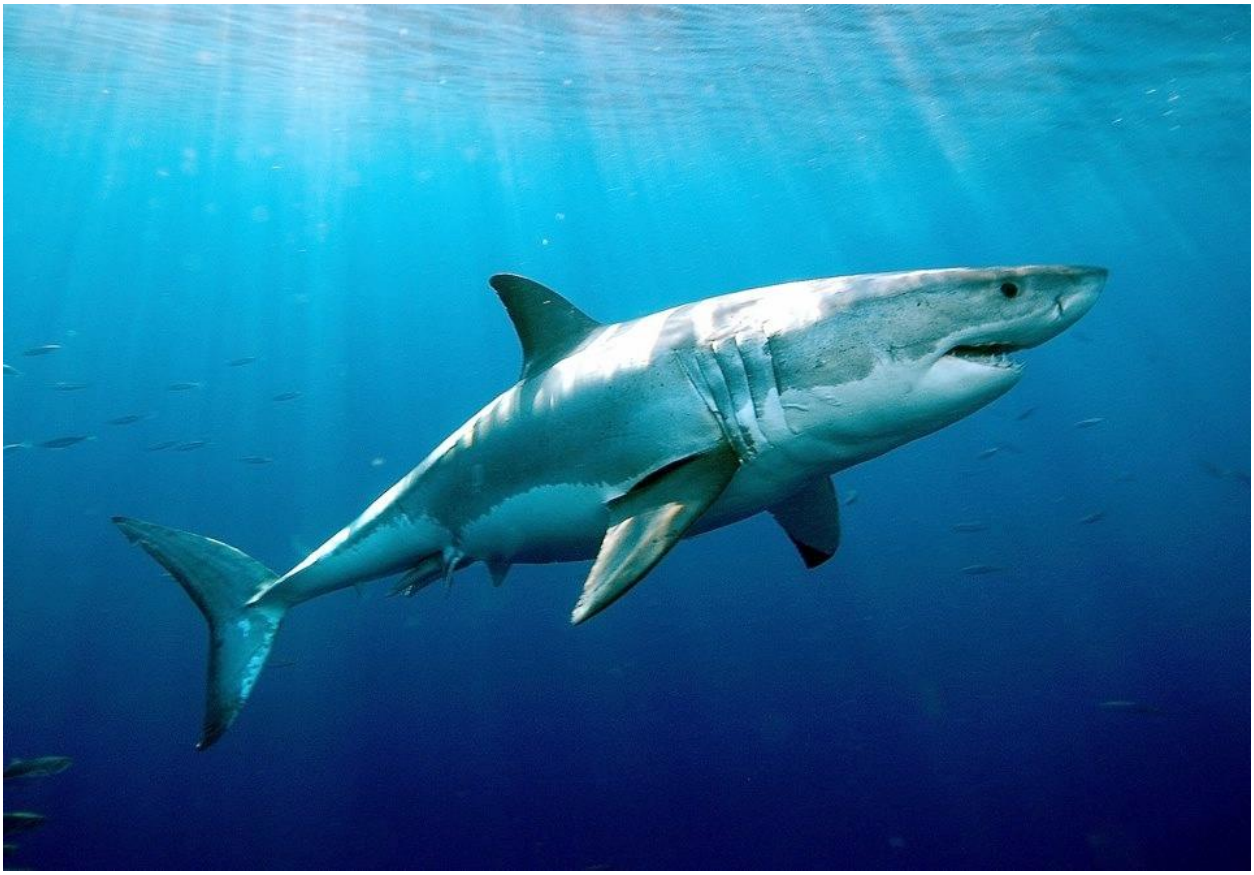
Management Plan of White Shark (*Carcharodon carcharias*) Populations in Massachusetts (2019-2079)



(The Atlantic White Shark Conservancy)

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A paper submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Fisheries and Wildlife – Wildlife Concentration at Paul Smith's College of Arts and Sciences.

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Acknowledgments

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Executive Summary

The Atlantic white shark (*Carcharodon carcharias*), hereafter known as white shark, is an understudied predatory species. The white shark is a species that is actively hunted for its jaws and fins. Not much natural history or basic information is known about the white shark. The goal of this management plan is to further understand the natural history of the white shark within the next 60 years. Objectives of this goal will be to carry out various surveys, and studies on the Atlantic white shark to understand habitat preferences, population sizes, fecundity, and food preferences. Actions will be to do mark-recapture studies, as well as aerial photo surveys. Another goal is to determine if the increasing gray seal population on the coast of Massachusetts is the main reason the populations of white sharks have increased in Massachusetts over the last 10 years. This will be done by taking the aerial surveys of populations of gray seals over a five-year study to determine if the population is increasing, decreasing, or stable. Then surveying the number of seals that are depredated on. It will also be determined by stomach contents if white sharks depredate any other species to determine if gray seals are the main food source for a white shark. Once the main food source is determined, researchers will be able to further manage the white shark. Outcomes of the management will be to understand the natural history of the Atlantic white shark and can more effectively manage for the population of white sharks in Massachusetts.

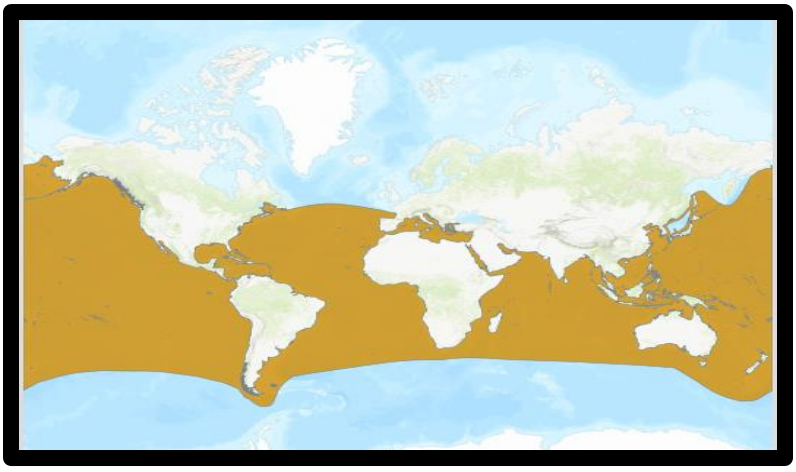
Natural History

Species Description

According to the Atlantic White Shark Conservancy, white sharks are the largest predatory fish across the globe. The white shark is also one of the most recognizable sharks that we have in our oceans. This shark can reach over 20 feet long and can get up to 4,000 pounds. This shark is slate gray on its dorsal side and has a white belly. This has been known to be an advantage for the shark's camouflage. White sharks have serrated teeth and have a powerful jaw. They mature over ten years of age and are slow growing. These sharks, as described further in this plan, have few pups and the gestation period is long. Any population decrease will impact the species for these reasons, and they are susceptible to bycatch and trophy fishing. Bycatch is anything that is caught fishing that is not the intended species.

