PATTERNS OF EASTERN OYSTER, *Crassostrea virginica* (GMELIN, 1791), RECRUITMENT IN SAPELO SOUND, GEORGIA: IMPLICATIONS FOR COMMERCIAL OYSTER CULTURE

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Abstract

In the past, eastern oyster, *Crassostrea virginica* (Gmelin, 1791), recruitment along Georgia's coastline has exhibited great site specific microgeographical variability ranging from 0 to 204,700 spat/m^2/month. The purpose of this research was to examine natural temporal and spatial variations in oyster recruitment throughout a range of potential oyster grow-out areas in coastal Georgia. The research provides a tool to control spat fouling in the development of an oyster aquaculture industry. Three commercial spat collection sticks were deployed on a monthly basis at seven sites within Sapelo Sound between March and September 2006. Recruitment was first observed in May and peaked in June 2006. The site located near the mouth of the Sapelo River had the highest recruitment (98,132 spat/m^2/month), and the site located in the headwaters of Ridge River had the lowest (482 spat/m^2/month) during the peak June 2006 recruitment period. High tidal amplitudes in Georgia flush larvae from headwater areas and smaller tidal creeks and may concentrate oyster larvae in areas of river confluence. Also, temperature, salinity, turbidity and available oyster broodstock may affect larval availability for settlement in headwater areas. Future oyster recruitment monitoring within Georgia's estuaries is essential in the determination of appropriate harvest techniques, seed collection, grow-out areas, and management strategies for an oyster-based aquaculture industry and restoration efforts.

Introduction

The eastern oyster, *Crassostrea virginica* (Gmelin, 1791), exhibits variations in its reproductive cycle and time of spawning associated with geographic location. The periodicity of spawning and subsequent oyster recruitment events ranges from June through August along the northeastern seaboard of the United States and from March through October along the southeastern Atlantic and Gulf coasts with variations in intensity of oyster recruitment between locations (Shumway, 1996). Oysters in Georgia estuaries initiate gametogenesis in January, become ripe by April/May, and spawn May through October (Heffernan et al. 1989). Young-of-the-year oysters spawned in April/May will grow rapidly, are sexually mature in two-to-three months, and spawn during late summer (O'Beirn et al. 1996b). There are also substantial microgeographical fluctuations in patterns of oyster recruitment and varying levels of recruitment intensity within a given reproductive season. In the Duplin River estuary within the Sapelo Island National Estuarine Research Reserve, oyster recruitment in a given season varies from highs of 350 – 2,120 oysters/0.01m^2/month at the mouth to highs of only 0 – 0.4 oysters/0.01m^2/month near the headwater areas (O'Beirn et al., 1994; Thoresen et al., 2005).

There is considerable interest in the development of an oyster aquaculture industry for Georgia. The result of heavy oyster recruitment in Georgia is that oysters on natural reefs are overcrowded, and competition for space is intense. Oysters from natural reefs tend to be long, thin, and narrow. Locally, the main market demand is for roast oysters, however the more lucrative half shell and raw markets require a single well-shaped oyster. In general it requires approximately 18 months for oysters on the bottom to grow to a marketable size of 76 cm in shell height in Georgia. Unfortunately, an oyster that might be produced as a single in year one will not remain a single in year two due to the high rate of new recruits settling in the second summer. In order to develop an oyster aquaculture industry for Georgia, a means of controlling oyster spat fouling must be found. This research examines the natural temporal and spatial variations in oyster recruitment throughout a range of potential oyster grow-out areas in coastal Georgia. It is hoped that this research will provide a mechanism to control oyster spat fouling in development of an oyster aquaculture industry.

Materials and Methods

Three 1-m long, 1.9-cm diameter commercial spat collectors made of longitudinally grooved PVC pipe with chips of calcium carbonate embedded within it were deployed monthly at seven sites within the Sapelo Sound system to determine oyster spat recruitment patterns. At each site spat collectors were driven into the mud substrate along the creek bank so that 0.61 m of the collector was above the substrate surface. Spat collectors were deployed on March 1, 2006 within the intertidal zone at the two-hour above-mean low-water mark in alignment with natural oyster reefs within Sapelo Sound, Georgia. All spat collectors were gathered monthly, and were replaced with new collectors. All plots were terminated on December 1, 2006.

