PRE-CONSTRUCTION *SABELLARIA VULGARIS* BASELINE MONITORING AT BROADKILL BEACH SAND PLACEMENT SITE, SUSSEX COUNTY, DELAWARE

FINAL REPORT

Contract Number: DACW61-01-P-0291

Dr. Douglas C. Miller
Graduate College of Marine Studies
University of Delaware
700 Pilottown Road
Lewes, DE 19958-1298 USA
Voice: 302-645-4277, fax: -4007
Email: dmiller@udel.edu

Revision Date: 3 January 2002

Table of Contents

Introduction

The sandbuilder worm or "reefworm," *Sabellaria vulgaris* Verrill 1873 is a tube-building, annelid polychaete worm common on the Mid-Atlantic coastline of the USA (Gosner 1978, Lippson and Lippson 1997, Pollock 1998). This species ranges from Cape Cod to Georgia, occurring from low in the intertidal zone to shallow subtidal in waters with salinity above 15 ‰ (parts per thousand) (Gosner 1978, Ruppert and Fox 1988). Their life cycle includes a planktonic larval stage (Curtis 1973, 1975), and the larvae settle gregariously on a wide variety of substrata, including rocks and cobbles, clamshells, oyster bars, horseshoe crab carapaces, other worm tubes and pilings (e.g., Hidu 1978, Karlson and Shenk 1983).

Sandbuilder worm tubes are built of sand grains cemented together into a hard encrustation or rock-like structure. For feeding and tube construction, the worms protrude their crown of tentacles from the tube openings. Worm tubes may be found singly or in small clusters attached to various substrata. In Delaware Bay, sandbuilder worms are also found in dense aggregations where the tubes grow in straight, parallel, spaghetti-like bundles that completely cover the substratum (e.g., Wells 1970). These bundles may extend 20 cm or more above the substratum and be firm enough to walk on, often forming worm reef. The surface of the reef is of brown, honeycomb-like tube openings, each representing an individual sandbuilder worm. Reef development appears to be a unique characteristic of Delaware Bay populations, although Wells (1970) describes masses on a shipwreck in North Carolina that closely resemble Delaware reefs in consistency, morphology and tidal elevation.

From their sizeable reef structure and outward appearance, these aggregations are sometime known locally as "corals." This term is taxonomically inaccurate as well as potentially misleading, and it will not be used in this report. Reef-forming corals are members of another phylum (the Phylum Cnidaria, Class Anthozoa, in part, known as hermatypic corals) and characteristic of warm, clear tropical waters (Lalli and Parsons 1997). Because of their particular habitat requirements, true reef corals are not found in the Mid-Atlantic region. However, at least one species of non-reef forming, true coral, *Astrangia danae*, is found in the region in subtidal habitats though it has little tolerance for brackish water and high turbidity (Gosner 1978). Again, because of differing habitat requirements, this star coral *A. danae* is not associated with the sandbuilder reefs.

The ecology of sandbuilder worms has been studied in the region, and in the Delaware Bay in particular, in a number of studies over the past 30 years, for example, Amos (1966), Wells (1970), Curtis (1973, 1975, 1978), and Pembroke (1976). These sandbuilder reefs form a habitat that is far more physically stable (termed "worm rocks" by Gosner 1978) and ecologically diverse than would otherwise be found on bare rock or sand substratum. Thus, their reef structure and associated invertebrates are likely to provide food for fish and therefore represent a productive nearshore marine habitat.

The Army Corps of Engineers is proposing to use dredge material from the deepening of the Delaware River Federal Navigation Channel for shoreline restoration at

Broadkill Beach (USACE 1997). This area has been known historically (e.g., Curtis 1975) and recently (R. Martin, personal communication 2000, D. Miller, personal observation 2000) to have sandbuilder worm reefs. Since shoreline restoration has the potential to bury and disrupt these reefs, it is necessary to determine the extent and location of present reefs as baseline data prior to construction activities.

Purpose / Objective of Study

The purpose of this study is to document the presence, extent and locations of *Sabellaria vulgaris* colonies at Broadkill Beach in summer, 2001, with respect to habitat type, tidal stage, and other environmental factors.

Methods

A survey of the sandbuilder worm colonies at the Broadkill Beach sand placement site was conducted on 20 - 21 July 2001. Within an hour of the afternoon low water, the beach was walked by the contractor and his associates in two segments: on 20 July, from the north end at California Avenue south to Route 16, and on 21 July, from the boundary of Beach Plum Island State Park north to Route 16. These dates were chosen to be near the lowest spring tides of the month and represent the best opportunity for the colonies to be observed and measured in the intertidal and nearshore subtidal zones along this beach. The following operational definitions were used: a colony is defined as an aggregation of worm tubes, usually small in size (< 1 m across) and somewhat isolated from other worm tubes. A reef is defined as a larger structure, a meter or more across, with 5 cm or more of vertical worm tube growth.

Where sandbuilder colonies or reefs were observed, their location was determined with a handheld GPS (Garmin model GPSMAP 76) and associated with nearby streets or landmarks. The dimensions of the colony or reef, along the shore and distance seaward from the beach-slope break, were determined with a measuring tape. Various digital photographs of the whole reef, as well as close-up sections, were made to document the reef shape and structure. An on-site determination of the overall condition of the reef was made as indicated by new tube growth (tubes with a "flare" or "porch," Wells 1970), tube erosion, over-settlement by mussels or tube worms, crab burrows, *et cetera*.

Reef observations and notes were recorded in the field on data sheets (see below and included in appendices) and additional observations were made on the study area shoreline, especially where rock, cobbles and gravel were present at the tidal level typically associated with sandbuilder reefs. At the *Sabellaria* reefs and other sites along Broadkill Beach, additional measurements were made to more fully characterize environmental conditions in the study area. These included: seawater temperature and salinity (handheld YSI model 30 meter), beach slope (inclinometer), and sediment grain size (standard dry sieving methods).

Results

Three large *Sabellaria* reefs were found on Broadkill Beach: two on the rock groins at Alabama and at Georgia Avenues (both north of Route 16, Fig. 1), and another on the Old Inlet Jetty (2.4 km south of Route 16 and 800 m north of the Beach Plum boundary, Fig 2). Table 1 summarizes the location, description and photo documentation of these three reefs. All *Sabellaria* documented in this survey were associated with large rocks comprising the groins and jetty, and none was found along the sand beaches or wooden groins.

Alabama and Georgia Avenue groin reefs

These two reefs are triangular in shape and occupy the bayward end of the rock groins (Figs. 4, 6, and 7) at the north end of the groin field north of Route 16. Near the bayward end of the reefs, sandbuilder worm tubes covered nearly all of the rock surface (Figs. 5 and 8) and extended farther out, beyond visibility in the wave swash. The worm tubes were colonized by macroalgae and mussels, and new tube growth was noted at the Alabama Avenue reef (Fig. 5).

Old Inlet Jetty reef

The reef observed at the Old Inlet Jetty is by far the largest on Broadkill Beach (Figs. 10 - 14). The jetty extends an estimated 65 m bayward, and the reef on both sides occurs along the full length of the jetty (Figs. 10, 11, and 14) from 2 - 5 m from the beach slope break. Coverage at the bay-end is essentially 100% by sandbuilder worm tubes. In places along the reef, there are dense settlements of mussels, and new tube growth (Fig. 12) was noted.

Sand beaches and wooden groins

No sandbuilder worm colonies or reefs were found on the sand beaches in the study area (e.g., Figs. 3 and 15). These beaches consisted of sand or small gravel at the beach slope break where it was expected to find sandbuilder colonies. Wooden groins north (Fig. 9) and south (Fig. 16) of Route 16 were examined and found to be colonized by barnacles, oysters and some tubicolous epifauna. No sandbuilder worm colonies were seen on these structures.

Within the study area, bay water salinity ranged from 25 – 28 ‰, and temperature ranged from 24 – 26.5 °C (Table 2). Beach sediments ranged from fine to coarse sands that were typically well sorted except at Alabama Avenue.

Discussion

Sandbuilder reefs at Broadkill Beach and nearby sites

At Broadkill Beach, there are three sandbuilder worm reefs within a 3 km length of the beach. Their total plan area is estimated to be approximately 320 m^2, and all colonies were on the rocks of artificial structures. The Old Inlet jetty reef has an estimated area more than twice that of the groin reefs combined. According to Wells (1970), it is apparently this reef that is depicted in the photograph in Amos (1966). No sandbuilder worm colonies were found on the sand beaches that comprise the remainder of the shoreline in the study area.

