Abstract. - Age, growth, and mortality of larval Atlantic bumper Chloroscombrus chrysurus were compared between cruise samples collected during August–September 1986 and September 1987 off the Louisiana–Mississippi barrier islands. Calcein-marked Atlantic bumper otoliths (sagitta) were used for age validation. The first growth increment formed on the sagitta approximately 2 days after spawning, and daily increments formed thereafter. Length at hatching was estimated at 0.7–0.9 mm SL. Growth rates were determined from sagitta and length-frequency data. Highest growth rates occurred in August 1986 (0.40 mm/day) and were associated with highest mean temperature and zooplankton standing stock estimates. The length exponent for Atlantic bumpers' dry weight-length relationship was 3.25. Instantaneous daily mortalities (M) ranged from 0.62 in August 1986 to 0.17 in late September 1987.

Age validation, growth, and mortality of larval Atlantic bumper (Carangidae: Chloroscombrus chrysurus) in the northern Gulf of Mexico

Deborah L. Leffler
Florida Marine Research Institute, Florida Department of Natural Resources
3 Jackson Street, Fort Walton Beach, Florida 32548

Richard F. Shaw
Coastal Fisheries Institute, Center for Wetland Resources
Louisiana State University, Baton Rouge, Louisiana 70803-7503

Atlantic bumper Chloroscombrus chrysurus, a carangid, is an abundant coastal pelagic fish that is widely distributed in the western Atlantic and Gulf of Mexico (Leak 1977). Exploratory fishing surveys indicate that Atlantic bumper may be abundant enough in the northern Gulf of Mexico to harvest commercially (Juhl 1966, Bullis and Carpenter 1968, Bullis and Thompson 1970, Klima 1971). Presently, Atlantic bumper is mainly a commercial bycatch, marketed primarily for petfood, with little potential as a food fish in the United States (Klima 1971, Leak 1977). It, however, may be an important food source for many predatory fish (Reintjes 1979).

Atlantic bumper spawn primarily in nearshore coastal waters, especially off Louisiana and Mississippi (Boschung 1957, Perret et al. 1971, Christmas and Waller 1973, Ditty 1986, Shaw and Drullinger 1990), and the larvae of this species were most abundant during surveys off the Louisiana–Mississippi (LA–MS) barrier islands (Stuck and Perry 1982, Leffler 1989). Larvae have been collected from June to October, with abundance peaks usually occurring in July or August (Sabins 1973, Stuck and Perry 1982, Williams 1983, Ditty 1986).

Very little early-life-history work has been conducted on Atlantic bumper (Shaw and Drullinger 1990). Early-life-history information is a critical component in estimating future year-class strength (Cushing 1975, Leak and Houde 1987). For example, slow larval growth rates influence mortality by extending the duration of vulnerable larval stages (Bannister et al. 1974, Houde 1987), while a fast growth rate can possibly increase interaction with predators (Pepin 1991), thereby influencing recruitment. Early-life-history data are needed for Atlantic bumper to determine their ecological role and to assist in the prudent development of any directed fishery.

The abundance of Atlantic bumper over a wide geographic range, their perceived potential as a commercial resource, and their probable ecological importance as a forage fish, provided the impetus for conducting this larval age-and-growth study. The goals of this ichthyoplankton study were to (1) validate the periodicity of growth increments on larval and juvenile Atlantic bumper otoliths, (2) estimate Atlantic bumper length at hatching, (3) estimate the age structure of the sample population, (4) describe larval growth and mortality rates, and (5) relate larval growth
and mortality rates to environmental parameters and food availability.

**Materials and methods**

**Sampling procedure**

Atlantic bumper larvae were collected during five cruises off the Louisiana–Mississippi barrier islands in the Gulf of Mexico (Chandeleur Is., Ship I., and Horn I.; 29°50′–30°15′N and 88°40′–89°00′W; Fig. 1). Three cruises were completed in 1986 (5–7 Aug., 8–9 Sept., and 22–24 Sept.) and two in 1987 (8–10 and 24–26 Sept.). Adverse weather conditions canceled the scheduled August 1987 cruise.

