Project Title: Bay scallop restoration through protecting transplants

Project Number: 06-EP-04 FRG

Principal Investigators: Charles H. Peterson and David Gaskill

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2 – 6. Abstract – Discussion
These sections of the final report are covered by the two manuscripts that are attached. We have chosen to deviate from the standard final report format and respond in this manner for two reasons. First, combining all of the research projects that we conducted as part of this study into a single draft produces a document that is cluttered and unwieldy. Separating the portions into self-contained papers improves the clarity of our presentation for all those who would benefit from reading it. Second, by preparing the report in this manner it decreases the interval of time until our results can be reported to the appropriate scientific and user communities as restructuring and rewriting of a single, complicated final report into separate reports need not be done. Immediately below, we provide a concise summary of our accomplishments. The manuscripts detailing the studies and their results are appended.

Meeting Grant Objectives (Grant proposal objectives are italicized)
1 & 2) Transplanting adult scallops into spawner sanctuaries enclosed in stockades and assessing the density of scallops in protected and unprotected grassbeds in the fall . These tasks were completed twice, once in each spawning season – in spring 2008 and again in fall 2008 - and are described in the Fegley et al. manuscript below.
3) Sample scallop recruits in 2007. This task was completed in both 2007 and 2008. The results are described in the Fegley et al. manuscript below.
4) Install complete and gaping spat collector bags to test their ability to protect scallop recruits from predation. This task was completed. A complete description is provided in the Wong et al. manuscript below.
5) Explore the potential for establishing a cownose ray fishery. We motivated fishermen from Pamlico County to capture, hold and market a few hundred cownose rays during 2006 as a test of whether developing a fishery in North Carolina can be readily achieved. The fishermen held the rays in pens and were successful in selling the meats to a fish dealer over about a month's time. However, by the end of that month the market demand had become saturated and they were unable to move any more product. This experience led us to conclude that substantial market development is necessary to make a cownose ray fishery viable in North Carolina, requiring substantial time and resources. No further details of this effort are provided.

7. Impacts and Benefits – We discuss how our results can improve existing practices associated with restoring bay scallops to North Carolina sounds in the Fegley et al. manuscript. Many components of this study were conducted at spatial scales appropriate for management; consequently adoption of our techniques could be readily done by the appropriate state or federal agencies. We are only now beginning to transfer our results to those agencies by the preparation and release of the appended manuscripts (see below), so we cannot identify specific changes that have been made in management policy as a consequence of this study's results.

8. Extension of Results – Newspaper reporter, Ryan Hutchins, wrote an article on our work with the spawner sanctuaries in stockades that appeared in the North Carolina section of the Virginian Pilot on 22 August 2008 (the archived article is appended below). A brief article was published in the Carteret County News Times one week later (also appended below).

On 7 April 2008 we gave an oral presentation on the results of our spat collector bags and the use of the shore-side pond at the National Shellfisheries Association annual meeting held in Providence, Rhode Island (abstract is appended below). The talk was part of a day-long special session on the status of bay scallops in North America. Almost all of the bay scallop researchers and many managers from

states along the entire eastern and gulf coasts were present to hear our results. We have had individual discussions with Mark Hooper, Jimmy Morris, and Dana Schmidt, among others, about our results. In November we submitted a written overview of our results to Tina Moore of the NC Division of Marine Fisheries. She requested the review for the specific purpose of keeping the Marine Fisheries Commission informed of our progress. Ms. Moore has also asked us to participate in discussions with the bay scallop management plan development team to assist in revising the existing management plan. We plan to publish our results in the Journal of Shellfish Research.

9. Students - No undergraduate or graduate students were supported with this project's funds.

Budget Summary – Other than two extensions, no budget revisions were requested or made for this project.

Disposition of Equipment – No equipment was purchased using the funds associated with this grant.

Attachments:
1. Wong et al. manuscript
2. Fegley et al. manuscript
3. The Virginian-Pilot news article followed by the Carteret County News-Times article
4. National Shellfisheries Association Annual Meeting abstract
5. Electronic copy of raw data and final report on CD.

Attachment #1

Do mesh bags used to hold settlement substrata in bay scallop spat (*Argopecten irradians*) collectors help inhibit predation?

Melisa C. Wong[1], Charles H. Peterson, David Gaskill
Institute of Marine Sciences, University of North Carolina at Chapel Hill, 3431 Arendell Street., Morehead City NC, 28557 USA

Running head: Do spat collectors inhibit predation of bay scallop spat?
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Abstract
The abundance of bay scallops (*Argopecten irradians*) in the sounds of North Carolina has declined sufficiently to require closure of the decades-old fishery. To date, most restoration efforts have focused on enhancing survival of adult scallops, with little emphasis on enhancing recruitment. Recently settled scallop spat and juveniles on the sea bottom and on seagrass blades often succumb to high rates of predation by benthic fish and crabs. In this study, we examine if spat collectors suspended in the water column serve not only as settlement substratum but also protect scallop spat from benthic predators. Spat collectors with access holes to allow predator entry and intact collectors without holes were deployed at 4 field sites in the fall 2006 settlement season for ~1 mo. Bay scallop spat were found in both types of collectors, but mean abundance did not differ between the two different types of spat collectors. Additionally, predatory crabs and fishes were also found inside both types of collectors. Comparison of our data to other studies in the literature that quantify predation of scallop spat on the sea bottom suggests that spat collectors may nonetheless enhance survival of spat, depending on site characteristics and timing of collector deployment.

Keywords: bay scallop, *Argopecten irradians*; North Carolina, predation refuge, predators, restoration, spat collector

Introduction

Bay scallops (*Argopecten irradians*) have traditionally supported an important fishery in central North Carolina, particularly during the winter months when yields of other commercial species are low. In recent years however, abundance of bay scallops has significantly declined over its range in the sounds of central North Carolina (Peterson et al. 2001; Myers et al. 2007). While red tides can negatively reduce scallop survivorship and recruitment (Peterson and Summerson 1992), a more recent cause of decreased scallop abundance is from cownose ray (*Rhinpotera bonasus*) predation (Peterson et al. 2001). Large schools of rays are present in North Carolina sounds during the southward migration in late summer. Exclusion experiments have shown that cownose rays significantly reduce densities of adult bay scallops during this migration (Peterson et al. 2001, Myers et al. 2007). These scallops are consumed before the main fall spawning period, depressing spawning stock biomass. Additionally, the surviving adult scallops are generally reduced to densities below that required to produce a viable year class of recruits that can support the fishery (< 2 scallops m^{-2}; Peterson and Summerson 1992; Powers and Gaskill 2005). Interference with successful fall recruitment represents a critical bottleneck to North Carolina bay scallops because, although they also spawn in spring, the spring cohort is heavily preyed upon and contributes little to adult populations (Bishop et al. 2005).

The observed increase in predatory rays (Meyers et al. 2007) suggests that bay scallops in North Carolina will not achieve sustainable population numbers without active restoration intervention. Previous restoration research has examined ways to enhance survival of adult bay scallops (Peterson et al. 2001). Research on bay scallop recruitment has been limited to optimizing collection of wild spat (Ambrose et al. 1992), relieving recruitment limitation by establishing spawner sanctuaries (Peterson and Summerson 1992; Peterson et al. 1996), and examining the seasonal dependence of recruit survival on predators (Bishop et al. 2005). Little research to date has focused on enhancing the short-term survival of new recruits by limiting predation. Active protection of scallop spat and juveniles from benthic predators, in conjunction with enhancing adult scallop survival, may provide a viable restoration option for bay scallop populations. Our objective was to determine if survival of bay scallop spat could be enhanced by reducing predation from benthic fish and crabs. Specifically, we tested if spat collector bags, commonly used by aquaculturists to collect wild scallop spat, help protect new recruits from predation. These bags are designed to hold an internal mesh substrate on which scallop larvae can settle. The bags are made of mesh to allow passage of larvae, food particles, and dissolved gasses. But this mesh may also serve an important function of reduction of predation on the small spat and juveniles. The mesh bags may even overcome an early population bottleneck for naturally exposed scallops. To test the protective ability of spat collector bags, we conducted an experiment to compare survival of spat inside intact collector bags to survival in bags with predator access holes.

Materials and Methods

Field experiments

Field experiments were conducted in Bogue and Core Sounds, North Carolina, USA (Figure 1). 2 sites were located in Bogue Sound (close to Intracoastal Waterway markers 34 (Bogue Sound 1) and 38 (Bogue Sound 2): 34.693, 76.988 and 34.691, 77.015, respectively) and 2 sites were located in Core Sound at Yellow Shoal (34.720, 76.471) and Goose Bay (34.740, 76.588). These sites were chosen based on previous studies indicating locally high spat production (Ambrose et al. 1992) and the presence of seagrass habitat suitable for natural spat settlement. The sites were all approximately 1.0 m deep at mean low water and water temperature ranged during our deployment periods from 24-29°C in August to 18-24°C in October 2006.

Two strings each containing 10 spat collector bags were deployed at all sites. The strings consisted of a 5-m length of polypropylene rope anchored at each end with a cinder block, with collector bags tied every 0.5m. Collector bags were constructed using 25-mm^2 mesh "onion" bags (82 cm long high x 48 cm wide) that were filled with $1m^2$ of 25 mm^2 mesh screen. Two pieces of styrofoam (30 cm long x 10 cm wide x 1.5 cm thick) were placed in each bag to achieve vertical flotation off the bottom. To test the protective ability of the bags, 5 bags on each string were left unaltered and intact, whereas 5 bags had a 10 cm x 10 cm hole cut out at the centre of both sides of the bag to allow predator entry. Intact and gaping bags alternated along each string.

Strings of collectors were deployed in both August 2006 and October 2006 for approximately 1 month. Upon retrieval, bags were individually packaged and frozen at the laboratory until sorting took place. During sorting, all animals in each bag were identified to species, counted and measured. The five largest bay scallop spat and the remaining scallops (or a subsample of 40 scallops if abundance was high) were measured to provide shell height (SH), the distance from the hinge to the outermost margin of the shell. Crabs were measured for carapace width (CW) (distance between the outermost points on the carapace), and fish were measured as standard length (SL) (distance from the mouth to the base of the caudal fin).

Data analyses

Data for animal abundances found in the collectors were analyzed using a nested analysis of variance (ANOVA). Site, time and bag integrity were fixed factors, and string was nested within the

interaction between site and time. The full analysis was initially performed using the appropriate error terms (Winer et al., 1991). When interactions with string were highly nonsignificant ($p \geq 0.20$), these interactions were pooled and a partial mixed model performed (Wong and Barbeau, 2003). When string was also highly nonsignificant ($p \geq 0.20$) we used a full fixed model ANOVA. Counts of spider crabs and mud crabs were combined to provide enough data for analysis. Data for size of animals in collectors were analyzed using a 3-way ANOVA, with site, time and bag integrity as fixed factors. String was excluded as a factor to provide enough size data for analysis. Additionally, scallop size was analyzed only for time 1, and blood ark and spider crab size were not statistically analyzed because of insufficient data. In all analyses, the homogeneity of variance assumption was tested using Cochran's test. The square root (datum) or log (datum+0.1) transformation corrected any violations of this assumption. For multiple comparisons, Student-Newman-Kuels (SNK) test was used.

Results

Scallop recruits were found in collectors at all combinations of site and time (Figure 2). However, bay scallop abundance did not differ significantly between intact and gaping bags (Table 1). Scallop abundance was significantly affected by the interaction between site and time: it was higher in August than in October at all sites, and at Yellow Shoal in August than at all other sites at this time. Another bivalve, the blood ark (*Anadara* sp), was also found in the collectors (Figure 3). As with scallops, ark abundance did not vary significantly with bag integrity (Table 1). Ark abundance was significantly higher in August than in October, and at Goose Bay than other sites, but there was no site x time interaction.

Potential predators of scallop spat found in the collectors included blue crabs (*Callinectes sapidus*), spider crabs (*Libinia* spp.), mud crabs (Xanthidae) and two fishes (*Mycteroperca microlepis* and *Opsanus tau*) (Figure 4). Abundance of predators did not significantly differ between bags with and without holes except for blue crabs. Blue crab abundance was significantly affected by the interaction between site and bag integrity (Table 1), and was higher in intact bags than bags with holes at Bogue Sound site 1. Abundance of spider and mud crabs was significantly influenced by the interaction between site and time (Table 1), and was highest at Goose Bay than the other sites in August. Only a small number of fish was found in the collectors in August: 2 gag groupers (*Mycteroperca microlepis*) at Bogue Sound site 1, and 6 oyster toad fish (*Opsanus tau*) in total at all other remaining sites. All fish except one gag were found in intact collectors without holes. Sizes of juvenile scallops, blood arks and predators did not differ significantly between intact bags and bags with holes (Table 2). The five largest scallops in each collector were significantly affected by the interaction between time and site, and were larger at Goose Bay and Yellow Shoal than at other sites in August. The five largest scallops were also significantly bigger in October than in August at both sites in Bogue Sound. Site had a significant effect on the remaining scallops smaller than the largest five (Table 2), but post-hoc comparisons could not identify where differences were. Mud crabs were significantly larger at Goose Bay and Bogue Sound site 2 than other sites. Blue crab size was not affected by any factor. Fish were 131±5.5 (n=4) and 92.3±17.0 mm in SL (n=6) for gag grouper and oyster toad fish, respectively.

Discussion

In our field experiment, collectors without holes did not have higher abundances of bay scallops than collectors with holes. Additionally, abundances of potential fish and crab predators did not differ with bag integrity, indicating that predators were able to enter collectors regardless of the presence of intentionally cut holes. At 100 mm x 100 mm, the holes cut into the outside mesh of some of our collectors were relatively large compared to the size of predators found in the collectors (~5-30 mm CW). Adult predators >80 mm CW were not found in either type of collector, despite gaping bags having holes large enough for entry of crabs ≤140 mm CW. The absence of large crabs in bags with holes and the

small sized crabs found in both types of bags suggests that predators invaded as larvae rather than from the sea bottom. Blue crab megalopae generally recruit to the sounds in central North Carolina between May and November, with a peak in September (D. Eggleston, pers. comm.). Mud crabs recruit from 166 July to October in Deleware Bay (Jones & Epifanio 1995); warmer water in North Carolina probably extends this to match blue crab recruitment. These recruitment periods overlap with bay scallops produced during the late summer spawning period, and the deployment of bags thus coincided with predator recruitment. Spat held in collector bags likely become susceptible to these rapidly growing predators shortly after settlement. In Atlantic Canada, sea star (*Asterias* sp.) and carnivorous gastropod (*Mytrilla lunata*) larvae often settle concurrently with sea scallops (*Placopecten magellanicus*) in collector bags, and are suspected of significantly reducing spat abundance (Tetu and Davidson, 2001). Freites et al. (2000) also found that pelagic larvae of potential predators such as gastropods (*Cymatium* sp.) and crabs (*Menippe nodifrons*, *Macrocoeloma diplacantum*) regularly recruited into suspended scallop (*Euvola ziczac*) culture nets. These predators reduced scallop densities significantly within a short time period (~35-96% scallop mortality after 1 month, 25 scallops net-1, 32 mm SH). Predation within collector bags is also evident during culture of other bivalve species. Friedman and Bell (1996) found that portunid crabs (e.g., *Thalamita quadridens*) and xanthid crabs (e.g., *Gaillardiellus orientalis*) set in collectors concurrently with blacklip pearl oyster spat (*Pinctada margaritifera*), and predation of spat occurred over the six-month period the collectors were deployed in the water. In our experiment, predatory crabs were likely capable of preying on the size of bay scallops present in the collectors. While no data to our knowledge of juvenile crab predation on bay scallop spat are available, Bisker and Castagna (1992) found that juvenile blue crabs (7-45 mm CW) consumed oysters (*Crassostrea virginica*) 1-30 mm SH. Also, MacKenzie (1977) found that juvenile blue crabs (8.1-20.2 CW) and mud crabs (6.2-17.2 mm CW) consumed hard clams (*Mercenaria mercenaria*) as small as 4.5 mm SL (the smallest size offered). Thus, the crabs found in our collectors were able to consume the scallops which ranged in size from 189 5 to 15 mm SH, and could potentially reduce scallop survivorship.

