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TAG AND RECAPTURE DATA FOR THREE PELAGIC SHARK SPECIES: BLUE SHARK (*PRIONACE GLAUCA*), SHORTFIN MAKO (*ISURUS XYRINCHUS*), AND PORBEAGLE (*LAMNA NASUS*) IN THE NORTH ATLANTIC OCEAN

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SUMMARY

Tagging and recapture (T/R) information from the National Marine Fisheries Service (NMFS) Cooperative Shark Tagging Program (CSTP) covering the period from 1962 through 2000 are summarized for the blue shark (Prionace glauca), shortfin mako (Isurus oxyrinchus), and porbeagle (Lamna nasus). The extent of the tagging effort, areas of release and recapture, sources of tags and recaptures, capture methods, and movements of tagged sharks are reported by species. Summary information includes number of males and females tagged and recaptured, overall recapture rate, maximum observed speed, distance traveled, and time at liberty. In order to examine regional trends in size and maturation categories, the North Atlantic Ocean is divided into geographical areas. General migration patterns and stock identity by species are summarized and discussed.

RÉSUMÉ

L'information sur la pose et la récupération de marques (T/R) du Cooperative Shark Tagging Program (CSTP) du National Marine Fisheries Service (NMFS) couvrant les années 1962 à 2000 est récapitulée pour le requin peau bleue (Prionace glauca), le requin-taupe bleu (Isurus oxyrinchus) et le requin-taupe commun (Lamna nasus). Le volume de marquage, la zone de pose et de récupération des marques, la source des marques et des récupérations, la méthode de capture et le déplacement des requins marqués sont donnés par espèce. Le récapitulatif comprend le nombre de mâles et de femelles marqués et recapturés, le taux global de récupération, la vitesse maximale observée, la distance parcourue et le temps écoulé en mer. Pour étudier la tendance régionale des catégories de taille et de maturité, l'Atlantique nord est divisé en zones géographiques. Les modes généraux de migration et l'identité des stocks par espèce sont résumés et discutés.

RESUMEN

En este documento se resume la información sobre marcado y recaptura (M/R) del Programa Cooperativo de Marcado de Tiburones (Cooperative Shark Tagging Program, CSTP) del National Marine Fisheries Service (NMFS), que abarca un período que va de 1962 a 2000, para el tiburón azul (Prionacea glauca), marrajo dientuso (Isurus oxyrinchus) y marrajo sardinero (Lamna nasus). Se presenta por especies la información sobre el alcance del esfuerzo de marcado, zonas de liberación y recaptura, fuentes de marcado y recapturas, métodos de captura y desplazamientos de los tiburones marcados. La información resumida incluye el número de hembras y machos marcados y recapturados, la tasa global de recuperación, la velocidad máxima observada, la distancia recorrida y el tiempo en libertad. Con el fin de examinar las tendencias regionales de talla y categorías de maduración, se dividió el océano Atlántico norte en diferentes zonas geográficas. Se resumen y discuten los modelos generales de migración e identidad de stocks por especies.

KEYWORDS

Tagging, Migrations, Geographical distribution, Life history, Sex ratio, Stock identification, Shark fisheries, Abundance, Behaviour, Pelagic environment

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1. INTRODUCTION

The National Marine Fisheries Service (NMFS) Cooperative Shark Tagging Program (CSTP) is part of continuing research directed to the study of the biology of large Atlantic Sharks. The CSTP was initiated in 1962 with an initial group of less than 100 volunteer fishermen involved in tagging feasibility studies. The program expanded in subsequent years and currently includes over 6,500 volunteers distributed along the Atlantic and Gulf coasts of North America, and Europe. An overview of the CSTP is included in Casey (1985) and Kohler et al. (1998).

Tagging programs, such as the CSTP, provide data on stock structure, distribution of life history intervals, the exploitation of a resource by multinational fisheries, and direct evidence of fish movements across national and international boundaries. In addition, tagging studies can be designed with experimental components to estimate critical population parameters such as population size, recruitment, and mortality and survival rates.

The purpose of this document is to summarize the tagging and recapture (T/R) information from the CSTP covering the period from 1962 through 2000 for the blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), and porbeagle (*Lamna nasus*). The report shows the extent of the tagging effort, areas of release and recapture, sources of tags and recaptures, capture methods, and movements of tagged sharks for these three pelagic shark species. Summary information includes number of males and females tagged and recaptured, overall recapture rate, and maximum observed speed, distance traveled, and time at liberty. Much of this information has been published previously (Casey 1985, Casey and Kohler 1992, Kohler et al. 1998, Kohler and Turner 2001) and excerpts from these reports are included here.

2. MATERIALS AND METHODS

The tagging methods used in the CSTP have been essentially unchanged during the past thirty years. The two principal tags in use are a fin tag (Jumbo Rototag) and a dart tag ("M" tag). The rototag is a two-piece, plastic cattle ear tag that is inserted through the first dorsal fin. The “M” tag is composed of a stainless steel dart head, monofilament line, and a Plexiglas capsule containing a vinyl plastic legend with return instructions printed in English, Spanish, French, Japanese and Norwegian. These dart tags, in use since 1965, are implanted in the back musculature near the base of the first dorsal fin. Numbered dart tags are sent to volunteer participants on self-addressed return post cards for recording tagging information: species, size, and sex of shark, date, location, and gear. In addition, first time taggers are sent a tagging needle, tagging instructions, an *Anglers Guide to Sharks of the Northeastern United States*, and the latest issue of the *Shark Tagger* newsletter. Tagging studies have been mostly single release events in which recoveries are made opportunistically by recreational and commercial fishermen. When a tagged shark is re-caught, information similar to that obtained at tagging is requested from the recapturer. Initially, a one-dollar reward was sent as an incentive for returning tags; after a few years, the reward was increased to five dollars. Since 1988, a hat with an embroidered logo has been used (Kohler et al. 1998).

The North Atlantic Ocean is divided into geographical areas in order to examine regional trends in size and maturation categories. These areas are defined solely based on tagging distributions, which largely reflects the fishing effort patterns of cooperative taggers aboard private, commercial, and research vessels. The authors do not believe that these boundaries can be associated with stock or management units at this time. The North Atlantic, defined as north of the Equator, is divided into 5 geographical areas: northwestern North Atlantic (NWNA) (west of 30°W and north of 25°N); southwestern North Atlantic (SWNA) (west of 40°W and south of 25°N including the Gulf of Mexico); northeastern North Atlantic (NENA) (east of 30°W and north of 25°N); southeastern North Atlantic (SENA) (east of 40°W and south of 25°N) and the Mediterranean Sea (MED) (east of 6°W).

Tagging and recapture sizes are recorded in fork length (FL), total length (TL) and/or weight. These sizes were primarily estimated at time of tagging and recapture but also include measured fish. All lengths, including those from previously published studies were converted to FL using the relationships reported in Kohler et al. 1995.

3. RESULTS AND DISCUSSION

3.1 Blue Shark (*Prionace glauca* Linnaeus 1758 Carcharhinidae)

3.1.1. Overview

The blue shark is probably the widest ranging chondrichthyian, circumglobal in tropical, subtropical, and warm-temperate seas including the Mediterranean (Bigelow and Schroeder 1948, Aasen 1966). In the Atlantic, the blue shark is considered the most abundant species among the pelagic sharks (Bigelow and Schroeder 1948, McKenzie and Tibbo 1964). It ranges from Newfoundland to Argentina in the west and from Norway to South Africa in the east (Bigelow and Schroeder 1948, Compagno 1984), and over the entire mid-Atlantic (Aasen 1966). The blue shark is an oceanic-epipelagic and fringe-littoral shark (Compagno 1984) that occurs from the surface to at least 600 meters (m) depth (Carey and Scharold 1990) and demonstrates tropical submergence (Compagno 1984, Nakano 1994). Blue shark movements are strongly influenced by water temperature (Vas 1990) and this species undergoes seasonal latitudinal migrations on both sides of the North Atlantic (Stevens 1976, Casey 1985, Silva et al. 1996), South Atlantic (Hazin et al. 1990), and in the North Pacific (Nakano 1994). It appears to have a wide thermal tolerance and is caught over a broad sea surface temperature range (Hoey 1983). Blue sharks seem to prefer layers of waters from 12°-21°C (McKenzie and Tibbo 1964, Gubanov and Grigor'yev 1975, Sciarotta and Nelson 1977, Casey 1982, Nakano 1994, Nakano and Nagasawa 1996) but have been caught in oceans with sea surface temperatures ranging from 8° to 29.5°C (Gubanov and Grigor'yev 1975, Casey and Hoenig 1977, Nakano 1994, Castro and Mejuto 1995, Nakano and Nagasawa 1996). In general, larger fish of both sexes are caught over a wider temperature range than smaller sharks (Nakano and Nagasawa 1996) and blue sharks demonstrate tropical submergence to remain in the deep, cooler waters in the tropical and equatorial parts of their range (Compagno 1984, Nakano 1994).

Blue sharks grow to a reported maximum size of 320 cm FL for both males and females (Bigelow and Schroeder 1948; Compagno 1984). The maximum size reported in a study of 4,529 blue sharks measured on NMFS research cruises and at recreational fishing tournaments in the western North Atlantic is 288 cm FL and 174 kg (Kohler et al. 1998). Free-living specimens have been reported as small as 36 cm FL (F. Williams, unpublished data[4]) for the Pacific and as small as 45 cm FL in the Atlantic (Bigelow and Schroeder 1948).

Size at maturity in the western North Atlantic is reported as 183 cm FL for the males whereas the females pass through a sub-adult phase from 145-185 cm FL (Pratt, 1979). In the Gulf of Guinea, 180 cm FL was the size at which 50% of the females had embryos, with the smallest female found with embryos was measured at 170 cm FL and the largest 260 cm FL (Castro and Mejuto 1995). In the Pacific, males and females reach maturity at 143-175 and 153-176 cm FL, respectively (Nakano 1994). Blue sharks are placentally viviparous (Pratt 1979). Gestation lasts from 9-12 months (Suda 1953, Pratt 1979, Nakano 1994) and in the western North Atlantic, young are born in the spring and summer (Pratt 1979). The number of young ranges from 1 to 135 per litter (Gubanov and Grigor'yev 1975, Nakano 1994) with a generally reported sex ratio at birth of 1:1 worldwide. Size at birth ranges between 30-43 cm FL (Suda 1953, Gubanov and Grigor'yev 1975, Pratt 1979, Nakano 1994, Castro and Mejuto 1995).

Age and growth for the blue shark has been extensively studied from several areas including the eastern and western Pacific Ocean (Cailliet et al. 1983, Tanaka et al. 1990, Nakano 1994); and the eastern and western Atlantic Ocean (Aasen 1966, Stevens 1975, Skomal 1990, Silva et al. (19xx), Henderson et al. 2001). Skomal and Natanson (2001) derived a validated age curve for the blue shark in

[4] Williams, F. 1977. Notes on the biology and ecology of the blue shark (*Prionace glauca* L.) in the eastern Pacific Ocean and a review of data from the world ocean. Unpublished manuscript.

the North Atlantic. They aged males and females at 16 and 13 years, respectively and estimated longevity to be between 20-26 years of age. Using their results, males mature at 4-5 years of age (183 cm FL); subadult females would mature at 3 years of age (145 cm FL), and females would become fully mature by 5 years of age(185 cm FL).

