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# Shark Nursery Areas in the Coastal Waters of Massachusetts

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*Abstract.*—To identify and characterize shark nursery habitat in the coastal waters of Massachusetts, longline and shark angler surveys were conducted from 1989 to 2002 in the neritic waters of Nantucket Sound, Massachusetts. Additional samples and information were opportunistically collected from recreational and commercial fishermen, as well as published sources. A total of 123 longline sets of 5,591 hooks caught 372 sharks consisting of 344 (92.5%) smooth dogfish *Mustelus canis*, 23 (6.2%) sandbar sharks *Carcharhinus plumbeus*, and 5 (1.3%) dusky sharks *C. obscurus*. The sharks were taken during the period of 16 June–24 September in water temperature and depth ranges of 16.0–27.2°C and 1.2–27.1 m, respectively. Longline catch rates (number of sharks per longline set) were stratified by species, area, month, year, water temperature, and depth. Angler surveys reported the capture of 294 sharks, including sandbar sharks (72%) and smooth dogfish (28%). Data from 540 neonatal and adult smooth dogfish ranging 27.5–121.0 cm fork length (FL) support the conclusion that the neritic waters of southern Massachusetts serve as primary nursery habitat for this species. Size and sex data from 235 juvenile sandbar sharks ranging 61.0–157.0 cm FL indicate that this region provides secondary nursery habitat for this species. Opportunistic samples of juvenile sand tiger *Carcharias taurus*, white shark *Carcharodon carcharias*, basking shark *Cetorhinus maximus*, and tiger shark *Galeocerdo cuvier* provide evidence that these species utilize Massachusetts coastal waters for secondary nursery habitat.

## Introduction

With the exception of trawl, gill-net, and longline fisheries that target spiny dogfish *Squalus acanthias*, there are no directed commercial fisheries for sharks in Massachusetts. Of the 1,740 metric tons (mt) of sharks landed in Massachusetts in 2002, 99% were spiny dogfish and the remaining 1% (15.8 mt) consisted of pelagic sharks, including shortfin mako *Isurus oxyrinchus*, porbeagle *Lamna nasus*, and blue shark *Prionace glauca* taken incidental to offshore trawl, longline, and gill-net fisheries. A substantial recreational fishery for sharks occurs off the coast of Massachusetts from June through September each year. The most recent estimates from the National Marine Fisheries Service (NMFS) Marine Recreational Fishery Statistics Survey (MRFSS) indicate that Massachusetts' recreational fishermen caught about 430,000 sharks in 2002, with spiny dogfish comprising 99% of the catch. The MRFSS estimated that the balance of the catch included blue sharks and shortfin makos as well as smooth dogfish *Mustelus canis* and sandbar sharks *Carcharhinus plumbeus*. Although Massachusetts recreational fishermen target sharks, few are landed; MRFSS estimated that 82% of the 2002 catch was released.

There are indications that MRFSS data do not adequately reflect the extent to which sharks utilize the neritic waters of Massachusetts. Specifically, the survey does not fully represent species composition, fails to generate accurate indices of relative abundance, and does little to identify the temporal and spatial distribution of sharks and shark nursery habitat in these waters. For example, it is well established that the sand tiger *Carcharias taurus* and dusky shark *Carcharhinus obscurus* are seasonal migrants to southern New England (Bigelow and Schroeder 1953); yet, their low abundance precludes detection by the survey.

The Massachusetts Division of Marine Fisheries (DMF) established the Massachusetts Shark Research Program (MSRP) in 1989 to more fully elucidate the ecology, distribution, and relative

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abundance of sharks subjected to fisheries off the coast of Massachusetts. The MSRP conducts angler and longline surveys as well as opportunistically collects information from recreational and commercial fishermen. Biological parameters, including age structure, feeding ecology, local movements, and reproductive status, are examined through dissection and tagging of shark specimens.

In the current study, information collected by the MSRP from 1989 to 2002 was compiled and analyzed for the identification of primary and secondary shark nursery habitat in the coastal waters of Massachusetts. Bass (1978) defined primary nursery habitat as areas where parturition occurs and neonatal sharks spend the first part of their lives, whereas secondary nursery areas are those inhabited by slightly older, but not yet adolescent or mature sharks. It has been suggested that shark populations may be limited by the amount of suitable nursery habitat (Springer 1967). Hence, information on nursery habitat is important to ensure adequate shark management and to assess potential anthropogenic impacts on these areas. The Final Fishery Management Plan for Atlantic Tunas, Swordfish, and Sharks identified the need for this information and emphasized that without more basic research on life history, habitat use, behavior, and distribution, it will be difficult to define essential fish habitat for shark species (NMFS 1999). The plan also noted the paucity of information correlating habitat use to physical habitat characteristics (NMFS 1999). Hence, relative abundance data derived from MSRP sampling were statistically analyzed in the current study to investigate spatial and temporal correlations to the physical characteristics of Massachusetts coastal waters. It is anticipated that the results of this study and others in this volume will provide fisheries managers with contemporary information vital to shark conservation and domestic management.

## Methods

The Massachusetts coastline is divided by Cape Cod into two general areas relative to shark nursery habitat (Figure 1). In the western North Atlantic, Cape Cod represents the northern limit of the geographic range of a few coastal shark species, which include the smooth dogfish, sandbar shark, dusky shark, and tiger shark *Galeocerdo cuvier*. The major coastal water masses south of Cape Cod include Buzzards Bay, Vineyard Sound, and Nantucket Sound. Those shark species that penetrate coastal waters both north and south of Cape Cod include spiny dogfish, sand tiger, white shark *Carcharodon carcharias*, and basking shark *Cetorhinus maximus*. Cape Cod Bay and Massachusetts Bay are the major coastal water bodies north of Cape Cod. Regardless of the region, the entire Massachusetts coastline is composed of hundreds of bays and estuaries.

Although sharks were provided to the MSRP from coastal waters throughout the state, longline and recreational surveys were actively conducted in Nantucket Sound and, more specifically, off the eastern portion of Martha's Vineyard Island called Chappaquiddick Island. This report will primarily focus on these areas.

### *Study site*

Vineyard Sound is bordered to the east by Martha's Vineyard Island and to the west by the Elizabeth Islands; it joins Nantucket Sound in the region of Woods Hole, Massachusetts (Figure 1). Nantucket Sound is enclosed by Martha's Vineyard and Nantucket Islands to the south and Cape Cod to the north. Both sounds flood to the east, ebb to the west, and have an average tidal range of 0.3–1.0 m, depending on geographic location. Depth in these water bodies is characterized by significant shoaling, broad areas less than 20 m deep, and deep pockets up to 28 m. The Vineyard and Nantucket sounds feed several coastal bays and estuaries on Cape Cod and on the Elizabeth, Martha's Vineyard, and Nantucket islands. Water temperatures in the sounds and their associated estuaries fluctuate seasonally from year to year, but range from freezing in the winter months to 28°C in the summer, depending on location. The coastal beaches, bays, and estuaries associated with Nantucket and Vineyard sounds are affected to varying degrees by anthropogenic activities, including boating, marinas, mooring fields, private docks and piers, road runoff, and fishing.

Chappaquiddick Island is connected to the eastern part of Martha's Vineyard Island by a thin barrier beach along its southern edge (Figure 2). This approximately 20-km$^2$ island is bordered by the Cape Poge Wildlife Refuge along its northern, eastern, and southern shorelines and Edgartown Harbor to the west. The eastern and