Distribution

While white sharks are found all throughout the globe (Fergusson, 2005), this management plan will specifically focus on the Atlantic white shark. All models will be based on data taken from literature found throughout the management plan. Please see Appendix A.



Food Needs

The understanding of the white sharks' diet in the Atlantic has been limited to examining the stomach contents and visual depredation events. The white shark is a generalist, eating fish and cetaceans (Curtis, 2014, Skomal, 2017). However, the increased abundance of pinnipeds has started to attract white sharks and has become a staple summer food source in Massachusetts for the white shark (Curtis, 2014, Skomal, 2017). The gray seal population has rebounded in Massachusetts since the passage of the US Marine Mammal Protection Act in 1972 (Skomal, 2017). It is speculated that white sharks will migrate long distances to feed on whale carcasses due to the high caloric value these carcasses hold (Curtis, 2014).

Cover Needs

Atlantic shark movements have two dramatic paths. The first path a white shark can take is coastal and along the east coast. Juveniles have been found to migrate along coastal shelves, along with sub-adult and adult sharks. The sharks spend the summer in the northeast and then migrate down to the southeast in the winter. They migrate to follow prey, but also to stay in the right temperature range, which generally was between 13-25 degrees Celsius. The second path a white shark might take is oceanic. These sharks appeared to have no true pattern for migration. The sub-adult and adult individuals are suggested to be foraging when they migrate through the open ocean, one more suggestion is that these individuals may also use the open waters to migrate (Skomal, 2017). However, studies are not conclusive that mating in open waters has any grounds. White sharks prefer depths of less than 50 meters and spend half of their time in waters of a depth less than 20 meters (Skomal, 2017).

Behavior

White shark behavior mostly comes from tagged white sharks. When a white shark is tagged, it goes onto the dorsal fin of that shark and has a set time for when the tag will come off of the shark and will send a signal to be retrieved. When the data is looked at the tag can record, depth, time, light intensity, and temperature. In a study that tracked a female white shark for 28 days, the young female was tracked and determined to be mostly diurnal. Spending most time within the top 50 meters of water, with many deep dives throughout the day. This pattern continued for the full 28 days that the shark was tracked (Dewer, 2004). Similar behavior has been seen across the globe, and similar behavior has been noted (Skomal, 2017, Curtis, 2014).

Reproduction

Very little is known about the reproductive habits of white sharks. Further studies need to be done to better understand how white sharks reproduce. The knowledge that we have of pregnant white sharks is limited to bycatch sharks. Bycatch sharks are sharks that have been fished and killed or netted and killed. However, in a study conducted in 2017, female sharks have not been observed giving birth in this area (Skomal 2017). It is currently thought that white shark mating systems may be opportunistic and not restricted to areas in the northeast like previously thought (Skomal 2017). White sharks are believed to give birth to pups between May and August (Curtis 2014). Though scientists do not know how large litter sizes are, and it has not been looked at in this region (Skomal 2017).

Population Demographics

This population model shows two different actions. The first action would be if no action was taken. If no action was taken white shark would be extirpated from the Massachusetts coastline. The second model is if we increase four of the five life stages. The life stages are

young of the year, juvenile, subadult, adult 1, and adult 2. The second action would stabilize the population but requires the young of the year, juvenile, subadult, and adult 1 by 20%. This increase assumes that mortality is mostly coming from bycatch and trophy fishing. With further regulations in place, this model assumes a stable population. In the making of the population models for the white shark population in Massachusetts, there were many assumptions made. Some of the assumptions were the population size of the white shark in the Massachusetts coastline. These assumptions came from a study that was done in the area, but it does not assume that this is the full population size (Skomal 2017). Another assumption that was made was that population sizes have remained the same since that study took place. The population model also assumes that conservationists will be able to raise each of the life stages, except for adult 2, by 20%.

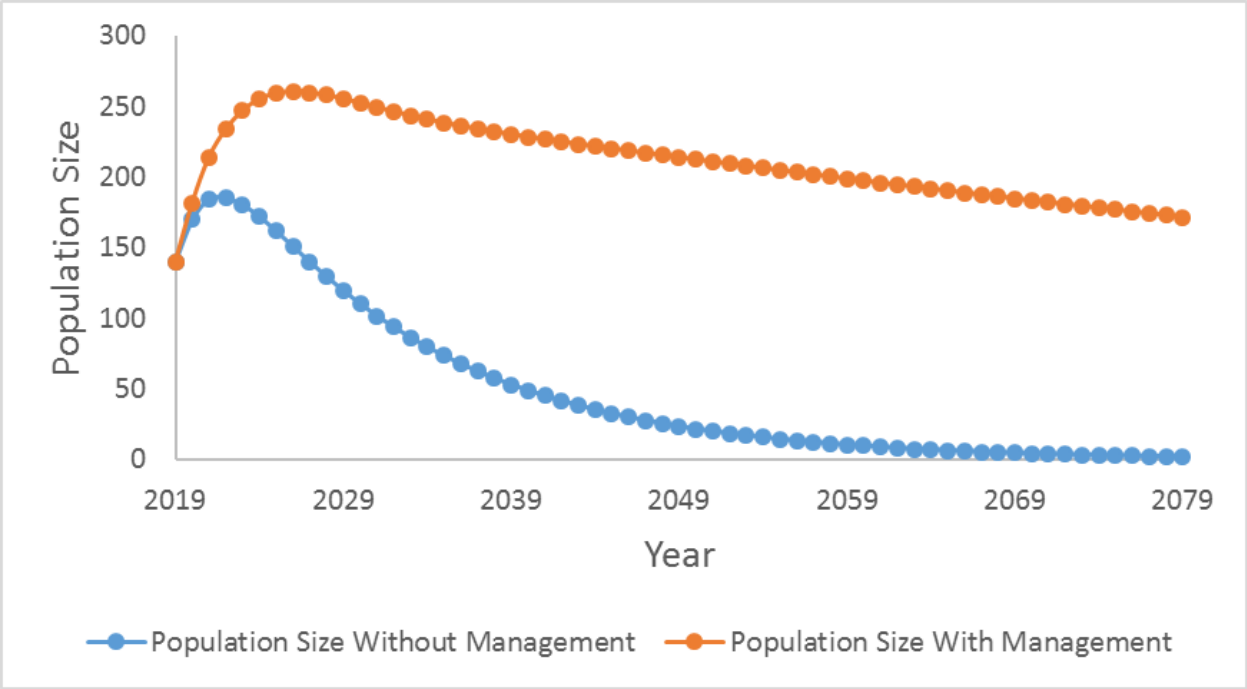


Figure 1: Population model showing the current population size in blue, and population size if management actions are taken in orange. If no action is taken (blue) white sharks will be extirpated from Massachusetts. If action is taken the population will begin to stabilize by 2079. See appendix B and C.