Because adult predators did not enter the bags with holes, the intact and gaping bags used in our experiment did not adequately test the protective potential of spat collectors. Instead, comparison of spat survival in collectors to survival on natural substrates may better reflect the protective ability of the bags. Bay scallop larvae settle preferentially on seagrass (*Zostera marina*) blades. This choice elevates the recruits off the bottom, providing a refuge from benthic crab predators (Pohle et al. 1991, Ambrose & Irlandi 1992). Pohle et al. (1991) found that survival of scallops (6-20 mm SH) 4 days after deployment in the field was ~60-80 % for scallops tethered high on grass blades compared to ~5-20 % for those tethered at the sediment surface. Complementary laboratory experiments suggested that most mortality was caused by crab predation. Ambrose and Irlandi (1992) found similar results, where scallops (12.3 mm SH) tethered at 15 cm off the bottom had higher survival than those tethered close to the bottom. Although scallop recruits high on seagrass blades gain some protection from predation, they remain susceptible to crab species that can readily climb grass blades (e.g., *Dyspanopeus sayi*) (Pohle et al. 1991). Collector bags provide an elevation refuge similar to seagrass blades, but may simultaneously enhance survival compared to that on the bottom, even with predator recruitment into the bags. Deploying collector bags early in the settlement period and removing before predators grow large enough to significantly reduce scallop abundance may also enhance survival. A direct test to compare survival rates on the bottom to those in suspended bags needs to be conducted.

The protective ability of spat collectors may also depend on the geographic location where collectors are deployed. In our field experiment, abundances of scallops and predators differed among sites. Scallop abundance was highest in August at Yellow Shoal, perhaps because crab abundances in collectors were relatively low here compared 213 to other sites. Collectors deployed at sites with naturally low predator abundances or poor delivery of predator larvae should yield relatively high scallop survival. Additionally, collectors deployed in locations with better food delivery may allow scallops to

grow at an accelerated rate and reach a size refuge from predation more quickly than at other sites. In our experiment, bay scallop recruits inside collectors were largest at Goose Bay and Yellow Shoal and may have attained a size refuge from some predation faster than scallops at other sites. Thus, the protective ability of collectors may be enhanced by taking specific site characteristics into account.

Because predator abundances did not differ between intact and gaping collector bags in our experiment, we were unable to demonstrate and quantify the refuge value of spat collector bags. However, based on results of tests of elevation alone (Pohle et al. 1991, Ambrose & Irlandi 1992), it is likely that collectors provide increased survival when compared to survival of spat directly on the sediment surface. This protection may only be short term, but could allow scallops to grow to sizes less susceptible to predation. Additionally, the degree of protection provided by collectors is likely influenced by additional factors such as specific site characteristics.

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Figure captions for Wong et al.

Figure 1. Map of central North Carolina coast showing where spat collectors were deployed. BS1=Bogue Sound site 1, BS2=Bogue Sound site 2, YS=Yellow Shoal, GB=Goose Bay.

Figure 2. Mean abundance of bay scallop recruits (*Argopecten irradians*) in collectors in (a) August 2006, and (b) October 2006. Site abbreviations as in Figure 1. Error bars=1 S.E., n=5-10.

Figure 3. Mean abundance of blood arks (*Anadara* sp.) in collectors in (a) August 2006, and (b) October 2006. Site abbreviations as in Figure 1. Error bars=1 S.E., n=5-10.

Figure 4. Mean abundance of (a, d) blue crabs (*Callinectes sapidus*), (b, e) spider (*Libinia* spp.) and mud crabs (Xanthidae) in August and October 2006, and (c) fish (*Mycteroperca microlepis* and *Opsanus tau*) in August 2006. Site abbreviations as in Figure 1. Error bars=1 S.E., n=5-10.

Table 1. ANOVA results for abundance of scallops, arks and predators 296 found inside spat collectors. Scallop, blue crab, and spider and mud crab abundance were square root transformed. Ark abundance was log(datum+0.1) transformed. T=time, S=site, B=bag integrity. T1=August 2006, T2=October 2006, BS1= Bogue Sound site 1, BS2= Bogue Sound site 2, GB=Goose Bay, YS=Yellow Shoal, B1=gaping bag, B2=intact bag. Significant p-values are indicated in bold.
For post-hoc comparisons, treatment level means are listed in increasing magnitude; those sharing a common underline do not differ significantly.

Dependent variable	Source of variation	Effect MS	Error MS	$F_{df1,df2}$	P	Post-hoc comparison
Scallop T		605.2	1.923	$313.9_{1,101}$	<0.0001	
	S	208.8	1.923	$108.3_{3,101}$	<0.0001	
	B	0.333	1.923	$0.17_{1,101}$	0.679	
	TxS	201.5	1.923	$104.5_{3,101}$	**<0.0001**	T1: <u>BS1 BS2 GB</u> YS T2: <u>BS1 BS2 YS GB</u> BS1: T2 T1 BS2: T2 T1 GB: T2 T1 YS: T2 T1
	TxB	2.611	1.923	$1.35_{1,101}$	0.247	
	SxB	1.072	1.923	$0.56_{3,101}$	0.645	
	TxSxB	3.040	1.923	$1.58_{3,101}$	0.200	
Ark	T	3.064	0.183	$16.8_{1,8}$	**0.004**	T2 T1
	S	10.53	0.183	$57.6_{3,8}$	**<0.0001**	<u>YS BS1 BS2</u> GB
	B	0.014	0.442	$0.03_{1,8}$	0.862	
	TxS	0.500	0.183	$2.73_{3,8}$	0.114	
	TxB	0.309	0.442	$0.70_{1,8}$	0.427	
	SxB	0.105	0.442	$0.24_{1,8}$	0.868	
	TxSxB	0.189	0.442	$0.43_{1,8}$	0.738	
Blue crab	T	1.933	0.612	$3.16_{1,101}$	0.078	
	S	1.135	0.612	$1.86_{3,101}$	0.142	
	B	1.136	0.612	$1.86_{1,101}$	0.176	
	TxS	0.233	0.612	$0.38_{3,101}$	0.767	
	TxB	0.012	0.612	$0.02_{1,101}$	0.894	
	SxB	1.960	0.612	$3.20_{3,101}$	**0.026**	B1: <u>BS1 GB YS BS2</u> B2: <u>YS GB BS2</u> BS1 BS1: B1 B2 BS2: <u>B1 B2</u> GB: <u>B2 B1</u> YS: <u>B2 B1</u>
	TxSxB	1.759	0.612	$2.88_{3,101}$	0.039	
Spider and mud crab	T	0.768	0.555	$1.38_{1,101}$	0.242	
	S	5.336	0.555	$9.61_{3,101}$	<0.0001	
	B	1.061	0.555	$1.91_{1,101}$	0.170	
	TxS	3.422	0.555	$6.16_{3,101}$	**0.0007**	T1: <u>BS1 YS BS2</u> GB T2: <u>YS BS1 GB BS2</u>

					BS1: Y2 T1 BS2: T2 T1 GB: T2 T1 YS: T2 T1
TxB	0.044	0.555	$0.08_{1,101}$	0.779	
SxB	0.179	0.555	$0.32_{3,101}$	0.810	
TxSxB	0.651	0.555	$1.17_{3,101}$	0.324	

Table 2. Fixed factor ANOVA results for sizes of scallops, arks and crabs 304 found inside spat collectors. Remaining scallops other than the largest 5 (or a subsample of 40 if abundance was high) were analysed only at time 1 because not enough data were available at time 2. Remaining scallop size was square root transformed and mud crab size was log(datum+0.1) transformed. T=time, S=site, B=bag integrity. T1=August 2006, T2=October 2006, BS1= Bogue Sound site 1, BS2= Bogue Sound site 2, GB=Goose Bay, YS=Yellow Shoal. Significant p-values are indicated in bold. For post-hoc comparisons, treatment level means are listed in increasing magnitude; those sharing a common underline do not differ significantly.

Dependent variable	Source of variation	Effect MS	Error MS	$F_{df1,df2}$	P	Post-hoc comparison
5 largest scallops	T	60.94	6.018	$10.1_{1,93}$	0.002	
	S	1.257	6.018	$20.9_{3,93}$	<0.0001	
	B	1.222	6.018	$0.20_{1,93}$	0.653	
	TxS	55.74	6.018	$9.26_{3,93}$	**<0.0001**	T1: <u>BS2 BS1</u> GB YS T2: <u>BS1 GB BS2 YS</u> BS1: T1 T2 BS2: T1 T2 GB: <u>T1 T2</u> YS: <u>T2 T1</u>
	TxB	6.257	6.018	$1.04_{1,93}$	0.311	
	SxB	1.089	6.018	$0.18_{3,93}$	0.909	
	TxSxB	7.208	6.018	$1.19_{3.93}$	0.315	
Remaining scallops	S	8.948	1.048	$8.54_{3,52}$	**<0.0001**	<u>BS1 BS2 GB YS</u>
	B 0.	145	1.048	$0.14_{1,52}$	0.711	
	SxB	1.210	1.048	$1.15_{3,52}$	0.336	
Blue crabs	T	$2.7x10^{-6}$	5.973	$4.6x10^{-7}{}_{1,102}$	0.999	
	S	1.040	5.973	$0.17_{3,102}$	0.914	
	B	1.482	5.973	$0.25_{1,102}$	0.619	
	TxS	6.591	5.973	$1.10_{3,102}$	0.351	
	TxB	2.245	5.973	$0.37_{1,102}$	0.541	
	SxB	7.482	5.973	$1.25_{3,102}$	0.295	
	TxSxB	8.513	5.973	$1.42_{3,102}$	0.240	
Mud crabs	T	0.784	0.896	$0.87_{1,102}$	0.352	
	S	4.429	0.896	$4.94_{3,102}$	**0.003**	<u>YS BS1 BS2 GB</u>
	B	1.243	0.896	$1.39_{1,102}$	0.242	
	TxS	1.852	0.896	$2.06_{3,102}$	0.109	
	TxB	0.026	0.896	$0.03_{1,102}$	0.864	
	SxB	0.522	0.896	$0.58_{3,102}$	0.627	
	TxSxB	1.467	0.896	$1.64_{3,102}$	0.186	

Table 3. Mean (±1 S.E.) sizes of animals found in collector bags deployed for approximately 1 month in August and October 2006. All measurements are in mm. BS1=Bogue Sound site 1, BS2=Bogue Sound site 2, GB=Goose Bay, YS=Yellow Shoal. The sizes of the five largest scallops (*Argopecten irradians*) and the remaining scallops (or a subsample of 40 if abundance was high) are provided as shell heights. Blood ark (*Anadara ovalis*) size is shell length. Sizes of mud crabs (Xanthidae), blue crabs (*Callinectes sapidus*) and spider crabs (*Libina* sp.) are carapace width. Numbers in parentheses are sample size (n).

Time	Site	Hole in collector	Scallops (5 largest)	Scallops (remaining)	Arks	Mud crabs	Blue crabs	Spider crabs
August 2006	BS1	Yes	8.6±0.5 (25)	6.8±0.2 (41)	8.1±1.1 (5)		24.6±2.7 (9)	18.2 (1)
		No	8.8±0.5 (25)	5.8±0.1 (46)	3.5 (1)	9.3±2.5 (3)	22.1±1 (31)	32.0 (1)
	BS 2	Yes	8.6±0.6 (25)	5.5±0.1 (36)	8.5 (1)	13.5±2 (4)	19.0±1.6 (8)	
		No	7.8±0.6 (31)	5.6±0.2 (37)	7.3±0.4 (3)	10.4±1.1 (9)	20.5±1 (31)	
	GB	Yes	11.7±0.9 (34)	7.1±0.5 (42)	8.8±0.2 (52)	11.8±0.7 (31)	27.3±3.8 (13)	50.0 (1)
		No	14.4±0.8 (36)	11.0±0.7 (60)	8.3±0.3 (59)	11.4±0.4 (52)	28.4±3.2 (7)	22.3±6.1 (5)
	YS	Yes	15.0±0.3 (50)	7.5±0.1 (400)	6.6±0.8 (5)	10.6±0.7 (7)	28.5±1.7 (23)	26.8±12.3(3)
		No	16.6±0.3 (45)	8.2±0.1 (360)		13.3±1.1 (9)	30.6±6.8 (8)	
October 2006	BS 1	Yes	11.5±0.5 (15)			10.3±0.5 (4)	21.5±1.2 (3)	
		No	11.9±0.5 (17)			9.3±0.3 (7)	25.5±1.4 (17)	
	BS 2	Yes	12.4±0.6 (16)			13.4±1 (11)	30.5±1.9 (13)	25.4 (1)
		No	13.2±0.6 (14)			12.2±0.8 (6)	27.2±2.2 (10)	22.3±2.4 (2)
	GB	Yes	13.1±0.3 (29)	9.4 (1)	6.0±0.7 (11)	9.3±1.1 (6)	27.0±1.8 (8)	24.0 (1)
		No	12.0±0.5 (13)		6.1±0.6 (11)	9.9±1 (7)	20.5±1.6 (6)	
	YSl	Yes	14.5±0.4 (32)	11.7±0.6 (11)		5.2±0.3 (3)	26.3±1.5 (7)	
		No	13.7±0.7 (13)	13.8±1.8 (3)	3.5 (1)	5.8±0.7 (8)	22.6±1.4 (9)	