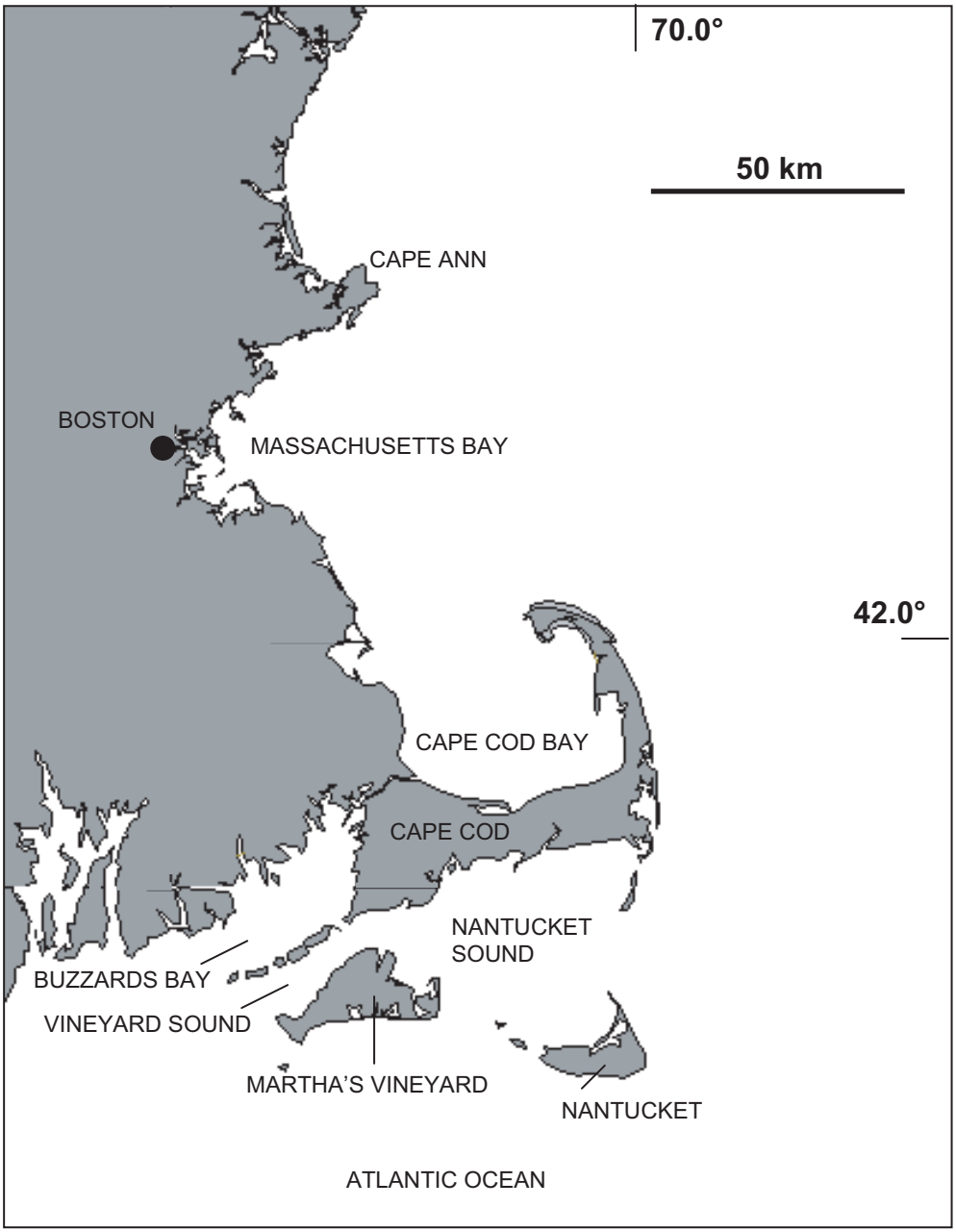


FIGURE 1. Massachusetts coastal waters.

southern sides of the island (East and South beaches, respectively) support seasonal recreational surf fishing activities that catch sharks. The neritic waters of East Beach are part of Muskegut Channel, a major connection between the Atlantic Ocean and Nantucket Sound. South Beach has direct exposure to the Atlantic Ocean.

Cape Poge Bay is a large (ca. 8-km$^2$) pristine estuary occupying the northern half of Chappaquiddick Island (Figure 2). The estuary is a homogeneous water mass with high tidal exchange through an inlet connected to the outer Edgartown Harbor on its western side (Figure 2). Water temperature and salinity (30–32 parts per thou-

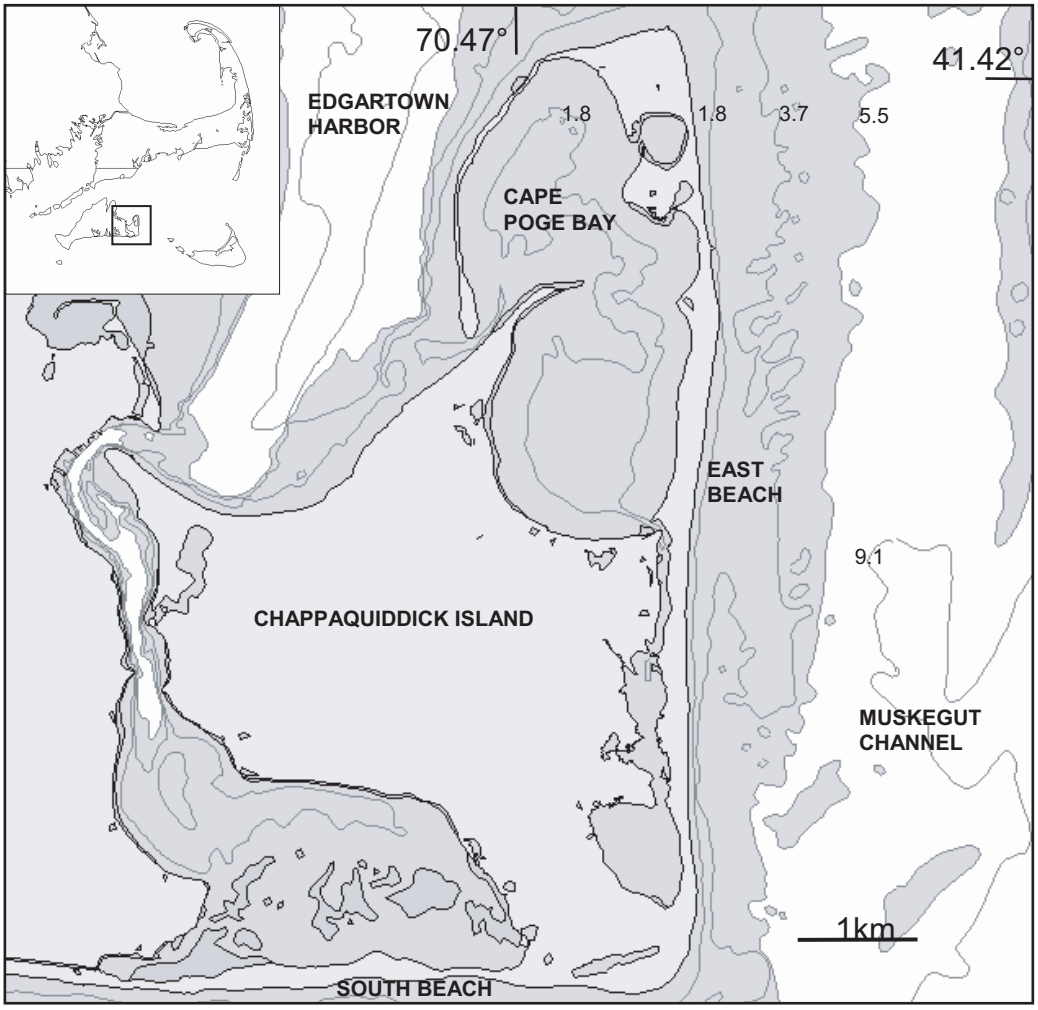


FIGURE 2. Chappaquiddick Island and Cape Poge Bay study area; isobaths (m) = 1.8, 3.7, 5.5, and 9.1.

sand) do not differ from the surrounding coastal waters of Nantucket Sound. Cape Poge Bay supports substantial commercial and recreational fisheries for shellfish and finfish. Although often used as an anchorage, Cape Poge Bay is a relatively shallow water body (<4 m) and remains a town-protected resource with minimal anthropogenic disturbances.

### *Longline survey*

Massachusetts Shark Research Program longlines were set from mid-June through mid-September of each year in two areas off Chappaquiddick Island: inside Cape Poge Bay and along East Beach. These areas were established to standardize sampling at fixed sites where recreational fishermen routinely target sharks. In some years, exploratory sets were deployed in other areas in Nantucket Sound. Longlines were typically 0.8 km in length, consisting of 6.3 mm braided nylon mainline and 40–60 Japanese tuna hooks (size 9/0) on 1.5-m stainless steel cable gangions. Longlines were baited with Atlantic menhaden *Brevoortia tyrannus*, squid *Loligo* sp., or Atlantic mackerel *Scomber scombrus* from 1990 to 1994 and American eel *Anguilla rostrata* from 1995 to 1999. Longline sets were typically allowed to fish for 10–12 h during day or night, meaning that lines were set in the morning and hauled before sunset or set in the evening and hauled after sunrise.

Sharks caught on longlines were measured (fork length) and either tagged with standard NMFS tags ('M' tags or blue Rototags) or retained for dissection. The latter involved the determination of stomach contents and reproductive condition.