Since fall of 1999, the contractor has observed and photographed sandbuilder worm colonies and reefs on sand beaches north of the study site at Slaughter Beach as well as south at Cape Shores in Breakwater Harbor, near Lewes.

Sandbuilder intertidal reefs in the lower Delaware Bay have been documented by Amos (1966), Wells (1970), Curtis (1973, 1975, 1978), Pembroke (1976) and Woodard (1978), ranging from Woodland Beach (Maurer and Watling 1973, cited in Pembroke 1976) to South Bowers Beach to the Inner Breakwater Harbor at Lewes (Wells 1970). In particular, Wells (1970) lists both the inlet jetty and Broadkill Beach as sites of well-developed reef masses. Curtis (1973) used the jetty as a site in his field experiments and reports of live colonies at nearby Beach Plum Island and Primehook Beach. Curtis (1975) also notes that intertidal colonies at Broadkill Beach are associated with firm substratum. Woodard (1978) studied Old Inlet Jetty populations and provides a photograph in her Plate 1. While the species ranges from Cape Cod to Georgia (Gosner 1978), the formation of reef structures seems unique to Delaware Bay (with a single documented exception in North Carolina, Wells 1970). Both historical studies and personal observation by the contractor show that intertidal sandbuilder colonies and reefs extend along the shoreline north and south of the Broadkill Beach study area.

The vertical distribution of sandbuilder colonies with respect to the tides is described by both Wells (1970) and Curtis (1975). At Big Stone Beach, Delaware, Wells (1970, Fig. 3) shows beach colonies bayward of the slope break, ranging from 0.0 to 0.35 m above mean low water (MLW). Curtis (1975) related the vertical distribution to exposure times during extreme spring tides at the Mispillion jetty sandflat. Almost no live worms were found above exposures of 175 minutes, and most of the live colony was found in the 101 – 150 minute exposure zone.

Beach sand near the reefs and elsewhere ranged from fine to coarse in grain size (Table 2). Sandbuilder worms are epifaunal and require water flow and wave action to provide sand grains for tube building. Broadkill Beaches are fully exposed to the Delaware Bay to the northeast and provide sufficient resuspension of sand to allow tube growth. Rees (1976) reported that sandbuilder worms from Big Stone Beach used coarse and medium sand to build tubes and employ increasing grain sizes with time.

Sandbuilder worm habitat in lower Delaware Bay

The distribution of the intertidal colonies and reefs of sandbuilder worm at Broadkill Beach is limited to artificial rock. At other beaches previously studied by the contractor, sandbuilder worm reefs are found on the sand beach near the beach slope break where cobble-sized or larger (i.e., ≥6.4 cm across, Gray 1981, Table 2.1, p. 13) natural stone, bricks or other construction debris are present at the beach slope break.

Shoreline dynamics and sediment sources for the lower Delaware Bay are discussed by Maurmeyer (1978). The lack of cobble at Broadkill Beach could be due to a lack of natural or artificial source or that coarse material has been removed or buried. Burial could have been facilitated by the sand trapping action of the groins currently on the Broadkill Beach.

Subtidal sandbuilder worms populations are more widely distributed both in Delaware Bay (Pembroke 1976, Fig . 1) and throughout this geographic distribution (Wells 1970, Gosner 1978). Sandbuilder worms inhabit a variety of hard-bottom communities, including the Bay's oyster beds (e.g., Maurer and Watling 1973) as well as the serpulid reefs located nearby offshore (e.g., Haines 1978, Haines and Maurer 1980a,b)

Sandbuilder worm life history

The life history of the sandbuilder worm in the lower Delaware Bay was extensively studied by Curtis (1973, 1975, 1978) and Pembroke (1976). Wells (unpublished and cited in Curtis 1975) noted that each winter there was a nearly complete kill of the sandbuilder worm adults in the intertidal region. Settling plate studies have found that sandbuilder larvae begin to settle from the plankton in late May or early June. Curtis (1973) extended these studies and reports (e.g., Curtis 1978) that larvae occur in the plankton from mid-April through October and settle in late May through October, with peaks in early summer and later in autumn. Persistence of the larvae in the plankton suggests that spawning occurs repeatedly in the April to October breeding season. Subtidal adults appear to have much higher survival rates and thus are the main contributor of the spring larvae. The intertidal colonies are settled in the spring by larvae spawned mainly by subtidal adults.

Curtis (1973) proposed that lunar or tidal spawning phasing and positive phototaxis were required to retain larvae in the region of the adults' habitat. Such a mechanism could account for the high sandbuilder abundances, settlement and reef formation in the Delaware Bay as opposed to the rest of the species' range. However, Pembroke (1976) investigated phototactic and geotactic responses of sandbuilder larvae and concluded that a light-dependent vertical migration was not capable of retaining larvae within the Bay. Eckelbarger (1975) reported gregarious settlement of larvae in laboratory experiments. Woodard (1978) concluded that subtidal and low intertidal worms contribute most heavily to the breeding population in Delaware Bay.

Sandbuilder worms have a persistent and well-documented distribution within the Delaware Bay. Subtidal populations appear to be more widespread and seasonally stable. Intertidal populations are more limited by availability of stable substratum and determined by seasonal recruitment and winter mortality.

Potential impacts of shoreline restoration and possible restoration options

Shoreline restoration at Broadkill Beach is anticipated to extend sand 67 m (220 feet) from mean high water to a depth of up to 2 m of sand. This will bury the groins and most of the length of the Old Inlet Jetty. Given that sandbuilder worms are sessile and tube dwelling, burial with substantial depths of sand will smother the worms and kill the intertidal colonies and reefs.

Analysis of the literature and recent observations indicates that sandbuilder worm populations (intertidal, but especially subtidal) are persistent and nearby, north and south of, Broadkill Beach. The habitat at Broadkill Beach is suitable for reef formation and intertidal populations, though limited to artificial rock structures by lack of cobble-sized or larger substratum on the beach at the beach slope break.

Sandbuilder colony and reef restoration options should focus on providing sufficiently stable rock substratum during the late May – October settlement period accessible to planktonic larvae from source populations. Accordingly, potential strategies include:

- Placing suitable substratum, large rock in groins or jetties or cobble-sized gravel on sand beaches at the 0.0 MLW tidal level during the summer months following shoreline restoration,
- Removal of the current reef masses to new shoreline locations to reconstruct or re-seed reefs via enhanced larval settlement,
- Reestablishing reefs by emplacement of colonized rocks from an extensive source population, e.g. that at the Mispillion jetty (Curtis 1975).

The efficacy of such restoration measures could be assessed in terms of the overall number or area of reef habitat created as compared to that presently occurring at Broadkill Beach. Successful establishment of new intertidal reef should be apparent as settlement, and new tube growth should be visible within a few months. It would also be useful to know the exact location and distance to the nearest intertidal and subtidal populations. Transport of sand away from the shoreline restoration site has the potential to impact naturally occurring sandbuilder worms at nearby beaches as well as subtidal populations. While outside the project limits, these populations are those most likely to provide larvae for settlement on emplaced, bare substratum. If sandbuilder worms can successfully out compete barnacles and mussels for intertidal rock surface, then it may be feasible to emplace substratum prior to the larval settlement period.

Conclusions

In a July, 2001 survey of Broadkill Beach, sandbuilder worm colonies were found in reef-like masses at three locations: two on the rock groins at Alabama and at Georgia Avenues, and the largest on the Old Inlet Jetty south of Route 16 and north of the Beach Plum Island boundary. At each location, sandbuilder reefs were associated with large rocks comprising the groins and jetty. No colonies were found along the beach near the beach slope break, low in the intertidal zone where they presently occur at nearby beaches in the lower Delaware Bay. In comparison with other sites studied by the contractor, sand beaches at Broadkill Beach lack the stable, cobble-sized or larger substratum to which colonies attach at nearby beaches. All colonies at Broadkill Beach are associated with large rocks on artificial structures.

Sandbuilder worms have a life cycle with a planktonic larval stage that permits broad dispersal. Larval settlement occurs over extended periods in the summer and early fall and is often gregarious. Stable substratum, for example gravel and rock of sufficient size not to be overturned by wave action, placed near mean low water should provide favorable habitat for sandbuilder worm settlement and reef development.

