growth of young-of-the-year greater amberjack (*Seriola dumerili*) associated with pelagic *Sargassum*

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Recruitment of marine fishes is highly variable and closely linked to early life events (Houde, 1996; Cole, 1999). Early life survival is dependent upon several biological and environmental factors including spawning time, prey availability, predation pressure, growth, and physical transport mechanisms (Bricelj, 1993; Schnack et al., 1998). Recruitment success is commonly assessed by examining patterns of relative abundance (Sano, 1997), whereas estimates of growth and mortality are commonly used to index recruitment potential (Rilling and Houde, 1999; Rooker et al., 1999). Early life growth and mortality are linked because fishes with high growth rates often exhibit decreased size-specific predator vulnerability (Meekan and Fortier, 1996). As a result, estimates of juvenile abundance, growth, and mortality provide insight into patterns of nursery habitat quality and thus may be used to delineate essential fish habitat (EFH) (Pihl et al., 2000; Sullivan et al., 2000).

Greater amberjack (*Seriola dumerili*) is a reef-associated species with a circumglobal distribution in subtropical and temperate waters (Manooch and Potts, 1997a). In the Gulf of Mexico, *S. dumerili* is the largest carangid and supports important recreational and commercial fisheries (Thompson et al., 1999). Owing to increased fishing effort and landings, *S. dumerili* in the Gulf are currently assessed as overfished (NOAA,

2000). Consequently, detailed life history information is needed to effectively guide fishery management of this valuable resource. To date, available life history data on *S. dumerili* have almost entirely been based on assessments of subadults and adults (Manooch and Potts, 1997a, 1997b; Thompson et al.¹). Despite the importance of early life processes, data on juvenile or young-of-the-year (YOY) *S. dumerili* are limited to qualitative surveys of pelagic *Sargassum* (Bortone et al., 1977; Settle, 1993).

The National Marine Fisheries Service has recently designated *Sargassum* as essential fish habitat (EFH) of several coastal migratory species including *S. dumerili* (NOAA, 1996). In response, the goal of this study was to examine the distribution and growth of *S. dumerili* associated with pelagic *Sargassum* mats in the NW Gulf of Mexico. Specifically, objectives of this research were to quantify spatial and temporal patterns of habitat use by *S. dumerili* and to determine age, hatching-date, growth, and mortality of *S. dumerili* by using otolith-based techniques.

¹ Thompson, B. A., C. A. Wilson, J. H. Render, M. Beasley, and C. Cauthron. 1992. Age, growth, and reproductive biology of greater amberjack and cobia from Louisiana waters. Final report NA90AA-H-MF722, 77 p. Marine Fisheries Initiative (MARFIN) program, National Marine Fisheries Service, NOAA, St. Petersburg, FL.

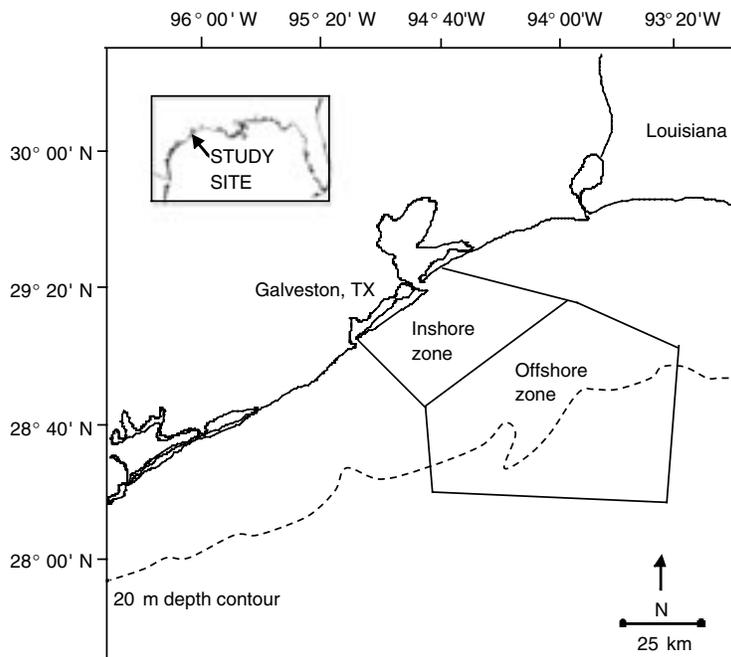


Figure 1

Map of sampling locations along the Texas Gulf coast for *S. dumerili*. Inshore (<15 nautical miles) and offshore (>15 nautical miles) zones off Galveston, TX, are shown.

