Journal of Coastal Research	22	5	1133–1144	West Palm Beach, Florida	September 2006

Habitat Preference and the Effects of Beach Nourishment on the Federally Threatened Northeastern Beach Tiger Beetle, *Cicindela dorsalis dorsalis*: Western Shore, Chesapeake Bay, Virginia

Michael S. Fenster, C. Barry Knisley, and Christopher T. Reed*

Randolph-Macon College
Environmental Studies Program
Ashland, VA 23005, U.S.A.
mfenster@rmc.edu

ABSTRACT

FENSTER, M.S.; KNISLEY, C.B., and REED, C.T., 2006. Habitat preference and the effects of beach nourishment on the federally threatened northeastern beach tiger beetle, *Cicindela dorsalis dorsalis*: Western Shore, Chesapeake Bay, Virginia. *Journal of Coastal Research*, 22(5), 1133–1144. West Palm Beach (Florida), ISSN 0749-0208.

This study examines the habitat preference of the US federally threatened northeastern beach tiger beetle, *Cicindela dorsalis dorsalis*, and the effect of beach nourishment on existing habitats along two western Chesapeake Bay beaches. Winter Harbor Beach and Smith Point Beach, located approximately 100 km to the north, historically have supported large populations of *C. d. dorsalis*. Grain size distributions, sediment compaction at two depths, temperature, moisture, and beach width habitat parameters were analyzed by analysis of variance and Tukey's honestly significant difference multiple comparison test and related to the distribution and abundance of *C. d. dorsalis*. The results from this study indicate that this species prefers beaches at least 6 m wide, with moderately well–sorted sands having a mean grain size of 0.5 to 0.6 mm, and relatively compacted sediment with averages of 69 psi and 110 psi at depths of 10 and 15 cm, respectively. In addition, the two nourishment projects had a positive short-term effect on the beetle habitat despite differences in deposition location. At Smith Point Beach, deposition occurred on top of the subaerial beach with a minimal increase in beach width. At Winter Harbor Beach, nearshore deposition caused a 50-m increase on average in beach width. Within weeks of deposition, adults of *C. d. dorsalis* rapidly moved onto the nourished sections of both beaches and produced large numbers of larvae. Winter Harbor Beach experienced the greatest increase in beetle numbers, most likely because of the additional habitat created by nearshore deposition. However, continued erosion from natural and anthropogenic sources could produce a chronic threat to productive habitats. These findings will assist coastal engineers and developers in determining effective measures designed to aid both economic and ecologic interests.

ADDITIONAL INDEX WORDS: *Beach habitat, tiger beetle, beach nourishment, compaction, grain size distribution.*

INTRODUCTION

The northeastern beach tiger beetle, *Cicindela dorsalis dorsalis*, is one of several species of tiger beetles that inhabits sandy beaches along the United States east coast. This species has a historic range from New Jersey to Cape Cod and along much of the eastern and western shorelines of the Chesapeake Bay from southern Maryland to Virginia (KNISLEY, LUEBKE, and BEATTY, 1987). Although *C. d. dorsalis* once swarmed on these Atlantic coast beaches (LENG, 1902), especially in the northeast, the species is now extirpated from nearly this entire region. Therefore, in 1990, the US Fish and Wildlife Service placed *C. d. dorsalis* on the list of threatened species under the Endangered Species Act because of its decline in range and abundance (KNISLEY and SCHULTZ, 1997; USFWS, 1990). KNISLEY, LUEBKE, and BEATTY (1987) attributed human development and coastal erosion to this decline in beetle numbers and habitat. However, little is known about the actual effect of natural processes and shoreline erosion control methods—both hard and soft—on tiger beetle beach habitat.

Studies of other beach organisms have provided some insight into preferred habitat parameters. For example, many studies of habitat preference and the effect of beach nourishment exist for the federally threatened loggerhead turtle (*Caretta caretta, e.g.*, ACKERMAN, 1996; BROADWELL, 1991; CRAIN, BOLTEN, and BJORNDAL, 1995; EHRHART, 1995; MORTIMER, 1982, 1990; NELSON and DICKERSON, 1988; NELSON, MAUCK, and FLETEMEYER, 1987; RAYMOND, 1984; RYDER, 1993; STEINITZ, SALMON, and WYNEKEN, 1998; WOOD and BJORNDAL, 2000). STEINITZ, SALMON, and WYNEKEN (1998), among others, documented an increase in surface hardness after beach nourishment and a decrease in beach width from long-term erosion as detrimental factors on

DOI:10.2112/05-0485.1 received 2 April 2005; accepted in revision 1 November 2005.

* Present address: Johns Hopkins University, 505 N Wolfe Street, Baltimore, MD 21205, U.S.A.

The US Fish and Wildlife Service; the US Army Corps of Engineers, Baltimore and Norfolk Districts; and Randolph-Macon College's Summer Undergraduate Research Fellowship (SURF) provided funding for this research.

C. caretta reproduction. WOOD and BJORNDAL (2000) determined that sediment moisture, salinity and beach slope are key factors in the nesting sites of *C. caretta*.

Additional studies have analyzed preferred habitat parameters of and examined the effect of beach nourishment on invertebrates. For example, BOWMAN and DOLAN (1985) showed that wave energy, wave refraction, grain size distribution, beach slope, and tide height control the spatial and temporal distribution of the mole crab (*Emerita talpoida*). In a study of the swash zone at Cape Hatteras National Seashore, HAYDEN and DOLAN (1974) showed that beach nourishment caused a redistribution of *E. talpoida* rather than an increase in mortality. REILLY and BELLIS (1983) attributed high water turbidity and a lack of compatible nourishment material on the drastic effects of beach nourishment on micro- and macrofauna along the intertidal zone at Bogue Banks, North Carolina. Postnourishment monitoring showed that these effects extended beyond the nourishment site and were more dramatic on species dependent on recruitment from pelagic larval stocks. DONOGHUE (1999) found that wave height, wave period, and water temperature in the swash zone influence the distribution and abundance of both *E. talpoida* and coquina clam (*Donax variabilis*). In a 10-year study along Pea Island, North Carolina, DOLAN (2003) attributed continued dredge spoil disposal to a decline in several species, including coquina clams and mole crabs. This study related the decline to "hardening" of the beach face as a result of an increase in fine-grained sands and heavy minerals coming from Oregon Inlet dredge disposal material. In short, most studies report a rapid reduction in organism abundance at the disposal site, with either a relatively immediate recovery (*e.g.*, GORZELANY and NELSON, 1987; LYNCH, 1994) or longer term effects (*e.g.*, CUTLER and MAHADEVAN, 1982; MCLACHLAN, 1996; OLIVER and SLATTERY, 1976; SALOMAN, 1976). Longer term effects typically have resulted from significant changes in the sediment grain size or timing (seasonality) of nourishment. However, we are not aware of any studies that have examined the habitat preference and effect of beach nourishment on beach-dwelling insects.

This project determined the habitat preference and the effects of beach nourishment on the distribution and abundance of *C. d. dorsalis* at two Chesapeake Bay beaches in Virginia. In particular, two beach nourishment projects conducted 1 year apart, on two different beaches along the western shore of the Chesapeake Bay, and with the use of two different deposition locations provided an excellent opportunity to examine the effect of anthropogenic alterations. Specifically, we tested the null hypotheses that: (1) differences in habitat parameters would have no influence on the abundance and distribution of the beetles along the beach, and (2) beach nourishment would have no effect on the distribution and abundance of adults and larvae of *C. d. dorsalis* in the nourishment area.

C. D. DORSALIS LIFE CYCLE

Adults of *C. d. dorsalis* emerge from their pupal chambers in the beach in mid-June, reach peak numbers in late June/early July, and decline through August. Mating occurs throughout the period of adult activity, and the females oviposit eggs in burrows located in the upper foreshore to the lower backshore (KNISLEY and SCHULTZ, 1997). The first instar larva hatches from the egg during summer and digs a burrow at the site of oviposition. Development continues through a second and third instar and a pupal stage, which all occur in 15–40-mm-deep burrows at or near the site of oviposition. The total life cycle generally lasts 2 years, but some proportion of the population develops in 1 year. Larvae are sedentary predators that feed on small arthropods, which they capture from the mouth of their burrows. Adults actively prey on arthropods, especially amphipods, but will also scavenge on dead fish and crabs (KNISLEY and SCHULTZ, 1997).