Disease

In most vertebrates, there are some forms of disease. While this is also true for white sharks, it is not studied well, and not published in the scientific literature. As for diseases that are passed onto humans through sharks there are a few. Vibrio alginolyticus, Vibrio fluvialis, Vibrio parahaemolyticus (Buck et al 1984). These are common bacterial infections that can be passed onto humans if a shark mistakenly bites a human as a prey species. Vibrio spp. is the most common bacterial infection spread to humans from shark teeth. Vibrio spp. is also known as vibriosis, and is commonly contracted by humans. While this bacterium is common in most

marine environments and humans can contract this disease easily from other methods in the environment it is also the only disease that can relate to white sharks (Buck et al 1984).

Currently, there are no scientific papers on diseases that white sharks contract, and is still mostly a mystery. There have been speculations that white sharks get cancer, but is very rare due to their evolutionary history. In future studies, white sharks should be analyzed for more diseases. White shark tissue and DNA structure have also been speculated to be used for future human medications and treatments.

Management Environment

Historical Issues

The white shark is a shark that has a wide distribution through the globe, and are the largest predatory sharks (Nasby-Lucas 2009). Currently, the International Union for Conservation of Nature red list has the white sharks listed as vulnerable (Fergusson, 2005). Mitochondrial DNA analyses show that there are two main lineages of the white shark; the Indo-Pacific and Mediterranean and other lineage is the South African and WNA (Western North Atlantic) which is the species that will be focused on in this management plan (Skomal 2017). One study suggests that populations had up to an 89% decrease in populations from 1986-2000, and an even more sharp decline that started in 1926 (Curtis 2014). Another study suggests that there was a 63-73% decrease in population in the 1970s (Curtis 2014). However, most of this data is from fishermen and sightings. Western North Atlantic sharks range has been observed from Newfoundland Canada to the Gulf of Mexico (Curtis 2014). The areas between New Jersey and Massachusetts are believed to be important feeding grounds for the white shark (Curtis 2014). White sharks primarily feed on pinnipeds, small cetaceans, and whale carcasses

(Curtis 2014). The pinniped population has been heavily declined over the last century, but more recently the pinniped population has been thriving due to regulatory efforts (Curtis 2014). This has made Cape Cod an important summer feeding ground for white sharks (Curtis 2014). Juvenile and adult white sharks will migrate south for the winter and return for the spring and summer months (Curtis 2014). While it is not known why the white sharks migrate south for the winter, it is speculated that is in the search for food (Curtis 2014). Mainly whale carcasses, and young whale calves that are born in the winter months in the south (Curtis 2014) (Skomal 2017). White sharks can also be found predating *Thunnus albacares*, *Prionotus carolinus*, *Brevoortia tyrannus*, *Urophycis regia*, *Dipturus laevis*, and *Pomatomus saltatrix* in times where they are migrating over their broad geographic area (Curtis 2014). Through conservation efforts and protections on white sharks, and their prey species of choice, pinnipeds, the population of white sharks has increased, and still growing (Curtis 2014). The US Marine Mammal Protection Act allowed the Atlantic gray seal (*Halichoerus grypus)* populations to rebound, allowing white sharks a stable food source. Scientists are still questioning many things about the white shark, such as what is their population sizes, what type of habitats do the white sharks thrive in, and many more questions of the shark's natural history (Curtis 2014).

Ecological Issues

White sharks (*Carcharodon carcharias*) have a broad range (Nasby-Lucas, 2009). This management plan specifically focuses on the white sharks that migrate to the coast of Massachusetts. Very little is known about the white shark across the globe, but there is even less known about the Atlantic white sharks. The traditional form of data gathered for the white sharks has been through incidental catches by fishermen, as well as shark attacks (Cailliet 1985,

Curtis 2014). This species may be prone to overexploitation, and with their natural history, they can be prone to population declines (Cailliet 1985). Populations of white sharks continue to be a concern with the low productivity of the sharks and the sensitivity that the sharks have to overexploitation for their jaws and trophy fishing (Curtis 2014). Looking at the vertebral bands of these sharks shows that they are slow growing, have a long life span, and take time to reach sexual maturity (Cailliet 1985, Skomal 2017). In a recent study, it is believed that the life span of a white shark is 70 years, and will not mature until 26 years old for males, and 36 years old for females (Skomal 2017). Still, almost nothing is known about how these sharks mate or where breeding grounds are (Skomal 2017, Curtis 2014). It is also a general idea that white sharks have low fecundity and long gestation periods (Cailliet 1985, Skomal 2017). It is believed that white sharks may give birth off the coast of New York, which would lead to young of the year sharks needing good foraging habitat (Curtis 2014). However, in a study conducted in 2017, female sharks have not been observed giving birth in this area (Skomal 2017). The habitat of the western North Atlantic white sharks shows patterns of coastal movements. The white sharks tend to be seen in waters that are less than 100 meters deep, and tend to migrate along the coastal shelf (Curtis 2014). A more recent study shows that tagged sharks spent most of their time less than 50 meters deep with half of that time being in water less than 20 meters deep (Skomal 2017). In a study done in 2017, white sharks were observed, through tags, to dive up to 1128 meters through temperatures 1.6-30.4 degrees Celsius, this behavior has been associated with finding or following food (Skomal 2017). Another hypothesis is that the sharks dive at these depths to mate, but there is little evidence for this (Skomal 2017). Other studies globally show that white sharks use habitats with large expanses of shelf occur (Curtis 2014). Because scientists know so little about the white shark it is hard to figure out why the sharks move the

way that they do. 62% of tagged sharks from a recent study that was conducted over three years showed to migrate and stay along the shelf of the east coast. While the remaining sharks in the study moved to deeper waters and had no definitive migration pattern. This behavior was only observed in subadult and adult sharks (Skomal 2017). White sharks were found more often in water that was between 14-23 degrees Celsius (Curtis 2014). In other surveys, the catch rate for white sharks was between 15-24 degrees Celsius (Curtis 2014). A more recent study shows temperatures of 13-25 degrees Celsius are preferable (Skomal 2017). See figures 1 and 2.

