Use of Telemetry in Fisheries Management: Juvenile Sandbar Sharks in Delaware Bay

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INTRODUCTION

The sandbar shark (Carcharhinus plumbeus) is a cosmopolitan species world wide and one of the most abundant sharks on the US east coast (Compagno, 1984). It is one of the most important species in east coast commercial shark fisheries due to its abundance, large size, quality flesh and fins (Castro et al., 1999). Declines in sandbar shark catches have been reported over the past decade and are indicative of the reduction in the east coast population (Musick et al., 1993; Castro et al., 1999).

Large numbers of young sandbar sharks are caught nearshore and in bays and estuaries, both by commercial and recreational fishermen (Camhi, 1998). Sandbar sharks are born from March to July in shallow bays and estuaries primarily between Cape Canaveral, FL and New

Jersey (Springer, 1960, Merson and Pratt, 2000?) and apparently also in the Gulf of Mexico (Carlson, 1999). Young sharks spend the first summer in these nurseries and near the end of September, those sharks in the northern nurseries such as Delaware Bay move south to warmer water off the Carolinas. The following June the juvenile sharks move north and again spend the summer in the nursery areas (Springer, 1960; Medved and Marshall, 1981; Castro, 1993). This cycle is repeated possibly for the first 7 years of the sharks' lives, after which, they remain offshore year-round (Casey et al., 1985).

Sandbar sharks are slow growing and may require as long as 30 years to reach maturity (Casey and Natanson, 1992) and therefore, recovery of the population from elevated fishing pressure may be slow, potentially requiring decades (Sminkey and Musick, 1996; Cortes, 1999). To reduce fishing pressure and to facilitate population growth, sandbar sharks were placed among the "large coastal" species category of sharks included in a fishery management plan for sharks of the Atlantic Ocean (Anonymous, 1993). Bag limits and quotas for commercial and recreational fisherman stipulated in the management plan apply to federal waters, greater than 4.8 km from shore, and thus are primarily of benefit to older sharks that no longer occupy nursery areas. Although a number of states have adopted fishing regulations that conform to the management plan, policy varies from state to state and sandbar sharks inhabiting nursery areas are exposed to varying levels of exploitation (Camhi, 1998). The slow growth rate and the low net reproductive rate of sandbar sharks limit the rate of population growth, and models predict that populations cannot withstand even a low rate of fishing mortality on immature individuals (Sminkey and Musick, 1996; Cortes, 1999). It is not surprising then that the necessity for research including delineation of shark nurseries, patterns of habitat use and environmental tolerances of sharks in nurseries, and the overall role of coastal/inshore habitats in supporting juvenile sharks has recently received much emphasis (Anonymous, 1998a, Anonymous, 1998b).

Acoustic telemetry is a technique that is emerging as an important tool in fisheries management. Telemetry studies yield information on fine-scale movements of individual sharks, which is useful for inferring habitat preferences and activity patterns (Nelson, 1990; Holland et al., 1993a). Such data is crucial for thorough evaluation of the effects of fishing and habitat degradation on populations, and in turn for assessment of the potential success of management techniques such as area/time closures (Holland et al., 1993b; 1996). As the number of telemetry studies conducted on marine fishes increases, inclusion of data from these studies in the process of fisheries management and conservation will also increase.

Delaware Bay, one of the principal nursery grounds for sandbar sharks on the US East Coast (Merson and Pratt, 2000?), was chosen as site for a telemetry study to investigate movement patterns and spatial requirements of these sharks. The results of our study are presented here as an example of the utility of telemetry for providing data useful for fishery management decisions.

