GLOBAL PERSPECTIVES ON THE BIOLOGY AND LIFE HISTORY OF THE WHITE SHARK

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CHAPTER 27

Implications of Increasing Pinniped Populations on the Diet and Abundance of White Sharks off the Coast of Massachusetts

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ABSTRACT

Although the occurrence of the White Shark, *Carcharodon carcharias*, is well documented in the North Atlantic, the species is relatively rare, and much of what is known about its distribution and movements is based on historical sightings data. The advent of new tagging technology coupled with the existence of White Shark "hot spots" near pinniped colonies have allowed researchers to investigate the ecology of this species in the Pacific and Indian Oceans, but its elusive nature in the Atlantic has hampered such studies in this region. However, the numbers of White Shark sightings and White Shark pinniped predation events have been rising off the coast of Massachusetts in recent years and, in particular, near Monomoy Island on Cape Cod, which hosts a large growing population of Gray Seals (*Halichoerus grypus*). Although the perceived increase in shark predation on Gray Seals can be attributed to several factors, it is feasible that White Sharks, which were thought to primarily scavenge cetaceans in the Atlantic, are expanding their diet in response to regional changes in seal abundance. Based on documented changes in White Shark populations exhibited in other parts of the world, we anticipate that the number of White Shark sightings and seal interactions will continue to rise off the coast of Massachusetts.

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INTRODUCTION

In the western North Atlantic, the White Shark (*Carcharodon carcharias*) is well documented from Newfoundland to the Gulf of Mexico, including the Bahamas and parts of the Caribbean (Bigelow and Schroeder, 1948; Templeman, 1963; Casey and Pratt, 1985; Compagno, 1984). Despite its well-established presence in the North Atlantic, the White Shark is not considered an abundant species, and efforts to study its life history and ecology have been hampered by the inability of researchers to predictably encounter these sharks. Indeed, much of what is known of this species in the North Atlantic comes from the analysis of distribution records (Templeman, 1963; Casey and Pratt, 1985), rare behavioral observations (Pratt et al., 1982; Carey et al., 1982), and the opportunistic examination of dead specimens (Pratt, 1996).

In their review of White Shark distribution in the western North Atlantic, Casey and Pratt (1985) compiled observations from numerous sources, including fisheries interactions, confirmed sightings, and published accounts dating back to 1874. The rarity of this species in this region is exemplified by their compilation of only 380 records and their observation that White Sharks represented only 0.04% of the sharks taken by over 2.1 million hooks of pelagic longline effort from the Grand Banks to the Gulf of Mexico (1963–1983). Nonetheless, Casey and Pratt (1985) concluded that White Sharks in the western North Atlantic were most abundant on the continental shelf in the Mid-Atlantic Bight (from Cape Hatteras, North Carolina to Cape Cod, Massachusetts). Moreover, the species is thought to exhibit seasonal movements, mediated by water temperature, into northern latitudes.

In the Pacific and Indian Oceans, the White Shark is known to feed on pinnipeds, and its ecology as it relates to large pinniped colonies is well studied (Klimley and Ainley, 1996; Chapter 9, this book). The high seasonal abundance of White Sharks near seal and sea lion colonies has also allowed researchers in these regions to study White Shark movements over broad spatial and temporal scales (Domeier and Nasby-Lucas, 2008; Jorgenson et al., 2010; Chapters 10, 11, 12, 13, 14, 16, 21, and 22, this book). The only behavioral observations of White Sharks in the North Atlantic come from a single acoustic tracking study conducted by Carey et al. (1982). These researchers acoustically tagged a 4.6 m total length White Shark that was scavenging a Fin Whale carcass 39 km southwest of Montauk Point, New York and tracked the shark for 83 h as it moved 190 km southwest along the 25-fathom bathymetric curve. The vertical movements of the shark were of particular interest in that it remained largely associated with the thermocline at approximately 10–20 m but made periodic excursions to the bottom. At the time, Carey at al. (1982) noted that "the seals, sea lions, and elephant seals, which are common items in the diet of White Sharks in other regions, are not available" in the western North Atlantic. Hence, they concluded that the observed diving behavior may be associated with searching for dead whales, which are an important food resource for large White Sharks (>3 m) on the continental shelf. Indeed, the presence of scavenging White Sharks on whale carcasses is well documented in this region (Pratt et al., 1982).