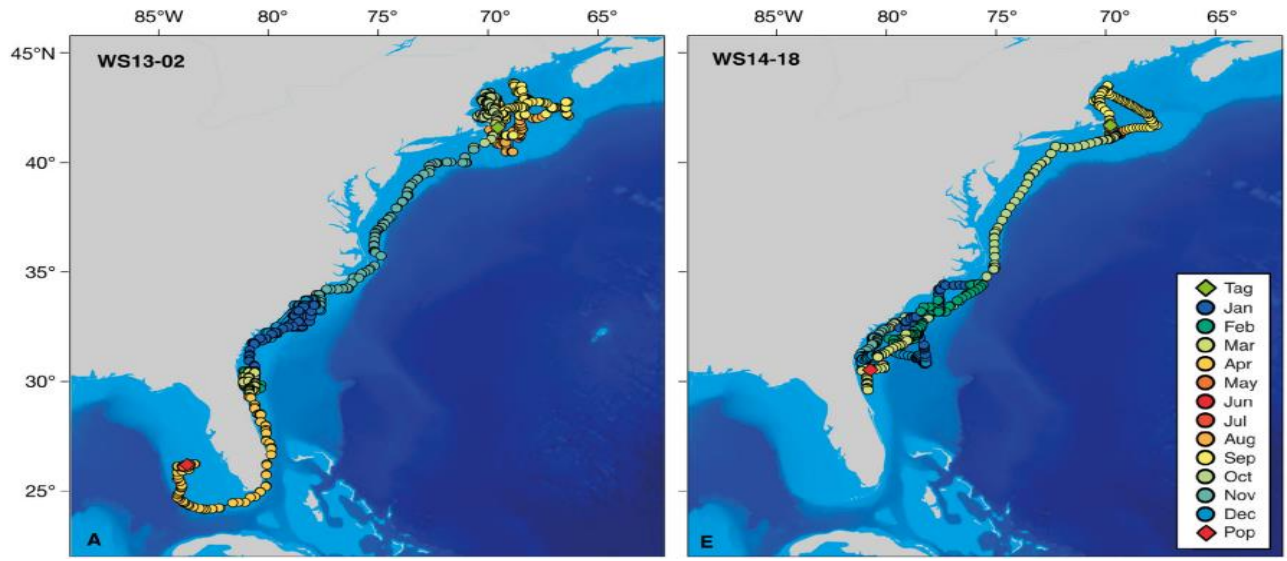


Figure 2. Migration patterns of white sharks that migrate along the eastern Atlantic coast. Subadult and adult white sharks are more likely to stay along the shelf. Patterns of white sharks along the coast are said to be for food (Skomal 2017). See appendix D.

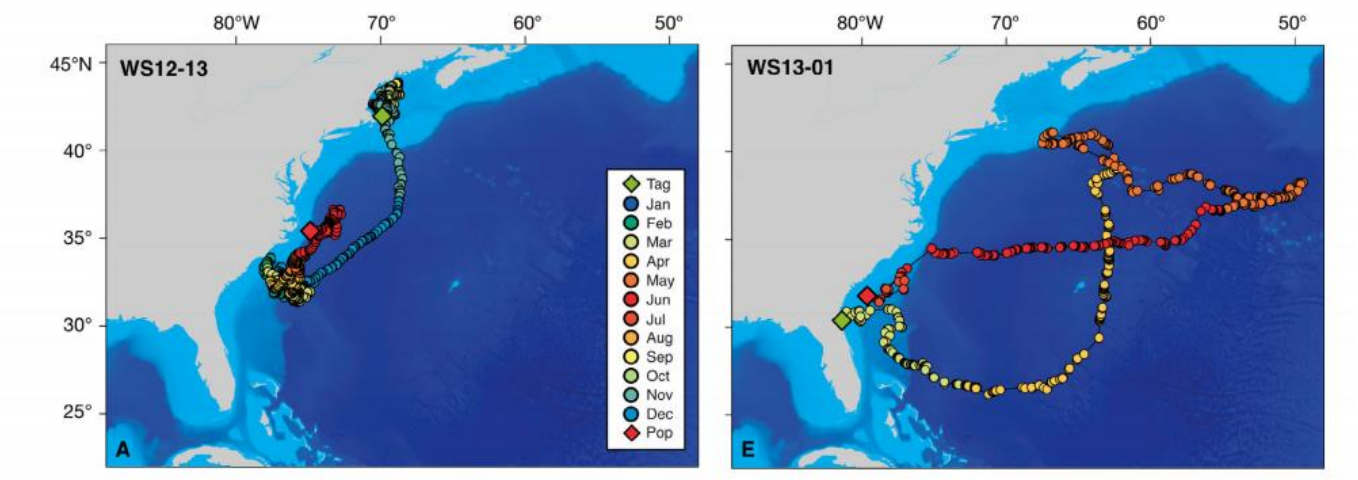


Figure 3. Migration patterns of white sharks that migrate along the eastern Atlantic coast. Young of the year and juvenile white sharks are more likely to migrate into deep water and stay off the coastline. Little is known why white sharks migrate offshore (Skomal 2017). See appendix E.

Economic Issues

The long term fishing may continue to harm the population size due to the white shark's low productivity (Curtis 2014). The market for shark jaws around the world can cost several thousand dollars for one jaw (Cailliet 1985). White sharks are also popular in trophy fishing communities (Curtis 2014). Due to their popularity to being caught more studies need to be done to accurately protect the species.

A topic that has come up recently has been sponsored shark killing tournaments. Over 70 of these tournaments take place each year in the United States. These shark tournaments comprise of catching, killing, and weighing the biggest shark. The fisherman who kills the biggest shark will receive either a cash prize or sponsorship. The companies do have some rules, but few on what sharks count for the competition. Some sharks that get caught in these

competitions are threatened or endangered. Only one company has pulled out of these competitions since the article was published (Ripley 2019). This article could potentially impact in a positive way for sharks. As this article gains more speed we may see a shift in where this money becomes allocated. It will negatively influence the companies that support these tournaments.

Sociocultural Issues

Conservation efforts surrounding white sharks has been difficult. The white shark is prone to bad publicity with shark attacks. They are also prone to overfishing, jaws of great white sharks are worth thousands of dollars (Cailliet 1985). With the negative image of the white shark, it may be difficult to change public perception to allow this species to thrive in the future. If public perception of the white shark is changed, being able to steady the population will be possible.

Some issues that may arise with the food and cover needs of the white shark are sociocultural issues. The increased pinniped populations in Massachusetts may lead to issues for tourists on Massachusetts beaches. There have not been studies done on the influence of the increased population. The increased population of pinnipeds is the reason Massachusetts has a population of white sharks (Skomal, 2017). The impact and carrying capacity of pinnipeds will be looked at in future studies. Another socio-cultural impact may be the trophy hunting of white sharks in the area. Increased populations may lead to increased poaching of white sharks. White shark fin and jaws are valuable and can be sold throughout the world (Skomal, 2017).

A continued population of white sharks in Massachusetts relies on a continued healthy population of pinnipeds. A cover issue that may arise is water temperature. Further studies

would need to take climate change into consideration. White sharks prefer water that is 13-25 degrees Celsius (Skomal, 2017). Tracking how ocean temperature changes will be vital to understanding possible shifts in migrations of white sharks.

