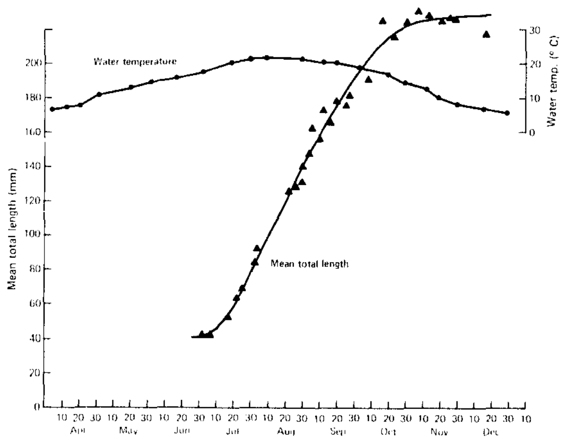

FIGURE 2.—First year growth of walleye and water temperature at John Day Dam on the Columbia river, 1979. Growth curve fitted by inspection (171 fish represented). Each point on the growth curve is the arithmetic mean of 3 to 12 specimens.

populations by the increasing abundance of walleye indicates a continuing need for monitoring walleye in this section of the Columbia River system.

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EFFECTS OF TEMPERATURE AND SALINITY ON EGG HATCHING AND LARVAL SURVIVAL OF RED DRUM, *SCIAENOPS OCELLATA*[1]

The red drum, *Sciaenops ocellata*, is a sciaenid fish distributed along the eastern coast of North America from Massachusetts to southern Florida and along the gulf coast at least as far south as Tampico, Mexico (Hildebrand and Schroeder 1928; Simmons and Breuer 1962). Spawning occurs in late summer through fall outside estuaries in nearshore coastal waters, and the young red drum is carried into the estuaries by tides and currents (Pearson 1929; Mansueti 1960). Late larvae and early juveniles have been collected in the shallow water of tidal flats and sea grass beds. The early planktonic stages, the eggs and yolk-sac larvae, have not been identified from field collections but have recently been described, based on specimens from laboratory-spawned red drum (Holt et al. 1981).

Temporal fluctuations in abundance of red drum result in annual variation in sport and commercial catches (Matlock and Weaver 1979). Variations in environmental factors such as temperature and salinity could affect egg incubation and larval survival, and ultimately year-class strength. Juveniles and adults are euryhaline and are found naturally in freshwater, in brackish

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water estuaries, and most abundantly in salinities of 20-35‰ (Simmons and Breuer 1962). A wide temperature range of 2°-33° C can be tolerated as long as the temperature change is gradual (Gunter and Hildebrand 1951; Simmons and Breuer 1962). Little is known about the upper and lower limits of temperature and salinity and their effects on survival of eggs and early larval stages, or on early development and growth.

The objective of this study was to determine the optimum temperatures and salinities for hatching and growth of red drum eggs and larvae. Similar work on temperature and salinity effects on survival and development have been detailed for other marine species (Alderdice and Forrester 1971; Alderdice and Velsen 1971; May 1975).

Methods

Eggs were obtained from laboratory spawnings induced by manipulations of temperature and photoperiod to simulate natural seasonal changes (Arnold et al. 1977). Brood tank temperatures ranged from 24° to 26° C and salinities from 26 to 32‰. The most successful method for rearing larvae under our experimental conditions was the following: 1) Hatching at a density of 50-100 eggs in a 100 ml beaker with 10 ppm erythromycin; 2) feeding sequentially the dinoflagellate *Prorocentrum micans* (500/ml, day 2) and the rotifer *Brachionus plicatilis* (50-100/ml, day 3); 3) transferring larvae after 3-4 h feeding on rotifers to a Nitex[2] holding chamber in a 1 l beaker; 4) feeding *Artemia salina* nauplii to larvae (2/ml, beginning on day 7).