It can be argued that the elusive nature of the White Shark in the North Atlantic may be a result of the lack of strong spatial overlap between White Sharks and large pinniped colonies. This may not have always been the case because at least one large pinniped, the Gray Seal (*Halichoerus grypus*), was once quite abundant in southern New England waters, an area identified by Casey and Pratt (1985) as having the highest White Shark abundance. If this were indeed the case, White Sharks may have exhibited a dietary shift to other prey, including dead cetaceans, as a result of the demise of the Gray Seal population in the seventeenth century (Wood LaFond, 2009). With the protection of marine mammals over the last 40 years, the western North Atlantic Gray Seal population has rebounded (National Marine Fisheries Service, 2009a; Wood LaFond, 2009). Hence, it is entirely plausible that White Sharks are expanding their foraging strategies to once again include active predation on pinnipeds, which may be becoming a viable food resource.

The purpose of this paper is to explore the dynamic predatory relationship of White Sharks and pinnipeds in the western North Atlantic. Based on documented changes in White Shark populations exhibited in other parts of the world, we have compiled the best available information on temporal and spatial changes in Gray Seal and White Shark abundance as well as shark-seal interactions to define the current and future status of this relationship.

MATERIALS AND METHODS

White Shark Sightings

Since the establishment of the Massachusetts Shark Research Project in 1987, we have been tabulating and investigating reports of White Shark sightings in New England waters. In most cases, these reports comprised fisheries gear interactions or observations by fisheries observers, spotter pilots working with commercial fishermen, whale-watch vessels, boaters, beach users, and recreational and commercial fishermen (Figure 27.1). To confirm species identification, we have taken into consideration physical evidence (i.e., a dead specimen), photographic/video evidence, eyewitness accounts, and observer experience. In most cases, those species typically confused for White Sharks included Basking Sharks (*Cetorhinus maximus*), Ocean Sunfish (*Mola mola*), and a variety of marine mammals (dolphins, porpoises). Sightings that were clearly not White Sharks based on descriptions and/or photographic evidence were discarded and not classified. All other sightings reports were categorized as follows:

1. Class A: Positive identification based on valid description, dead specimen, and/or photo/video support
2. Class B: Accurate description, but no photographic evidence
3. Class C: Suspect description, no corroborative support
4. Class F: False report or misidentification (witness acknowledges after being shown photos)

Seal Interactions

In the United States, marine mammal strandings data are collected and compiled by regional strandings networks with oversight from the National Marine Fisheries Service. In the northeast region and, more specifically, Massachusetts, marine mammal strandings are primarily investigated by the New England Aquarium and the International Fund for Animal Welfare (IFAW)/Cape Cod

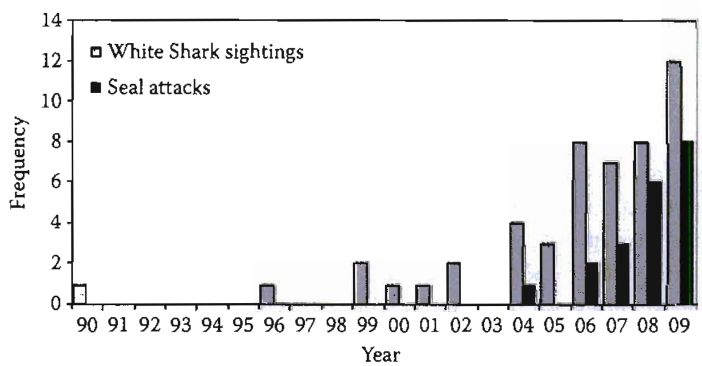

Figure 27.1 The annual number of White Shark sightings and attacks on seals based on information reported to the Massachusetts Shark Research Project, 1990–2009.

Stranding Network. The responsibilities of each program are divided geographically. The New England Aquarium's Marine Animal Rescue Program is responsible for much of the eastern shoreline of Massachusetts and New Hampshire but also includes Martha's Vineyard and Nantucket Islands. The IFAW/Cape Cod Stranding Network (CCSN) covers the Cape Cod region, extending west to the Rhode Island border.