Seven sites were distributed throughout the Sapelo Sound system (Figures 1). Site 1 was located at the mouth of the Sapelo River off the northern end of Creighton Island. Site 2 was located at the mouth of Front River. Sites 3-5 were located in the headwaters of two marsh creeks. Site 6 is located within an unnamed creek in close proximity to Creighton Narrows near an area where the Front River merges with the Crescent River. Site 7 is located in the open sound to the north of Sapelo Island near the convergence of the Sapelo and Mud Rivers. Site 6 was the most inland site, while site 7 was the most seaward location.

To determine a fast, efficient and inexpensive means of collecting natural oyster spat, various spat-collecting methods were deployed on 7 April 2006 within the intertidal zone at the two-hour-above mean low water mark in alignment with natural oyster reefs at Ridge River Mouth, Creighton Island in the Sapelo Sound, Georgia. All plots were terminated on 1 August 2006.

Each month, all three spat collectors were gathered from each site. Oyster density was quantified per $0.01m^2$ sample (= 15 cm section of stick). Three 15-cm length sections of each collector were manually counted for the number of spat attached. Salinity and temperature data were collected at each site on ebb tide using a hand held refractometer and thermometer. One-way Analysis of Variance (ANOVA) and Tukey's Studentized Range Test (α =0.05) using SAS for PC (SAS Institute Inc., 1989) were carried out on density and shell height data.

