水研センター研報，第 6 号，18－55，平成15年
Bull. Fish. Res. Agen. No. 6, 18-55, 2003

総　説

# Synopsis of biological data on the blue shark, *Prionace glauca* Linnaeus

Hideki NAKANO[*1] and Michael P. SEKI[*2]

**Abstract** Blue sharks, *Prionace glauca*, are wide ranging oceanic sharks found worldwide in tropical and temperate waters and the most abundant pelagic shark species. Blue shark is the most successful elasmobranch in the pelagic waters and frequently major by-catch species into the fisheries operating in high seas. Occupation of the pelagic niche in the temperate waters may be one of the key components of its domination in the pelagic ecosystem. The systematics, biology, life history, population, exploitation, and utilization on blue shark were reviewed based on more than eighty scientific publications during the past five decades. Over the years, numerous studies describing the biology, ecology and fisheries of blue sharks have been published, however, the information are more often than not patchy and local in scope. The synopsis thus compiles available information pertaining to blue sharks to establish what is known, where gaps in our knowledge exists, and identifies where additional and future research efforts should be focused. Although a comprehensive stock assessment of blue shark in the North Pacific is still lacking, no overly deviant fluctuations are obvious in the various CPUE series, and no evidence currently exists to suggest that the stock status of North Pacific blue sharks is in a critical state. Nevertheless, further research is needed to assess the true catch levels in each fishery and their impacts on the population. Our mutual interests leads us to focus our efforts on the population of blue sharks inhabiting the North Pacific Ocean, although where relevant, information from the other oceans of the world are also reviewed and presented for comparison.

**Key words:** blue shark, synopsis, biology, life history, population

Table of Contents



2002年10月 2 日受理（Received on October 2, 2002）
水産総合研究センター業績 A 第31号（Contribution No. A 31 from The Fisheries Research Agency）
[*1] 遠洋水産研究所　〒424-8633　静岡県清水市折戸5-7-1（National Research Institute of Far Fisheries, Orido, Shimizu, Shizuoka 424-8633, Japan）
[*2] National Marine Fisheries Service, NOAA Southwest Fisheries Science Center Honolulu Laboratory 2570 Dole St., Honolulu, HI96822-2396, USA

## Introduction

Blue sharks, *Prionace glauca*, are wide ranging oceanic sharks found worldwide in tropical and temperate waters. The most abundant pelagic shark species, large numbers of blue sharks are frequently and incidentally caught by the world's fisheries. Over the years, numerous studies describing the biology, ecology and fisheries of blue sharks have been published, however, the information are more often than not patchy and local in scope. For the conservation and management of this wide ranging resource, it is imperative to develop a more coherent, holistic understanding of the species' biology, life history, and role in the ecosystem. This synopsis thus compiles available information pertaining to blue sharks to establish what is known, where gaps in our knowledge exists, and identifies where additional and future research efforts should be focused. Our mutual interests leads us to focus our efforts on the population of blue sharks inhabiting the North Pacific Ocean, although where relevant, information from the other oceans of the world are also reviewed and presented for comparison.

## 1.0 Systematics

### 1.1 Scientific name

*Prionace glauca* (Linnaeus, 1758)

### 1.2 Synonymy (after Compagno, 1984)

? *Squalus adscentionis* Osbeck, 1765; ? *Squalus rondeletii* Risso, 1810; *Squalus caeruleus* Blainville, 1825; ? *Galeus thalassinus* Valenciennes, *in* Cuvier, 1835; ? *Thalassorhinus vulpecula* Valenciennes, *in* Bonaparte, 1838; also *in* Müller & Henle, 1839; *Carcharias* (*Prionodon*) *hirundinaceus* Valenciennes, *in* Müller & Henle, 1939; *Thalassinus rondelettii* Moreau, 1881; *Carcharias pugae* Perez Canto, 1886; *Carcharias gracilis* Philippi, 1887; *Hypoprion/Hemigaleus isodus* Philippi, 1887; ? *Carcharias aethiops* Philippi, 1896; *Prionace macki* Phillipps, 1935.

### 1.3 Taxonomy

Phylum Vertebrata
Superclass Pisces
Class Chondrichthyes
Subclass Elasmobranchii
Superorder Galea
Order Carcharhiniformes
Family Carcharhinidae
Genus Prionace

Classification under superorder follows that of Shirai (1996). Genus *Prionace* was defined by Linnaeus (1758) and includes only one species, *Prionace glauca*, the blue shark.

### 1.4 Local names

| language | local name |
|---|---|
| English | blue shark, great blue shark, blue whaler |
| Japanese | yoshikiri-zame, yoshikiri, aota, aobuka, guda, mizu-zame |
| French | Peau bleue |
| Spanish | Tiburon azul |

### 1.5 Field identification

The body of the blue shark is slender and elongate. Distinguishing characteristics of the shark include a long snout that is parabolic in dorsoventral view, large eyes without posterior notches, the absence of spiracles, and the presence of unique papillose gillrakers on the internal gill openings. The sickle-shaped pectoral fins are large and long, especially in relation to the remaining other moderately sized fins. Typical of carcharhinid sharks, the elongated, compressed caudal fin bears a notch just below the end of the upper lobe and there is a nictitating membrane over each eye (Bigelow and Schroeder, 1948; Compagno, 1984).

The coloration of the blue shark is also quite distinctive. Upon capture, the dorsal portions of the body will be a brilliant, dark blue, becoming a lighter but still bright blue on the sides, and then abruptly white ventrally (Fig. 1; Bigelow and Schroeder, 1948; Compagno, 1984).

## 2.0 Biology and life history

### 2.1 Biometrics

Blue sharks are relatively large sharks with the maximum size recorded at 383cm in total length (TL) from the Northwest Atlantic Ocean (Bigelow and Schroeder, 1948). Most blue sharks caught, however, are less than 3 m in length.

#### 2.1.1 Length measurement conversion factors

Several types of length measurement have


**Fig. 1.** The blue shark, *Prionace glauca* Linnaeus

been used among various nations and researchers in describing shark morphometrics. Most commonly, these include total length (TL), fork length (FL), precaudal length (PL), and eye-to-fork length (EFL). Total length is defined as the distance between the tip of the snout and the posterior end of the caudal fin. Fork length and precaudal length are the straight line distances measured from the tip of the snout to the fork of the caudal fin and to the precaudal notch, respectively. Eye-to-fork length is measured from the rear margin of the eye to the fork in the caudal fin. For comparative purposes, several relationships to convert between length types have been developed and published. For the North Pacific Ocean, Nakano *et al.* (1985) reported the relationship between TL and PL for sharks taken by research driftnet sets, and McKinnell and Seki (1998) present regression equations between lengths of blue and salmon sharks (*Lamna ditropis*) including TL, PL, and EFL using multinational observer data from the now defunct Japanese high-seas squid driftnet fishery (Table 1, Fig. 2).

For the Atlantic Ocean, Hazin *et al.* (1991) reported relationships among TL, FL, PL and

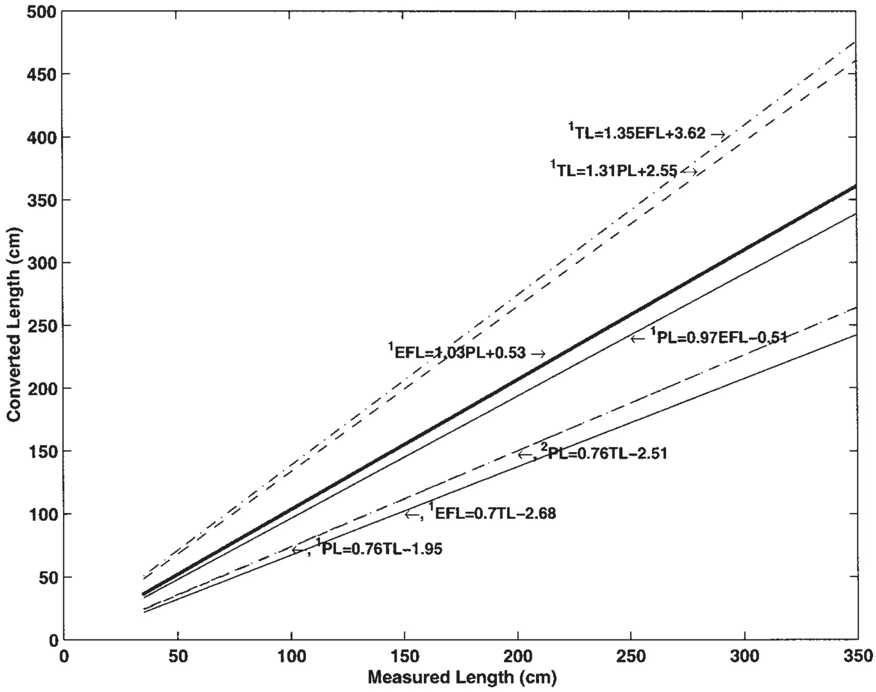



**Fig. 2.** Relationships between total length (TL), precaudal length (PL) and eye-fork length (EFL) measurements of North Pacific blue sharks collected from [1]Japanese commercial and Canadian experimental squid driftnet operations (McKinnell and Seki, 1998) and from [2]research driftnet sets (Nakano, 1985)

**Table 1.** Relationship between various length measurements (in cm) applied in North Pacific blue shark morphometric assessments

| Study | Equation | *r* | *n* |
|---|---|---|---|
| Nakano *et al.* (1985) | PL = 0.762 TL−2.505 | 0.999 | 267 |
| McKinnell and Seki (1998) | PL = 0.76 TL−1.95 | na | 187 |
| | TL = 1.31 PL+2.55 | na | 187 |
| | TL = 1.35 EFL+3.62 | na | 242 |
| | EFL = 0.70 TL−2.68 | na | 242 |
| | EFL = 1.03 PL+0.53 | na | 190 |
| | PL = 0.97 EFL−0.51 | na | 190 |

interdorsal space (IS, the distance from the end of first dorsal fin to the beginning of the second dorsal base) for blue sharks by sex, and Pratt (1979), Castro and Mejuto (1995) and Kohler *et al.* (1995) calculated the regression between TL and FL (Table 2).

There are three length units (i. e. total length, fork length and precaudal length) used for length measurements of sharks as standard length depending by countries or scientists. Total and fork lengths are frequently used in the western societies. While, precaudal length is used in Japan only. It is desired that one of three length units is going to be a common standard for length measurement of sharks among scientists and countries.

### 2.1.2 Length-weight relationship

The relations between length (cm) and weight (kg) of the blue shark are reported in several published studies. In the North Pacific Ocean, Strasburg (1958) calculated the relation between TL and weight (Wt) measured in pounds, Nakano *et al.* (1985) and Nakano (1994) presented the relation between PL and Wt by sex, and Harvey (1989) reported the length-weight relationship (TL-Wt) for 150 blue sharks caught in Monterey Bay, California (Table 3, Fig. 3).

In other oceans, length-weight relationships of blue shark were reported by Stevens (1984) for sharks taken off New South Wales in the South Pacific and by Stevens (1975), Hazin *et al.* (1991), Kohler *et al.* (1995) and Draganik and Pelczarski (1984) for blue sharks in the Atlantic Ocean (Table 4). Shark lengths were measured as TL in all of the above studies with the exception of Hazin *et al.* (1991) who employed FL.

Since length-weight relationship for sharks are known to differ among sexes and between geographical areas, new length and weight data collection efforts should focus on addressing these differences. The use of different units used for length measurement among scientists also affects on the relationships between length and weight. For direct comparison it is desired to have one common unit of length used among scientists .

### 2.1.3 Length-processed weight and round weight-processed weight conversion

Hazin *et al.* (1991) described the relationship between FL (cm) and gutted weight (GWT in

**Table 2.** Relationship between various length measurements (in cm) applied in the North Atlantic blue shark morphometric assessments

| Study | Relationship | Sex | *r* | *n* |
|---|---|---|---|---|
| Hazin *et al.* (1991) | FL = 11.27 + 0.78 TL | male | 0.94 | 73 |
| | FL = 23.52 + 0.73 TL | female | 0.92 | 59 |
| | PL = 3.92 + 0.74 TL | male | 0.95 | 72 |
| | PL = 28.95 + 0.63 TL | female | 0.82 | 59 |
| | IS = −4.24 + 0.22 TL | male | 0.86 | 73 |
| | IS = 10.10 + 0.16 TL | female | 0.74 | 59 |
| | PL = −3.00 + 0.93 FL | male | 0.99 | 75 |
| | PL = 5.15 + 0.88 FL | female | 0.92 | 66 |
| | IS = −6.62 + 0.28 FL | male | 0.92 | 75 |
| | IS = 3.16 + 0.23 FL | female | 0.84 | 66 |
| | IS = −4.96 + 0.30 PL | male | 0.93 | 84 |
| | IS = 6.80 + 0.23 PL | female | 0.81 | 69 |
| Castro and Mejuto (1995) | FL = −1.061 + 0.8203 TL | both sexes | 0.9993 | 62 |
| | TL = 1.716 + 1.2158 FL | both sexes | 0.9993 | 62 |
| Kohler *et al.* (1995) | FL = 1.3908 + 0.8313 FL | both sexes | 0.9966 | 572 |

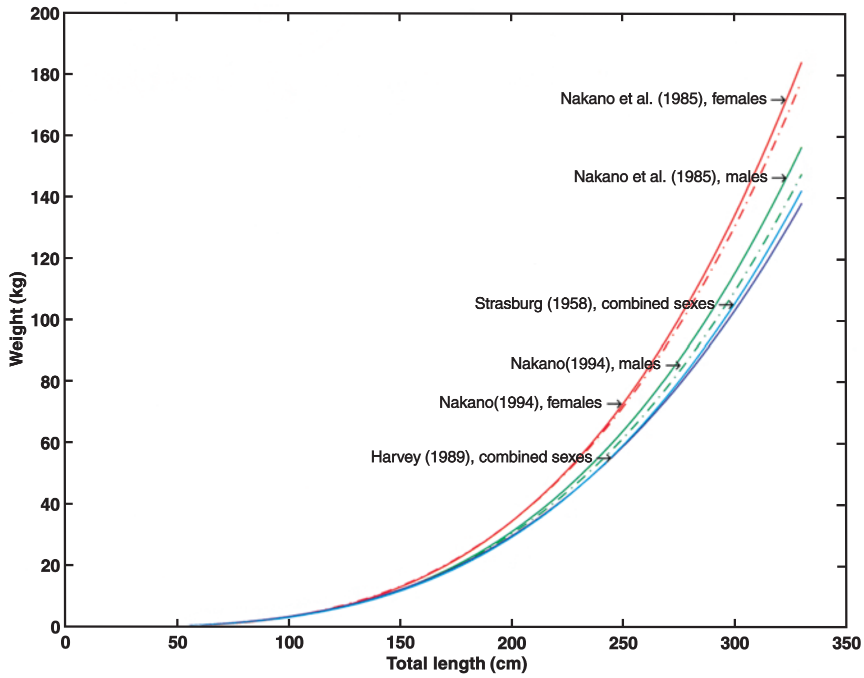



**Fig. 3.** Standardized total length (cm) - weight (kg) relationships for North Pacific blue shark. [note: curves standardized from PL (cm) - Wt (kg) in Nakano *et al.* (1985) and Nakano (1994), TL (mm) - Wt(kg) in Harvey (1989) and TL (cm) - Wt (pounds, lbs.) in Strasburg (1958) ].

**Table 3.** Length (cm) - weight relationships for blue shark published in the North Pacific Ocean [1originally reported in the form: log Wt = −5.396 + 1.13439 log TL]

| Study | Sex | Relationship | *r* | *n* |
|---|---|---|---|---|
| Strasburg (1958)[1] | combined | WT (lbs) $=4.018\times10^{-6}$ TL$^{3.134}$ | | |
| Nakano *et al.* (1985) | Male | WT (kg) $=3.838\times10^{-6}$ TL$^{3.174}$ | 0.997 | 285 |
| | Female | WT (kg) $=2.328\times10^{-6}$ PL$^{3.294}$ | 0.994 | 148 |
| Harvey (1989) | combined | WT (kg) $=2.57\times10^{-5}$ TL$^{3.05}$ | 0.849 | 150 |
| Nakano (1994) | Male | WT (kg) $=3.293\times10^{-6}$ PL$^{3.225}$ | 0.993 | 2910 |
| | Female | WT (kg) $=5.388\times10^{-6}$ PL$^{3.102}$ | 0.992 | 2890 |

**Table 4.** Length (cm) - weight (kg) relationships for blue shark published in the Atlantic Ocean

| Study | Sex | Relationship | *r* | *n* |
|---|---|---|---|---|
| Stevens (1975) | Male | WT $=0.392\times10^{-6}$ TL$^{3.41}$ | 0.999 | 17 |
| | Female | WT $=0.131\times10^{-5}$ TL$^{3.20}$ | 0.968 | 450 |
| Castro (1983) | combined | WT $=3.1841\times10^{-6}$ TL$^{3.1313}$ | 0.976 | 4529 |
| Hazin *et al.* (1985) | Male | WT $=1.377\times10^{-7}$ FL$^{3.672}$ | 0.95 | 37 |
| | Female | WT $=5.677\times10^{-6}$ FL$^{2.928}$ | 0.83 | 60 |
| Draganik and Pelczarski (1984) | Male | WT $=9.94\times10^{-4}$ TL$^{2.0005}$ | na | 260 |
| | Female | WT $=7.95\times10^{-4}$ TL$^{2.0473}$ | na | 31 |

**Table 5.** Relationships of fork length (cm) and round weight (kg) with gutted weight (kg) by sex for blue sharks in waters off Brazil Hazin *et al.* (1991)

| Sex | Equations | $r$ | $n$ |
|---|---|---|---|
| Male | GWT $=9.821+10^{-8}$ $FL^{3.695}$ | 0.95 | 33 |
| Female | GWT $=1.827+10^{-6}$ $FL^{3.154}$ | 0.82 | 60 |
| Male | GWT $=0.50+0.80$ WT | 0.99 | 39 |
| Female | GWT $=0.90+0.76$ WT | 0.98 | 61 |

**Table 6.** Precaudal length (cm) - maximum girth (cm) relationships for driftnet caught blue sharks in the North Pacific (Nakano and Shimazaki, 1989)

| Sex | Equations | $r$ | $n$ |
|---|---|---|---|
| Male | MG $=-2.42+0.43$ PL | 0.98 | 82 |
| Female | MG $=-7.47+0.51$ PL | 0.98 | 60 |

kg) and between round weight (kg) and GWT of blue shark by sex caught off Brazil (Table 5).