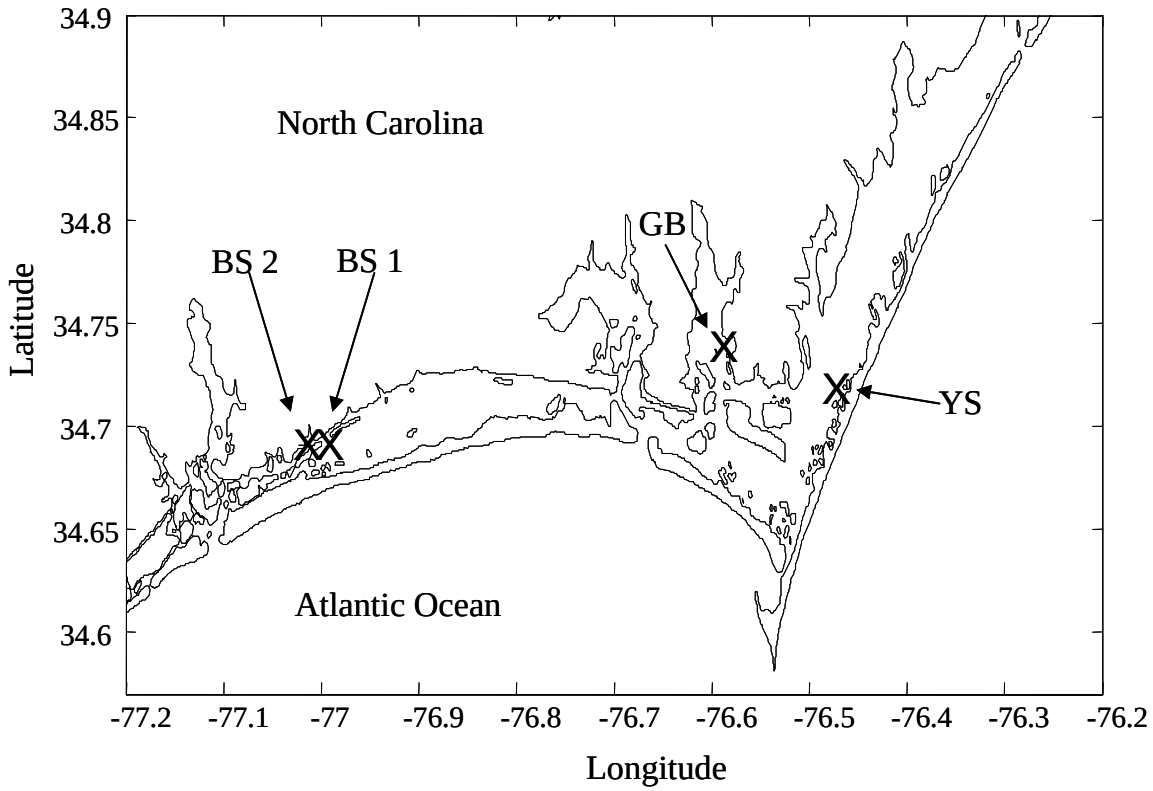

Figure 1 Wong et al.

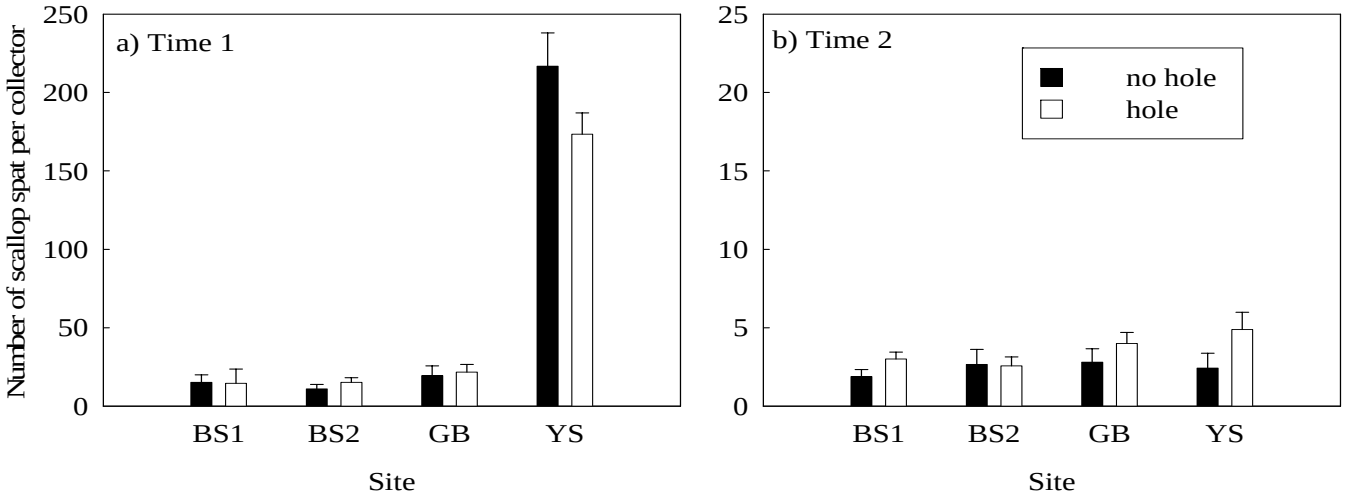

Figure 2 Wong et al.

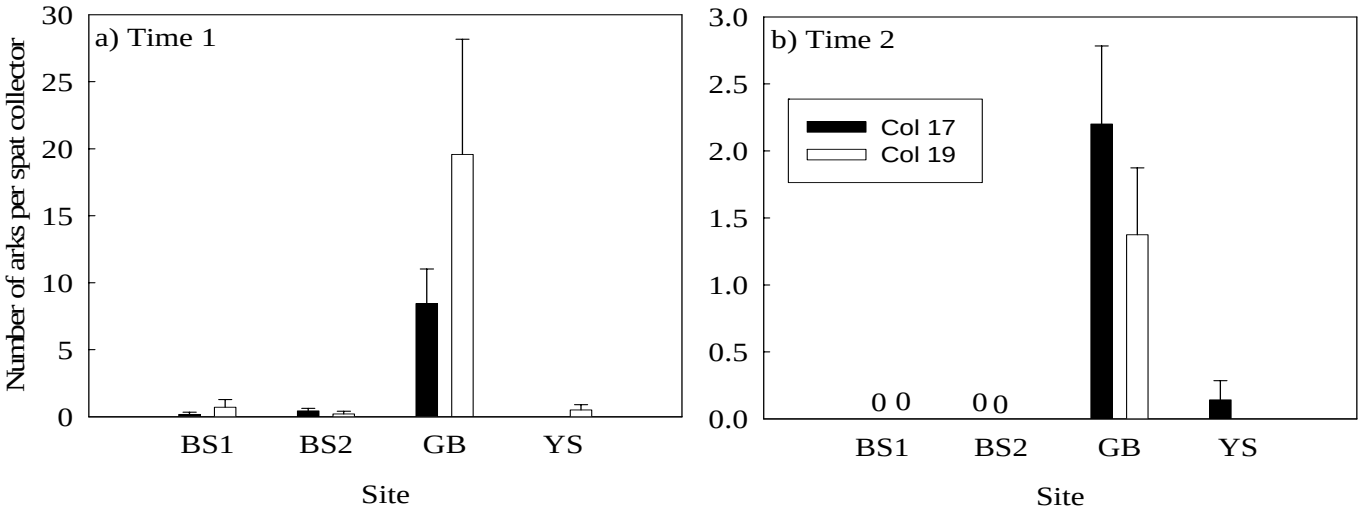

Figure 3 Wong et al.

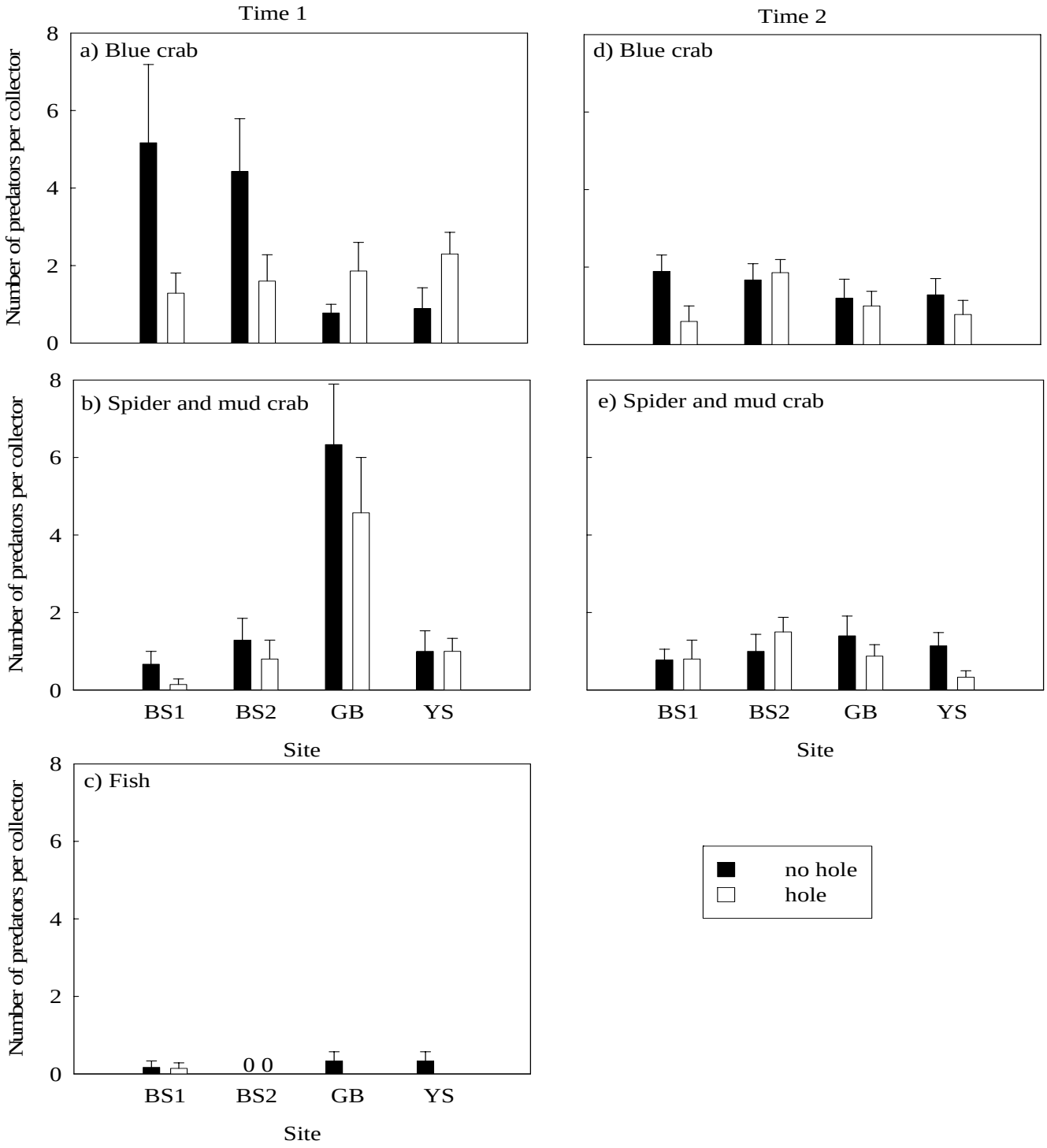

Figure 4 Wong et al.

Attachment #2

Enhancing the potential for population recovery: restoration options for bay scallop populations, *Argopecten irradians concentricus,* in North Carolina

Stephen R. Fegley, Charles H. Peterson, Nate Geraldi, and David Gaskill
UNC Institute of Marine Sciences
Morehead City, NC 28557

Abstract
Historically depressed bay scallop populations in North Carolina have retained some capacity to replenish themselves. However, continued abnormally high predation by cownose rays and growing degradation of seagrass beds may limit bay scallop population recovery. We modified existing methods for protecting spawning adult scallops from cownose rays (stockades) and enhancing scallop set (spat collectors in the natural habitat and in managed shore-side ponds) to determine whether the population growth of bay scallops could be enhanced. We found, with one important exception, that spawner sanctuaries inside stockades could be used to concentrate and protect adult scallops during a time when they are susceptible to ray predation. Spat collector bags proved effective not only in gathering scallop spat but serving as nurseries for juvenile scallop grow-out. The results from our pond experiments were mixed: spat collector bags did not do well in the pond but an alternative collector design holds promise for making shore-side ponds important sources for inexpensive scallop seed. The simple techniques examined in this study can be used to enhance the potential of bay scallop populations to recover from low abundances, and were applied successfully to enhance North Carolina bay scallops during the two years of this project.

Introduction

Justifications for investing resources to restore depleted shellfish populations have relied upon the need to revitalize moribund fisheries (MacKenzie 1983, Stotz 2000, Booth and Cox 2003) or to recreate lost ecosystem services (Coen and Luckenback 2000, French McCay et al. 2003) that are dependent on the target species. Multiple methods have been employed in shellfish restoration including: 1)) transplanting and protecting broodstock (e.g., Peterson et al. 1996), 2) seeding with hatchery-reared juveniles (e.g., Karney 1991, Summerson et al. 1995, Wilbur et al. 2005), and 3) habitat modification designed to enhance survival of early life-history stages (e.g., Thayer 1992). Which method is used depends on the status of the target species population and socio-economic factors (Booth and Cox 2003).

Bay scallop populations have decreased along the entire eastern coast of the United States in the past 50 years as a result of overexploitation, harmful algal blooms, and habitat loss (Peterson and Summerson 1992, Tettlebach and Wenczel 1993, Marelli et al 1999, Bologna 2008, Murphy and Walton 2008). Within North Carolina, bay scallops (*Argopecten irradians concentricus*) have experienced dramatic declines in population size over the past two decades. From October 1987 to February 1988, a red tide (*Karenia brevis*) outbreak in North Carolina sounds induced mortalities so severe in bay scallop populations that scallop recruitment was severely reduced in several subsequent years (Peterson and Summerson 1992). An attempt to restore bay scallop populations by transplanting adult bay scallops into a depleted water basin revealed that this species is recruitment-limited and that populations in different basins are largely hydrographically and reproductively isolated from each other (Peterson et al. 1996). This transplantation effort with subsequent natural recruitment from the spawning adults was

successful such that during the latter half of the 1990's bay scallop populations and fisheries recovered in most North Carolina sounds (NCDMF 2007). In the new century, North Carolina bay scallops have suffered a progressively severe and persistent decrease in population size that ultimately progressed to a complete collapse of the fishery, with no opening now for four years (NCDMF 2007). Schools of fall-migrating cownose rays (*Rhinoptera bonasus*) that have undergone dramatic population increases in response to release from their own predators, the great sharks, (Myers et al. 2007), migrate southward through North Carolina sounds in late summer and now apply sufficient predation pressure that they consume virtually all adult bay scallops before they complete spawning and before the opening of the fishery (Peterson et al. 2001).