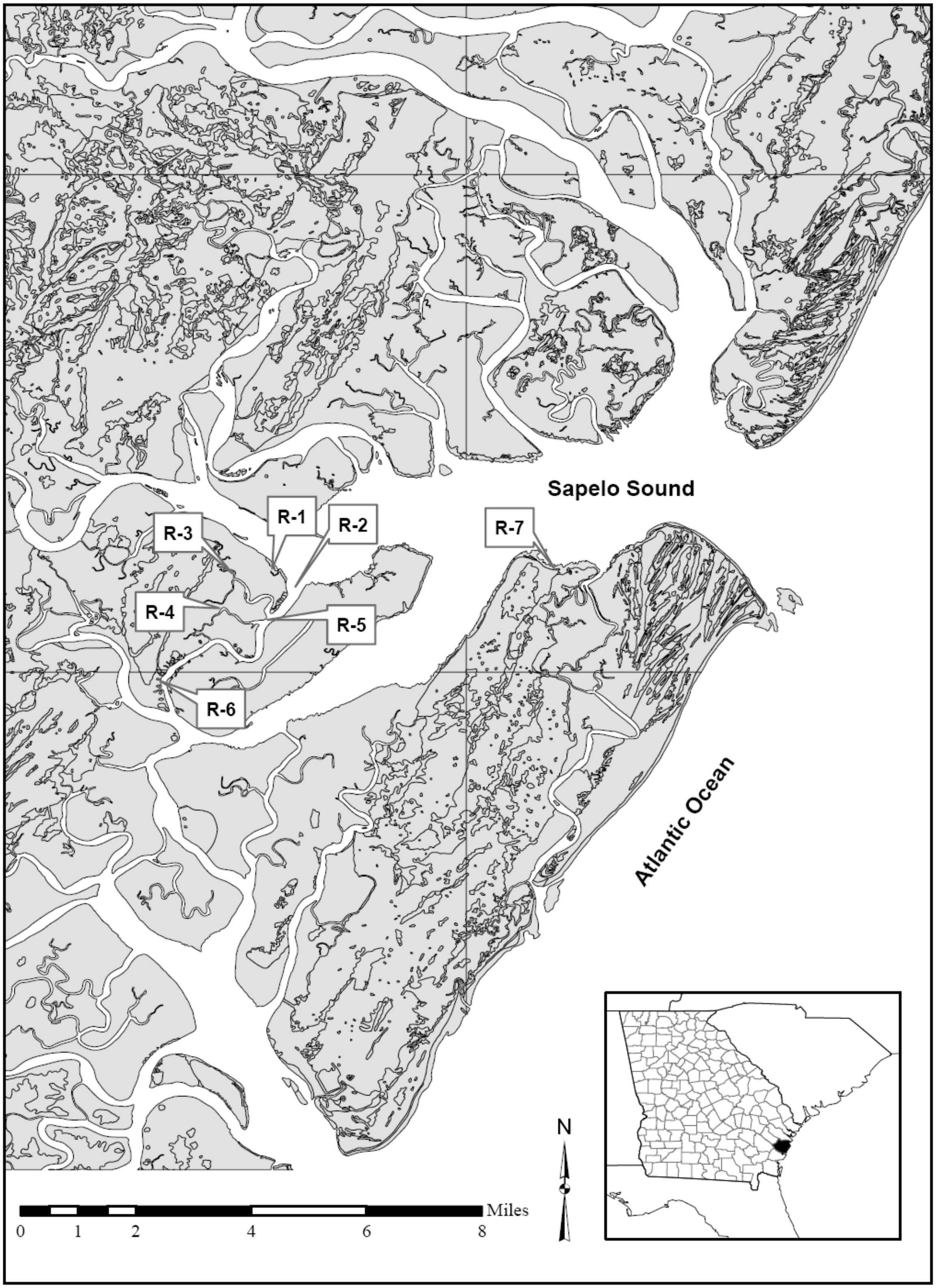

Figure 1: Map of Sapelo Sound with oyster recruitment monitoring sites R-1 – R-7.

Results

Water temperature and salinity fell within normal ranges for the coastal waters of Georgia. Water temperatures ranged from a low of 19ºC at site 3 in October to a high of 33ºC at sites 4 and 5 in June 2006 (Figure 2). Temperature varied the most (4 C) between site 1 (29ºC) and sites 4 and 5 (33ºC) in June. This probably was a result of water depth and location. Site 2 is in the sound in a large volume of water, while sites 4 and 5 are in the shallow waters of small tidal creeks. Salinity ranged from a low of 24 PSU at site 4 in June to highs of 35 at sites 1, 2, 4, 5, 6, and 7 in October 2006 (Figure 3). Salinity varied from a low of 24 PSU at site 4 to a high of 30 PSU at site 7 in June 2006. Likewise salinity at site 3 (25 PSU) was lower than the maximum of 30 PSU at site 7 in July 2006. Again sites 3 and 4 are located in the headwaters of small tidal creeks where rain may have caused the lower saline events observed in these shallow areas.

Overall mean oyster spat recruitment for the season was significantly ($p<0.0001$) higher at sites 1 and 2 than at all other sites (Figure 4; Table 1). Two peak settlement events occurred: one in June and one in August (Figure 5; Table 2). Oyster spat recruitment was consistently higher at site 1. Spat density ranged from a low of 32.2 ± 9.1 (SE) spat per 0.01 cm^2 in August to a high of 924.9 ± 66.1 spat per 0.01 m^2 in June 2006. In general recruitment was consistently low at sites 3, 4, and 5 with densities obtaining highs of 7 spat per 0.01 cm^2 and 6.6 spat per 0.01 m^2 at site 4 in August and June, respectively. Maximum spat densities at site 3 (4.6 spat per 0.01 m^2) and site 5 (5.4 spat per 0.01 m^2) were obtained in May. Essentially no recruitment occurred at other times.