Blue sharks consume cephalopods as a primary component of their diet (Strasburg 1958, Tricas 1979, Stevens 1984, Kohler 1987). Various species of locally abundant pelagic and demersal teleosts as well as marine mammals and elasmobranchs are also preyed upon (Bigelow and Schroeder 1948, LeBrasseur 1964, Stevens 1973, Harvey 1979, Kohler 1987). Food was present in a range of 32-94% of the stomach samples worldwide and in 52% of the stomachs sampled in the western North Atlantic where regional and seasonal differences in diet were reported (Kohler 1987).

3.1.2. Sources of Releases and Recaptures

A total of 91,450 blue sharks were tagged by members of the NMFS CSTP from 1962-2000. Cooperators returned information on 5,410 recaptured blue sharks during this time period for an overall recapture rate of 5.9% (Table 1). Recreational fishermen (67%), using rod and reel, accomplished the bulk of the tagging with biologists and commercial fishermen using primarily longlines and hand lines accounted for the majority of the remainder. Recreational (55%) and commercial (41%) fishermen were responsible for the majority of the tag returns using rod and reel and longline gear, respectively (Figures 1 and 2). Overall, fishermen representing 44 countries and island territories returned information on tagged blue sharks. Blue shark recaptures were originally tagged on vessels from a total of 18 nations (Table 2).

The percent recapture rate was calculated for the major tagging gear types. Blue sharks originally captured by rod and reel and those tagged free swimming (no capture gear) each had a 7% recapture rate. Fish originally caught on hand lines and longlines had a 5.5% and 3.2% recapture rate, respectively. These recovery percentages are preliminary and may be influenced by differences in gear, Captain's experience level, geographic area of tagging and times at liberty.

3.1.3. Distances Traveled and Times at Liberty

Distances traveled for the blue shark ranged from no movement to 3,740 nautical miles (nm) (Table 1). The maximum distance was for a blue shark that was tagged by a sport fisherman southeast of Shinnecock Inlet, New York and recaptured approximately 560 miles east of Natal, Brazil 1.4 years later. Over 75% of the blue sharks traveled less than 1000 nm from their original tagging location with a mean distance of 463 nm (Figure 3). Times at liberty ranged from 1 day to 9.1 years. The 9.1-year recapture was a male blue shark caught with a hand line that was tagged south of Nantucket by a biologist and was recaptured within 62 nm of its tagging location more than 9 years later. Overall, 75% were at liberty for less than 2 years with a mean of 0.9 years (Figure 4).

Distance and time at liberty records exist for the blue shark in the Atlantic from other tagging studies. These include 579 nm and 9.5 years in the Canadian Atlantic (Burnett et al. 1987), 4,250 nm and 3.9 years off Ireland (Green[5] personal communication), and 3,875 nm and 10.7 years off England (Stevens 1990).

3.1.4. Distribution of Sizes and Sex Ratios

Northwestern North Atlantic (NWNA)

The majority of the tagging effort has taken place in this area. Because of the large numbers of fish tagged, the full size range of blue sharks can be found (31 to 429 cm FL) (Figure 5). Of the 61,460 blue sharks with the sex identified at tagging, 57% were males ranging in size from 34 to 429 cm FL (mean = 172 cm FL). There is a mix of male maturity stages, with 61% immature and 39% mature (Figure 6).

[5]Green, P. Central Fisheries Board, Glasnevin, Dublin, Ireland. 1999. Personal communications.

Females in this area represented 43% of the total sexed fish and ranged in size from 31 to 396 cm FL (mean = 150 cm FL). Nearly all (88%) females were immature or sub-adult (Figure 7). There were few (12%) adult females found in the area. The overall male to female sex ratio for this area is 1:0.8. Thus, the NWNA consists primarily of immature males and sub-adult females; some adult males are present, and a nearly equal sex ratio.

Southwestern North Atlantic (SWNA)

A total of 426 fish (262 sexed) were tagged in this area. Males represented 53% of the sexed fish and ranged in size from 46 to 306 cm FL (mean = 197 cm FL). There was a mix of male maturity stages with 31% immature and 69% mature. Females represented 47% of the sexed sample and ranged in size from 65 to 305 cm FL (mean = 171 cm FL). Most (62%) of the females in this area are in the immature and sub-adult size range. The overall male to female sex ratio is 1:0.9. Thus, the SWNA consists of some immature, but mostly mature males and some mature, but mostly immature and sub-adult females with a nearly equal sex ratio.

Northeastern North Atlantic (NENA)

Only 32% of the 1,176 sexed blue sharks were male ranging in size from 32 to 255 cm FL (mean = 98 cm FL). Nearly all (94%) of the males in this area are immature. Females make up 68% of the tagged (sexed) blue sharks and range in size from 30 to 381 cm FL (mean = 133 cm FL). Once again, nearly all (77%) of the females fall in the immature and sub-adult maturity size range. The overall male to female sex ratio is 1:2.1. Thus, the NENA consists of primarily immature males and immature and sub-adult females with some mature females and a sex ratio heavily favoring the females. These results are substantiated by numerous published fishing and tagging records from commercial and sport fisheries showing higher incidences of juveniles and females in the NE Atlantic including the waters off Norway (Pethon 1970), England (Tucker and Newnham 1957, Tucker 1958, Stevens 1976, 1990, Henderson et al. 2001), Ireland (M. Kennedy[6]unpublished data, Whelan in Henderson et al. 2001), Azores (Silva et al. 1996), and Africa (Buencuerpo et al. 1998).

Records of blue sharks, caught in Norwegian waters by longline, harpoon, net, and fishing line, show that mainly young immature specimens occur between July to January (Pethon 1970). These sharks reach Norwegian waters by following the branch of the North Atlantic Drift west of Great Britain and through the Faeroes-Shetland passage and are most frequent along and off the west coast. Blue sharks in these northern areas are mainly immature specimens composed of more females than males.

Data from angling records off Ireland (Kennedy[6]) indicate that female blue sharks greatly outnumber males, and in general, are larger than males. Not many of the blue sharks reach or exceed 191 cm FL or 100 pounds. There were no reports of pregnant females on the Irish coast by 1973. Whelan 1991 (reported in Henderson et al. 2001) and Berrow (1994) state that the sex ratio in Irish coastal waters favor females, all of which were immature.

Tucker and Newnham (1957) state that the recreational shark-fishers of Looe, England, generally agree that female blue sharks dominate the annual catch such that, the Looe shark fishery is effectively based on gravid blue sharks. There is little reported difference in the time of delivery in Mediterranean and NE Atlantic waters and that the period May-July is normal to both. Tucker (1958) describes the annual arrival of the blue sharks approximately 18 miles offshore of Looe in early June, with the main pulse soon followed with larger fish at the beginning of the season with less than 1% males caught.

Results from a 1950's sport fishery off southwest England, showed that the catch consisted of mostly immature or adolescent females (Stevens 1976). Length range at tagging off South-west England was 68-184 cm FL with a mode at approximately 126 cm FL (n=952). Blue sharks tagged off Portugal were smaller ranging from about 35-134 cm FL with a mode at about 84 cm FL (n=126). About 76% of the tagged population in both areas was female. An additional 561 blue sharks were tagged from 1976-

[6] Kennedy, M. The Inland Fisheries Trust Incorporated, Glasnevin, Dublin, Ireland. 1973. unpublished data.

1981 (395 with lengths). These ranged from 99-190 cm FL with a mode of about 130 cm FL (n=279) off south-west England and off Portugal from 51-122 cm FL off Portugal with a mode of about 84 cm FL (n=116) (Stevens 1990).

Blue sharks were examined in a later study from offshore oceanic waters southwest of Britain and Ireland that were taken from the by-catch of the tuna drift-net fishery from July to October (Henderson et al. 2001). Of 159 fish, 59% were female (range 55-191 cm FL; mean = 130 cm FL; mode = 110 cm FL) and 41% were males (80-183 cm FL; mean = 123 cm FL; mode = 111 cm FL). All but two males were immature and all females were immature. They reported that in the North Atlantic, blue sharks migrate northward during the summer and so occur primarily between May and September in Irish and British waters. Henderson et al. (2001) further report that since Stevens (1976) recorded mature females off the south coast of England, they are present in the North-east Atlantic, although in small numbers.

In the Azorean region, seasonal data from a large pelagic fish longline survey show a high occurrence of juveniles and sub-adults in approximately equal proportions, and a low occurrence of the adult stage in an equal sex ratio in autumn. However, the spring sample was clearly dominated by the juvenile stage (~80% of the total sample) with the sex ratio dominated by females (Silva et al. 1996). The authors suggest that the Azores represent an important spring nursery ground for juvenile blue sharks in the North Atlantic.

Buencuerpo et al. (1998) analyzed shark bycatch data from the Spanish longline fleet operating in the eastern North Atlantic, north central Atlantic, and the Mediterranean Sea. Their data were divided into 5 sectors of which one corresponded with parts of our NENA (sector 2, 3, and 4: 25°N to 40°N). Blue shark catch in sectors 2, 3, and 4 is where a greater proportion of immature fish were observed and the largest size males were found.

Southeastern North Atlantic (SENA)

A total of 79% of the 1,026 sexed blue sharks were males ranging in size from 60 to 292 cm FL (mean = 205 cm FL). Nearly all (86%) of the males in this area are mature fish. Females make up only 21% of the fish in this area and range in size from 60 to 242 cm FL (mean = 204 cm FL). Nearly all (84%) of the females in this area are mature fish. The overall male to female sex ratio is 1:0.3. Thus, the SENA consists of primarily mature fish of both sexes with a overwhelming predominance of males.

Published studies from this area support these conclusions. Castro and Mejuto (1985) found large male (mode = 225 cm FL) and female (mode = 220 cm FL) blue sharks in the waters of the Gulf of Guinea from a commercial longline fishery. Overall, size range for both sexes is 150-260 cm FL. There was a shift in the sex ratio from a predominance of females in the smaller sizes to predominately males in the larger fish. Size distribution by sex and zone indicates that males are slightly more numerous and significantly larger than females. A total of 491 out of 548 female blue sharks were gravid in this area. An indication of a reproductive gradient was reported and the authors suggest that the blue sharks may have a west-east migration to give birth along the Atlantic equatorial line.

Another study examining longline catches of blue sharks from a research vessel, conducted between 2° and 38°N and 15° to 35°W off the African coast, show that the dominant size range for males was 218-251 cm FL and 201-226 cm FL, respectively for a northern and southern area separated by the 20°N latitude line. The ratio of males to females differed although males prevailed in both areas (3:1 in the north, 10:1 in the south) (Draganik and Pelczarski, 1983).

Buencuerpo et al. (1998) analyzed shark bycatch data from the Spanish longline fleet operating in the eastern North Atlantic, north central Atlantic, and the Mediterranean Sea. Their data were divided into 5 sectors of which one corresponded with parts of SENA (sector 1: 20°N to 25°N). This sector is where the total mean sizes for both males and females was greatest (mean = 205 cm FL in longline landings), the largest size females were found, and the mature males were most abundant (Buencuerpo et al. 1998).

Mediterranean Sea (MED)

In the Mediterranean Sea, males make up 40% of the 570 tagged (sexed) fish and range in size from 30 to 259 cm FL (mean = 65 cm FL). Most (99%) of the male blue sharks were immature in this area. Females represented 60% of the total number and ranged in size from 30 to 251 cm FL (mean = 73 cm FL). Most (98%) of the female blue sharks were not mature. The overall male to female sex ratio is 1:1.5. Thus, the MED consists of primarily small fish of both sexes with a sex ratio favoring the females.