The sampling design consisted of a 4 × 4 grid of stations (N 16) randomly sampled on two consecutive nights, and a 3 × 3 grid of stations (N 9) randomly sampled during daylight, starting 12 hours after the initiation of the first nocturnal sampling. The sampling grid had a fixed compass orientation with respect to three windowshade, subsurface current drogues (five drogues were used in 1987) which were released at the beginning of each cruise (Shaw et al. 1988). The change to five drogues in 1987 allowed for a more defined sampling grid. Surface-water temperature and salinity, as well as water depth, were recorded for each ichthyoplankton tow.

Three-minute surface tows were taken at ~1.0 m/s using a 60 cm “bongo-type” plankton sampler fitted with a flowmeter (General Oceanics model 2030). In 1986, samples were collected using a 202 μm mesh net, while in 1987 a 333 μm mesh net was used. During the two cruises in September 1987, the bongo sampler was fitted with one 202 μm mesh net and one 333 μm mesh net for comparisons of daytime collections. Atlantic bumper collected using the two mesh sizes were placed into 1 mm size-classes and tested for differences using a Median test (α 0.05; SAS Inst. 1985). Ichthyoplankton samples used for age determination were preserved with 95% ethanol, stored in ice water, and later transferred to 70% ethanol in the lab.

Live larval and juvenile Atlantic bumper were collected for an age-validation experiment and length-weight measurement analysis by dipnetting the jelly-fish *Aurelia aurita* with which the fish are often associated (Reid 1954, Franks 1970). Fish were then transferred to a cooler containing 100 ppm calcein (2,4-bis-[N,N’-di(carbomethyl)aminomethyl]fluorescein) in 13 L of aerated ambient seawater to create a fluorescent mark in their otoliths using the method described by Wilson et al. (1987). Fish were held between 6 and 12 h in the seawater-calcein solution and then transferred into a 127 L aquarium. Fish were held under a 12 h photoperiod in 23°C and 25 ppt water and fed *ad libidium* on brine shrimp. Fish were sacrificed 2, 7, and 10 days after marking.

**Lab analysis**

Ichthyoplankton samples from the bongo net collections were split once with a Folsom plankton splitter (Van Guelpin et al. 1982). *Chloroscombrus chrysurus* larvae were sorted, counted, and measured to the nearest 0.1 mm standard length (SL). Preflexion larvae were measured to the end of their notochord, otherwise larvae were measured to the posterior tip of the hypural plate. When more than 52 fish were present,
a random subsample of 50 fish were measured, as well as the shortest and longest. Ethanol-related shrinkage was assumed to be uniform for each fish collected and preserved (3-min tow, alcohol preservation; see Radtke 1989).

Validation, age, and growth

Sagittal otoliths were removed from each Atlantic bumper larva using a dissection microscope equipped with polarized light. The sagitta from nine postlarval and juvenile Atlantic bumper (8.3–25.0 mm SL) that were immersed in the calcein-seawater solution were prepared and viewed using the method described by Wilson et al. (1987). Growth increments, following the fluorescent mark, were counted at 400 x and verified at 1000 x. The number of growth increments counted from the calcein mark to the otolith edge were compared with the number of days fish were held in captivity after marking.

Age estimation of larval Atlantic bumper was performed using sagitta that were air-dried and mounted in S/P Accu-mount 60 on a glass microscope slide. Most larval otoliths were thin enough that only viewing under a compound microscope was necessary to make total increment counts and otolith radius measurements. A few larger otoliths were ground with 600 WetorDry grit sandpaper and polished using 0.3μm Alumina 2 Alpha Micropolish until growth rings were countable. The counting and measurement procedure was enhanced by using a digital imaging system which produced images on a video monitor at 400 x or 1000 x. Independent increment counts were made twice by the same person without knowledge of fish length or previous otolith count. Only otoliths for which replicate counts were identical were used in the analysis. Eleven of the 170 otoliths prepared were discarded.

Separate linear growth equations of standard length on increment number were developed for fishes collected on the five cruises. These five equations were compared using analysis of covariance (ANCOVA, a = 0.05; SAS Inst. 1985). Exponential and other non-linear models (e.g., Laird-Gompertz) used to describe larval growth were also tested (Campana and Neilson 1985). A General Linear Model ANOVA, followed by a multiple comparisons test (Duncan, a = 0.05; SAS Inst. 1985), were used to detect differences in surface-water temperature between years, months, and cruises.