Materials and methods

Field collections

Seriola dumerili associated with pelagic *Sargassum* mats were collected off Galveston, Texas, from May to July over a two-year period (2000 and 2001) (Fig. 1). Inshore (<15 nautical miles [nmi]) and offshore (15–70 nmi) zones were sampled to evaluate the potential importance of physiochemical conditions because inshore waters off the coast of Texas are heavily influenced by estuarine processes (Smith, 1980; Sahl et al., 1993). Replicate samples (3–5 per trip) in both the inshore and offshore zones were collected monthly by using a larval purse seine (20 m long × 3.3 m deep, 1000- μ m mesh). The purse seine was deployed into the water as the boat encircled a randomly chosen mat. The seine was pursed, the *Sargassum* was discarded, and fishes were funneled into the codend, collected, and frozen on dry ice. Distribution and abundance were expressed as relative abundance, and catch per unit of effort (CPUE) represented the number of fishes per purse-seine collection. In addition, a small number of YOY *S. dumerili* were collected with hook-and-line for age and growth information only. Standard lengths (SL) were measured to the nearest 0.1 mm, and weights to the nearest 0.1 g before otolith extraction. GPS locations and mat volume (length × width × depth) were recorded at each sample location. Environmental parameters measured included sea surface temperature, salinity, and dissolved oxygen. Daily sea surface tem-

perature data were also taken from NOAA buoy 42035, 22 nmi offshore of Galveston, TX.

Otolith procedures

Sagittal otoliths were extracted from *S. dumerili*. Otoliths were measured to the nearest 0.001 mm and weighed to the nearest 0.0001 g. Left or right sagittae were randomly selected and mounted in epoxy resin (Spurr, 1969). Once mounted, a Buehler isomet low-speed saw equipped with a diamond wafering blade was used to transversely cut embedded otoliths. Otolith sections were then attached to petrographic slides with Crystalbond thermoplastic cement. Type A alumina powder (0.3 μ m) and 400- and 600-grit sandpaper were used to grind both sides of the otolith, and a polishing cloth was used for final preparations.

Age was determined by counting growth increments along the sulcus from the core to the outer margin by using a Nikon Labophot-2 light microscope and Optimas 6.2 image analysis software (Media Cybernetics, Silver Spring, MD). Because of the difficulty of enumerating some inner increments near the otolith core, a relationship between age and otolith radius of several clear specimens was used to predict the number of increments within the unclear region. Age was determined by adding the correction factor to the increment count from the first identifiable increment to the otolith margin (Rooker and Holt, 1997). Correction factors consisting of more than five days were applied to 49%

of the fishes and the average correction accounted for 9.5% of the actual age estimate. Otolith readings with correction factors accounting for more than 20% of the predicted age were not used for estimates of growth. The following correction factor was used

$$\text{Age (d)} = 2.88 \times \text{otolith radius } (\mu\text{m}) - 0.096$$

($r^2=0.88$, $n=20$).

Additionally, all otolith counts were repeated twice to ensure adequate precision. Differences in readings of more than 20% were not incorporated into growth estimates.

Daily deposition of growth increments on sagittal otoliths was validated by using wild *S. dumerili* ($n=14$, 136–193 mm SL). Fishes caught in the wild were brought into the laboratory and placed in a circular holding tank (1.71 m diameter \times 0.75 m depth) for 48 hours. Fishes were then placed in a separate tank containing 80 liters of seawater with 100 mg/L of alizarin complexone for two hours (Thomas et al., 1995) and returned to the circular holding tank. Individuals were fed approximately 10% of their body weight daily. Fishes marked with alizarin were removed from the tank after 5 ($n=5$), 10 ($n=5$), and 15 ($n=4$) days. The number of otolith increments between the alizarin mark and outer edge were then counted for daily increment verification. Otolith slides were coded so that all readings were blind.

Hatching dates were determined for all individuals by subtracting daily age from date of capture. An age-specific mortality adjustment was made for individuals because larger *S. dumerili* have spent more time in the early life stages and hence individuals from these cohorts have experienced greater cumulative mortality. Because of the limited number of individuals in 2001, the mortality correction was calculated only for year 2000 collections and applied to hatching-date distributions in 2000 and 2001. Age-specific mortality adjustments were made according to the method described by Rooker and Holt (1997).

Growth and mortality of *S. dumerili* were estimated by using otolith-derived ages. Daily growth rates were estimated by using the linear growth equation

$$SL = \text{slope (age)} + y\text{-intercept}$$

and were reported as mm/d. Length-at-age data were also fitted with curvilinear growth models (von Bertalanffy, Laird-Gompertz). Percent variation in length explained by age for both curvilinear models was slightly better at times than the percent variation in length explained by age for the linear model; however, certain model parameters (i.e. L_∞) were biologically unrealistic and thus the linear model was deemed more appropriate. Moreover, when possible, L_∞ values were used to model length-at-age data and the nonlinear models were essentially linear over the limited size range examined. Mortality estimates for year 2000 *S. dumerili* were determined by using a regression on the decline in \log_e -

transformed abundance on age. A regression coefficient (slope) was used to predict the instantaneous mortality rate:

$$\ln N_t = \ln N_0 - Zt,$$

where N_t = abundance at age t (expressed in days);
 N_0 = an estimate of abundance at hatching;
 and
 Z (slope) = the instantaneous mortality coefficient.