Buencuerpo et al. (1998) analyzed shark bycatch data from the Spanish longline fleet operating in the eastern North Atlantic, north central Atlantic, and the Mediterranean Sea. Their data were divided into 5 sectors of which one corresponded with parts of our MED (sector 5: southern coast of Iberian peninsula into the Mediterranean 3° to 7°W). This sector is where the total mean sizes for both males and females was lowest (mean = 85 cm FL in longline landings) and a greater proportion of immature fish were observed.

3.1.5. Regional Comparisons

Overall, based on tagging data, the smaller, immature fish are found in the Mediterranean Sea with the northeastern North Atlantic as the area containing the next smallest size group of blue sharks. The northwestern North Atlantic is also an important area for the immature males and females and subadult females. The larger fish and the majority of the mature fish of both sexes are found in the southern areas of the North Atlantic with the largest mean sizes for males and females and the highest percentage of mature fish found in the southeastern North Atlantic.

Investigators in other oceans have supported this phenomenon of increasing blue shark size with decreasing latitude. Suda (1953) examined blue sharks landed at the Tokyo Fish Market and reported that the fish from the south always exhibited greater lengths. He also noted that the deeper the water, the greater the length of the fish. In his study, both male and female blue sharks were longer south of 30°N in the Pacific Ocean. Gubanov and Grigor'yev (1975) described the western part of the equatorial zone of the Indian Ocean as where the living conditions for blue sharks are evidently most favorable. They report maximum abundance, size, and weight of the blue shark between latitudes 10°N and 10°S and the east coast of Africa and 60°E.

3.1.6. Trans-Regional Movements

A total of 446 blue sharks exhibited trans-regional movements (Figure 8). Recaptures from tagging on both sides of the Atlantic show that blue sharks may return in succeeding years to the area in which they were tagged (Casey 1985, Stevens 1990). Therefore, blue sharks recovered in their original tagging areas after various times at liberty may not imply residence time.

Northwestern North Atlantic (NWNA)

Approximately 92% of the immature (623) and sub-adult (729) females were recaptured in the same region as tagged while 2-3% traveled into adjacent areas (SWNA-22, NENA-14, SENA-20). In contrast, about 13% (21) of the mature females were recaptured in adjacent areas with a clear tendency favoring movement south into the SWNA (14, 8.5%) as compared to 2.4% to the NENA (4) and 1.8% in the SENA (3).

Approximately 93% (1,137) of the juvenile males were recaptured in the NWNA with 2-3% each returned from the SWNA (33), NENA (24), and SENA (26). In a manner similar to mature females, more mature males demonstrated movement out of the original tagging area, again favoring movement to the south. More (10%, 93) of the adult males moved out of the NWNA and were recaptured in the SWNA (4.8%, 46), NENA (2.3%, 22), SENA (2.5%, 24), and MED (0.1%, 1).

Overall, a higher percentage of the mature fish of both sexes traveled out of their original tagging area than the other life history stages. More were recovered in the southwestern North Atlantic after various time periods. Only one adult male has been recaptured in the Mediterranean Sea.

Southwestern North Atlantic (SWNA)

One out of two of the juvenile females were recaptured in the original tagging area and the other one moved to the NENA. Of the six subadult females recaptured, one was recovered in the SWNA, one in the NWNA, and two each in the NENA and the SENA. Of the three adult females, one each was recaptured in the SWNA, the NWNA and the NENA.

One out of two of the juvenile males were re-caught in the SWNA and the other one moved to the NWNA. Two out of six of the mature males were recaptured in their original tagging area, three moved to the NWNA, and one to the NENA.

Overall, 50% or less of the fish of both sexes and all life history stages were recaptured in the original tagging area. A higher percentage of the larger males and females traveled to two other regions (NWNA and NENA). None were recaptured in the Mediterranean Sea. Results are preliminary, however, due to the small sample sizes recaptured from the area.

Northeastern North Atlantic (NENA)

The majority of the immature (89%, 31) and sub-adult (70%, 7) females were recaptured in the NENA. The immature fish moved to the NWNA (11%, 4) and the sub-adults traveled to the SENA (20%, 2) and the MED (10%, 1). One-half of the adult females (2 out of 4) were re-caught in the NENA and 25% (1) each went to the SENA and the SWNA.

Approximately 82% (23) of the juvenile males were recaptured in the NENA with the rest recaptured in the SENA (4%, 1) and NWNA (14%, 4). One-half of the adult males (3 out of 6) were re-caught in the NENA and the other half traveled to the SENA.

Overall, one-half of the adults of both sexes were recaptured outside of NENA after various time periods with all recaptured in the southern most areas. More (70% +) of the smaller males and females were re-caught in their original tagging area. One sub-adult female was recaptured in the Mediterranean Sea.

Stevens (1976, 1990) reports on the results of blue shark tagging in the northeastern North Atlantic. Areas of recapture from tagging off southwest England, north Biscay, and Portugal include southwest England, southern Ireland, France, northern Spain, Portugal, Canary Islands, Algeria, and France. Two recaptures demonstrated trans-Atlantic migrations, both originally tagged off Cornwall, England and recaptured off Long Island, NY. Other long distance returns included fish recaptured in the central Atlantic, west of Liberia, and in the southeastern North Atlantic.

Southeastern North Atlantic (SENA)

Only three tagged females in the SENA were recaptured. All three were adults that were recaptured in the original tagging area.

Of the eight recaptured males, all were adults. Most (88%, 7) were recaptured in the SENA and one moved to the NENA.

Overall, only adult males and females were recaptured. Most were recaptured in their original tagging area or moved to the NENA. Results are preliminary, however, due to the small sample sizes recaptured from the area.

Mediterranean Sea (MED)

All of the females were immature fish except for one subadult. The immature sharks all remained in the MED whereas the subadult female moved a short distance to the NENA.

All of the males were immature fish that remained in the MED.

Overall, all of the immature tagged blue sharks of both sexes were recaptured in their original tagging area. The one subadult female moved a short distance into the northeastern North Atlantic. Results are preliminary, however, due to the small sample sizes recaptured from the area.

Eastern Atlantic/Western Atlantic

A total of 214 (4.4%) blue sharks were recovered in the northeastern and southeastern North Atlantic and the Mediterranean regions from northwestern and southwestern Atlantic releases (N=4,862). In contrast, 10 (7.2%) were recovered in the western Atlantic from tagging effort in the eastern Atlantic (N=138).

North Atlantic/South Atlantic

Information was returned on four blue sharks that had crossed the equator into the South Atlantic. These fish were primarily mature male sharks (163-228 cm FL estimated at recapture). Two were originally tagged off the northeast coast of the U.S. (NWNA), and two originally tagged south of the Cape Verde Islands (SENA). Minimum and maximum times at liberty and distance traveled are 0.2-1.7 years and 938-3,740 nm, respectively.

Stevens (1990) also reports on one blue shark tagged off southwest England that was recaptured in the South Atlantic. This fish was released off Salcombe, England and recaptured off South America after 3.1 years at liberty.

Limited information on blue sharks from the South Atlantic is found in Hazin et al. (1990, 1994). Catch data from the Brazilian tuna longline fishery in the southwestern equatorial Atlantic showed a predominance of males (156-250 cm FL) over females (162-226 cm FL) with a 4:1 sex ratio.

3.1.7. Migrations and Reproductive Cycle

In the western North Atlantic, the winter range of the blue shark is defined as eastward of the northern margin of the Gulf Stream (including the Sargasso Sea) where they can be found during all months of the year. Beginning in April and May, as the shelf waters warm, there is a shoreward movement from the Gulf Stream onto the continental shelf toward North Carolina to Newfoundland (Casey 1985).

Female blue sharks (145-185 cm FL; 3-5 year olds) arrive on the mating/feeding grounds of the continental shelf in the northwestern North Atlantic in late May and early June where they interact with adult males (4-5 year olds). The high incidence of mating scars and the presence of sperm in the oviducal gland indicates a summer breeding season for the blue shark. This process continues as late as November off the northeast coast of the United States. Once the females are inseminated, they move offshore where the sperm is stored until the following spring when they fertilize their eggs (Pratt 1979).

From May through October, the blue shark is commonly caught by recreational and commercial fishermen from Cape Hatteras, North Carolina to the Grand Banks. They are common in shallow water off southern New England and found offshore from the outer edge of the continental shelf, Gulf Stream, Georges Bank, Nova Scotia, the Grand Banks, and beyond. In late summer and fall, most of the blue sharks along the eastern North American coast begin moving south and offshore (Casey 1982, 1985) to areas including the southeastern United States, Caribbean Sea, Central, East and South Atlantic.

In the eastern North Atlantic, results show a seasonal migration of blue sharks from about 30^{o}N to 50^{o}N in the northeast Atlantic and different patterns of movement for different segments of the population (Stevens 1976, 1990). In the summer, blue sharks travel north to the west of Ireland and Scotland and even penetrate into the North Sea and the outer areas of the Baltic. They are also found during the summer along the west coast of Norway as occasional "visitors" (Aasen 1966). Small fish of modal length 100-110 cm FL remain within a relatively confined area and do not take part in the more extensive north-south migration of larger fish. Off southwest England there are two main movements of blue sharks into the area in summer (Stevens 1976, 1990). An initial movement of larger females at the beginning of the season is followed by a movement of smaller fish, including more males around the end of July or beginning of August. The sharks off southwest England were almost entirely these small fish of modal length 150-160 cm FL that remain until about September. They are present until at least November off northern Spain after which they may move further south, possibly as far as the Canary Islands (Stevens 1976, 1990). Aasen (1966) captured blue sharks in February off Cape Finnisterre and results from cruises off the continental shelf to northern Biscay in 1973 suggested that blue sharks were as abundant in that region in early December as in June (Stevens 1976, 1990).

In the eastern Atlantic, adult females are found in the area between the African coast, Madeira, and Canary Islands where at which time many are pregnant (Aasen 1966). It also appears that the Mediterranean area serves as an important nursery ground where young are born and remain during the first few years of life (Casey 1985).

3.1.8. Conclusions

It is generally acknowledged that most shark species segregate by size and sex during various times of their life history (Strasburg 1958, Springer 1960). The blue shark is no exception. Evidence from tagging studies and catch data suggest that there are distinct seasonal abundances and seasonal latitudinal migrations that take place for discrete parts of the blue shark population. The separation of the sexes other than at the time of mating may be an adaptation for females to avoid the dangers associated with male mating behavior (Nakano 1994). Distribution and movements of this species is strongly influenced by seasonal variations in water temperature, reproductive condition, and availability of prey. This is true for blue sharks in the North Atlantic (Tucker and Newnham 1957, Casey 1985, Stevens 1976, 1990, Silva et al. 1996, Henderson et al. 2001), South Atlantic (Hazin et al. 1990, 1994), Pacific Ocean(Nakano 1994, Nakano and Nagasawa 1996), and Indian Ocean (Gubanov and Grigor'yev 1975).

Based on evidence from tagging data, blue sharks of the North Atlantic constitute a single stock of fish. They make frequent trans-Atlantic movements between the western and eastern regions as well as some exchange taking place from east to west. Blue sharks utilize the major North Atlantic current systems to accomplish these extensive movements. In addition, this species is segregated by sex and size in vast regions of the Atlantic with larger, mature fish of both sexes caught in the southern part of their range. Immature males and females and sub-adult females dominate the northern regions with the smallest fish found in the Mediterranean Sea. Sex ratios of nearly 1:1 are found in the western North Atlantic with primarily females in the northeastern Atlantic and Mediterranean and primarily males in the southeastern region. Similar localized results in the Atlantic have been found by other investigators that support this one stock hypothesis involving a complex reproductive cycle with mating areas in the northwestern North Atlantic and pupping areas in the eastern North Atlantic. Documented seasonal migrations to the higher latitudes take place on both sides of the North Atlantic. Size of the blue shark generally decreases with increasing latitude. Relative abundance for the blue shark has been reported as lowest in the equatorial waters and increasing with latitude in the Pacific Ocean (Strasburg 1958). No data on blue shark abundances are presented here for the North Atlantic. Some partial exchange exists between the North and South Atlantic Ocean with the return of data on four blue sharks crossing the Equator. The magnitude of this movement is unknown at this time. It is imperative to understand the complex movements and life history strategies of the highly migratory blue shark in the Atlantic Ocean in order to rationally exploit and manage this important pelagic shark species.