MATERIALS AND METHODS

Sandbar sharks were caught using longline or rod and reel either on the Delaware or New Jersey side of Delaware Bay. Each shark was measured, weighed (time permitting), and a Roto tag was applied to the first dorsal fin. Neonate sharks were fitted with a V8 (8 mm diameter, 36 mm length, 3.5 g in water) transmitter (Vemco, Nova Scotia, Canada) and V16 (16 mm diameter, 59 mm length, 11 g in water) transmitters were used on larger juveniles. Each transmitter was individually coded (60-76.8 kHz, 1000-1500 ms) and had a battery life of approximately 20 days. Transmitters were attached to the Roto tag with thin-gauge galvanized wire and represented less than 1% of the body weight of the sharks. Field tests showed that the wire corroded and broke in approximately 1 month of exposure to seawater.

Tracking was conducted from a 5.8 m motor boat equipped with a directional hydrophone, Vemco VR60 receiver, notebook computer, GPS, and depth sounder. It was estimated that the distance between the shark and the tracking boat was usually several hundred meters and boat position was presumed to be representative of shark location. Three latitude and longitude positions were recorded to the computer automatically at 5 min intervals and position and water depth were recorded manually at 15 min intervals. When multiple sharks carrying transmitters were present individuals were distinguished using Vemco VSCAN software. Maximum convex polygon analysis was used to quantify activity space, and grid-square analysis was used to examine patterns of habitat use (MacDonald et al., 1980; Winter and Ross, 1982).

Catch per unit effort data (CPUE), expressed as sharks/hour, was obtained from gillnet and longline surveys during June through September in 1998 and 1999. A total of 181 sets (33 gillnet and 148 longline) was dispersed among 79 stations throughout Delaware Bay.

A sinking gillnet (213 m long, 3 m deep), anchored at both ends with stretch mesh (10.6 cm) made of #177 nylon monofilament was used. The net was generally set perpendicular to shore across the tidal current in 1-10 m of water, and sampling began approximately 20 min after setting. The net was continuously checked by pulling it across the boat while leaving the net ends anchored. Total net soak time was 3 h, although weather, catch and other conditions sometimes altered soak time.

A 50 hook bottom line was used in areas of high current, deep water, and heavy boat traffic. Fifty gangions (each with a 4/0 longline snap, 100 cm of 1.5 cm braided nylon line, 50 cm of 3 mm stainless steel cable, and a 12/0 Mustad hook with barb depressed) were attached to a mainline that consisted of 305 m of 1.5 cm braided nylon line anchored at both ends. Fresh menhaden (*Brevoortia tyrannus*) and other local species of fish were used for bait. Soak times for longlines were 1 h.

RESULTS

A total of 25 sharks was tracked during June-September, 1998 and 1999; 19 tracks on the Delaware side of the bay and 6 on the New Jersey side (Table 1). Fourteen neonate and 11 juvenile sharks were tracked for 2.5-75 h. Sharks moved throughout much of the lower bay, with activity concentrated near shore.

Behavior of sharks differed with side of the bay where tracking was initiated. Activity spaces of sharks tracked on the Delaware side of the bay were generally close to shore (<3 km) over shallow water (<5 m) (Fig. 1a). Sharks tracked on the New Jersey side of the bay had less restricted movements; they ranged farther from shore, spent considerable time in deeper channels (6-9 m), and had larger activity spaces (Fig. 1b). Average activity space for sharks tracked on the Delaware side of the bay was 44.9 ± 51.9 km^2, compared to 107.6 ± 124.9 for those on the New Jersey side (Table 1). Two sharks crossed the bay, one from Delaware to New Jersey and one from New Jersey to Delaware, and two sharks moved offshore into a deep channel (37 m); consequently these sharks had large (177.4 ± 118.5) activity spaces (Fig. 1c).

Although the activity space of several sharks was extensive and the combined activity spaces of all sharks encompassed much of the lower bay, grid square analysis showed that activity was concentrated in shallow, near-shore waters, particularly between Broadkill and Primehook beaches, DE (Fig. 2). Grid-square analysis also illustrated the more diffuse distribution of positional data for sharks on the New Jersey side of the bay.