The relative abundance index of catch per unit effort (CPUE) was calculated from longline data to investigate temporal and spatial trends in shark distribution. Species-specific CPUE, defined as the number of sharks caught per hook, was calculated and stratified by area, month, year, time of day, sea surface temperature (SST), and depth based on set information. When sample sizes were adequate, a one-way analysis of variance (ANOVA) or *t*-test was used to test for significant differences ($p < 0.05$) in mean CPUE among months (July–September), time of capture (day versus night), area of capture (East Beach versus Cape Poge Bay), and year (1990–2002). To investigate habitat use relative to physical habitat characteristics, catch rate correlations to depth of capture and water temperature were conducted with regression analysis.

### *Recreational angler survey*

Since 1989, recreational surf anglers who routinely target coastal sharks were asked to report catch information on a standardized survey form. This information included area of capture, date and time of capture, disposition of catch, fork length, sex, and bait. Most angler survey participants fished sharks along the eastern and southern shores of Chappaquiddick Island, Martha's Vineyard, but additional data were provided by Cape Cod and Nantucket fishermen.

### *Opportunistic samples*

Coastal sharks have been incidentally captured or observed off Massachusetts and reported to the MSRP by recreational and commercial fishermen. In some cases, these sharks were provided to the MSRP for examination.

All lengths reported herein are fork length (FL). When necessary, total length was converted to fork length using the published morphometric relationships of Branstetter and Musick (1994) for the sand tiger, Francis and Duffy (2002) for the basking shark, and Kohler et al. (1996) for the white shark. For smooth dogfish, FL was derived from total length (TL) using the following relationship: $FL = 0.89(TL) - 1.26$ ($n = 105$, $r^2 = 0.998$, $p < 0.05$). For all species sampled by the MSRP, reproductive stage (neonate, juvenile, adult) was determined from published reports on lengths at birth and maturity.

## Results and Discussion

From 1990 to 2002, 123 longlines consisting of 5,591 hooks were set in the primary sampling areas of Cape Poge Bay (61 sets, 2,268 hooks) and East Beach (54 sets, 2,879 hooks). Additional sets included South Beach (5 sets, 254 hooks), west of Cape Poge Bay (2 sets, 142 hooks), and Vineyard Haven Harbor (1 set, 48 hooks). Catch-per-unit-effort indices for sharks caught by the MSRP longline survey are summarized in Table 1 and Figure 3.

Several sharks were reported or provided to the MSRP from 1989 to 2003. In many cases, these reports entailed the casual observation of "a shark," and this typically resulted in the inability to properly identify the animal. However, some instances resulted in photo documentation or the specimen being provided to the program. Data collected in this manner have resulted in valuable nursery habitat information on the sand tiger, white shark, basking shark, and tiger shark (Table 2).

### *Smooth dogfish*

The longline survey caught smooth dogfish off East Beach (72%) and in Cape Poge Bay (22%), as well as off South Beach (3%), west of Cape Poge Bay (2%), and in Vineyard Haven Harbor (1%), but these percentages were not standardized by effort. Excluding the latter three areas with low sample sizes, the average catch rate of smooth dogfish was significantly greater off East

TABLE 1. Smooth dogfish mean longline CPUE stratified by set location, time of day, and month, 1990–2002.

| Variable | CPUE | SE | Sets (*N*) |
|---|---|---|---|
| Cape Poge Bay | 3.29 | 0.77 | 61 |
| East Beach | 8.33 | 0.71 | 54 |
| South Beach | 2.82 | 1.73 | 5 |
| West of Cape Poge Bay | 5.64 | 0.24 | 2 |
| Vineyard Haven Harbor | 10.42 | 0.00 | 1 |
| Day | 3.96 | 0.74 | 40 |
| Night | 6.36 | 0.71 | 83 |
| June | 8.63 | 4.62 | 5 |
| July | 4.11 | 0.92 | 39 |
| August | 6.21 | 0.78 | 58 |
| September | 5.84 | 1.20 | 21 |

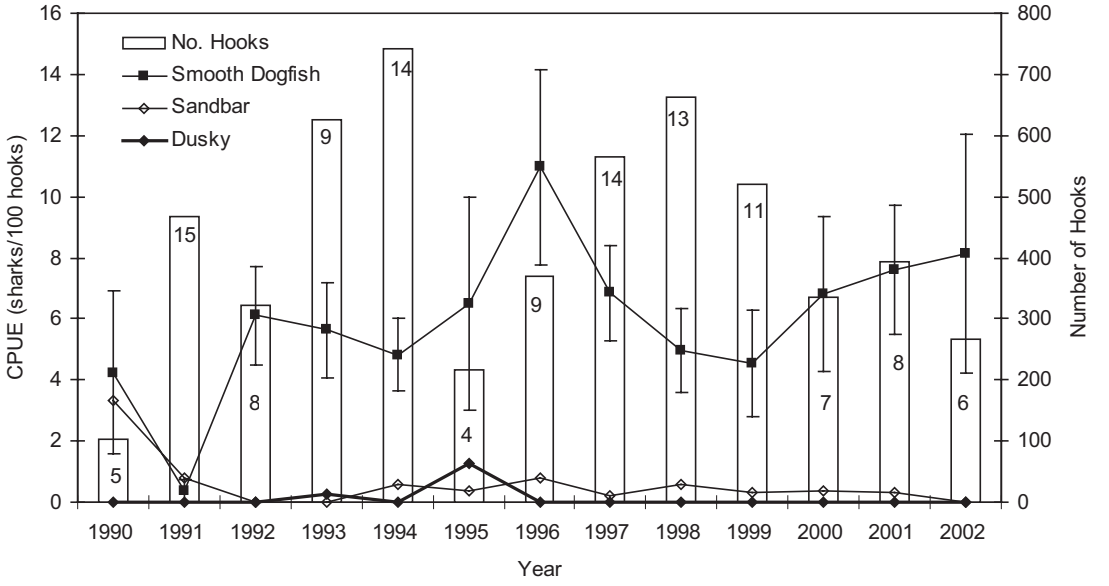


FIGURE 3. Annual longline sampling effort and shark catch per unit effort in coastal waters of Massachusetts, 1990–2002; number in bar = number of longline sets.

Beach (8.3 sharks/100 hooks) than in Cape Poge Bay (3.3 sharks/100 hooks, $t = -4.76$, $p < 0.01$; Table 1), indicating that smooth dogfish were more abundant in Nantucket Sound than in the enclosed estuary. This is further substantiated by a weak, yet significant, positive relationship between set depth and catch rate (Figure 4, $r^2 = 0.22$, $p < 0.01$). Smooth dogfish were captured from mid-June through late September. Although June CPUE (8.6 sharks/100 hooks) was higher than July (4.1 sharks/100 hooks), August (6.2 sharks/100 hooks), and September (5.8 sharks/100 hooks), these differences were not statistically significant (Table 1). With the exception of the low and peak years of 1991 and 1996, respectively, smooth dogfish CPUE has ranged from 4.2 to 8.2 sharks/100 hooks over the 13-year time series (Figure 3). Smooth dogfish were caught over the broad SST range of 16–27°C, but catch rates were weakly correlated with temperature in two ways. There was a weak, yet significant ($r^2 = 0.15$, $p = 0.03$) linear increase in catch rates to 21°C, followed by a equally significant ($r^2 = 0.24$, $p < 0.01$) decline in catch rates at higher temperatures (Figure 5). Longlines caught significantly more smooth dogfish at night (6.4 sharks/100 hooks) than during the day (4.0 sharks/100 hooks, $t = -2.26$, $p = 0.03$; Table 1), supporting the conclusion that the species is more active at night (Casterlin and Reynolds 1979). Smooth dogfish caught on longlines ranged from 63.0 to 121.0 cm FL, and 97% were female.