3.2 Shortfin Mako (*Isurus oxyrinchus* Rafinesque 1810 Lamnidae)

3.2.1. Overview

The shortfin mako has a worldwide distribution in tropical and warm temperate seas (Compagno 1984). In the Atlantic, it ranges from Newfoundland to Argentina in the west and from Norway to South Africa in the east (Bigelow and Schroeder 1948, Compagno 1984). It is a common offshore littoral and epipelagic species in coastal and oceanic waters (Compagno 1984) that occurs from the surface down to at least 500 m depth (Carey et al. 1978). Shortfin makos are an important species to commercial and recreational fisheries because of its high-quality meat and also is a prime game fish prized by sport anglers (Compagno 1984).

Makos are reported to grow to a maximum size of about 366 FL (Bigelow and Schroeder 1948, Compagno 1984). The maximum size reported in the Atlantic is 338 cm FL from a study of 2,081 sharks measured on NMFS research cruises and at recreational fishing tournaments in the western North Atlantic (Kohler et al. 1995). Free-living specimens have been measured as small as 65 cm FL (Buencuerpo et al. 1998, Kohler et al. 1995) in the Atlantic and as small as 58 cm FL worldwide (Gilmore 1993).

Stevens (1983) reports size at maturity for male and female shortfin makos as 179 and 258 cm FL, respectively. A median size at maturity of females from the western North Atlantic is given as 275 cm FL. This is larger than that of females from the Southern Hemisphere (252 cm FL) (Mollet et al. 2000).

The shortfin mako is ovoviviparous and oophagous (Gilmore 1993). Embryo length-at-capture data from makos caught worldwide predicted a gestation period of 15-18 months (Mollet et al. 2000). Gestation period for Atlantic specimens is estimated at approximately 12 months (Pratt and Casey 1983) and 21 months for makos in New Zealand waters (Duffy and Francis 2001). Parturition occurs mainly in late winter to mid-spring in both hemispheres (Mollet et al. 2000). The number of young generally ranges from 4 to 18 per litter (Branstetter 1981, Stevens 1983, Gilmore 1993) with a possible maximum number of 25-30 reported by Sanzo (1912). A mean litter size of 12.5 is given in Mollet et al. (2000). Litter size is reported to increase with maternal length (Mollet et al. 2000). Sex ratio at birth is considered 1:1 (Stevens 1983, Mollet et al. 2000) and size at birth is approximately 63 cm FL worldwide (Mollet et al. 2000) ranging between 59 to 68 cm FL in the western North Atlantic (Pratt and Casey 1983).

Age of the shortfin mako has been reported for the Atlantic (Pratt and Casey 1983) and Pacific (Cailliet et al. 1983) Oceans. Non-validated age estimates for the mako in the western North Atlantic were determined using four methods (temporal length-month analysis, tag/recapture data, length-frequency data, and vertebral band counts) and it was concluded that band pairs were deposited biannually (Pratt and Casey 1983). Age estimates for this species are currently under revision using updated techniques and increased sample sizes with an emphasis on obtaining validation (Natanson 2001).

Casey and Kohler (1992) report that in the North Atlantic, the preferred water temperature of the mako shark appears to lie in rather narrow range between 17° and 22°C. Hoey (1983) analyzed surface temperature data from 2,766 sets of swordfish longline gear between the Gulf of Mexico and the Grand Banks and found that the mean minimum and maximum temperatures in which makos were caught were 18.5° and 20.5°C, respectively. The Spanish swordfish longline fishery, which covers an extensive area between Spain and the Grand Banks, also shows the highest catch rates for mako sharks in surface temperatures of 18°C in the region east of the Grand Banks (Mejuto and Iglesias 1987). Hoey (1983) reported that the overall surface temperature range in which fishing gear was used was 4° to 31°C, which was largely due to pelagic longline gear being set along strong surface temperature anomalies, particularly along the margins of the Gulf Stream north of Cape Hatteras and in the vicinity of the Grand Banks. Nakano and Nagasawa (1996) report that high CPUEs of shortfin makos in the North Pacific high seas salmon research gillnet surveys occurred at both 13° to 14°C and 18° to 21°C. Recreational catches of mako sharks off the middle Atlantic states of the U.S. also show that mako sharks do not move inshore onto the continental shelf in spring until surface temperatures reach about 17°C (Casey and Kohler 1992). Other evidence on the preferred water temperatures is provided by sonic tagging experiments (Carey et al. 1978). A 160-180 kg mako shark was followed for four days from Florida across the Gulf Stream and into the Sargasso Sea. The shark swam at depths ranging from the surface to 500 m but spent most of its time at depths where the temperature range was between 17° and 22°C (Carey et al. 1978). A similar behavior pattern and temperature preference was shown by two other tracked fish (Casey and Kohler 1992).

Shortfin makos, like other members of the Lamnidae family, have the ability to conserve metabolic heat and maintain their bodies 7° to 10°C above ambient temperatures. This is accomplished through highly developed countercurrent heat exchangers located in the vascular system that forms a thermal barrier which prevents heat from being carried off by the circulating blood and lost in the gills (Carey and Teal 1969). The large suprahepatic rete mirabile in these fish is identified as a heat exchanger, which retains metabolic heat to warm the visceral organs (Carey et al. 1981).

Analysis of the stomach contents of shortfin mako sharks from shark fishing tournaments and from longline catches taken between Cape Hatteras, North Carolina and the Grand Banks shows that teleost remains occurred in 67% of the diet with bluefish (*Pomatomus saltatrix*) constituting 78% of the diet by volume (Stillwell and Kohler 1982). Other fish consumed included scombrids, clupeids, alepisaurids and swordfish (*Xiphias gladius*). Cephalopods amounted to 15% of the overall diet by frequency of occurrence and were consumed primarily offshore. Bluefish was the major inshore food item. Food was present in 68% of the stomach samples and averaged approximately 2% of its body weight. Average food volume increased with increasing predator length suggesting that makos may shift to larger prey items such as swordfish as they grow larger (Bigelow and Schroeder 1948, Lineaweaver and Backus 1969, Stillwell and Kohler 1982).

3.2.2. Sources of Releases and Recaptures

A total of 5,333 shortfin makos were tagged by members of the NMFS CSTP from 1962-2000. Cooperators returned information on 608 recaptured fish (Figure 9) during this time period for an overall recapture rate of 11.4% (Table 1). Recreational fishermen (53%), using rod and reel, accomplished most of the tagging. Commercial fishermen (14%) and fisheries observers aboard commercial vessels (23%) using primarily longlines accounted for the majority of the remainder. Commercial (50%) and recreational (46%) fishermen were responsible for the majority of the tag returns using longline gear and rod and reel, respectively (Figures 1 and 2). Overall, fishermen representing 14 countries and island territories returned information on tagged mako sharks. Shortfin mako shark recaptures were originally tagged on vessels from a total of 12 nations (Table 2).

The percent recapture was calculated for the major tagging gear types. A 12% and 10.9% recapture rate was calculated for fish originally caught on rod and reel and longlines, respectively.

3.2.3. Distances traveled and times at liberty

Distances traveled for the mako shark ranged from no movement to 2,867 nm (Table 1). The maximum distance was for a mako shark tagged off the northeastern U.S. and recaptured approximately 90 nm northwest of the Western Sahara, Africa, 1.4 years later. Approximately 75% of the makos traveled less than 500 nm from their original tagging location with a mean distance of 398 (Figure 3). Times at liberty ranged from 1 day to 12.8 years (Table 1). The 12.8-year recapture was a male mako tagged off North Carolina that was recaptured 247 nm away, off South Carolina, Overall, 75% were at liberty for less than 2 years with a mean of 1.2 years. (Figure 4).

Limited tagging records exist for the shortfin mako in the Atlantic from other tagging studies. These include one fish that was originally tagged off Looe, England and recaptured in the Bay of Biscay after traveling 210 nm in 4.6 years (Stevens 1990) and 5 recaptured of 110 makos originally tagged in the Canadian Atlantic with the longest distance traveled of 555 nm and time at liberty of 0.7 years (Burnett et al. 1987).

3.2.4. Distribution of Sizes and Sex Ratios

Casey and Kohler (1992) analyzed the tagging data from the CSTP from 1962-1989 and divided the western North Atlantic into 5 areas to look at fork length frequencies by area. These areas included the Grand Banks, Northeastern U.S., Southeastern U.S., and the Gulf of Mexico. Overall, the mean fork length of makos found for all areas combined was 140 cm (N=2452). With the exception of the Grand Banks which has primarily small makos, all other areas had the complete size range with larger mean lengths found off the southeastern U.S. (180 cm FL) and the Gulf of Mexico (166 cm FL). Mean length decreased in the more northern areas with means of 140 cm FL and 94 cm FL found for the Northeastern U.S. and Grand Banks, respectively. In the Grand Banks area, shortfin makos as small or smaller than reported birth size were caught, measured, tagged, and released. The captains of several swordfish longline vessels felt that small makos were more common in the Gulf Stream off the Grand Banks than in other areas they fished (Casey and Kohler 1992).

The 1:1 sex ratio for all measured mako sharks was the same as the ratio reported at birth. The sex ratio changed with increasing size in the areas sampled in this study. The 1:1 sex ratio held true until approximately 240 cm FL, after which there was a shift to a preponderance of females (Casey and Kohler 1992). Overall, information on adults larger than 240 cm FL is extremely sparse, but a few males and females exceeding this size have been reported from both the western (Casey and Kohler 1992) and eastern Atlantic (Mejuto 1985).

Length frequencies of mako sharks taken in Spanish longline fisheries also confirm smaller sizes near the Grand Banks than in the northeastern Atlantic (Mejuto 1985, Mejuto and Iglesias 1987). Sex ratio data provided by Mejuto and Garces (1984) for mako sharks taken in the eastern Atlantic longline fishery shows that for the area between Spain and the Azores, there are a much higher percentage of males at sizes of more than 200 cm FL (male/female sex ratio of 1:0.4). Mean total weight for 5,525 makos caught was 66.2 kilograms (Mejuto and Garces 1984).

Buencuerpo et al. (1998), reporting on catches from the Spanish longline fleet operating in the eastern North Atlantic, north-central Atlantic, and the Mediterranean Sea, determined that Atlantic catch rates were always higher than in the Mediterranean and that the number of shortfin makos decreased as they fished north. The maximum size of females landed by longlines tended to increase from 20° to 35°N. The maximum size of males tended to increase in Atlantic sectors from south to north with the smallest maximum sizes for both sexes occurred in the Mediterranean Sea. The males ranged in size from 66-253 cm FL, females ranged in size from 65-306 cm FL with an overall sex ratio of 1:0.9. There was an increasing percentage of males from south to north suggesting sexual segregation. Most males in all sectors were adults with the largest sized fish reported from the Mediterranean area. The authors suggest that this area may represent a breeding area for the shortfin mako.