The high degree of overlap of activity spaces for sharks tracked on consecutive days indicated a repeatable behavior, which suggests some degree of site fidelity in young sandbar sharks (Fig. 3). This behavior also differed between Delaware and New Jersey sides of the bay. For example, a shark tracked for 70 h off Delaware spent most of nearly 3 days in a small area off Fowler Beach following an initial move north after release. Overlap of activity spaces for this shark comparing consecutive days was 94.4% and 85.5% (Fig. 3a). A shark tracked for 75 h on the New Jersey side of the bay had overlap values of only 11.2% and 60.8% between consecutive days (Fig. 3b).

Catch data from long line and gill net fishing supports the results obtained in our telemetry study. Sharks were caught throughout much of the bay, but shark distribution was uneven. Highest catch rates were attained in shallow, near-shore waters, particularly off Broadkill and Bigstone beaches, DE (Fig. 4). Catch rates were lower in areas more distant from shore, and tended to be higher on the Delaware side of the bay than on the New Jersey side.

DISCUSSION

Young sandbar sharks are common nearshore on both sides of Delaware Bay, and are not abundant in the deeper, middle section of the bay, presumably as a means of avoiding predation by large sharks that occur in the central bay. Based on nearly 850 h of tracking data, movement patterns exhibited by juvenile sandbar sharks in this study were generally heavily influenced by tidal currents, restricted to a limited portion of the bay, and dependent upon the side of the bay where tracking was initiated.

Although the intent of this paper is to document habitat use by sandbar sharks for evaluation of fishery management policy, there are a number of factors that may influence the behaviors we observed. The more restricted movements in shallow, nearshore water on the Delaware side may be a reflection of the presence of a more extensive, shallow shelf on that side of the bay in comparison to the New Jersey side. Differences in substrate may also explain the behavioral patterns observed in sharks; the New Jersey side of the bay is characterized by large oyster beds, whereas the Delaware side is predominately soft sediment. Since the diet of young sandbar sharks consists largely of blue crabs (Medved et al., 1985; Stillwell and Kohler, 1993), and blue crabs prefer soft sediment, the movements of the sharks may be related to prey distribution.

Behavior patterns of young sandbar sharks in Delaware Bay appear to include repetitive movements on several scales, and are indicative of site fidelity for these sharks. Movements of sharks were strongly associated with tidal currents and were generally repeated with each tidal cycle. Medved and Marshall (1983) also found that tides influenced movements of sandbar sharks in a small Virginia bay. Repeatability of behavior within individual sharks tracked in Delaware Bay was demonstrated by the high degree of overlap of daily activity spaces for sharks occupying areas of high shark activity. Similar findings have been reported previously for several species of shark (Holland et al, 1993a; Gruber et al., 1988; Goldman and Anderson, 1999). Repeatability of behavior among sandbar sharks in our study was demonstrated by overlap of activity spaces of different individuals, which has also been reported for young scalloped hammerhead sharks (*Sphyrna lewini*) in a nursery area (Holland et al., 1993a). Our tracking studies were conducted over the course of the entire summer, indicating that there is a degree of site fidelity in sandbar sharks during the entire time they are residents in Delaware Bay.

Sandbar sharks restrict the majority of their movements to a relatively small portion of Delaware Bay. There are clearly areas in the bay where activity of sharks is concentrated, such as Broadkill and Bigstone beaches, DE. Telemetry data showed that multiple sharks spend considerable time in common areas during summer months, and catch data suggests that large numbers of sharks inhabit these areas. Shared core areas of activity have been reported for other species of shark that inhabit nearshore locations or nurseries (McKibben and Nelson, 1986; Holland et al., 1993a).