Dry weight-length relationship

Larval and juvenile Atlantic bumper (N 120, 8.0–32.0 mm SL) collected by dipnetting for jellyfish, were measured to the nearest 0.1 mm SL, oven dried for 6 h at 62°C, and then weighed to the nearest 1.0 mg. A log-log dry weight-length relationship was established and described by the equation \( W = aL^b \), where \( W = \log_{10}\) dry weight (mg), and \( L = \log_{10}\) standard length (mm). A 95% confidence interval placed around the estimated slope \( b \) was used to test for differences in the estimated length power term \( b \) and the classical \( b \) estimate of 3.0 for adult fish (LeCren 1951) and 4.0 for larval fish (Power 1989).

Mortality

Atlantic bumper densities for each 1 mm SL category were converted into mortality estimates following the length-frequency method described by Essig and Cole (1986). Sampling with respect to the windowshade drogues allowed us to monitor larval densities from the same mass of water for an entire collecting period. Only nighttime collected larvae >2.0 mm or <5.0 mm were utilized in our mortality estimates to minimize biases from net avoidance by larger larvae or extrusion through the mesh openings by the smallest larvae. The descending limb of each age-frequency distribution corresponding to a length range of 2.0–5.0 mm SL was described by the equation \( D_t = D_0 e^{(-M_t)} \), where \( M = \) the instantaneous daily mortality coefficient, \( D_t = \) larval fish density at time \( t \), \( D_0 = \) larval fish density in the first fully recruited group (i.e., time = 0), and \( t = \) time in days (Peebles and Tolley 1988). Mortality estimates were tested for statistical differences between cruises and years using ANCOVA (a = 0.05).

Results

Validation, age, and growth

Daily increment formation on Atlantic bumper sagitta was validated using calcein. Each otolith from the nine fish treated had distinct growth increments between the green fluorescent calcein mark and the edge of the otolith (Fig. 2). On each sagitta examined, the number of increments counted after the calcein mark was
equivalent to the number of days the fish was held in captivity. The slope (1.02) of a least-squares linear regression (Fig. 3) was not significantly different from 1.0 (t-test, p > 0.05), confirming daily increment formation in otoliths of larval and juvenile Atlantic bumper.

Larval Atlantic bumper have circular sagitta, with a central core. Yolksac larvae (0.8 mm SL, preserved length) lacked increments. However, all other aged fish between 1.0 and 5.0 mm (preserved length; N 158) had countable increments (i.e., 1–11 increments or 3–13 days old; Fig. 4). Growth models were based only on 2–13 day-old fish.

Larval Atlantic bumper growth rates during the first two weeks of life were best described using a linear model. A separate growth curve was estimated for the 5–7 August 1986 data (Table 1). Growth curve comparisons for the two cruises in September 1986 (days 8–9 and 22–24) showed no significant differences within month (intercept, p = 0.44; slope, p = 0.48). Similarly, no significant difference was found between the two September cruises in 1987 (days 8–10 and 24–26; intercept, p = 0.07; slope, p = 0.42). Therefore, the paired September data sets were combined into a single regression for each year (1986 and 1987; Table 1). Atlantic bumper length-frequencies displayed no significant differences (p = 0.93) between the two different mesh sizes (202 vs. 333 μm) during the 1987 daytime
Table 1
Estimates of three linear growth equations used to describe the growth rate (mm/day) of larval Chloroscombrus chrysurus (0.8-4.8 mm) collected off the Louisiana-Mississippi barrier islands during 1986 and 1987, and the associated mean surface-water temperatures (°C) including ranges. $R^2$ is the coefficient of determination for the respective models; $L$ = standard length (mm); $X$ = age (days).