Several biotic and abiotic factors limit the survival of *C. d. dorsalis*. Birds, wolf spiders, and asilid flies prey on adults, whereas an antlike parasitic wasp of the genus *Methocha* limits larval survival (KNISLEY and SCHULTZ, 1997). Mortality during development is high in *C. d. dorsalis*, and only 5% of the larvae survive to the adult stage (USFWS, 1993). In a 3-year study of unmodified ("natural") beaches and those with various engineered projects, KNISLEY and HILL (1996) found that natural beaches, especially those wider than several meters, had larger numbers and greater densities of both adult and larval *C. d. dorsalis* than those sites with engineered modifications.

STUDY AREAS

Two beaches along the western shore of the Chesapeake Bay provided an excellent opportunity to examine the effect of beach nourishment on the distribution and abundance of *C. d. dorsalis*. Prior to these two nourishment projects, the US Fish and Wildlife Service (USFWS) and the US Army Corps of Engineers (USACE) developed agreements that would permit nourishment at these two sites if deposition minimized the effect on beetle habitat. Monitoring of the population followed, and effects on the population were studied. This information would be used to evaluate future deposition projects and the protection and recovery of this rare insect. Both projects took place in May during the period of low larval activity and before adult emergence.

Smith Point Beach is located at the mouth of the Potomac River, northwest of Smith Point, Virginia (Figure 1). This wave-dominated beach exhibits semidiurnal tides with a tidal range of 0.5 m and fetch-limited, deep-water maximum wave heights of 0.6–1.8 m (HARDAWAY and GUNN, 1999; MILLER, 1983). An extensive nearshore platform (paleoriver terrace) reduces approaching wave energy. However, a northwest–southeast shoreline orientation places Smith Point in direct exposure to frequent northeast extratropical storms (nor'easters). Storm surge estimates for Windmill Point, with a similar shoreline orientation but located approximately 25 km south of Smith Point Beach, range from 1.0 to 1.5 m, with a recurrence interval of 10–100 years (HARDAWAY and BYRNE, 1999). In addition, the beach has experienced a reduction in sand supply, primarily from updrift erosion control devices (MILLER, 1987). As a result, the beach has eroded almost 100 m over the past 60 years at the northern end (Figure 2). In recent decades, severe storms have completely

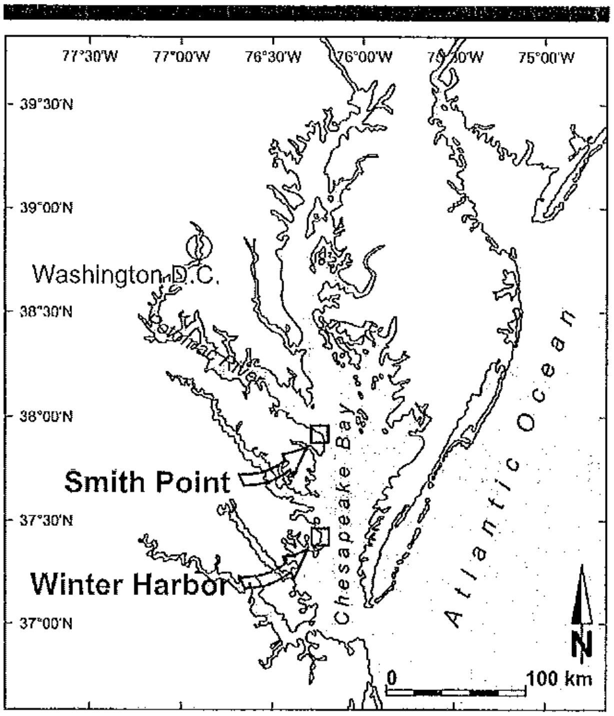
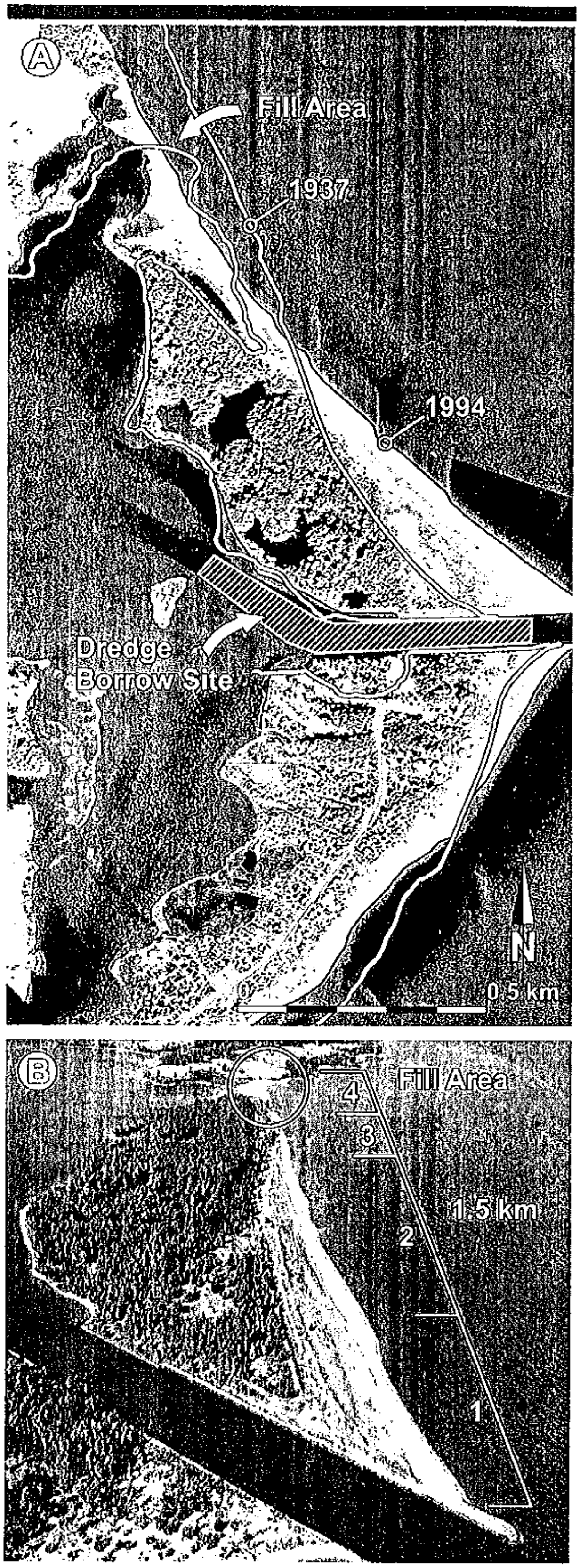


Figure 1. Study areas: Smith Point Beach and Winter Harbor Beach on the western shore of the Chesapeake Bay, approximately 60 km apart.

removed the dune system at the north end and have produced a broad, relatively flat overwash deposit.

As a result of the severe erosion at the north end of Smith Point, the USACE placed spoil material dredged from the Little Wicomico River tidal inlet (stabilized with jetties) and backbarrier into the nearshore of the northernmost reach in July 1977, April 1990, and January 1994. As part of the agreement with the USFWS, the USACE placed over 11,900 m^3 of inlet dredge spoils onto the existing subaerial beach during May 2001 with little increase in beach width (Figure 3). Although Smith Point has supported a relatively large population of *C. d. dorsalis*, only a small portion of the population occurred in the deposition reach. The southernmost 300 m of the beach, adjacent to the Little Wicomico River tidal inlet, has also supported few beetles. Historically, the middle 850 m of the beach had served as the prime habitat area for *C. d. dorsalis* (Figure 2).

Winter Harbor Beach is located 97 km south of Smith



→

Figure 2. (A) Digital Ortho Quarter Quadrangle (DOQQ) from 1994 of Smith Point Beach with the 1937 shoreline superimposed. Note the landward shoreline migration at the north end and the seaward migration at the south end during the past 60 years. (B) Oblique aerial photograph taken 13 December 2000, before nourishment, showing the division of the beach at Smith Point into four sections on the basis of previous *C. d. dorsalis* counts. Section 2 is the primary habitat area and section 4 was the site of beach nourishment. Note the severe erosion at the northern end evidenced by the lack of dunes in section 4 and maritime forest on the backshore in sections 3 and 4. (Photograph and DOQQ courtesy of C.S. Hardaway, Jr., of the Virginia Institute of Marine Sciences).