Bay scallop biology in North Carolina has been described in detail in several reports (Peterson and Summerson 1992, Bishop et al. 2005, NCDMF 2007). The relevant features of their biology for this study are that bay scallop populations exhibit discrete, patchy distributions over their range (Gutsell 1930), within a region (Peterson et al. 1996, Arnold et al. 1998) and on a local scale (Thayer and Stuart 1974, Peterson et al. 2001), where higher abundances are generally restricted to patchily-distributed seagrass beds. The patchiness of their populations requires restoration efforts be directed at appropriate spatial scales to be effective. For example, water exchange among some North Carolina sounds is limited by hydrographic connectivity, which can create semi-isolated basins (Peterson et al. 1996). Restoration efforts must recognize this connectivity and direct efforts towards each basin. In addition, the important processes of scallop spawning and cownose ray predation are discrete temporally. Most bay scallop spawning occurs in mid August to late September in North Carolina: a smaller spring spawning event occurs but generally contributes few recruits to the fishery (Bishop et al. 2005). Cownose ray predation occurs from mid August to mid September (Peterson et al. 2001, Myers et al. 2007). Consequently, management practices enhancing scallop spawning and reducing cownose ray predation need occur only during this late summer, early fall window of time.

Milke et al. (2006) state that scallop restoration efforts that depend on hatchery-reared seed are limited by costs, insufficient numbers of scallop juveniles, and the slow growth of hatchery-produced scallops prior to seeding. Developing inexpensive means of producing large numbers of larger juvenile scallops from natural sets would help in bay scallop restoration efforts throughout its range. In addition, relying on natural set, as opposed to hatchery-raised larvae, avoids the problems associated with inbreeding that has burdened some scallop breeding programs (Zheng et al. 2008) and the costs of maintaining a hatchery. In this study we compare several, relatively inexpensive, practical methods designed to: 1) enhance adult bay scallop survival to the time of spawning and 2) increase bay scallop spat set, survival, and growth. For the first goal, we use temporary stockades made of plastic pipe to exclude rays from dense concentrations of adult scallops prior to and during the fall scallop spawning period. For the second goal, we deploy spat collector bags both to increase the available surface area for scallop settlement and then subsequently to serve as field-based nurseries for those scallops. Spat collectors have been used to collect and grow natural spat for enhancing *Placopecten magellanicus* stocks (Parsons and Robinson 2006), but collectors have been underutilized as a means of enhancing bay scallops. We also examine alternative spat collector designs to test whether spat collector bags are the best design for attracting and growing scallops. Finally, we explore the use of shore-side salt ponds for scallop production. Bishop and Wear (2005) provide evidence that increased fish predation on juvenile crabs in the fall enhances juvenile bay scallop survival through a depression of crab predatory pressure. Isolated ponds can be managed to reduce the abundance of scallop predators and, by suppressing predation on juvenile scallops, could allow methods of increasing production for scallop spat and juveniles that are not possible in the field.

Materials and Methods

Study Sites

In North Carolina, commercially viable bay scallops populations have historically been highest in three contiguous sounds: Core, Back, and Bogue Sounds (Fig. 1). In almost every year in which harvest of bay scallops occurred in NC, at least 75%, and usually more, of the harvest came from these three water bodies (NCDMF 2007). Our study sites encompassed this entire region in both 2007 and 2008. In the first year (2007) we established spawner sanctuaries inside stockades in Back Sound (at Middle Marsh) and western Bogue Sound (near Lovett Island) and in the second year (2008) at Middle Marsh, Lovett Island and in northern Core Sound (at the Swash). In both years, we also introduced spat collectors at Middle Marsh, Lovett Island, Yellow Shoal (southern Core Sound), and in a shore-side, mesocosm pond at the UNC Institute of Marine Sciences (eastern Bogue Sound). In the second year we also placed spat collectors at the Swash (Fig. 1).

Detailed descriptions of these sites can be found in other studies (Peterson et al. 1989, Peterson et al. 2001, Bishop et al. 2005, NCDMF 2007). In general, all of sites (except the mesocosm pond) are shallow (generally <1 m water depth at low tide), subtidal locations within or near seagrass beds dominated by *Zostera marina*. All of the sites: 1) have supported abundant bay scallops historically; 2) experienced cownose ray predation during their September migrations in the past decade; and 3) maintained persistent, if greatly reduced, scallop production since 2007.

The 18 m x 29 m shore-side mesocosm pond at IMS was 1.2 m deep at the center and remained ~1 m deep to within 1 – 2 m of the pond edge, where the basin graded upwards to dry land. The basin substrate consisted of fine sand. Unfiltered seawater, pumped from nearby Bogue Sound, entered the pond in 2007 at 6 L s^{-1} from a pipe on the southern edge and flowed out of the pond through a centrally located standpipe. In April of 2008 before introducing spat collector bags, we relocated the pipe that supplies water from the southern edge to the southwest corner of the pond to increase the distance between where the water entered to where it drained into the standpipe. We chose to use a shore-side salt pond as one of our sites for several reasons. The pond provided greater environmental control so spat collector bags would not be damaged or lost by wind or waves. The pond enabled us to reduce predation risk dramatically on juvenile scallops by using baited, commercial crab pots, lined with 2-mm plastic mesh, as well as by draining the pond periodically to kill predators not captured by the crab pots. Finally, the pond allowed efficient examination, manipulation, and retrieval of spat collectors.

Spawner sanctuaries inside stockades

During the latter half of August or very early September in 2007 and 2008, prior to the expected season of southerly migration of cownose rays through Core, Back, and Bogue Sounds, we created spawner sanctuaries for adult scallops and protected them by erecting stockades modified from those used by Peterson et al. (2001). Each stockade consisted of 2.5-m long poles of 2.54-cm diameter PVC pipe, inserted 30 - 40 cm vertically into the sediments at 0.25-m intervals, extending 1 - 1.5 m above the water at high tide. Except for the stockade at Middle Marsh in 2007, all of the stockades were circular in shape with a 13-14 m radius. The Middle Marsh stockade in 2007 was rectangular (10 m wide x 27 m long). After we erected each stockade, we collected, by hand, all adult bay scallops readily located in the immediate vicinity (5 m) of the stockade, and added them to those already inside. After a minimum of 1000 scallops had been transferred into the stockade, we estimated initial scallop densities at low tide inside and within a 5-m wide donut outside the stockade by haphazardly placing at least 30 replicate 0.25 m^2 quadrats throughout each area and counting the adult bay scallops in each quadrat.

We resampled and dismantled the stockades several weeks after we had evidence that: 1) bay scallops had spawned locally (based on visual inspections of bay scallop gonads); and 2) cownose rays had completed their migration (based on reports from local gill-net, pound-net, and trawl fishermen and our own visual searches). In October and November of each year, we revisited each site to assess the

density of scallops inside and outside of the stockades (using the same sampling procedure as before) and to retrieve the poles. The poles were brought back to land, allowed to sit outside and dry for two months, and then scraped clean of all fouling organisms in preparation for reuse in a subsequent year.

Deployment of spat collector bags

We modified slightly the design of the spat collector bag used by Ambrose et al. (1992). Our spat collector bag consisted of 4 m^2 (4.33 x 0.93 m) of transparent, 8.33-mm mesh netting stuffed into a 5-mm mesh "onion" bag (0.82 x 0.48 m) in which two, 30 x 10 x 1.5 cm pieces of Styrofoam had already been placed as far from the opening as possible. The drawstring on the open end of each "onion" bag was cinched and knotted to secure the Styrofoam and netting. Based on the thickness of the plastic strands of the mesh and the total area of meshed used, the internal netting provided a maximum of 850 cm^2 of potential surface area for setting (the actual area would be somewhat less and variable depending on how each piece of netting folded when placed within the bag). Surfaces of the interior of the "onion" bag and of the Styrofoam could also serve as setting substrate, bringing the total, possible available surface area on the interior of each spat collector to 1.48 m^2.

In 2007, as we deployed the spat collector bags, we attached ten (or occasionally five) bags at 1.0-m intervals to a continuous, 12-m length of 3/8" polypropylene rope, by braiding the onion bag draw strings into the rope strands. Cinder blocks were tied to each end of the rope and at the middle to anchor the cinched end of each bag within 20-cm of the bottom substrate (Fig 2). We placed each ten-bag array of spat collectors in water depths sufficiently deep (~1.5-m at MLW) that bags would remain fully submerged at low water. When we returned to the sites later in the year, we found that chaffing of the anchor lines against the cinder blocks often led to torn anchor lines and losing collectors before their recovery. In response, we modified the method of securing collector bags in 2008. We replaced each cinder block in the collector array with a 3.05-m long piece of 2" (5.08-cm) diameter PVC pipe. One end of each pipe was beveled and a hole was drilled through the pipe 0.75 m from the beveled end. In the field, we threaded the anchor rope through the hole in the pipe, tying it firmly, and inserted the pipe vertically (beveled end down) into the sediments until the hole, and attached anchor line, was at the substrate surface. Pipes were placed at both ends and at the middle of the rope anchor line. We attached spat collector bags, as before, at 1-m intervals to complete the array.

In August and September 2007, we installed 35 spat collectors in each of five locations: Yellow Shoal (southern Core Sound), Middle Marsh (western Back Sound), Lovett Island (western Bogue Sound), Hoop Pole Creek (eastern Bogue Sound) and the UNC Institute of Marine Sciences (IMS) mesocosm pond (also eastern Bogue Sound). In October, November, and December, we revisited each site and removed five, haphazardly selected, spat collector bags, which were immediately enclosed within large plastic bags for transport to the laboratory. There, each bag was immediately examined or held within a cold-room at 40°C until they could be processed. Examination of each collector involved: 1) opening the onion bag exterior and removing the interior mesh; 2) collecting any scallops attached to the interior of the onion bag or the Styrofoam pieces; 3) collecting all scallops attached to the interior mesh; and 4) washing all surfaces onto a 1-mm mesh screen that was then examined for the presence of any scallops. All recovered scallops were placed in labeled jars containing formalin. We counted all scallops from each spat collector and estimated their size-frequency distribution by measuring, to the nearest 0.1 mm, shell height (umbo to ventral margin distance) of each scallop (up to a maximum of 40 individuals per collector bag). Because haphazard sampling can underestimate small individuals, we identified and counted all scallops <3mm in shell height in each sample. In March 2008, we retrieved all remaining spat collector bags and processed them as before, except that we counted and measured (up to a maximum of 50 individuals per bag) the scallops while alive.

In August and September 2008, we placed a total of 20 spat collector bags, in strings of 10 as before but anchored by PVC poles, in each of five locations: Yellow Shoal, Middle Marsh, Lovett Island,

the Swash, and the IMS mesocosm pond. The bags were retrieved in December and processed like the March set, when all counts and measurements were made on live individuals and a maximum of 50, haphazardly-selected individuals was measured from each collector bag.

Spat Collectors Reclining on the Bottom

We tested the ability of alternative spat collector designs to collect scallops by comparing their returns against the standard spat collector bag in a protected environment, the IMS mesocosm pond, in spring and fall 2008. The natural spring recruitment of bay scallops in North Carolina is generally trivial in large part because of intense predation on juveniles by crabs and fishes entering the estuarine nursery (Bishop et al. 2005). We hypothesized that our ability to control predators through the use of traps and periodic drainings of the pond could allow us to collect and protect substantial numbers of recruiting bay scallops even when recruitment success in nature was minimal. Three new spat collector designs (Fig. 3) were created to test spat collecting success across a range of alternative designs and to take advantage of the expected higher growth rates experienced by juvenile scallops when they are attached close to the substrate (Ambrose and Irlandi 1992) as opposed to suspended in bags higher above the bottom. An "artificial seagrass bed" (ASB) collector consisted of a 1 m x 1m frame made of 0.5" PVC pipe with a grid of monofilament lines criss-crossing the frame at 5-cm intervals along each margin. At every intersection of lines, four 12-cm long, 0.5-cm wide pieces of plastic ribbon were tied: the ribbon has the buoyancy and dimensions of an eelgrass blade (Micheli et al. 2008). An X-shaped (X) collector was made by interweaving the middle of two, 90 cm long x 31 cm high strips of 0.5-cm plastic mesh strips to produce a structure that, when standing vertically, was x-shaped as viewed from above. At the intersection of the mesh strips and at each end, a 40-cm long, 3/8" iron rebar stake was attached, with the top of the rebar flush with the top of the mesh and extending about 10 cm below the bottom of the mesh. A half-pipe (HP) collector was produced by cutting a 16-cm diameter, 94-cm long, corrugated, plastic drainage pipe into half longitudinally. A brick was attached to the lower surface of the cut pipe so that the collector would rest on the bottom with the concave surface upward. Based on overall dimensions and direct measurements of surface dimensions, we estimated the potential surface area (on all exposed surfaces in each case) of each collector type available for setting by juvenile scallops as: ASB = 2.08 m^2; X = 0.42 m^2; and HP = 0.93 m^2 (versus the 1.48 m^2 available on the inside of each spat collector bag).

On 29 April 2008 three replicates of each collector type were arranged randomly in a Latin Square design within each of four blocks, spatially defined by each of the four quadrants of the IMS mesocosm pond. The pond, which had been drained and dried for three weeks, was filled with unfiltered seawater two days before the experiment began. Two linear arrays (using the same design that we used in the field, as described above), each with 10 spat collector bags, were placed along the midline of the pond. Two, baited, commercial crab pots that had been completely lined with 0.5-cm plastic mesh were placed in the pond and fished every 2-3 days throughout the period of the experiment. On 2 June 2008 the pond was drained. Before the spat collectors were completely exposed, all were carefully lifted from the substrate, a 0.1-cm mesh net was placed under each, and all scallops and any crabs that were present were collected from the collectors or mesh net by hand and counted. The spat bags were processed as described above.

On 19 August 2008 three replicates of the "X" collector and three replicates of the "half-pipe" were randomly placed into each of four blocks located within the IMS mesocosm pond. As in the experiment conducted in the spring, the pond had been drained and allowed to dry for three weeks prior to starting the experiment. Two linear arrays of spat bag collectors (10 bags each) were installed along the midline of the pond. The pond was fished in the same manner as in the spring, using two meshed crab pots. On 19 December 2008 sixteen of the spat collector bags were removed from the pond and processed as in the spring. While retrieving the spat collector bags, we observed that some of

the scallops on the bottom collectors had reached the size at which they detached from substrate. Because some of the scallops that had been collected by these devices may have already fallen to the substrate surface, we changed our procedure, from what we did in the spring trial, when we sampled the bottom collectors. Specifically, on 22 December 2008 the pond was drained completely and all scallops attached to each collector, or below each collector, were gathered, counted, and measured (shell height to the nearest 0.1 mm). The presence of any crab was noted, but none was counted or measured.

Results

Spawner sanctuaries inside stockades

In both years and at all locations, stockades maintained almost complete structural integrity during the entire field deployment. The stockades were visited at irregular intervals of four to six weeks. Very few (0 – 5) gaps (created by poles falling into the water) occurred along the perimeter of any stockade and never was any gap greater than 0.5 m. Any gaps noticed during a visit were repaired by restoring the pole to its vertical position.