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Number fish aged</th>
<th>Number</th>
<th>Size (range)</th>
<th>Equations</th>
<th>$R^2$</th>
<th>Growth rate (mm/day)</th>
<th>Mean surface-temperature (°C) (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5–7 August 1986</td>
<td>9</td>
<td>0.8–3.7</td>
<td>$L = 0.40X - 0.13$</td>
<td>0.94</td>
<td>0.40</td>
<td>29.6 (29.0–30.8)</td>
<td></td>
</tr>
<tr>
<td>8–9, 22–24 Sept. 1986</td>
<td>81</td>
<td>1.2–4.8</td>
<td>$L = 0.26X + 0.70$</td>
<td>0.61</td>
<td>0.26</td>
<td>28.4 (28.0–29.0)</td>
<td></td>
</tr>
<tr>
<td>8–10, 24–26 Sept. 1987</td>
<td>69</td>
<td>1.3–4.5</td>
<td>$L = 0.31X + 0.71$</td>
<td>0.72</td>
<td>0.31</td>
<td>27.8 (26.5–30.0)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2
Zooplankton standing-stock estimates (mL/m$^3$±SE) with 1987 values converted to equivalent 202μm mesh net values, based on the conversion study done during both September cruises in 1987. The number of samples taken during each cruise is indicated in parentheses. The following equation was used in the conversion: $Y = 0.785X - 0.054$ ($R^2$ 0.86).

<table>
<thead>
<tr>
<th>Month</th>
<th>1986</th>
<th>Converted</th>
<th>1987</th>
</tr>
</thead>
<tbody>
<tr>
<td>August</td>
<td>0.83±0.17</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>(34)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>early Sept.</td>
<td>0.61±0.13</td>
<td>0.57±0.04</td>
<td>0.39±0.04</td>
</tr>
<tr>
<td>(25)</td>
<td>(40)</td>
<td>(40)</td>
<td></td>
</tr>
<tr>
<td>late Sept.</td>
<td>0.32±0.05</td>
<td>0.39±0.03</td>
<td>0.25±0.03</td>
</tr>
<tr>
<td>(41)</td>
<td>(40)</td>
<td>(40)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5
Regression of larval standard length (mm) on sagittal otolith radius (μ) for Atlantic bumper Chloroscombrus chrysurus larvae collected off the Louisiana-Mississippi barrier islands, 1986-87.

Atlantic bumper standard lengths were regressed on the otolith radius (measured in microns; Fig. 5). The coefficient of determination ($r^2$) for the relationship was 0.77 and the equation is $L = 120 + 0.05X$, where $L$ = standard larval length (mm) at the otolith radius, $R$ (Fig. 5). The relationship between the age and otolith radius explained less variability ($r^2$ 0.68) and fit the following equation $A = 2.96 + 0.13R$, where $A$ = age in days at the otolith radius, $R$. Otolith radius was observed to increase with both larval length and age.

Zooplankton biomass
Zooplankton mean biomass values for 1986 were similar to the converted 1987 values. The 202 vs. 333μm mesh regression equation $Y = -0.054 + 0.785X$ ($r^2$ 0.86), where $Y$ = the 333μm zooplankton standing-stock value, and $X$ = the 202μm zooplankton value, was used to establish a correction factor to convert the 1987 zooplankton values into estimates comparable to the 1986 values. The highest mean zooplankton biomass estimate (0.88 mL/m$^3$) was found in August 1986 (Table 2). The mean standing-stock estimates declined throughout the September cruises within each year (Table 2).
Dry weight-length relationship

The dry weight-length relationship for postlarval and juvenile Atlantic bumper (Fig. 6) is described by the exponential model \[ \text{Weight} = 0.0016 \times \text{Length}^{3.25} \] (\( r^2 = 0.94 \)), where weight = dry weight of the fish (mg) and length = standard length (mm). The dry weight-length power term for larval and juvenile Atlantic bumper, 3.25, is significantly different from the classical standard length-weight power term of 3.0 for adult fish (LeCren 1951) and 4.0 for larval fish (Power 1989) at the 95% confidence level (\( p > 0.05 \)).

Discussion

The age of larval and juvenile Atlantic bumper was estimated from counts of growth increments on sagittal otoliths. One growth increment formed daily on each sagitta of Atlantic bumper between 8 and 25mmSL. We, like others (Pritcher 1988, Fowler 1989, Parsons and Peters 1989), assumed that this relationship held true for smaller larvae (1-8 mm). We validated the periodicity of otolith growth increments and established an otolith age-and-growth analysis for larval Atlantic bumper in the northern Gulf of Mexico.