From 1989 to 2002, the MSRP examined 540 smooth dogfish consisting of fish caught by the longline (337) and angler (82) surveys, taken during other DMF sampling programs (82), and

TABLE 2. Sharks sampled by the Massachusetts Shark Research Program from Massachusetts coastal waters, 1989–2002.

| Species | *N* | Tagged | Size range (cm FL) | Neonates | Juveniles | Adults | Unknown |
|---|---|---|---|---|---|---|---|
| Smooth dogfish | 540 | 146 | 27.5–121.0 | 91 | 12 | 356 | 81 |
| Sandbar shark | 235 | 33 | 61.0–157.0 | | 167 | 5 | 63 |
| Sand tiger | 10 | | 87.4–132.0 | 5 | 5 | | |
| Dusky shark | 5 | 2 | 175.0–254.0 | | 3 | 1 | 1 |
| White shark | 1 | | 109.4 | 1 | | | |
| Basking shark | 7 | | 310.0–695.5 | | 6 | 1 | |
| Tiger shark | 1 | | 133.0 | | 1 | | |

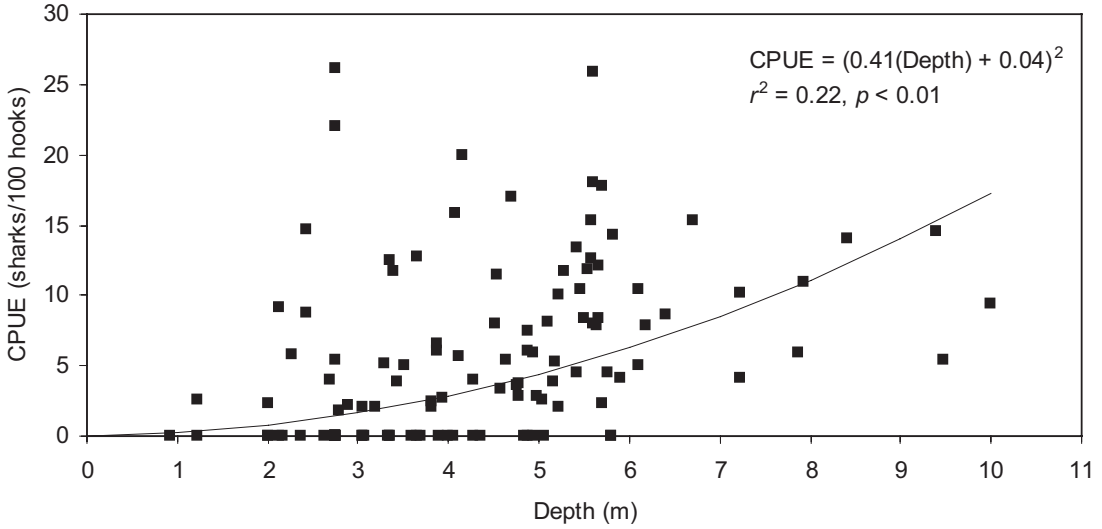


FIGURE 4. Relationship between longline set depth and smooth dogfish catch per unit effort; CPUE = (0.41(Depth) + 0.04) $^2$, $r^2$ = 0.22, $p$ < 0.01.

provided by commercial fishermen (39). Although smooth dogfish are routinely captured by recreational anglers, they are released and not recorded by most survey participants. Smooth dogfish were mostly (424) sampled from the neritic waters of Chappaquiddick Island and Cape Poge Bay, but samples also came from other parts of Nantucket Sound. The size range of all smooth dogfish sampled by the MSRP was 27.5–121.0 cm FL (Figure 6). The smooth dogfish sampled from Massachusetts waters consisted of primarily neonates and adults based on the lengths at birth and maturity estimates of Conrath and Musick (2002) and Conrath et al. (2002) (Table 2; Figure 6). Of the adults, females (95%) were 85.0–121.0 cm FL and males (5%) were 71.0–99.0 cm FL. The

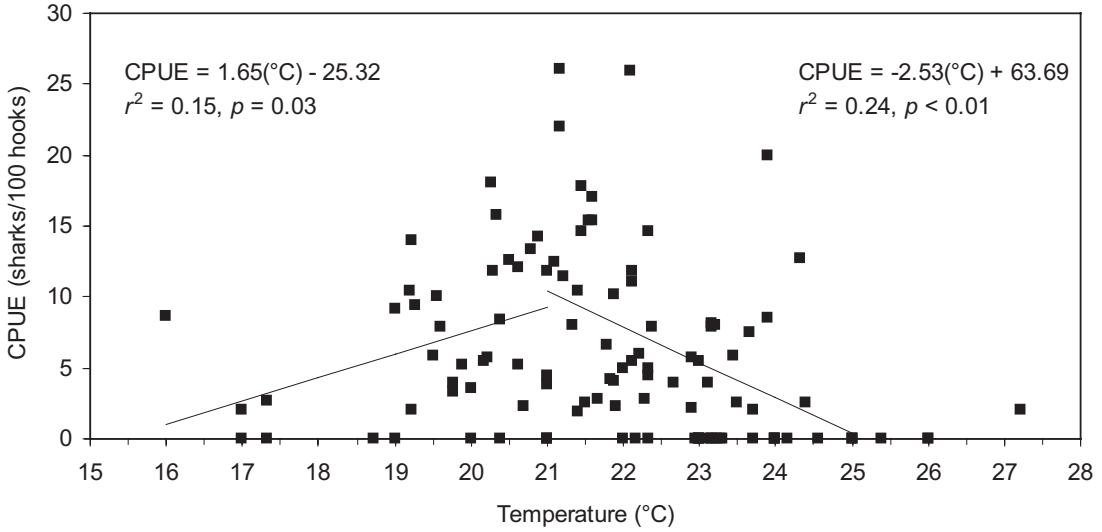


FIGURE 5. Relationship between water temperature and smooth dogfish longline catch per unit effort showing linear increase [CPUE = 1.65(Temperature) – 25.32, $r^2$ = 0.15, $p$ = 0.03] in catch rate to 21°C followed by a linear decline [CPUE = –2.53(Temperature) + 63.69, $r^2$ = 0.24, $p$ < 0.01] in catch rate at higher temperatures.

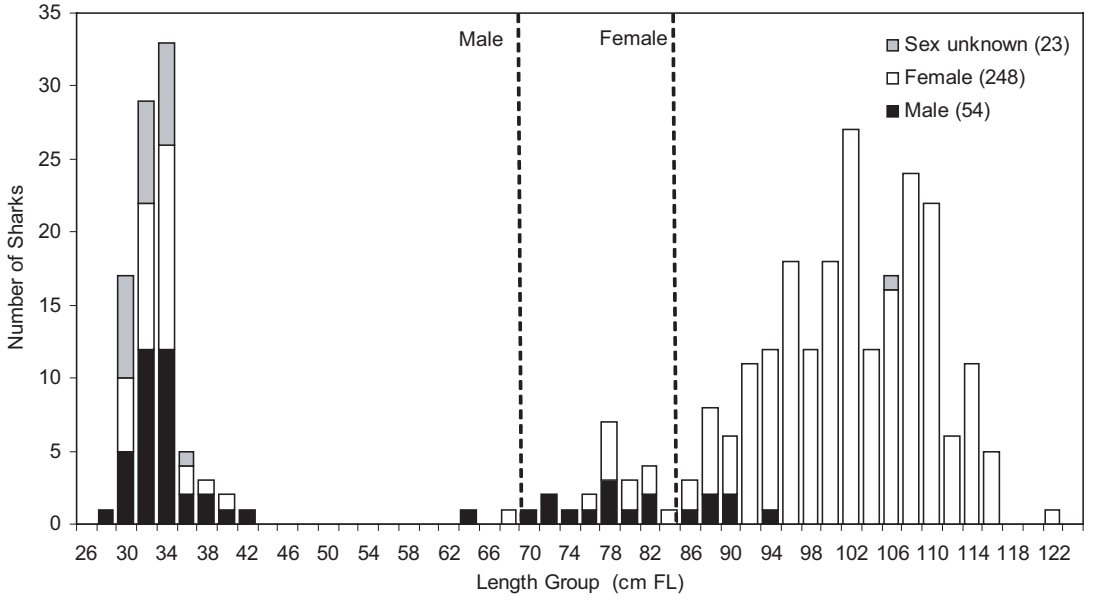


FIGURE 6. Sex-specific length frequency distribution of smooth dogfish sampled by the Massachusetts Shark Research Program, 1989–2002. Size at sexual maturity is shown for each sex (dotted lines) and (*N*) = total number of sharks sampled.

neonates ranged 27.5–41.9 cm FL and comprised a more even sex ratio of 48% females. Similarly, Rountree and Able (1996) reported the near-absence of (non-neonatal) juveniles in a New Jersey estuary.