The shark killing tournaments that was talked about in the economic portion of the management plan discussed how it impacts the economy. However, this issue also can be sociocultural. Will the increased popularity for shark conservation, largely due to televised shark conservation efforts, news like this may influence what the public buys from these companies, and what the public thinks about sharks. This may be negative right now, the killing of various sharks for money. But as companies feel more pressure from the public the tournaments may stop. One company has pulled out of these tournaments since this knowledge has come out.

Something that was discussed about these tournaments was making catch and release, this way companies could still hold the tournaments and not influence their business at all, and have smaller mortality for these sharks. However, in talking to the fishermen that attend these tournaments, they are very attached to weighing the dead body of the shark on a dock and then take pictures next to the shark. If this change were to happen there would need to be more incentives, and education so the fishermen would also be on board with changing how the tournaments are run.

Legal and Regulatory Policy

Due to the white shark's sharp decline in the population they have been granted several types of protections globally. The white sharks are protected under The United Nations Convention on Law of the Sea (UNCLOS), the Convention for the Conservation of Migratory Species (CMS), the Convention on International Trade in Endangered Species of Wild Fauna and

Flora (CITES), and is listed as vulnerable on the IUCN red list (Fergusson, 2005, Curtis 2014). In 2011 a shark finning law was signed to ban all shark finning in the United States. Sharks that are fished and caught in the United States must be landed with all their fins intact (16 U.S.C. § 1857).

Conservation Needs

The Atlantic white shark needs adequate food, water depth and ability to migrate. It is stated in this management plan that white sharks may have returned to the Massachusetts area with the increase of gray seals in the area. The gray seal population is believed to be coming back due to the increase in marine mammal protections that have been put in place. This gives the white sharks an adequate source of food in a region they previously were not able to get a high caloric intake. Besides food, humans can have a negative influence on white sharks. If nothing is done in Massachusetts to conserve its new population of white sharks, they will be extirpated from the area. White sharks are a keystone species, and if conservation efforts for white sharks continue it will promote a healthy ocean for Massachusetts.

Goals, Objectives, Actions, and Assessment

Goal 1: To further understand the natural history of the white shark.

Timeline: 60 years (2019-2079)

Rationale: Three generations is approximately 60 years. Very little information exists for the natural history of the white shark.

Objective 1: Determine habitat preferences of the Atlantic white shark.

Action 1.1: Begin a study to determine the depth of water used by white sharks throughout their lifespan.

White sharks use a certain depth of water to hunt, breed and maintain most of their life functions. Conducting depth surveys to determine the most used depths of white sharks (Bruce et al. 2006).

Action 1.2: Begin a study to determine the temperature of water used by white sharks throughout their lifespan.

Temperature determines the movement of white sharks. By determining the temperature that the white shark utilizes most often we will better determine the movement patterns of the white shark (Robbins 2007)

Action 1.3*:* No action

If no action is taken, then the preferences of the white shark for depth and temperature of the water will remain unknown.

Final Course of Action*:* 1.1, 1.2

Assessment Protocol*:* A survey of shark densities in found preferred habitat will be taken to determine if the data is correct. More studies like Skomal 2017 need to be continued. Satellite tracking, and recording more depths and migration patterns will be further analyzed. Using Skomal's methods from Movements of the white shark Carcharodon carcharias in the North Atlantic Ocean, researchers will then satellite tag white sharks to determine depth preferences as well as the temperature and light intensity (Skomal, 2017). Skomal's study is also relevant to

this because his study took place in the same study area of the management plan. From this, further studies will be published.

Objective 2**:** Determine the survivorship of the Atlantic white shark over 60 years.

Action 2.1*:* Run mark-recapture studies of white sharks to determine vital rates.

Almost no information is known about the vital rates of the white shark. Determining these vital rates by mark and recapture techniques over a three-generation life cycle will give the best result of new information of vitality in white sharks (Mara et al. 2019).

Action 2.2*:* No action

No action will result in no knowledge of the Atlantic white shark vitality. This may result in miss-management of the white shark and population decline.

Final Course of Action*:* 2.1

Assessment Protocol*:* Determining the vitality of the white shark will allow researchers to better manage for the white shark in Massachusetts. When determining the survivorship of white sharks a long-term mark-recapture study must be done. The researchers will use dorsal tags and following the same materials and methods of (Anderson 2011). This study was done in California, it may need to be modified for the Atlantic white sharks. The abundance of white sharks in the Atlantic Ocean and the Pacific Ocean is variable. The Pacific Ocean tends to have a higher population (Anderson et al 2011). This study should be conducted over a long period of time, ideally, one lifespan, to determine an average age of a white shark. A lifespan of a white

shark could last up to 60 years. Over this period researchers should be able to publish papers on findings throughout the study, but continue long term monitoring of white sharks.

Objective 3**:** determine the food requirements and preferences of the Atlantic white shark over a five-year period.

Action 3.1*:* determine the daily energy expenditure of white sharks.

Design a study to indicate the caloric intake and output of a white shark to determine the necessary food requirements (Jorgensen et al. 2015).

Action 3.2*:* Evaluate previous research that gray seals are the primary food source for white sharks in Massachusetts.

Using aerial surveys to find white sharks feeding on gray seals (Hammerschlag et al. 2006). When possible looking at stomach contents of the white shark will also prove beneficial to understand the diet more thoroughly.

Action 3.3*:* No action

If no action is taken researchers will not fully understand which food source to manage for.

Final Course of Action*:* 3.1, 3.2

Assessment protocol*:* To further understand the diet of the white shark researchers will further understand how to manage the food resources to keep a stable population of white sharks in Massachusetts. Healthy management of gray seals will allow for a healthy population of white sharks. Further studies need to be done to determine if the gray seal population is the most

abundant food source in Massachusetts for the white shark. Once determined the gray seal carrying capacity will need to be determined, as well as sociocultural issues surrounding increasing the gray seal populations along the coastline (Hunter et al 2002). This study should be conducted within a five-year period. Then the next five years should be looked at to observe if white shark populations increase, decrease, or stabilize.

Objective 4***:*** Determine the reproduction behavior of the Atlantic white shark.

Action 4.1: create a study to determine the breeding behaviors of the white shark.

By determining; when, where and what time of year white sharks breed and give birth, researchers will better be able to manage habitat and determine pupping grounds for protection of the white shark. A surrogate species will be looked at to find similarities between the species and the Atlantic white shark (Feldheim et al. 2002).

Action 4.2*:* determine fecundity rates of the white shark.