Mortality estimates were based upon 10-day cohort groupings. Individuals <40 days old were not included in the mortality regression because of an ascending catch curve and because there were too few individuals >139 days old in our sample—probably owing to gear avoidance or emigration (or both). Therefore, only *S. dumerili* between 40 and 139 days (45–192 mm) were used to estimate mortality.

Data analysis

Effects of location and date on CPUE and size estimates were examined by using a two-way analysis of variance (ANOVA). Levene's test and residual examination established if the homogeneity of variance assumption was met. Normality was evaluated by plotting residuals versus expected values. Abundance data were $\log(x+1)$ transformed when necessary to normalize data and reduce heteroscedasticity. Tukey's honestly significant difference (HSD) test was used to determine *a posteriori* differences among means. Comparisons of spatial and temporal variation in growth were performed by using analysis of covariance (ANCOVA). Prior to ANCOVA testing, the homogeneity of slopes assumption was examined using an interaction regression (Ott, 1993). If no significant interaction was detected, ANCOVA models were used to test for differences in length-at-age (y -intercepts) (Ott, 1993). Statistical analysis was carried out by using SYSTAT 8.0 (SYSTAT Software Inc., Richmond, CA), and significance was set at the alpha level of 0.05.

Results

Environmental conditions

Average temperatures from May to July ranged from 27.9 to 30.1°C in 2000 and from 24.5 to 30.4°C in 2001 (Fig. 2). Mean temperatures over the sampling period were 29.2°C and 27.9°C for 2000 and 2001, respectively. Zonal differences occurred: the inshore zone averaged 28.7°C (± 0.3) in 2000 and 28.1°C (± 0.9) in 2001, and the offshore zone averaged 29.8°C (± 0.3) in 2000 and 27.6°C (± 0.9) in 2001. Similar to temperature trends, mean salinity was higher in 2000 (34.6‰) than in 2001 (31.9‰) (Fig. 2). Average salinity values gradually increased from an average of 31.5‰ in May to 37.2‰ in July of 2000. A large drop in salinity occurred during

mid-summer of 2001, from 37.6‰ in May to 25.7‰ in June (owing to tropical storm Allison) and rose to 32.3‰ in July. Salinity values were lower and more variable within the inshore zone, ranging from 29‰ to 37‰ (33.4‰ average) in 2000 and from 15‰ to 37‰ (average 28.8‰) in 2001. In contrast, the offshore zone exhibited higher and more stable salinity values, ranging between 33‰ and 38‰ (36‰ average) in 2000, and between 28‰ and 36‰ (34.9‰ average) in 2001. Temperature and salinity values are likely to be influenced by variation in precipitation between years. Precipitation from January through July of 2000 (14.29 inches) was half that of 2001 (29.92 inches) and well below the 30-year average of 22.17 inches (National Weather Service, Dickinson, TX). Dissolved oxygen content was similar between years; values decreased throughout the summer months and were higher within the inshore zone.

Spatial and temporal distribution

A total of 181 YOY *S. dumerili* was collected from 42 purse seines over the two-year study period. CPUE values were fourfold higher in 2000 than in 2001, averaging 6.38 (± 3.0) and 1.50 (± 0.8) per seine, respectively (Fig. 3A). A significant year effect indicated that relative abundance was higher in 2000 ($P=0.019$). Additionally, CPUE values were higher in the offshore zone in both years (Fig. 3, B and C). However, no significant zonal difference existed in abundance between the inshore and offshore zones in 2000 ($P=0.063$) or 2001 ($P=0.058$). Temporal patterns indicated *S. dumerili* was highly abundant in May and June, declining in July in both years (Fig. 3A). A significant seasonal effect occurred for 2000 when highest relative abundance occurred in June with a CPUE of 16.2 (± 0.8) (Tukey HSD, $P<0.05$).

Size comparison

Sizes of *S. dumerili* ranged from 33 to 210 mm SL (mean 125 mm SL ± 3.8). Juveniles greater than 100 mm accounted for 68% of the total catch, whereas individuals less than 50 mm accounted for only 15%. Size differences of *S. dumerili* were observed between 2000 (average 125.5 mm) and 2001 (average 141.5 mm); significantly larger *S. dumerili* were collected from the offshore zone in 2001 ($P=0.001$). A significant interaction (year \times month) occurred that indicated that the magnitude of size differences was variable over time. Sizes were also significantly different between zones in 2000; larger individuals were collected within the offshore zone ($P=0.025$). No zonal comparison was performed for 2001 because few individuals were collected from the inshore zone. In addition, a trend existed within both years: mean sizes significantly increased from May to June, then decreased in July (Tukey HSD, $P<0.05$).