Water was changed every fourth day. The holding chambers were made from a cylinder of 300 μm Nitex net glued to a plastic Petri dish; the dish forming the bottom and the Nitex net the sides of the container. Air was introduced into the beaker outside the holding chamber to avoid producing turbulence and bubbles within the chamber. Test salinities were made with filtered seawater (1 μm) diluted with deionized water or concentrated with artificial sea salts (Instant Ocean). Temperatures were maintained within 0.5° C and illumination from fluorescent room lamps was continuous. Percentage hatch, percentage survival of the larvae to 24 h and 14 d, and standard length (millimeters) of 14-d-old larvae were measured to determine the influence of temperature and salinity. Analyses were conducted on the arc sine transformation of the percentages. Two-way factorial analysis of variance was used to test for significant differences among eggs and larvae reared at 12 salinity-temperature conditions.

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

Results

Results of initial tests of the influence of different temperature-salinity combinations on hatching and survival of red drum showed poor hatching rates at low salinity (10‰) over all temperatures except 25° C. Red drum eggs floated in 25‰ or greater salinity and sank to the bottom in lower salinities. High temperatures (30° and 35° C) and high salinities were associated with poor survival of the yolk-sac larvae. Based on these results four salinities (15, 20, 25, and 30‰) and three temperatures (20°, 25°, and 30° C) were used to determine conditions for optimum survival and growth of red drum eggs and larvae. The ranges of salinity and temperature selected are representative of conditions occurring in coastal waters during the normal spawning period.

TABLE 1.—Percentage hatch and larval survival of red drum for each salinity-temperature condition tested. Initially each replicate contained 50-100 eggs.

Salinity (‰)	Temp (° C)	Hatch (%) Replicates								Hatch (%) Mean	24-h-old larvae (%) Replicates						24-h-old larvae (%) Mean
15	20	100	95	91	79	94	100	100	97	96	95	93	100	100	97	98	97
	25	87	58	3	10	84	80	100	100	65	87	28	98	95	94	93	83
	30	89	50	72	64	61	79	100	100	77	89	22	84	98	1	1	49
20	20	100	96	94	85	98	92	100	100	96	97	96	100	100	98	97	98
	25	86	98	34	74	92	88	100	100	84	86	98	100	100	100	99	97
	30	90	71	94	72	57	56	100	100	80	90	55	86	83	25	83	70
25	20	100	98	84	87	96	98	100	100	95	97	96	100	100	98	97	98
	25	100	98	95	89	98	97	100	100	97	100	98	100	100	99	100	100
	30	96	100	96	80	96	100	100	100	96	79	72	98	100	94	95	90
30	20	100	98	91	94	94	100	100	100	97	98	98	100	100	100	98	99
	25	100	100	100	100	98	98	100	100	100	100	98	100	100	100	100	100
	30	100	100	91	100	98	100	100	100	99	82	79	100	100	96	98	93

The best conditions for hatching and 24-h larval survival were 30‰ salinity and 25° C (Table 1). Analysis of variance of the hatching data showed temperature (T) and the temperature-salinity interaction ($T \times S$) effects to be of borderline significance ($0.10 > P > 0.05$); only salinity was significant ($P < 0.05$) (Table 2). A pattern of decrease in percent hatch with increase in temperature at the lower salinities (15 and 20‰), but not at the higher salinities (Table 1), is indicative of the $T \times S$ interaction. Hatching was significantly greater at the two higher salinities than at lower salinities (Table 3).

Survival of larval red drum to 24 h was influenced by both temperature and salinity. Poorest survival was at 30° C and 15‰ (Table 3).

Temperature was associated with significant differences in survival of 2-wk-old larvae (Table 2). The lowest temperature (20° C) resulted in reduced survival rate. The effect of temperature on larval growth rate was pronounced; growth at 20° C was much slower than at 25° or 30° C (Table 4). Salinity had little influence on growth.

TABLE 3.—Mean percentage hatch, 24-h survival, and 2-wk survival of red drum over all conditions. Individual means were compared using Duncan's multiple range test. Any two means connected by the same line were not significantly different ($P < 0.05$).

Item	15‰	20‰	25‰	30‰	20° C	25° C	30° C
% hatch	76.46	86.54	96.17	98.42	96.09	86.47	87.87
% 24-h survival	64.57	75.19	81.79	84.20	98.04	94.71	75.42
% 2-wk survival	6.00	4.17	5.42	4.92	0.37	8.00	7.00

TABLE 4.—Standard length (millimeters) of red drum larvae that survived 2 wk.