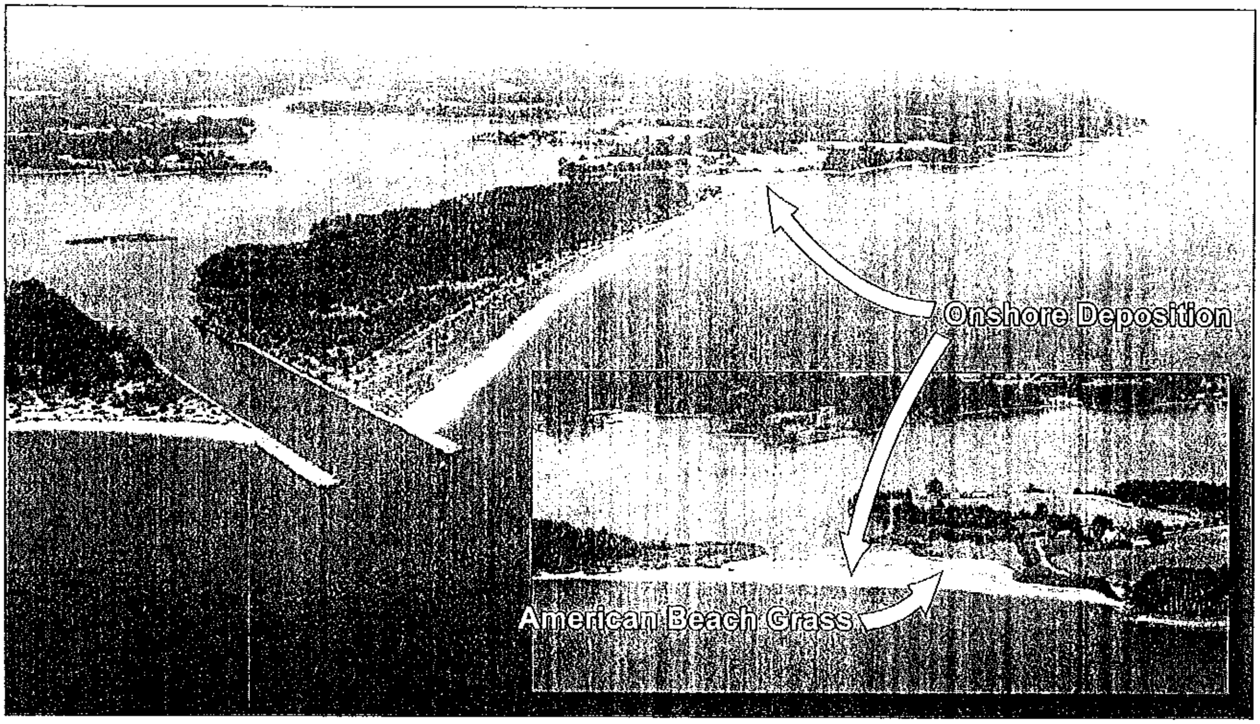


Figure 3. Postnourishment oblique aerial photograph of Smith Point Beach taken June 2002 showing the placement location of beach nourishment. Nourishment occurred primarily on the subaerial beach and inshore in section 4 at the northern end. American beach grass was planted to create a low vegetated dune.

Point, also on the western shore of the Chesapeake Bay (Figure 1). Similar to Smith Point Beach, this site has experienced chronic erosion at the northern end. Again, as part of the agreement with the USFWS, the USACE nourished this site in May 2002 with 50,000 m^3 of outer channel dredge spoils. Deposition occurred in the nearshore of an 800-m reach and widened the beach by approximately 50 m (Figures 4 and 5). Winter Harbor, like Smith Point, has also supported a large *C. d. dorsalis* population along its shoreline. However, most of the population has been concentrated in the southern/middle 1000 m of the beach (KNISLEY, HILL, and SCHULZ, 1998).

METHODS

This research consisted of developing an experimental design capable of statistical hypothesis testing, field and laboratory analyses, and quantitative data analyses. The following sections describe the method used for each component of this study.

Sampling Design

Seven years of historical adult population data between transects enabled us to divide Smith Point Beach into habitat and nonhabitat sections (Figure 2): (1) the south end of the site adjacent to the northern jetty of Little Wicomico tidal inlet (400 m long, nonhabitat, transects 1–5), (2) to the north (500 m long, habitat, transects 6–10), (3) highly eroded and to the north of section 2 (350 m long, nonhabitat, transects 11–14), and (4) in the nourishment area at the northernmost end (300 m long, transects 15–21). Dividing the beach into sections enabled us to examine beetle habitat preference and to determine the effect of beach nourishment on the habitat selection process.

We also divided Winter Harbor into sections, but previous beetle surveys indicated that habitat of *C. d. dorsalis* extended along the entire reach. Therefore, we divided the beach into two sections (Figure 4): (1) natural beach (control area, transects 1–9) and (2) the nourishment area (transects 10–18). This division also allowed us to determine the effects of beach nourishment on beetle distribution and abundance.

Within these sections, we developed and used a systematic random sampling design to collect sediment samples, measure habitat parameters, and quantitatively analyze these data. At each site, we sampled at predetermined intervals along the beach beginning from a random starting position (determined by drawing from a hat a number that represented distance) within each section. The number of samples needed per section for a statistically significant quantitative analysis determined the sampling interval at each beach. We determined the number of samples needed per section with a statistically derived sample size estimate based on data from previous studies along these beaches. For each habitat parameter, we used a 95% confidence level, a mean squared

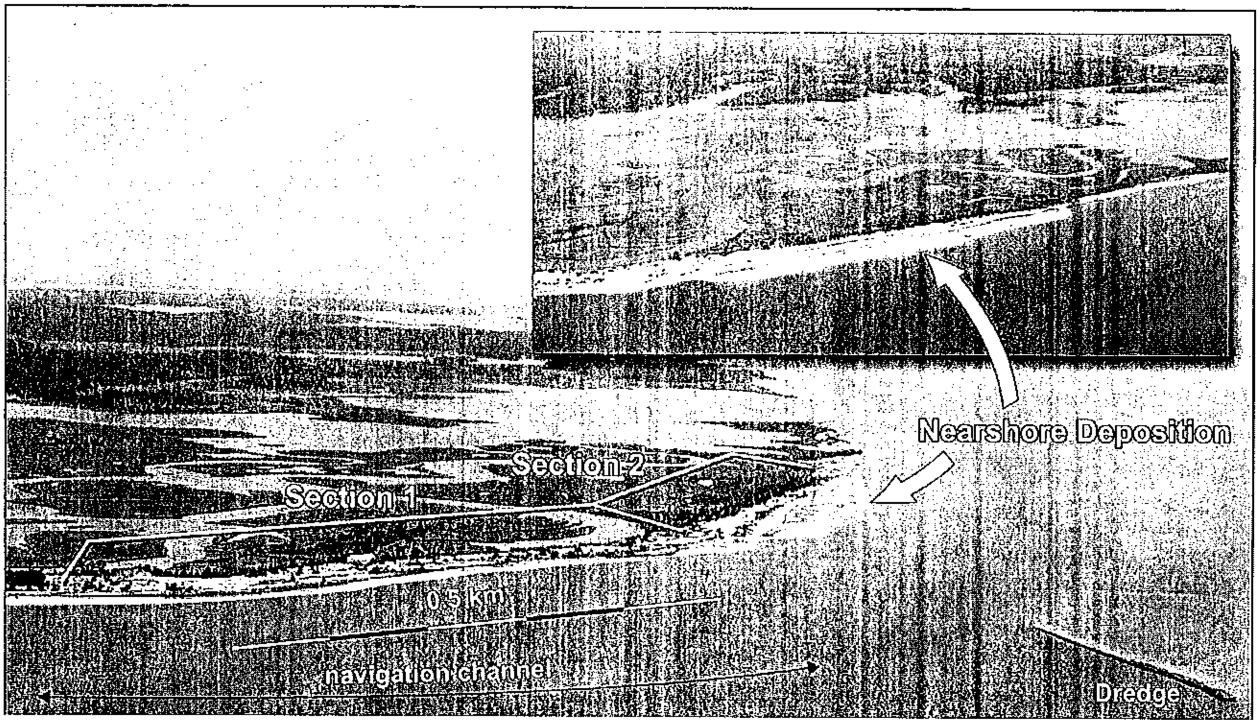


Figure 4. Oblique aerial photographs taken June 2002 showing the division of the beach at Winter Harbor Beach into two sections on the basis of natural and modified beach sections and the location and style of beach nourishment. At Winter Harbor Beach, nearshore deposition widened the beach by an average 50 m. The navigation channel shown on the larger photograph shows the location of source material.

error (MSE), and tolerance level to determine sample size (Table 1). This scheme provided 155 sample sites every 10 m along the 1.5-km-long Smith Point Beach and 87 sample sites every 20 m along the 1.7-km-long Winter Harbor Beach for a total of 242 samples of each parameter. Sampling occurred shortly after nourishment on 27 June 2002 at Winter Harbor and approximately 1 year after nourishment on 2 July 2002 at Smith Point.