Sandbuilder worms are epifaunal and require water flow and wave action to provide food particles, oxygen and sand grains for tube building. While they have some capability to withstand burial under thin layers of sand, shoreline restoration would be expected to bury the present reefs at Broadkill Beach resulting in a substantial loss of this habitat. This impact could be compensated by placing suitable substratum, large rock in groins or jetties or cobble-sized gravel on sand beaches at mean low water during the summer or early fall following shoreline restoration. Other possibilities include removing current reef masses to new shoreline locations to reconstruct or reseed from enhanced larval settlement on the restored reefs.

Bibliography

Amos, W.H. 1966. The life of the seashore. McGraw-Hill.

Curtis, L.A. 1973. Aspects of the life cycle of *Sabellaria vulgaris* Verrill (Polychaeta: Sabellariidae) in Delaware Bay. Ph.D. Dissertation. Department of Biological Sciences, University of Delaware, Newark.

Curtis, L.A. 1975. Distribution of *Sabellaria vulgaris* Verrill (Polychaeta: Sabellariidae) on a sandflat in Delaware Bay. Chesapeake Science 16: 14-19.

Curtis, L.A. 1978. Aspects of the population dynamics of the polychaete *Sabellaria vulgaris* Verrill in Delaware Bay. Estuaries 1: 73-84.

Eckelbarger, K.J. 1975. Post settling stages of *Sabellaria vulgaris*. Mar. Biol. 30: 137-149.

Gosner, K.L. 1978. A field guide to the Atlantic seashore. Houghton Mifflin.

Gray, J.S. 1981. The ecology of marine sediments. Cambridge.

Haines, J.L. 1978. The *Hydroides dianthus* assemblage and its structural complexity. College of Marine Studies. Master's Thesis. University of Delaware, Newark, DE.

Haines, J.L. and D. Maurer. 1980a. Benthic invertebrates associated with a serpulid polychaete assemblage in a temperate estuary. Int. Revue ges. Hydrobiol. 65: 643-656.

Haines, J.L. and D. Maurer. 1980b. Quantitative faunal associates of the serpulid polychaete *Hydroides dianthus*. Mar. Biol. 56: 43-47.

Hidu, H. 1978. Setting of estuarine invertebrates in Delaware Bay, New Jersey, related to intertidal and subtidal gradients. Int. Revue ges. Hydrobiol. 63: 637-661.

Karlson, R.H. and M.A. Shenk. 1983. Epifaunal abundance, association, and overgrowth patterns on large hermit crab shells. J. Exp. Mar. Biol. Ecol. 70: 55-64.

Lalli, C.M. and T.R. Parsons. 1997. Biological oceanography. An introduction. Second edition. Butterworth Heinemann.

Lippson, A.J. and R.L. Lippson. 1997. Life in the Chesapeake Bay. Johns Hopkins.

Maurer, D. and L. Watling. 1973. Studies on the oyster community in Delaware: the effects of the estuarine environment on the associated fauna. Int. Revue ges. Hydrobiol. 58: 161-201.

Maurmeyer, E.M. 1978. Geomorphology and evolution of transgressive estuarine washover barriers along the western shore of Delaware Bay. Ph.D. Dissertation. Department of Geology. University of Delaware, Newark, DE.

Pembroke, A.E. 1976. Ontogenetic changes in the phototactic and geotactic responses of larvae of *Sabellaria vulgaris* Verrill. M.S. Thesis. College of Marine Studies. University of Delaware, Newark, DE.

Pollock, L.W. 1998. A practical guide to the marine animals of northeastern North America. Rutgers University Press.

Rees, C.P. 1976. Grain size distribution in tubes of *Sabellaria vulgaris* Verrill. Ches. Sci. 17: 59-61.

Ruppert, E.E., and R.S. Fox. 1988. Seashore animals of the Southeast. U. South Carolina Press.

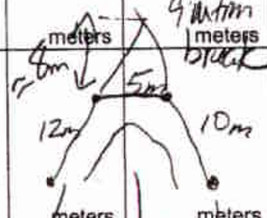
USACE (U.S. Army Corps of Engineers). 1997. Delaware River Main Channel Deepening Project Draft Supplemental Environmental Impact Statement. January 1997. U.S. Army Engineer District Philadelphia.

Wells, H.W. 1970. *Sabellaria* reef masses in Delaware Bay. Chesapeake Science 11: 258-260.

Woodard, D. 1978. The effect of different tidal zones on the oogenesis and fecundity of the poloychaete *Sabellaria vulgaris* Verrill. M.S. Thesis. Department of Biology. University of Delaware, Newark, DE.

APPENDICES

Broadkill Data Sheet: Date 7/20 / Beach Segment NORTH / Observers Susannah Conrad, Stephanie + Abigail, Darcy / Start 1300 / End ______

Time	Colony #	Lat + Long	Along-shore	Seaward Extent	Shape	% Cover & Substratum	Condition	Additional Samples	Comments
13:51	# —	38° 50.438 75° 13.593 (46m)	— meters	— meters	photo # 1 ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	___ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope 6 ° T 26.6 °C S 24.4 ‰	1st sand bar BN1
14:13	# —	38° 50.239 75° 13.304	— meters	— meters	photo # 2 ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	___ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope 8 ° T 25.8 °C S 25.3 ‰	gravel sample G2
14:29	#	38° 49.997 75° 12.966 10.1	6.3 meters	5.0 9 within meters break	photo # 4-5 ☐ rectangular ☒ triangular ☐ scattered ☐ isolated ☐ at edges	50-100 % cover ☒ rock 60in ☐ cobbles ☐ gravel ☐ sand ☐ mud	☒ mussels + algae ☐ tubeworms ☐ crab holes ☒ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope 7 ° T 25.3 °C S 22.2 ‰	Sediment sample G3
14:42	#	38° 49.938 75° 12.911	 meters	meters	photo # (1) ☐ rectangular ☒ triangular ☐ scattered ☐ isolated ☐ at edges see sketch	edges only to 100 % cover ☒ rock 60in ☐ cobbles ☐ gravel ☐ sand ☐ mud	☒ mussels + algae ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	~~voucher jar #~~ (sed sample) G4 ~~bag or tube #~~ beach slope 6 ° T 25.2 °C S 25.2 ‰	G4 angelwing 10cm thick

Notes: around margin no SV 4m from slope break

Sheet # ___ of ___ (form revised 20 July 2001)

Broadkill Data Sheet: Date 7/20 / Beach Segment NORTH / Observers ______ / Start ______ / End ≈1600

Time	Colony #	Lat + Long	Along-shore	Seaward Extent	Shape	% Cover & Substratum	Condition	Additional Samples	Comments
15:08	Wood piling + #Goin	38° 49.876 75° 12.860 (4.8)	meters	meters	photo # ____ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	____ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	(voucher jar #) → 65 ~~sed sample~~ bag or tube # beach slope 8 ° T 25.3 °C S 25.5 ‰	65
__:__	#	38° __.__ 75° __.__	meters	meters	photo # ____ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	____ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope ___ ° T ___ °C S ___ ‰	
__:__	#	38° __.__ 75° __.__	meters	meters	photo # ____ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	____ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope ___ ° T ___ °C S ___ ‰	
__:__	#	38° __.__ 75° __.__	meters	meters	photo # ____ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	____ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope ___ ° T ___ °C S ___ ‰	

Notes:

Sheet # 2 of 2 (form revised 20 July 2001)

Broadkill Data Sheet: Date 7/21/01 / Beach Segment South / Observers Stephanie, Conrad, Abigail & DDJ / Start 1400 / End 1615

Time	Colony #	Lat + Long	Along-shore	Seaward Extent	Shape	% Cover & Substratum	Condition	Additional Samples	Comments
14:14	Christine #transect	38° 48.04 75° 11.383	— meters	— meters	photo # 1 ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	___ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope 6 ° T 26.6 °C S 26.5 ‰	S1
14:21	#	38° 48.743 75° 11.668	3-4 meters	65 est 5m from slope edge ~2 meters	photo # 2+ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges lightly/100%	10-100 % cover at end ☒ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☒ mussels - dense ☐ tubeworms grass ☐ crab holes ☒ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope 5 ° T 26.8 °C S 25.7 ‰	S2 mussels sample
15:18	#	38° 49.150 75° 12.070	— meters	— meters	photo # 3 ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	___ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope 5 ° T 28.0 °C S 26.4 ‰	S3
15:46	#	38° 49.646 75° 12.586	— meters	— meters	photo # ___ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	___ % cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope 7 ° T 28.0 °C S 20.0 ‰	S4

Notes: ✓

Sheet # 1 of 2 (form revised 20 July 2001)

Broadkill Data Sheet: Date 7/21 / Beach Segment ______ / Observers ______ / Start ______ / End ______