The presence of core areas occupied by large numbers of sandbar sharks in Delaware Bay presents different options for management of the population than would be available if the sharks were randomly distributed or present in the bay during the entire year. Area closures have been used for management of several species of sharks and teleosts, and are most successful when movement patterns or important life processes occur at a specific place at a specific time and the fishery can be directed away from these animals (Cailliet et al., 1993; Holland et al., 1996). Area/time closure of specific portions of Delaware Bay where shark activity is concentrated has potential for protecting a large number of sharks from fishing pressure while minimizing disruption to fishing activities in the bay. The method used by fishermen who capture sandbar sharks in the bay would also influence policy decisions concerning area closures. For example, juvenile sharks are caught in gillnets used by commercial fishermen targeting other species, and by rod and reel by recreational fishermen. Gillnets often result in a high mortality for sharks when deployed in core areas, whereas a very high proportion of sharks caught on rod and reel can be released alive. Therefore, rod and reel fishing that targets other species of fish may be acceptable in core areas if local fishing regulations require release of sharks in a specific area or during a specific time of the year. Based on the results of this study closure of small areas on the Delaware side of the bay would probably offer protection for more sharks per unit area than on the New Jersey side. An additional consideration for enhancement of shark populations in Delaware Bay is a limit on development and degradation of essential shark habitat. The relatively limited movements of sandbar sharks in Delaware Bay increases the feasibility of protection from degradation of small, discrete areas that are important habitat in the shark nursery.

SUMMARY

This study demonstrates the usefulness of telemetry in providing data that can be integrated into management policies. Our tracking data have revealed patterns of fine-scale movements and habitat use of sandbar sharks in the Delaware Bay nursery. This in turn has helped to identify specific areas that are heavily utilized by sharks, which has been confirmed by CPUE data. These areas of concentrated shark activity are relatively small, and area closures in even these limited locations would likely reduce fishing pressure on large numbers of sharks and enhance population growth with a minimum of disturbance to angling activity in the bay. It appears that the effectiveness of area closures as a management technique would differ between the Delaware and New Jersey sides of the bay since movement patterns of sharks appear to differ

between the two sides. In addition to providing information vital to the establishment of effective 'no fishing zones', our study has identified areas where human disturbance should be restricted to achieve maximum conservation of essential habitat for juvenile sandbar sharks in Delaware Bay.

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Table 1. Description of juvenile and neonate sandbar sharks tracked in Delaware Bay in 1998.
Distance travelled and speed calculated from distance between successive 15 minute locations.

Track	Stage	Sex	TL (cm)	Wt (kg)	Date	Duration (h)	Distance (km)	Speed (km/h)	Polygon Area (km^2)	Tans. #	Trans. Type	Trans. Freq. (kHz)
1	Juv.	F	74.0	1.2	6/24/98	12.3	15.1	**1.2**	7.3	4504	v-16	60.0
2	Juv.	M	111.0	9.1	6/25/98	10.0	18.3	1.9	11.6	4505	v-16	60.0
3	Neo.	F	61.0	1.8	7/29/98	6.0	7.3	1.2	2.2	5231	v-8	76.8
4	Juv.	F	131.0	15.0	7/30/98	7.3	10.3	1.7	24.0	4506	v-16	65.5
5	Juv.	M	132.0		8/2/98	70.0	107.5	1.9	37.5	4508	v-16	69.0
6	Juv.	F	88.0		8/13/98	53.5	59.3	1.3	29.5	4509	v-16	76.8
7	Neo.	F	61.0	1.7	8/15/98	48.3	57.9	1.2	13.5	5234	v-8	76.8
8	Neo.	M	61.0	1.5	8/18/98	8.0	10.4	1.3	6.6	5235	v-8	76.8
9	Neo.	F	59.0		9/15/98	31.0	43.8	1.4	7.0	5233	v-8	76.8
10	Neo.	M	63.0	1.7	9/16/98	56.0	97.6	1.8	115.7	5232	v-8	76.8
11	Neo.	M	68.0	2.5	9/18/98	54.0	58.6	1.1	24.0	5650	v-8	76.8
12	Neo.	F	70.0		9/24/98	24.0	55.9	2.3	121.3	5236	v-16	69.0