At Lovett Island (in western Bogue Sound) in both 2007 and 2008, and the Swash (in northern Core Sound) in 2008, adult scallop densities inside the stockades remained elevated above those outside from the time when we first established the sanctuaries through the season when cownose rays typically migrate through the region and prey on scallops (Table 1). The changes in scallop density through the fall differed between years at Lovett Island and between sites in 2008. As revealed by separate, two-way ANOVA's, at no site in either year, was there a significant interaction between time and location (inside or outside of a sanctuary) (Table 2). In 2007, the density of scallops inside the Lovett Island sanctuary decreased by 21.4% from August to October, while the scallop density outside decreased by 78.6%. At the same location in 2008, adult scallop density stayed roughly the same inside the sanctuary (increased by 0.3%), while the outside density increased by 42.4% from August to November. In the Swash, scallop density decreased to a similar degree inside (-54.9%) and outside (-57.1%) from August to November. The only significant decrease in scallop densities over the fall time interval occurred in the Swash in 2008 (Table 2).

In both 2007 and 2008, either no, or almost no, adult scallops were found, either inside or outside of the stockade at the Middle Marsh (in Back Sound) when we returned to sample at the end of the experiment. In 2007, we received a eye-witness report that the scallops in Middle Marsh stockade had been poached. In 2008, we moved the location of the sanctuary to a more publicly visible site, hoping to reduce the chance that our scallops would be pirated. The similarity of the 2008 Middle Marsh sanctuary results to the 2007 results and the difference between the performance of this site's sanctuary and sanctuaries at other sites in both years suggests that we were not successful.

Spat collector bags - Year One: August 2007 – March 2008

The fate of spat collectors themselves differed among sites. In October 2007, all spat collectors remained where they had been established. In November 2007, three spat collectors were missing from Yellow Shoal and two from Lovett Island. Inspection of collector moorings at Middle Marsh, Yellow Shoal, and Lovett Island revealed that some anchor lines had abraded near where the cinder blocks held the array to the bottom. We repaired the spat collector arrays at that time. In December 2007, only one collector remained at Yellow Shoal, three at Lovett Island, whereas only four collectors were missing at Middle Marsh. By March 2008, collectors were present only at Middle Marsh. We never lost collector bags from the IMS mesocosm pond throughout the entire experiment. Unlike the other field sites, Hoop Pole Creek suffered burial of its collector bags by sediments. In November, some of the Hoop Pole collector bags were discovered during laboratory processing to be partially filled (>15% of

collector volume) with sand. During the December through March period, all of the remaining collector bags at Hoop Pole Creek became completely buried by sand.

Sites differed in the numbers of scallops collected per bag (Fig. 4A). A two-way (site by month of collection) analysis of variance (ANOVA) conducted on the homoscedastistic (based on a non-significant O'Brien's test), untransformed data from all sites for October through December produced significant main effects and a significant interaction (Sites F = 70.97, P <0.0001; Month F = 3.43, P = 0.0399, Sites x Month F = 2.19, P = 0.0432). An unplanned Tukey's HSD test revealed overlapping sets of non-significant interaction means attributable primarily to temporal differences at two sites, Yellow Shoal and Hoop Pole Creek (Fig. 4). Only one spat collector remained at Yellow Shoal in December so the low value observed here must be interpreted cautiously: it may not be representative. The sand in the bags retrieved in November from Hoop Pole Creek would have decreased the surface area available for scallops to settle and induced mortality on any scallops buried within the bag. If we omit the unreplicated datum and the November bag counts from Hoop Pole Creek, two patterns emerge: 1) there are site-specific differences in the number of scallops per bag (Middle Marsh > Lovett Island and Yellow Shoal > Hoop Pole >> IMS pond); and 2) there is no evidence of decreasing scallop numbers per bag throughout the period. The last observation is further supported by the results of a two-way ANOVA conducted on counts from collector bags located at just Middle Marsh and the IMS pond for all months (October 2007 through March 2008), in which only the site main effect was significant (Sites F = 394.00, P <0.0001; Month F = 1.38, P = 0.2604, Sites x Month F = 1.53, P = 0.2174). Replicate spat bags collected similar numbers of scallops at Middle Marsh, Lovett Island, and Yellow Shoal, where coefficients of variation among replicates within a sampling time were low (<40%) and consistent throughout the experiment (Fig. 4B). Hoop Hole Creek and IMS pond spat collector bags showed much greater variability among replicates in collecting scallops.

Shell height of scallop spat differed among times and sites. Scallops <3 mm in shell height were only found in spat collector bags retrieved in October 2007 (Fig 5). A two-way ANOVA conducted on the mean shell height of juvenile scallops in each bag (based on the subsamples of 40 individuals) from each site in October, November, and December produced a non-significant interaction of site x month (F = 1.44, P = 0.2047), while both main effects were highly significant (Site F = 8.23, P < 0.0001 and Month F = 104.68, P < 0.0001). Mean shell height, pooled across all sites, increased by 84.3% from October to November and by 21.2% from November to December (Fig. 6A). Two sites, Middle Marsh and Hoop Pole Creek, had significantly larger scallops than Yellow Shoal and the IMS pond, while Lovett Island scallops were intermediate in size (as determined by a Tukey's HSD test, Fig. 6B). The December 2007 difference in mean size between Middle Marsh and IMS persisted into the subsequent spring (Fig. 7). A one-way ANOVA on scallop shell height (power-transformed to achieve homoscedasticity) contrasting the only two sites to yield scallops in March 2008 (Middle Marsh and IMS) was significant (F = 370.71, P <0.0001), with shell height 34% larger at Middle Marsh than IMS.

When we drained the pond in March of 2008 to retrieve the last spat collector bags, we hand-collected 2,060 scallop recruits not associated with any collectors, mostly from areas of the pond several meters away from where the collectors had been located. The mean (±1 SE) shell height of these scallops was 37.02 (0.74) mm, exceeding the mean size recorded from any spat collector bag at any location on any date. We hypothesize that these scallops had set on the abundant stubble of terrestrial grasses that persisted in the pond when we filled it with water in the fall (the pond had gone unused for several years prior to our experiment and terrestrial grasses had grown in much of the empty basin). By measuring the dimensions of 100 of these haphazardly-chosen, grass blades and using replicate tosses of a 0.25-m^2 quadrat to estimate blade (stubble) density, we calculated that the total approximate surface area available for scallop spat attachment, not including the inside of spat bags, in the entire pond was about 40 m^2 (surface area of the plant remnants as well as the outsides of the spat collector bags held the pond).

Spat collector bags - Year Two: August 2008 – December 2008

As in 2007, the mean number of scallop recruits per spat collector bag differed among sites (Fig. 8). A one-way ANOVA (on power-transformed data), followed by a Tukey's HSD comparison of the means, demonstrated that the spat collectors in the IMS pond collected fewer scallops than any of the field sites, which did not differ from each other ($F = 6.46$, $P = 0.004$). Unlike 2007, there was no relationship among sites between mean numbers of scallops per bag and the coefficient of variation among bags.

Mean shell height of scallop recruits found in the collector bags also differed significantly among sites (one-way ANOVA on reciprocal-transformed data: $F = 75.94$, $P < 0.0001$). Tukey's comparison of the means revealed that the largest scallops were found at Middle Marsh and Lovett Island, with the smallest at the Swash (Fig. 9). Scallops from Yellow Shoal and the IMS pond were intermediate in mean shell height.

A two-way, factorial ANOVA on the mean shell height in December of scallops collected from those sites that held collectors in both 2007 and 2008 (Middle Marsh, Lovett Island, and IMS pond) produced a significant site effect but no significant year effect or interaction of site x year (site $F = 40.81$, $P <0.0001$, year $F = 3.36$, $P = 0.075$, and site x year $F = 1.64$, $P = 0.196$). In both years of the study, scallops were significantly larger in collector bags held at Middle Marsh and Lovett Island than the IMS pond in December.

Alternative spat collector designs

In the April – May 2008 experiment, scallop recruits were virtually absent from all three substrate-based collectors. Only four recruits were found (3 on the artificial seagrass bed (ASB) design and 1 on the "X" design). In contrast, all three of these collectors harbored predatory crabs (primarily xanthids with some portunids; Fig 10). A mixed model, two-way ANOVA (collector type versus block) on square-root transformed crab abundances (# individual crabs / collector) indicated that each main effect, but not the interaction, was significant (collector type $F = 22.98$, $P = 0.0015$, block $F = 7.90$, $P = 0.0166$, and collector type x block $F = 1.12$, $P = 0.3823$. A Tukey's HSD test revealed that there were significantly more crabs associated with the ASB design than the other two. Collector bags in those blocks closer to the pond's water inlet had higher crab abundances than those further from the inlet. Only three, large (>5 cm carapace width) blue crabs (*Callinectes sapidus*) were captured in the meshed crab pots (and removed) during this experiment.

In the IMS pond, the mean number of scallops per spat collector bag in the spring did not differ from that observed in fall 2007 (mean ±1 SE for spring, 20.4 ±2.7 vs. 25.7 ±5.7 for the preceding fall; t-test $P = 0.51$). Crab abundances in the bags averaged 12.0 ±2.6 individuals per bag, which is intermediate between the mean abundances seen among the different substrate-based spat collectors.

The significantly high numbers of crabs in the ASB collectors led us to exclude this design from our comparison of substrate-based collectors in the September – December 2008 experiment. In contrast to the preceding spring, both the X collector and the half-pipe collector attracted scallop recruits (Fig. 11). Inspection of the half-pipe collectors showed that fine sediments had accumulated on the upper surfaces of the half-pipes in a continuous layer ranging from 1 – 2 cm in depth. The X collectors supported some algal growth on their surfaces but very little sediment was present on any of them. To compare the capabilities of the two types of substrate-based collectors and the bag collectors to achieve bay scallop recruitment, we standardized the number of scallops found on each type of collector to the respective surface areas available for scallop spat settlement. Separate, one-way ANOVA's conducted first on the untransformed, standardized number of scallops m^{-2} of collector area and second on the mean scallop shell height were both significant. Tukey's HSD tests revealed that the half-pipe collector had significantly fewer scallops per unit surface area than either of the other two

collectors (x-type or bag), whereas the scallops retrieved from the collector bags were smaller on average than those from either bottom collector. Xanthid crabs were observed in association with all three types of collectors. Over the three months of this experiment, we captured a total of 8 blue crabs in the meshed crab pots.

Discussion

Site- and year-dependency of benefits of installing stockades to protect spawners

We were able at different locations and in separate years to establish and maintain sufficiently high adult scallop densities to promote effective spawning (>2 scallops m^{-2}, Peterson and Summerson 1992) throughout the time interval when migrating cownose ray predation had decimated North Carolina scallops in previous years (Peterson et al. 2001, Myers et al. 2007). Increasing the density of scallops inside a stockade has a potential benefit for improving scallop spawning success as external fertilizing, free-spawning, marine invertebrates show low fertilization rates at low population densities (Levitan and Petersen 1995). In western Bogue Sound in 2007, the relative decrease in adult scallop abundances outside the stockade was almost 4x greater than inside the stockade, implying that the stockade successfully inhibited predation by some source. The results in 2008 are different in both Bogue and Core Sounds. In Bogue Sound unprotected adult scallops outside the stockade did not experience apparent mortality, even by mid November. In Core Sound, adult bay scallop abundances decreased both inside and outside of the stockade at roughly the same proportion (≅55%). Scallops outside the Core Sound stockade could have experienced predation relatively early in this experiment, such that the balance between immigration and emigration over a period of weeks resulted in a homogeneous decline inside and outside the stockade (Powers and Peterson 2000, Peterson et al. 2001). However, changes in scallop density at this site could have resulted from a mortality source unaffected by the presence of the stockade. The results in 2008 from both Lovett Island and the Swash are consistent with the near absence of cownose ray predation. Our observations and reports from fishermen suggest that migrating cownose rays were much less abundant in Core, Back, and especially Bogue Sounds during fall 2008 than any fall in the previous decade. Our suggestion that cownose ray predation on bay scallops in these sounds during the fall migration season was trivial in 2008 gains support from the North Carolina Division of Marine Fisheries scallop dredge surveys showing no decline in adult scallop density in Core or Bogue Sound from July to October 2008 (T. Moore, NCDMV, pers. com).

Peterson et al. (2001) and Myers et al. (2007) demonstrated that cownose ray predation on bay scallops can be site-specific. Spatial and temporal variability in predation intensity would provide unpredictable, but potentially important, refuges for spawning scallops that could serve to repopulate bay scallops in many areas within the same hydrologic basin. Such predation variability could influence how management protects spawning scallops. If the loss of adult scallops prior to spawning can be confidently predicted for a particular location, then even an expensive protection intervention may have merit. If, however, ray predation is less predictable, either from location to location or year to year, then an expensive protection program may not be cost-effective. Nevertheless, an inexpensive protection could still be justified in this situation. Our stockades can be erected or removed in a single tide by three to four individuals. They can be placed where scallops are already abundant, reducing or eliminating the need to collect and transport adult scallops. The cost of the pipe for a stockade of about 15-m diameter is $600 - $700 (depending on local PVC costs) and the poles show no structural decay or wear even after two years of use and are thus reusable.

Human depredation of bay scallops inside spawner sanctuaries is not a trivial concern. The stockades exclude cownose and other rays but not humans. The constituent poles are designed to have high visibility above the waterline, allowing boaters to easily avoid them. Unfortunately, stockade visibility can serve as a beacon to those who would illegally exploit the scallops concentrated in the

sanctuary. Human behavior and inadequate fisheries law enforcement may limit the locations where stockade-style sanctuaries may be effectively employed.

Efficacy of bags as spat collectors and fall-winter nurseries

In both 2007 and 2008 spat collector bags deployed in the field during late summer to autumn allowed us to accumulate thousands of bay scallop recruits. Pooling across all dates of retrieval, a total of 12,041 juvenile scallops was collected from 106 spat collectors deployed in 2007 and 11,334 juvenile scallops from 44 spat collectors deployed in 2008 (mean (±1 SE) number of scallops per collector: 122.9 (10.2) in 2007 and 257.6 (30.3) in 2008). Both of these annual totals include scallops gathered from spat collector bags held in the IMS pond, which collected significantly fewer juvenile scallops per collector on average compared to most field sites in either year. Excluding the IMS pond data shows that bag spat collectors located in the sounds produced a mean (±1 SE) of 176.8 (10.6) scallops in 2007 and 328.3 (40.6) scallops in 2008.

Based on previous studies (Ambrose et al. 1992, Peterson et al. 1996), we had expected that the spat collector bags would successfully yield substantial numbers of scallop spat. These earlier studies used spat collectors to test questions about short-term scallop survival associated with height in the water column or as a means to assess the abundance of competent scallop larvae in specific water bodies. We tested whether scallops could be maintained in spat bags for several months, using these bags not only as a means to collect scallop recruits but to serve as nurseries for grow-out of scallops to sizes large enough to reintroduce into the natural habitat. Although we found crabs in the spat collectors at all locations in both years, predation by these crabs did not prevent us from collecting 100's of scallops per bag, even after allowing the bags to sit undisturbed for 4 - 7 months. From October 2007 to March 2008, we detected no significant decline in the number of scallop individuals per bag at either site where we could make this assessment, Middle Marsh or the IMS pond.