### 2.1.4 Length-girth relationship

Nakano and Shimazaki (1989) described the relationship between PL (cm) and maximum girth (MG in cm) for blue shark in the North Pacific while examining the mesh selectivity of driftnets (Table 6). A significant difference was found in the relationship between sexes ($P<0.01$). Female is more fecund to male.

## 2.2 Age and growth

Several studies on the age and growth of the blue shark have been conducted over the years. In the North Pacific, Cailliet *et al.* (1983) and Tanaka (1984) obtained estimates of blue shark age and growth parameters using vertebral staining techniques with silver nitrate and haematoxylin-eosin, respectively. Nakano (1994) also published a growth curve for blue sharks derived from observations of vertebral rings stained by silver nitrate considered together with length frequency analysis of sharks from embryo to adults. All of the studies fit their respective data to the von Bertalanffy growth function (Table 7).

In the North Atlantic, Von Bertalanffy growth parameters (in TL) were also estimated by Aasen (1966) using length frequency and by Stevens (1975) using vertebrae stained with silver nitrate (Table 8). Stevens (1976) reported that annual growth rate of blue shark was 32cm/yr (in TL) based on tag-recapture records. Skomal (1990) also estimated annual growth rate of 39.2cm/yr and 29.3cm/yr in fork length from measured tag-recapture data and refined tag-recapture data, respectively. Stevens (1990) revised annual growth rate of 12.6cm/yr from tagging data.

A comparison of growth curves standardized to total length for blue sharks from both the North Pacific and the Atlantic Oceans is graphically presented in Fig. 4 Growth functions among the various studies in the North Pacific appear quite similar, while models of Atlantic blue sharks predict faster and larger growth than their Pacific counterparts. While looking at a comparison of growth functions between the Northwest and Northeast Pacific by cross-exchange, dual method, and a comparative reading approach, Tanaka *et al.* (1990) pointed out sample and size biases, differences in preparation techniques, variable growth zone criteria, and low reader precision are the principle factors contributing to observed variances which preclude concluding that blue sharks in different parts of the world's oceans have different growth characteristics.

It is interesting that growth of blue shark appears similar among different parts of the world. Although some difference on the growth are recognized among areas, the similarity of its rate and small variations among areas are more remarkable characteristics of the species when compared with other species of sharks.

## 2.3 Reproduction

### 2.3.1 Size and age at maturity

Based on the frequency distribution of pregnant females by size, Suda (1953) reported the minimum size at maturity to be approximately 150cm PL (199cm TL) for female blue sharks in the Northwestern Pacific Ocean. Strasburg (1958) reported 18 pregnant females ranging from 208-247cm TL from the equatorial and Northeastern Pacific Ocean. Nakano *et al.*

**Table 7.** Von Bertalanffy growth parameters published for blue shark inhabiting in the North Pacific Ocean

| Study | Sex | $L_4$ | $K$ | $t_0$ | $n$ | Remarks |
|---|---|---|---|---|---|---|
| Cailliet and Bedford (1983) | Male | 295.3 | 0.175 | −1.113 | 38 | as TL |
| | Female | 241.9 | 0.251 | −0.795 | 88 | |
| Tanaka (1984) | Male | 308.2 | 0.094 | −0.993 | na | as PCL |
| | Female | 256.1 | 0.116 | −1.306 | na | |
| Nakano (1994) | Male | 289.7 | 0.129 | −0.756 | 148 | as PCL |
| | Female | 243.3 | 0.144 | −0.849 | 123 | |

**Table 8.** Von Bertalanffy growth parameters published for blue shark inhabiting in the North Atlantic Ocean

| Study | Sex | $L_4$ | $K$ | $t_0$ | $n$ | Remarks |
|---|---|---|---|---|---|---|
| Aasen (1966) | combined | 394 | 0.133 | −0.801 | | in total length |
| Stevens (1975) | combined | 423 | 0.110 | −1.035 | 82 | in total length |

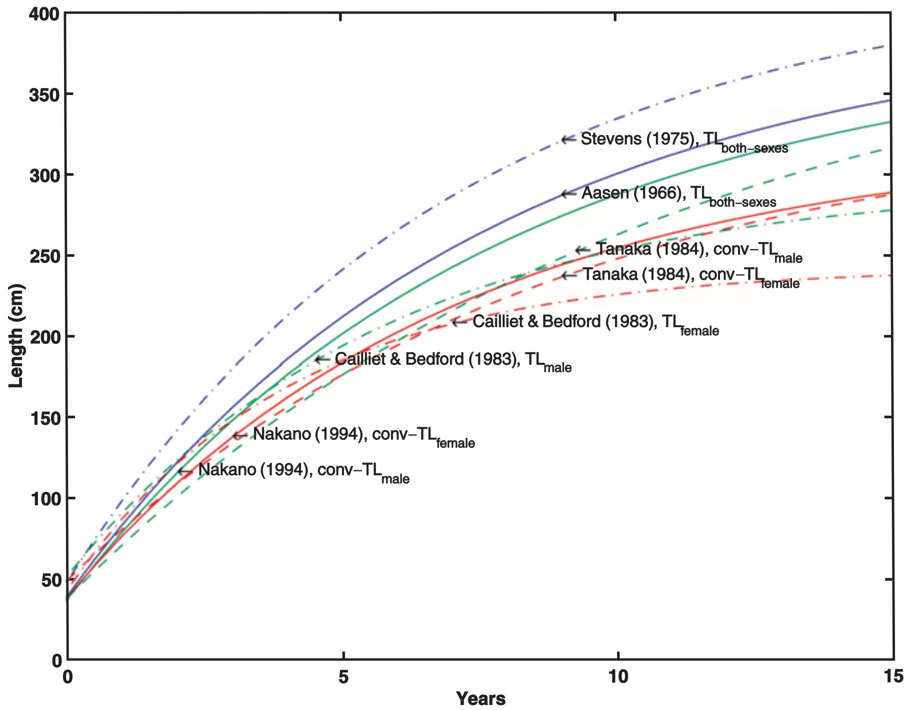
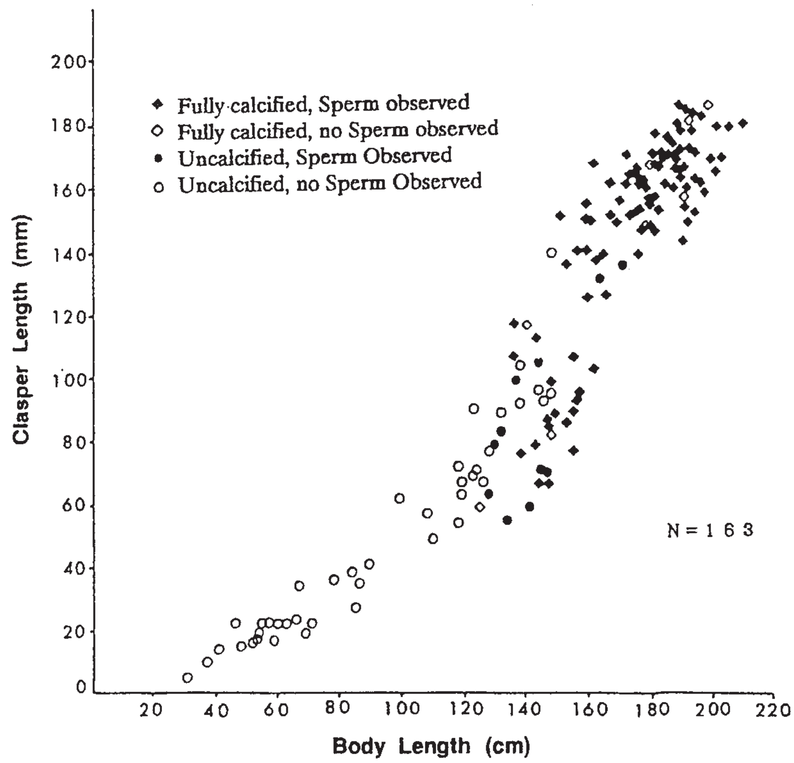



**Fig. 4.** Von Bertalanffy growth models for blue shark in total length (TL). [Note: growth models by Tanaka (1984) and Nakano (1994) originally developed in precaudal length (PL); function converted to TL with the relationship: TL=0.76PL+2.55 (McKinnell and Seki, 1998)].



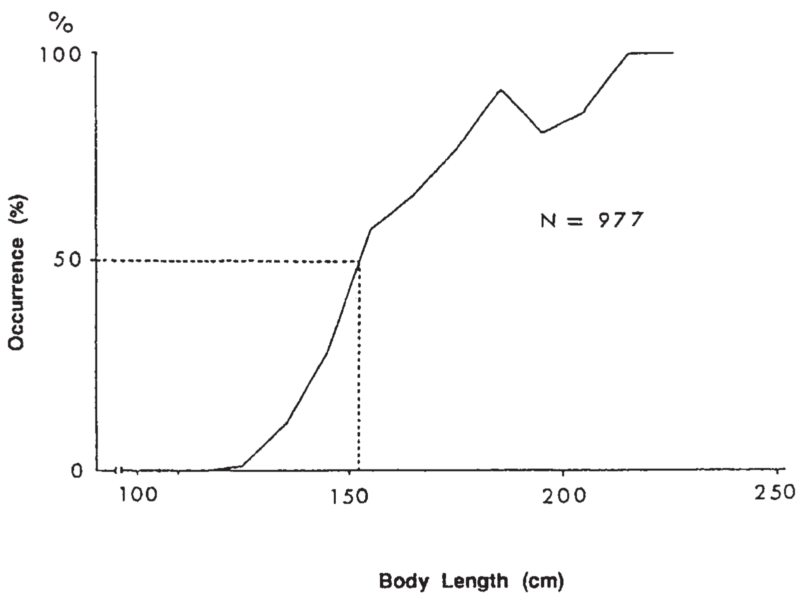




**Fig. 5.** Relationship between precaudal length and clasper length for blue shark caught in the North Pacific Ocean (top) and occurrence percent of males with sperm by 10cm interval of precaudal length (bottom) after Nakano (1994)

(1985) estimated that both sexes matured at about 150cm PL (199cm TL) from observations on the relative growth and calcification of the claspers and the presence of spermatophore for males, and the length frequency distribution of 203 pregnant females. Nakano (1994) corroborated prior conclusions with additional information and reported 153cm PL (203cm TL) as 50% maturity for males (Fig. 5) and 140-160cm PL (186-212cm TL) for females. Applying the age and growth model for Pacific blue sharks to the size at maturity suggests that the age of maturity should be 4-5 years old for males and 5-6 years old for females.

In the Atlantic Ocean, Bigelow and Schroeder (1948) reported that females with young were at least 7-8ft (213-244cm TL). In British waters, Stevens (1974) estimated the size at maturity for female blue shark to be around 180cm TL based on the smallest females with mating scars. Pratt (1979) reported maturity at 180cm and 145-185cm FL (220cm and 178-227cm TL) for 6 and 4-5 years old, males and females respectively, based on histological and anatomical observations of blue sharks caught in the Northwest Atlantic. Castro and Mejuto (1995) applied a non-linear functional relationship to the proportion of 419 pregnant females by size (170-260cm FL, 208-317cm in TL) in determining that 50% of females have embryos at 180cm FL (220cm TL).

In the Indian Ocean, Gubanov and Grigor'yev (1975) and Gubanov (1978) reported that blue shark do not reach maturity until at least 180cm in TL and 55kg in weight. In the equatorial Indian Ocean, the majority of pregnant females (around 80%) were more than 250cm and 70kg. The largest pregnant female was found to be 352cm and 210kg.

Comparing size at maturity of blue shark reported from the North Pacific and Atlantic Oceans, there does not seem to be significant differences between areas. Bigger size of mature females were reported from the Indian Ocean, it might be due to the different exploitation rate of stocks.

#### 2.3.2 Mating and parturition season, and gestation period

Suda (1953) suggested that in the Northwestern Pacific, the blue shark mating season occurs between June and August based on observations of mating scars on females. In the same study conducted in southern, coastal waters of Japan, parturition was estimated to occur in December-April following a nine month gestation since no pregnant females are observed after May. Nakano *et al.* (1985) and Nakano (1994), however, reported the appearance of pregnant females all year round in the North Pacific Ocean and suggested parturition occurs in May-June following a 12 month gestation period based on analysis of length frequency distributions of embryos and new-born sharks (Fig. 6).

Tucker and Newnham (1957) summarized occurrences of blue shark breeding in the Atlantic Ocean off Europe, with two cases of breeding observed in May-July and the smallest free-living young captured in June-August. In the Western Atlantic, Backus (1957) also reported breeding in September-November. From observations of sex ratio, mating scars, and presence of spermatozoa in the oviducal gland of females, Pratt (1979) hypothesized a two year parturition cycle for blue sharks in New England waters. Female sharks arrive on the continental shelf off south New England at 4-5 years old in late May and early June and copulate with males 6 years and older and acquire mating scars. The following spring these females remain offshore and fertilize their eggs in May or June with stored sperm. Embryos reach full term in 9-12 months and parturition occurs in April-July.

Although mating appears to coincide with the spring to early summer season, blue shark parturition has been reported over a wide seasonal range from spring to fall suggesting considerable variability between areas or among individuals.

Pratt (1979) recorded sperm storage in both sexes. For females in particular, spermatozoa can persist in the oviducal gland for at least the

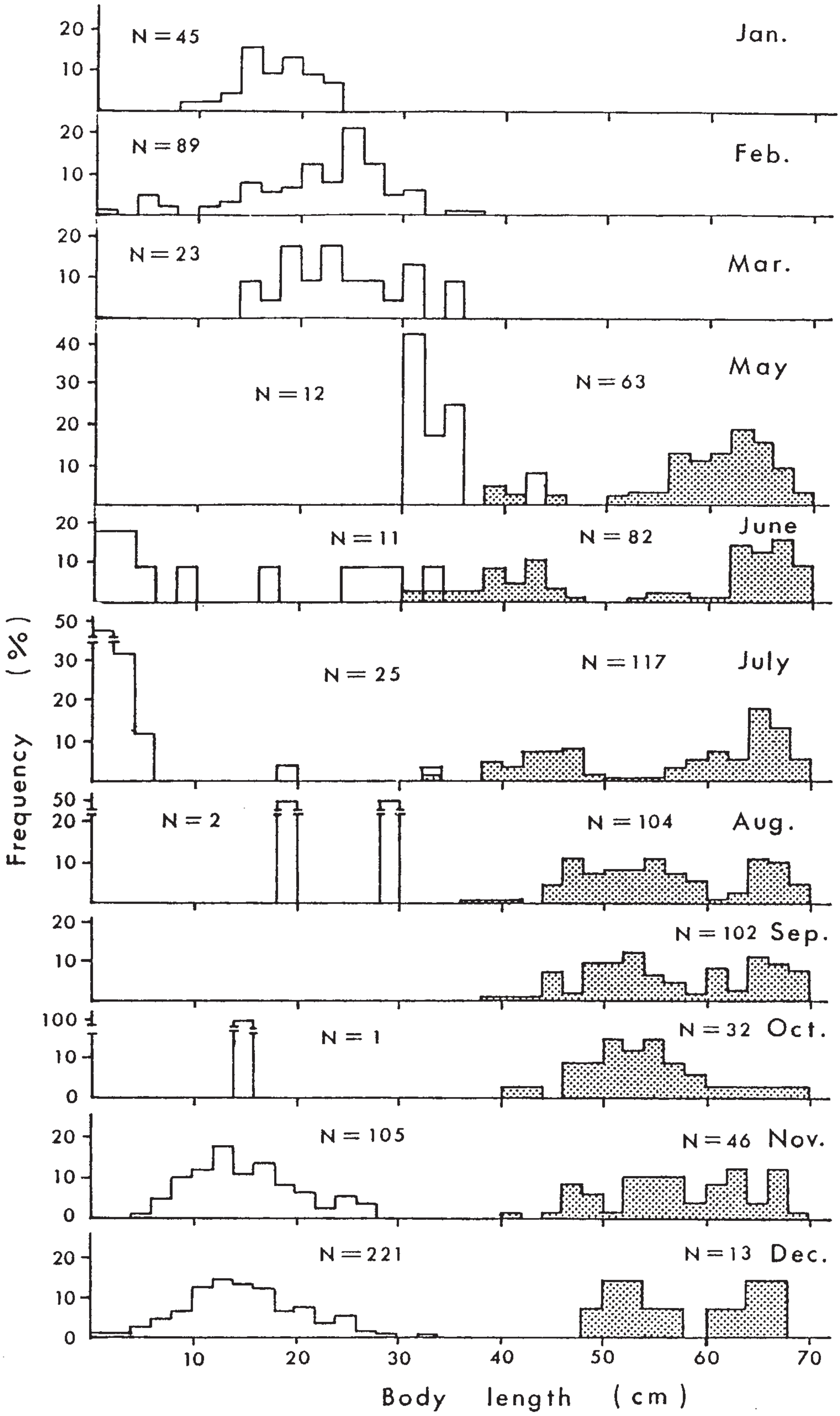



**Fig. 6.** Figure shows frequency distribution of precaudal length for blue shark embryo (white; monthly distribution of average embryo size by mother) and new-born shark (shadow) in the North Pacific Ocean. Both length frequencies overlapped in May to July. Overlapped length is considered size at birth of blue shark (Nakano 1994).