Growth increments were not visible in the otoliths of yolksac Atlantic bumper larvae (0.8mmNL), but at least one increment was visible in 1.0mmSL larvae. The length at hatching appears to be between 0.7 and 0.9 mmSL (after preservation) based on the larval length measurements. Atlantic bumper larvae, therefore, appear to begin otolith increment deposition after yolksac absorption, approximately 2 days after spawning (allowing 1 day each for egg incubation and yolksac absorption). Pelagic species, such as Atlantic bumper, often begin growth increment formation on their sagitta at the time of yolksac absorption (Radtke 1984).

An isometric or linear relationship between the size of otolith radius and standard length was revealed for Atlantic bumper larvae. The variation observed in our otolith radius–fish size relationship could be influenced by growth- and age-related factors. For example, under unfavorable environmental conditions the fish may not continue to experience an increase in otolith radius or fish size, while daily increment formation may continue (Lyczkowski-Shultz et al. 1988, Secor and Dean 1989).

Table 3

<table>
<thead>
<tr>
<th>Sampling dates</th>
<th>Number of fish</th>
<th>Instantaneous daily mortality estimates</th>
<th>( R^2 )</th>
<th>Atlantic bumper total densities</th>
<th>Total larval fish density</th>
</tr>
</thead>
<tbody>
<tr>
<td>5–7 Aug. 1986</td>
<td>1912</td>
<td>0.62</td>
<td>0.82</td>
<td>609.9</td>
<td>1538.1</td>
</tr>
<tr>
<td>8–9 Sept. 1986</td>
<td>576</td>
<td>0.35</td>
<td>0.98</td>
<td>121.7</td>
<td>799.8</td>
</tr>
<tr>
<td>22–24 Sept. 1986</td>
<td>291</td>
<td>0.18</td>
<td>0.86</td>
<td>227.9</td>
<td>599.9</td>
</tr>
<tr>
<td>8–10 Sept. 1987</td>
<td>573</td>
<td>0.30</td>
<td>0.90</td>
<td>62.2</td>
<td>262.4</td>
</tr>
<tr>
<td>24–26 Sept. 1987</td>
<td>122</td>
<td>0.17</td>
<td>0.92</td>
<td>42.4</td>
<td>298.2</td>
</tr>
</tbody>
</table>

The Atlantic bumper growth rate calculated over the two cruises in September 1987 may have been higher than the September 1986 growth rate because of the increase in zooplankton availability (Tables 1 and 2). Zooplankton displacement volume values calculated from the samples taken in 1986 declined from August to September. Relative zooplankton biomass values have peaked, however, as late as October off the Chandeleur Is. within Chandeleur Sound (102,000 animals/100 m³; Gillespie 1971; Fig. 1). Our zooplankton standing-stock estimates were high compared with values obtained from Mississippi River plume fronts during July 1987 (0.04–0.43 mL/m³; R.F. Shaw, unpublished data).

Atlantic bumper larvae had a dry weight-length exponent value of 3.25 which is similar to that of 3.32 determined for larval northern anchovy Engraulis mordax (Lasker et al. 1970). This power term, however, is lower than values determined for seven laboratory-reared, cold-water marine larval species (3.76–4.77; Laurence 1979), or the hypothesized standard value for developing larval fish (4.0; Power 1989).

The highest Atlantic bumper instantaneous daily mortality estimate (M 0.62), observed during August, was similar to that reported for estuarine larval spotted seatrout Cynoscion nebulosus (0.64; Peebles and Tolley 1988) and, to some extent, another carangid, jack mackerel Trachurus symmetricus (0.80; Hewitt et al. 1985). Mortality estimates, which declined throughout September 1986 (0.35–0.18) and 1987 (0.30–0.17), were similar and were within the reported range for several larval marine species (Essig and Cole 1986, Houde 1987 and 1989, Pepin 1991). The highest daily mortality rate was associated with highest temperatures, highest macrozooplankton displacement volumes, and highest larval Atlantic bumper densities (Tables 1–3). In late September 1986, however, there was a low mortality rate during a time of relatively high Atlantic bumper densities, lower zooplankton biomass estimates, and lower temperatures. Two factors—larval size and lower water temperatures—may have influenced this lower mortality rate (Weinstein and Walters 1981). Mean larval Atlantic bumper standard lengths (1.2 mm) were similar for all the cruises. Lower surface-water temperatures, therefore, may have enhanced survival, reducing the Atlantic bumper mortality estimate. Larval growth (i.e., daily development) and mortality rates have been reported to increase with temperature (Houde 1989, Pepin 1991). The high growth-rate and mortality estimate observed in August 1986 is consistent with these findings.