Castro and Mejuto (1995) reported on 98 shortfin mako caught in the Gulf of Guinea where 62 were females and one found to be gravid. This fish was 266 cm FL and had seven embryos in the left uterus and six in the right with an average size of 29 cm FL.

Limited information on shortfin makos from the southwestern Equatorial Atlantic is reported in Hazin et al. (1990). Makos constituted 2.6% of the catch with their distribution similar to that of the blue shark and their abundance increasing steadily eastward.

3.2.5. Hypothesis of Mako Migrations in the Western North Atlantic

A seasonal cycle of abundance off the northeastern U. S., beginning in January shows that shortfin makos are common along the western margin of the Gulf Stream, with at least one area of high abundance (based on commercial catches) off Cape Hatteras, where the Gulf Stream flows near the continental shelf (Casey and Kohler 1992). From January through April, shortfin makos are seldom taken on the continental shelf north of Cape Hatteras. Beginning in April and May, as inshore shelf waters warm and the Gulf Stream moves farther north, mako sharks begin moving northward onto the continental shelf between Cape Hatteras and the southern part of Georges Bank. In most years, makos are taken off southern New Jersey in early June and off New York and the southern New England states by late June (Casey and Kohler). The movement inshore and northward takes place simultaneously along the Gulf Stream from Cape Hatteras to the Grand Banks (Hoey 1983, Mejuto and Iglesias 1987).

From June through October, makos are caught by anglers on the continental shelf between Cape Hatteras and Cape Cod and, in recent years, in southern parts of the Gulf of Maine. During this season, swordfish and tuna longline fishermen also catch makos between the continental shelf and the Gulf Stream from Cape Hatteras to the southern tip of the Grand Banks. This entire area, particularly on the continental shelf south of Cape Cod, may be the primary feeding grounds for a large part of the juvenile mako population in the western North Atlantic (Casey and Kohler 1992).

During late fall and early winter (November-December), makos move from the area between Cape Hatteras and the Grand Banks to offshore wintering grounds in the Gulf Stream and the Sargasso Sea. If we assume that 18°C Sargasso Sea water represents the preferred habitat for makos, then the core of their distribution in the western North Atlantic covers a latitudinal range between 20° and 40°N, bordered by the Mid-Atlantic Ridge on the east and the Gulf Stream on the west. Certainly, mako sharks occur outside of these boundaries at different seasons, and they make trans-Atlantic crossings. However, most of the recaptures can be explained based on a “Sargasso Sea” hypothesis, including those returns from the Caribbean Sea. The route that makos might travel in this water into the Caribbean and then into the Gulf of Mexico and the Florida Straits is consistent with the tag returns from those areas. However, the distribution of recaptures suggests that the principal wintering grounds of juvenile makos are the western margin of the Gulf Stream and the northern part of the Sargasso Sea (Casey and Kohler 1992).

If the above hypothesis offers a partial explanation for the pattern of tag returns for the mako shark in the western North Atlantic, the picture is far from complete (Casey and Kohler 1992). Moreover, attempts to understand the life history of the shortfin mako cannot truly advance until more is known about the reproductive biology of the species and the distribution of large adults. Only four pregnant specimens have been reported from the western North Atlantic; all were taken in southern areas off Florida and in the Gulf of Mexico. On the other hand, very small makos, considered to be recently born, have been reported during the summer months in an area extending from the Gulf of Mexico to the Grand Banks. One explanation for this distribution of young is that adult females remain far offshore and/or are widely distributed in tropical waters. If so, newborn makos may be dispersed over a broad geographical area by the Gulf Stream. A reproductive strategy that ensures widely separated pregnant females and the dispersal of young over a broad area would offer some protection for the young from predation by large oceanic predators, including other mako sharks (Casey and Kohler 1992).

3.2.6. Recent Data

Casey and Kohler (1992) hypothesized that this preference for the 18°C water explains why, through 1989, only one tagged shortfin mako (out of 231) was recovered from the eastern Atlantic. Since that time, ten more fish have been recovered in the eastern Atlantic. Overall, using the current regions defined in this document, only 2% (N=11) of the 564 western North Atlantic recaptures have moved into the eastern Atlantic, and 1 out of 10 (10%) have moved from the eastern Atlantic to the western Atlantic.

Additional information on stock identity for the shortfin mako in the Atlantic and worldwide was reported in Heist et al. (1996). They used restriction fragment length polymorphism analysis of mitochondrial DNA to investigate genetic population structure. Samples for analysis were collected from the western North Atlantic, central North Atlantic (Azorean region), western South Atlantic, western South Pacific, and eastern North Pacific. Considerable genetic variation was detected in the shortfin mako compared to other species of sharks. The two North Atlantic sample sites were not statistically different and were pooled for analysis (Heist et al. 1996). Moreno and Moron (1992) described several individual makos from the Azores (Central Atlantic) with atypical pigment patterns. They suggested that these fish represented a special form endemic to that area. Tagging results (Casey and Kohler 1992) support a frequent exchange between these two geographical areas in the Atlantic. Heist et al. (1996) did report a significant difference, however, between the North and South Atlantic shortfin mako samples implying a separation between these two areas. Unfortunately, no samples were collected from the eastern North Atlantic for analysis. Thus, based on extant tagging and genetic data, there is not enough evidence at this time to support or reject the existence of one stock for the shortfin mako in the North Atlantic.

3.3 Porbeagle (*Lamna nasus* Bonnaterre 1788, Lamnidae)

3.3.1. Overview

The porbeagle is a coastal and oceanic shark that inhabits the cold temperate waters of the North and South Atlantic, Mediterranean Sea, South Pacific, and South Indian Ocean (Castro 1983, Compagno 1984). In the eastern North Atlantic, the porbeagle has been reported from Iceland, northern Norway and western Barents Sea, and Mediterranean to Morocco and northwestern Africa. In the western North Atlantic, it is found from Newfoundland and the Gulf of St. Lawrence to New Jersey and possibly to South Carolina in a narrower latitudinal belt with the center of abundance in the Gulf of Maine to the Grand Banks (Bigelow and Schroeder 1948, Compagno 1984). Porbeagles are a littoral and epipelagic shark species that is found from the surface to the bottom, as deep as 366 m or more (Compagno 1984).

The porbeagle prefers colder water and does not occur in equatorial seas (Compagno 1984). This species is commonly occurs in waters from 6° to 12°C, and not less than 16° to 19°C (Castro 1983, Compagno 1984, Scott and Scott 1988).

Porbeagles, like the shortfin mako and other members of the Lamnidae family, have the ability to conserve metabolic heat and maintain their bodies at considerably warmer internal temperatures than the surrounding water (Carey and Teal 1969). Body temperatures of 7° to 10°C above ambient has been recorded for these species with the porbeagle reported to be as efficient as the mako in warming the visceral organs (Carey and Teal 1969, Carey et al. 1981).

Porbeagles reportedly grow to about 271 cm FL (Bigelow and Schroeder 1948) and possibly to 334 cm FL (Compagno 1984). The largest reliably measured male and female porbeagles in the western North Atlantic are 262 and 317 cm FL (Natanson et al. in press).

Porbeagles are ovoviviparous and the embryos are oviphagous (Gilmore 1993, Jensen et al. in review). They breed on both sides of the North Atlantic; off the coast of Europe and the British Isles and off North America from Maine to Canada. Young are produced throughout their range in the Eastern Atlantic (Bigelow and Schroeder 1948). In the western Atlantic, embryos have been recorded from Maine to Massachusetts and Atlantic Canada (Bigelow and Schroeder 1948, Jensen et al. in review). Litter sizes range from 1 to 5 young with a mean of 4.0 given in Jensen et al. (in review) and usually four embryos present in the southwest Pacific Ocean (Francis and Stevens 2000). Size at birth is generally given as between 66 and 75 cm TL (Aasen 1963, Compagno 1984). Francis and Stevens (2000) estimated birth size of 58-67 cm FL in the southwest Pacific Ocean. Gestation is estimated at 8-9 months in the northwest Atlantic (Aasen 1963, Jensen et al. in review), 8 to 9 months in the southwest Pacific Ocean (Francis and Stevens 2000) and to one year in the eastern Atlantic (Gauld 1989).

Maturity of the porbeagle in western North Atlantic has been reported by Jensen et al. (in review) as 174 cm FL for the males and 218 cm FL for the females. Other maturity estimates include that by Aasen (1961) in the western North Atlantic of males between 136-181 cm FL and females at 181-226 cm FL; and Francis and Stevens (2000) in the southwest Pacific Ocean with 165-180 cm FL maturity for females.

Growth parameter estimates were calculated for the porbeagle in the western North Atlantic using band counts on vertebral annuli, length-frequency analysis, and tag-recapture data (Natanson et al. in press). Annual band pair periodicity was validated up to 11 years with oxytetracycline-injected and known age sharks. The median ages at sexual maturity were 7.5 and 14 years for males and females, respectively. Earlier age studies (Aasen 1963) generated a growth curve for the western North Atlantic population based on length-frequency data and vertebral readings from one fish. Francis and Stevens (2000) used length frequency analysis to estimate growth of juvenile porbeagles in the South Pacific.

Porbeagle stomach contents have included small pelagic schooling fishes such as mackerels, clupeids, gadids, and dogfishes, as well as squid (Stevens 1973, Compagno 1984, Gauld 1989). In the western North Atlantic, teleosts and squid were found in 47% and 12%, respectively, of 553 porbeagle stomachs examined from longline caught fish. Teleost species found included lancetfishes, herring and sand lance (Joyce, in review).

A directed fishery for the porbeagle began in the western North Atlantic in 1961 by fishermen from Norway and the Faroe Islands, which lasted until about 1967, and thereafter, a low level fishery existed until 1994. Canadian (O'Boyle et al. 1998) and U.S. fishermen began targeting this species in the early 1990's. In the eastern North Atlantic, the porbeagle has supported a commercial fishery at some level since the early 1800's, first by the Scandinavians and then by the Norwegians (Gauld 1989).

3.3.2. Sources of Releases and Recaptures

A total of 1,300 porbeagles were tagged by members of the NMFS CSTP from 1962-2000. Information on 143 recaptured fish (Figure 10) was returned during this time period for an overall recapture rate of 11.0% (Table 1). Commercial fishermen (35%) and fisheries observers on commercial vessels (19%), using primarily longline gear, accomplished the bulk of the tagging. Commercial fishermen (85%) were responsible for the majority of the tag returns (Figures 1 and 2). Overall, fishermen representing six countries and island territories returned information on tagged porbeagle sharks. Porbeagle sharks recaptures were originally tagged on vessels from a total of 10 nations (Table 2).

The percent recapture rate was calculated for the major tagging gear types. For porbeagles originally captured by rod and reel and longline gear, 12% and 11% were recaptured, respectively.

3.3.3. Distances Traveled and Times at Liberty

Distances traveled for the porbeagle ranged from 4 to 1,005 nm (Table 1). The maximum distance was for a porbeagle that was tagged south of Munson Canyon off the continental shelf of the northeast U.S. and recaptured approximately 400 nm south of the Flemish Cap. Over 90% of the porbeagles traveled less than 500 nm from their original tagging location with a mean distance of 234 (Figure 3). Times at liberty ranged from 1 day to 9.2 years. The 9.2-year recapture was a male porbeagle that was originally tagged by a fisheries observer approximately 200 nm east of Massachusetts. This fish was recaptured by a commercial fisherman 268 nm to the northeast of Nova Scotia, Canada. Overall, nearly 75% were at liberty for less than 4 years with a mean of 2.7 years (Figure 4).