9-12 months of gestation and possibly 18-22 months in the case of delayed fertilization. Pratt and Tanaka (1994) examined the histological structure of male sperm storage in 14 species of Chondrichthyes; for the blue shark, they reported that males possess large quantities of spermatozeugmata in the robust ampulla during all seasons of the year.

### 2.3.3 Size at birth

The litter size of blue shark for the various oceans has been reported in several studies and is summarized in Table 9. Suda (1953) reported a maximum embryo size of 30 to 35cm PL (42 to 48cm TL) during December-April and small free-swimming young ranged of 50 to 70cm PL (68 to 94cm TL) in December-February from the Western Pacific Ocean. Strasburg (1958) observed the largest embryos ranging from 34 to 48cm TL in the area of 24-35°N in latitude. in the central Pacific during February; the smallest free-swimming shark caught by longline was 1.5 feet in length (46cm TL) and the maximum embryos observed were near full term. In the transitional-subarctic North Pacific, Nakano (1994) observed that the length frequency of embryos and newborn young overlapped in the 30-43cm PL (42-59cm TL) range and corroborated the size of birth reported by Suda (1953). (see Fig. 6 in section 2.3.2).

In the other areas of the world, the largest embryo measured by Bigelow and Schroeder (1948) from the Northwestern Atlantic Ocean was 35-45cm TL and the smallest free swimming shark measured 54-91cm TL. Tucker and Newnham (1957) reported a birth size of 35-60 cm TL and a free swimming size of 62-94cm TL in European waters. Pratt (1979) observed full term embryos ranging from 37.1-46.6cm FL (47-58cm TL) during June-July in the Northwestern Atlantic Ocean and estimated size at birth between 35 and 44cm FL (44 and 55cm TL). Although Castro and Mejuto (1995) reported embryo sizes of 3 to 35cm FL (5-44cm TL) in the equatorial eastern Atlantic, no size at birth was estimated.

From the equatorial Indian Ocean, Gubanov and Grigor'yev (1975) observed embryonic growth from 5-15cm TL in February to 8.5-35cm TL in July. No full term embryos, however, were found and they considered parturition to possibly occur outside of the sampled area.

### 2.3.4 Litter size and sex ratio of embryos

The blue shark has relatively high fecundity among Carcharhiniformes. In the Pacific Ocean, Suda (1953) reported a litter size of 30 embryos on average from the investigation of 47 pregnant females. Strasburg (1958) observed 4-38 embryos in a litter. Based on 189 pregnant females from the northern North Pacific, Nakano *et al.* (1985) recorded an average litter size of 25.7 (range 1-59). Nakano (1994) updated this information on the basis of 600 pregnant

**Table 9.** Litter size of blue sharks reported from different areas

| Area | Range | Average | Max | females examined | Study |
|---|---|---|---|---|---|
| NW Pacific | | 30 | | 47 | Suda (1953) |
| NE Pacific | 4-38 | | 38 | | Strasburg (1958) |
| Northern Pacific | 1-62 | 27.6 | 62 | 600 | Nakano (1994) |
| Southeast Pacific (Sydney area) | 4-57 | 32 | | 17 | Stevens (1984) |
| Southeast Pacific (New Caledonia area) | 11-75 | 43 | 75 | 29 | Stevens (unpublished) |
| NW Atlantic | 28-54 | 41 | 54 | 2 | Bigelow & Schroeder (1948) |
| NW Atlantic | | | 82 | 13 | Pratt (1979) |
| European waters | 14-63 | 36.6 | 63 | 11 | Tucker and Newnham (1957) |
| Equatorial East Atlantic | 4-75 | 37 | 75 | 128 | Castro and Mejuto (1995) |
| Equatorial Indian Ocean | 13-135 | 56 | 135 | | Gubanov & Grigor'yev (1975) |

females, recording an average litter size of 25.6 (range 1-62).

In the Mediterranean, Bigelow and Schroeder (1948) reported litter sizes of 28 and 54, Tucker and Newnham (1957) reported litter sizes of 14 to 63 in British seas, and Pratt (1979) found as many as 82 embryos in a single female taken in the Northwestern Atlantic Ocean. Castro and Mejuto (1995) found an average of 37 embryos per litter (range 4-75) in 128 pregnant females examined from the equatorial eastern Atlantic Ocean. They also noted a difference in the number of embryos in each uterus; averaging 14.9 in the left and 22.1 in the right. Gubanov and Grigor'yev (1975) reported the largest litter size with 135 embryos in a single female from the equatorial Indian Ocean; litter sizes averaged 56 pups.

Increased fecundity with increased mother size were described by Nakano (1994) and Castro and Mejuto (1995) from the North Pacific and the equatorial Eastern Atlantic Ocean, respectively. Both regressions between mother and litter size obtained for the areas were statistically significant (Table 10).

The sex ratios of embryos have been described in several studies. Suda (1953) found that the sex ratios of embryos from 51 individual pregnant females caught in the Northwestern Pacific ranged from 20-75% (proportion of females per litter), but the average was almost 1: 1. Nakano (1994) examined the null hypothesis of an equal sex ratio in litters of 114 pregnant females from the North Pacific Ocean and only two cases were statistically rejected. The null hypothesis of an equal sex ratio also could not be rejected in a pooled sample of 2,963 embryos (Nakano, 1994).

In the Mediterranean, Tucker and Newnham (1957) reported a sex ratio of unity with the exception of one case (26 males, 37 females) among four pregnant females. Stevens and McLoughlin (1991), however, noted a male dominant sex ratio in litters off New South Wales (60% male, $P^2$ test, $p < 0.001$). Castro and Mejuto (1995) reported equal sex ratio ($P^2$ test, $p < 0.001$) among 62 litters of females caught in the equatorial Eastern Atlantic. Gubanov and Grigor'yev (1975) reported the sex ratio among embryos in 6 pregnant females from the equatorial Indian Ocean on average is close to unity. The sex ratio of all embryos combined was 180: 189 (female: male).

#### 2.3.5 Abnormal embryonic development

Abnormal embryonic development in the form of stunted embryos were found in the uterus of a blue shark in the Northwestern Atlantic Ocean (Pratt, 1979), a phenomenon also observed quite frequently by the senior author in the Pacific Ocean. Four specimens, dicephalous, duplicitas anterior, duplicitas symmetros, conjoined twins, were reported from the waters adjacent to the Sea of Japan (Goto *et al.*, 1981).

### 2.4 Distribution and migration

#### 2.4.1 Geographical distribution

The blue shark is an oceanic, epipelagic elasmobranch with a circumglobal distribution in temperate and tropical waters of all oceans (Parin, 1970; Compagno, 1984) (Fig. 7). In the North Pacific, blue sharks are found from the equator to waters north of 57°N in the Gulf of Alaska during summer (Strasburg, 1958; Neave and Hanavan, 1960). The species is frequently caught by pelagic fisheries and is the dominant elasmobranch taken by tuna longline and driftnet fisheries, but is replaced by the oceanic whitetip shark (*Carcharhinus longimanus*) or other sharks in the tropical region, i.e., from the equator to

**Table 10.** Relationship between litter size and length of mother for the blue shark

| Study | Relationship | *r* | *n* |
|---|---|---|---|
| Nakano (1994) | Litter $= -3.349 + 0.179$ PL | 0.299 | 599 |
| Castro and Mejuto (1995) | Litter $= -91.97 + 0.6052$ FL | 0.806 | 128 |

20°N (Strasburg, 1958; Sivasubramaniam, 1963; Nakano, 1994; McKinnell and Seki, 1998). Hence, the relative abundance of blue shark is generally lowest in equatorial waters and increases with latitude (Fig. 8) (Strasburg, 1958; Sivasubramaniam, 1963; Nakano, 1994). As an oceanic species, blue shark catches also reportedly increase with distance from land not only in the Pacific but in the Atlantic and Indian Oceans as well (Strasburg, 1958; Gubanov and Grigor'yev, 1975; Hazin *et al.*, 1990).

In the North Atlantic Ocean, the blue shark is found from the equator to the shelf waters off New England, Cape Hatteras and Grand Newfoundland Banks and off England and Norway on the European side during summer (Aasen, 1966; Stevens, 1974, 1976; Pratt, 1979; Draganik and Pelczarski, 1984). Blue sharks

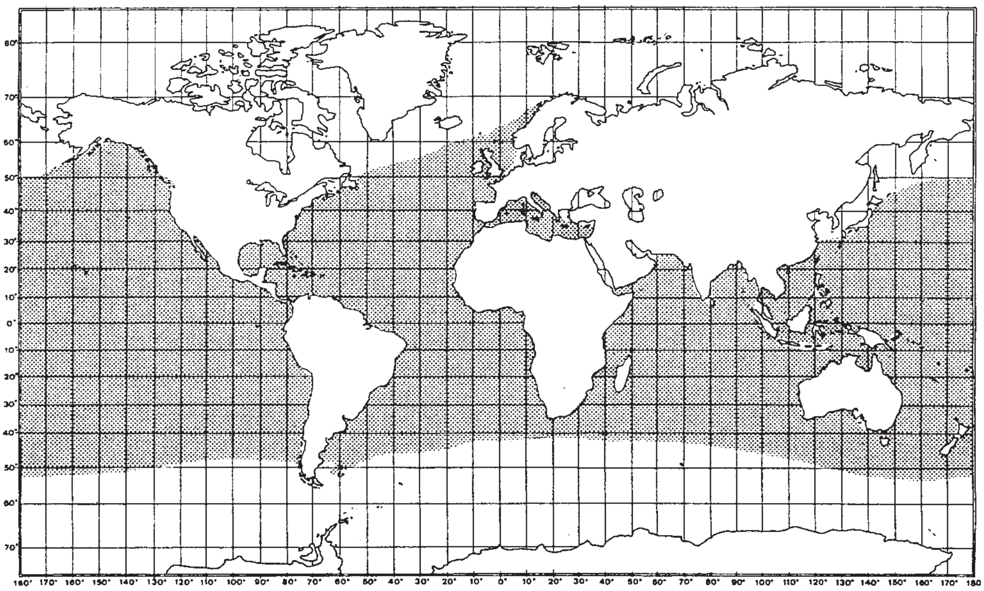


**Fig. 7.** Geographical map of blue shark distribution (Compagno, 1984)

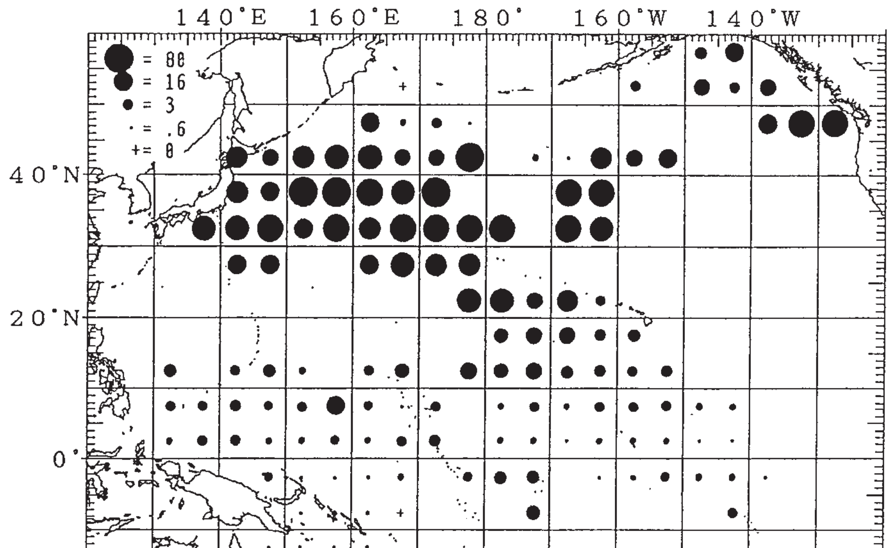



**Fig. 8.** Relative abundance of blue shark is expressed number of shark caught by 1,000 hooks in the North Pacific Ocean observed by Japanese longline research cruise (Nakano, 1994)

also inhabit the Mediterranean Sea (Tucker and Newnham, 1957; De Metrio *et al.*, 1984). Seasonal changes in catch per unit effort (CPUE) are observed in the southwestern equatorial Atlantic (off north Brazil) where catches are high in the southern hemisphere winter and spring and low in summer (Hazin *et al.*, 1990, 1994).

Intra and interspecific association were examined by Rey and Muńoz-Chapuli (1992) using the records of species catch by basket of longline gear from the tropical eastern Atlantic. The frequency distribution of catches along the longline was well explained by the negative binomial distribution, pointing to a clear tendency for intraspecific grouping. An interspecific association for blue sharks was also observed with silky (*Carcharhinus falciformis*) and shortfin mako shark (*Isurus oxyrinchus*) but a negative relationship was identified with the bigeye thresher shark (*Alopias superciliosus*).

The limited information on the distribution of blue shark in the tropical Indian Ocean is gleaned from longline catches (Gubanov and Grigor'yev, 1975). Blue sharks decrease in the proportion of longline catch from 46.6% in the west (from the east coast of Africa to 60°E) to 7-23% of the east (from 90°E to the territorial waters of Indonesia and India). A seasonal change of the proportion catch was observed in the eastern region, i. e., 15.6% in February-April and 23-7% in June-September.

The Blue shark is the most successful elasmobranch in pelagic waters and frequently the major by-catch species in fisheries operating on the high seas. Occupation of the pelagic niche in the temperate waters may be one of the key components of its domination in the pelagic ecosystem.

### 2.4.2 Distribution by depth

Strasburg (1958) compared hook rates of blue sharks in grouped branch lines by three depth bins, i. e., shallow 160-280ft (49-85m), intermediate 280-430ft (85-131m), deep 370-500ft (113-152m). Hook rates increased in shallower waters north of 30°N, while no evidence of a depth effect between the equator and 30°N was found. Similarly, Nakano *et al.* (1997) found no difference in blue shark catch rates by hook depth (80-280m) on three research cruises conducted in the equatorial area and northeast of Hawaii (Fig. 9). In contrast, Sivasubramaniam (1963) reported higher hook rates in deeper waters (hook depth between 50-150m) of the Atlantic, Pacific, and Indian Oceans, but the exact areas fished were not reported. Hazin *et al.* (1994) examined blue shark catch by depth and sex in the equatorial western Atlantic. Although both sexes were caught in all ranges of hook depth (87-206m), males were taken on deeper hooks (90-180m) than females (130-165m). In the tropical Indian Ocean, blue shark catch at depth var-

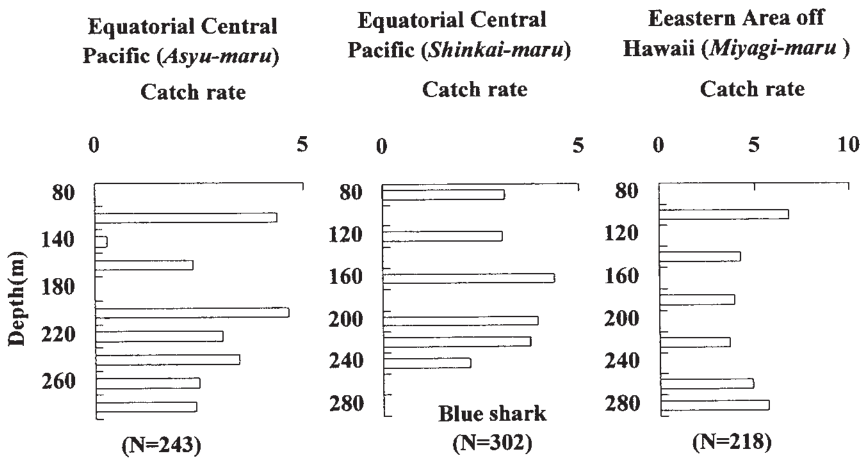



**Fig. 9.** Relative abundance of blue shark (number of sharks caught per 1,000 hooks of longline gear) by depth and area observed in the Pacific Ocean are shown in the figure (Nakano *et al.*, 1997)

ied zonally across the ocean (Gubanov and Grigor'yev, 1975). The maximum number of blue sharks (35.5%) was caught on hooks lowered to a depth of 130-140m in the western part of the equatorial Indian Ocean. In the central part of the equatorial Indian Ocean, the highest catches occurred at depth between 80-130m (around 20%) and 220m (30%) and to the east, catches were maximized around 170-180m (>25%).

Blue shark is distributed over a relatively wide range of water depths, but it tends to occur shallower in temperate waters and to concentrate deeper in the tropics. Varying vertical distribution patterns might be explained with shark size, sex, water temperature, or geographical area; however further study is needed to investigate the influence of these factors on the blue shark occupation of the water column.

### 2.4.3 Water temperature preference

Several studies have examined the relationship between blue shark catch and seawater temperature using longline catch data and oceanographic observations. In the Pacific, Strasburg (1958) reported 99% of blue sharks were caught in the water temperature range of 45 to 69°F (5.6 to 18.9°C) and 86% were in or below the thermocline in waters north of 25°N in latitude. The depth of the highest catches also became shallower following the shoaling of the thermocline to the north. In the eastern side of the North Atlantic, Draganik and Pelczarski (1984) observed maximum catches at depths of 18 to 40m with sea surface temperatures (SST) 24-25°C, and 16-20°C at a depth of 75m. Temperatures at depth of capture were reported for blue sharks in the tropical Indian Ocean by Gubanov and Grigor'yev (1975). In the western Indian Ocean, water temperatures at the 130-140m capture depths measured 14-15°C, in the central region largest catches occurred between 80-130m (around 20%) and 220m (30%) with corresponding temperatures of 19-25°C and 12-13°C, respectively and to the east, sharks were taken at 170-180m in water 12.5-15.5°C. In the North Pacific, Nakano (1994) reported that blue sharks were caught in the SST range of 10-25°C and 10-22°C by salmon research and large mesh driftnet gears, and that most catches were made at SSTs 16-18°C and 14-17°C respectively (Fig. 10). The driftnet gear typically fishes within 10m of the surface.