Time	Colony #	Lat + Long	Along-shore	Seaward Extent	Shape	% Cover & Substratum	Condition	Additional Samples	Comments
15:54	#	38° 49.701 75° 12.659	— meters	— meters	photo # ____ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	____% cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope ____° T ____°C S ____‰	S5
__:__	#	38° __.__ 75° __.__	meters	meters	photo # ____ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	____% cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope ____° T ____°C S ____‰	
__:__	#	38° __.__ 75° __.__	meters	meters	photo # ____ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	____% cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope ____° T ____°C S ____‰	
__:__	#	38° __.__ 75° __.__	meters	meters	photo # ____ ☐ rectangular ☐ triangular ☐ scattered ☐ isolated ☐ at edges	____% cover ☐ rock ☐ cobbles ☐ gravel ☐ sand ☐ mud	☐ mussels ☐ tubeworms ☐ crab holes ☐ new Sv growth ☐ new Sv settlement ☐ eroding tubes ☐ vacant tubes	voucher jar # sed sample bag or tube # beach slope ____° T ____°C S ____‰	

Notes:

Sheet # 2 of 2 (form revised 20 July 2001)

FIGURES

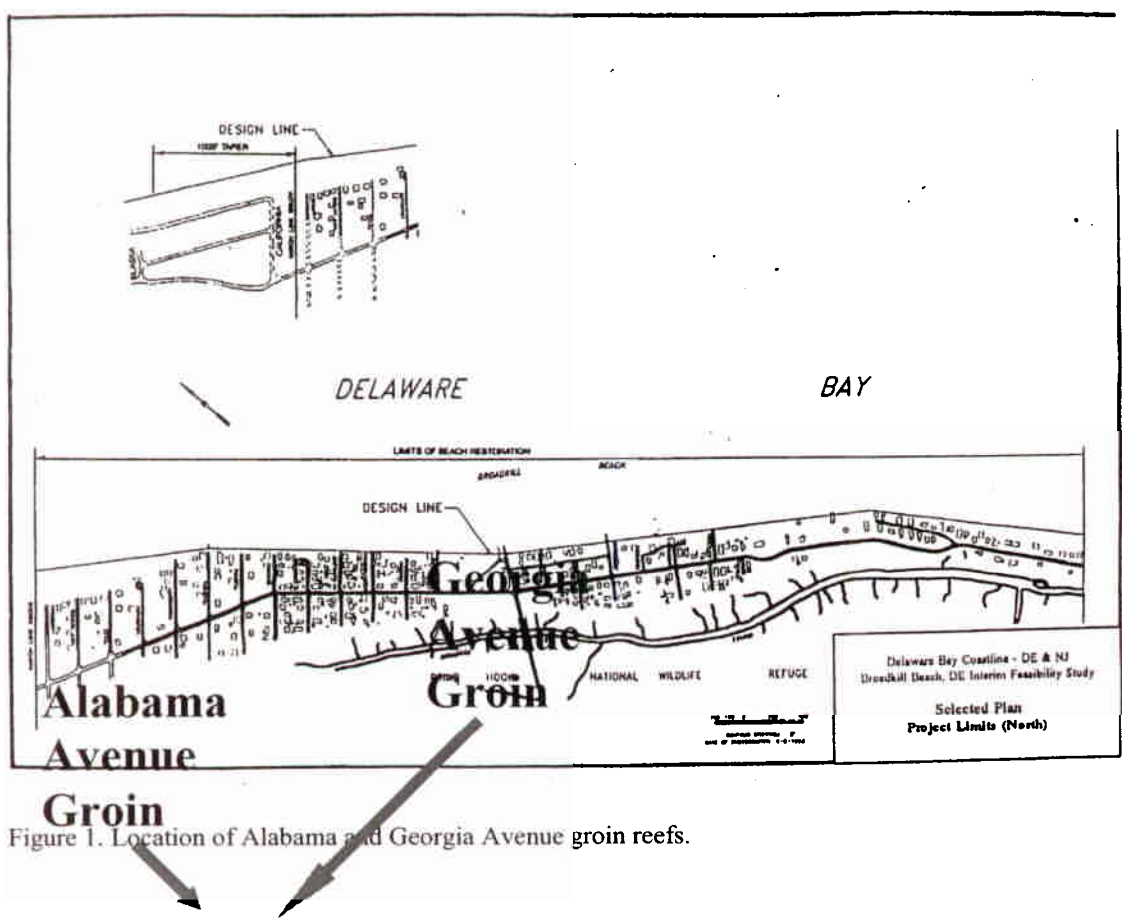


Figure 1. Location of Alabama and Georgia Avenue groin reefs.

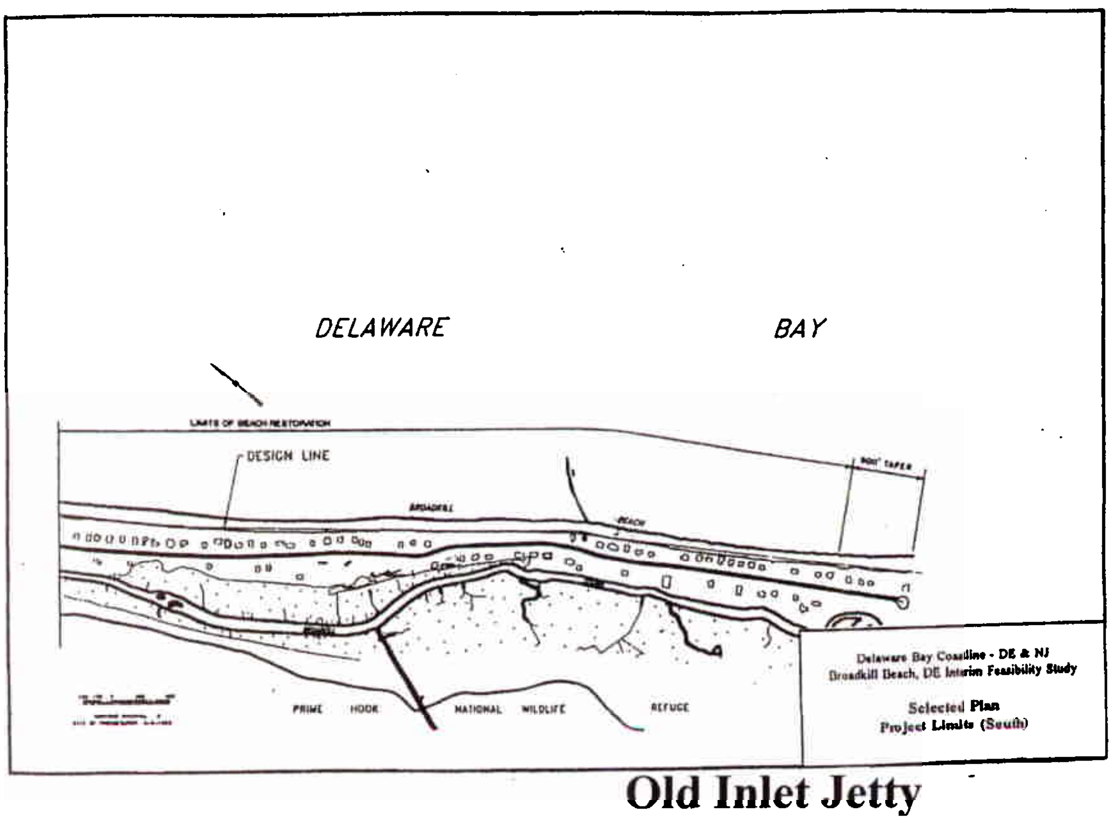


Figure 2. Location of Old Inlet Jetty reef.

Figure 3. Survey team for Broadkill Beach, 20 July 2001. Left to right: Stephanie Roberts (Howard U.), Abigail Bradley (U. Delaware), Susannah Karin (U. Delaware), Conrad Pilditch (U. Waikato). GPS Location: at north end of survey area, 38° 50.438′ N, 75° 13.593′ W.