In situ scallop size within bags was similar in both years. In the winter months of 2008, the mean size of scallops held in spat collectors at the IMS pond and Middle Marsh (the only two locations where bags remained until March) increased beyond the December shell heights by 55.6% and 32.8%, respectively. The majority of scallops that we collected in March 2008 from the collectors held at both sites had achieved large enough size that they would suffer relatively low predation in the spring (Bishop et al. 2005) and exceeded the size of byssal dettachment from substrate (Peterson and Summerson 1992). Enhancing native stocks could be accomplished by visiting the field site where the collectors have been held until spring of the year, retrieving the spat collector bags, opening them, discarding crabs, and immediately introducing the scallops into a nearby seagrass bed.

The design of our spat collector bag experiment rendered difficult the marking and following the fate of individual scallops through time. Nevertheless, we infer that the observed stasis in scallop abundance per bag from October onwards at each site corresponds to high juvenile scallop survivorship and that the increases in mean scallop size reflect scallop growth. The presence of very small scallops (<3 mm) only in October implies that subsequent settlement of new cohorts was absent. Inspection of the size-frequency distributions further supports this conclusion. No detectable mode of such small scallops appeared after October at any field site: at IMS, where juvenile scallops grew so slowly in some locations, small scallops persisted until December, although not as small as the 3-mm size class. A temporal increase for the dominant (or sole) mode is apparent at all sites, attributable to the growth of scallop cohorts already present in October (Figs. 5 and 7).

Previous studies demonstrated that current speeds affect scallop growth (Kirby-Smith 1972, Ekman et al. 1989). Although we do not have direct measurements of current flow in or around our spat collector bags, we suspect that decreased flow into spat collector bags held in the IMS mesocosm pond accounts for the lower numbers of recruiting scallops, their generally smaller sizes, and their higher size variation at any given date. The >2,000 scallop recruits collected in the IMS pond outside of spat bags in

March 2008 were much larger than those inside the bags at that time, implying that the slow flows of currents inside the protected pond limited the capacity of the water to penetrate into the bags and thereby caused lower fluxes of scallop larvae and greater food limitation inside bags. At all field sites the numbers of scallops per bag were greater than the those in the IMS pond and at all field sites except Swash in 2008 (a location often subjected to persistently lower salinities), bay scallop recruits in bags were larger than those in the IMS spat collectors, consistent with higher flow and food delivery into the bags under the higher-energy conditions of tidal currents and wind-driven exchanges in nature. Redesigning flow in the IMS pond to increase water exchange into spat collector bags held there could substantially improve their scallop production in the protected environment of the pond.

Attrition of spat collectors at the field sites decreased the yield of scallops and provides guidance to where spat collector bags should be installed in future deployments. Our modifications to the anchoring system in the second year reduced, but did not eliminate, the losses of bags at Yellow Shoal (74.3% lost by December 2007 versus 50.0% lost by December 2008) and Lovett Island (62.9% lost by December 2007 versus 30.0% lost by December 2008). We observed no change in the loss of spat collector bags at Middle Marsh from 2007 to 2008 (25.7% versus 30.0%). Survival of bags was generally greater at sites that were protected from long wind fetch by surrounding marshes, namely Hoop Pole Creek and Middle Marsh. However, Hoop Pole Creek suffered from unexpectedly high sediment deposition, resulting in loss of all bags by March 2008. Thus, to some degree, appropriate site locations will have to be determined by trial and error.

Performance of alternative spat collector designs

Observed high settlement of bay scallop spat on grass stubble on the bottom of the IMS mesocosm pond in fall 2007 at 51.5 scallops m^{-2} at levels much higher than on collector bags in the pond (5.9 scallops m^{-2}) and equivalent to the highest recruitment efficiency observed at any field site in that year (51.2 scallops m^{-2} at Middle Marsh) motivated us to design and test new substrate-based spat collectors. The spring 2008 trial of the three substrate-based designs produced little but crabs. Recruitment of scallops onto spat collector bags in spring (May) 2008 exhibited a density equivalent to the fall (October) 2007 recruitment onto identical bags in this pond, so lack of larval settlement potential cannot explain why substrate-based collectors failed to produce spat in spring 2008. In fall 2008, the results for the X-type collector were dramatically different. The X-type collector had a high recruitment (38.5 scallops m^{-2}) of scallops that grew well, as compared to those in the spat collector bags in the same pond at the same time. In fact, the scallop recruitment on X-type collectors was four times greater per unit surface area than on the traditional spat collector bags deployed in the pond and sampled at the same time (December 2008). The half-pipe collectors again produced few recruits, with extensive sedimentation on the upper surfaces a likely inhibitor of success. Consequently, X-type collectors may hold real promise for producing bay scallop recruits. However, understanding the radically different results between spring and fall is necessary before reaching any firm conclusions. In addition, the mesh bag around the internal collecting mesh of traditional spat collectors has been assumed to provide some protection against predators such that bags would represent better long-term nurseries. Further studies of temporal change in scallop numbers on the X-type and bag-type collectors are needed to test the hypothesis that bags do limit predation on early life stages.

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Table 1. Mean (±1 SE) densities (individuals m^{-2}) of adult bay scallops at each location within each year immediately after each spawner sanctuary inside a stockade was created (initial) and several months later (final). Dates when the respective stockades were created and sampled are presented in the top row. x – not tested at this location in this year

		LOCATION					
		Bogue Sound		**Back Sound**		**Core Sound**	
		initial	**final**	**initial**	**final**	**initial**	**final**
YEAR		29 Aug	22 Oct	10 Sep	23 Oct	x	x
2007	**inside**	2.8 (0.7)	2.2 (0.6)	2.8 (0.7)	0.2 (0.1)	x	x
	outside	1.4 (0.4)	0.3 (0.2)	0	0	x	x
		18 Aug	10 Nov	14 Aug	7 Nov	11 Aug	31 Oct
2008	**inside**	6.3 (0.8)	6.5 (1.2)	18.4 (2.6)	0	25.3 (3.1)	11.4 (1.1)
	outside	1.9 (0.4)	2.7 (0.6)	2.5 (0.6)	0.3 (0.2)	2.8 (0.5)	1.2 (0.4)

Table 2. Results of separate, model I, two-way ANOVA's (time = initial vs. final, location = inside vs outside of the stockade) conducted on the densities of scallops in - and outside the stockade spawner sanctuaries. In each case transformation (shown after the site name) of the original data was needed to achieve homoscedasticity (as determined by a modified Levene's test) and residual plots with no obvious patterns.

<u>Bogue Sound (Lovett I.) in 2007 : $((x + 1)^{-1}-1) / (-0.176)$</u>

time	1	13.19	2.38	0.1249
location	1	53.68	9.69	0.0022
time x location	1	9.09	1.64	0.2021
error	158	5.54		

<u>Bogue Sound (Lovett I.) in 2008 : $\ln(x + 1) * 3.2$</u>

time	1	4.68	0.47	0.4926
location	1	233.49	23.62	<0.0001
time x location	1	3.20	0.32	0.5702
error	156	9.89		

<u>Core Sound (the Swash) in 2008 : $\ln(x + 1) * 5.596$</u>

time	1	351.00	14.5	0.0002
location	1	4626.70	191.1	<0.0001
time x location	1	11.99	0.5	0.4826
error	158	24.24		

Fig. 1. Map of eastern North Carolina showing the locations where either stockades or spat collector bags were located. The black rectangle on the map of North Carolina shows the location of the larger map. LI = Lovett Island, HP = Hoop Pole Creek, IMS = Institute of Marine Sciences pond, MM = Middle Marsh, YS = Yellow Shoal, S = Swash.

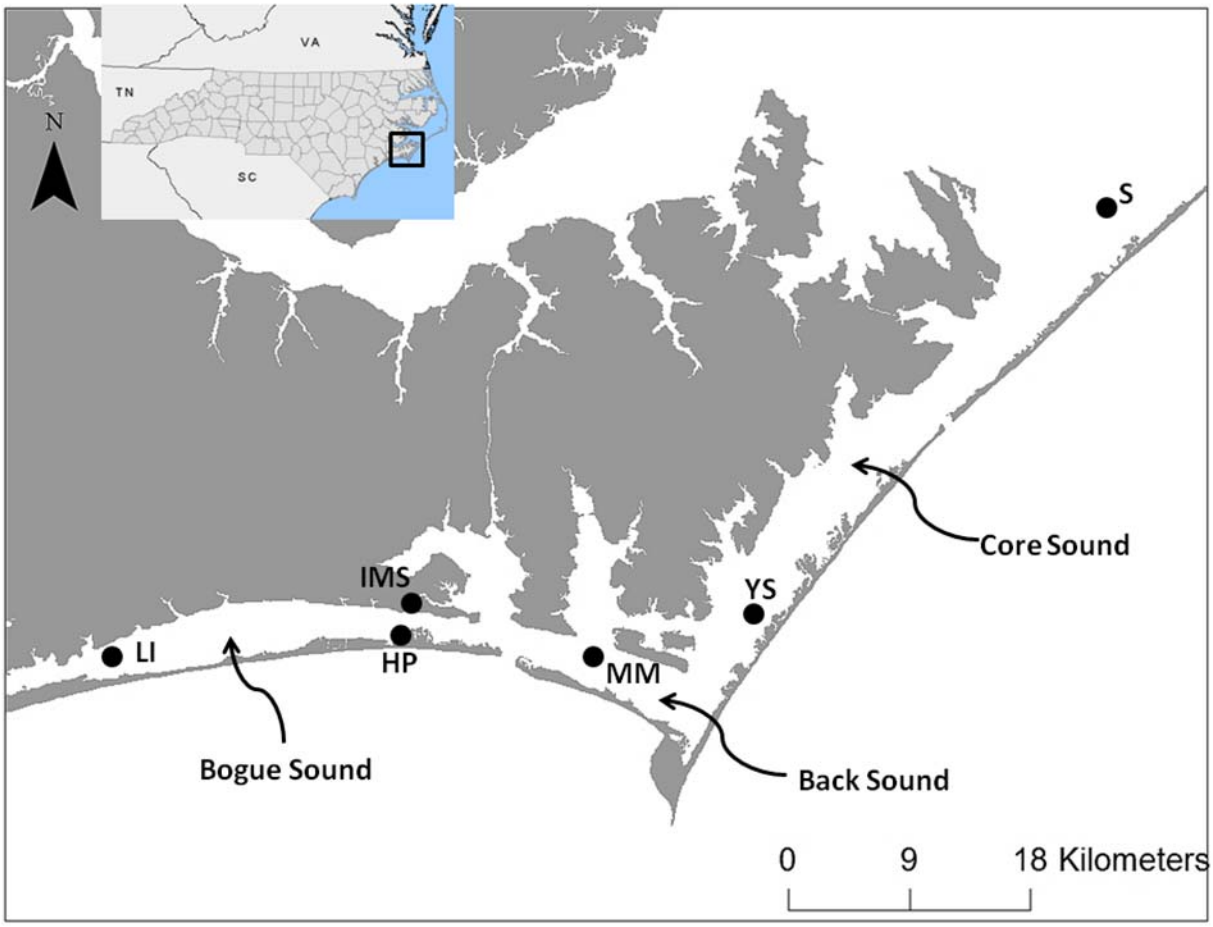


Fig. 2. Schematic diagram showing how spat collector bags (S) were arrayed in the field and anchored to the substrate in 2007. In 2008, the cinder blocks (C) holding the anchor line were replaced by vertical, PVC poles inserted vertically into the sediments. The blue curve at the top of the diagram indicates the approximate position of water level at low tide.

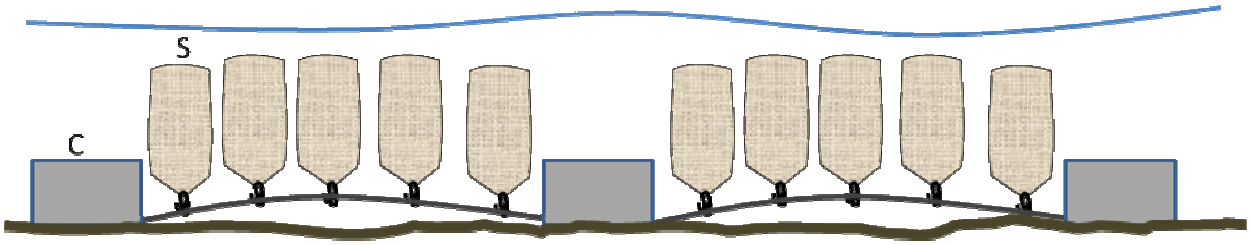


Fig. 3. Photograph demonstrating the structure of the alternative, substrate-based designs used as collectors in the IMS mesocosm pond experiments. The rule in the center of the photograph is 31 cm long. ASB = artificial seagrass bed, X = X-shaped collector, HP = half-pipe collector

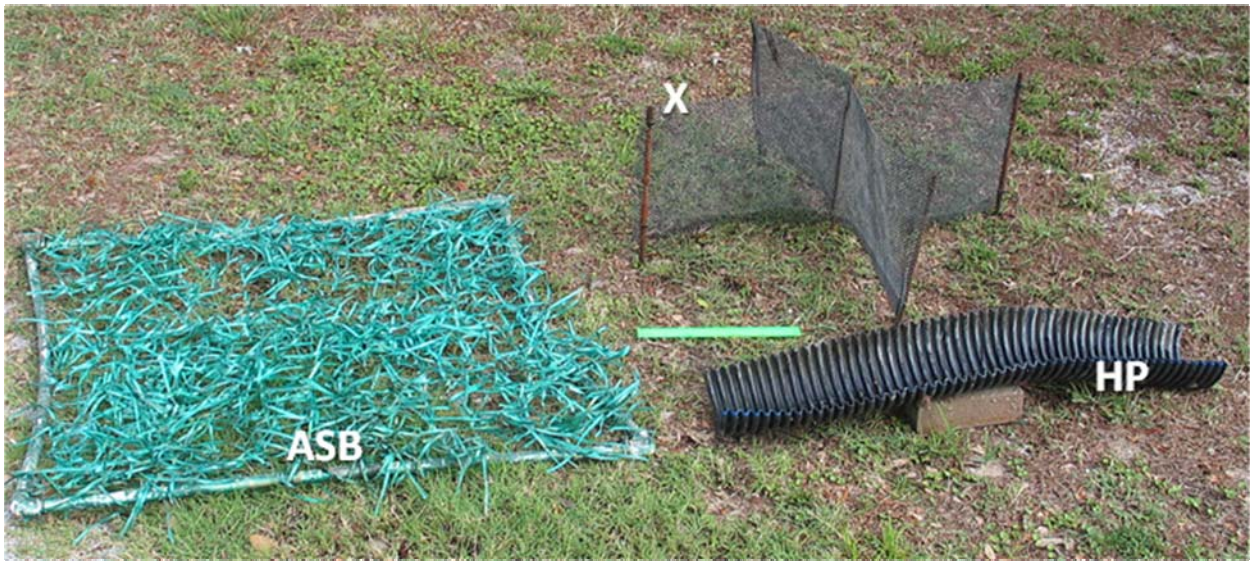


Fig. 4. A - Mean (±1 SE) # juvenile scallops per spat collector for each location and time in 2007 when spat collectors were retrieved. Means (for just Oct – Dec) overlapped by the vertical lines are not significantly different based on a Tukey's HSD unplanned comparison. B- Coefficient of variation associated with each mean presented in A.