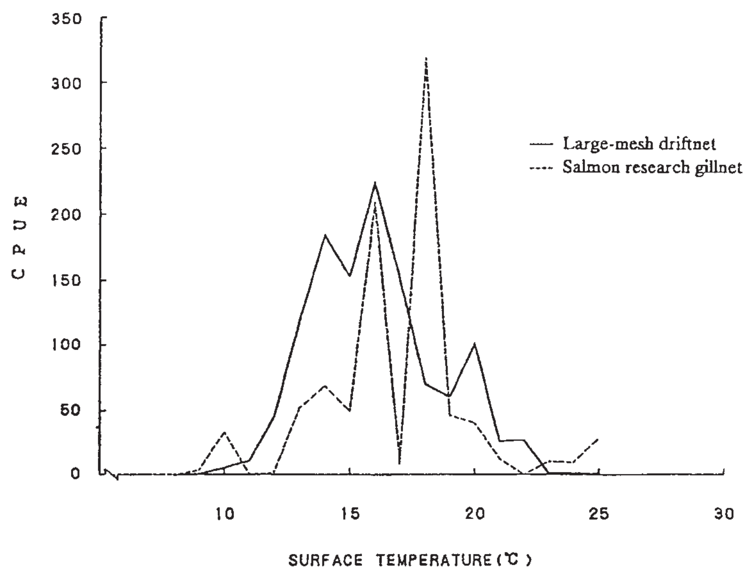



**Fig. 10.** Water temperature preference of blue shark is expressed as relative abundance (number of sharks caught per 100 tan of net units) by sea surface temperature observed by large-mesh driftnet and salmon research gillnet in the northern Pacific Ocean (Nakano, 1994)

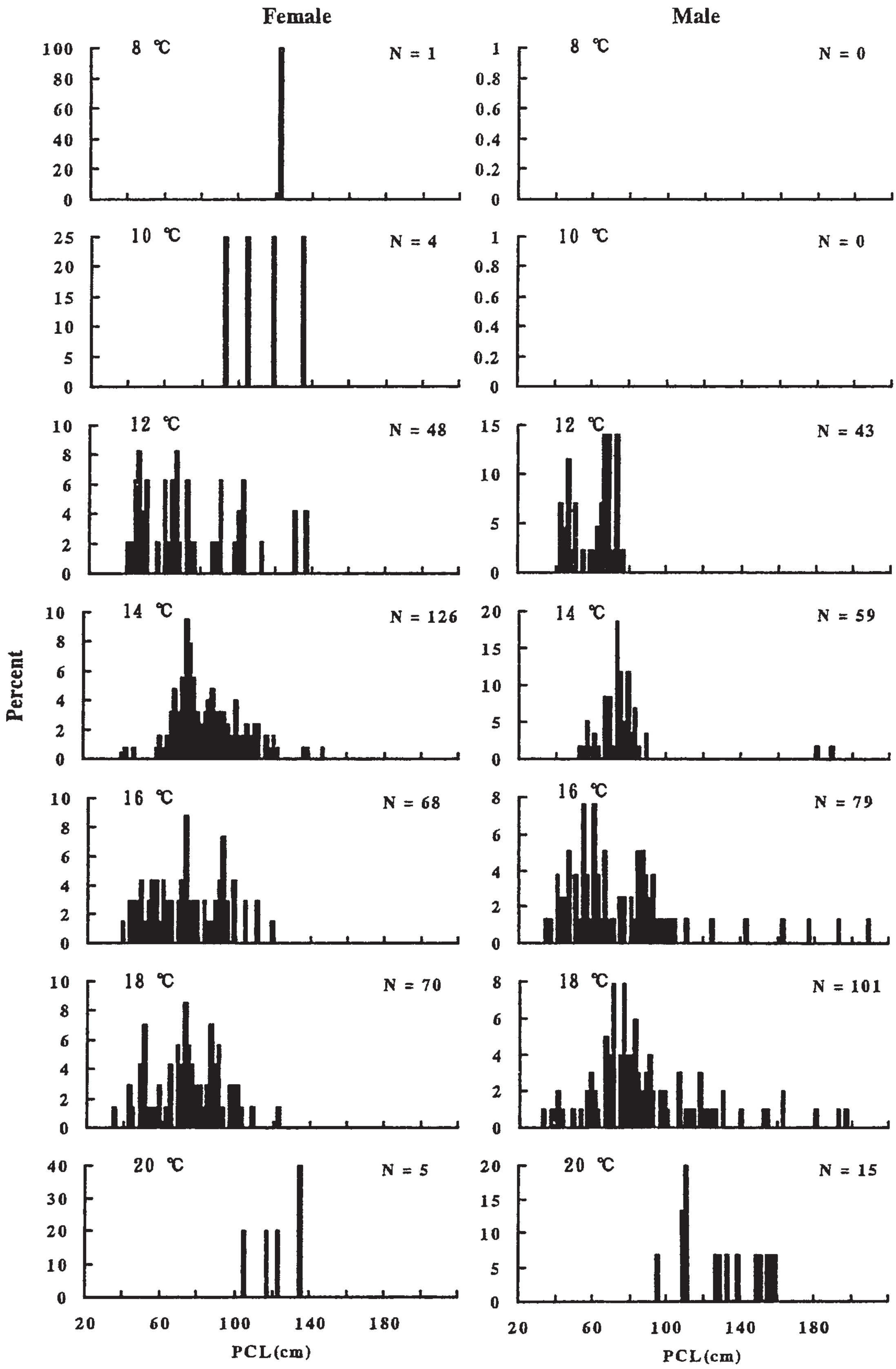



**Fig. 11.** Water temperature preference of blue shark by sex and size are expressed as relative abundance (number of shark caught per 100 tan of net units) observed by salmon research gillnets (Nakano and Nagasawa, 1996)

The range of water temperatures has also been assessed during acoustic tracking of blue sharks. Sciarrotta and Nelson (1977) reported that the occurrence of blue sharks off California is limited by the narrow temperature range of 8.5-17.5°C and that sharks spend 73% of tracking time in waters 14-16°C. Carey and Scharold (1990) observed blue sharks to frequently make vertical excursions between a minimum temperature of 7°C and a SST of 26°C.

Catches of blue shark with respect to water temperature, size, and sex were described by Nakano and Nagasawa (1996) from research surveys using surface salmon driftnet gear in the northern North Pacific (Fig. 11). Female blue sharks were caught at 8-21°C and males at 12-21°C. Young sharks smaller than 50cm PL (68cm TL) of both sexes were caught at 12-19°C. Large females tend to occur in cooler waters than males. Females over 90cm PL (120cm TL) were caught in a wider range of 8-21°C, while males were captured in warmer waters at 14-21 °C. Hazin *et al.* (1994) examined the vertical distribution of blue sharks by sex and temperature in the equatorial western Atlantic. In February-July, female CPUE was highest in 130-165m depth at temperatures 13.8-20.4°C, while males were caught mainly at about 165-180m deep and 12.9-17.1°C. Males were caught from 90-180m at 15-28°C in July-December. Water temperature preference by size and sex appears to play a significant role in determining the differences in catch and distribution observed by researchers in different areas.

### 2.4.4 Segregation by sex and size

Segregation by sex and size is commonly exhibited by elasmobranchs (Springer, 1970). Using longline catches, Suda (1953) reported several patterns of segregation among blue sharks in the western North Pacific. These include an increase in size of sharks in the southern tropics-subtropics, occurrence of smaller sharks (<100cm PL (134cm TL)) in waters to the north of 30°N in latitude near Japan, less occurrence of females in September-November (oceanographic summer) around 30-40°N in latitude and March-May between 20 and 30°N in latitude, and a dominance of females during summer near 0-10°N in latitude. Strasburg (1958) also examined segregation by sex and size of longline caught blue sharks but focused on the relationship between unisexual and mixed catches. He concluded (1) that if both unisexual and mixed catch represented schools then unisexual schools were derived from mixed schools by a behavioral size-sorting mechanism and (2) that the average length of mixed schools are smaller than unisexual schools, mixed schools decrease in average length to the north, and male schools appear farther south than female schools. Limitations in geographic coverage of both Suda and Strasburg's datasets, however, preclude a comprehensive assessment of the distribution by sex and size of North Pacific blue sharks. Using data collected by research vessels employing four fishing gear types, i. e., salmon research driftnet, large mesh driftnet, shark and tuna longline gear, Nakano (1994) developed a general model describing the sex-specific distribution including a biological interpretation of male and female blue sharks in the North Pacific (Fig. 12). A band (35-45°N) in the North Pacific Transition Zone (NPTZ) was identified as the primary region of parturition for blue sharks and a slightly wider band as the nursery area for 50-100cm PL (68-134cm TL) sharks. The distribution of subadult females, 100-150cm PL (134-199cm TL), reportedly extends north of the parturition grounds into the Gulf of Alaska, while subadult males, 100-150cm PL (134-199cm TL), occupied waters south of the parturition grounds. Nakano and Nagasawa (1996) further reported that the blue shark nursery ground complements that of salmon shark (*Lamna ditropis*) with some overlapping of distributions. Segregation of adult males and females in the subtropics and tropics has yet to be determined.

In other areas of the North Pacific, Harvey (1989) observed female dominance in Monterey Bay, California and noted that all females captured were reproductively immature. Taniuchi

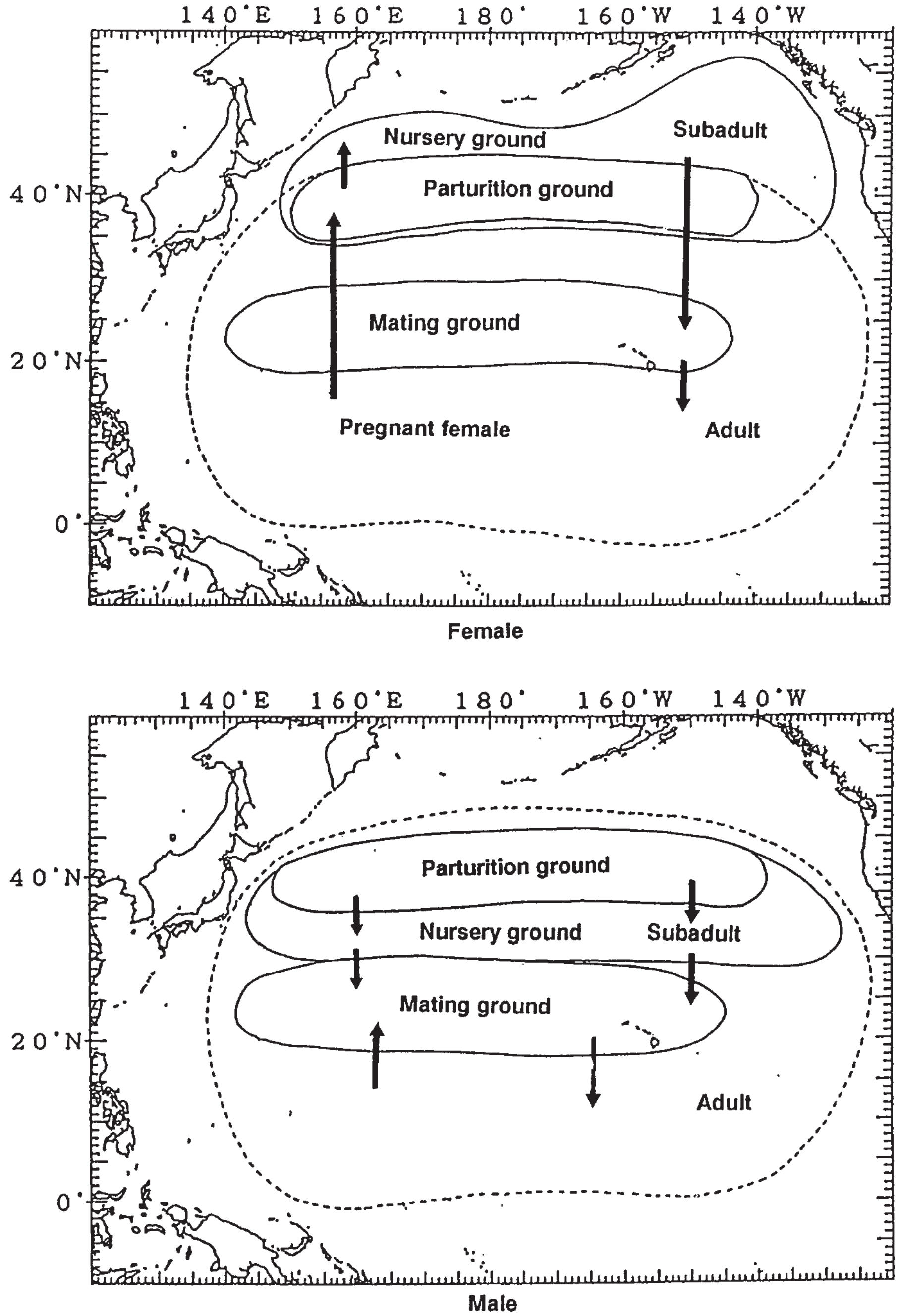



**Fig. 12.** Schematic blue shark migration model by sex proposed by Nakano (1994)

(1995) reported male dominance in the East China Sea and Okinawa waters, where males larger than 50kg appeared in the former area and rather small males modally 30kg in weight occupied the latter area. McKinnell and Seki (1998) examined blue shark catches from the high seas squid driftnet fishery in the NPTZ and the experimental fishery off west coast of North America and reported that blue sharks caught in the driftnet fishery consisted mainly of smaller sharks (<100cm PL) and found no significant difference in the sex ratio and size between sex; sharks caught by the experimental fishery were larger. Males were dominant in international waters while females were dominant in waters farther north into the Gulf of Alaska and in coastal waters. Observations from the two fisheries were consistent with

Nakano's model.

In the Atlantic, Bigelow and Schroeder (1948) reported male dominance in waters off the northeastern U.S. and Canada in summer. Similarly, Pratt (1979) also reported the absence of mature females in the area of the northeastern U.S. in summer, although immature and subadult sharks exhibited a sex ratio about unity. Across the ocean basin, female dominance was reported in British waters where males composed only 6 % of the catch and all were considered reproductively immature (Stevens, 1976) and in the English channel where only 1 of 73 captured sharks was male (Vas, 1990). In the eastern Atlantic along the continental shelf from the equator to 40°N, Draganik and Pelczarski (1984) reported dominance of males and sex ratios (female: male) of approximately 1: 3 to the south of 20°N in latitude and 1: 10 to the north of 20°N in latitude.

In the equatorial eastern Atlantic, Castro and Mejuto (1995) used the size distribution by sex and area as evidence that males are slightly more numerous and significantly larger that their female counterparts. A sex ratio shift by size class (females) begins around 50% for the smaller sizes and increases gradually up to 185cm FL (227cm TL), and then decreases in larger sizes. In the equatorial western Atlantic off northern Brazil, males dominate all year round except March (Hazin *et al.*, 1994). Male's ratios were especially high during September-December (89-98%).

In the equatorial Indian Ocean, Gubanov and Grigor'yev (1975) reported male dominant sex ratios in the western part for 68.6%, in the area of Maldives Islands for 96%, and in the eastern part for 87.2%. The greatest sex ratio of female was found at 47.1% in the region of the Mascarene ridge. For the entire Indian Ocean region studied, females accounted for only 26.1%.

Around Tasmania Island, Australia, longline caught blue sharks ranged from 30-312cm FL, with the mode for both sexes at 80-90cm FL (Stevens, 1992). The sex ratio was dominated by females (65%), although there were proportionately more males above 200cm FL (44% female). Larger sharks were caught further north in relatively low latitudes (Fig. 13). Between 15-34 °S in latitude, sharks ranged in length from 120 to 310cm FL, with the mode at 200-210cm FL and 68% of sharks greater than 200cm FL. In contrast, the modal shark length was 80-90cm FL between 35-39°S in latitude with only 1 % of sharks greater than 200cm FL. Females were more abundant in the catches from southern waters where the sex ratio were 56% female in

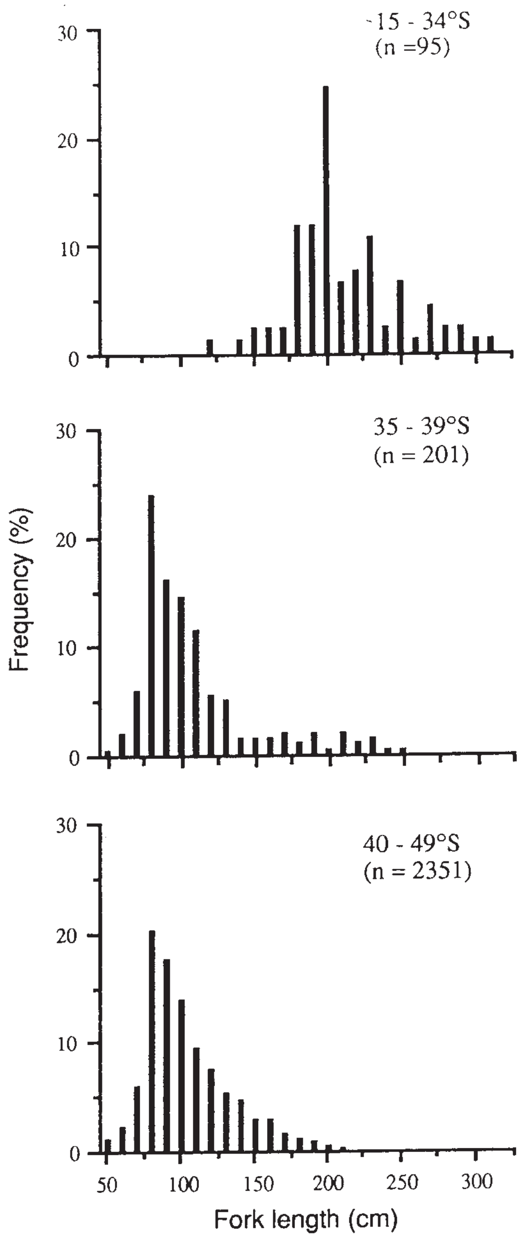



**Fig. 13.** Size composition of blue shark by latitude caught by Japanese longline fishery off south-eastern Australia (Stevens, 1992)

the area 15-39°S in latitude and 66% female in the area 40-49°S in latitude.