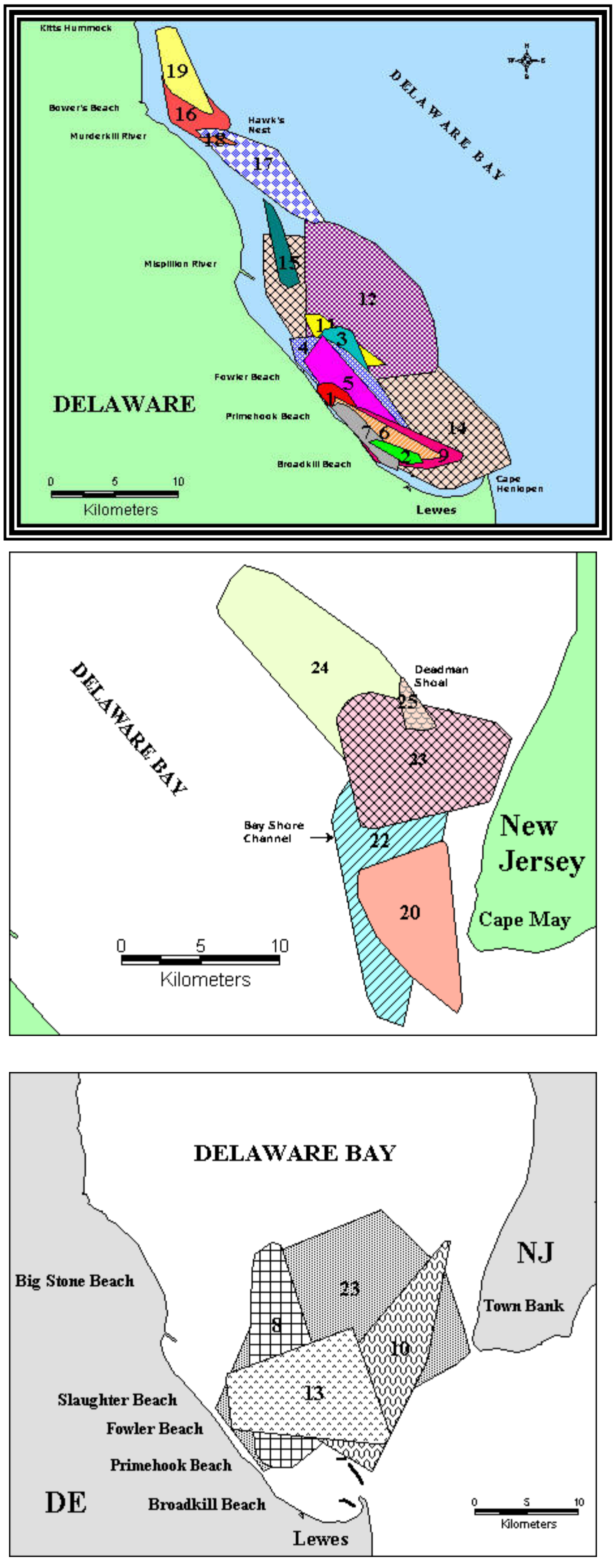
Kitts Hummock
Bower's Beach
Murderkill River
Hawk's Nest
DELAWARE BAY
Mispillion River
Fowler Beach
DELAWARE
Primehook Beach
Broadkill Beach
Cape Henlopen
Lewes
0 5 10
Kilometers
24
Deadman Shoal
25
23
DELAWARE BAY
Bay Shore Channel
22
New Jersey
20
Cape May
0 5 10
Kilometers
DELAWARE BAY
Big Stone Beach
23
8
10
13
NJ
Town Bank
Slaughter Beach
Fowler Beach
Primehook Beach
DE
Broadkill Beach
Lewes
0 5 10
Kilometers