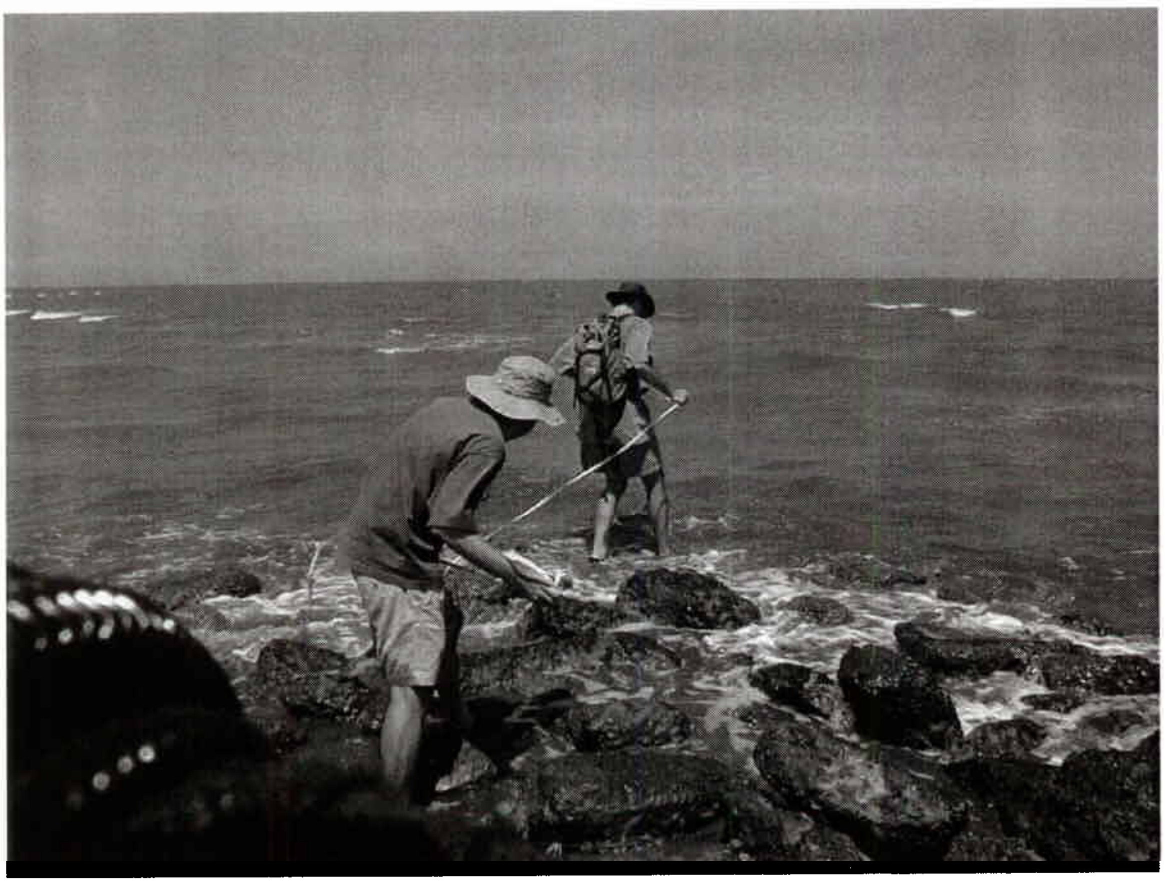


Figure 4. Alabama Avenue groin, 20 July 2001, 38° 49.997′ N, 75° 12.996′ W. Wide photograph of the triangular reef at the bayward end of the rock groin.

Figure 5. Alabama Avenue groin, 20 July 2001, 38° 49.997′ N, 75° 12.996′ W. Close photograph of rocks covered with sandbuilder worm colonies with 0.5 m x 0.5 m quadrat for scale. Note colonization by mussels and macroalgae.

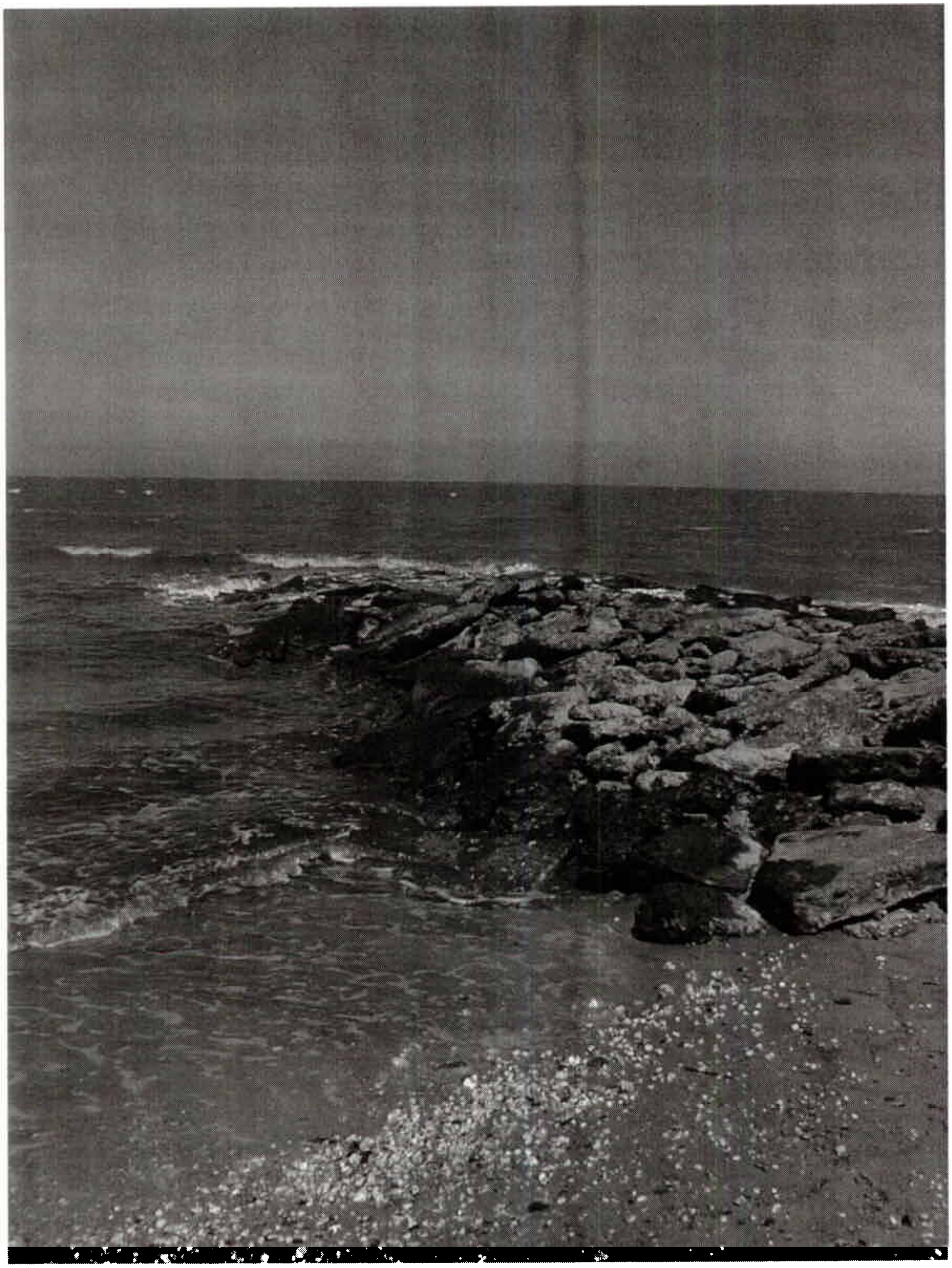


Figure 6. Georgia Avenue groin, 20 July 2001, 38° 49.938′ N, 75° 12.911′ W. Wide photograph of rocks covered with sandbuilder worm.

Figure 7. Georgia Avenue groin, 20 July 2001, 38° 49.938′ N, 75° 12.911′ W. Wide photograph of rocks covered with sandbuilder worm colonies with 0.5 m x 0.5 m quadrat for scale.