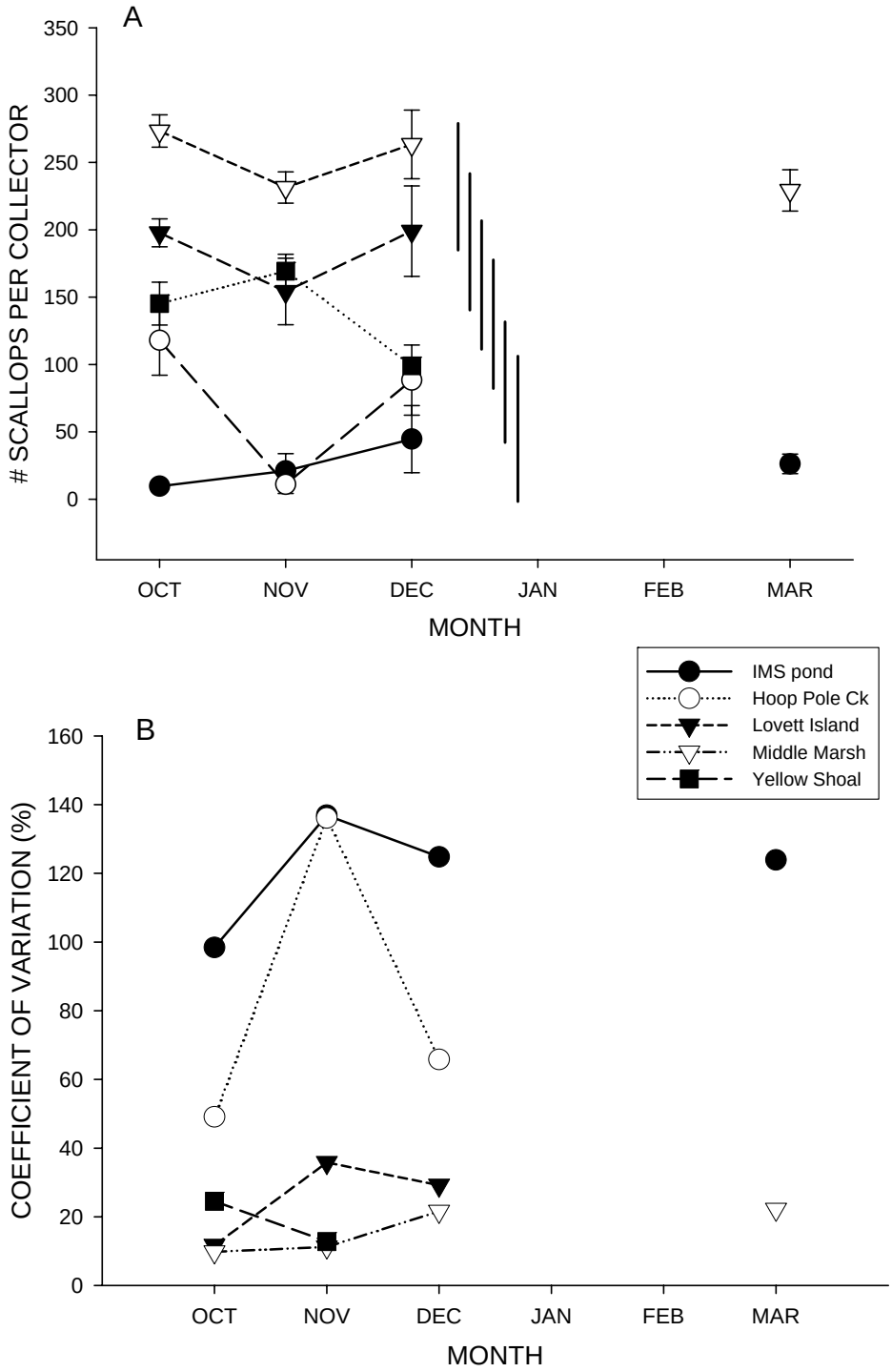


Fig. 5. Size frequencies of scallops found in spat collector bags from October to December 2007. Size frequencies are based on pooling all individuals measured in subsamples from each bag for each site by month combination. Listed next to each distribution is the mean shell height in mm (±1 SE) based on the mean size within each bag (above) and the percentage of scallops that were <3 mm in shell height (bottom). Five collectors were examined each month except for Lovett Island (n = 3) and Yellow Shoal (n = 1) in December.

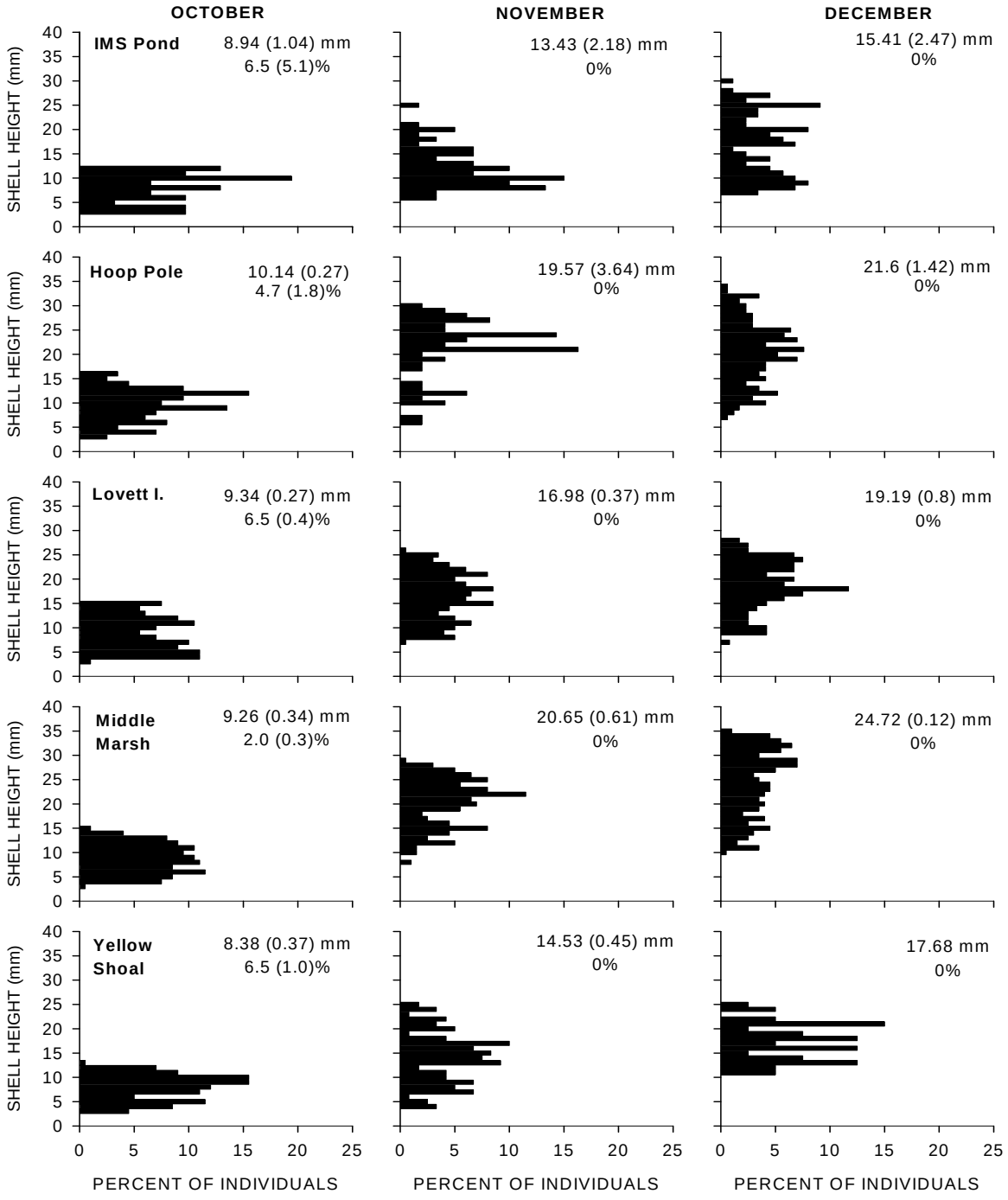


Fig. 6. A - Mean (±1 SE) shell height of juvenile scallops for each month in 2007 in which spat collectors were retrieved from each site. A Tukey's HSD test indicated that each monthly mean was significantly different from each other mean. B- Mean (±1 SE) shell height of juvenile scallops for each site in which spat collectors were retrieved over the interval from October through December 2007. Vertical bars to the right overlap means that are not different as revealed by a Tukey's HSD test.

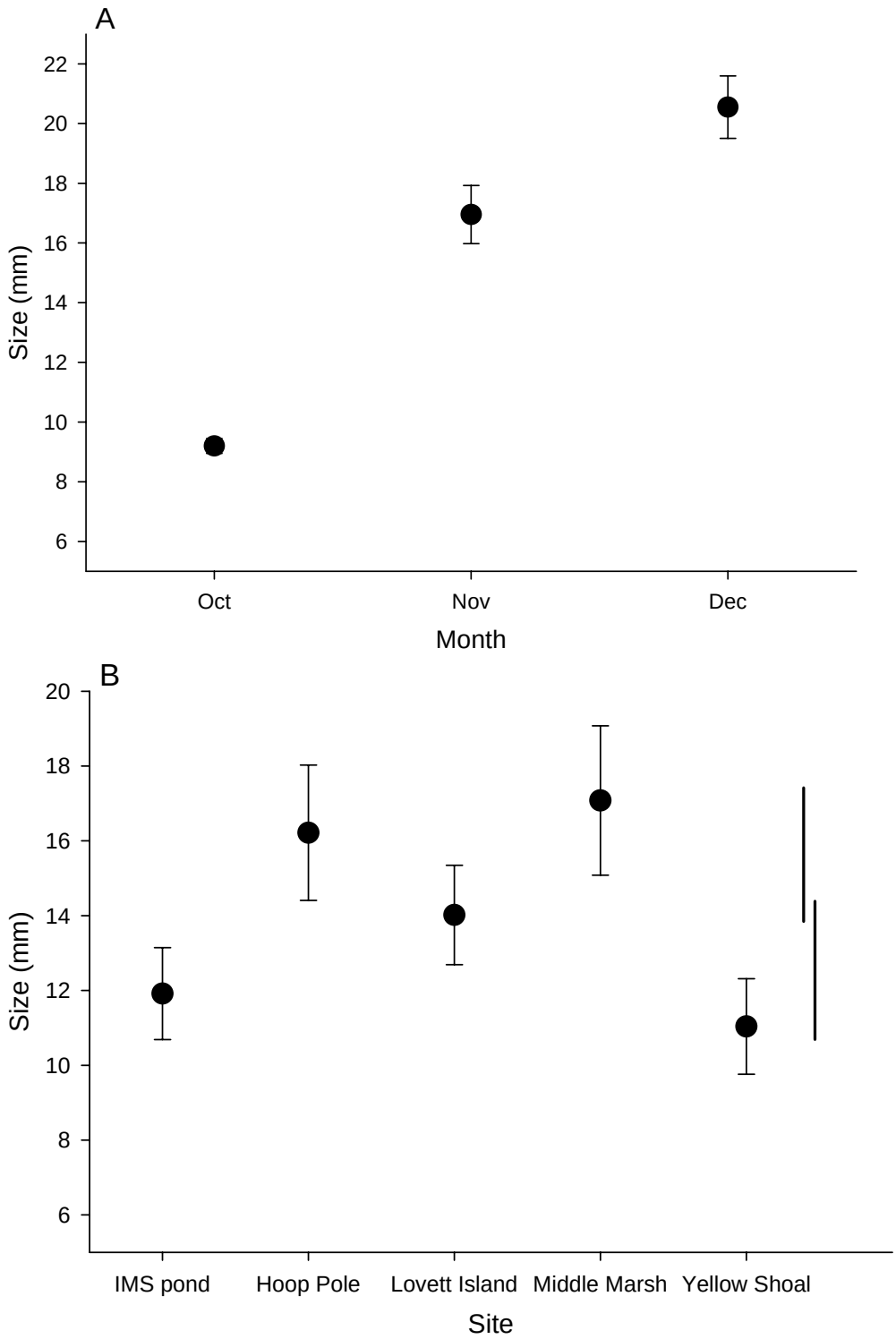


Fig. 7. Size frequency distributions for juvenile scallops found in spat collector bags from Middle Marsh and IMS pond in March of 2008. Mean (±1 SE) shell heights were 32.8 (6.8) and 24.4 (7.7) mm, respectively.

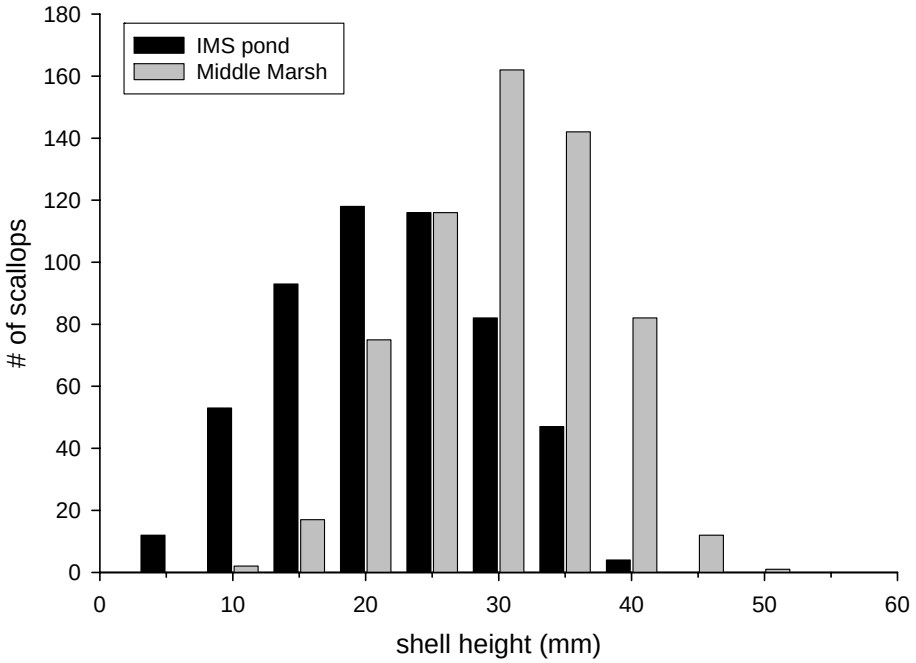


Fig. 8. Mean (±1 SE) # juvenile scallops per spat collector for each location in December 2008 where spat collector bags were deployed. A one-way ANOVA on power-transformed data detected a significant effect. Vertical bars to the right overlap means that are not different as revealed by a Tukey's HSD test.