Figure 1

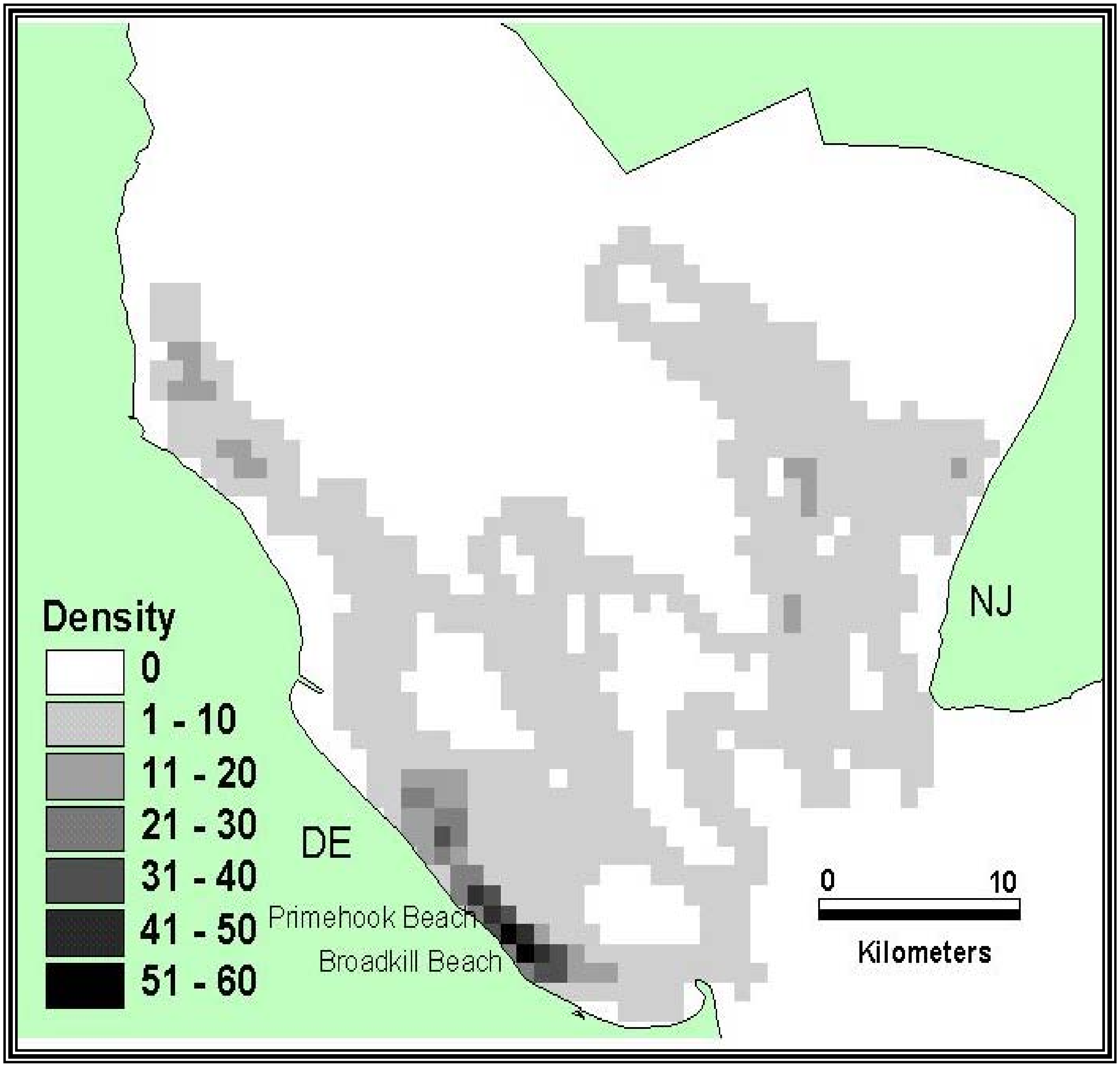
Density
0
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
DE
NJ
Primehook Beach
Broadkill Beach
0
10
Kilometers