Field Methods

Beetle Surveys

To determine the number of adults on the beach, we used the standard visual index count method (KNISLEY and SCHULTZ, 1997). This survey method is carried out during conditions of maximum adult activity and involves walking slowly along the water's edge and counting all adult beetles between the transect markers. At Smith Point, we surveyed the adult beetles before nourishment (30 June 2000), approximately 1 and 2 months after nourishment (26 June and 20 July 2001), and approximately 1 year later (19 June 2002). At Winter Harbor, we also surveyed the adult beetles before nourishment (3 July 2001), approximately 1 and 2 months after nourishment (18 June 2002; 3 July 2002), and 1 year later (7 July 2003).

Larval abundance is quantified by counting all larval burrows present within the 2-m-wide transects across the width of the beach during times of peak larval activity. Like adult surveys, larval surveys were conducted at Smith Point and Winter Harbor before and after deposition. At Smith Point, we surveyed the beetles on 11 October 2000, 20 October 2001, and 15 October 2002. At Winter Harbor, we surveyed the beetles on 12 October 2001, 18 October 2002, and 25 October 2003.

Beach Habitat Surveys

We obtained surficial sediment samples (2.5–5.0 cm deep) near the preferred adult foraging and oviposition sites approximately 1 m landward of the high waterline. At each sediment sample site, we also measured moisture and temperature with an Aquaterr meter and compaction (shear resistance) with a Spectrum Technologies penetrometer. Compaction readings were obtained at depths of 10 and 15 cm to analyze the potential effect of different levels of shear resistance on adult oviposition and larval burrowing. All other probe readings took place at depth (d) = 10 cm. Sampling took place at Smith Point on 20 June 2002 (1 y after the most recent nourishment) and at Winter Harbor on 2 July 2002 (<1 mo after the most recent nourishment). Beach profiles were obtained by standard field (stadia) survey techniques from a transect marker landward of the foredune ridge (where present) to an area seaward of the shoreline. Beach

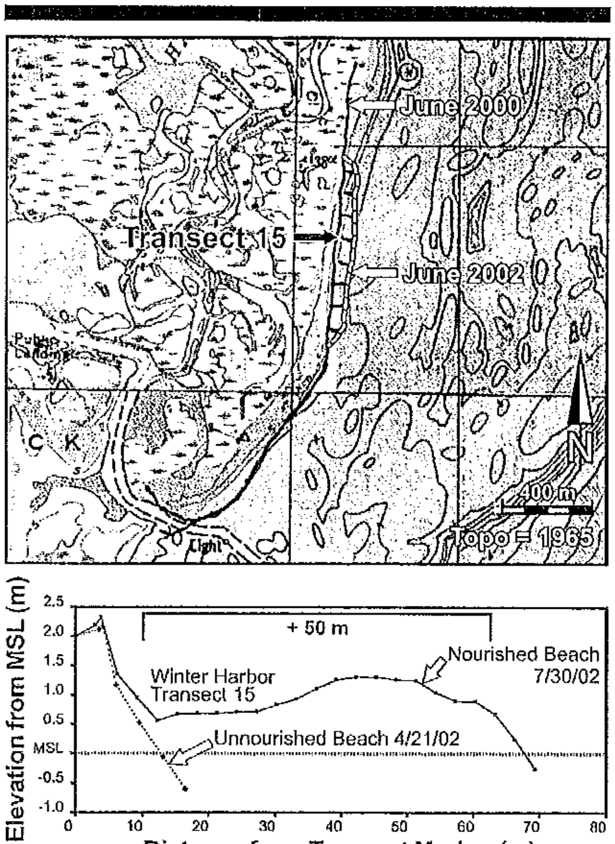


Figure 5. Topographic base map showing the 1965 shoreline position at Winter Harbor, a June 2000 prenourishment surveyed shoreline, and a June 2002 postnourishment shoreline (top). A representative beach profile before and after nourishment at sample transect 15 shows the morphologic changes and beach widening that occurred along this reach (section 2; bottom).

widths were measured from the dune toe, where present, or the vegetation line seaward to mean sea level.

Lab Methods

Percent Moisture

Percent moisture (sand percent wet weight) was determined with gravimetric methods by drying 150 cm^3 of each of the 242 sand samples from Smith Point and Winter Harbor at 38°C in an oven until constant weight was achieved with a minimum drying time of 24 hours. We obtained the water percentage with the use of the ratio of the difference between the wet and dry masses divided by the dry mass multiplied by 100 (Black, 1965).

Grain Size Analysis

To determine grain size distributions, we used a sample splitter to provide a 25–40-g subsample of each field sample. Each subsample was shaken in a Ro-Tap Mechanical sand shaker for 10 minutes with sieves stacked at 1-ϕ intervals.

Table 1. *Mean squared errors (MSE) and tolerance levels used to determine sample sizes for each habitat parameter used in this study.*

Habitat Parameter	MSE	Tolerance
Beach compaction	827	25 psi
Mean grain size	0.22	0.5 ϕ, 0.7 mm
Sorting	0.04	0.2
Skewness	0.47	0.6
Moisture	34.9	5

We then used standard methods to calculate grain size percentage by weight (Krumbein and Pettijohn, 1938). The mean, sorting, skewness, and kurtosis were determined for each of the sand samples with the use of statistical moment measures (Folk, 1966).

Statistical Analysis

To determine whether statistically significant differences existed between and among sections of the beach, we used a one-way analysis of variance (ANOVA) at a 95% confidence level on each of the habitat parameters collected. If significant differences existed, we used a Tukey's honestly significant difference (HSD) multiple comparison test to determine between or among which sections these differences occurred.

RESULTS

Cicindela d. dorsalis Adult and Larval Surveys

Results from the four adult surveys at Smith Point revealed a generally consistent large number of adults both before and after nourishment. Numbers varied among the four sections on the four survey dates but showed a progressive increase in numbers of adults in section 4 (nourishment area) through time (Figure 6). Numbers also increased significantly in section 2 in 2001 and 2002 and decreased dramatically (more than fivefold) in section 3 in July 2001 and June 2002 (Figure 6). Despite the three- to fourfold increase in numbers in section 4 over the study period, section 2 contained more than three times the number of adults than did section 4—even after nourishment. The increased numbers in section 1 evidenced during 2002 most likely resulted from downdrift beach fining and more suitable compaction at the transect (#4) located next to section 2 (Figure 6).

Larval abundance among the four sections at Smith Point was generally similar to that of adults. However, more larvae were found in section 4 than in section 2. In particular, the results show that larva numbers increased by an order of magnitude following nourishment in section 4 (2001; Figure 7). Before nourishment, this section had one of the lowest number of larvae, but in the three subsequent years, this section had the highest number of larvae. These counts indicate that, after nourishment, adults moved into this section and oviposited, and the resulting larvae survived. Numbers of larvae were consistently low in section 1 and decreased in section 3 over time (Figure 7).

Winter Harbor Beach trends mirrored those of Smith Point Beach (Figure 8). In particular, immediately after nourishment, the number of adults increased in the nourished sec-

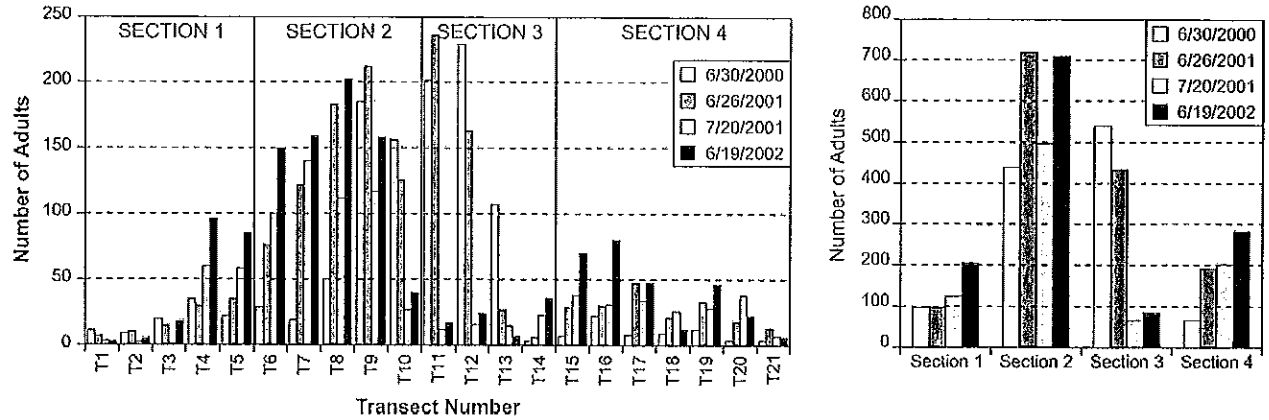


Figure 6. Smith Point Beach adult pre- and postfill *C. d. dorsalis* counts by transect (top) and by section (bottom). Note the consistently high numbers in section 2, the decrease in section 3, and the increase in section 4 after nourishment.