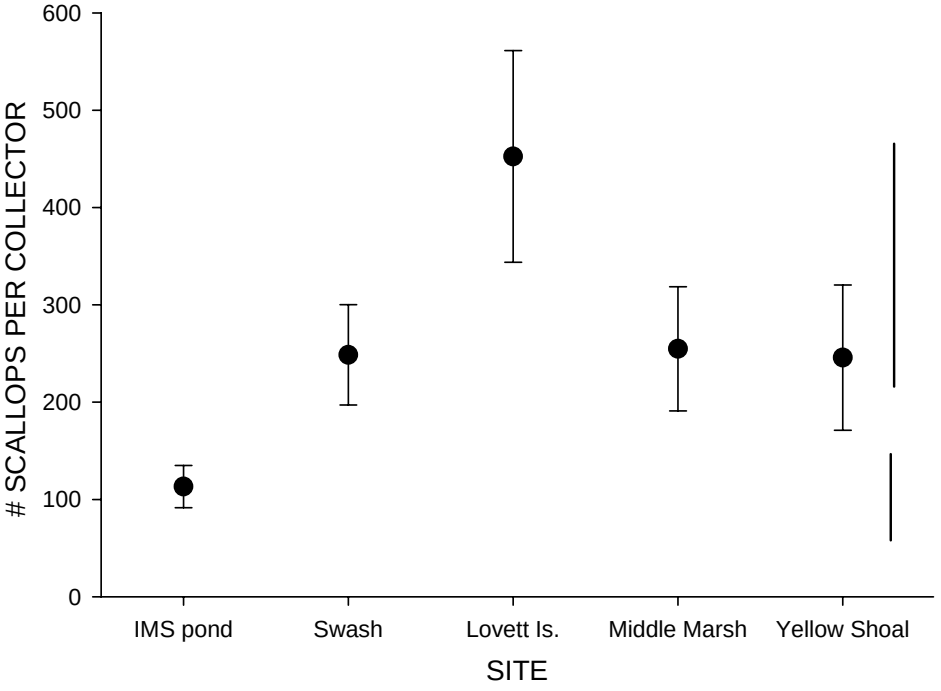


Fig. 9. Mean (±1 SE) shell height of juvenile scallops in December 2008 for each site where spat collector bags had been deployed. Vertical bars to the right overlap means that are not different as revealed by a Tukey's HSD test.

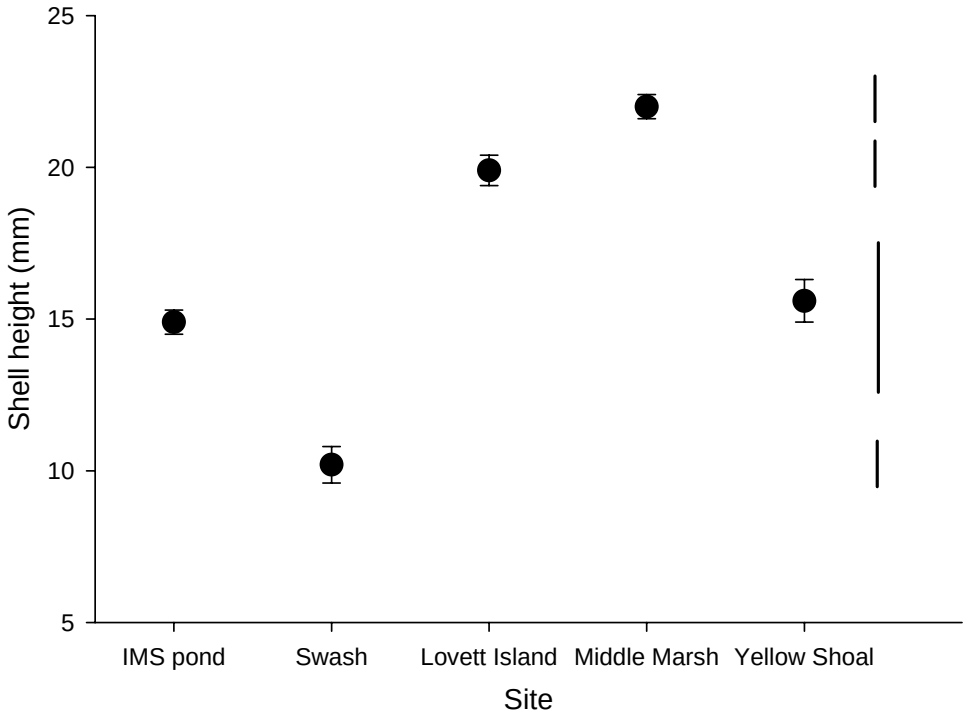


Fig. 10. Mean crab abundances found associated with the different bottom-based collectors in the spring of 2008. The number of crabs per collector is not standardized by the respective collector surface areas because crabs do not attached themselves to surfaces and their abundances are likely to be subject to several factors including three-dimensional complexity and food availability. Means not overlapped by vertical bars to the right are significantly different as determined by a Tukey's HSD test. ASB = artificial seagrass bed collector, HP = half-pipe collector, and X = X-shaped collector.

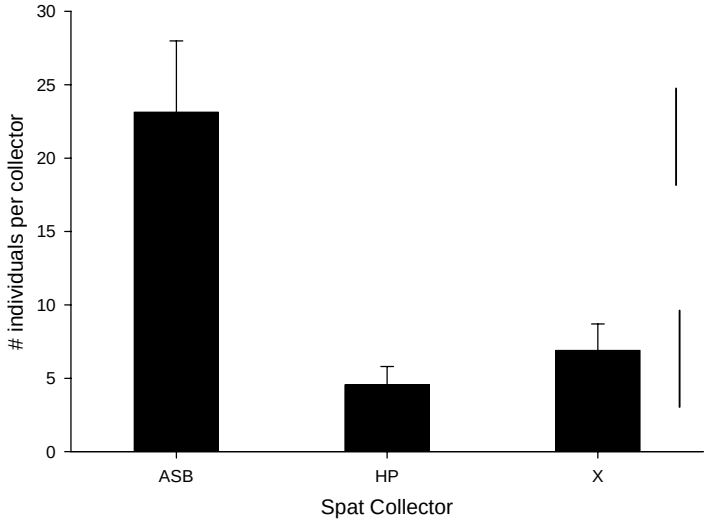
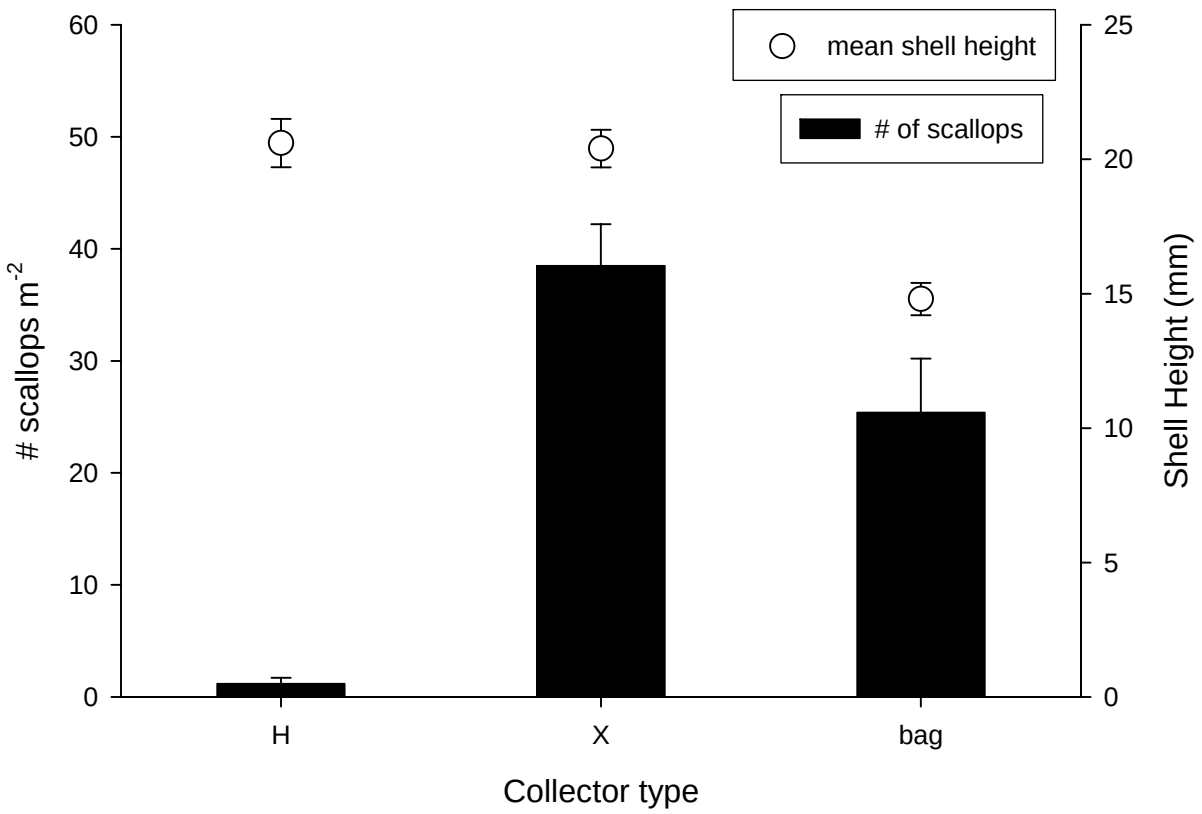


Fig. 11. Mean number of scallop recruits per m^{-2} of collector surface area and the mean shell height of scallop recruits associated with a particular collector. For both parameters, individual one-way ANOVA's detected significant differences in the mean # of scallops m^{-2} and mean shell height among collector designs. Subsequent Tukey's HSD tests indicated the following: for mean # of scallops m^{-2}, half-pipe (H) < x-collector (X) = bag collector and for mean shell height, half-pipe (H) = x-collector (X) > bag collector.



Attachment #3

New sanctuaries in N.C. reviving scallops threatened by rays

The threat
The cownose ray has been blamed for depleting Chesapeake Bay oysters and North Carolina's scallop fishery. The cownose rays crush shells with their razor-sharp teeth and also eat oysters, soft- and hard-shell clams, and other small bivalves.

The Virginian-Pilot © August 22, 2008

By Ryan Hutchins

Breaking a link in the food chain may be the first step toward reviving a North Carolina scallop population decimated by millions of migrating cownose rays. Scientists believe that three new sanctuaries in coastal sound waters will protect scallops during the summer onslaught of feeding rays, which have proliferated with the decline of great shark species. "They range upwards to the size of the infield of a baseball diamond," UNC Chapel Hill Professor Charles "Pete" Peterson said of the sanctuaries, which are referred to as stockades. Peterson is part of a team from the school's Institute of Marine Sciences in Morehead City that worked in recent weeks to build the sanctuaries in the Bogue, Back and Core sounds. The enclosures, which Peterson said have proved successful in the past, will keep the rays from eating some of the scallops during the spawning season. They are created by placing PVC pipes vertically in the water close enough together that the rays can't enter. Peterson said the hope is that enough scallops survive the ray migration that the population can start to rebuild itself. "We know that it works," he said. "The issue is on what level do you do this?"

The cownose ray has been blamed for nearly finishing off a Chesapeake Bay oyster population already ravaged by disease. The winged marine animal has also taken a heavy toll on North Carolina's scallop fishery, which has been closed since 2004. The ray population has grown as the number of great sharks - their predators - has fallen from overfishing, Peterson said. Peterson co-authored an article published in the journal Science last year. He and fellow marine researchers presented the results of numerous marine studies conducted since the early 1970s. "In that 30-year period, they're down dramatically - almost to the point of disappearance," Peterson said of the great sharks during a recent phone interview. And that trickled down to the scallops, according to the article. As the great sharks died off, their prey found themselves with no threats and no population control. The cownose ray population was estimated at 40 million several years ago based on projections taken from flights over the Chesapeake Bay and knowledge of their rate of increase, Peterson said. David Gaskill, a commercial fisherman who lives on Cedar Island, said the business of catching scallops in North Carolina's sounds had been popular until the past decade or so. "Maybe 15 or 20 years ago, there were a bunch of people doing it," he said. But leading up to the closure, the industry had fizzled out, he said. This year, Gaskill has seen an increase in scallops. They are "everywhere you look," he said. The cownose

rays crush shells with their razor-sharp teeth and also eat oysters, soft- and hard-shell clams, and other small bivalves. Peterson said the return of the scallop population will largely depend on whether enough great sharks can be brought back to provide population control for the rays again. That will require continued government intervention, he said. "It's all a function of the management of the fishing, plain and simple."

Ryan Hutchins, (252) 441-1627, ryan.hutchins@pilotonline.com

From the Carteret County News-Times

Scallop sanctuary

Published: Wednesday, August 27, 2008 6:06 AM EDT
Spawning stockade sanctuaries like this one east of Middle Marsh were built in Core, Back and Bogue Sound by Dr. Pete Peterson and Dr. Stephen Fegley of UNC IMS. The sanctuaries are used to protect North Carolina scallops from cownose rays, which have preyed on the scallops almost to the point of disappearing . (Dr. Stephen Fegley photo)

Attachment #4

Maximizing bay scallop, *Argopecten irradians,* population reproductive capacity: pilot tests of potential restoration options in North Carolina. Stephen R. Fegley, David Gaskill, and Charles H. Peterson. Univ. of North Carolina Institute of Marine Sciences, Morehead City, NC 28557.
Since 2004 no harvest of bay scallops has occurred in North Carolina due to extremely low adult abundances. Additionally, intense late summer ray predation reduces spawning scallop densities below levels previously demonstrated necessary to support natural scallop population recovery. To enhance the existing low scallop population reproductive capability we need to collect and protect juvenile scallops until they are old enough to spawn. We placed replicate spat collectors, consisting of plastic mesh inside onion bags, in four locations known to support scallop populations historically and in a shore-side, relatively predator-free, salt pond that continuously received seawater. Through the fall we assessed site-specific settlement, survival, and growth of bay scallops in the collectors. Site-specific differences occurred but scallops recruited and survived in collectors at all sites. Some sites experienced spat collector attrition due to storms. We also observed high recruitment of juvenile scallops onto grass shoots outside of spat bags in the salt pond with subsequent high scallop survival and growth suggesting an alternative restoration option. Finally, we protected patches of unspawned, adult scallops by constructing PVC pole stockades to exclude rays. Stockades were effective in protecting scallops from rays but not from illegal human predation.

Attachment #5 See accompanying CD for raw data in MS Excel files