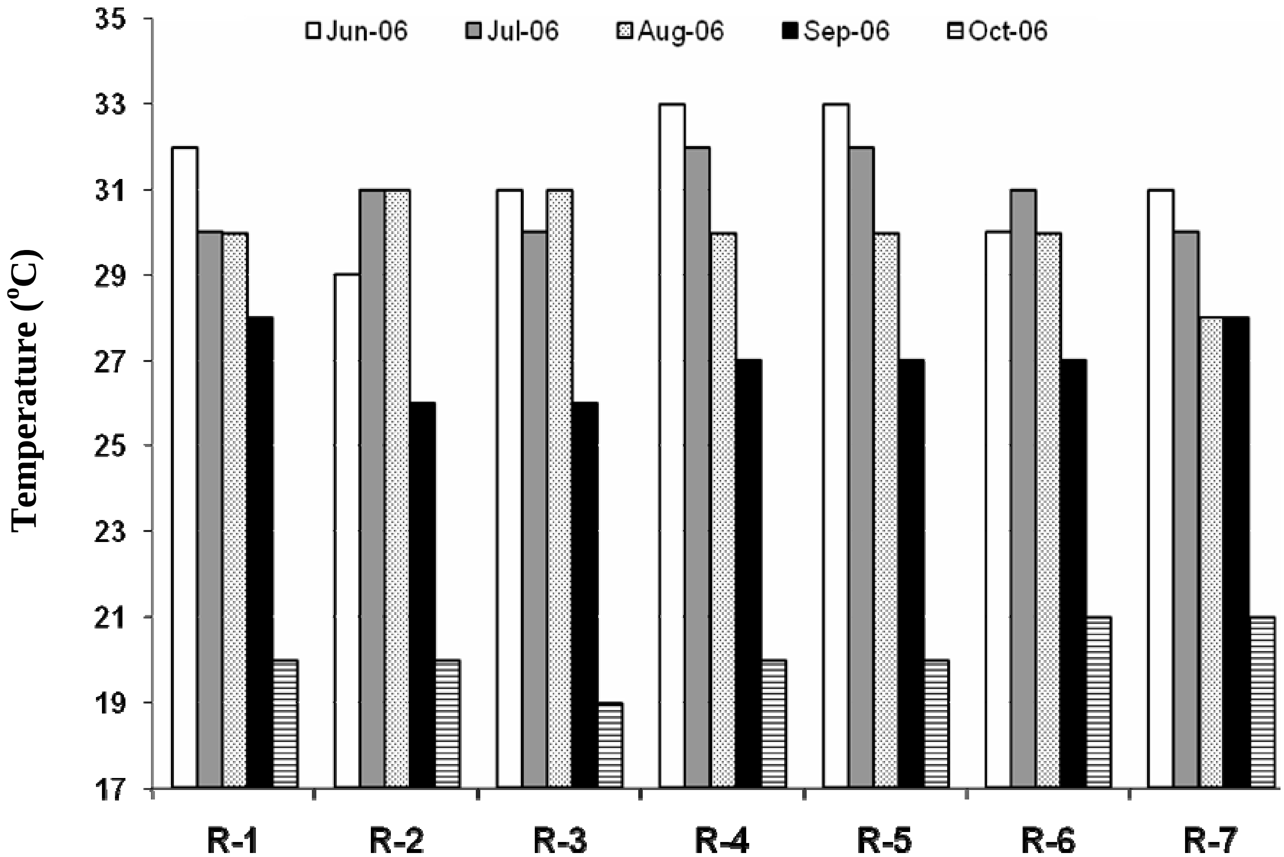

Figure 2: Surface water temperature at each of seven sites (R-1 – R-7) from June to October 2006 within Sapelo Sound, GA.