From the mid 1980s to 1998, marine mammal strandings on Cape Cod were compiled by several animal-welfare and conservation organizations under the authorization of the New England Aquarium. In 1998, the nonprofit CCSN was formed with dedicated staff and over 300 volunteers trained to respond to marine mammal and turtle strandings on Cape Cod. More recently, the CCSN has become a project of the IFAW. These organizational changes did not result in greater observational effort because virtually all pinniped strandings have been and continue to be reported by the general public (e.g., beach users, lifeguards, etc.).

Among the goals of these programs is to respond to live and dead stranded marine mammals, including seals, and, when possible, perform postmortem necropsies to determine the cause of death. Over the last decade, we have been working closely with these programs to identify seal injuries and mortalities that may be indicative of interactions with sharks. If it was suspected that injuries sustained by a seal may have been the result of a shark attack, the stranding network contacted our program to examine the seal. Given the prey item (seal), the temperate location (New England), the size and nature of the lacerations [based on examples given by Long and Jones (1995)], and the limited number of shark species that inhabit this region (Bigelow and Schroeder, 1948), the White Shark was the most likely species implicated in these attacks.

Data Analysis

Annual White Shark counts were modeled with a Poisson regression using year as a covariate. To take into consideration uncertainty over effort, we deployed two methods. First, we refit the generalized linear model (GLM) with a 3% annual increase in effort as an offset. Second, we used an approach recently developed by McPherson and Myers (2009) to examine population trends from observational data. In short, this method fits a GLM to extract the abundance trend in relative terms but also tests the sensitivity of trend estimates to changes in observer effort (McPherson and Myers, 2009). We ran the model for the time period of 1990–2009 and tested the sensitivity of the results to annual observational effort changes of +50%, 0%, and −50%.

RESULTS

From 1990 to 2009, we recorded 63 White Shark sightings classified as A (n = 32), B (n = 18), C (n = 8), and F (n = 5). Given the tenuous nature of the latter two categories, they were eliminated from subsequent analyses, resulting in a total of 50 credible reports (Figure 27.1). The bulk of these fish (70%) was reported by commercial fisherman (44%: gillnet, bottom trawl, trap, longline, and tuna rod and reel), spotter pilots working with Bluefin Tuna purse seiners and harpooners (16%), and chartered fishing vessels (10%). The balance (30%) was reported by beach users, kayakers, paddleboarders, recreational boaters, and seal-watch vessels. Although White Sharks were reported over a broad geographic area north, east, and south of Cape Cod, 26 (52%) were in close proximity to Monomoy Island, an established Gray Seal colony (Figure 27.2). Using Poisson regression with year as a covariate, we found a significant ($p < 0.001$) increasing trend in annual White Shark counts (Figure 27.3). Sensitivity of the trend to increasing effort was tested by using an effort series that increased 3% per year as an offset. A comparison of the predicted counts from the model with no effort changes to the sensitivity model suggests that the direction of the trend is not sensitive to the 3% increase in effort (Figure 27.3). The approach developed by McPherson and Myers (2009) also