Figure 2

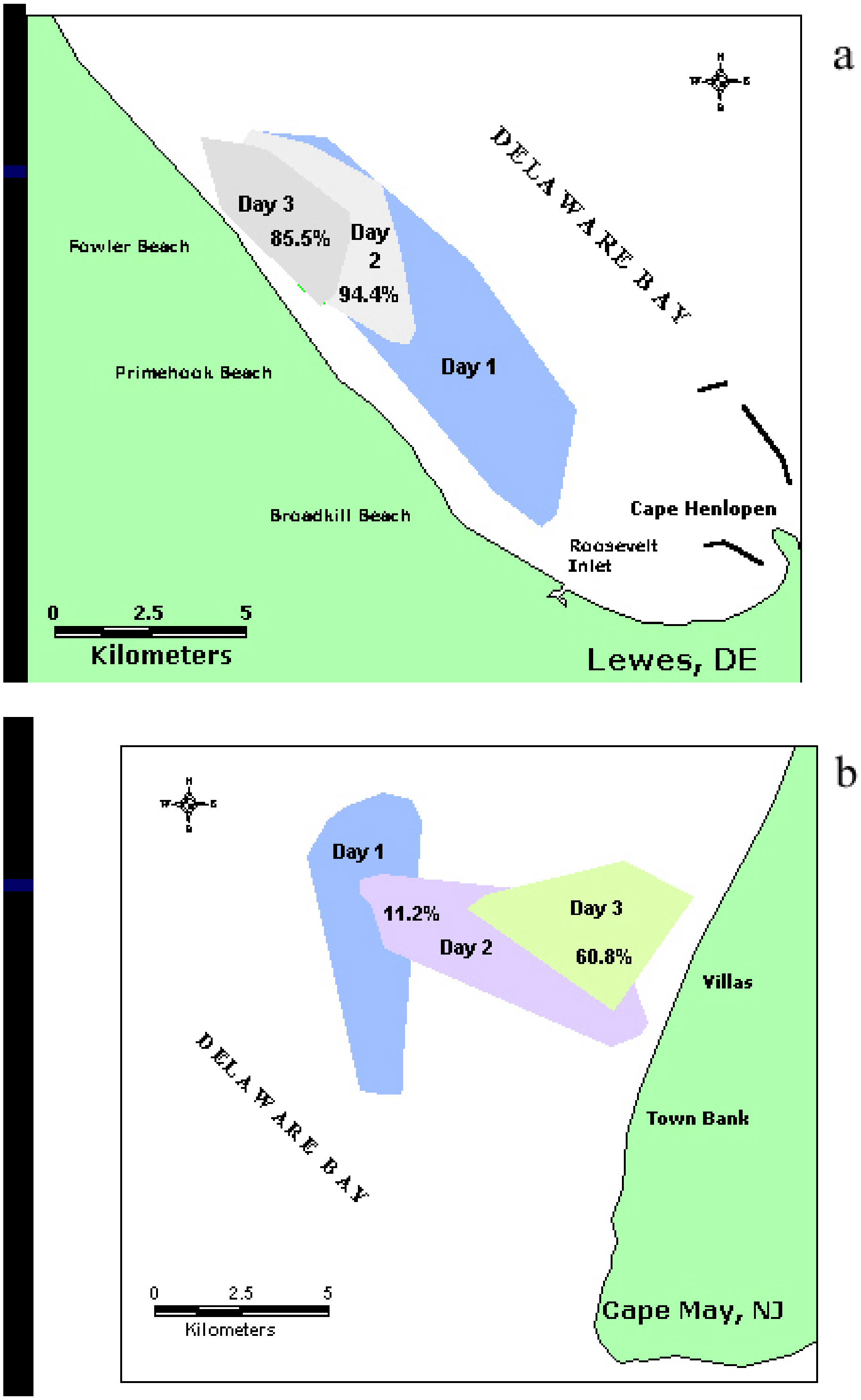
a
Day 3
85.5%
Day
2
94.4%
Fowler Beach
Primehook Beach
Day 1
DELAWARE BAY
Broadkill Beach
Cape Henlopen
Roosevelt
Inlet
0
2.5
5
Kilometers
Lewes, DE
b
Day 1
11.2%
Day 2
Day 3
60.8%
Villas
Town Bank
DELAWARE BAY
0
2.5
5
Kilometers
Cape May, NJ

Figure 3