tion 2 after all of the adults had apparently emerged. Unlike Smith Point, however, where numbers remained high in the historical habitat reach (section 2), the adults at Winter Harbor decreased in section 1 and simultaneously increased in section 2 (Figure 8). Of the total adults that populated the beach on 3 July 2001, section 1 had 62.4% and section 2 had 37.6% of the adults. Two weeks after deposition on 18 June 2002, 78.5% of the total population occupied section 2. On 3 July 2002, the numbers remained high, with 71.8% of the adult population inhabiting section 2 (note the increase in both sections on 3 July 2002; Figure 8). The pattern remained similar in 2003. These results indicate that, at Winter Harbor Beach, a relatively large shift in the distribution of the adult population occurred toward the nourished reach (Figure 8).

The results of the larval survey at Winter Harbor indicated that, like the adults, the numbers of larvae increased significantly in the nourished beach in the 2 years after nourishment (Figure 9). Conversely, the numbers decreased in the control reach in section 1. However, the decrease in this section was not evident until the year after nourishment. In addition, the numbers of larvae decreased in both the control and nourished areas 1 year after deposition (Figure 9).

Habitat Parameters

The ANOVA revealed that all habitat parameters at Smith Point and Winter Harbor were statistically significantly different from at least one other section (Table 2). We present the results of Tukey's HSD multiple comparison test that shows, by habitat parameter, which sections were significantly different from the other sections.

Grain Size Distributions

The mean grain size in section 1 at Smith Point (0.22 ϕ, 0.86 mm) was statistically significantly different from the mean grain sizes of sections 2, 3, and 4 (0.85 ϕ, 0.55 mm;

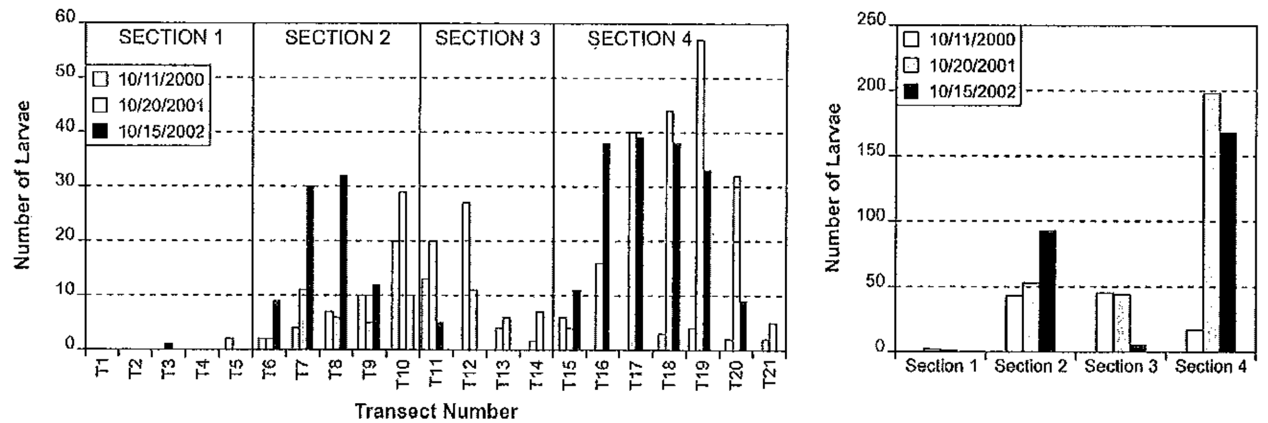


Figure 7. Smith Point Beach larval pre- and postfill *C. d. dorsalis* counts by transect (top) and by section (bottom). Note the consistently low numbers of larvae in section 1, high numbers in section 2, decrease in section 3 after nourishment, and increase in section 4 after nourishment.

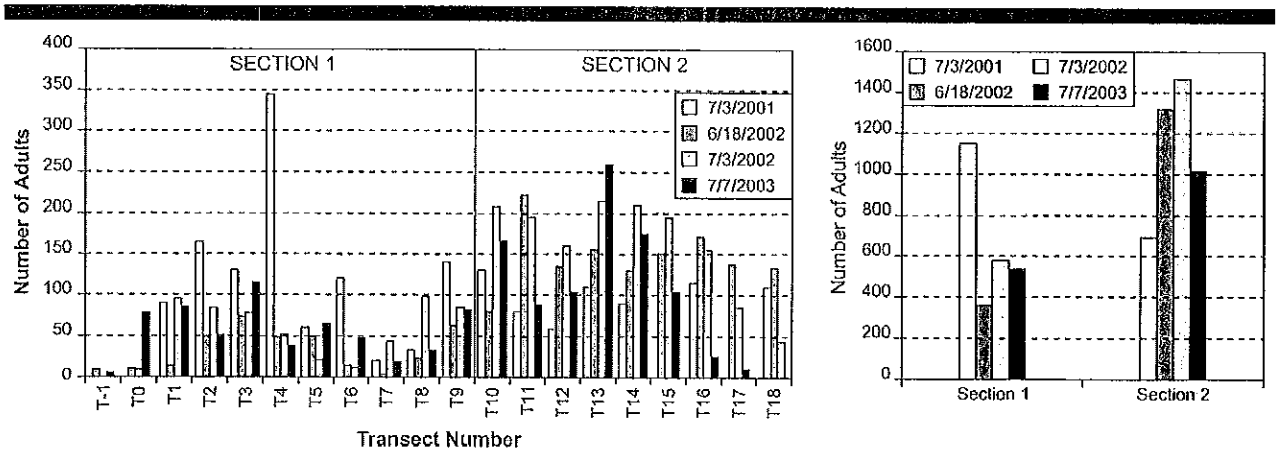


Figure 8. Winter Harbor Beach adult pre- and postfill *C. d. dorsalis* counts by transect (top) and by section (bottom). Note the population shift from section 1 (control area) to section 2 (nourishment area).

0.98 ϕ, 0.51 mm; and 1.03 ϕ, 0.49 mm, respectively; Table 2). Additionally, the mean grain size within section 2 differed significantly from the mean grain size in section 4. These results show that the beach at Smith Point is dominated by medium to coarse sands that coarsen to the south toward the Little Wicomico River tidal inlet. At Winter Harbor, a statistically significant difference in mean grain size occurred between sections 1 and 2 (Table 2). The mean grain size for section 1 was 0.90 ϕ (0.54 mm) and for section 2 was 1.21 ϕ (0.43 mm). These results show that section 1 contained coarse sand and section 2 consisted of medium sand on average.

The sorting of sediments within section 2 was significantly different from all of the other sections at Smith Point. The average sorting value of the other three sections clustered around 0.64 ϕ, whereas section 2 had an average sorting value of 0.77 ϕ (Table 2). These values show that moderately well–sorted sands dominate all of Smith Point, but that the beach within section 2 was less well sorted. A statistically significant difference also existed between sections 1 and 2 of Winter Harbor. Section 1 had an average sorting value of 0.53 ϕ, and section 2 had an average sorting value of 0.63 ϕ (Table 2). Similar to Smith Point, the beach along its length displayed moderately well–sorted sands, but section 2 was less well sorted than section 1.

At Smith Point, the skewness of beach sands within sections 1 and 2 differed from that of section 4. The average skewness per section varied greatly among sections. The skewness had a range from −0.50 (strong coarse skew, section 1) to +0.16 (fine skew, section 4; Table 2). In general, the results show that the frequency distributions of the sands become more symmetrical and slightly positive (finer) to the north. Winter Harbor also showed significant differences between sections 1 and 2 for average skewness. Section 1 averaged −0.16 (coarse skew) and section 2 averaged 0.16 (fine skew). Similar to Smith Point, skewness became more positive to the north (Table 2).