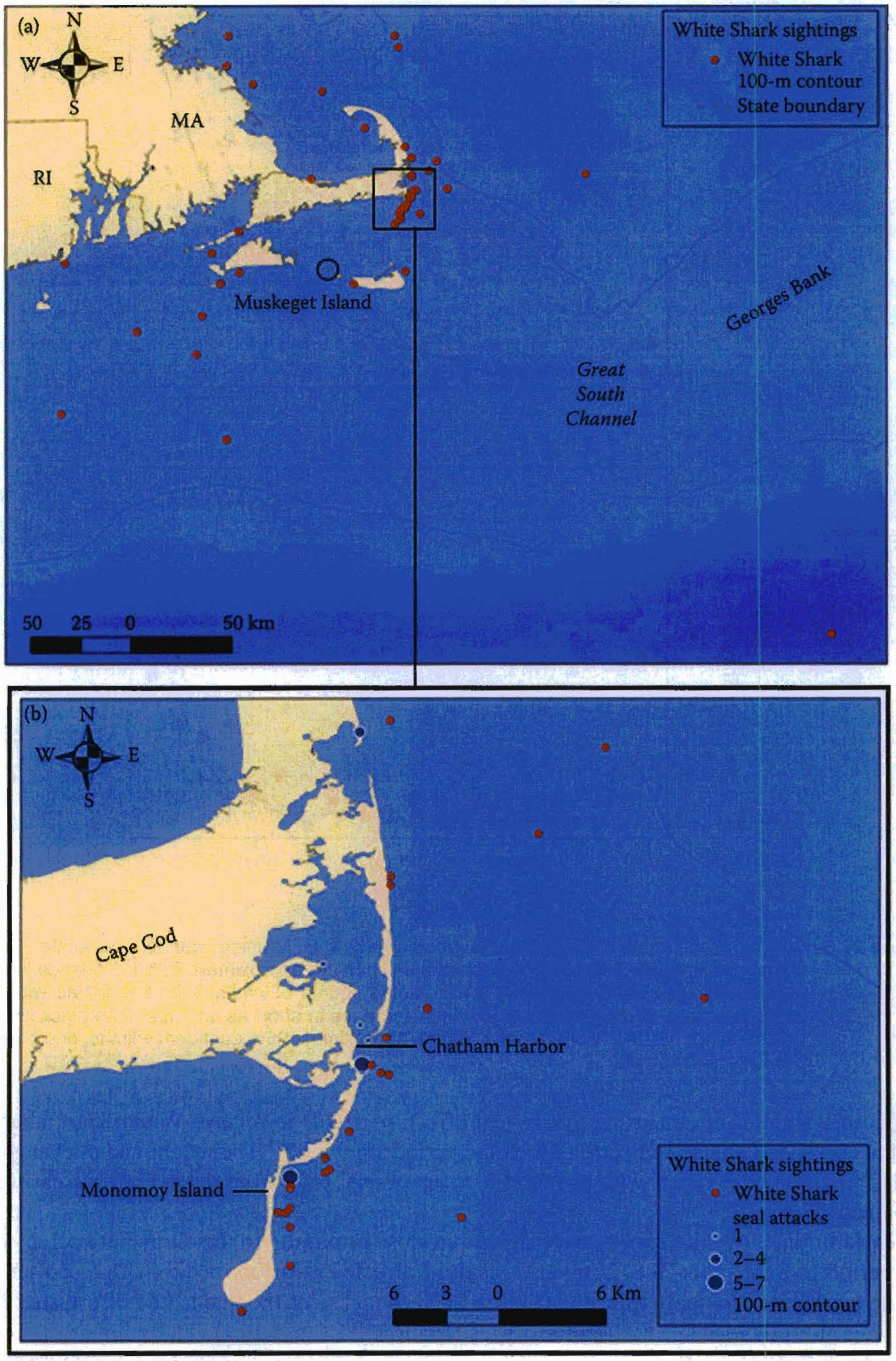

Figure 27.2 (a) Locations of White Shark sightings off the coast of Massachusetts, 1990–2009 (n = 50). (b) Locations of White Shark sightings and attacks on seals adjacent to the large Gray Seal colony on Monomoy Island, Massachusetts.