Determine the fecundity of the white shark is very important for the management of the white shark. Keeping populations stabilized is dependent on how many white sharks are produced by females every two years. Almost no data is known about the fecundity of white sharks.

Action 4.3*:* no action

If no action is taken, pregnant white sharks and pupping grounds may be at risk. The population sizes will continue to suffer.

Final Course of Action*:* 4.1, 4.2.

Assessment Protocol*:* Fecundity rates need to be determined to manage for this species and to stabilize the population of white sharks. I am proposing a minimally invasive technique that has not been used for live white sharks. White sharks do not handle interactions and stress well which is a reason they have not been successful at keeping them in captivity. However, within a short 5 period time being able to bring a part of the deck of the boat into the water, and having the ability to get your hands on a white shark, then being able to use ultrasound on the shark could prove to be helpful in understand more about the gestation period of white sharks.

While the shark is in the care of the researchers they are responsible for care and stress. Within five minutes of having the shark the researchers should be taking vitals, and an ultrasound, if the shark is female. Ultrasounds have been used in captive animals, such as dolphins and the same methods should apply for the white sharks (Williamson et al 1990). This study conducted over a ten-year period should give researchers more insight on gestation period, and the average number of pups. As well as what a female exhibit when pregnant. Data should then be published on findings.

Objective 5**:** Determine diseases that affect Atlantic white sharks.

Action 5.1*:* further research of cancer in white sharks to determine prevalence and impact.

With mark and recapture, studies take note of any unusual parasite or deformity of the white shark to determine if the species is susceptible to disease. Further data is needed for this across the globe.

Action 5.2: research to determine if any other diseases affect the white shark.

Look at surrogate species to determine if other species of shark contract disease that may spread to white sharks.

Action 5.3*:* no action

If no action is taken, then no knowledge of possible diseases of the white shark will be known.

Final Course of Action: 5.1, 5.2

Assessment Protocol: Mark and recapture studies will be important to determine if the Massachusetts population of white shark's contract diseases. One study talks about cancer of the mouth with white sharks but it has not been widely studied (Buck et al 1984). Further, mark and recapture studies to determine the prevalence of this cancer is needed. Researchers could also use camera trapping which would be much less invasive and less stressful for the shark (Witte 1999). This study should be conducted over a five-year period to determine the prevalence, and to determine if it plays a role within the shark's health and wellbeing.

Goal 2: Increase survival rates of young of the year, juvenile, subadult, and adult 1 white sharks by 20% each, and adult 2 by .2%.

Timeline: 60 years (2019-2079)

Rationale: In each age class a 20% increase needs to occur. When white sharks are young they are susceptible to being caught as bycatch. When white sharks mature, they are susceptible to trophy fishing.

Objective 6*:* Decrease shark mortality over the next five years (2019-2024).

Action 6.1*:* implement measures to reduce bycatch.

Reduce the frequency of nets being used in areas where white sharks frequent. Once young white sharks are caught in nets they often die, even if the fisherman is able to release the shark (Cliff 1989).

Action 6.2*:* no action

If no action is taken sharks will continue to be caught and killed as bycatch in nets, further reducing the population size of the white sharks in Massachusetts.

Final course of Action*:* 6.1

Assessment protocol*:* To reduce mortality in white shark's researchers must get a better understanding of the starting population. Then researchers will take a five-year span with public outreach of fisherman; recreational and professional, about the dangers of extirpating this species from the area. During the five-year span researcher's will watch the population determine if mortality of white sharks have diminished.

Objective 7: Increase gray seal populations along the Massachusetts coastline over five years.

Rationale: Currently unknown, the presence of gray seal populations is the leading factor in the presence of white shark populations. This will be based on objective 3.1.

Action 7.1: Conduct field research to determine the current population size of gray seals.

Establish a group of field technicians that will conduct aerial surveys. With aerial surveys technicians, will be able to estimate the number of gray seals on land and on the

coastline. While taking aerial surveys, technicians will take pictures to better determine the size of the gray seal population (Brown et al. 2006).

Action 7.2*:* Determine the current carrying capacity of gray seals along the coast of Massachusetts.

Various geographic information systems (GIS) techniques will be used to determine habitat for gray seals, and map population sizes. Habitat suitability index will be used from the United States Geological Survey (USGS) as the basis for analysis for the current available habitat. Fisheries data will be used to determine the types of fish in the area, to determine the food source for the gray seal populations.

Action 7.3: Increase suitable habitat for gray seals.

Increasing habitat for gray seals will increase the population and expansion of gray seals along the Massachusetts coast. Increased gray seal populations will allow white shark populations to increase in Massachusetts.

Action 7.4: Increase available food sources for gray seals.

Increasing available food for gray seal populations will allow a larger population of gray seals in Massachusetts.

Action 7.5*:* No action.

If no action is taken, gray seal populations may decrease. If gray seal populations decrease, then white shark populations off the coast of Massachusetts will also decrease.