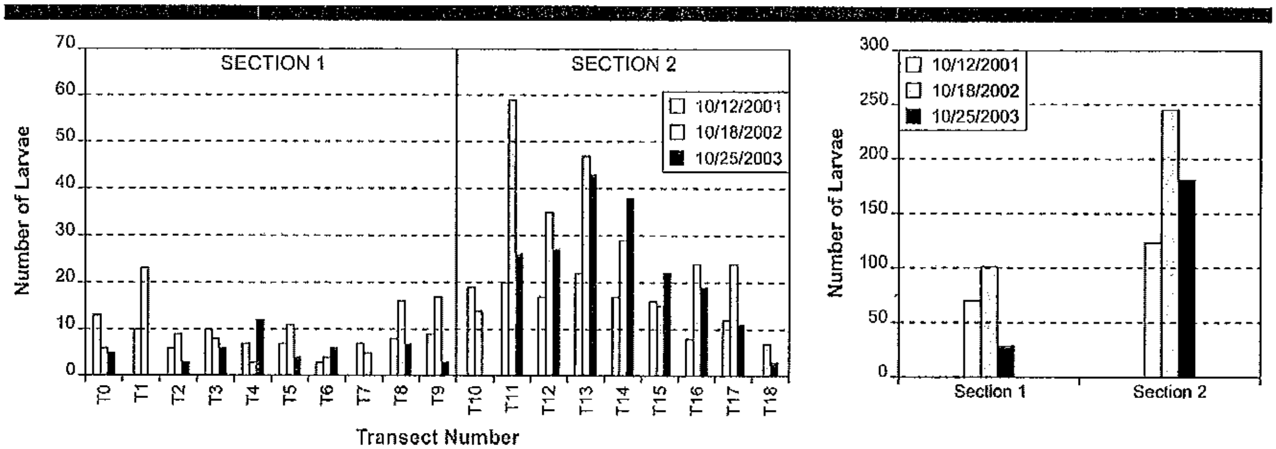


Figure 9. Winter Harbor Beach larval pre- and postfill *C. d. dorsalis* counts by transect (top) and by section (bottom). Note the similar trends found for adults in Figure 8.

Table 2. *Mean values with ±1 SD for habitat variables analyzed in each section at Smith Point Beach and Winter Harbor Beach. Statistically significant variables at α = 0.05 in boldface.*

Section	Compaction, 10 cm (psi)	Compaction, 15 cm (psi)	Moisture (%)	Moisture (% weight)	Temperature (°C)	Grain Size Distribution: Mean (φ/mm)	Grain Size Distribution: Sorting (φ)	Grain Size Distribution: Skewness	Grain Size Distribution: Kurtosis
Smith Point Beach									
1	39.4 (±7.1)	68.6 (±11.0)	96.6 (±1.4)	1.31 (±0.78)	33.3 (±1.6)	0.22/0.86 (±0.57/0.35)	0.66 (±0.15)	−0.50 (±0.82)	−0.88 (±1.67)
2	68.6 (±20.3)	112.8 (±11.9)	95.3 (±2.1)	2.34 (±1.67)	31.3 (±1.9)	0.85/0.55 (±0.43/0.17)	0.77 (±0.17)	−0.22 (±0.66)	1.33 (±1.19)
3	71.1 (±12.3)	114.3 (±15.8)	96.7 (±1.0)	1.18 (±1.08)	33.7 (±1.4)	0.98/0.51 (±0.32/0.11)	0.62 (±0.13)	±0.08 (±0.21)	±0.29 (±0.29)
4	68.5 (±10.8)	109.7 (±13.5)	87.6 (±16.2)	0.25 (±0.37)	33.9 (±1.2)	1.03/0.49 (±0.43/0.15)	0.64 (±0.12)	0.16 (±0.36)	0.48 (±0.60)
Winter Harbor Beach									
1	69.4 (±11.8)	110.2 (±14.0)	95.6 (±1.6)	0.88 (±1.10)	31.8 (±2.1)	0.90/0.54 (±0.39/0.15)	0.15 (±0.17)	−0.16 (±0.86)	0.84 (±1.88)
2	79.2 (±18.3)	123.0 (±16.6)	91.3 (±2.2)	1.67 (±1.56)	36.5 (±1.9)	1.21/0.43 (±0.30/0.09)	0.53 (±0.10)	0.16 (±0.15)	0.18 (±0.21)

No significant difference existed in the kurtosis between or among sections at Smith Point. The wide range of unexplained variance produced a situation in which no significant differences could be identified (Table 2). At Winter Harbor, a significant difference in kurtosis existed between sections 1 and 2, which had average kurtosis values of 0.84 and 0.17, respectively.

Compaction

At Smith Point, beach sand compaction measurements taken after nourishment within section 1 differed significantly from compaction within sections 2, 3, and 4 for both d = 10 cm and d = 15 cm (Table 2). The average 10-cm depth compaction values by section show that the compaction in sections 2, 3, and 4 (68.5–71.1 psi) were nearly twice as great as the compaction values in section 1 (39.4 psi; Table 2). Likewise, the average compaction at 15 cm depth in sections 2, 3, and 4 (109.7–114.3 psi) exceeded compaction within section 1 (68.6 psi) by a factor of 1.6 (Table 2). These results indicate that coarser grained, less compact sands dominated section 1.

A significant difference also existed in compaction between sections 1 and 2 at Winter Harbor. The average compaction of 79.2 psi within section 2 exceeded the average compaction of 69.4 psi for the sands within section 1 at d = 10 cm. At d = 15 cm, the average compaction within section 2 of 123.1 psi also exceeded the compaction of 110.2 psi within section 1. However, the magnitude of differences among averages was greater at Smith Point than at Winter Harbor. Finally, the compaction within both sections at Winter Harbor was generally similar to sections 2, 3, and 4 at Smith Point.

Percent Moisture and Percent Moisture by Weight

The moisture measurements obtained in section 4 of Smith Point were significantly different from the other sections of the beach. However, the average moisture per section varied from 87.6% (section 4) to 96.7% (section 3). Again, at Winter Harbor, a significant difference existed between sections 1 and 2 despite the similar average values for each section (section 1, 91.3%; section 2, 95.6%; Table 2).

Similar to percent moisture, percent moisture by weight was statistically significantly different in section 4 from all other sections at Smith Point (Table 2). In addition, section 2 displayed statistically different values from sections 1 and 3. In particular, section 2 values exceeded other sections by a factor of two to nearly an order of magnitude (from section 4). Sections 1 and 2 of Winter Harbor were also significantly different from each other. The mean percent moisture for sections 1 and 2 were 0.88% and 1.67%, respectively. The section 2 average percent moisture by weight value was nearly double the average value for section 1.

Temperature

Even though average temperature values were very similar among all sections at Smith Point, the ANOVA indicated that the section 2 average temperature (31.3°C) was significantly different from all other sections at this site. Section 1 (33.3°C) was also statistically different from section 4 (33.9°C).

Beach Width

Mean beach widths were determined but not analyzed statistically because of the large number of transects (*i.e.*, small spacings between transects) required for an ANOVA. However, we did use beach profile data in a qualitative manner to compare beetle counts to beach widths.

Beach widths at Smith Point transects varied from 1.8 m (section 3) to 17.6 m (section 1). The narrowest reach occurred in the highly eroded section 3 (average = 3.2 m). Highly scarped dunes, overwash deposits, the lack of a backshore, and maritime forest in foreshore attest to the vulnerability of this section (Figure 2). The widest reach occurred in section 1 adjacent to the northern jetty of Little Wicomico River tidal inlet (average width = 9 m). Aerial photographs indicate that the beach in section 1 accreted nearly 250 m in 57 years because this jetty blocks the southeast longshore transport of sediment (Figure 2). The beach abutting the jetty continued to accrete through the 1960s and had stabilized by the 1970s (HARDAWAY *et al.*, 2002). However, recent profile data indicate that the average beach width in this section has narrowed by a factor of two between 2000 and 2003 (11.8 to 5.5 m). These data suggest that a reversal in the long-term shoreline migration trend has occurred. In the preferred tiger beetle habitat area between sections 1 and 3, beach widths averaged 8.3 m. In the chronically eroding section 4 reach (2.8 m/y), the onshore nourishment raised the backshore by nearly 2 m in some locations and expanded the beach width by up to 20 m. After nourishment, the US Corp of Engineers planted American beach grass (*Ammophila breviligulata*) to create a low vegetated dune in this reach.

At Winter Harbor, prenourishment beach widths averaged 5.8 m (range 4–8 m) in section 1 and 5.6 m (range 2–10 m) in section 2. After nourishment, the beach in section 2 widened by 56.3 m on average (range 46–68 m; Figures 4 and 5). No plantings were conducted at this site. The year after nourishment (2003), the average width increased to 9.3 m in section 1 and decreased to 39.5 m in section 2. These data indicate that erosion continued in the northern section 2 and sediment migrated to the south in the predominant longshore transport direction.