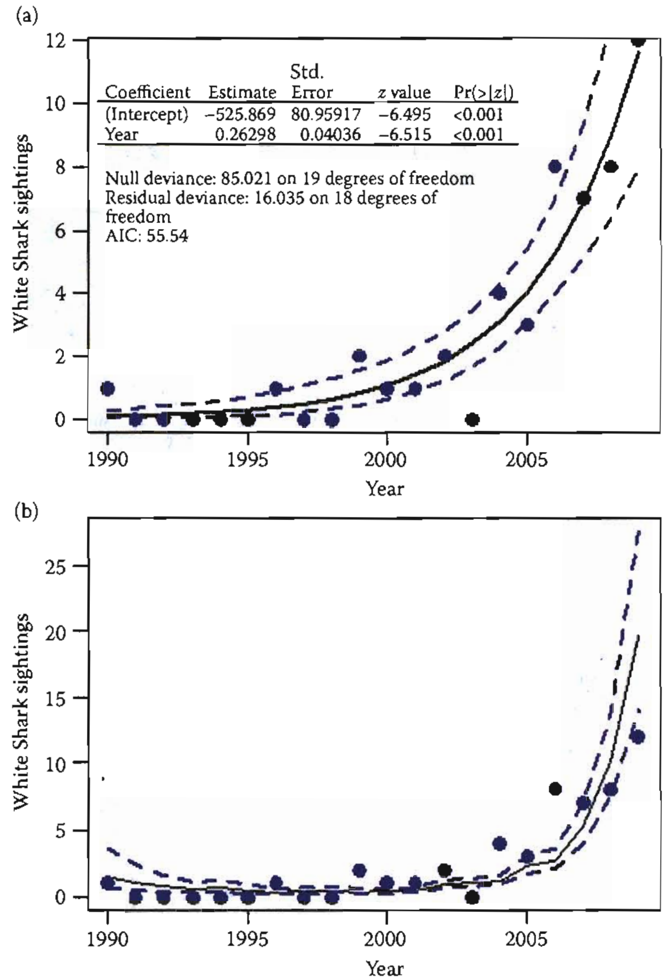

Figure 27.3 (a) Predicted counts of White Sharks modeled with a GLM using year as a covariate. The black line shows predicted counts, the dashed blue lines are approximate 95% confidence limits, and blue points are observed counts. (b) Predicted counts of White Sharks modeled with a GLM using year as a covariate with a 3% annual increase in effort as an offset. The black line shows predicted counts, the dashed blue lines are approximate 95% confidence limits, and blue points are observed counts.

produced a significant increasing trend (year effect, $p < 0.01$) in relative White Shark abundance off the coast of Massachusetts during the time period 1990–2009. The magnitude of change determined by the model varied with changes in observational effort, but the overall increasing trend remained (Figure 27.4).

In addition, 29 White Sharks were sighted in close proximity to this Gray Seal colony during the period of September 3–8, 2009 as a result of directed effort to locate (with a spotter plane) and to tag White Sharks in this area (Figure 27.5). Because of the intensified effort, these sighting were not included in the trend analyses (Figures 27.3 and 27.4). The number of sightings during this 5-d period does not necessarily reflect the actual number of individual White Sharks because many may have been counted more than once. Nonetheless, we believe that the group of White Sharks around Monomoy Island at that time represents a minimum of ten to twelve individual fish because of concurrent sightings by two spotter pilots and our tagging efforts during that period.

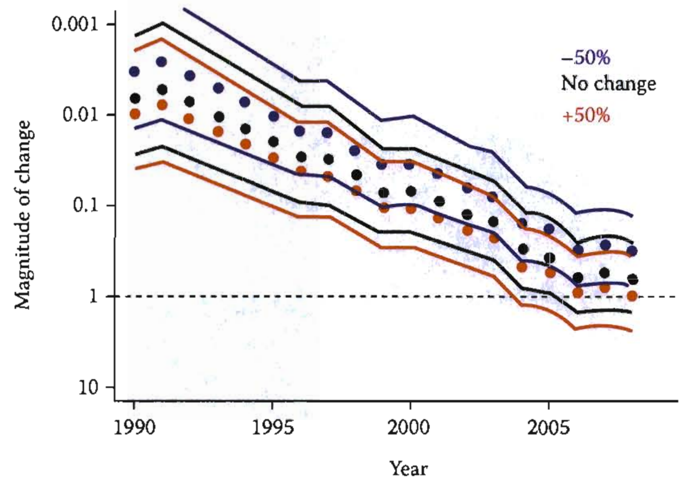

Figure 27.4 Ratio of predicted counts in reference year to predicted counts in 2009 using methodology of McPherson and Myers (2009). The black points and lines are with no changes in effort, blue points are sensitivity to 50% decline in effort from 1990 to 2009, red points are sensitivity to 50% increase in effort, and the dashed line = 1. Values less than or equal to 1 mean that the counts are increasing (<1) or stable (1).

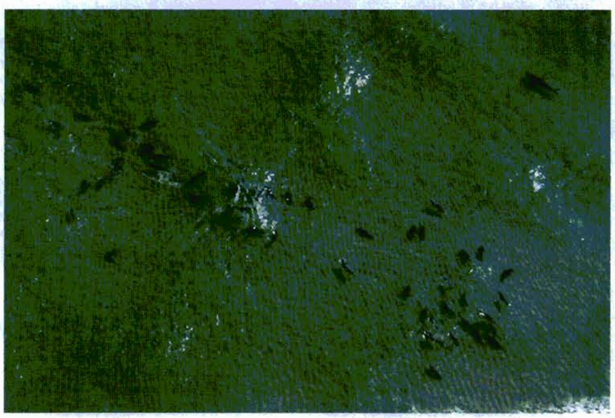

Figure 27.5 Aerial photograph of White Shark swimming in close proximity to Gray Seals off Monomoy Island, Massachusetts, September 2009. (Courtesy of Dan McKiernan, Massachusetts Division of Marine Fisheries.)