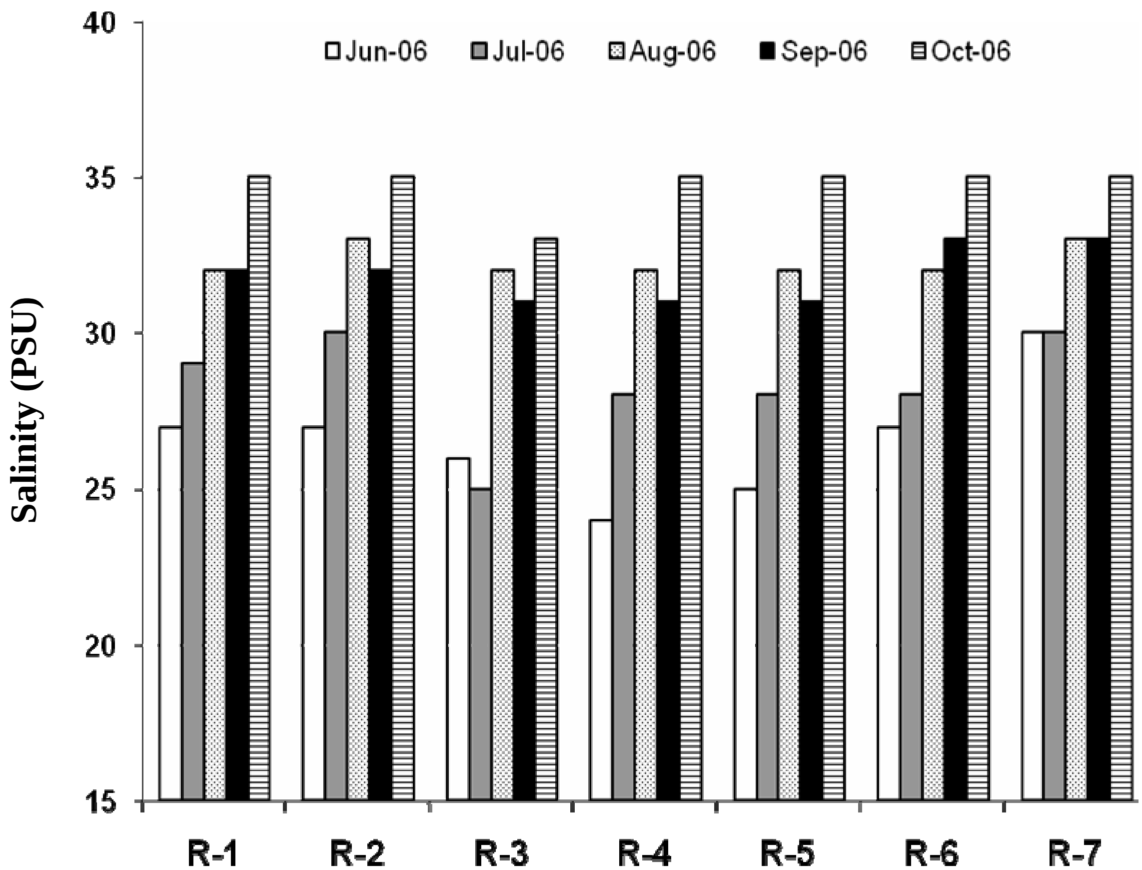

Figure 3: Percentage of oysters with fatally damaged shells (± S.E.) for oysters collected from house screen with cement slurry, house shingle, PVC sticks with cement slurry, commercial spat sticks, and bamboo treatments.