Distance and time at liberty records exist for the porbeagle in the Atlantic from other tagging studies. Stevens (1990) reports on a porbeagle that was originally tagged in the Channel Islands and recaptured about 13.0 years later in Vest fjord, Norway 1,280 nm away.

3.3.4. Distribution of Sizes and Sex Ratios

Porbeagles were tagged in two areas, the western North Atlantic (N=1,228) and the eastern North Atlantic (N=65). In the NWNA, males ranged in size from 40-275 cm FL with a mean of 116 cm FL. Females ranged in size from 52-244 cm FL with a mean of 108 cm FL. An overall sex ratio for that area is 1:1 (Figure 11).

In the NENA, males and females ranged in size from 106-221 cm FL and 86-193 cm FL, respectively. Their overall fork length means were similar: 147 cm FL for males and 154 cm FL for females with a sex ratio favoring the males of 1:0.25.

On both sides of the Atlantic, analysis of catch and tagging studies give supportive results. Aasen (1963) reported an overall sex ratio of 1:1 in the western North Atlantic with the size of the porbeagle increasing from west to east. In the eastern North Atlantic, Mejuto (1985) reported that the majority of porbeagle bycatch from the Spanish swordfish longline fishery off Spain and the Azores was males with a sex ratio of approximately 1:0.5. Analysis of the porbeagle bycatch data from the Spanish swordfish longline fishery in an area north and northwest of Spain gave a sex ratio of 1:0.6 favoring males (Mejuto and Garces 1984). Gauld (1989) noted a male to female sex ratio of 1:1.3 off the Shetland Islands in Scottish waters. Berrow (1994) reports on the incidental capture of sharks in the static gill-net fishery off the south coast of Ireland. He found mostly females off Ireland but few specimens overall were caught.

Campana et al. (1999) summarizes the annual movements of porbeagles in the Canadian Atlantic. They report that porbeagles first appear in the Gulf of Maine, Georges Bank and southern Scotian shelf in January-February, move northeast along the Scotian Shelf through spring, and then appear off the south coast of Newfoundland and in the Gulf of St. Lawrence in the summer and fall. Catches in the late fall suggest a return movement to the southwest. Tagging data supports this annual migration where tags applied in the first half of the year tended to be recaptured in more easterly and northerly locations, while the reverse was seen for tags applied in the summer and fall (Campana et al. 1999). O'Boyle et al. (1998) suggests that based on published data in the western North Atlantic, mating occurs in autumn and parturition in the spring when the porbeagle ascend from the deeper water into the surface water to feed intensively. Segregation by size and sex is common with pregnant females reported to move to separate areas during gestation and pupping and remain separate from males and juveniles and discrete nursery areas (O'Boyle et al. 1998, Jensen et al. in review).

3.3.5. Trans-Regional Movements

No movements between areas occurred for any porbeagle recaptured in this study. Similar results were found by other investigators in both regions when tagging data was analyzed. O'Boyle et al. (1998) reports on 12 recoveries from 270 porbeagles tagged in the Canadian Atlantic. Recapture locations included: Gulf of Maine and Grand Banks with the majority recaptured on the Scotian Shelf. Recovery locations from 92 tagged porbeagles in the northwest Atlantic included the Scotian Shelf, Gulf of St. Lawrence, and on the Grand Banks (Aasen 1963).

Eastern Atlantic recaptures from Irish tagging include six porbeagles at liberty for a maximum of 10.8 years and traveling a maximum distance of 2,300 nm. Stevens (1976, 1990) gave details on eight recaptured porbeagles originally tagged off southwest England and recaptured off southwest England, west coast of Denmark, San Sebastian, Spain, Bay of Biscay, and in Vestfjord, Norway. The Norway recapture had traveled a minimum distance of 1,280 nm after 13.0 years at liberty. Based on these tag returns, Stevens (1990) suggests a homogenous stock structure in the eastern Atlantic.

3.3.6. Conclusions

Tagging and catch data from the entire Atlantic give clear evidence that the eastern and western Atlantic stocks of porbeagle sharks are distinct. Results from this study and others (Stevens 1990, Campana et al. 1999) support this statement.

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Table 1. Summary of tag releases and returns for three species of shark from the CSTP, 1962-2000.

	Blue Shark	Shortfin Mako	Porbeagle
Tagged	91450	5333	1300
Recaptured	5410	608	143
Recapture Rate	5,9%	11,4%	11,0%
Maximum Distance Traveled (nm)	3740	2867	1005
Mean distance traveled (nm)	463	398	234
Maximum time at liberty (yrs)	9,1	12,8	9,2
Mean time at liberty (yrs)	0,9	1,2	2,7
Maximum speed (nm/day)	44,5	35,7	22
Mean speed (nm/day)	2,7	2,4	0,8

Table 2. Summary of country of origin for tag releases and returns for three species of shark from the CSTP, 1962-2000.

	Country	Blue Shark		Shortfin Mako		Porbeagle	
		Tag	Recap	Tag	Recap	Tag	Recap
41	Algeria		x				
46	Azores	x	x				
5	Barbados		x				
36	Bermuda	x	x				
	Brazil		x				
8	Canada	x	x	x	x	x	x
3	Canary Islands	x	x	x			
9	Columbia		x				
61	Croatia		x				
10	Cuba		x		x		
40	Denmark	x					
65	Dominica, West Indies		x				
11	Dominican Republic		x				
48	Faroe Islands						x
14	France	x	x	x			x
12	Germany	x	x	x		x	
69	Ghana		x				
35	Great Britian	x	x	x		x	x
55	Greece		x				
38	Grenada, West Indies		x		x		
67	Guadeloupe, West Indies		x				
53	Ireland	x	x				
28	Italy	x	x	x	x	x	
16	Japan	x	x	x	x	x	x
17	Korea		x		x		
18	Lithuania		x				
50	Malta		x				
19	Martinique, West Indies		x				
20	Mexico		x		x		
60	Morocco		x				
21	Netherlands	x				x	
24	Panama	x		x			
68	Peru		x				
25	Poland	x	x	x	x	x	
26	Portugal	x	x	x	x		
27	Puerto Rico		x				
29	Russia	x	x			x	
2	Spain	x	x	x	x	x	
52	St Johns, West Indies		x				
47	St. Croix, West Indies		x				
30	St. Lucie, West Indies		x				
13	Taiwan		x		x		
51	Tobago, West Indies		x				
34	Trinidad		x				
1	United States	x	x	x	x	x	x
59	Uruguay		x		x		
32	Venezuela		x		x		
54	Yugoslavia		x				

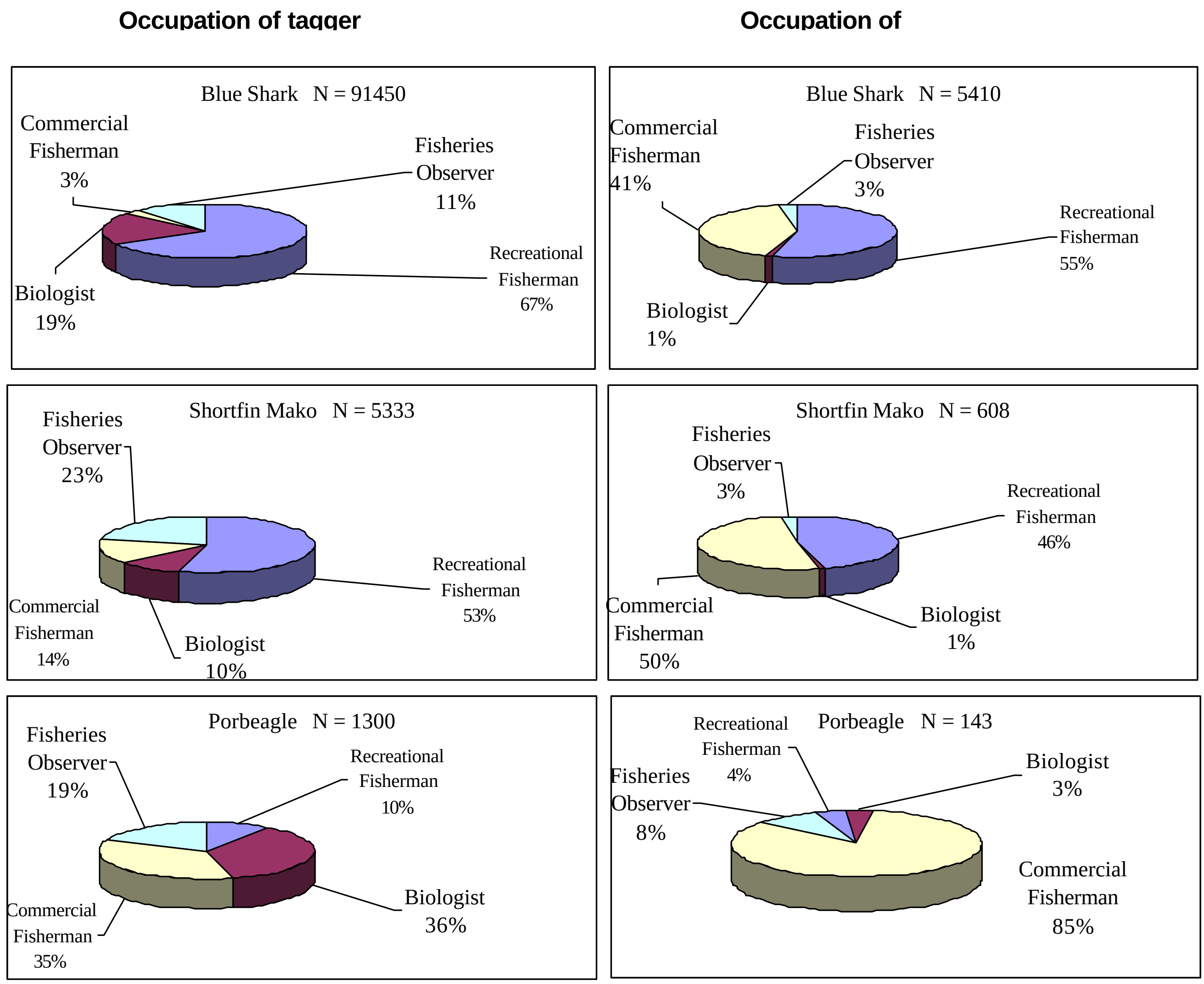

Figure 1. Summary of tag releases and returns for three species of shark by occupation of participants in the CSTP, 1962-2000.