The number of shark-bitten seals has been increasing off the coast of Massachusetts and, in particular, off Monomoy Island over the last decade (Figures 27.1 and 27.6). Working closely with the CCSN, we have compiled information on twenty attacks on seals. All of these interactions involved Gray Seals (Figure 27.6); the White Shark was the shark species implicated in the attacks. In at least five cases, fishermen or beach goers witnessed the attacks in close proximity to the large Gray Seal colony on Monomoy Island (Figure 27.2). These eyewitness accounts further bolster our contention that White Sharks are feeding on seals in this area.

DISCUSSION

Based on sightings data, there is evidence that the local seasonal population of White Sharks off Massachusetts and, particularly, off the east coast of Cape Cod has increased in recent years.

Figure 27.6 Stranded Gray Seal (a) on Monomoy Island, Massachusetts, with large wound (b) attributed to an attack by a White Shark, July 2005.

Although it is plausible that this trend may reflect an increase in effort, we do not believe this to be the case for the following reasons. The majority of sightings (70%) come from commercial fisherman targeting groundfish and Bluefin Tuna. It has been illegal for fishermen to capture and kill White Sharks since 1997 (National Marine Fisheries Service, 1997). Hence, there has been no incentive for commercial fishermen to report White Shark interactions with fishing gear because it may result in a fine. Moreover, fishing effort and landings by these commercial fishing groups over the last decade have been in steep decline because of struggling fish stocks, restrictive fisheries regulations, and changes in fish distribution.

Off the northeastern United States, regulatory efforts to reduce groundfish [a complex of demersal species, including Atlantic Cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*), and Yellowtail Flounder (*Limanda ferruginea*)] landings have resulted in a dramatic reduction in the number of days that fisheries participants are allowed to fish annually [termed "days at sea" (DAS)]. From 2001 to 2009, the number of DAS allocated to this fishery was reduced 72%, and the actual number of DAS used (i.e., fishing effort) declined by 52% (Figure 27.7; New England Fishery Management Council, 2009). Similarly, the commercial Bluefin Tuna (*Thunnus thynnus*) fishery off the east coast of the United States has experienced a decline in fishing effort and landings over the last decade. In short, this fishery comprises three gear-specific National Marine Fisheries Service-permitted categories: general (primarily rod and reel), purse seine, and harpoon. As evidenced by