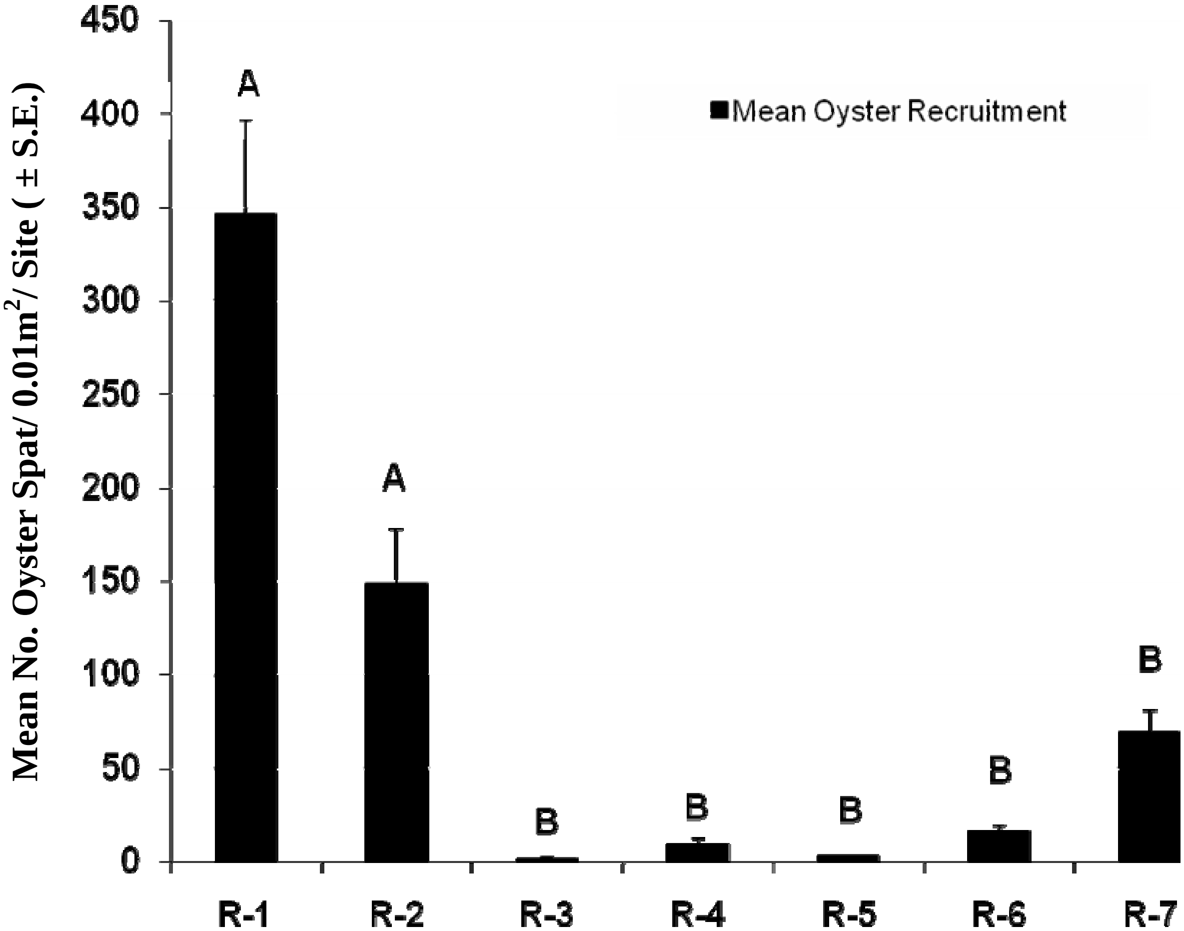

Figure 4: Overall mean oyster recruitment at each of seven sites from June to October 2006 within Sapelo Sound, GA. Different letters over means indicate if means are significantly ($P<0.0001$) different between sites.

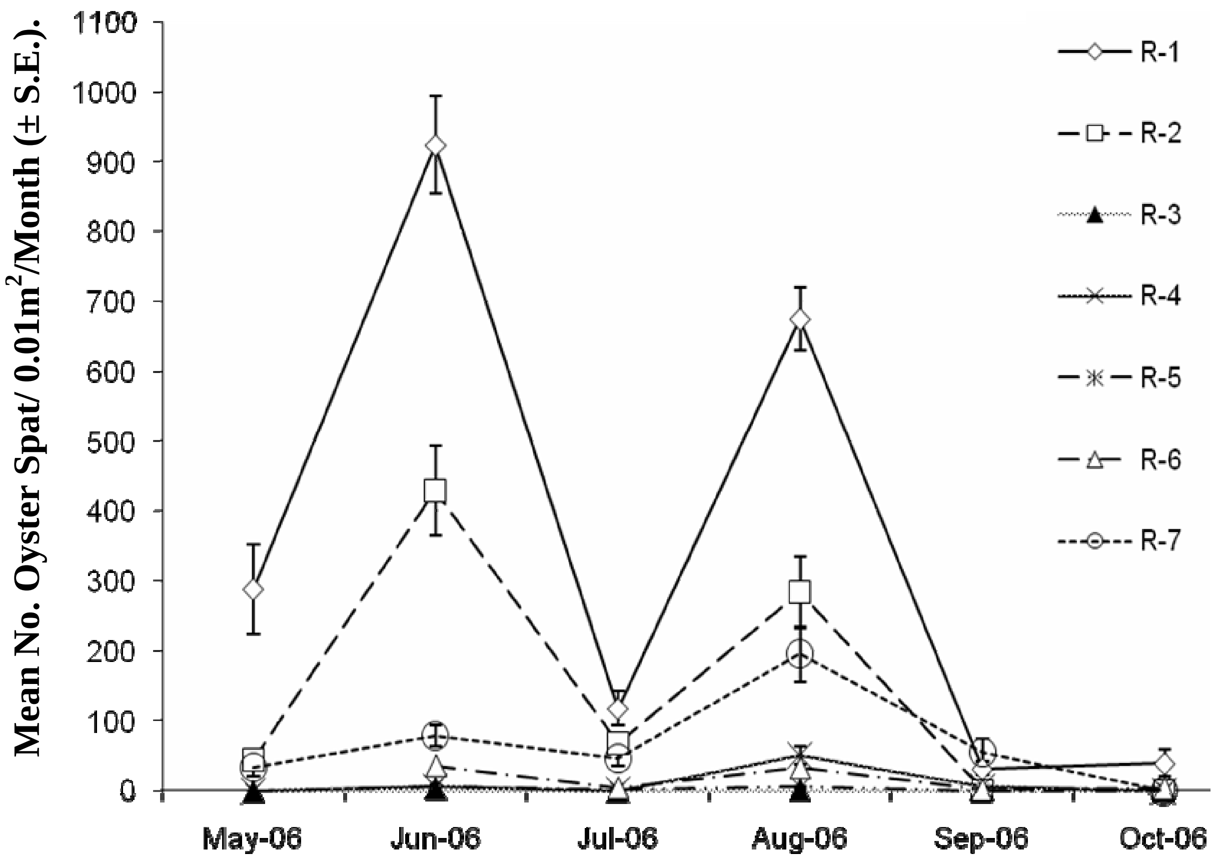

Figure 5: Mean monthly oyster recruitment at each of seven sites (R-1 – R-7) from June to October 2006 within Sapelo Sound, GA.