As explained by Nakano's migration model, segregation by size is observed by latitude. Smaller sharks occur in cold water at temperate and sub-arctic area. Larger sharks appear in warm waters at tropical area. Segregation by sex is clearly recognized at nursery ground in temperate and sub-arctic area where immature females are dominant. Segregation by sex is also observed in tropical waters, however the general segregation pattern is not known.

#### 2.4.5 Migration and movement

A large scale north-south movement is well documented for blue sharks in the North Pacific (Strasburg, 1958; Neave and Hanavan, 1960; Mishima, 1981; Nakano, 1994; Nakano and Nagasawa, 1996). From observations of even sex ratios, minimum embryo, uterine eggs, and occurrence of mating scars as evidence, it is believed that mating in blue sharks occurs during the summer (peaking in July) in the area of 20-30°N in latitude. (Suda, 1953). Pregnant females then move north and give birth early the ensuing summer near 35-45°N in the NPTZ. The young-of-the-year (YOY), sharks 50-100cm PL (68-134cm TL), occupy and feed in the same region but over a slightly wider latitudinal band than the nursery area. Subadult females, 100-150cm PL (134-199cm TL), reportedly occupy the nursery grounds and the region immediately to the north including the Gulf of Alaska. Alternatively, subadult males 100-150cm PL (134-199cm TL), extend their distribution to the south of the area of parturition. Upon maturity, blue sharks migrate south to the subtropics and tropics and join the reproductively active population. Blue sharks generally stay in the northern transitional-subarctic water for five to six years prior to reaching maturity (Mishima *et al.*, 1981; Nakano, 1994; Nakano and Nagasawa, 1996) (Fig. 14). A general blue shark migration model for the North Pacific incorporating CPUE distribution by size and sex was also developed (see Fig. 12 in section 2.4.4).

In the Northeast Atlantic, tag-recapture information indicates a seasonal migration of blue sharks between 30-50°N latitudes (Stevens, 1976) (Fig. 15). Higher return rates from small sharks (modal length 100-110cm TL) suggest that younger sharks remain within a relatively confined area and do not make the more extensive north-south migration undertaken by larger sharks. An initial southward movement of larger females at the beginning of the season is followed by a movement of smaller sharks, including more males, around the end of July or beginning of August (Clarke and Stevens, 1974). Two transatlantic and the furthest three long-distance recaptures suggest that some sharks travel right around the north Atlantic gyre which could provide some interchange between blue sharks in the eastern and western Atlantic (Stevens, 1976).

From these movement models, patterns of north-south migration, gender and ontogenetic differences, and possibly transoceanic migration have emerged. Evidence for east-west movement and migration among adult sharks in the tropics has yet to be obtained. A complete understanding of blue shark migration will require further study on the distribution of adults in the tropical and subtropical regions of the world's oceans.

#### 2.4.6 Diel behavior

Diel swimming behaviors of the blue shark were observed using acoustic telemetry near Santa Catalina Island, California and off the Northeast USA by Sciarrotta and Nelson (1977), Carey and Scharold (1990), respectively. The studies reveal a clear day-night difference in swimming patterns, with the largest vertical oscillations and deepest dives occurring during the day and smaller vertical excursions occurring in the region of the thermocline at night. The shoreward movements shown in Fig. 16 were observed in nighttime seasonally between late March and early June off California (Sciarrotta and Nelson, 1977). The sharks occupied a depth range of 18-42m for 92% of the time and appeared to equal or exceed 100m in only

3.9% of the observations. Vertical excursions were undertaken more frequently at night moving through a depth range of 0-110 m. Alternatively off the northeast USA coast, sharks took a rather steady course and made frequent vertical excursions during the day through depths ranging from 0 to 600m depth (Fig. 17, the figure cited does not include the individual which recorded the maximum depth) (Carey and Scharold, 1990). At night, shark oscillations were smaller in amplitude and confined to the depths near the thermocline. These activity

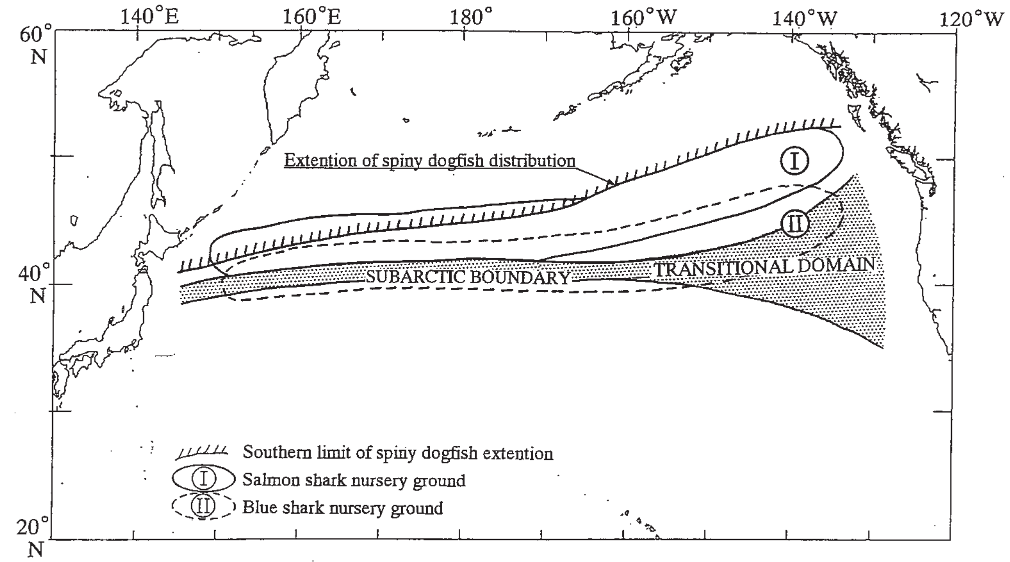



**Fig. 14.** Schematic map of blue shark nursery area and relation with other species presented by Nakano and Nagasawa (1996)

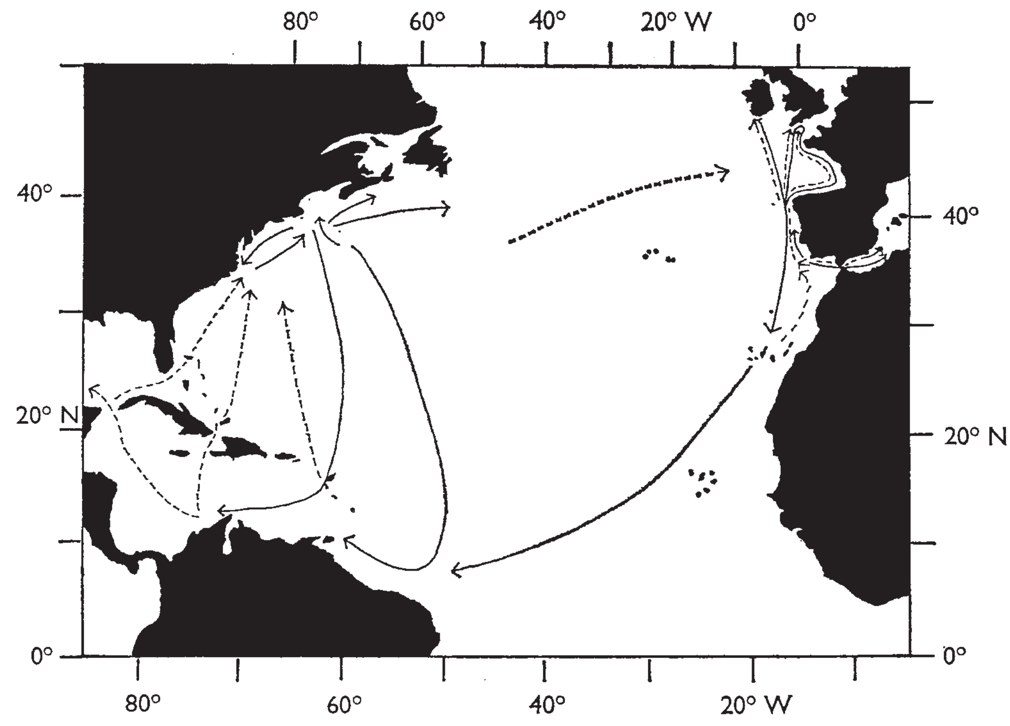



**Fig. 15.** Blue shark migration model in the North Atlantic Ocean suggested by tag-recapture data (Stevens, 1976)

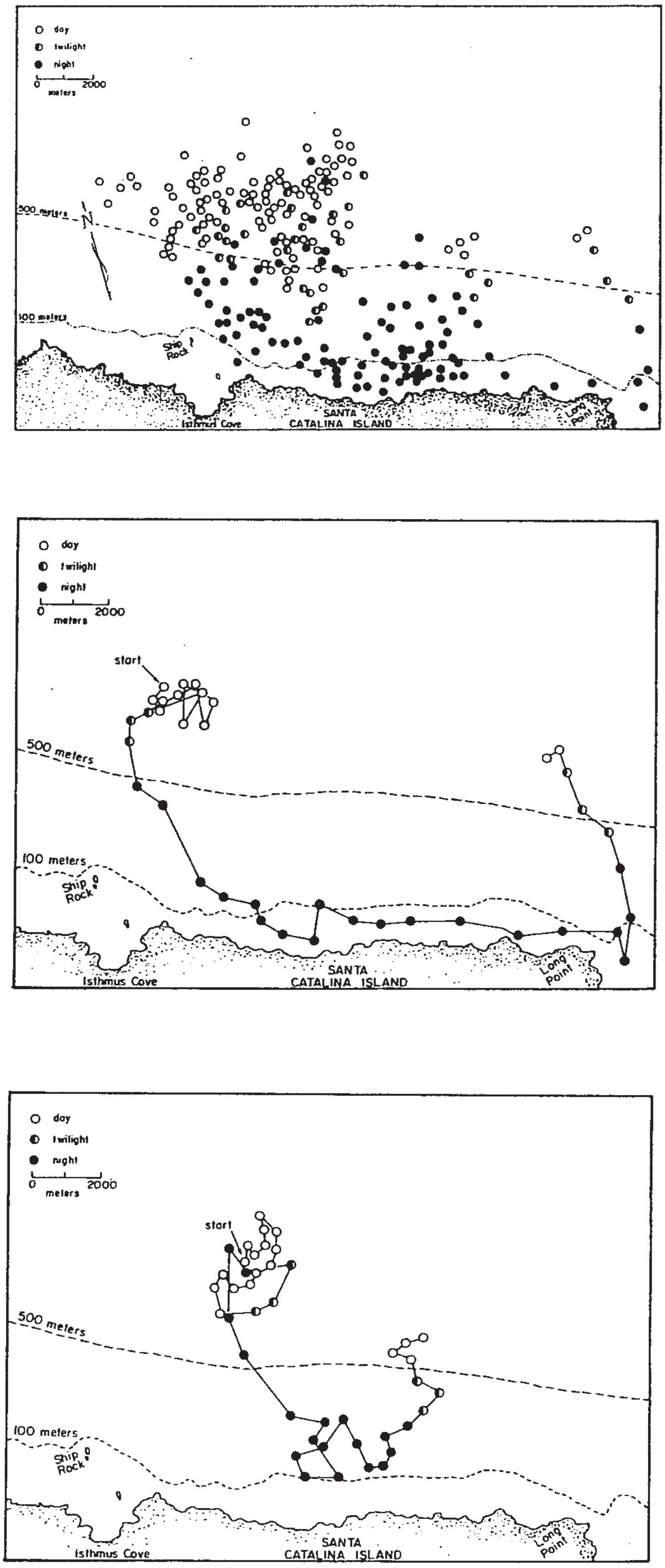



**Fig. 16.** Night shoreward movement of blue shark were observed and reported by Sciarrotta and Nelson (1977). Positions of seven blue sharks tracked from late March through early June 1972. White and black circles indicate position at day and night time respectively and all day positions are offshore, while the majority of night positions are near shore (top). Two individual tracking of blue shark at approximately 0.5-h intervals were shown middle and bottom figures. Both individuals revealed inshore movement at night time (black dots).

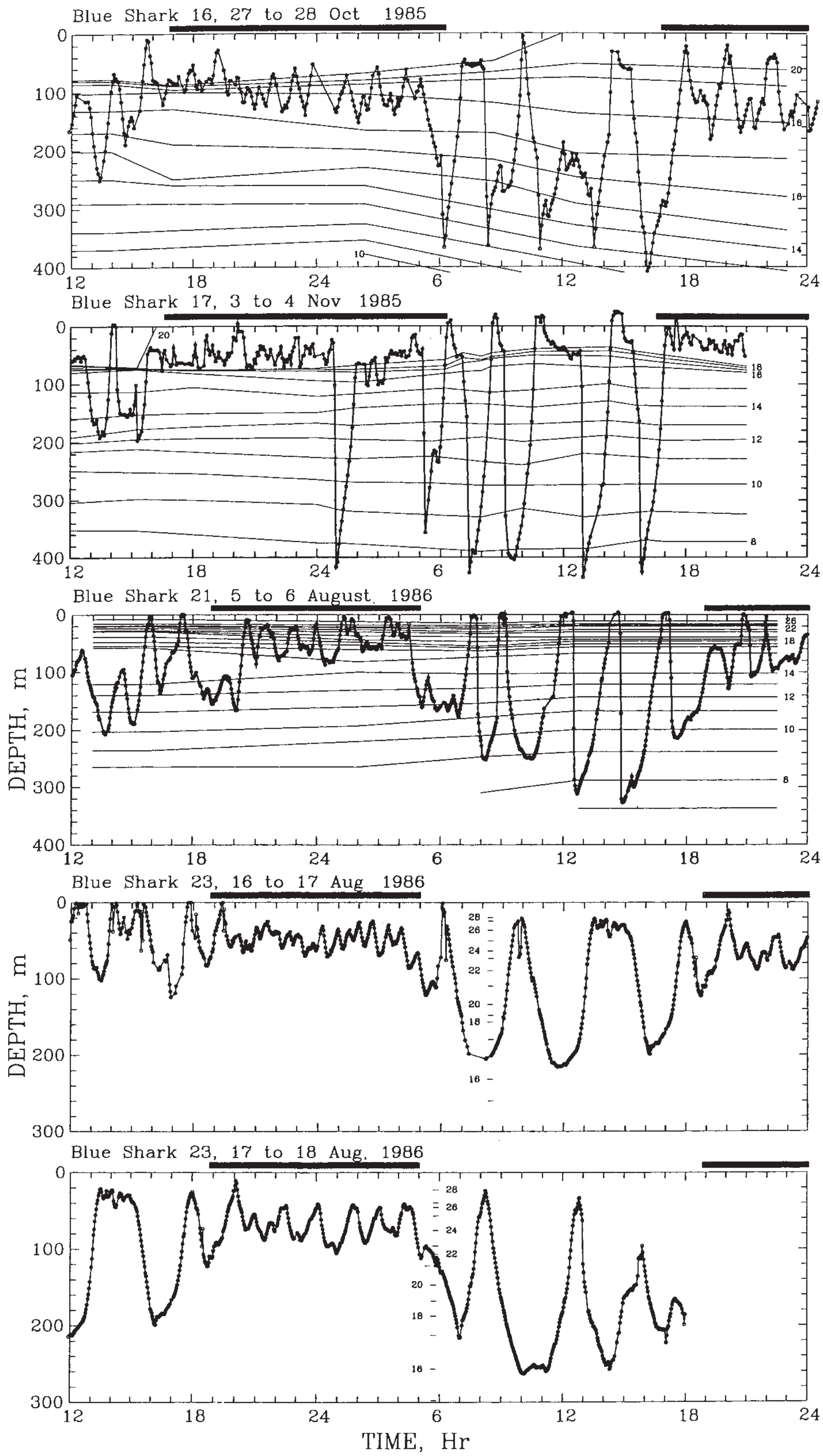



**Fig. 17.** Swimming depth observed by acoustic telemetry for five individual sharks in the Atlantic Ocean (Carey and Scharold, 1990), the horizontal axis is time. The light horizontal lines are 1℃ isotherms, the black horizontal bar indicates night. The sharks swam in or near the thermocline at night and made large excursions between the surface and depths of several hundred meters during the day, experiencing sharp temperature changes as they moved through the thermocline.

patterns were observed during August-November and March but not June through July suggesting seasonal changes in diving patterns.

The mean swimming speed for sharks off California was 1.3 km/h during the day and 2.8 km/h for night (Sciarrotta and Nelson, 1977). The highest mean speeds occurred at relatively great depth, 4.8 km/h of 69m, while the lowest speeds occurred at much shallower depths, 0.5km/h at 20m. Off the northeast USA, swimming speeds were recorded in the range of 30-48cm/s (1.08-1.73km/h) (Carey and Scharold, 1990). Like other sharks, blue sharks utilize the ambient electric and magnetic fields for orientation (Carey and Scharold, 1990).

## 2.5 Trophic relationships

### 2.5.1 Feeding

Despite being amongst the most common large fishes in pelagic and coastal water of the world's oceans, rather surprisingly little detail is known about the trophic relationships of the blue shark. Blue sharks are recognized as apex predators that generally feed indiscriminately on relatively small pelagic fishes and cephalopods (Strasburg, 1958; LeBrasseur, 1964; Clarke and Stevens, 1974; Tricas, 1979; Compagno, 1984; Brodeur *et al.*, 1987; Seki, 1993).