Final Course of Action: 7.1, 7.2, 7.3, 7.4

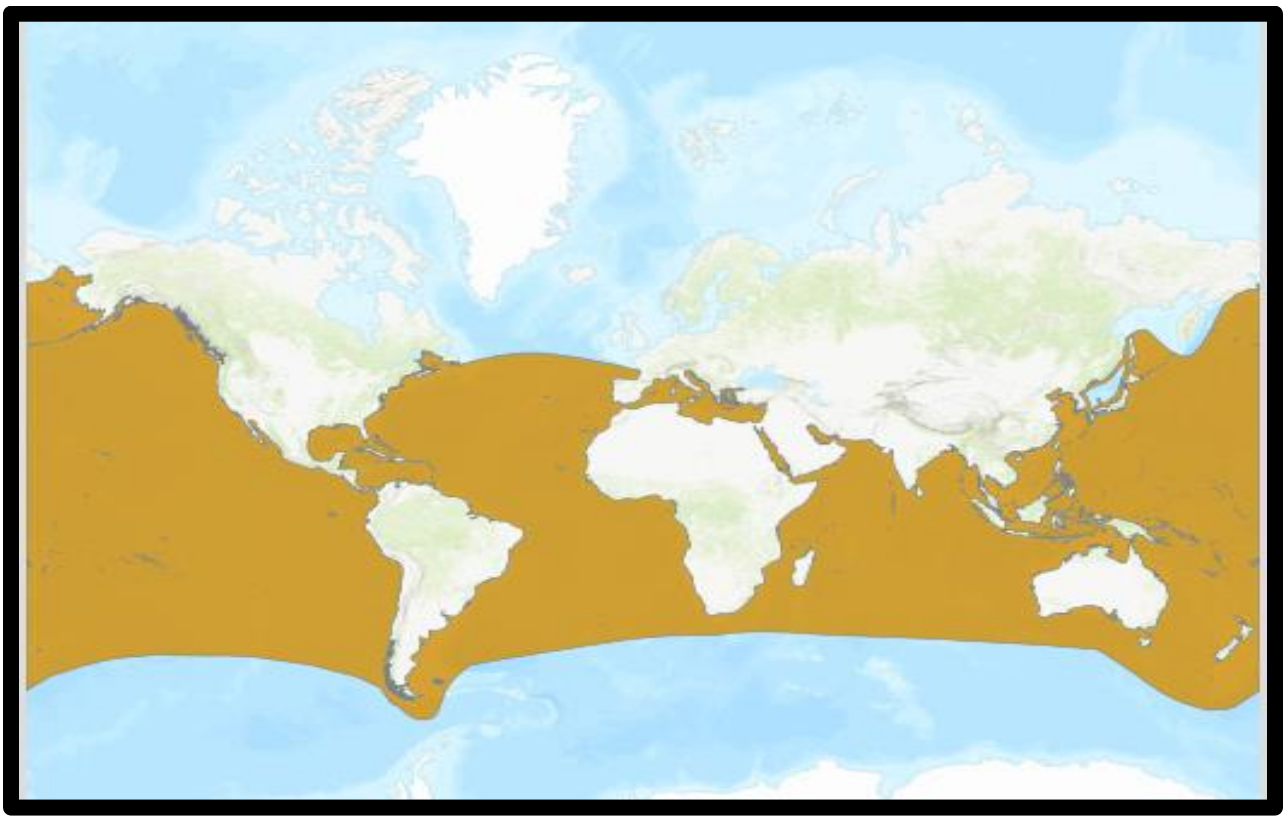
Assessment Protocol: A survey after the management of seals to see if population increases. This will once again be done by aerial surveys and taking pictures to get a more accurate representation of the population. The researchers should conduct an initial survey of the population, then continue monitoring the population over the next five years to increase or stabilize the population of gray seals to a healthy population (Hunter et al 2002). The populations of white sharks may depend on the population of gray seals reference objective 3.1.

Conclusion

More research needs to be done to understand the white shark further. With further knowledge of the white shark in the Atlantic Ocean, researchers and conservationists will be able to manage for this species. When top predators are taken out of the environment it creates a top-down effect that will negatively impact the environment. Further outreach to the public will create a better understanding of the species. Along with further knowledge, shark finning, trophy fishing, and bycatch will decrease. If conservation persists and researchers can raise shark survival by 20% in each age class and then by .2% in the adult 2 stages then the population will stabilize and white sharks will be able to thrive in Massachusetts once again.

Appendix A

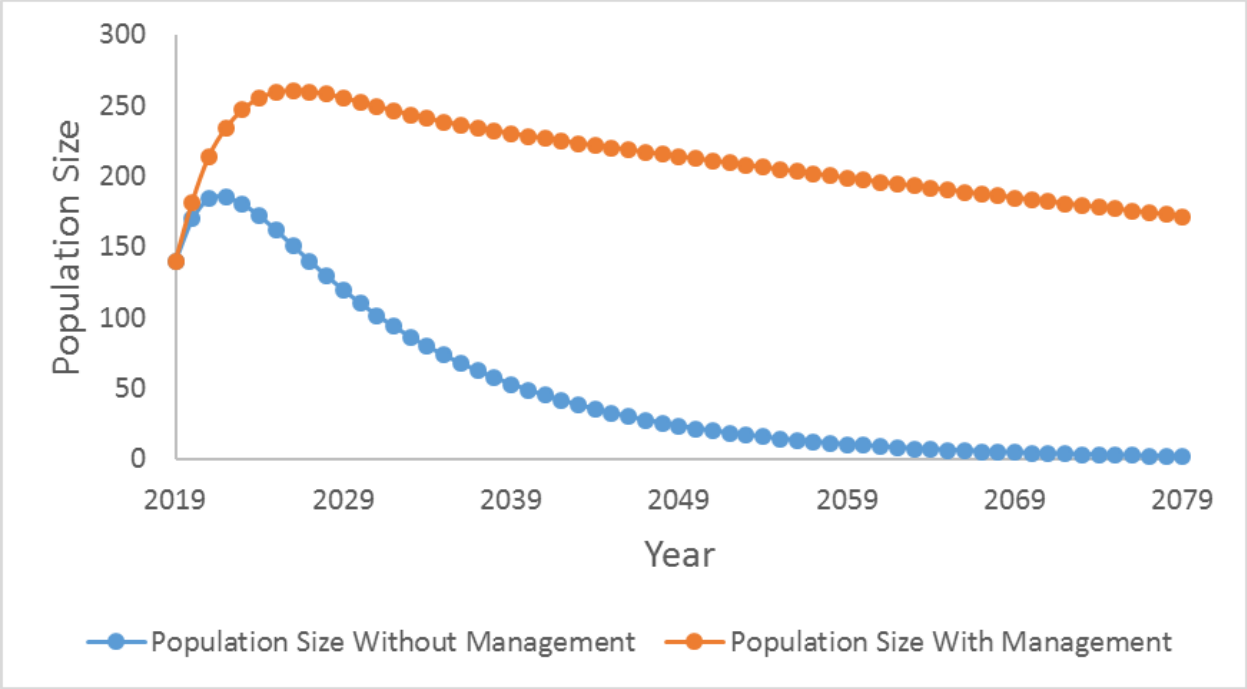
Distribution of white shark



The white shark is distributed across the globe, however, this management plan focuses on the Atlantic white shark in Massachusetts.