Table 1. Location type (headwater, mid-creek, river mouth and open sound), mean seasonal oyster spat recruitment per site (spat/0.01m^2/site), mean salinity (PSU), mean temperature (ºC), oyster broodstock availability (present = P or absent = A), type of oyster reef present (fringing = F, mound = M, or Patch = P), and oyster density characteristics per reef type (low, moderate, or high) for oyster recruitment monitoring sites 1 - 7 in Sapelo Sound Georgia.

Site	Location	Spat/0.01m^2	PSU	ºC	Broodstock	Type	Density
1	River mouth	346.7 ± 28.8	31.4 ± 1.3	27.4 ± 2.0	P	F,P	High
3	Headwaters	1.14 ± 0.29	29.6 ± 1.5	27.2 ± 1.8	A	N/A	N/A
4	Headwaters	8.83 ± 2.85	30 ± 1.8	28.4 ± 2.3	P	P	Low
5	Headwaters	2.1 ± 0.48	30.2 ± 1.7	28.4 ± 2.3	P	P	Low
6	Mid Creek	16.02 ± 3.1	31 ± 1.5	27.8 ± 1.8	P	F, M, P	Moderate
7	Open Sound	68.8 ± 11.5	32.2 ± 0.9	27.6 ± 1.7	P	F	High

Table 2. Monthly mean (± S.E.) Oyster spat settlement density at each of seven sites about Creighton Island, Sound, GA. Lines under means indicate means that are not significantly different.

Density

May (p<0.0001)

1	2	7	4	3	5	6	Site
289.1	45.5	34.9	0.11	0	0	0	Mean
60.2	10.6	13.3	0.1	0	0	0	SE
———	———	———	———	———	———	———	Tukey's

June (p<0.0001)

1	2	7	6	4	5	3	Site
924.9	430.6	78.9	35.6	6.6	5.4	4.6	Mean
66.1	60.9	13.21	8.27	1.42	1.33	0.92	SE
———	———	———	———	———	———	———	Tukey's

July (p<0.0001)

1	2	7	6	4	5	3	Site
118.2	69.3	47.1	4.17	1.78	1.44	0.33	Mean
23.5	11.0	9.44	1.14	0.56	0.70	0.22	SE
———	———		———	———	———	———	Tukey's
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August (P<0.0001)

7	1	4	2	6	5	3	Site
55.8	32.2	7.0	1.78	1.11	0	0	Mean
18.7	9.1	2.55	0.62	0.51	0	0	SE
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	———	———	———	———	———	———	Tukey's

September (p<0.0018)

1	6	5	7	4	2	3	Site
39.89	2.89	0.78	0.44	0	0	0	Mean
18.26	1.66	0.49	0.23	0	0	0	SE
———	———	———	———	———	———	———	Tukey's

Discussion

The overall temporal pattern of oyster recruitment within the study sites was typical of that seen elsewhere in Georgia. In general two patterns of recruitment occur in Georgia: one major peak recruitment period in May/June with gradually lower rates throughout the summer into fall; or two peaks, one in May/June followed by a second peak in August (O'Beirn et al. 1995, 1996a,c, 1997, Thoresen et al. 2005; Walker 2002-2008 Sapelo Island National Estuarine Research Reserve [(SINERR) oyster recruitment data unpublished]. The two peak recruitment patterns observed in this study were also seen in the oyster spat harvesting research conducted during the same period of time (Manley et al. 2008), in Sapelo Sound and St. Catherine's Sound (Justin Manley unpublished data), as well as, in the Duplin River during 2007 [Walker 2002-2008 SINERR oyster recruitment data unpublished].