Some blue shark distribution and movement patterns appear linked to feeding habits. In the central North Pacific, young-of-the-year sharks occupy the more productive waters of northern Transition Zone (ca. 38-45°N in latitudes) and Subarctic Boundary where a large food base is available. Nakano (1994) speculated that the food availability in the region may dictate the location of the nursery grounds.

Swimming patterns observed from telemetered blue sharks off the southwest and northeast coasts of North America provide clues towards the sharks' feeding behavior (Sciarrotta and Nelson, 1977; Carey and Scharold, 1990). Extensive vertical excursions of several hundred meters were typically observed for blue sharks and were in part attributed to foraging activities (Carey and Scharold, 1990). Sharks were observed to descend fairly rapidly followed by a slower return ascent; a pattern consistent for a visual predator that might backlight its prey against light from the surface. Both studies suggested increased feeding activity in late evening and night when vertical excursions through the water column were smaller in amplitude and confined to depths near the thermocline. Diel differences observed in the diving depths of blue sharks were suggested to be associated with pursuit of vertically migrating prey. Seasonal offshore-inshore horizontal movement patterns were suggested as a response to seasonal availability of prey (Sciarrotta and Nelson, 1977).

### 2.5.2 Food

Stomach content studies of the blue shark conducted in both coastal and oceanic waters have revealed a diet composed largely of relatively small pelagic fishes and cephalopods and seasonal swarms of crustaceans (Table 11). Of particular importance among forage items are pelagic squids (Clarke and Stevens, 1974; Dunning *et al.*, 1993). In the central oceanic North Pacific, longline and gillnet caught blue sharks fed on commonly occurring pelagic nekton such as sauries, pomfrets, and squid (Strasburg, 1958; LeBrasseur, 1964; Seki, 1993). Towards the coasts, schooling coastal small pelagics such as northern anchovy, *Engraulis mordax*, and Pacific hake, *Merluccius productus* and seasonally on swarming euphausiids, *Thysanoessa spinifera* composed the diets of blue sharks taken with longlines (Harvey, 1989), handlines (Tricas, 1979), and purse seines (Brodeur *et al.*, 1987) off the U.S. west coast. Young-of-the-year blues sharks (<65cm PL) had stomach contents dominated by micronektonic myctophids and small gonatid squids (Seki, 1993). Principal forage base in young and adults alike tend to be schooling species and are believed to be exploited when the prey migrates near the surface at night. Compagno (1984) suggested that the presence of papillose gillrakers in blue sharks, a characteristic unique among

**Table 11.** Food items reported in diet of North Pacific blue shark (list does not include bait)

| PREY ITEM | Strasburg (1958) | LeBrasseur (1964) | Tricas (1979) | Harvey (1989) | Seki (1993) |
|---|---|---|---|---|---|
| **Fishes** | | | | | |
| Petromyzonidae | | | | | |
| *Lampetra tridentata* | | | | × | |
| Squalidae | | | | | |
| *Squalus acanthias* | | | × | × | |
| Salmonidae | | | | | |
| *Oncorhynchus* sp. | | × | | | |
| Clupeidae | | | | | |
| *Clupea harengus pallasi* | | | | × | |
| Engraulidae | | | | | |
| *Engraulis mordax* | | | × | × | |
| Alepisauridae | | | | | |
| *Alepisaurus ferox* | | | | | × |
| *Alepisaurus* sp. | × | | | | |
| Anotopteridae | | | | | |
| *Anotopterus pharao* | | × | | | |
| Echeneididae (remoras) | × | | | | |
| Sternoptychidae | | | | | |
| *Argyropelecus* sp. | | | | | × |
| Myctophidae | × | × | | | × |
| *Stenobrachius leucopsarus* | | | | × | |
| Merlucciidae | | | | | |
| *Merluccius productus* | | | × | × | |
| Ophidiidae | | | | | |
| *Chilara taylorix* | | | | × | |
| Batrachoididae | | | | | |
| *Porichthys notatus* | | | | × | |
| Exocoetidae | | | | | |
| *Cypselurus californicus* | | | × | | |
| Scomberesocidae | | | | | |
| *Cololabis saira* | | × | | | |
| Syngnathidae | | | | | |
| *Syngnathus californiensis* | | | × | × | |
| Scorpaenidae | | | | | |
| *Sebastes goodei* | | | | × | |
| *Sebastes paucispinus* | | | | × | |
| *Sebastes* spp. | | | × | × | |
| Anoplopomatidae | | | | | |
| *Anoplopoma fimbria* | | | | × | |
| Bramidae | | | | | |
| *Brama japonica* | | × | | | × |
| Carangidae | | | | | |
| *Trachurus symmetricus* | | | × | | |
| Pentacerotidae | | | | | |
| *Pseudopentaceros wheeleri* | | | | | × |
| Pomacentridae | | | | | |
| *Chromis punctipinnis* | | | × | | |
| Sciaenidae | | | | | |
| *Genyonemus lineatus* | | | | × | |
| Gempylidae | | | | | × |
| Ostraciidae (trunkfishes) | × | | | | |
| Bothidae | | | | | |
| *Citharichthys sordidus* | | | | × | |
| Pleuronectidae | | | | | |
| *Lyopsetta exilis* | | | | × | |
| | | | | | |
| Flying fish eggs | × | | | | |
| Unidentified fishes | × | | × | × | × |
| Unidentified elasmobranch | | | | × | |
| | | | | | |
| | | | | | |
| Empty stomachs (%) | 54.3 | 17.2 | 6 | 5.3 | 55.6 |
| Number stomachs examined | 140 | 29 | 81 | 150 | 72 |
| Capture methodology | longline | gillnet | handline | longline | longline |
| | East/Central Pacific | Gulf of Alaska | Santa Catalina, U.S. west coast | Monterey Bay, U.S. west coast | N. Central Pacific |

| PREY ITEM | Strasburg (1958) | LeBrasseur (1964) | Tricas (1979) | Harvey (1989) | Seki (1993) |
|---|---|---|---|---|---|
| **Cephalopods** | | | | | |
| Loliginidae | | | | | |
| *Loligo opalescens* | | | × | × | |
| Octopoteuthidae | | | | | |
| *Octopoteuthis deletron* | | | × | × | |
| Onychoteuthidae | | | | | × |
| *Onychoteuthis borealijaponica* | | | × | × | |
| Gonatidae | | | | | × |
| *Gonatus spp.* | | | | × | |
| Histioteuthidae | | | | | |
| *Histioteuthis heteropsis* | | | × | | |
| *Histioteuthis* spp. | | | × | × | |
| Ommastrephidae | | | | | |
| *Dosidicus gigas* | | | × | × | |
| *Ommastrephes bartramii* | | | | | × |
| Thysanoteuthidae | | | × | | |
| Chiroteuthidae | | | | | |
| *Chiroteuthis calyx* | | | × | | |
| Mastigoteuthidae | | | | | |
| *Mastigoteuthis pyrodes* | | | × | | |
| Cranchiidae | | | | | |
| *Leachia* sp. | | | × | | |
| Argonautidae | | | | × | |
| *Argonauta pacifica* | | | | | |
| Ocythoidae | | | | | |
| *Ocythoe tuberculata* | | | × | | × |
| Vampyroteuthidae | | | | | |
| *Vampyroteuthis infernalis* | | | × | × | |
| Octopodidae | | | | | |
| *Octopus* spp. | | | × | × | |
| Unidentified squids | × | × | | | × |
| Unidentified octopods | × | | | | |
| Cephalopod (unidentified) | × | | | × | |
| | | | | | |
| **Crustaceans** | | | | | |
| Amphipoda (Lysianassidae) | | | × | | |
| Lophogastridae | | | | | |
| *Gnathophausia* sp. | | | | | × |
| Euphausiacea | | | | | |
| *Euphausia pacifica* | | | | × | |
| *Thysanoessa spinifera* | | | | × | |
| Unidentified euphausiids | | | | × | |
| Reptantia (crabs) | × | | | | |
| Natantia (shrimps) | × | | | | |
| Pandalidae | | | × | | |
| *Pandalus jordani* | | | | × | |
| Oplophoridae | | | | | |
| *Hymenodora* sp. | | × | | | |
| | | | | | |
| **Tunicata** | | | | | |
| Salpidae | | | | | |
| *Salpa fusiformis* | | × | | | |
| | | | | | |
| **Plants** | | | | | |
| *Renilla kollikeri* | | | × | | |
| *Phyllospadix torreyi* | | | × | | |
| Unidentified plant | | | | × | |
| | | | | | |
| **Miscellania** | | | | | |
| Seabirds (Sulidae--boobies) | × | | | | |
| Feather | | | × | | |
| Blubber (?) | × | | | | |
| Plastic | | | × | | |
| Unidentified remains | | | | × | |
| | East/Central Pacific | Gulf of Alaska | Santa Catalina, U.S. west coast | Monterey Bay, U.S. west coast | N. Central Pacific |

the requiem sharks, may facilitate retaining smallish prey (such as euphausiids) from slipping through the internal gill slits. Additionally, blue sharks have also been reported to attack the cod-ends of trawls to gain access to the catch and have been seen biting at floating debris at the surface (Compagno, 1984). Similar diet compositions have been reported for blue sharks in the North Atlantic (Stevens, 1973; Clarke and Stevens, 1974), and in the South Pacific off Australia (Dunning *et al.*, 1993).

#### 2.5.3 Predators

No known predators exist for adult blue sharks; however predation on young may occur by larger sharks and marine mammals.

## 3.0 Population

### 3.1 Stock unit

The population structure of the blue shark is not known. Although some trans-equatorial tag recaptures have been reported in the Atlantic (Casey *et al.*, 1989), there is also evidence suggesting separate northern and southern hemisphere blue shark populations. Such evidence includes: high density in high latitude areas and low density in the equatorial water of the Pacific (Strasburg, 1958; Nakano, 1994), existence of parturition and nursery grounds in the high latitudes (Tucker and Newnham, 1957; Nakano, 1994), and trans-Atlantic movement of sharks (Stevens, 1976).

Hazin *et al.* (1991) compared morphometrics of blue sharks caught in the equatorial western Atlantic with those collected in the Pacific and northwestern Atlantic. Overall differences were not found to be significant, confirming the general similarity between the Atlantic and Pacific stocks. Sharks from the Canadian Atlantic, however, possessed a considerable shorter anal fin than those from the equatorial Atlantic and the Pacific suggesting the possibility of a distinct population. Litvinov (1990) also suggested distinct north and south populations for both the Pacific and Atlantic Oceans between based on teeth morphology.

Although there is no strong evidence presented on the stock unit hypothesis for blue shark, separate stock unit for northern and southern hemisphere may be suggested. Because of the low density at the equator and existing separated nursery grounds at the northern and southern hemisphere.

### 3.2 Stock status

Concern over the status of blue shark stocks has grown with heavy fishing pressures on pelagic elasmobranchs around the world (Stevens, 1992). Unfortunately, the total blue shark catch by ocean is not known. Stevens (1992), using a very conservative assumption of catch at 1 shark per 1,000 hooks, estimated that the global blue shark catch by the Japanese longline fishery was 433,447 sharks and 13,000 MT. Nakano and Watanabe (1992) suggested that high seas fisheries of the North Pacific (i. e., combined longline and driftnet fisheries of Japan, Korea and Taiwan), took 4.9 million blue sharks during 1988. Bonfil (1994) estimated the blue shark catch in the North Pacific high seas longline fishery at 1,953,432 blue sharks and 39,069 MT in weight by combining the CPUE data of Strasburg (1958) and fishing effort data of Nakano and Watanabe (1992). The Hawaii-based longline fishery in the central North Pacific caught an average of 101,118 blue sharks per year during 1991-1996 (Ito and Machado, 1997).

Nakano and Watanabe (1992) presented the first attempt of assessment on the impact of high seas fisheries on blue shark stocks. By estimating bycatch and using cohort analysis, the study concluded that the catch levels during the late 1980s did not have a significant impact on the blue shark populations of the North Pacific. Wetherall and Seki (1992), however, suggested that appropriate information is lacking for an assessment of this kind.

Taniuchi (1990) presented annual blue shark CPUE from surveys conducted by Japanese research and high school training vessels in the tropical Indian and Pacific Ocean during 1973-1985 (Fig. 18) and showed no significant decline

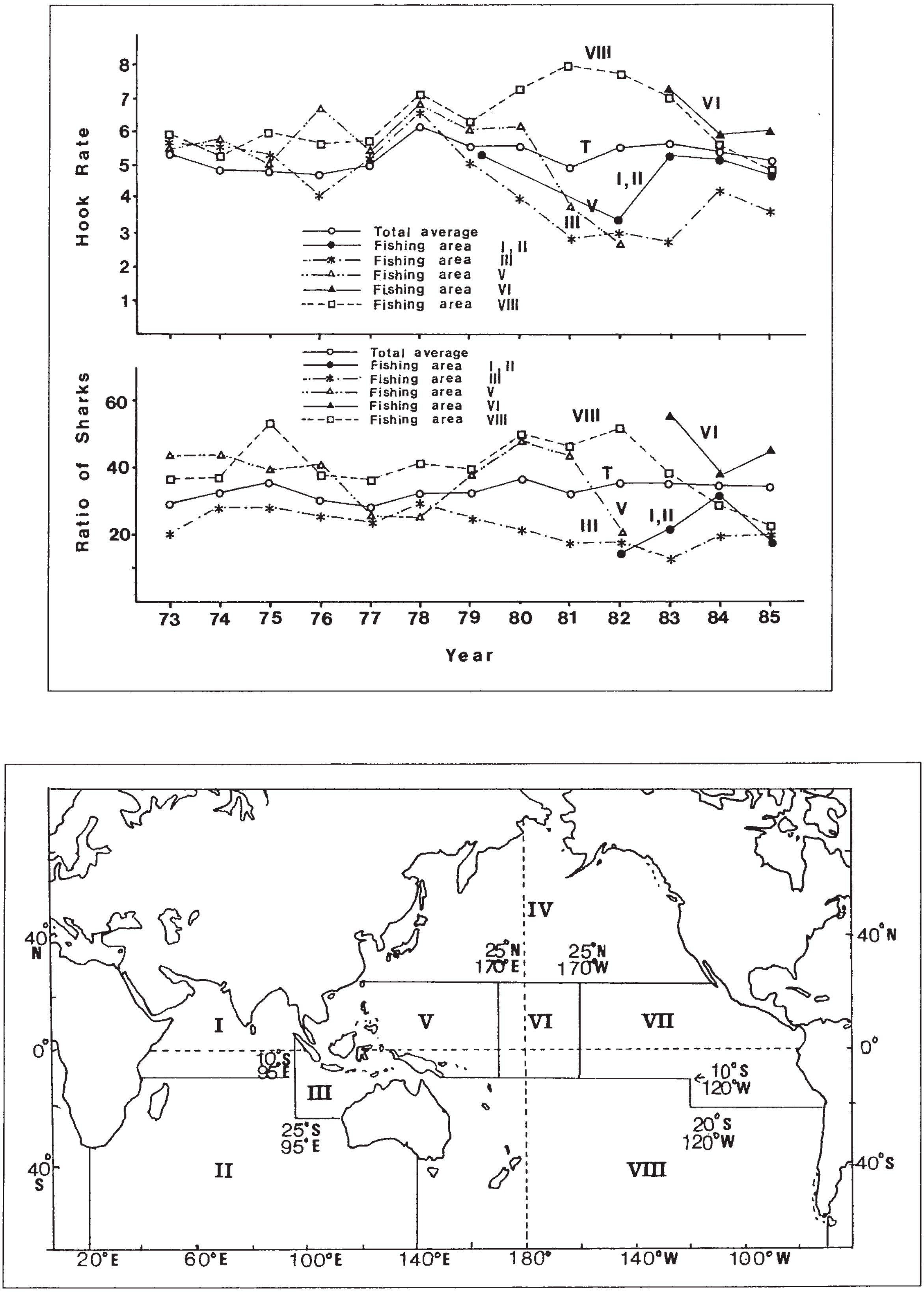



**Fig. 18.** Historical change of sharks catch ratio to catches of tunas and billfishes and hook rates of sharks by area expressed by number of sharks caught per thousand hooks observed Japanese longline research cruises (Taniuchi, 1990). "T" indicates a total overall average. Shark catch mainly consists of blue shark catches. And area classification is indicated in bottom figure.