In the northern end of its range, the smooth dogfish moves into the neritic waters of Nantucket Sound, Vineyard Sound, Buzzards Bay, and associated estuaries in late May and early June to give birth. Neonates were captured in Nantucket Sound and Cape Poge Bay during the period of 20 June–14 August. Conrath and Musick (2002) reported that parturition occurs in May in the species, while Bigelow and Schroeder (1953) and Rountree and Able (1996) presented a more protracted period of mid-May through July. Based on the size of neonates and time of capture, it is likely that parturition occurs in June and July in Massachusetts waters. Rountree and Able (1996) suggested that adults use Mid-Atlantic Bight estuaries and inshore coastal waters as parturition grounds. The presence of adult females and neonates in Massachusetts estuaries and inshore coastal waters supports a similar conclusion for this species in the northern end of its range. This is substantiated by the capture of neonatal smooth dogfish in Nantucket Sound by commercial trawlers. One notable catch on 28 June 1994 consisted of close to 2,000 dogfish pups taken in a discrete area 3 km off the northeast shore of Nantucket Island at a depth of 9–12 m. Sixty-three fish sampled from this catch ranged 28.0–36.0 cm FL, clearly overlapping the estimated size at birth of 25.0–34.0 cm FL (Conrath and Musick 2002). It is likely that Buzzards Bay, Nantucket Sound, Vineyard Sound, and their associated bays and estuaries provide important primary nursery habitat for young-of-the-year smooth dogfish.

The virtual absence of adult males (3%) in longline catches provides little evidence for inshore mating. However, in this study, 31% of the smooth dogfish caught by commercial trawlers in the deeper waters of Nantucket Sound were adult males. Moreover, large aggregations of male and female smooth dogfish have been observed in the upper reaches of Cape Poge Bay in mid- to late June. In June 1992, smooth dogfish in one of these aggregations displayed behavior that may be associated with mating activity. Several smaller males were observed at the surface biting and harassing solitary larger females. While the males eluded longline gear, several females were obtained and mating wounds were apparent. Since this behavior is typical of mating elasmobranchs (Pratt and Carrier 2001), this is likely the first

known report of mating behavior observed in this species.

The smooth dogfish is a seasonal migrant and generally remains in inshore Massachusetts waters until October when it moves offshore and south. Of the 146 smooth dogfish tagged to date, 4 (2.7%) have been recaptured (Nancy Kohler, NMFS, Rhode Island, personal communication). Three of these fish were recaptured off the coasts of Rhode Island (1.7 years, May), New Jersey (2.2 years, October), and Virginia (1.8 years, May). One of these sharks was tagged and recaptured in Cape Poge Bay after 4.1 years at liberty, possibly demonstrating site fidelity to a nursery area.

### *Sandbar shark*

Longline CPUE for this species ranged from 0.0 to 3.3 sharks/100 hooks over the 13-year period (Figure 3). However, so few sandbar sharks have been taken on longline each year that a single fish could significantly influence CPUE. The highest catch rate of 3.3 sandbar sharks/100 hooks in 1991 was driven by two sandbars taken on a single set in Cape Poge Bay. When one considers the number of variables that can influence the presence of a species in a particular area, this index must be viewed with caution relative to this species. Nonetheless, the data do have some ecological implications. All of the sandbar sharks taken on longline were caught in SST and depth ranges of 20–24°C and 2.4–6.4 m, respectively. Similarly, Carlson (1999) did not catch juvenile sandbar sharks in the nursery areas of the northeastern Gulf of Mexico until water temperatures reached 22°C. In the current study, 23 sandbar sharks were captured on longline from 1 July to 5 September off East Beach (56%) and in Cape Poge Bay (43%). As noted above, sample size limitations precluded the statistical analysis of catch rates, but night sets appeared to catch more sandbar sharks (0.68 sharks/100 hooks) than day sets (0.21 sharks/100 hooks).

During the period of 1989–2002, 212 sandbar sharks were reported to the MSRP by recreational anglers (Figure 7). Although the sandbar shark is less abundant than the smooth dogfish, more were reported by anglers because the latter was considered a nuisance fish and not recorded, thereby resulting in reporting bias. Most of the sandbar sharks were taken off East Beach (85%), but others were caught off South Beach (5%), in Cape Poge Bay (2%), and off the south shore of Cape Cod (8%). The proportional catch of sandbar sharks from these areas is indicative of survey effort and not relative abundance. Published reports of sandbar sharks from the south side of Cape Cod and off Nantucket Island provide evidence that the distribution of this species is more widespread in Nantucket Sound than portrayed by this survey (Bigelow and Schroeder 1953;

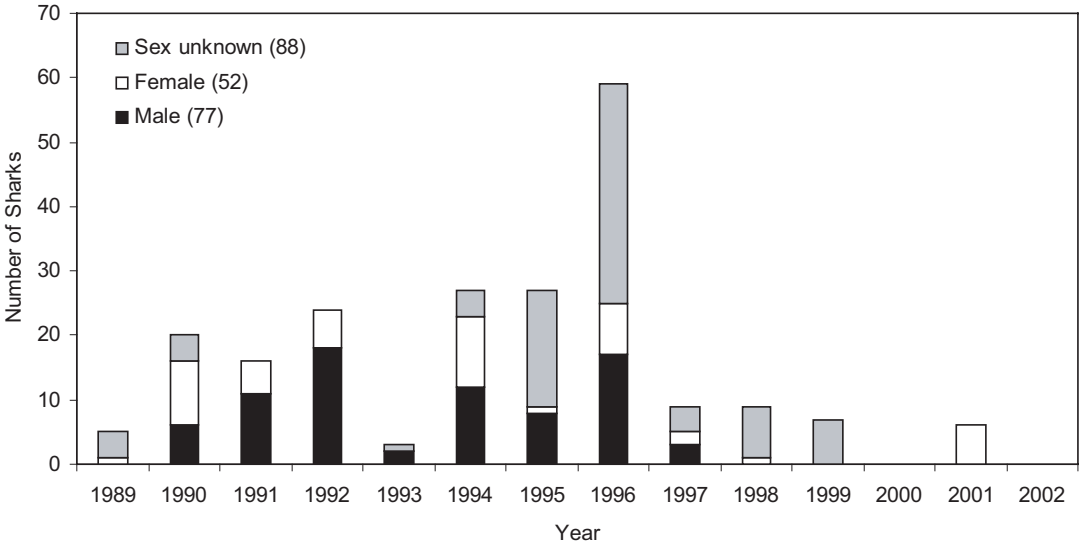


FIGURE 7. Number and sex ratio of sandbar sharks reported to the Massachusetts Shark Research Program by recreational fishermen, 1989–2002; (*N*) = total number of sharks sampled.

Andrews 1973). Moreover, the rapid decline in sandbar shark reports from 1997 to 2002 is likely due to the dramatic decrease in effort associated with beach closures for nesting birds. All the sandbar sharks reported to the MSRP were caught between 21 June and 2 October.

In total, 235 (88 males, 63 females, 84 unknown) sandbar sharks were examined or reported to the MSRP since 1989 (Table 2; Figure 8). Although sandbar sharks were taken between 21 June and 2 October, the species was most abundant in July (Figure 9). The size range of those sharks measured was 61.0–157.0 cm FL with no sexual differences (Figure 10). If size at maturity is 143.0 cm FL and 149.0 cm FL for males and females, respectively (Sminkey and Musick 1995), then 5% of the males and 2% of the females sampled over the 13-year period were mature. Based on the age estimates of Casey et al. (1985) and Sminkey and Musick (1995), the sandbar sharks sampled over the 13-year period ranged from 2 to 15 years of age. Thus, the majority of sandbar sharks occurring inshore in Massachusetts are juveniles utilizing these areas as secondary nurseries.

Sandbar sharks move out of Massachusetts coastal waters in early October, which likely coincides with seasonal cooling of inshore waters.