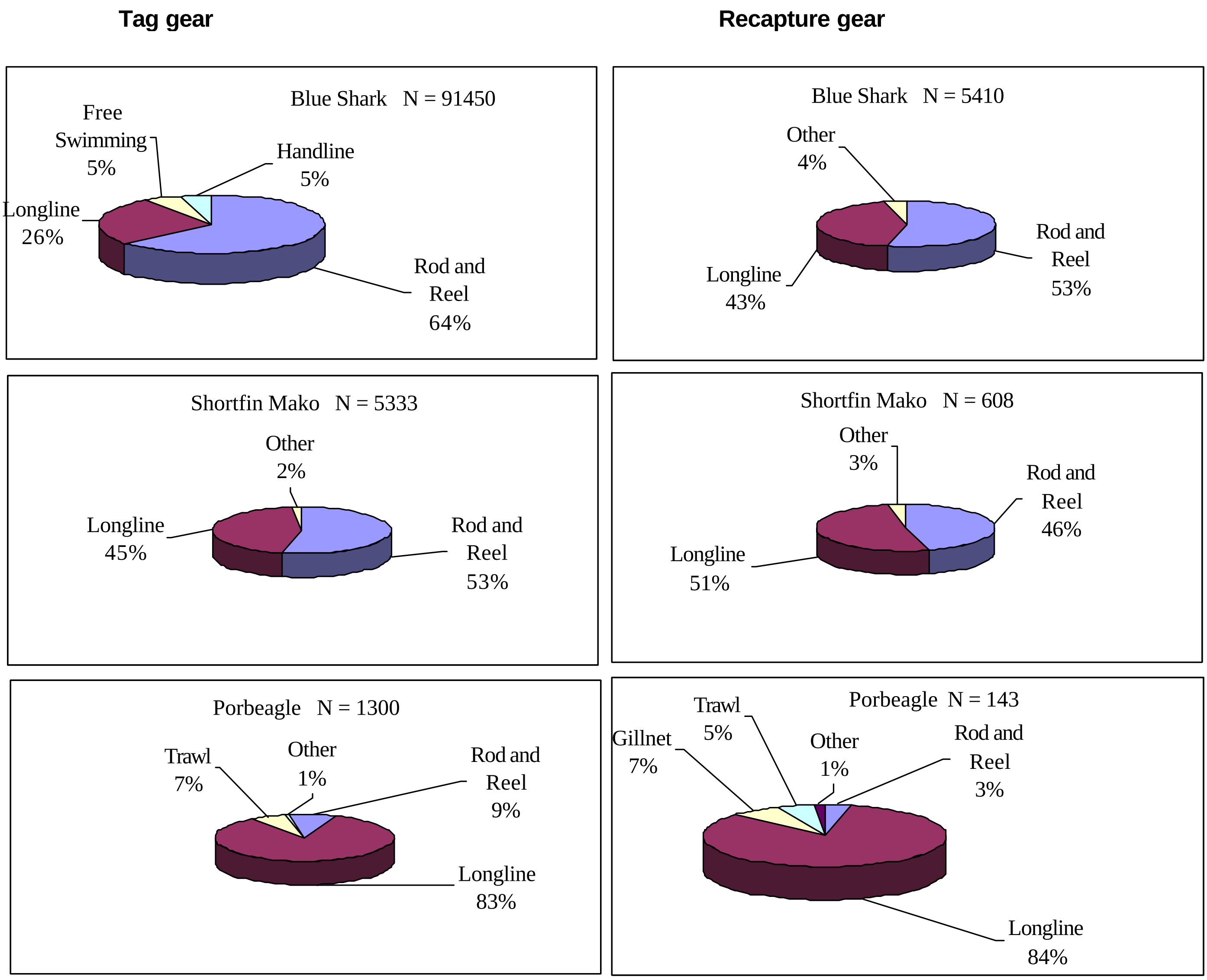

Figure 2. Summary of tag releases and returns for three species of shark by capture gear in the CSTP, 1962-2000.

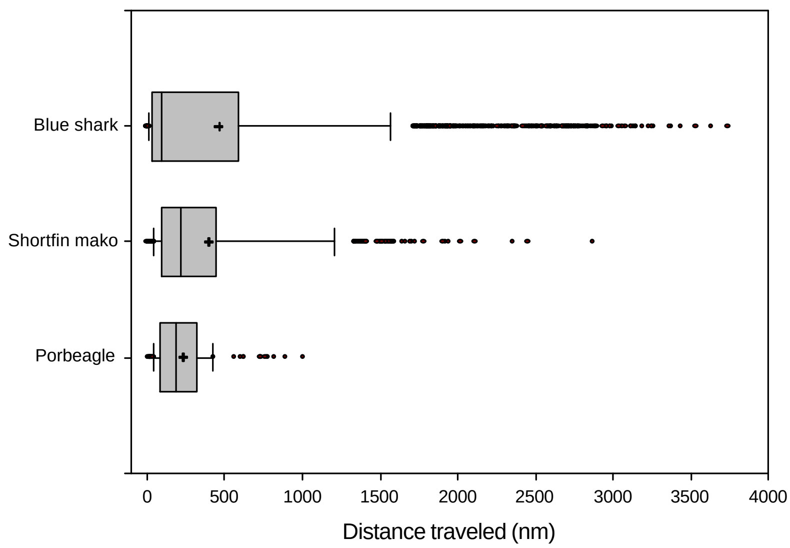

Figure 3. Box and whisker plots of distance traveled for three species of shark from the CSTP, 1962-2000. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the + within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers to the right and left of the box indicate the 10th and 90th percentiles, with the outliers shown by small dots.

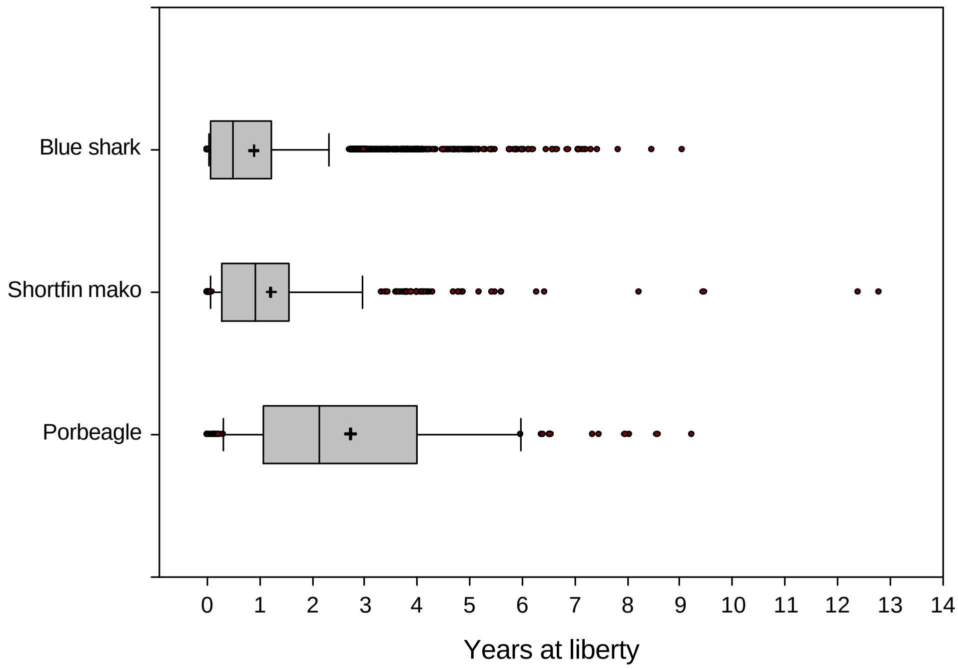

Figure 4. Box and whisker plots of time at liberty for three species of shark from the CSTP, 1962-2000. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the + within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers to the right and left of the box indicate the 10th and 90th percentiles, with the outliers shown by small dots.

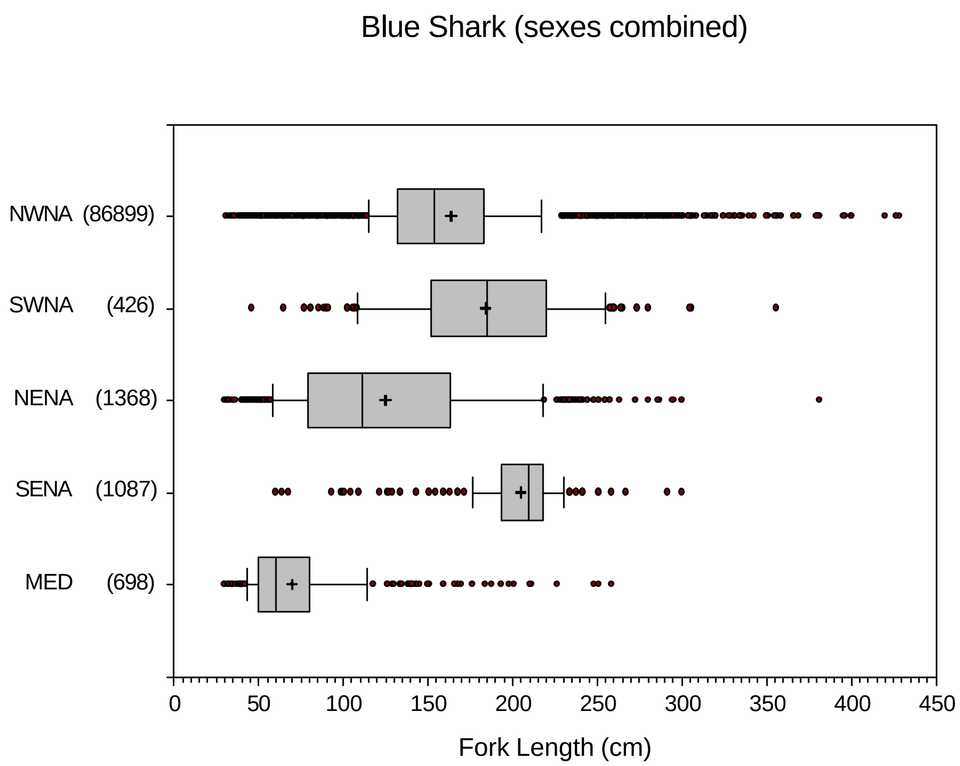

Figure 5. Box and whisker plots of reported fork length of tagged blue sharks by area from the CSTP, 1962-2000. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the + within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers to the right and left of the box indicate the 10th and 90th percentiles, with the outliers shown by small dots.

Male Blue Sharks

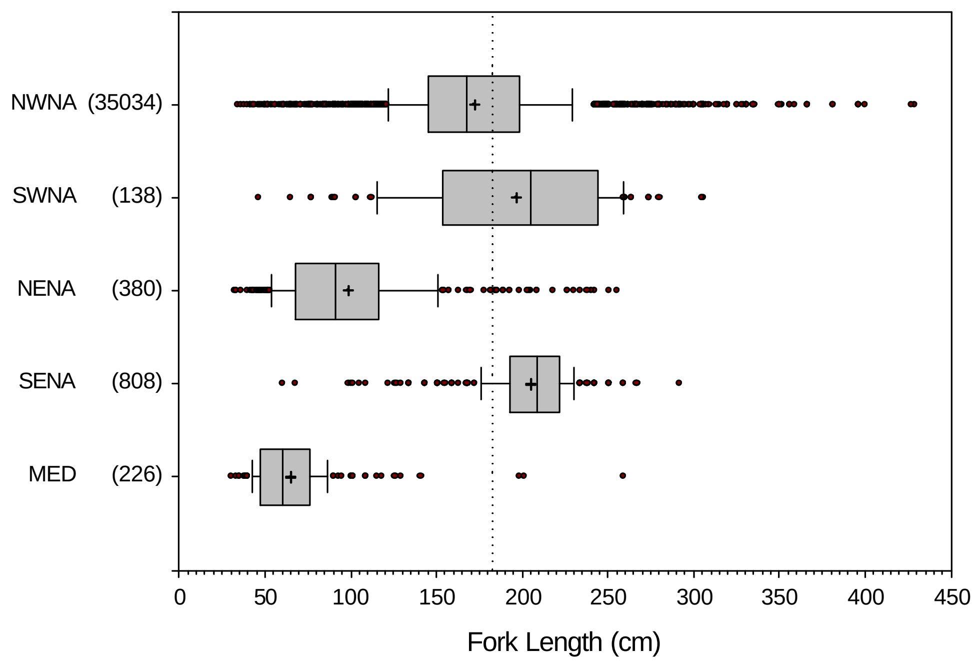

Figure 6. Box and whisker plots of reported fork length of tagged male blue sharks by area from the CSTP, 1962-2000. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the + within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers to the right and left of the box indicate the 10th and 90th percentiles, with outliers shown by small dots. The dotted line indicates fork length at maturity.