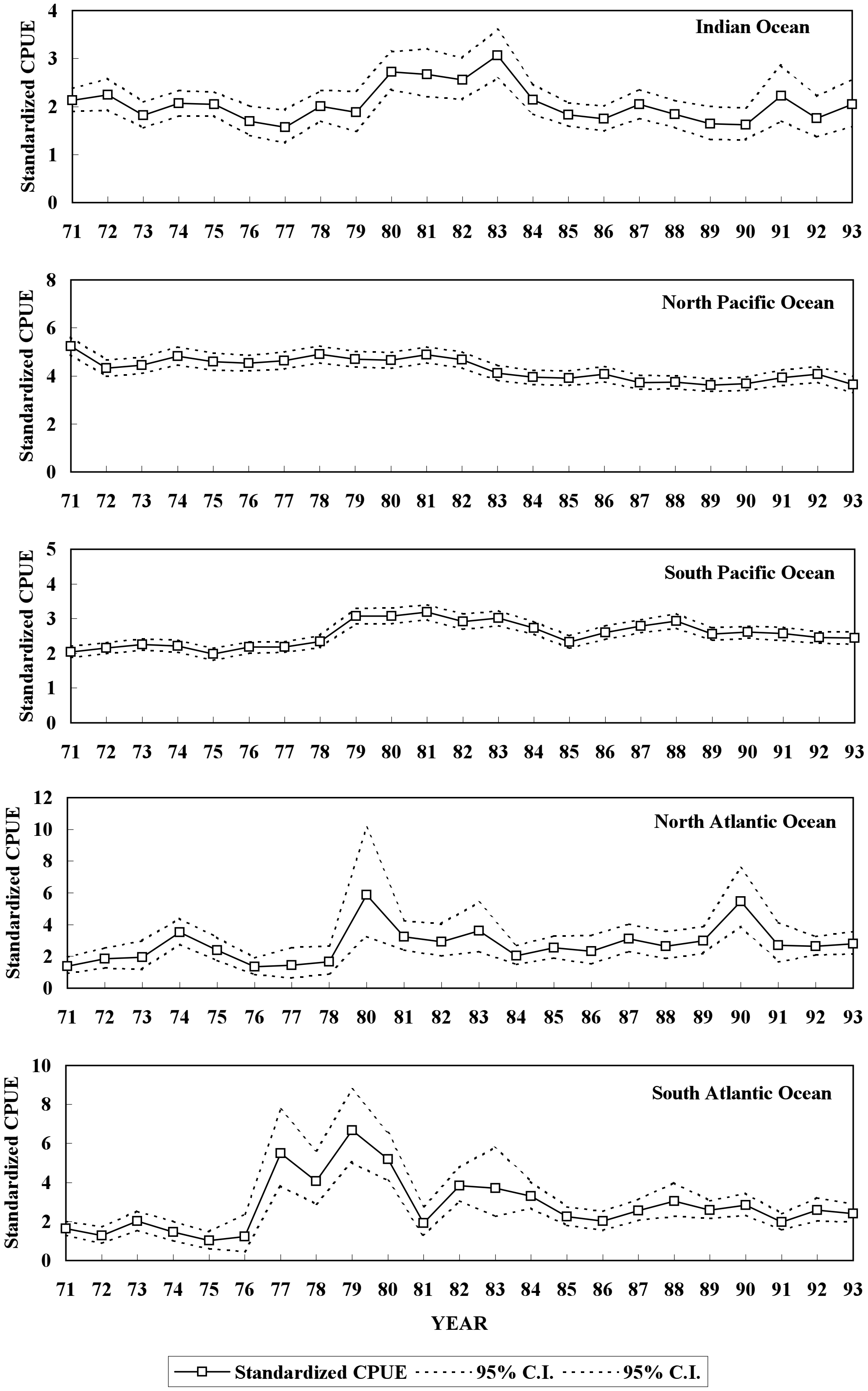



**Fig. 19.** Standardized CPUE (number of catch per thousand hooks) of blue shark caught by Japanese longline fishery in the North and South Pacific (upper 2 figs), North and South Atlantic (middle 2 figs), and Indian Ocean (bottom) (Nakano, 1996)

during the period. Matsunaga and Nakano (1999) calculated CPUE distribution for blue shark in the Pacific Ocean during two different research periods, 1967-1970 and 1992-1994, and observed no significant change in the blue shark CPUE between the periods. Nakano (1996) standardized shark CPUE from commercial logbooks using only data that more than 80% of the recording rate was considered an adequate representation of shark catch. The CPUE of overall shark take was considered to represent annual blue shark CPUE change since the latter composes more than 70% of the total shark catch. The results revealed a 20% decline of CPUE during 23 years of fishing in the North Pacific Ocean, while no significant changes were evident in other areas (Fig. 19).

The most comprehensive assessment for the North Pacific blue shark was done by Kleiber *et al.* (2001) and maximum sustainable yield (MSY) was firstly calculated using MULTIFAN-CL (Fournier *et al.*, 1998). They concluded that even the most pessimistic scenarios show current catches and fishing mortalities to be comfortably below MSY and $F_{msy}$, and the blue shark population appears to be in no danger of annihilation or stock collapse. Although a comprehensive stock assessment of blue shark in the North Pacific is still lacking, no overly deviant fluctuations are obvious in the various CPUE series, and no evidence currently exists to suggest that the stock status of North Pacific blue sharks is in a critical state. Nevertheless, further research is needed to assess the true catch levels in each fishery and their impacts on the population.

## 4.0 Exploitation

### 4.1 Fisheries

Many blue sharks are caught by the various high seas and coastal fisheries throughout the world's oceans. For example, in the North Pacific, the major fisheries exploiting the blue shark resource are the high seas tuna longline fisheries of Japan and Korea, the coastal shark longline fishery of Japan and Taiwan, and Hawaii (and west coast U.S.) based tuna/-swordfish longline fisheries in the eastern and central Pacific (Nakano and Watanabe, 1992; Ito and Machado, 1997).

The driftnet fishery targeting thresher sharks and swordfish off the west coast of California, the Mexican-Japanese joint venture longline fishery off Baja California, and the tuna purse seine fishery in the tropical eastern Pacific Ocean also catch blue shark (Holts, 1988; Au, 1991; Hanan *et al.*, 1993; Bonfil, 1994). Official landing statistics of blue sharks, however, are scarce and thus is difficult to assemble a complete picture of the world blue shark catch from these data. Available official landing statistics of blue shark in the world are compiled and presented in Table 12. In some cases, the reported figures represent blue shark landings by nation. For example, U.S. landings as reported by Rose (1998) do not include sharks landed in Hawaii. Landings for Taiwan include only those landed at Chengkung fish market (Chen *et al.*, 1996). Japanese landings during 1951 to 1967 are national statistics, but after 1968, represent only sharks landed at the Kesennuma fish market; i.e., the national fisheries statistics do not include blue shark landings after 1968. Landings at Kesennuma fish market do, however, represent more than 90% of the blue shark landings in Japan (Anon, 1952-1968, 1969-1995). France, Denmark and Portugal submit national landing statistics for blue shark to the Fish and Agricultural Organization of the United Nations (FAO) (FAO, 1982-1996). Hayes (1969) reports landings from the New Zealand EEZ but excludes the foreign longline landings; blue shark catches by South African longliners are reported by Smale (1997). Although not included on the list presented here due to the uncertainty of the landing statistics, Australia, Brazil, Italy, Ireland, Korea, Maldives, Spain, UK and Uruguay are reported as fishing nations which catch blue shark by Bonfil (1994) and Rose (1998).

Several studies have presented estimations of blue shark catches by high seas fisheries. A summary of these catch estimations by

**Table 12.** Available published landing statistics of blue shark (MT) in the world

| Country | France | Denmark | Portugal | Canada | USA | Taiwan | Japan | New Zealand | South Africa |
|---|---|---|---|---|---|---|---|---|---|
| 1951 | | | | | | | 17,419 | | |
| 1952 | | | | | | | 19,350 | | |
| 1953 | | | | | | | 17,989 | | |
| 1954 | | | | | | | 15,821 | | |
| 1955 | | | | | | | 16,774 | | |
| 1956 | | | | | | | 19,073 | | |
| 1957 | | | | | | | 17,385 | | |
| 1958 | | | | | | | 18,174 | | |
| 1959 | | | | | | | 18,946 | | |
| 1960 | | | | | | | 21,184 | | |
| 1961 | | | | | | | 20,559 | | |
| 1962 | | | | | | | 21,271 | | |
| 1963 | | | | | | | 19,717 | | |
| 1964 | | | | | | | 16,306 | | |
| 1965 | | | | | | | 14,456 | | |
| 1966 | | | | | | | 16,035 | | |
| 1967 | | | | | | | 15,097 | | |
| 1968 | | | | | | | 11,803 | | |
| 1969 | | | | | | | 10,685 | | |
| 1970 | | | | | 0.1 | | 9,944 | | |
| 1971 | | | | | 0.6 | | 9,639 | | |
| 1972 | | | | | 0.1 | | 9,685 | | |
| 1973 | | | | | 0.4 | | 10,574 | | |
| 1974 | | | | | 0 | | 9,230 | | |
| 1975 | | | | | 0.2 | | 8,825 | | |
| 1976 | | | | | 4.5 | | 9,852 | | |
| 1977 | | | | | 44.6 | | 13,769 | | |
| 1978 | | | | | 16.3 | | 10,752 | | |
| 1979 | | | | | 39.3 | | 12,602 | | |
| 1980 | | | | | 87.1 | | 12,523 | | |
| 1981 | | | | | 92.1 | | 10,434 | | |
| 1982 | 9 | | | | 26.2 | | 10,845 | | |
| 1983 | 8 | | | | 6.3 | | 13,007 | | |
| 1984 | 14 | | | | 1.8 | | 11,702 | | |
| 1985 | 39 | 4 | | | 1.1 | | 12,314 | | |
| 1986 | 50 | 2 | | | 1.5 | | 13,341 | | |
| 1987 | 67 | 2 | | | 1.5 | | 11,072 | | |
| 1988 | 91 | 1 | | | 3.2 | | 11,778 | | |
| 1989 | 83 | 2 | | | 6.1 | | 9,954 | 12.5 | |
| 1990 | 135 | 2 | | 125 | 19.8 | 20.8 | 9,529 | 2.2 | |
| 1991 | 193 | 1 | | 236 | 0.5 | 22.8 | 11,027 | 18.4 | |
| 1992 | 276 | 1 | | 213 | 1.4 | 46.3 | 11,753 | | 6 |
| 1993 | 329 | 0 | 352 | 83 | 3.6 | 47.6 | 13,261 | | 2.7 |
| 1994 | 358 | | 360 | 111 | 11.6 | 48.6 | 10,140 | | 3.7 |
| 1995 | 266 | | | | | | | | |
| 1996 | 302 | 3 | | | | | | | |

Source: France, Denmark and Portugal: FAO Yearbook Fishery Statistics
Canada and USA: Rose (1998). Landing statistics does not including landing at Hawaii.
Taiwan: Chen *et al.* (1996). Landing statistics of Chengkung fish market.
Japan: Anon. (1952-1968, 1969-1995). After 1968, values are landings of Kesennuma fish market.
New Zealand: Hayes (1996)
South Africa: Smale (1997)

fisheries and regions based mainly on Bonfil (1994) is presented in Table 13. For high seas driftnet fisheries in the South Pacific and Indian Oceans, estimation of blue shark catch were not available in the literature, although catch of total elasmobranches are reported. Estimated catch of the longline fisheries in the Atlantic and Indian Oceans were computed from Bonfil's (1994) estimation of total shark catch, assuming the suggested 40% blue shark proportion. Blue shark catch has been estimated at several hundred to more than 10,000 metric tons by high seas driftnet fisheries and from about 30,000 to around 50,000 metric tons by longline fisheries in each ocean. High seas driftnet fisheries ceased to operate at the end of 1992. Although there are concerns over the accuracy of the estimations, these values represent the only available insight into the magnitude of the blue shark exploitation.

There are large differences between landing statistics and catch estimations. Since landing statistics of sharks are not divided by species in many countries, blue shark landings might be included in the broader category of sharks, sharks and rays, or chondricthyans or even elasmobranches. Catch disposition may also contribute to the discrepancy between landings and catches. Blue sharks are often released due to low market value and demand or sometimes are only harvested for their fins, the most valuable part of the shark.

### 4.2 Utilization

In parts of the world, blue shark meat can and has been utilized fresh, smoked, and dried salted for human consumption and for fishmeal (Compagno, 1984). Often, however, blue shark flesh is unmarketable because of the rapid breakdown of urea in the muscle tissue into ammonia soon after death and the subsequent tainting of the meat. This is the case in the California driftnet fishery and generally why only fins are utilized from blue sharks taken in the Hawaii-based longline fishery (Holts, 1988; Ito and Machado, 1997). In addition to its flesh, other blue shark commodities include its hide (for leather), fins (for shark-fin soup), cartilage, and liver oil. Blue sharks also have recreational value. Considered a game fish, this shark is taken by sports anglers with rod and reel. In Japan, official landing statistics has separately

**Table 13.** Estimations of blue shark catch (MT) published for high seas fisheries and region

| Fisheries | Region | Major fishing country | Year used | Estimated catch |
|---|---|---|---|---|
| Driftnet fisheries | | | | |
| Salmon driftnet | North Pacific | Canada, Japan, USA | 1989 | 18.3-701 |
| Squid driftnet fishery | North Pacific | Japan, Korea, Taiwan | 1990 | 12,802 |
| Large-mesh driftnet | North Pacific | Japan | 1990 | 1,141 |
| High seas driftnet fishery | South Pacific | Japan, Taiwan | 1989 | n.a. |
| High seas driftnet fishery | Indian Ocean | Taiwan | 1989 | n.a. |
| High seas driftnet fishery | Atlantic | France | 1991 | 430-865 |
| Longline fisheries | | | | |
| Spanish swordfish longline | Mediteranian | Spain | 1989 | 1,067 |
| Spanish swordfish longline | Atlantic | Spain | 1989 | 4,977 |
| Longline | South and central Pacific | Australia, Japan, Korea, Taiwan | 1989 | 8,193 |
| Longline | North Pacific | Japan, Korea, USA | 1988 | 39,069 |
| Longline | Atlantic | Canada, Japan, Taiwan, USA | | 30,527 |
| Longline | Indian Ocean | Australia, Japan, Korea, Taiwan | | 30,072 |

Source: Bonfil (1994)

* Calculated from estimation by Bonfil (1994) for total shark catch, assuming composition of blue shark as 40%

reported the landing of blue shark 13,000-20,000 MT in gutted weight until 1967 (Taniuchi, 1990). Around 10,000 MT of blue shark are still landed and utilized for the production of boiled fish paste ("kamaboko" or "hanpen"), shark fins, leather, liver oil, and chondroitine of cartilage (Kiyono, 1996; Makihara, 1980; Nakano, 1999). In Australia, blue shark meat is utilized as shark jerky for export (Rose, 1996).

### 4.3 Trade

Despite the large number of blue sharks caught in the various world fisheries, international trade of blue shark meat is relatively small. Rose (1996) summarized world trade on sharks and reported, some parts including description of blue shark trade; (1) the establishment of a processing plant for shark meat, i. e. tiger shark, mako shark, saw sharks, and blue shark in northern Australia for shark jerky production for export principally to North and South Korea, (2) that small amounts of blue sharks are landed in the UK for consumption and typically exported to France and (3) in Canada, blue shark (along with porbeagle) are typically exported to Europe, while mako shark is consumed domestically or exported as steaks to the U.S.

Among shark species, blue shark fins are not recognized as the highest of quality because of their low fin needle content. They are, however, abundant and relatively inexpensive, and are therefore important in the trade. Estimates by fin traders suggest that blue sharks may contribute 50-70% of shark fins traded in Hong Kong although the amount of traded by species are not known. Exports from longline fishing nations, i. e. Japan, Korea and Taiwan, in particular may contain higher proportion of blue shark. Shark fin trades among the major fishing nations in the Pacific are as follows (Rose, 1996):

－Japan exported an average of 661t of shark fins annually during the period 1980-1994, declining in numbers from 1,073t in 1981 to 399t in 1993. Over the past decade, eighty-three per cent of shark fins were exported to Hong Kong with the remainder destined for Singapore, Thailand, China, and the USA.

－In Taiwan, more than 96t of dried shark fin were imported in 1989, but imports have since declined to just over 20t in 1995. Exports totaled just over 41t during the period 1980-1986, then increased to more than 140t per year in 1987 and 1988, to 259t in 1989, and 283t in 1990. Thereafter, exports declined to 2.3t in 1994 and 4.5t in 1995.

－South Korea reported production averaged 23t annually during 1980-1994, declining from 115t in 1980 to two tons in 1994. Imports of shark fins averaged only five tons annually during 1987-1994. Exports of shark fin from South Korea averaged 60t annually during 1980-1994, declining from 94t in 1980, to 31t in 1994. During 1987-1994, Singapore received 78.3% of South Korean exports.

－Australia imported an average of 8.5t of shark fins annually during 1988-1994. Although Australian Customs do not report the export of shark fins, data from the Australian Quarantine and Inspection Service reports that exports of shark fins, mostly in dried form, totaled 65.5t in 1992-1993, 49.9t in 1993-1994, and 45.9t in 1994-1995.

－Imported shark fins by the USA averaged some 54t annually during 1972-1985, then increased rapidly to a peak of 281t in 1992. Exports of shark fins are not reported in Customs records, but Hong Kong reports imports of shark fins from the USA averaging 366t annually during 1988-1994, increasing from 261t in 1988, to a peak of 479t in 1992, then declining to 418t in 1994. Singapore reports average annual imports from the USA of 17t during 1990

-1995, increasing from three tons in 1990, to 34t in 1995. China's Customs data, available for 1992 and 1994 only, report imports from the USA of 37t and 44t, respectively.

—For the years 1978-1988, Mexico's Ministry of Fisheries reports average exports of 137t of shark fins annually. Hong Kong Customs report average imports of shark fin from Mexico of 150t annually during 1984-1994, peaking in 1994 at 207t. Much of Mexico's shark fin exports are, however, likely to be shipped first to the USA, which country's Customs report imports of shark fin from Mexico averaging 29t annually during 1986-1995.

Little information is available regarding the use of shark hide. Neither domestic nor trade data are available from the majority of producing countries, including Australia, Japan, China, Bangladesh, Thailand, or Europe. In late 1995, an Australian processor and exporter established facilities to export the hides of tiger shark, saw sharks, and blue sharks to Japan. During the 1980s, a significant trade in shark skins occurred across the US-Mexico border when shark skins were imported by U.S. companies for boot making. In addition to this cross-border trade, a number of shark skins and shark leather goods entered the U.S. directly from Mexico; unfortunately the species used for processing shark skins are not known (Rose, 1996).

Blue shark cartilage is considered a good source of chondroitine, a pharmaceutical substance used in eye drops. A relatively new product on the market, neither national fisheries agencies nor Customs agencies report the volume of production or trade of shark cartilage. Shark cartilage is processed in Taiwan, and both processed and unprocessed cartilage are exported to Australia, New Zealand, Japan, and the U.S. Japan is known as a key producer country for shark cartilage powder and capsules, and shark cartilage products of Japanese origin are widely marketed abroad, for example in the U.S. and Mexico. Blue shark cartilage is reportedly sold for US$7.00 per kg, while cartilage from other species sold for US$3.80 per kg (Rose, 1996).