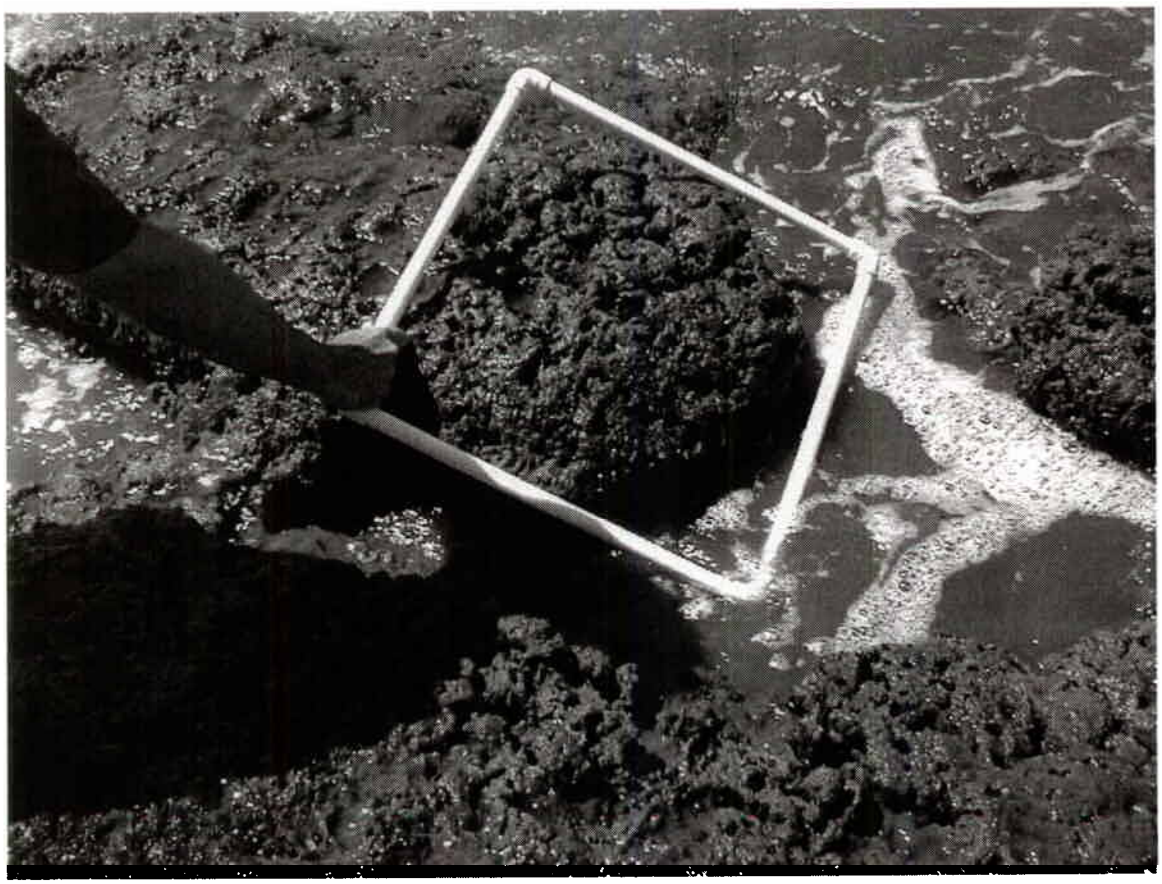


Figure 8. Georgia Avenue groin, 20 July 2001, 38° 49.938′ N, 75° 12.911′ W. Close photograph of rocks covered with sandbuilder worm colonies with 0.5 m x 0.5 m quadrat for scale.

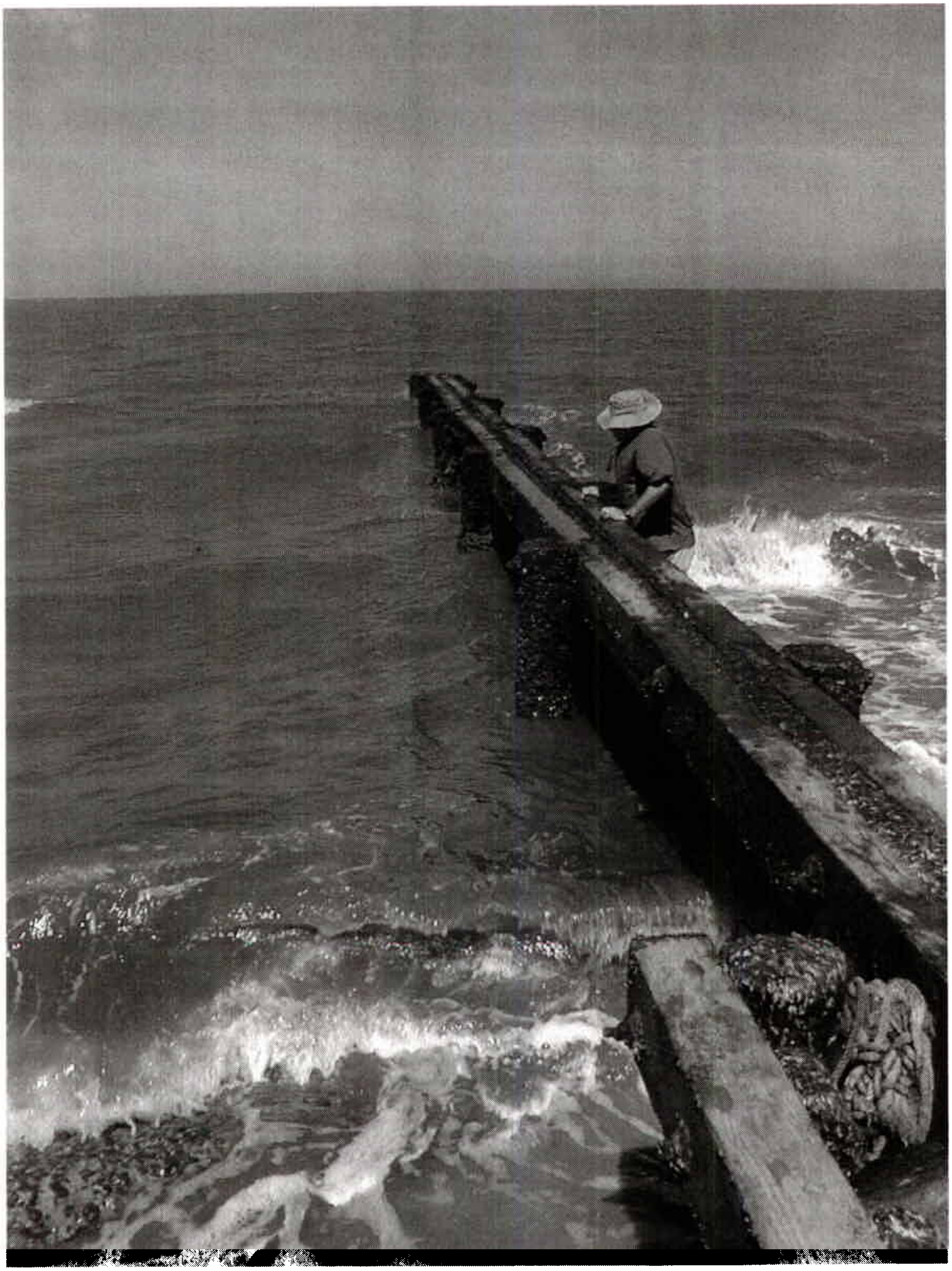


Figure 9. Wooden groin, 20 July 2001, 38° 49.876′ N, 75° 12.860′ W. No sandbuilder worm colonies observed.

Figure 10. Old Inlet Jetty, 21 July 2001, 38° 48.743′ N, 75° 11.668′ W. Wide photograph showing full length of jetty.