Female Blue Sharks

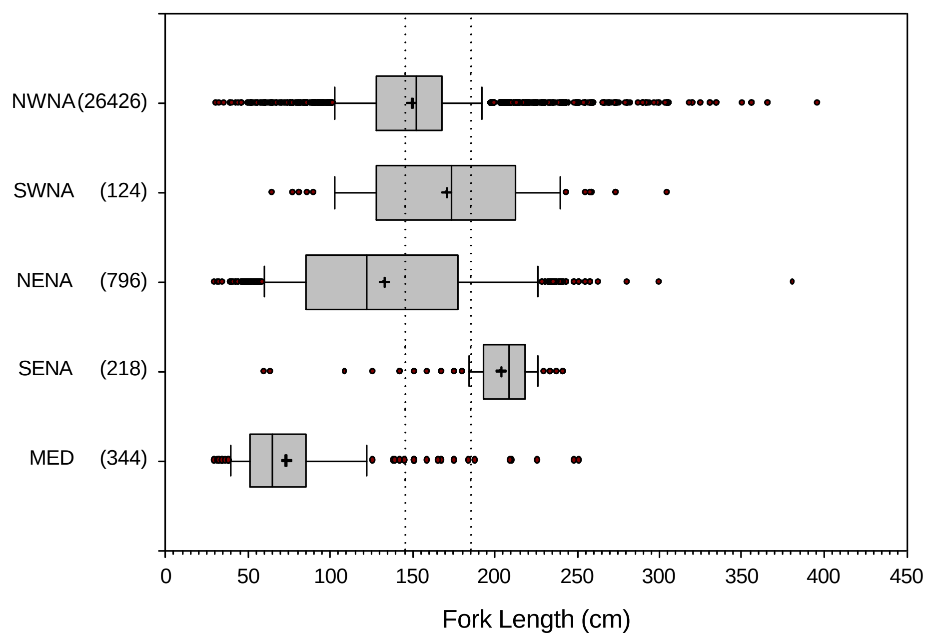

Figure 7. Box and whisker plots of reported fork length of tagged female blue sharks by area from the CSTP, 1962-2000. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the + within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers to the right and left of the box indicate the 10th and 90th percentiles, with outliers shown by dots. The dotted lines indicate sub adult and adult maturity sizes.

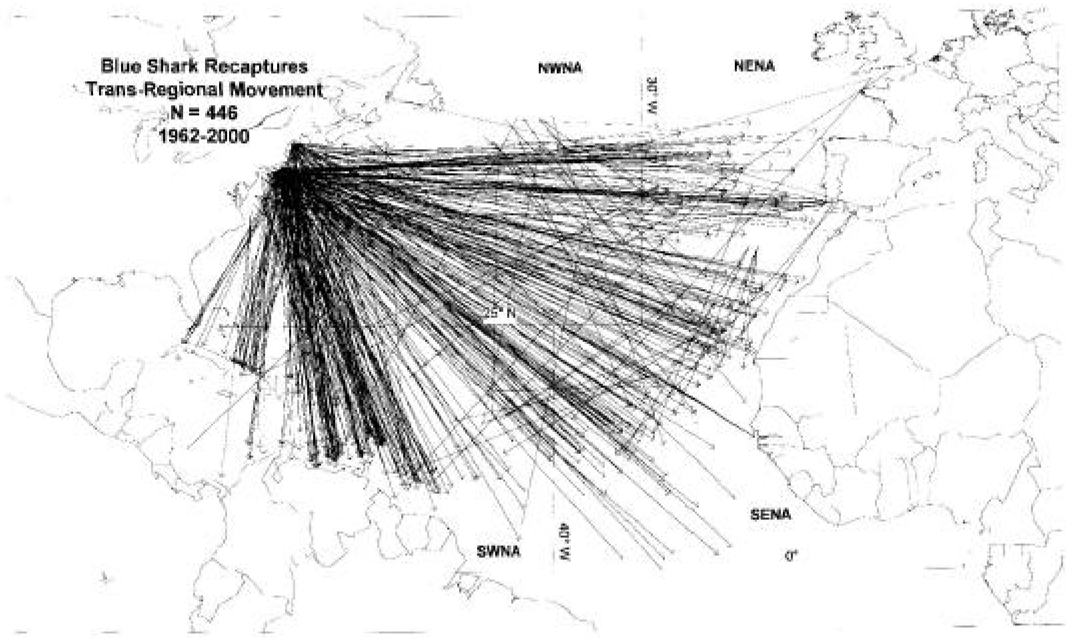

Figure 8. Recapture distribution for trans-regional movements of the blue-shark, *Prionace glauca*, from the CSTP. 1962-2000. Area definitions can be found in the text.

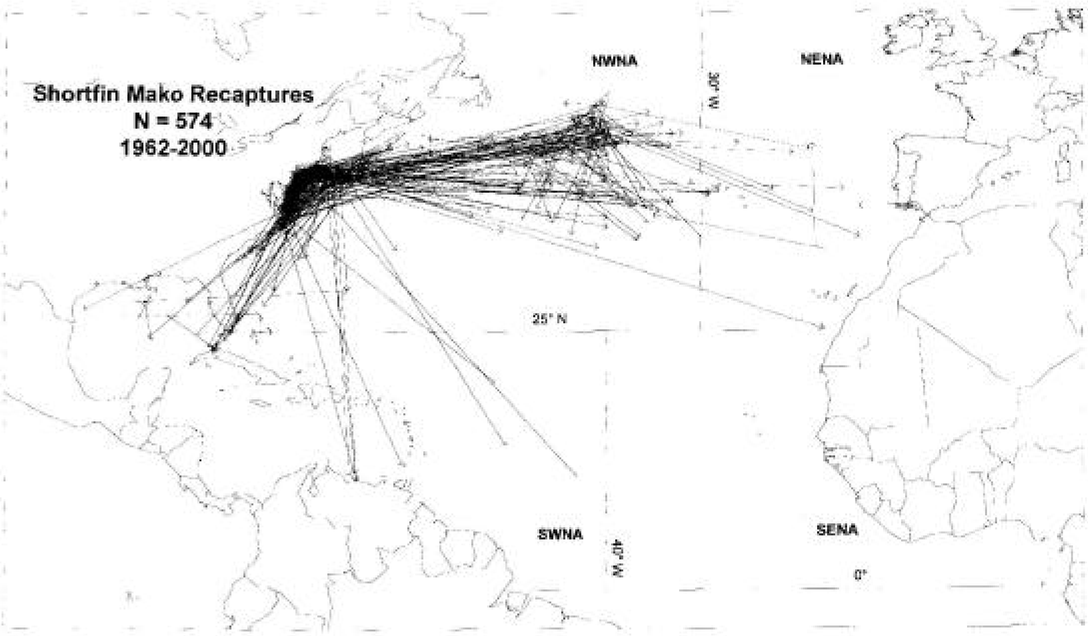

Figure 9. Recapture distribution for the shortfin mako, *Isurus oxyrinchus*, from the CSTP. 1962-2000. Area definitions can be found in the text.

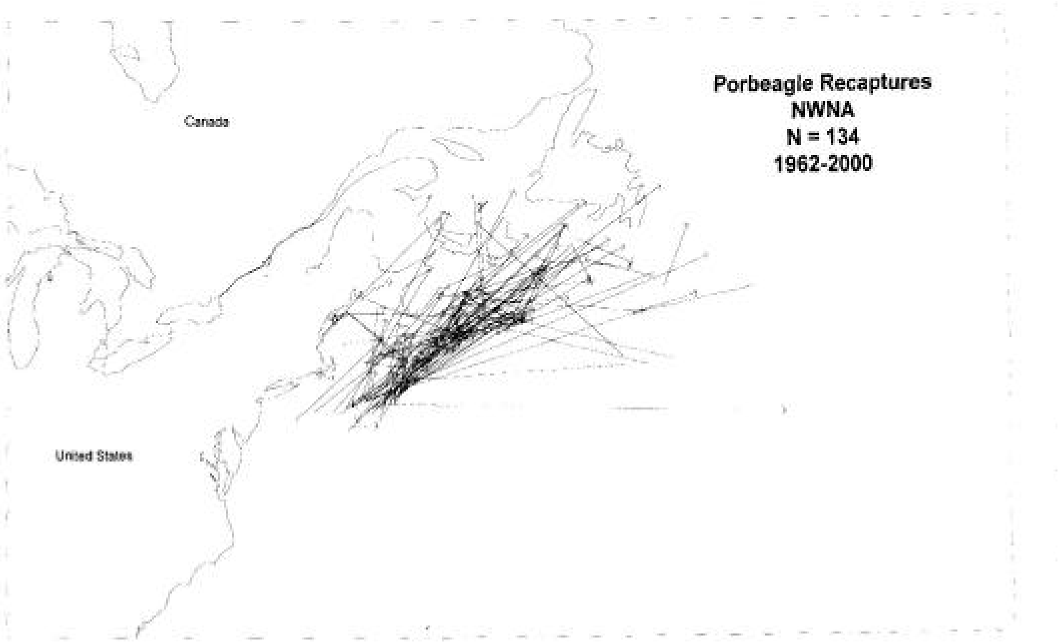

Figure 10. Recapture distribution in the NWNA for the porbeagle, *Lamna nasus*, from the CSTP, 1962-2000.

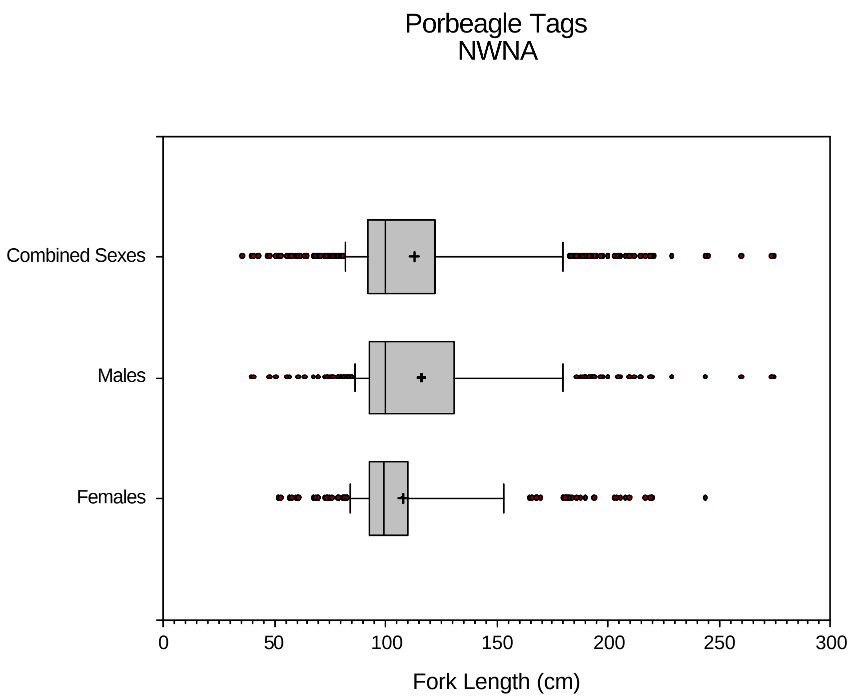

Figure 11. Box and whisker plots or reported fork length of porbeagles tagged in the NWNA from the CSTP, 1962-2000. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the + within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers to the right and left of the box indicate the 10th and 90th percentiles, with outliers shown by small dots.