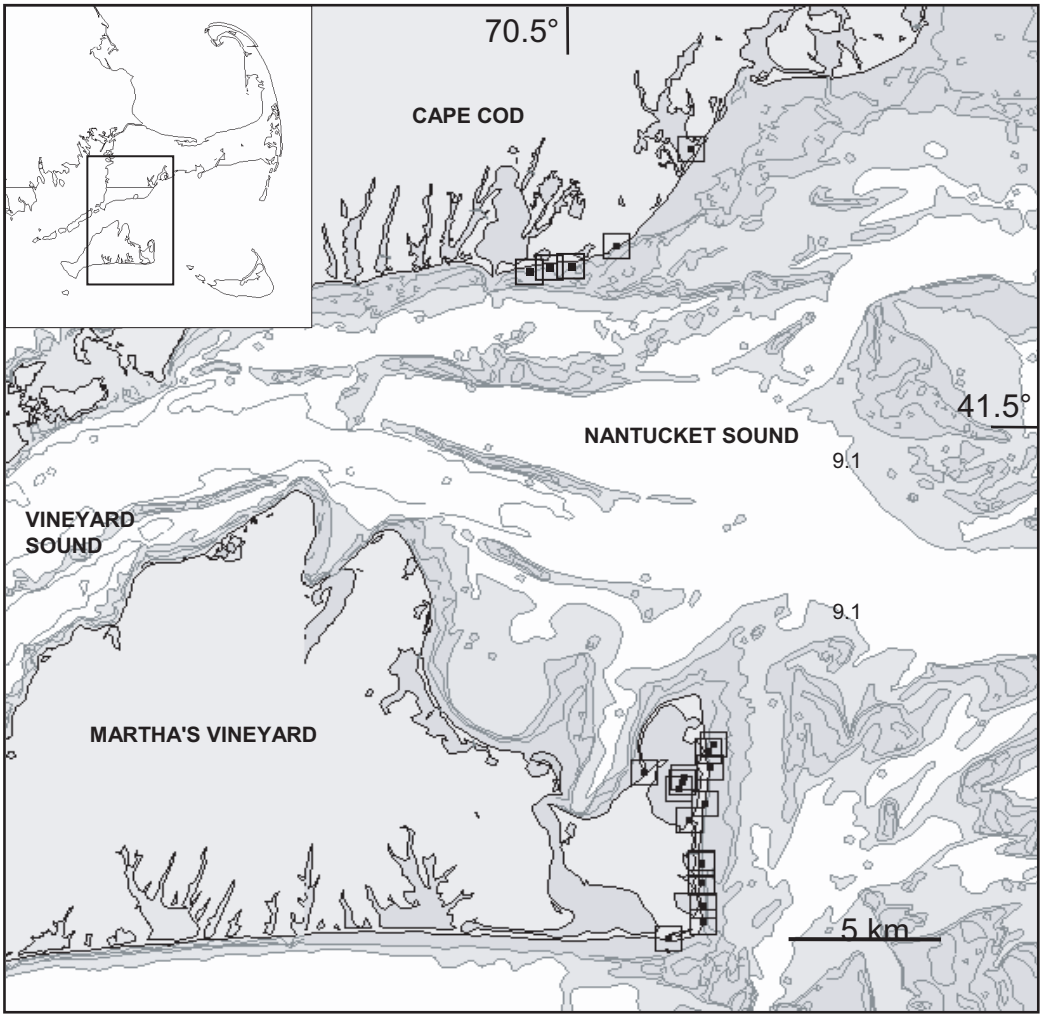


FIGURE 8. Capture locations of sandbar sharks ($N$ = 235) sampled by the Massachusetts Shark Research Program; isobaths (m) = 1.8, 3.7, 5.5, and 9.1.

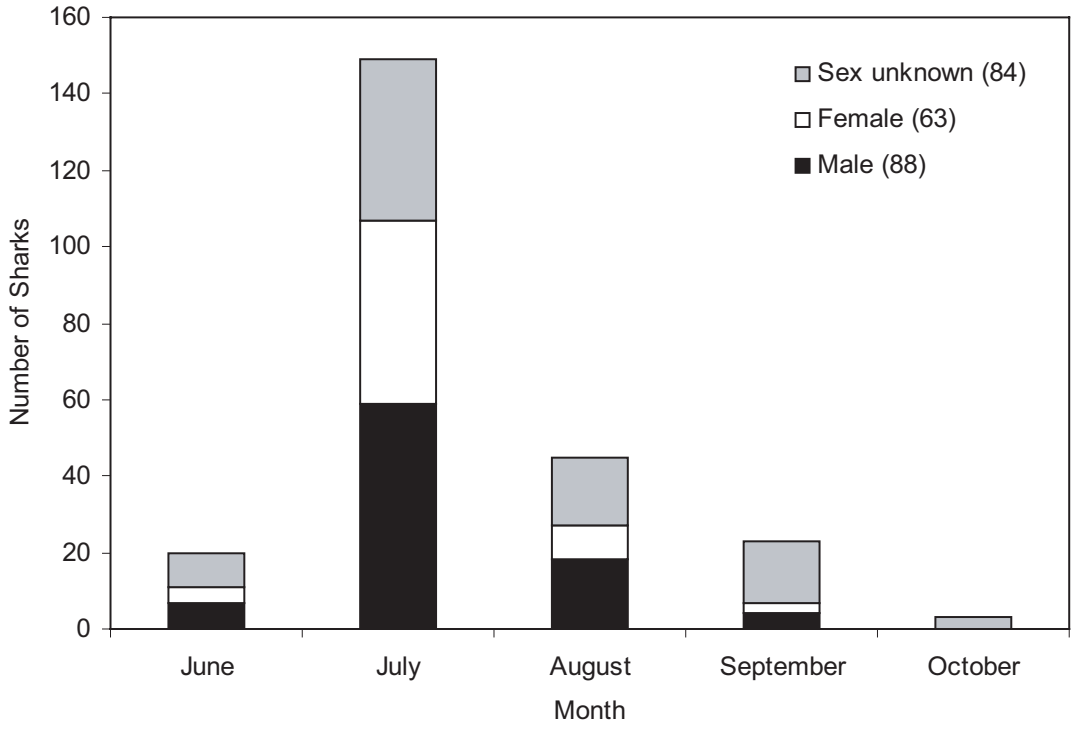


FIGURE 9. Monthly distribution of sandbar sharks sampled by the Massachusetts Shark Research Program, 1989–2002; (*N*) = total number of sharks sampled.

Merson and Pratt (2001) reported that sandbar sharks moved out of the nursery habitat of Delaware Bay by early October. In the current study, 33 sandbar sharks were tagged and 3 were recaptured. The recapture rate of 9.1% is higher than that reported for this species (4.7%) by Kohler et al. (1998). These three fish were at liberty for 6–9 years and recaptured off the coasts of Florida (January, July) and Texas (July).

### *Sand tiger*

Despite their historical abundance in Nantucket Sound, no sand tigers were caught during the 13-year history of the longline survey. However, 10 sand tigers have been reported to the MSRP since 1989. Eight of these were taken by recreational fishermen, one was entrained by the intake lines of a power plant, and one was photographed by a recreational diver; all were reported during the months of August to October.

Along with the dogfishes, the sand tiger was once considered the most abundant shark in Massachusetts coastal waters (Bigelow and Schroeder 1953). In the early 1900s, sand tigers supported a commercial fishery in Nantucket Sound until it was thought to be locally exhausted (Bigelow and Schroeder 1953). Photographs provided to the MSRP by the Nantucket Historical Society confirmed that this fishery landed large adult sand tigers. Although considered "the most common of the large sharks" off Nantucket by Andrews (1973), not a single adult sand tiger has been reported to the program since its inception in 1989, despite the extensive commercial and recreational multispecies fisheries in this state. This provides evidence that intensive commercial fisheries can lead to the long-term depletion of local shark populations.

The 10 sand tiger sharks were reported from two general locations in coastal Massachusetts (Figure 11): south of Cape Cod in coastal waters off East Beach, Chappaquiddick Island and from bays and estuaries in Massachusetts Bay. All of these were small immature sand tigers in the size range of 87.0–132.0 cm FL; the five sexed were all female. According to the length-at-age estimates of Branstetter and Musick (1994), these fish