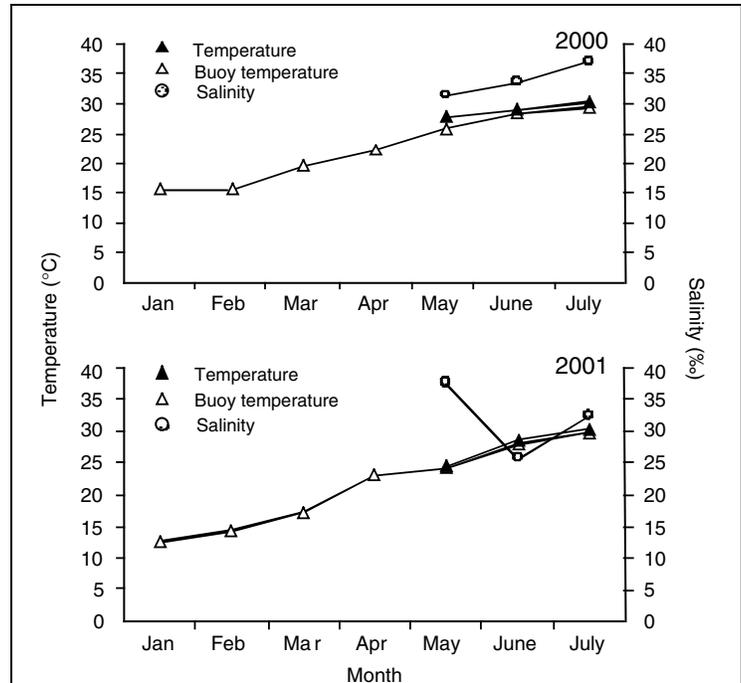


Figure 2

Environmental conditions from January to July of 2000 and 2001. Average temperature ($^{\circ}\text{C}$) and salinity (‰) values. Open triangles represent temperature data from NOAA buoy 42035, located 22 nautical miles offshore of Galveston, TX.

Hatching-date distribution

Hatching-date distributions for *S. dumerili* were protracted in both 2000 and 2001. Fishes collected in 2000 exhibited hatching-dates from 29 January to 25 May (117 days), whereas those collected in 2001 hatched from 11 January to 30 May (139 days) (Fig. 4). In 2000, over 80% of the fishes appeared to result from spawning events in March and early April. The adjusted distributions from the age-specific mortality correction for both 2000 and 2001 were indistinguishable from those without the correction.

Age and growth

Results of the age-validation exercise indicated that juvenile *S. dumerili* deposit otolith increments on a daily basis (Fig. 5). Average increment counts at day 5, 10, and 15 were 4.8 (± 0.2 SD), 9.2 (± 0.4), and 14.0 (± 0.7), respectively. A relationship between the observed versus expected increments was described by the following equation:

$$\text{Observed increments} = 0.92 (\text{expected increments}) + 0.14$$

$$(r^2 = 0.95)$$

where days after staining represent expected increment count.

Validation of daily growth increments has been observed in a similar study involving juvenile (0–60 days) *Seriola quinqueradiata* (Sakakura and Tsukamoto, 1997).

Age of *S. dumerili* was similar between years; estimated ages ranged from 41 to 150 days (35 to 210 mm SL) in 2000 and from 35 to 120 days (33 to 198 mm SL) in 2001 (Fig. 6). Interannual differences in growth were observed: 2000 (1.65 mm/d), 2001 (2.00 mm/d) (ANCOVA, slope, $P < 0.001$) (Fig. 7). A significant cohort effect was also observed; the late-season (April) cohort experienced the fastest growth (ANCOVA, slopes, $P < 0.001$) (Fig. 8). Average cohort-specific growth rates of *S. dumerili* spawned in February, March, and April of 2000 were 0.85 mm/d, 1.15 mm/d, and 2.76 mm/d, respectively. In addition, a significant difference in growth was observed for *S. dumerili* collected from inshore (1.55 mm/d) and offshore (1.65 mm/d) zones of 2000 (ANCOVA, slope, $P < 0.001$) (Fig. 9). Again, the lack of individuals within the inshore zone in 2001 precluded a comparison between zones for that year.

Mortality

Owing to the limited number of *S. dumerili* collected in 2001, a single catch curve was developed for the 2000 year class, and the mortality coefficient (Z) was 0.0045 (0.45%/d) for individuals between 40 and 139 days (Fig. 10). Cumulative mortality was estimated for the 100-day period (40–139 days), resulting in an overall mortality of 36%.

Discussion

The size range of *S. dumerili* collected in association with *Sargassum* ranged from approximately 30 to 210 mm (SL), and these sizes are similar to those reported in other studies investigating fish assemblages associated with pelagic *Sargassum*. Bortone et al. (1977) collected several small *S. dumerili* (12–72 mm SL) in the eastern Gulf, whereas individuals collected in the western Atlantic by Dooley (1972) ranged from 13 to 108 mm (SL). Cho et al. (2001) found juvenile *S. dumerili* (35–120 mm TL) associated with drifting *Sargassum* in the western Pacific. Additionally, Sakakura and Tsukamoto (1997) collected over 200 juvenile Japanese amberjack (*S. quinqueradiata*) (18–114 mm TL) associated with pelagic *Sargassum* in the East China Sea. Results of the present study and others indicate that pelagic *Sargassum* mats in the NW Gulf of Mexico serve as nursery habitat for *S. dumerili*.