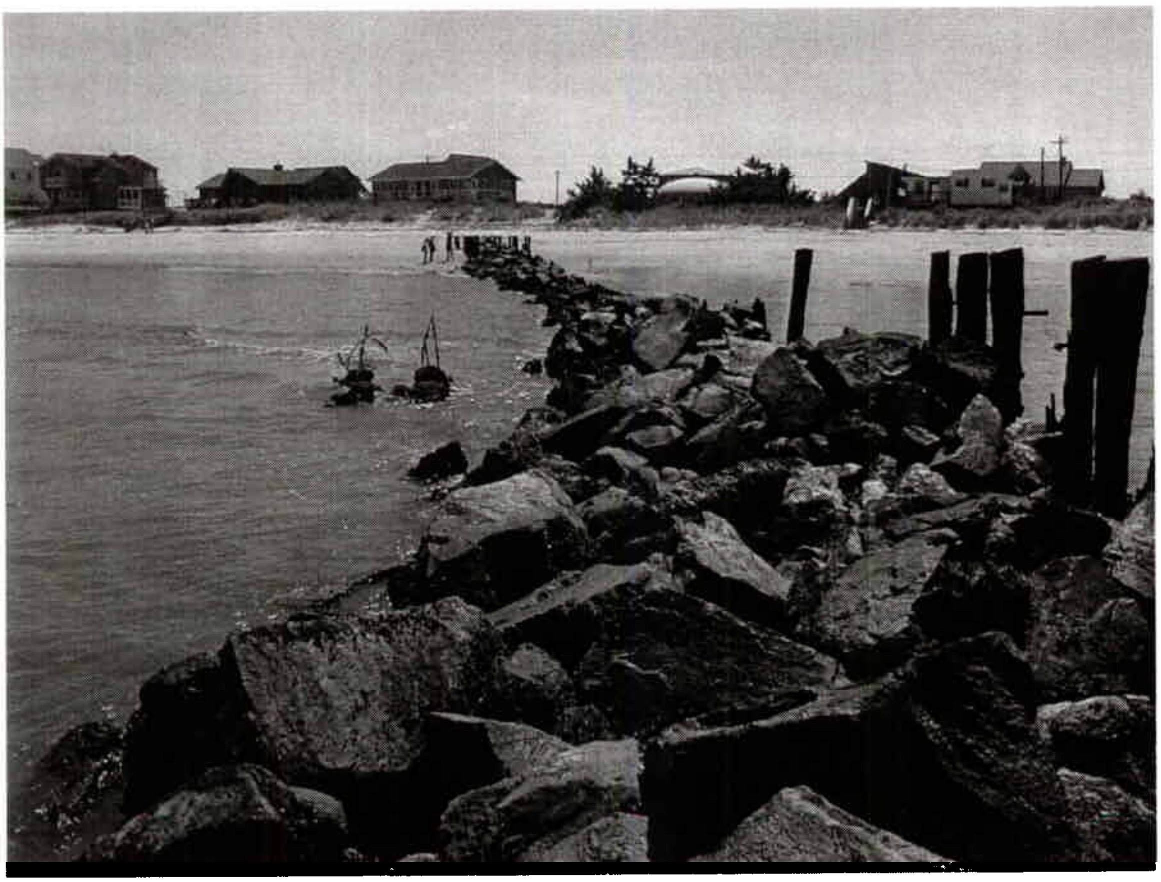


Figure 11. Old Inlet Jetty, 21 July 2001, 38° 48.743′ N, 75° 11.668′ W. Wide photograph from mid-jetty towards shore.

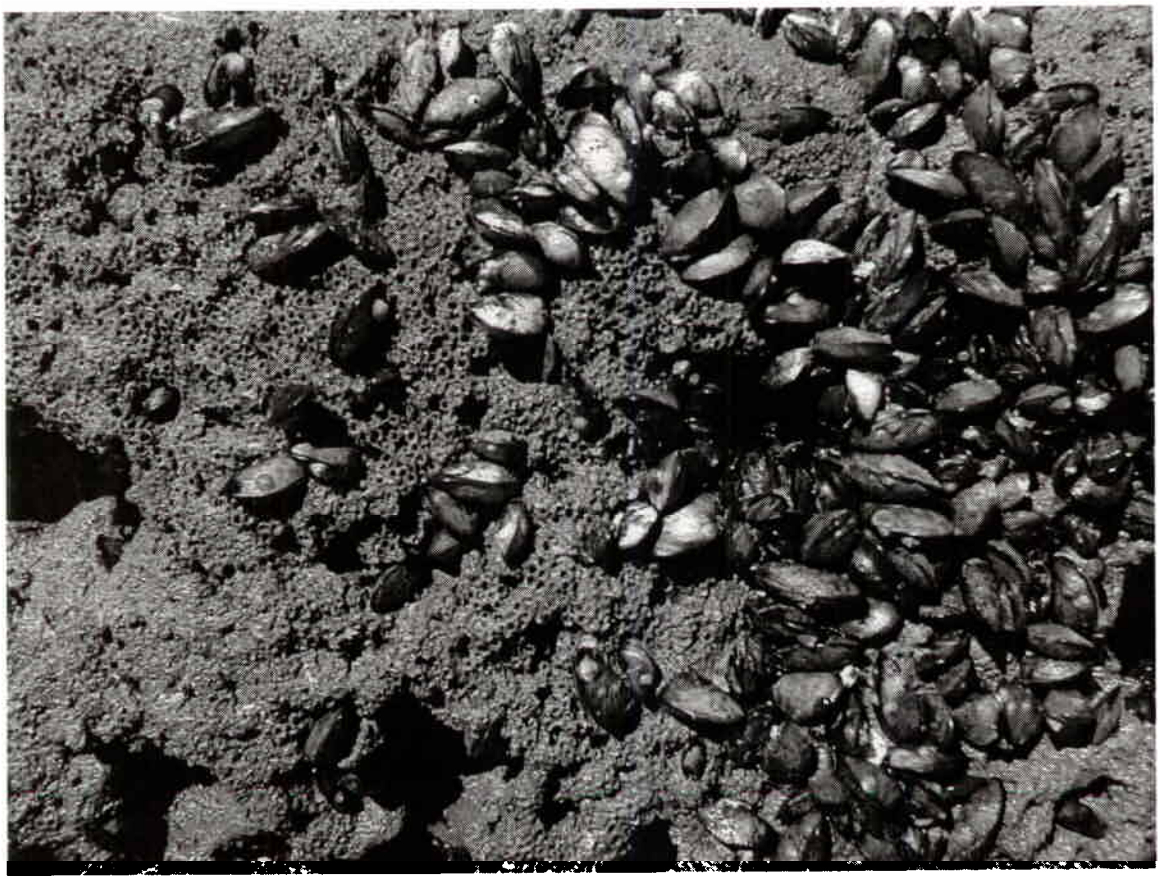


Figure 12. Old Inlet Jetty, 21 July 2001, 38° 48.743′ N, 75° 11.668′ W. Close photograph showing sandbuilder reef with mussels and new tube growth.

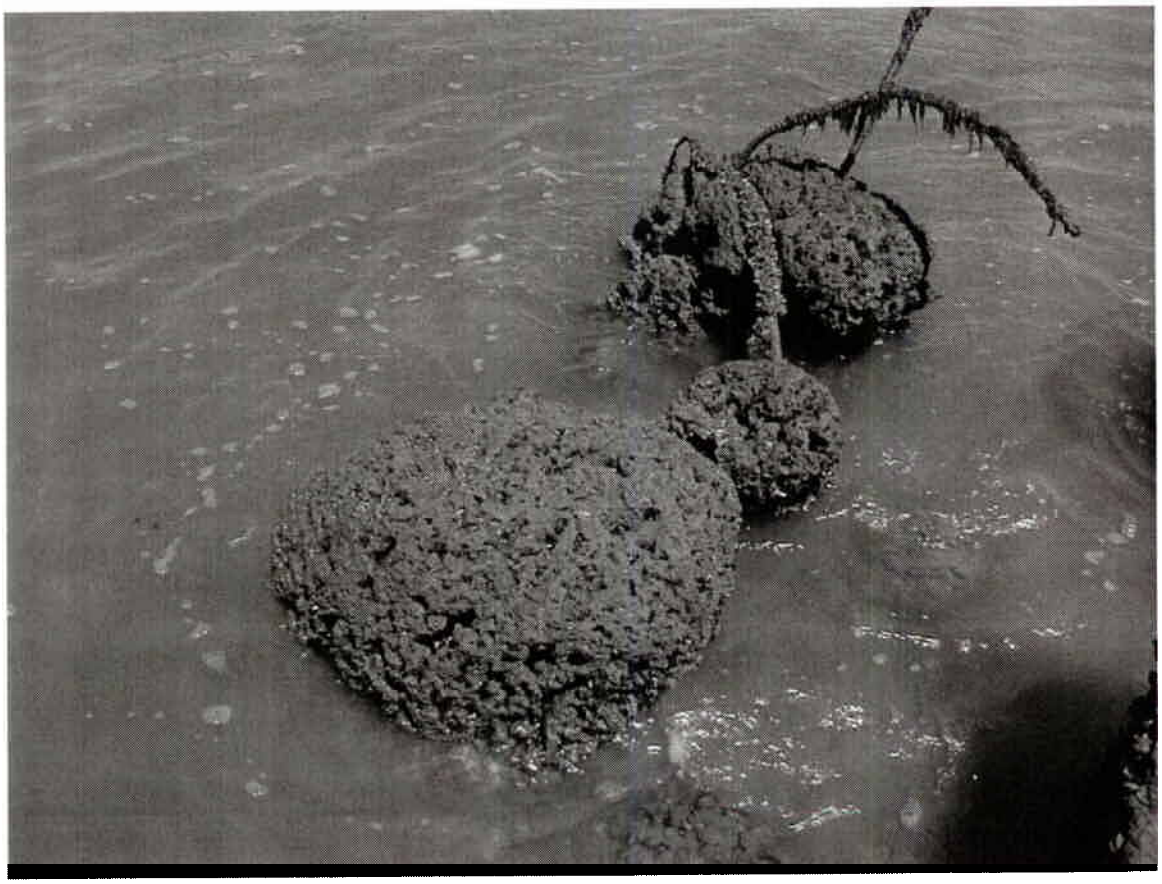


Figure 13. Old Inlet Jetty, 21 July 2001, 38° 48.743′ N, 75° 11.668′ W. Close photograph showing sandbuilder worm colonies completely covering rocks and other debris.