DISCUSSION

This study analyzed beach parameters suitable for *C. d. dorsalis* habitat and examined the effect of beach nourishment on the populations at two beaches on the western shore of the Chesapeake Bay. First we discuss why some beach variables emerged as statistically, but not biologically, significant. We then identify the significant (emergent) habitat parameters that explain beetle distribution and abundance of *C. d. dorsalis*. Finally, we examine the effects of beach nourishment on the population. Given the increased numbers in adult and larval populations, the question remains as to what in particular the beetles found favorable about the nourished beaches.

The variables that we consider to be biologically unimportant include temperature, moisture, grain size skewness, and grain size kurtosis—despite statistically significant differences among beach sections. Beach temperature and moisture vary as a function of ambient conditions. Consequently, the time of day, weather conditions, tidal phase, wave conditions, or a combination of factors contribute to sample bias. Moreover, the low variability among sample means suggests that the statistical significance is highly sensitive to within section variation. Skewness and kurtosis do not explain beetle distribution and abundance because of the large differences in the averages among sections of suitable tiger beetle habitat and the similarity in values between habitat and nonhabitat sections.

The mean grain size and sediment compaction at 10 and 15 cm emerged as the statistically and biologically significant habitat variables at all of the habitat reaches (sections 2 and 4 of Smith Point; sections 1 and 2 of Winter Harbor). Additionally, the parameter values from the nonhabitat sections differed significantly (statistically) from those of the habitat areas. Our results indicate that *C. d. dorsalis* prefer low to moderately compacted (69 and 110 psi at depths of 10 and 15 cm on average, respectively) medium- to coarse-grained sand (range 0.43–0.55 mm). Moreover, tiger beetles favor moderately well–sorted sands.

Previous research has shown that adults and larvae of most tiger beetle species occupy the same habitat (KNISLEY and SCHULTZ, 1997). Consequently, mean grain size and sediment compaction are biologically important because female tiger beetles oviposit in particular sediment types related to their ovipositor shape. For example, sand-inhabiting species, like *C. d. dorsalis,* have long thin ovipositors and prefer habitats with medium to slightly coarse, moderately compacted sand for oviposition. Coarser, less compact sediment makes digging by larvae difficult and could result in burrow collapse. Conversely, finer grained sediment with increased compaction is more suitable for species with broader ovipositors.

Beach width is a predominant factor that controls habitat suitability because wider beaches provide more adult and larval habitat and reduce mortality from erosion and high-energy events. However, wide beaches might not accommodate beetles if other parameters are not suitable. For example, the wide beach adjacent to the jetty at Smith Point historically has had low numbers of tiger beetles. The results of this study indicate that the coarse-grained sediments and low compaction restrict adult use of this section. The low beetle counts within the highly eroded section 3 at Smith Point indicate that, although a suitable mean grain size and compaction exist, severe erosion has produced a beach too narrow for beetle presence.

Contrary to previous studies that showed detrimental effects of beach nourishment on open ocean coast organisms (*e.g.*, CUTLER and MAHADEVAN, 1982; DOLAN, 2003; MCLACHLAN, 1996; OLIVER and SLATTERY, 1976; SALOMAN, 1976), the beach nourishment projects along the two western Chesapeake Bay beaches provided suitable beetle habitat at both sites. This phenomenon directly relates to the suitable particle size and compaction, and an increase in beach width afforded by the nourishment projects. In concert, these beach parameters provided habitat for adult foraging, ovipositing and larval survival.

The highly eroded section 4 along the northern reach of

Smith Point historically had displayed low beetle counts (KNISLEY, HILL, and SCHULZ, 1998). However, adults moved immediately into the deposition area (section 4) soon after their emergence during the summer of 2001 and continued to occupy this reach in proportionally high numbers until 2002. In fact, 1 year after deposition, the nourished section 4 contained larger numbers of adults than sections 1 or 3 to the south. Moreover, the adults oviposited in the deposition reach, and their larvae developed there in larger numbers than in other sections. Among the four sections of Smith Point Beach, section 4 had the second highest adult count and was second in total numbers only to the known habitat in section 2. In addition, after deposition, sections 2 and 4 displayed similar habitat conditions in terms of the statistically and biologically significant emergent variables—namely mean grain size and compaction and increased beach width.

The nourished section 2 at Winter Harbor Beach also provided suitable habitat for *C. d. dorsalis*. In particular, prenourishment adult tiger beetle surveys showed that adults of *C. d. dorsalis* were more abundant in the southern reach (section 1) than in the northern reach (section 2) at the site of the proposed dredge deposition. Following nourishment, however, many adults immediately moved into the deposition beach from the south, and the adults used the newly deposited beach to a greater extent than the adjacent nondeposition reach. The results showed that the beetle population in section 2 more than doubled after deposition (from 31% to 73%). Additionally, because nourishment occurred in the nearshore, a large number of beetles apparently emerged from larvae that pupated on the "new" backshore of the nourished area or the "old" foreshore of the original beach. Our observations during the deposition revealed no disturbances landward of the original shoreline that would have interfered with adult emergence.

CONCLUSIONS

This study is the first to examine the effect of beach nourishment on a federally threatened insect. A high-density sampling scheme allowed us to use a one-way ANOVA and Tukey's HSD multiple comparison analysis to test two null hypotheses: (1) differences in habitat parameters within each study area would not influence the abundance and distribution of the northeastern beach tiger beetle (*C. d. dorsalis*) along the beach, and (2) beach nourishment would have no effect on the distribution and abundance of adults and larvae of *C. d. dorsalis* in the nourishment area.

These analyses demonstrated that we could reject null hypothesis 1 because *C. d. dorsalis* preferred beaches at least 6 m wide that have moderately well-sorted sand with a mean grain size of 0.5 to 0.6 mm and sediment compaction averaging 69 and 110 psi at depths of 10 and 15 cm, respectively. In addition, we rejected null hypothesis 2 because the two nourishment projects resulted in an increase in adults and larvae of *C. d. dorsalis* in the nourished sections of both Smith Point and Winter Harbor. The greater increase in the numbers of adults and larvae in the deposition area at Winter Harbor compared with Smith Point most likely resulted from the additional habitat (beach width) provided by the nearshore deposition. This finding further documents the importance of beach width as a significant habitat requisite for *C. d. dorsalis*. Favorable habitats develop and subsist when sufficient (natural or artificial) space (beach width) exists and when the sediment characteristics of the dredge disposal material and natural beach habitat closely match. However, wave refraction studies indicate that the bathymetry offshore of these two areas might concentrate storm wave energy at the north ends of these two beaches (SHIFFLETT, FENSTER, and KNISLEY, 2001). These natural conditions, in concert with updrift sediment deprivation (reduction of source material input because of shoreline armoring and other engineering projects), might produce a chronic threat to productive habitats. In fact, continued monitoring has revealed erosion at both sites. Consequently, longer term studies are needed to assess these threats relative to the longevity of the nourishment projects and beetle habitat. These findings will assist coastal engineers and developers in determining effective measures designed to aid both economic and ecologic interests.

ACKNOWLEDGMENTS

We thank the staff in the Baltimore District (Robert Blama and Heather Batchelder) and Norfolk District (Betty Gray Waring and Keith Lockwood) of the US Army Corps of Engineers for supplying data related to the dredge and disposal projects and for logistical field support. We also thank Ryan Knisley and Brad Knisley for assisting in the field work and the Virginia Outdoors Foundation for giving us permission to conduct the study at Smith Point Beach. Finally, we thank Dr. Charles Gowan for his expertise in and guidance with the experimental design and statistical analyses and Norbert Irnberger of the University of Vienna for his assistance with the illustrations.

LITERATURE CITED

ACKERMAN, R.A., 1996. The nest environment and the embryonic development of sea turtles. *In*: LUTZ, P.L., and MUSICK, J.A. (eds.), *The Biology of Sea Turtles*. Boca Raton, Florida: CRC Press, pp. 83–106.

BLACK, C.A., 1965. *Methods of Soil Analysis*, Part I and II. Madison, Wisconsin: American Society of Agronomy, 770p.

BOWMAN, M. and DOLAN, R., 1985. The relationship of *Emerita talpoida* to beach characteristics. *Journal of Coastal Research*, 1(2), 151–163.

BROADWELL, A., 1991. The Fate of Loggerhead Sea Turtle Nests on a Natural and Renourished Beach. Boca Raton, Florida: Florida Atlantic University, Master's thesis, 32p.