Salinity (‰)	20° C			25° C			30° C		
	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
15	2.80		1	4.90	1.137	18	6.20	1.316	38
20	3.35	0.212	2	4.60	1.046	34	5.80	1.500	17
25	3.20		1	4.70	1.078	27	7.00	1.794	29
30	3.55	.071	2	4.75	.937	30	6.80	2.019	13

Discussion

Salinity was important for hatching and 24-h survival but not for 2-wk survival. Red drum eggs developed successfully to feeding larvae at salinities of 10-40‰ at 25° C; at other temperatures the salinity range for 75% hatch was reduced to 15-30‰. In low salinities, eggs sank to the bottom; as Fonds (1979) explained for the common sole, *Solea solea*, crowding and possible respiratory stress contributed to reduced survival under these conditions. In natural populations high mortality of eggs developing on the bottom would be expected.

Red drum eggs may have been acclimated to the higher salinities since salinities for best hatching were very near the salinities of the maturation and spawning tanks (26-30‰). Solemdal (1967) reported that the osmotic concentration of the ovarian fluid affected the buoyancy of flounder eggs and that both could be changed experimentally. Kinne and Kinne (1962) found that the salinity of the water in which the parents lived affected the response of developing cyprinodont fish to salinity. Differences in response were explained as being primarily nongenetic adaptations to the spawning salinity (Kinne 1962). Conversely, May (1975) found salinity tolerance of *Bairdiella icistia* eggs was not affected by acclimation of the parent fish to low salinity and suggested that salinity responses determined for eggs accurately predict reaction to different salinities in nature.

Temperature became increasingly important as the larvae developed. Apparently contradictory results showed low temperature (20° C) to be superior for 24-h survival, but inferior for 2-wk survival and growth. With low temperature, development and probably metabolism were slowed to the extent that growth and even mortality were delayed. The time spent in the yolk-sac stage is temperature dependent; ranging from 40 h at 30° C to 85 h at 20° C (Holt et al. 1981). Blaxter (1969) cautioned that high yolk-sac utilization efficiency may result from low activity which becomes a liability when it is reflected in

TABLE 2.—Analysis of variance of percent hatch and survival of red drum eggs and larvae subjected to various temperature-salinity conditions.

Source	% hatch				24-h-old larvae				2-wk-old larvae			
	df	MS	*F*	*P*	df	MS	*F*	*P*	df	MS	*F*	*P*
Temperature (T)	2	459.94	2.44	0.09	2	3,090.70	16.43	0.00	2	450.69	20.66	0.00
Salinity (S)	3	1,634.80	8.67	0	3	1,386.77	7.37	0	3	4.56	.21	.89
$T \times S$	6	400.18	2.12	.06	6	352.40	1.87	.10	6	6.54	.30	.92
Error	84	188.41			60	188.12			12	21.82		

low feeding activity. This was clearly the case with the few fish that survived 2 wk in 20° C. These larvae were inactive, were not seen catching prey, and they grew very slowly. Larvae raised at higher temperatures actively attacked and ate prey as soon as it was introduced to the chamber.

Based on these results we hypothesize that red drum spawning success and subsequent year-class strength will be adversely affected by the early onset of low water temperatures. Red drum is a fall spawner and the young must survive and grow at the winter temperatures found in low-temperate estuaries; bay water temperatures often fall below 20° C in November and average 15°-17° C in December in Texas (Martinez 1975). The results indicate that for the first week or so the larvae are stenothermal. The ability to find and catch prey when the yolk sac has been absorbed is a critical phase in larval survival (May 1974). Once temperature in the coastal water declines to 20° C red drum larvae that have reached the critical phase may not be able to find and catch prey. An early reduction in nearshore water temperatures could result in an unsuccessful red drum reproductive effort for that year. Indirect evidence implicates the importance of temperature to reproductive success in that our laboratory-reared red drum stop spawning when the temperature drops below 20° C. This phenomenon may account for the earlier spawning of red drum in its more northerly range (Mansueti 1960) and prolonged spawning in warmer regions (Jannke[3]).

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