The limited size range of *S. dumerili* associated with pelagic *Sargassum* indicates that a shift in habitat use may occur at approximately 5–6 months of age. Individuals greater than 210 mm (SL) have not been found in association with pelagic *Sargassum*, and larger *S. dumerili* (ca. 300 mm TL) are relatively common in the recreational headboat fishery in the Gulf of Mexico (Ma-

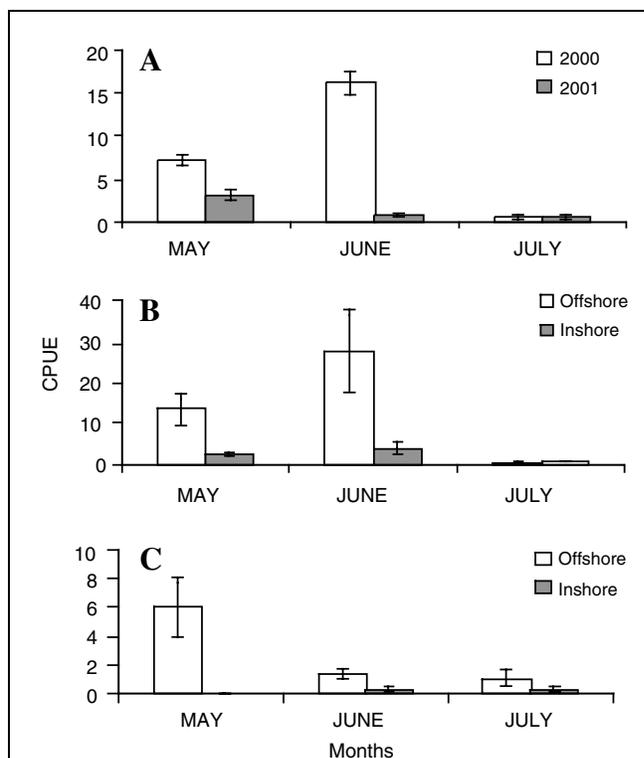


Figure 3

Relative abundance (number per purse seine) (± 1 SE) of *S. dumerili* collected in association with *Sargassum* mats: (A) 2000 and 2001; (B) 2000 by zones; (C) 2001 by zones.

nooch and Potts, 1997a). As a consequence, *S. dumerili* may transition from a pelagic to a demersal existence at the late juvenile stage (between 200 mm SL and 300 mm TL). Pipitone and Andaloro (1995) found a shift in the diet of *S. dumerili*, from a diet predominately consisting of crustaceans toward one of fish >200 mm (SL), further supporting this hypothesis.

Seriola dumerili abundance was greater in the offshore zone than the inshore zone throughout the sampling period. These patterns of habitat use are consistent with earlier information that indicates *S. dumerili* is an offshore species (Hildebrand and Cable, 1930). The proximity to spawning grounds may contribute to the observed spatial patterns because *S. dumerili* are known to spawn in offshore areas (Fahay, 1975). Physiological preferences may also contribute to the dominance of *S. dumerili* in the offshore zone. In our study, salinity values were higher in the offshore zone but more variable within the inshore zone, suggesting that freshwater inflow influences conditions within the inshore zone. Chen et al. (1997) determined that optimum salinity conditions for *S. dumerili* larvae were between 32‰ and 35‰, and larvae remained inactive below a salinity of 30‰. Zonal differences in temperature and dissolved oxygen were also observed. Tzeng et al. (1997)