Appendix B

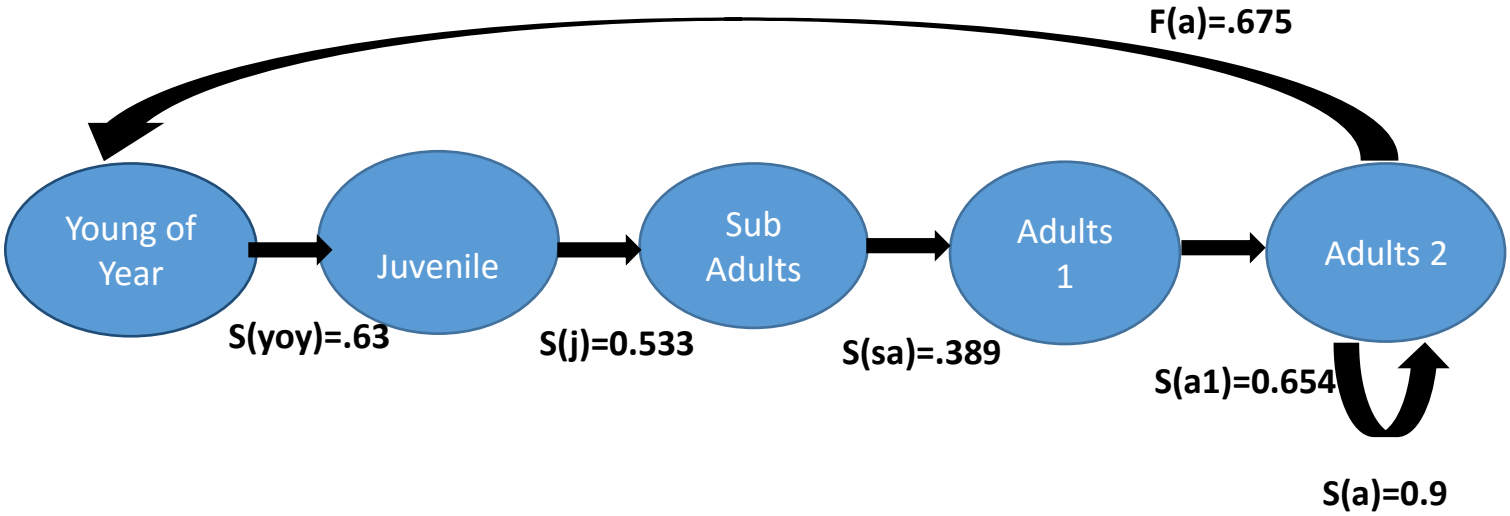
Management Model



Population model showing current population size in blue, and population size if management actions are taken in orange.

Appendix C

Life History Diagram



With Proper management, the white shark population in Massachusetts will stabilize after 60 years (2079). Increasing the young of the year, juvenile, subadult, and adult 1 age class by 20% each.

Appendix D

Coastal Movements of White Sharks

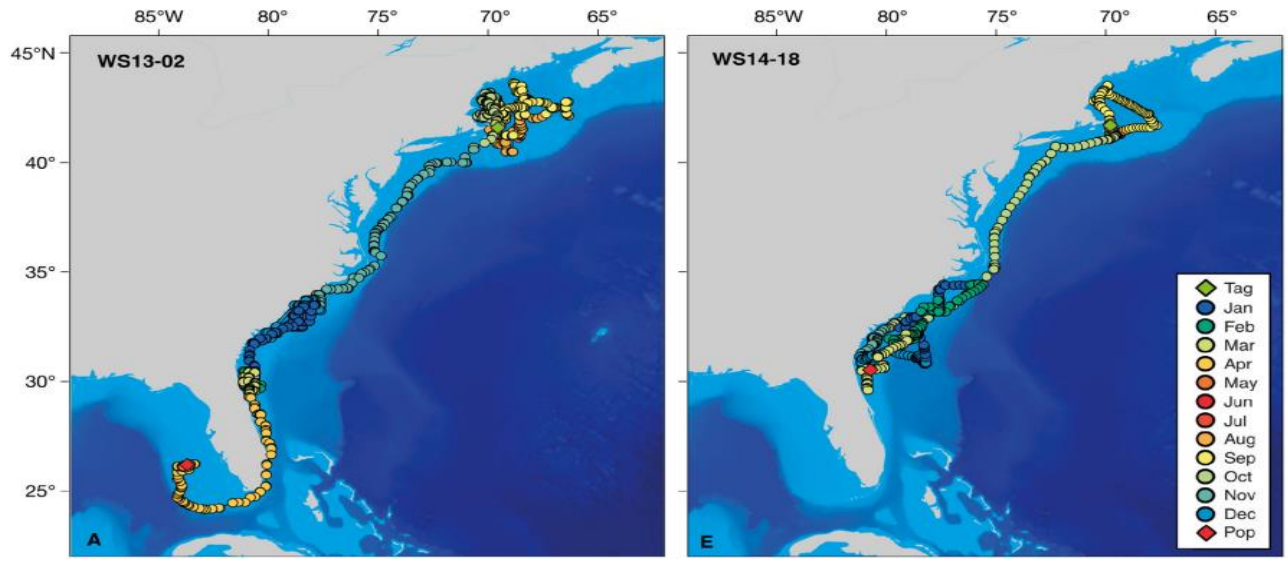


Figure 2. Migration patterns of white sharks that migrate along the eastern Atlantic coast. Subadult and adult white sharks are more likely to stay along the shelf. Patterns of white sharks along the coast are said to be for food (Skomal 2017).

Appendix E

Open Water Movements of White Sharks

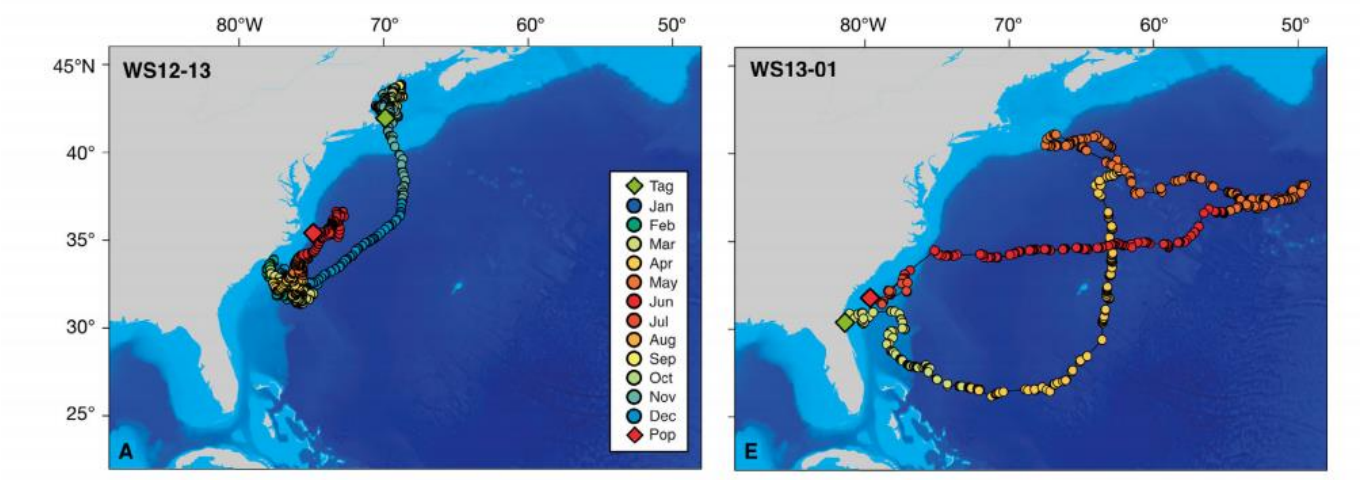


Figure 3. Migration patterns of white sharks that migrate along the eastern Atlantic coast. Young of the year and juvenile white sharks are more likely to migrate into deep water and stay off the coastline. Little is known why white sharks migrate offshore (Skomal 2017).

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