The high natural mortality observed in August is probably related to predation, based on two existing theories. Larval Atlantic bumper are usually aggregated in patches (Leffler 1989) and, therefore, may offer exceptional feeding opportunities to any predator that encounters them (McGurk 1987). Pepin (1991) suggested that increased mortality rates were associated with increased growth rates, resulting from increased encounters with predators. These higher growth rates require a higher intake of food, causing increased activity which leads to increased predator encounters.

Another possible cause for the high August mortalities may be associated with competition for limited food resources, i.e., density-dependent mortality (Cushing 1974). Food availability as indexed by the zooplankton biomass estimate was highest during August, but the high total larval fish density may have rapidly depleted the food source, causing elevated mortalities. Larval Atlantic bumper density was high during the August cruise (608.9 larvae/100 m³) as was the total larval fish density (1838.1 larvae/100 m³; Leffler 1989).

This study provides preliminary information on the early life history of larval Atlantic bumper. Further studies need to be conducted on larval Atlantic bumper to determine the relationship between these early-life-history parameters and fluctuating temperatures and food availability.

Acknowledgments

The authors would like to thank J. Ditty, D. Drullinger, R. Raynie, and K. Edds for assistance in the field and laboratory. Also we would like to acknowledge L. Rouse, E. Turner, C. Wilson, R. McMichael, and two anonymous reviewers for critical reviews of the manuscript, and M. Mitchell and B. McLaughlin for their assistance in preparing the graphics. Special thanks to the captains and staff at Gulf Coast Research Laboratory, Ocean Springs, MS, for use of their boats and aquarium facilities.

Financial support was provided through the Louisiana Sea Grant College Program, a part of National Sea Grant College Program maintained by NOAA U.S. Department of Commerce.
Citations

Bannister, C.A., D. Harding, and S.J. Lockwood

Boschung, H.T.

Bullis, H.R. Jr., and J.S. Carpenter

Bullis, H.R. Jr., and J.R. Thompson

Campana, S.E., and J.D. Neilson

Christmas, J.Y., and R.S. Waller

Cushing, D.H.

Ditty, J.G.

Essig, R.J., and C.F. Cole

Fowler, A.J.

Franks, J.S.
1970 An investigation of the fish population within the inland waters of Horn Island, Mississippi, a barrier island in the northern Gulf of Mexico. Gulf Res. Rep. 3:3–104.

Gillespie, M.C.

Hewitt, R.P., G.H. Thielacker, and N.C.H. Lo

Houde, E.D.

Houde, E.D.

Juhl, R.

Klima, E.F.

Lasker, R., H.M. Feder, G.H. Thielacker, and R.C. May

Laurence, G.C.
1978 Comparative growth, respiration, and delayed feeding abilities of larval cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) as influenced by temperature during laboratory studies. Mar. Biol. (Berl.) 60:1–7.

LeCren, E.D.

Leffler, D.L.

Leak, J.C.

Leak, J.C., and E.D. Houde

LeCren, E.D.

Methot, R.D. Jr., and D. Kramer

Parsons, G.R., and K.M. Peters

Peebles, E.B., and S.G. Tolley

Pepin, P.

Leffler and Shaw: Age, growth, and mortality of larval Chloroscombrus chrysurus 719

Power, J.H.

Pritcher, C.R.

Radtke, R.L.

Reid, G.K.

Reintjes, J.W.

Sabins, D.S.

SAS Institute Inc.

Secor, D.H., and J.M. Dean

Shaw, R.F., and D.L. Drullinger

Shaw, R.F., D.L. Drullinger, K.A. Edds, and D.L. Leffler

Stuck, K.C., and H.M. Perry

Van Guelpin, L., D.F. Markle, and D.J. Duggan

Warlen, S.M.

Weinstein, M.P., and M.P. Walters

Williams, L.W.

Wilson, C.A., D.W. Beckman, and J.M. Dean

Yentsch, C.S., and J.F. Hebard