## Acknowledgments

The authors thank to Drs. R. Michael Laurs and Jerry Wetherall of the U.S. National Marine Fisheries Service Honolulu Laboratory, Yasuhiko Shimazu and Ziro Suzuki of the National Research Institute of Far Seas Fisheries, Japan who provided the opportunity for this collaborative project. We also thank Drs. John Stevens and Greg Cailliet for their reviews on earlier drafts of this manuscript.

## Literature Cited

Aasen O., 1966: Blahaien, *Prionace glauca* (Linnaeus), 1758. *Fisken og havet*, **1**, 1-15.

Anon 1952-1968: Annual Statistics of Fishery and Aquaculture Production, Statistics and information department, Ministry of Agriculture, Forestory and Fisheries of Japan.

Anon 1969-1995: Fishery of Kesennuma, Kesennuma city office, Kesennuma, Miyagi, Japan.

Au D. W., 1991: Polyspecific nature of tuna schools: shark, dolphin, and seabird associates. *Fish. Bull.*, **89**, 343-354.

Backus R. H. 1957: Notes on Western North Atlantic sharks. *Copeia,* **1957**, 246-248.

Bigelow H. B. and Schroeder W. C., 1948: Sharks, *In* Fishes of the western North Atlantic, Part one, p.59-546. Parr A. E. and Olsen Y. H. (eds.), Sears Found. Mar. Res., Yale Univ. Mem. 1.

Bonfil R., 1994: Overview of world elasmobranch fisheries, FAO Fisheries Technical Paper, No. 341, United Nations Food and Agriculture Organization, Rome.

Brodeur R. D., Lorz H. V., and Pearcy W. G., 1987: Food habits and dietary variability of pelagic nekton off Oregon and Washington, 1979-1984. NOAA Technical Report

NMFS No. 57, 32pp.

Cailliet G. M., Martin L. K., Harvey J. T., Kusher D., and Welden B. A., 1983: Preliminary studies on the age and growth of blue, *Prionace glauca*, common thresher, *Alopias vulpinus*, and shortfin mako, *Isurus oxyrinchus*, sharks from California waters. NOAA Technical Report NMFS No. 8, pp.179-188.

Carey F. G. and Scharold J. V., 1990: Movements of blue shark (*Prionace glauca*) in depth and course. *Mar. Biol.* **106**, 329-342.

Casey J. G., Pratt H. W. Jr., Kohler N., and Stillwell C. E., 1989: The shark Tagger, 1988 summary, Newsletter of the Cooperative Shark Tagging Program, NOAA, NMFS, Northeast Fisheries Center, pp.12.

Castro J. A. and Mejuto J., 1995: Reproductive parameter of blue shark, *Prionace glauca*, and other sharks in the Gulf of Guinea. *Mar. Freshwater Res.,* **46**, 967-973.

Chen G. C. T., Liu K. M., Joung S. J., and Phipps M. J., 1996: TRAFFIC report on shark fisheries and trade in Taiwan, *In* Phipps M. J., (Comp.), TRAFFIC [East Asia] report on shark fisheries and trade in the East Asian region, TRAFFIC East Asia, Taipei, 48pp.

Clarke M. R. and Stevens J. D., 1974: Cephalopods, Blue shark and migration, *J. Mar. Biol.* Ass. *U.K.*, **54**, 949-957.

Compagno L. J. V., 1984: FAO species catalog, Vol. 4: Sharks of the world; Part 2-Carcharhiniformes. Fisheries Synopsis No. 125., Food and Agricultural Organization of the United Nations, Rome, Italy, 655pp.

De Metrio G. Petrosino G., Montanaro C., Matarrese A., Lenti M., and Cecere E., 1984: Survey on summer-autumn population of *Prionace glauca* L. (Pisces, chondrichthyes) in the gulf of Taranto (Italy) during the four year period 1978-1981 and its incidence on sword-fish (*Xiphias gladius* L.) and albacore (*Thunnus alalunga* (Bonn)) fishing. *OEBALIA*, **vol. X, N. S.**, 105-116.

Draganik B. and Pelczarski W., 1984: The occurrence of the blue shark, *Prionace glauca* (L.), in the North Atlantic. *Rep. Sea Fish. Inst.***19**, 61-75.

Dunning, M. C., Clarke M. R., and Lu C. C., 1993: Cephalopods in the diet of oceanic sharks caught off eastern Australia, p.119-131, *In* Recent advances in cephalopod fisheries biology, T. Okutani, R.K. O'Dor and T. Kubodera (eds.) Tokai University Press, Tokyo.

Fournier D. A., Hampton J., and Sibert J. R., 1998: MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga. Can. J. Aquat. Sci.* **55**, 2105-2116.

Goto M., Taniuchi T., Kuga N., and Iwata M., 1981: Four dicephalous specimens of the blue shark, *Prionace glauca*, from Japan. *Jap. J. Ichthy.,* **28**(**2**), 157-165.

Gubanov Ye. P. and Grigor'yev V. N., 1975: Observation on the distribution and biology of the blue shark *Prionace glauca* (Carcharhinidae) of the Indian Ocean. *Vopr. Ikhtiol.*, **15**(**1**), 43-50.

Gubanov Ye. P., 1978: The reproduction of some species of pelagic sharks from the equatorial zone of the Indian Ocean. *J. Ichthyol.*, **18**(**5**) 781-792.

Hanan D. A., Holts D. B., and Coan A. L. Jr., 1993: The California drift gill net fishery for sharks and swordfish, 1981-82 through 1990-91, State of California, The Resources Agency, Department of Fish and Game, Fish Bulletin 175, 95pp.

Harvey J. T., 1989: Food habits, seasonal abundance, size, and sex of the blue shark, *Prionace glauca*, in Monterey bay, California. *Calif. Fish Game*, **75**(**1**), 33-44.

Hazin F. H. V., Couto A. A., Kihara K., Otsuka K., and Ishino M., 1990: Distribution and abundance of pelagic sharks in the south-western equatorial Atlantic. *J. Tokyo Univ. Fish.*, **77**(**1**), 51-64.

Hazin F. H. V., Lessa R., Ishino M., Otsuka K., and Kihara K., 1991: Morphometric description of the blue shark, *Prionace* *glauca,* from the southwestern equatorial Atlantic. *J. Tokyo Univ. Fish.*, **78**(**2**), 137-144.

Hayes E., 1996: New Zealand. *In* Sant, G. and Hayes, E. (eds), The Oceania region's harvest, Trade and management of sharks and other cartilaginous fish: an overview, TRAFFIC Oceania.

Hazin F. H. V., Boeckman C. E., Leal E. C., Lessa R. P. T., Kihara K., and Otsuka K., 1994: Distribution and relative abundance of the blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean. *Fish. Bull.* **92**(**2**), 474-480.

Holts D. B., 1988: Review of U. S. west coast commercial shark fisheries. *Mar. Fish. Rev.* **50**(**1**), 1-8.

Ito R. Y. and Machado W. A., 1997: Annual report of the Hawaii-based longline fishery for 1996, NOAA, Administrative Report H-97-12, 48pp.

Kiyono H., 1996: TRAFFIC report on shark fisheries and trade in Japan. *In*: Phipps, M. J. (Comp.), TRAFFIC [East Asia] report on shark fisheries and trade in the East Asian region, TRAFFIC East Asia, Taipei.

Kleiber P., Takeuchi Y., and Nakano H., 2001: Calculation of plausible maximum sustainable yield (MSY) for blue sharks (*Prionace glauca*) in the North Pacific, NOAA, Administrative report H-01-02, 10pp.

Kohler N. E. and Stillwell C. E., 1981: Food habits of the blue shark (*Prionace glauca*) in the Northwest Atlantic. International Council for the Exploration of the Sea, Pelagic Fish Committee, ICES C. M. 1981/H:61, 12pp.

Kohler N. E.,Casey J. G., and Turner P. A., 1995: Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull., U.S.* **93**, 412-418.

LeBrasseur R. J., 1964: Stomach contents of blue shark (*Prionace glauca* L.) taken in the Gulf of Alaska. *J. Fish. Res. Bd. Can.,* **21**(**4**), 861-862.

Litvinov F. F., 1990: Structure of epipelagic elasmobranch communities in the Atlantic and Pacific Oceans and their change in recent geological time. *J. Ichthy.* **29**(**8**), 75-87.

Makihara M., 1980: Toward effective utilization of the abundant shark resources. *Suisan Shuho*, **898**, 22-26. (In Japanese)

Matsunaga H. and Nakano H., 1999: Species composition and CPUE of pelagic sharks caught by Japanese longline research and training vessels in the Pacific ocean. *Fish. Sci.*, **65**(**1**), 16-22.

McKinnell S. and Seki M. P., 1998: Shark bycatch in the Japanese high seas squid driftnet fishery in the North Pacific Ocean. *Fish. Res.*, **39**, 127-138.

Mishima S., 1981: On the passing over of subtropic fishes to the subarctic region in the summer season. *Res. Inst. N. Pac. Fish., Hokkaido Univ.*, **Spec. Vol.**, 61-71 (In Japanese with English abstract).

Mishima S., Ogi H., Shimazaki S., and Ohsako M., 1981: Dominant fish groups in the pelagic fish community around the subarctic boundary, September-October, 1979, *Res. Inst. N. Pac. Fish., Hokkaido Univ.*, **Spec. Vol.**, 105-118 (In Japanese with English abstract).

Nakano H., 1994: Age, reproduction and migration of blue shark in the North Pacific Ocean. *Bull. Nat. Res. Inst. Far Seas Fish.,* **31**, 141-256.

Nakano H., 1996: Historical CPUE of pelagic shark caught by Japanese longline fishery in the world, Information paper submitted to the 13th CITES Animals Committee, Doc. AC. 13. 6. 1 Annex, 7pp.

Nakano H., 1999: Fishery management of sharks in Japan, p.552-579, In: Shotton R. (ed.), Case studies of the management of elasmobranch fisheries, FAO Fisheries Technical Paper 378/2, Rome, 920pp.

Nakano H. and Honma M., 1997: Historical CPUE of pelagic sharks caught by Japanese longline fishery in the Atlantic Ocean. *ICCAT CVSP*, **XLVI**(**4**), 393-398.

Nakano H., Makihara M., and Shimazaki K., 1985: Distribution and biological characteristics of the blue shark in the central North

Pacific. *Bull. Fac. Fish. Hokkaido Univ.* **36** (**3**), 99-113 (In Japanese with English abstract).

Nakano H. and Nagasawa K., 1996: Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. *Fish. Sci.* **62**(**6**), 860-865.

Nakano H., Okazaki M., and Okamoto H., 1997: Analysis of catch depth by species for tuna longline fishery based on catch by branch lines, *Bull. Nat. Res. Inst. Far Seas Fish.*, **34**, 43-62.

Nakano H. and Shimazaki K., 1989: Gill net mesh selectivity for the blue shark (*Prionace glauca* L.). *Bull. Fac. Fish. Hokkaido Univ.* **40**(**1**), 22-29 (In Japanese with English abstract).

Nakano H. and Watanabe Y., 1992: Effect of high seas driftnet fisheries on blue shark stock in the North Pacific, 15pp, Compendium of documents submitted to the Scientific Review of North Pacific Highseas Driftnet Fisheries, Sidney, B. C., Canada, June 11-14, 1991, Vol. 1.

Neave F. and Hanavan M. G., 1960: Seasonal distribution of some epipelagic fishes in the Gulf of Alaska region. *J. Fish. Res. Bd. Can.*, **17**(**2**), 221-223.

Parin N. V., 1970: Ichthyofauna of the epipelagic zone. Moscow: Academy of Sciences of the U. S. S. R. (Translated from Russian by Israel Program for Scientific Translations), Reproduced by the National Technical Information Service, Springfield, Virginia, 1970, 206pp.

Pratt H. W. Jr., 1979: Reproduction in the blue shark, *Prionace glauca. Fish. Bull.*, **77**(**2**), 445-470.

Pratt H. W. Jr. and Casey J. G., 1990: Shark reproductive strategies as a limiting factor in directed fisheries, with a review of Holden's method of estimating growth-parameters. Pratt H. L. Jr., Gruber S. H. and Taniuchi T. (eds) pp.97-109, United States Department of Commerce, NOAA Technical Report NMFS No. 90.

Pratt H.W.Jr. and Tanaka S., 1994: Sperm storage in male elasmobranches: A description and survey. *J. Morph.*, **219**, 297-308.

Rey J. C. and Munoz-Chapuli R., 1992: Intra and interspecific association of large pelagic fishes inferred from catch data of surface longline. *Env. Biol. Fishes*, **35**, 95-103.

Rose D. A., 1996: An overview of world trade in sharks and other cartilaginous fishes. TRAFFIC International, 106pp.

Sciarrotta T. C. and Nelson D. R., 1977: Diel behavior of the blue shark, *Prionace glauca*, near Santa Catalina Island, California. *Fish. Bull.*, **75**(**3**), 519-528.

Seki M. P., 1993: The role of the neon flying squid, *Ommastrephes bartrami*, in the North Pacific pelagic food web. *Bull. INPFC.,* **53**(**II**), 207-215.

Shirai S., 1996: In interrelationships of fishes, Stiassny M. L. J., Rarentil L. R., and Johnson G. D. (eds.), Academic Press, San Diego, pp.9-34.

Sivasubramaniam K., 1963: On the sharks and other undesirable species caught by tuna longline. *Records Oceanogr. works Jap.,* **7** (**1**), 73-85.

Skomal G. B., 1990: Age and growth of the blue shark, *Prionace glauca*, in the Atlantic, MSc thesis, University of Rhode Island, Kingston, 103pp.

Smale M. J., 1996: Trade in sharks and shark products in South Africa, *In* Marchall, N. T. and Barnett, R. (eds), THE Trade in sharks and shark products in the western Indian and southeast Atlantic Oceans, TRAFFIC East/Southern Africa. pp.80-100.

Springer S., 1967: Social organization of shark population, *In* Sharks, skate and rays, Gilbert P. W., Mathewson R. F., and Rall D. P. (eds.), The John Hopkins Press, Baltimore, pp.149-174.

Stevens J. D., 1973: Stomach contents of the blue shark (*Prionace glauca* L.) off southwest England., *J. Mar. Biol.* Assoc. *U.K.,* **53**, 357-361.

Stevens J. D., 1974: The occurrence and significance of tooth cuts on the blue shark

(*Prionace glauca* L.) from British waters. *J. Mar. Biol. Assoc. U.K.*, **54**, 373-378.

Stevens J. D., 1975: Vertebral rings as a means of age determination in the blue shark (*Prionace glauca* L.). *J. Mar. Biol. Assoc. U.K.*, **55**, 657-665.

Stevens J. D., 1976: First results of shark tagging in the north-east Atlantic. *J. Mar. Biol. Assoc. U.K.*, **56**, 929-937.

Stevens J. D., 1990: Further results from a tagging study of pelagic sharks in the north-east Atlantic. *J. Mar. Biol. Ass. U. K.,* **70**, 707-720.

Stevens J. D., 1992: Blue and mako shark by-catch in the Japanese longline fishery off south-eastern Australia. *Aust. J. Mar. Freshwater Res.*, **43**, 227-236.

Stevens J. D. and McLoughlin K. J., 1991: Distribution, size and sex composition, reproduction biology and diet of sharks from Northern Australia. *Aust. J. Mar. Freshwater Res.*, **42**, 151-199.

Strasburg D. W.,1958: Distribution, abundance, and habits of pelagic sharks in the Central Pacific Ocean. *Fish. Bull.*, **138**, 335-361.

Suda A., 1953: Ecological study of blue shark (*Prionace glauca* LINNÉ). *Bull. Nankai Fish. Res. Lab.,* **1**(**26**), 1-11.

Tanaka S., 1984: Present status of fisheries biology, *In* Elasmobranchs as fisheries resources, Taniuchi T. and Suyama M. (eds.), pp.46-59. Jpn. Soc. Sci. Fish., Fish. Ser. 49, Kousei-sha Kousei-kaku, Tokyo.

Tanaka S., Cailliet G. M., and Yudin K. G., 1990: Differences in growth of the blue shark, *Prionace glauca*: thechnique or population? *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and status of the fisheries. Pratt H. L., Jr, Gruber S.H., and Taniuchi T. (eds), pp.177-187, United States Department of Commerce, NOAA Technical Report NMFS No. 90.

Taniuchi T., 1990: The role of elasmobranchs in Japanese Fisheries, *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and status of the fisheries. Pratt H. L., Jr, Gruber S. H., and Taniuchi T. (eds), pp.415-426, United States Department of Commerce, NOAA Technical Report NMFS No. 90.

Taniuchi T., 1995: Some biological aspects of sharks caught by floating longline - 2. Sex ratios and weight composition. *J. Jap. Elasmobranch study Group,* **32**, 1-15.

Tricas T. C., 1979: Relationship of the blue shark, *Prionace glauca*, and its prey species near Santa Catalina Island. *Calif. Fish. Bull.* **77**(**1**), 175-182.

Tucker D. W. and Newnham C. T., 1957: The blue shark *Prionace glauca* (L.) breeds in British Seas. *A. M. N. H. Ser.* **12**(Ⅹ), 43-688.

Vas P., 1990: The abundance of the blue shark, *Prionace glauca*, in the western English channel. *Env. Biol. Fish.*, **29**, 209-225.

Wetherall J. and Seki M. P., 1992: Assessing impacts of North Pacific high seas driftnet fisheries on Pacific pomfret and sharks: progress and problems, Compendium of documents submitted to the Scientific Review of North Pacific Highseas Driftnet Fisheries, Sidney, B.C., Canada, June 11-14, 1991, Vol. 2.