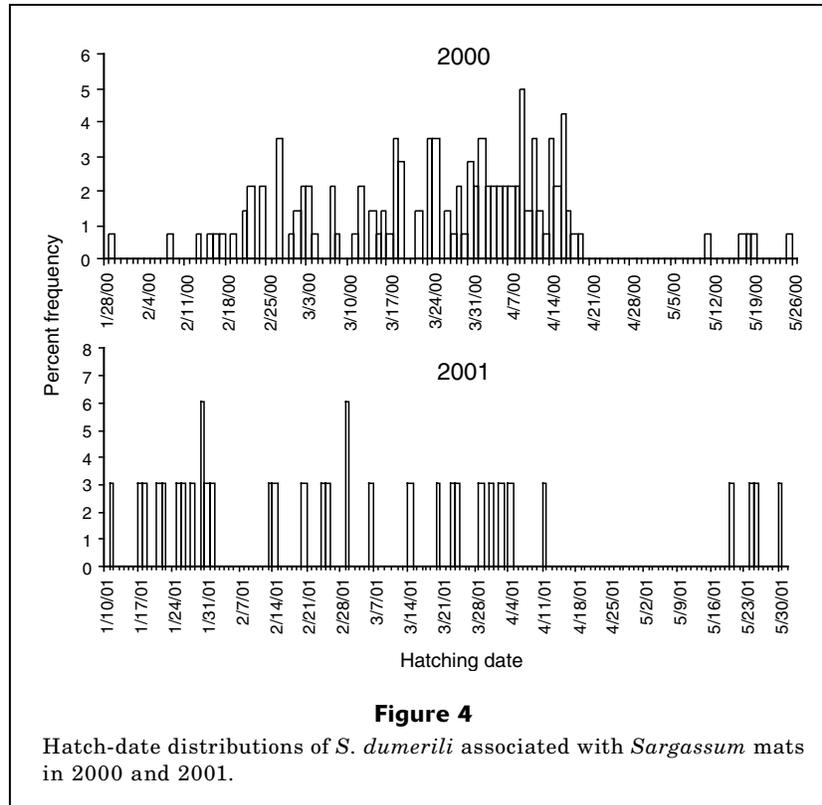


Figure 4
Hatch-date distributions of *S. dumerili* associated with *Sargassum* mats in 2000 and 2001.

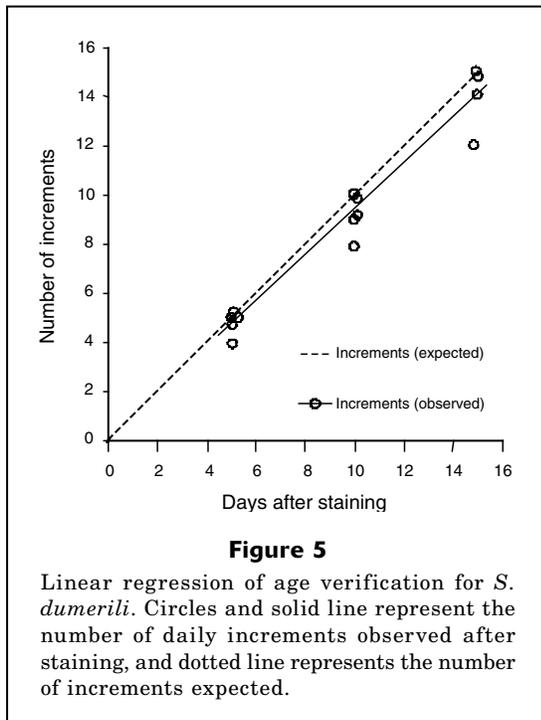


Figure 5
Linear regression of age verification for *S. dumerili*. Circles and solid line represent the number of daily increments observed after staining, and dotted line represents the number of increments expected.

attributed the distribution of fishes from nearshore to offshore stations to environmental factors, season, and life history strategies. Furthermore, the combination of

available resources (i.e. food and habitat), seasons, and physiochemical tolerances may account for the observed spatial patterns of habitat use.

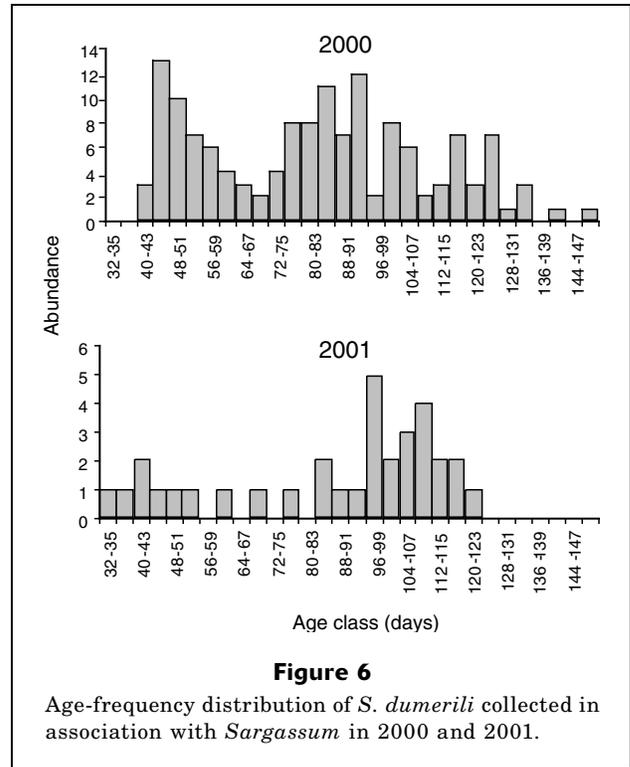
Temporal patterns of size-specific habitat use showed similar trends between years and appeared to be related to spawning season. Relative abundance of small *S. dumerili* was highest early in the season (May), declined in June, and further increased late into the season (July) for both 2000 and 2001. Nevertheless, small juveniles were collected during the entire collection period, which suggests that *S. dumerili* spawning in the NW Gulf is protracted. Previous studies have found that *S. dumerili* spawn throughout the spring and summer months (March–July) (Marino et al., 1995; Cummings and McClellan, 1996). In addition, Fahay (1975) suggested, on the basis of larval collections in the western Atlantic, that spawning occurs in the winter. Despite the limited duration of our collection efforts, our results are consistent with these findings with 63% of year-2000 *S. dumerili* and 36% of year-2001 fish resulting from spring spawning events. The remaining individuals were spawned January through early March.