CRAIN, D.A.; BOLTEN, A.B., and BJORNDAL, K.A., 1995. Effects of beach nourishment on sea turtles: review and research initiatives. *Restoration Ecology*, 3, 95–104.

CUTLER, J.K. and MAHADEVAN, S., 1982. Long-term Effects of Beach Nourishment on the Benthic Fauna of Panama City Beach, Florida. Fort Belvoir, Virginia: U.S. Army Corps of Engineers, Coastal Engineering Research Center Miscellaneous Report MR 82-2.

DOLAN, R., 2003. Compatibility Study of Sand Bypassed from Oregon Inlet to the Pea Island National Wildlife Refuge (North Carolina). Charlottesville, VA: Coastal Research Associates Technical Report, 19p.

DONOGHUE, C.R., 1999. The Influence of Swash Processes on *Donax variabilis* and *Emberita talpoida*. Charlottesville, Virginia: University of Virginia, Doctoral dissertation, 197p.

EHRHART, L.M., 1995. The Relationship Between Marine Turtle

Nesting and Reproductive Success and the Beach Nourishment Project at Sebastian Inlet, Florida, in 1994. Melbourne, Florida: Florida Institute of Technology Technical Report, 55p.

FOLK, R.L., 1966. A review of grain-size parameters. *Sedimentology,* 6, 73–93.

GORZELANY, J.F. and NELSON, W.G., 1987. The effects of beach replenishment on the benthos of a sub-tropical Florida beach. *Marine Environmental Research,* 21, 75–94.

HARDAWAY, C.S., JR., and BYRNE, R.J., 1999. Shoreline Management in Chesapeake Bay. Gloucester Point, Virginia: Virginia Institute of Marine Science Special Report in Applied Marine Science and Ocean Engineering 356, VSG-99-11, 54p.

HARDAWAY, C.S., JR., and GUNN, J.R., 1999. Chesapeake Bay: design and early performance of three headland breakwater systems. *In:* KRAUS, N.C., and MCDOUGAL, W.G. (eds.), *Coastal Sediments '99: Proceedings of the 4th International Symposium on Coastal Engineering and Science of Coastal Sediment Processes* (Long Island, New York), pp. 828–843.

HARDAWAY, C.S., JR.; VARNELL, L.M.; MILLIGAN, D.A.; THOMAS, G.R., and MENEGHINI, L.M., 2002. Chesapeake Bay Dune Systems: Monitoring Year One. Gloucester Point, Virginia: Virginia Institute of Marine Science Technical Report, 26p.

HAYDEN, B.P. and DOLAN, R., 1974. Impact of beach nourishment on distribution of *Emerita talpoida,* the common mole crab. *Journal of Waterways, Harbors and Coastal Engineering Division,* 100, 123–132.

KNISLEY, C.B. and HILL, J.M., 1996. Distribution and abundance of the northeastern beach tiger beetle, *Cicindela dorsalis dorsalis,* in relation to shoreline modifications. in Virginia. Richmond, Virginia: Report to Virginia Department of Agriculture and Consumer Affairs, 33p.

KNISLEY, C.B. and SCHULZ, T.D., 1997. The Biology of Tiger Beetles and a Guide to the Species of the South Atlantic States. Martinsville, Virginia: Virginia Museum of Natural History Special Publication 5, 210 p.

KNISLEY, C.B.; HILL, J.M., and SCHULZ, C.A., 1998. Distribution and abundance of *Cincindela dorsalis dorsalis,* the northeastern beach tiger beetle, along the western shoreline of the Chesapeake Bay in Virginia. *Banisteria,* 12, 23–29.

KNISLEY, C.B.; LUEBKE, J.I., and BEATTY, D.R., 1987. Natural history and population decline of the coastal tiger beetle, *Cicindela dorsalis dorsalis* Say (Coleoptera: Cicindlidae). *Virginia Journal of Science,* 38, 293–303.

KRUMBEIN, W.C. and PETTIJOHN, F.J., 1938. *Manual of Sedimentary Petrology.* New York: Appleton-Century-Crofts, 549p.

LENG, C.W., 1902. Revision of the *Cicindelidae* of boreal America. *Transactions of the American Entomological Society,* 28, 93–186.

LYNCH, A.E., 1994. Macroinfaunal Recolonization of Folly Beach, South Carolina, after Beach Nourishment. Charleston, South Carolina: University of Charleston, South Carolina, Master's thesis, 45p.

MCLACHLAN, A., 1996. Physical factors in benthic ecology: effects of changing sand particle size on beach fauna. *Marine Ecological Progress Series,* 16, 51–63.

MILLER, A.J., 1983. Shore Erosion Processes, Rates and Sediment Contribution to the Potomac Tidal River and Estuary. Baltimore, Maryland: John Hopkins University, Doctoral thesis, 341p.

MILLER, A.J., 1987. Shore erosion as a sediment source to the tidal Potomac River, Maryland and Virginia. U.S. Geological Survey Water-Supply Paper, Report W2234-E, pp. E1–E45.

MORTIMER, J.A., 1982. Factors influencing beach selection by nesting sea turtles. *In:* BJORNDAL, K.A. (ed.), *Biology and Conservation of Sea Turtles.* Washington, DC: Smithsonian Institution Press, pp. 45–51.

MORTIMER, J.A., 1990. The influence of beach sand characteristics on the nesting behavior and clutch survival of green turtles (*Cheslonia mydas*). *Copeia,* 1990, 802–817.

NELSON, D.A. and DICKERSON, D.D., 1988. *Response of Nesting Sea Turtles to Tilling of Compacted Beaches, Jupiter Island, Florida.* Vicksburg, Mississippi: U.S. Army Corps of Engineers, Waterways Experiment Station, 26p.

NELSON, D.A.; MAUCK, K., and FLETEMEYER, J., 1987. *Physical Effects of Beach Nourishment on Sea Turtle Nesting, Delray Beach, Florida.* Vicksburg, Mississippi: U.S. Army Corps of Engineers, Waterways Experiment Station, 56p.

OLIVER, J.S. and SLATTERY, P.H., 1976. *Effects of Dredging and Disposal on the Benthos at Monterey Bay, California.* Fort Belvoir, Virginia: U.S. Army Corps of Engineers, Coastal Engineering Research Center Technical paper 76-15, 82p.

RAYMOND, P.W., 1984. The Effects of Beach Renourishment on Marine Turtle Nesting in South Brevard County, Florida. Orlando, Florida: University of Central Florida, Master's thesis, 116p.

REILLY, F.J., JR., and BELLIS, V.J., 1983. *The Ecological Impact of Beach Nourishment with Dredged Materials on the Intertidal Zone at Bogue Banks, North Carolina.* Fort Belvoir, Virginia: U.S. Army Corps of Engineers, Coastal Engineering Research Center Miscellaneous Report MR 83-3, 74p.

RYDER, C.E., 1993. The Effects of Beach Renourishment on Sea Turtle Nesting and Hatching Success at Sebastian Inlet State Recreation Area East-Central, Florida. Blacksburg, Virginia: Virginia Polytechnic Institute and State University, Master's thesis, 109p.

SALOMAN, C.H., 1976. *The Benthic Fauna and Sediments of the Nearshore Zone Off Panama City Beach, Florida.* Fort Belvoir, Virginia: U.S. Army Corps of Engineers, Coastal Engineering Research Center MR 76-10, 256 p.

SHIFFLETT, S.A.; FENSTER, M.S., and KNISLEY, C.B., 2001. A threatened species of northeastern tiger beetle, *Cincindela dorsalis dorsalis* as an indicator of beach health. Geological Society of America Annual Meeting (Boston), Abstracts, 33(6), A102.

STEINITZ, M.J.; SALMON, M., and WYNEKEN, J., 1998. Beach renourishment and loggerhead turtle reproduction: a seven year study at Jupiter Island, Florida. *Journal of Coastal Research,* 14(3), 1000–1013.

USFWS (U.S. FISH AND WILDLIFE SERVICE), 1990. Endangered and threatened wildlife and plants, determination of threatened status for puritan tiger beetle and the northeastern beach tiger beetle. *Federal Register,* 55(152), 32088–32094.

USFWS, 1993. Northeastern Beach Tiger Beetle (*Cicindela dorsalis dorsalis* Say). Hadley, Massachusetts: Recovery Plan, 51p.

WOOD, D.W. and BJORNDAL, K.A., 2000. Relation of temperature, moisture, salinity and slope to nest site selection in Loggerhead Sea Turtles. *Copeia,* 1, 119–128.