Consistent spatial patterns in oyster recruitment are beginning to emerge based on location within a tidal creek or river and sound system. High recruitment in the mouth of tidal rivers versus low recruitment in the headwaters has been previously reported in Georgia (O'Beirn et al. 1995, 1996a,c, 1997 and Thoresen et al. 2005). Thoresen et al. (2005) in 1999-2001 reported high recruitment rates at Marsh Landing located near the mouth of the Duplin River where it enters Doboy Sound, intermediate recruitment at Jack Hammock, a site in the middle of the Duplin River, and negligible recruitment at the Flume Dock site. The Flume Dock site is located near the headwaters of the Duplin River. O'Beirn et al. (1996c) observed no recruitment within the Flume Dock site during 1991 and 1992. For data on oyster recruitment patterns in the Duplin River (SINERR 2002 to 2008 Walker unpublished), no recruitment was observed at Flume Dock site in 2007, with low or negligible (<1 spat per 0.01 m^2 per month) rates occurring in 2002, 2003, 2004, 2005, 2007 and 2008. In 2006, a record high of 25 spat per 0.01 m^2 per month occurred in August. The Duplin River, like other creeks in this study, is a coastal tidal river, with no influence of freshwater other than rain runoff.

O'Beirn et al. (1994; 1997) suggested that tidal flushing associated with increased tidal amplitudes in Georgia influenced patterns of oyster recruitment in the upper reaches of tidal creeks resulting in low oyster recruitment in headwater areas. While removal of oyster larvae from headwater areas by tidal flushing is a valid assumption, research by Seim et al. (2006) indicated that the upper reaches of some smaller tidal creeks have diminished water velocities and net movement of water over a tidal cycle. Thus, it is likely that patterns of oyster recruitment in headwater areas of well mixed estuaries may be directly related to the density of reproductively capable adult oysters, which in most cases is low compared to densities found near the mouth of creeks and areas of river confluence (Bahr 1981). During this research headwater areas which recorded the lowest oyster recruitment values also were observed to have low oyster densities or no oyster stock at all (Table 1). Shallow headwater areas are also exposed to the air for longer periods during low tide than deeper areas near the mouth of tidal creeks and rivers. Therefore any oysters present in headwater areas generally have less submergence time and exposure to spat fouling. Other factors affecting oyster recruitment in shallow headwater areas are salinity and temperature; however neither parameter exceeded the optimal range for oyster survival (Shumway 1996) over the course of this research. It is important to note that during this research, the only freshwater input to the areas surrounding the research sites was precipitation.

Headwater areas of tidal creeks that are observed to have consistently low oyster recruitment can be used as grow-out areas for a commercial industry focused on producing market quality single and roast oysters. Headwater areas minimize the oyster spat fouling that results in a clustered unmarketable product. This study's application for aquaculture is that oyster spat can be gathered from areas of high recruitment such as sites 1, 2 and 7. Once the spat have settled, collectors with oyster spat can be moved to low recruitment areas in creeks to eliminate or greatly reduce additional settlement throughout the spawning season. Oysters could be allowed to grow to a marketable size on the spat collector sticks or even collected as single spat and placed in racks. Manley (2007) showed that oyster spat gathered at the start of the spawning season could grow on commercial spat sticks to a marketable size in time for the end of the oyster roast season, i.e., March. Thus, a crop can be produced within 8-to-9 months. Alternatively, spat collected in the early part of the spawning season can be allowed to grow at the collection site, removed from the collectors into singles and then moved to the headwater areas for grow-out to market size. These oysters could grow over the following summer into fall in an area where oyster spat fouling is greatly reduced. Thus a marketable product could be available for the start of the next fall/winter oyster roast season. Adams et al. (1994) showed that by stocking oysters for grow-out at a high density, oyster spat fouling could be reduced even in areas of high spat recruitment. Thus, detailed knowledge of oyster recruitment rates at potential grow-out sites is essential to the implementation of particular grow-out techniques on a site-by- site basis in Georgia.

Resource management aimed at preserving oyster habitat should discourage commercial harvest of naturally occurring oysters from low recruitment areas that will not be able to recuperate as rapidly as high recruitment sites. River mouths and areas of river confluence that are characterized by intense periods of oyster recruitment provide a unique opportunity by providing large quantities of wild oyster spat for use in aquaculture operations within headwater areas and for stock enhancement initiatives. Oyster habitat restoration programs that rely on local oyster recruitment patterns should incorporate recruitment monitoring to determine when to attempt restoration and what methods to employ at any given site. Oyster recruitment monitoring is an essential tool when developing management strategies for shellfish lease stock enhancement, oyster habitat restoration, oyster culture, and overall management of oyster resources within any particular estuary.

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