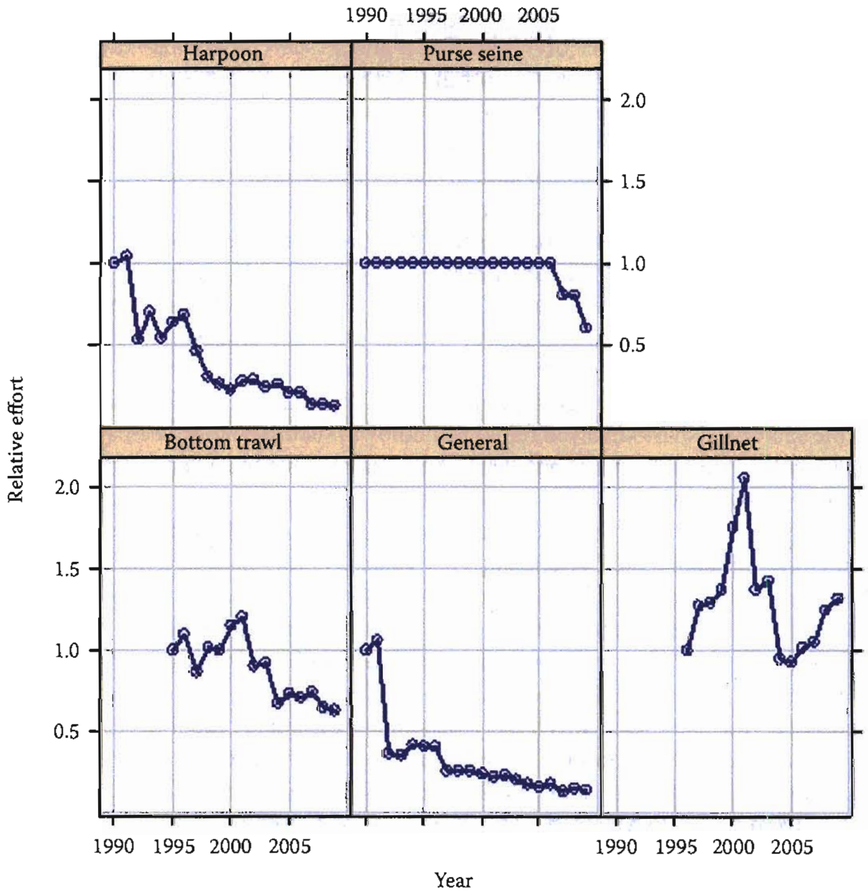

Figure 27.7 Trends in commercial groundfish and Bluefin Tuna fishing effort off the northeastern United States standardized as fraction of effort in first year; bottom trawl and gillnet in DAS; and general category tuna, tuna purse seine, and harpoon in number of permits.

the number of permits issued, fishing effort declined 45, 40, and 54% in the general, purse seine, and harpoon categories, respectively, from 1990 to 2009 (Figure 27.7; National Marine Fisheries Service, 2009b). This was also reflected in the Bluefin Tuna landings, which declined 49, 95, and 64%, respectively (National Marine Fisheries Service, 2009b). Although purse seine and harpoon fishermen do not catch White Sharks, they are the primary employers of spotter planes and, as such, are indicative of spotter-plane effort.

In summary, the amount of fishing effort by those fisheries that typically report White Sharks declined by roughly 50% during the period when White Shark sightings were dramatically increasing. Using GLM, we found a significant increasing trend in local White Shark abundance off the coast of Massachusetts (Figure 27.3). When we tested the sensitivity of this trend to changes in observational effort, the trend remained positive regardless of simulated increases in fishing effort (Figures 27.3 and 27.4). Given the strong evidence that fishing and, hence, observational effort declined by as much as 50% over this time period, the positive trend in White Shark sightings may be stronger than evidenced in our dataset. In contrast, when McPherson and Myers (2009) used this approach to model changes in White Shark abundance based on sightings data from eastern Adriatic and eastern Canada waters, they found a significant decreasing trend. We do not believe that the trend in our sightings data necessarily reflects actual population growth but rather a change in local abundance because of other factors, namely the growing Gray Seal population.

The increasing number of White Shark sightings in southern New England coupled with the concurrent increase in the number of White Shark attacks on Gray Seals may be indicative of a change in White Shark predatory behavior off the northeastern United States. White Sharks, which were thought to primarily scavenge cetaceans in this part of the Atlantic (Carey et al., 1982; Pratt et al., 1982), may be expanding their diet in response to regional changes in seal abundance. Shifts in predatory behavior have been documented in some species of sharks and are generally associated with ontogeny, changes in prey abundance, changes in predator density, and/or ease of prey capture (Heithaus, 2004; Wetherbee and Cortés, 2004). White Sharks are known to exhibit an ontogenetic dietary shift (Tricas and McCosker, 1984; Estrada et al., 2006) and have been documented to respond to changes in pinniped abundance (Pyle et al., 1996). White Shark predation on pinnipeds is well documented in the Pacific and Indian Oceans (Klimley and Ainley, 1996; Chapter 9, this book), but the only published evidence of shark predation on seals in the Atlantic occurs on Sable Island, 170 km southeast of Nova Scotia, Canada (Brodie and Beck, 1983; Lucas and Stobo, 2000). Although the species of shark involved remains unknown, such predation seems to be in response to a growing Gray Seal population and appears to be impacting the much smaller Harbor Seal (*Phoca vitulina*) population (Lucas and Stobo, 2000; Bowen et al., 2003).

Given our observations, we believe that this predatory behavior is tightly linked to the dramatic increase in Gray Seal abundance. Archeological evidence dating back several thousand years from Native American shell middens indicates that Gray Seal colonies were historically distributed along the northeast coast of the United States from Maine to Connecticut (Wood LaFond, 2009). By the end of the seventeenth century, however, subsistence and bounty hunting had extirpated these colonies (Wood LaFond, 2009). In subsequent years, Gray Seals were infrequently reported in the United States, and the population was largely sustained by a single breeding colony on Sable Island off Nova Scotia. The prohibition of bounty hunting during the 1960s followed by the passage of the Marine Mammal Protection Act in 1972 have allowed the Gray Seal to recolonize parts of the United States from Maine to Massachusetts (Wood LaFond, 2009).