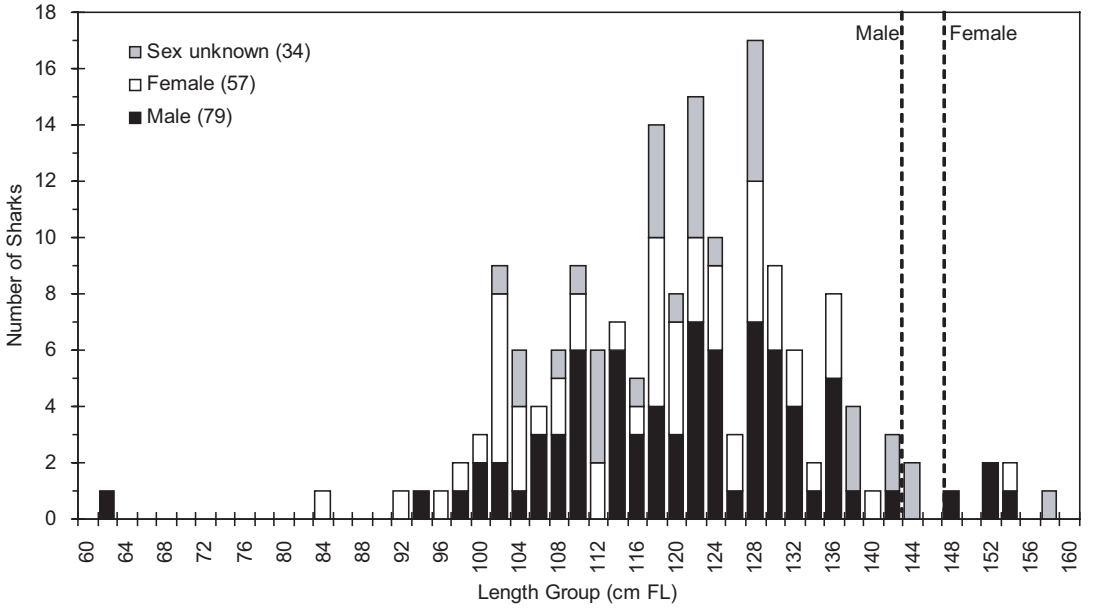


FIGURE 10. Sex-specific length frequency distribution of sandbar sharks sampled by the Massachusetts Shark Research Program, 1989–2002. Size at sexual maturity is shown for each sex (dotted lines) and (*N*) = total number of sharks sampled.

ranged in age from 0 to 2 years. In the western North Atlantic, the sand tiger gives birth from December through March and length at birth is 85.3 cm FL (Gilmore et al. 1983). Five of the sand tigers sampled by the MSRP were 87.0–91.0 cm FL, close to or in their neonatal stage. Bigelow and Schroeder (1953) reported that most sand tigers caught from the northern part of their range are immature, with the exception of those taken in the aforementioned Nantucket fishery. Therefore, the coastal waters of Massachusetts provide secondary nursery habitat for sand tigers that move north from southeastern pupping grounds (Gilmore et al. 1983).

### *Dusky shark*

From 1989 to 2002, only five dusky sharks have been sampled by the MSRP and these were taken on longline (Table 2; Figure 12). These sharks were caught in SST and depths ranging 17–24°C and 4.8–19.2 m, respectively. Four were captured along East Beach and one was taken off South Beach in deeper water (Figure 12). Of the four reliably measured, three (two females, one male) were in the size range of 173.0–183.0 cm FL and one female was 254.0 cm FL. Based on the size at maturity estimates of Springer (1960), the three smaller dusky sharks were immature and the larger female had reached maturity. Although Bigelow and Schroeder (1953) examined 12 dusky sharks from Woods Hole, Massachusetts, including six taken in August of 1944, the species is not common in southern New England. Nonetheless, the southern coastal waters of Massachusetts may provide secondary nursery habitat to those dusky sharks that venture north.

### *White shark*

In August 2002, a small white shark (ca. 109.0 cm FL) was captured in a trawl net and reported to the MSRP. The commercial vessel was bottom trawling in Vineyard Sound (Figure 11) at a water depth of 18–21 m and an SST of 21.1°C. The white shark is a seasonal migrant to the coastal and offshore waters of New England (Bigelow and Schroeder 1953), and each year, the MSRP fields anecdotal reports of white sharks, which in most cases are misidentified. Casey and Pratt (1985) reviewed the distribution of the white shark in the western North Atlantic and noted that this species is most abundant in the Mid-Atlantic Bight on the continental shelf between Cape Hatteras,

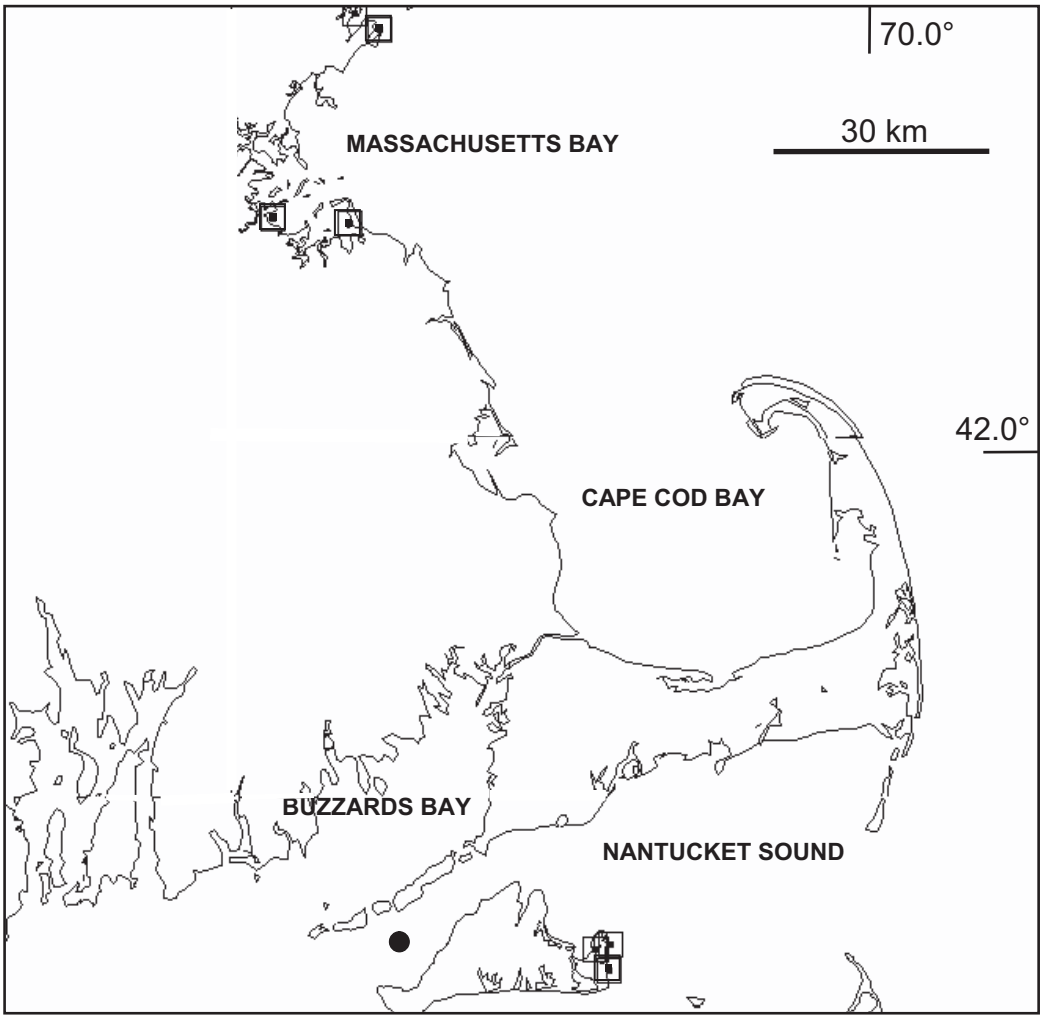


FIGURE 11. Capture locations of sand tigers ($n$ = 10, open squares) and a juvenile white shark (filled circle) sampled by the Massachusetts Shark Research Program, 1989–2002.

North Carolina and Cape Cod, Massachusetts. Moreover, they observed that more young white sharks have been caught in this region than in any area of comparable size in the world. Bigelow and Schroeder (1953) reported two very small white sharks, one harpooned off Boston in 1948 (ca. 81.0 cm FL) and one netted off Rhode Island in 1939 (ca. 138.0 cm FL). The five smallest white sharks reported by Casey and Pratt (1985) from the Atlantic ranged from 109.0 to 123.0 cm FL. Uchida et al. (1996) and Francis (1996) estimated that length at birth of the white shark is 108.0–136.0 cm FL. Therefore, the white shark examined in 2002 was one of the smallest reported free-swimming white sharks and clearly a young-of-the-year animal. Casey and Pratt (1985) postulated that white sharks use the neritic waters of the Mid-Atlantic Bight as a nursery area. Their observations coupled with those of Bigelow and Schroeder (1953) and the current study warrant the inclusion of Massachusetts coastal waters in this broad nursery region.