Growth estimates indicated that *S. dumerili* have rapid growth throughout early life stages. Based on linear growth models, average growth of *S. dumerili* was 1.45 mm/d—an estimate similar to that of Manooch and Potts's (1997b) study in the Gulf (average growth of 1.17 mm/d for age-1 individuals). However, growth comparisons may be invalid because their study estimated growth based on counts of annuli and no temperature

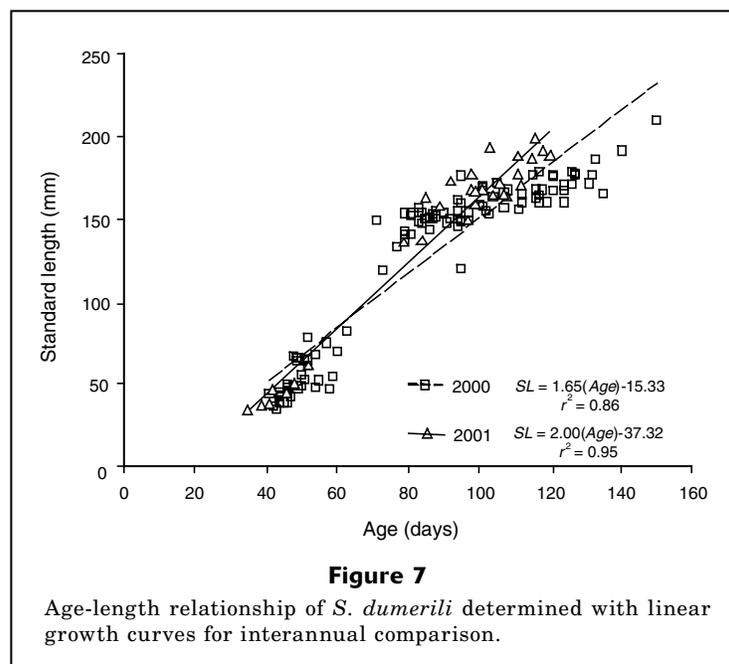
data were presented. Because of the lack of studies investigating growth of YOY *S. dumerili*, we compared our estimates to those in Sakakura and Tsukamoto's (1997) study of YOY *S. quinqueradiata* where growth rates were estimated at 1.3 mm/d. Average temperature in their study was 21.2°C, which was considerably lower than the average during our study (28.6°C) and may account for their slower growth rates.