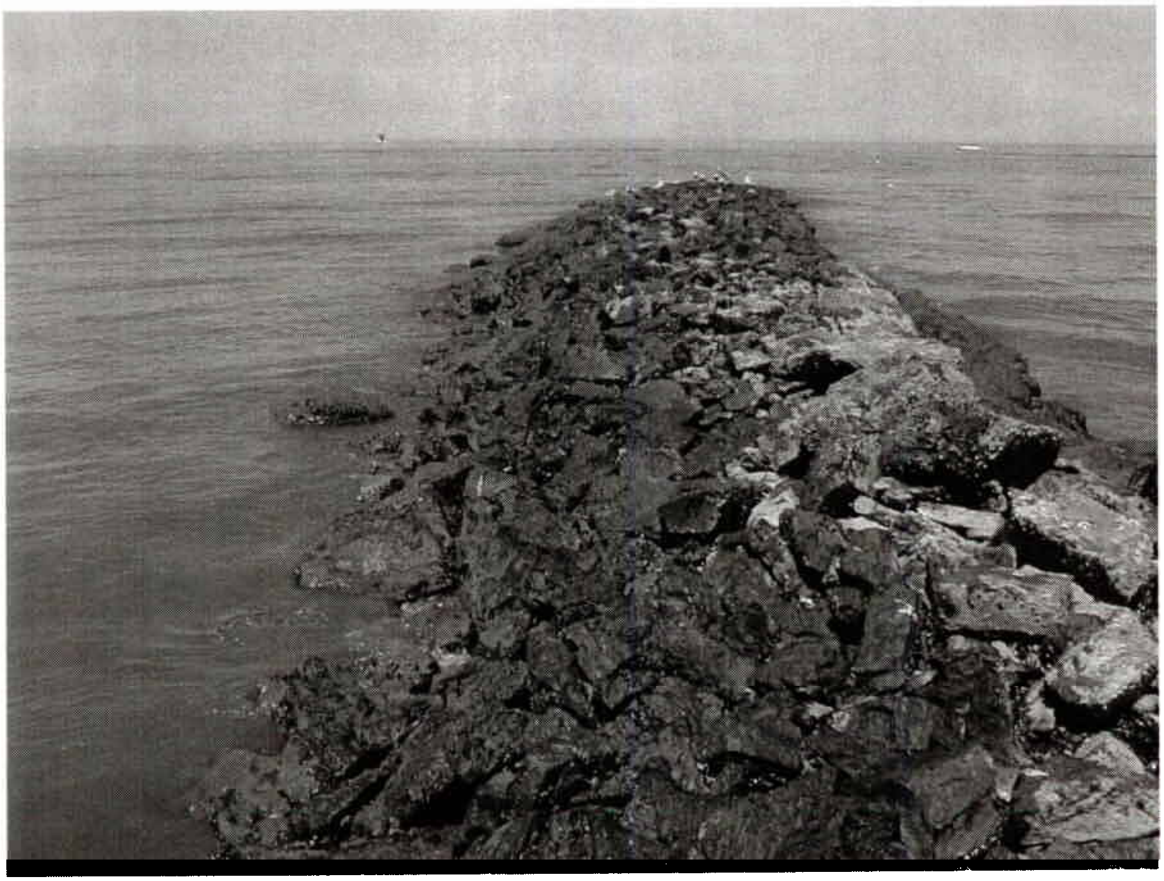


Figure 14. Old Inlet Jetty, 21 July 2001, 38° 48.743′ N, 75° 11.668′ W. Wide photograph from mid-jetty towards bay showing sandbuilder reef on flanks of jetty structure.

Figure 15. Sand beach, 21 July 2001, 38° 49.150′ N, 75° 12.070′ W. No sandbuilder worm colonies observed at beach slope break.

Figure 16. Wooden groin, 21 July 2001, 38° 49.646′ N, 75° 12.586′ W. No sandbuilder worm colonies observed.

TABLES

Table 1. Summary of locations and characterization of *Sabellaria* reefs at Broadkill Beach, surveyed 20-21 July 2001.

Sabellaria Reef	GPS Location	Dimensions	Reef Description	Figure #s
Alabama Avenue Groin	38° 49.997′ N 75° 12.966′ W	• Triangular reef at bayward end of groin • 6.3 m wide alongshore × 5 m visible bayward, starting 9 m from beach slope break • Plan area: 16 m^2	• Rock substratum, 50-100% covered • Reef settled with blue mussels and algae (sea lettuce and filamentous green) • New *Sabellaria* tube growth • Seawater: 25.3 °C, 22.2 ‰	• Location: Fig. 1 • Reef: Figs. 3, 4, 5
Georgia Avenue Groin	38° 49.938′ N 75° 12.911′ W	• Chevron-shaped reef at bayward end of groin • 5 m wide alongshore × 8 m visible bayward, plus band 27 m × 2 m wide, starting 4 m from beach slope break • Plan area: 74 m^2	• Rock substratum, edges of rocks to 100% covered • Reef settled with blue mussels and algae (sea lettuce and filamentous green), and false angel wing mollusc in burrows • Seawater: 25.5 °C, 25.2 ‰	• Location: Fig. 1 • Reef: Figs. 6, 7, 8
Old Inlet Jetty	38° 48.743′ N 75° 11.668′ W	• Long jetty • 3-4 m wide alongshore × 65 m (estimate) bayward, starting 2 – 5 m from beach slope break • Plan area: 228 m^2	• Coverage from 10% near beach to 100% at seaward end • Reef settled with mussels, porous, new tube growth • Seawater: 26.8 °C, 25.7 ‰	• Location: Fig. 2 • Reef: Figs. 10, 11, 12, 13, 14
Summary: three reefs in 3.0 km of beach		Of total area: 318 m^2	All on artificial rock	

Table 2. Summary of seawater temperature, salinity, beach slope and sediment grain size data Broadkill Beach, surveyed 20-21 July 2001.

Date, Local Time and Location	GPS Latitude and Longitude	Seawater Temperature, °C	Salinity, ‰	Beach Slope, °	Sediment Median Grain Size and Sorting Coefficient	Comments
20 July 13:51	38° 50.438′ N 75° 13.593′ W	26.6	24.4	6	582 µm coarse sand 0.21 ϕ sorting coefficient	Sandbar at north end Fig. 3
20 July 14:13	38° 50.239′ N 75° 13.304′ W	25.8	25.3	8	760 µm coarse sand 0.36 ϕ sorting coefficient	
20 July 14:29 Alabama Avenue	38° 49.997′ N 75° 12.966′ W	25.3	22.2	7	798 µm coarse sand 1.13 ϕ sorting coefficient	Sandbuilder reef Figs. 3-4
20 July 14:42 Georgia Avenue	38° 49.938′ N 75° 12.911′ W	25.2	25.2	6	648 µm coarse sand 0.63 ϕ sorting coefficient	Sandbuilder reef Figs. 6-8
20 July 15:08	38° 49.876′ N 75° 12.860′ W	25.3	25.5	8	225 µm fine sand 0.33 ϕ sorting coefficient	Wooden groin Fig. 9
21 July 14:14	38° 48.407′ N 75° 11.383′ W	26.6	26.5	6	196 µm fine sand 0.38 ϕ sorting coefficient	Student's transect site
21 July 14:31 Old Inlet Jetty	38° 48.743′ N 75° 11.668′ W	26.8	25.7	5	196 µm fine 0.24 ϕ sorting coefficient	Sandbuilder reef Figs. 10-14
21 July 15:18	38° 49.150′ N 75° 12.070′ W	28.0	26.4	5	900 µm coarse sand 0.11 ϕ sorting coefficient	Fig. 15
21 July 15:46	38° 49.646′ N 75° 12.586′ W	28.0	26.0	7	601 µm coarse sand 0.21 ϕ sorting coefficient	Fig.16
21 July 15: 54	38° 49.701′ N 75° 12.659′ W	Not determined	Not determined	Not determined	Not determined	Last wooden groin, no sandbuilder colonies
Summary	Ranges:	25.2 – 28.0 °C	22.2 – 26.5 ‰	5 – 8 °	Fine or coarse sands, well sorted to poorly sorted	