### *Basking shark*

In the western North Atlantic, the basking shark is known to concentrate in the spring and summer in areas of high productivity and along thermal fronts on the continental shelf from southern

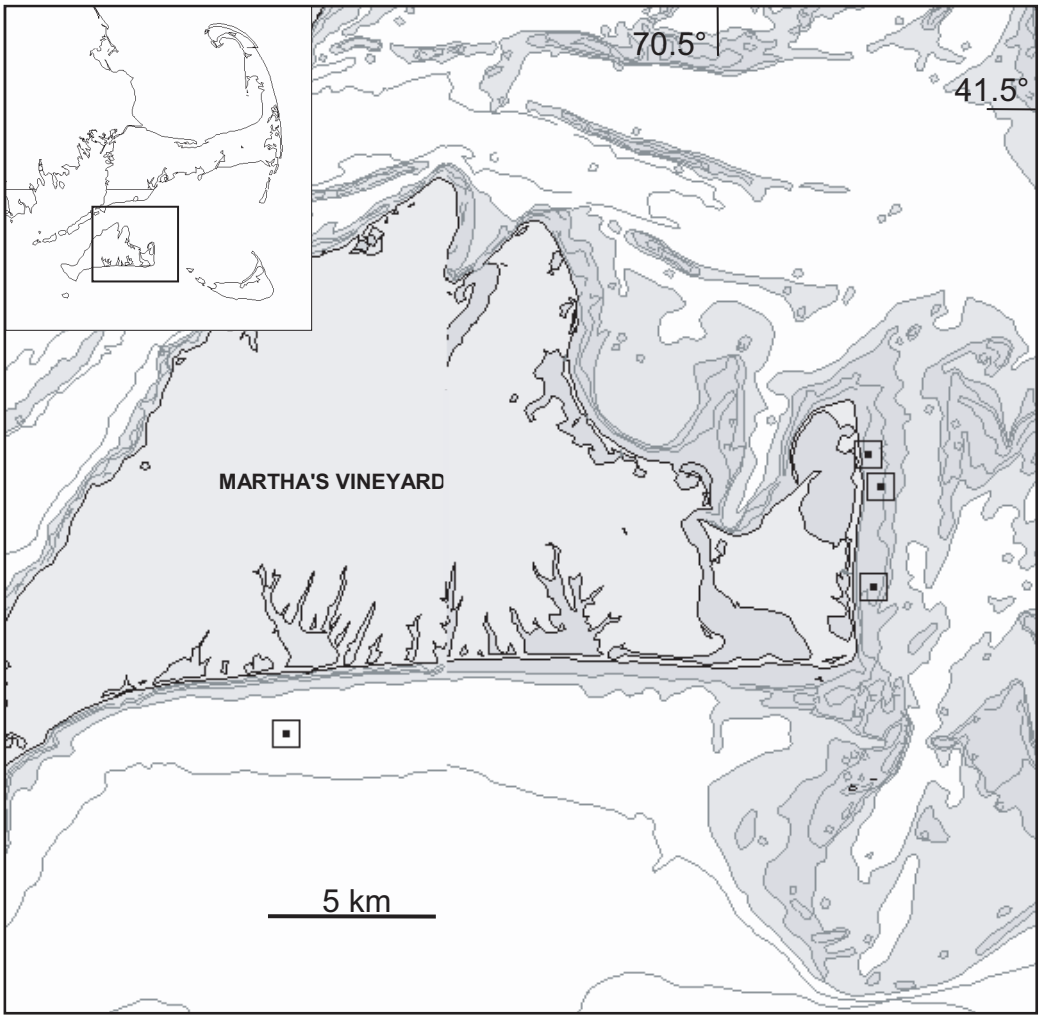


FIGURE 12. Capture locations of dusky sharks sampled by the Massachusetts Shark Research Program, 1989–2002; isobaths (m) = 1.8, 3.7, 5.5, and 9.1.

New England to Newfoundland (Templeman 1963; Owen 1984; Lien and Fawcett 1986). The basking shark is well documented off the coast of Massachusetts (Bigelow and Schroeder 1953; Owen 1984). Basking shark reports to the MSRP have ranged from the coastal waters of Buzzards Bay, Vineyard Sound, Cape Cod Bay, and Massachusetts Bay to the offshore waters of the Great South Channel and Stellwagen Bank. Very little is known of the size and age structure of the basking shark population in these waters, but it is thought to consist of juveniles and adults. From 1984 to 2003, seven stranded or incidentally captured basking sharks (three males, four females) were examined by the MSRP and/or NMFS personnel (Lisa Natanson, NMFS, Rhode Island, personal communication). Six of these fish stranded in Cape Cod Bay (3), in Boston Harbor (1), on Martha's Vineyard (1), and on the east side of Cape Cod (1), while one was entangled in a trawl net in the Great South Channel east of Nantucket. Males ranged from 320.0 to 696.0 cm FL and females ranged from 310.0 to 690.0 cm FL. Size at maturity is thought to be 691.0 cm FL and 700.0 cm FL in males and females, respectively (Mathews 1950). Hence, two of the males and all four of the females were immature. The coastal and offshore waters of southern New England, therefore, pro-

vide important secondary nursery habitat for this planktivorous species. The extent to which this region serves as primary nursery habitat is unknown because neonates and pregnant females were not observed.

### *Tiger shark*

The tiger shark is generally reported from tropical and warm temperate waters of the western North Atlantic, but it is rarely encountered north of the Mid-Atlantic Bight. Bigelow and Schroeder (1953) reported the capture of juvenile tiger sharks in the nearshore waters of Woods Hole (presumably Vineyard and Nantucket sounds) "every year." From 1987 to 2002, five tiger sharks were recorded by offshore fishing tournaments based in Massachusetts, but all were caught several miles south of Martha's Vineyard and Nantucket islands. In June 2001, a juvenile female tiger shark (133.0 cm FL) was taken by a recreational fisherman off South Beach on Martha's Vineyard. Although historically present, tiger sharks have been rare in recent years, as is their utilization of Massachusetts coastal waters for secondary nursery habitat.

## Conclusions

Data collected and compiled from 1989 to 2003 by the MSRP indicate that the coastal waters of Massachusetts provide important nursery habitat for several species of sharks.

For the smooth dogfish, sandbar shark, dusky shark, and tiger shark, this region represents the northern limit to their geographic range in the western North Atlantic. For the sand tiger, basking shark, and white shark, these inshore nursery areas may extend farther north into the Gulf of Maine. In all cases, future management to protect shark nursery habitat for these species should include the coastal waters of Massachusetts.

The presence of adult and neonatal smooth dogfish in Nantucket Sound and its associated bays and estuaries suggests that these areas provide important primary nursery habitat for this species. Moreover, it is highly likely that Buzzards Bay and Vineyard Sound serve a similar role since this species is known to occur in both. This region also provides suitable opportunities for mating.

The seasonal occurrence of juvenile sandbar sharks off Chappaquiddick Island, in Cape Poge Bay, and off Cape Cod and Nantucket beaches suggests that the neritic waters of Nantucket Sound and its associated bays and estuaries provide secondary nursery habitat for this species. Although the lack of angler reports from Buzzards Bay and Vineyard Sound indicates that these water bodies do not play a similar role, this cannot be said with certainty without an expansion of the survey. The apparent higher relative abundance of juvenile sandbar sharks in the coastal waters of Chappaquiddick Island may be a function of effort or may be related to the pristine nature of this area. The extent to which the southern beaches and bays of Cape Cod contribute to the ecology of this species is not fully understood. These areas are known to suffer from greater anthropogenic effects than Chappaquiddick Island (Bowen and Valiela 2001), and this may influence the relative abundance of sandbar sharks in these areas. Great South Bay (Long Island, New York) was once a primary nursery for the sandbar shark (Nichols 1916; Thorne 1916), but the species is no longer found in this well-developed embayment (Merson and Pratt 2002). Similarly, Grubbs and Musick (2002) hypothesized that the low abundance of sandbar sharks in lower western portions of Chesapeake Bay may be related to habitat degradation associated with relatively higher levels of urbanization in this area. Additional research is needed to assess the temporal and spatial effects of water quality on shark nursery habitat.

The occurrence of neonatal and juvenile sand tigers in the coastal areas of Massachusetts indicates that these waters serve as secondary nursery habitat for this species. Similarly, this is the first report to document secondary nursery habitat for the dusky shark, tiger shark, and white shark in Massachusetts. However, the extremely low occurrence of these species in this region may be indicative of low population sizes or annual fluctuations in habitat suitability. Much of the biology of the basking shark remains a mystery, but the seasonal occurrence of juveniles in Massachusetts coastal and offshore waters warrants the designation of secondary nursery habitat in this region.

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