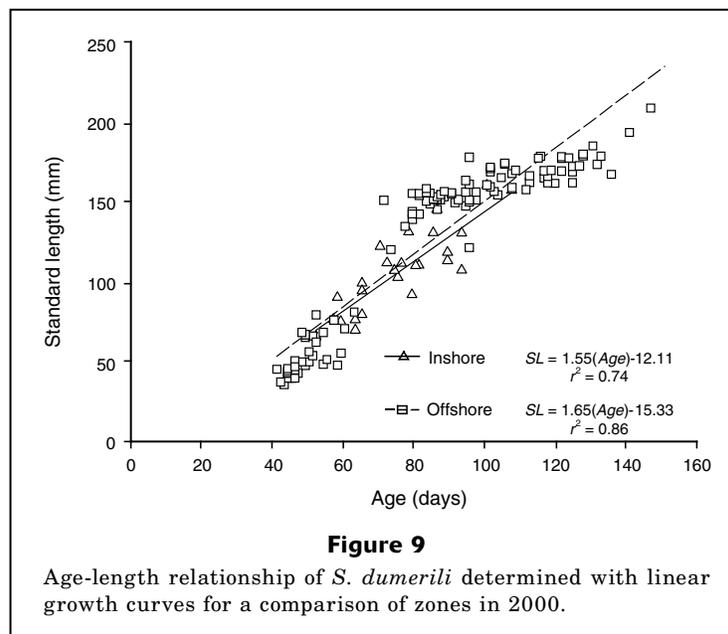
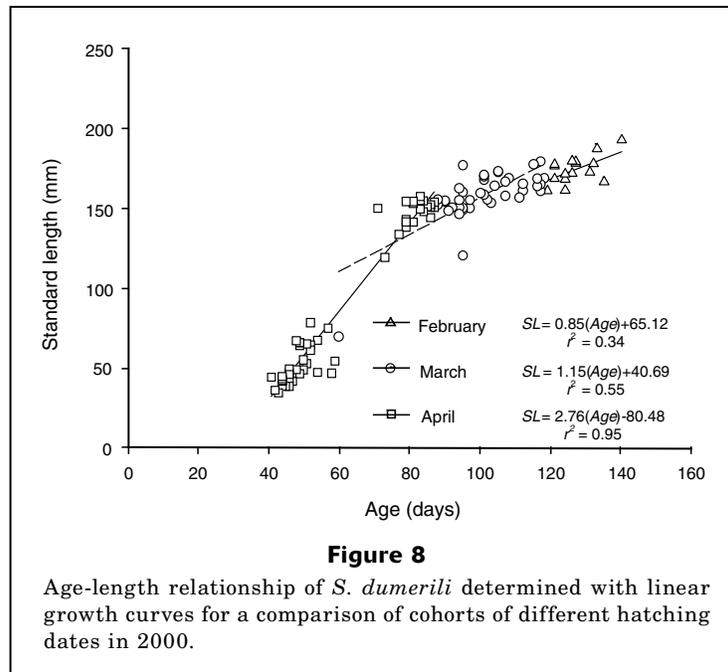
Variation in growth of *S. dumerili* was observed and rates were significantly higher in the offshore zone and greater for the late season cohort. Differences in water temperature may be partly responsible for observed differences in growth. Planes et al. (1999) suggested that spatial differences in growth of juvenile sparid fishes were a result of water temperature and currents. The proximity between zones in this study may have masked differences in hydrography; however, temperatures were higher in the offshore zone (29.8°C, CV=0.03) than in the inshore zone (28.7°C, CV=0.04), and warmer temperatures were likely contributing to faster growth rates in offshore waters. Intra-annual (cohort-specific) growth patterns indicated that the late-season cohort had the fastest growth. Similar to trends between zones, temperature was lowest for the slowest growing cohort (early season) and highest for the fastest growing cohort (late season). Although temperature may affect early life growth of *S. dumerili*, differences in growth may be attributed to other factors such as prey availability and predator activity (Houde, 1987; Paperno et al., 2000; Plaganyi et al., 2000). Moreover, a clear distinction exists in the size classes of YOY *S. dumerili* in comparisons of growth rates and these differences likely contribute to the observed results.

The mortality rate of YOY *S. dumerili* associated with pelagic *Sargassum* was estimated at 0.45 %/d for fishes



collected in 2000. These findings are well below similar studies investigating mortality of YOY individuals. Nelson (1998) calculated a mortality estimate of 2.1–2.3%/d for pinfish in three different bay areas in the eastern Gulf of Mexico. In addition, Deegan (1990) estimated YOY menhaden mortality between 1.7 and 2.1%/d in the northern

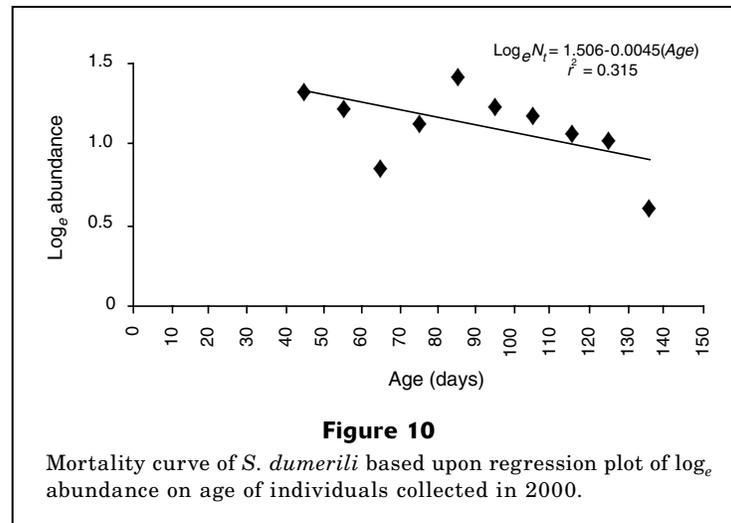




Gulf. These studies included estuarine-dependent species and consisted of smaller individuals. Because our estimates were limited to age 40–139 d individuals, the lack of smaller fishes precluded any mortality estimates of younger *S. dumerili*. These estimates provide baseline information on mortality of YOY *S. dumerili*; however, more detailed studies will be needed to adequately determine mortality rates of YOY *S. dumerili*.

Based on the observed patterns of distribution and growth in the NW Gulf of Mexico, early life survival of

S. dumerili may depend on pelagic *Sargassum*. Results of this study suggest that *S. dumerili* are associated with this habitat over a limited size range and exhibit rapid growth during the first six months. Additionally, *S. dumerili* were more abundant and exhibited higher growth in offshore areas where potential spawning may occur. Thus, *Sargassum* appears to provide nursery habitat for YOY *S. dumerili*, and may influence the recruitment potential of this valuable fishery species.



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