There are currently three major Gray Seal breeding colonies in the United States: Seal and Green Islands off the coast of Maine and Muskegut Island, which lies just west of Nantucket Island, Massachusetts (Figure 27.2). The latter is the largest breeding colony, annually producing approximately 80% of the Gray Seal pups in the United States (Wood LaFond, 2009). Based on annual aerial-survey counts, pup production has steadily increased on Muskegut Island from six in 1991 to 2095 in 2008 (Figure 27.8). Much (~20% in 2008) of this pup production comes from female immigrants from Sable Island (Wood LaFond, 2009).

In addition to the large breeding colony on Muskegut Island, Gray Seals frequent other large haulouts along the coast of Massachusetts. The largest and most frequently used area is on

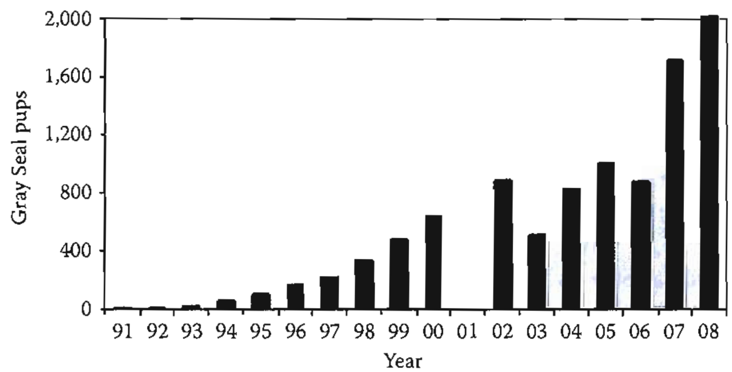

Figure 27.8 Annual Gray Seal pup counts on Muskegut Island, Massachusetts, the largest Gray Seal breeding colony in the United States, 1991–2008 [data are from Wood LaFond (2009)].

Figure 27.9 Thousands of Gray Seals fringe the intertidal zone of Monomoy Island, Massachusetts, 2010. (Courtesy of Charlotte Richardson.)

Monomoy Island, a large National Wildlife Refuge stretching 13 km south into the Atlantic from Chatham, Massachusetts (Figure 27.9). The refuge largely comprises the two barrier islands of North and South Monomoy. Gray Seals are most frequently seen on the east coast of the barrier islands and on adjacent shoals from Chatham Harbor to the southern tip. Although counts from formal seal surveys are currently lacking, the number of Gray Seals using these areas is typically in the thousands (Figure 27.9). Gray Seals have also periodically pupped on Monomoy Island (Wood LaFond, 2009).

With this expansion of the western Atlantic Gray Seal population, there has been an increase in White Shark sightings as well as seal interactions over the last decade. Although White Sharks will probably continue to scavenge whale carcasses, active predation on Gray Seals is likely a return to a preexisting trophic scenario, which changed with the demise of the Gray Seal population several hundred years ago. A similar scenario between White Sharks and their pinniped prey has been well-documented at the Farallon Islands on the west coast of the United States. Pyle et al. (1996) described two general phases that occurred in this area. As the Northern Elephant Seal (*Mirounga angustirostris*) population rebounded during the 1970s and early 1980s, increases in individual predation rates by a relatively static number of White Sharks caused the attack frequency to increase. It was hypothesized that there were probably six or less White Sharks in the area at that time, because the number of attacks declined markedly when four of these sharks were removed in 1982. As the seal population stabilized in the late 1980s, individual predation rates stabilized as well, but the number of White Sharks attacking and consuming this resource climbed (Pyle et al., 1996).

Although accurate Gray Seal population estimates are lacking, the western North Atlantic population is thought be in excess of 200,000 animals and increasing in the United States

(National Marine Fisheries Service, 2009a; Figure 27.9). Given this upward trajectory and the relatively low number of attacks on seals, the number of individual White Sharks utilizing this resource is likely low as well. If the western scenario is applicable to the east, we are in the early stages of this relationship but can anticipate additional White Sharks utilizing this food resource. However, the size and status of the White Shark population in the western North Atlantic remains unknown. Although the species has been prohibited from retention in this region for more than a decade, high levels of incidental mortality will result in population declines, which will also influence these trophic dynamics.

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