Length frequencies of the blue shark (*Prionace glauca*) in the eastern Pacific Ocean

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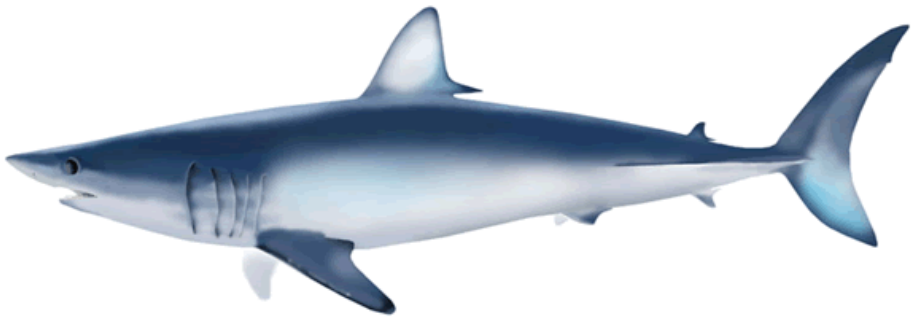

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ABSTRACT

The objective of this study was to investigate the length frequency data available for the blue shark from U.S. west coast fisheries. Specifically, we provide a summary of blue shark lengths based on two fishery datasets: 1) California drift gillnet fishery and 2) a fishery-independent NOAA Southwest Fisheries Science Center (SWFSC) juvenile shark longline survey. The primary factors investigated were blue shark lengths relative to dataset (hereafter survey type), year, and quarter. A total of 17,806 blue sharks ranging in size from 41 to 273 cm fork length (FL) and mean size of 109.8 cm FL (± 31.5 standard deviation, SD) were used to investigate trends in size distributions. Mean length of blue sharks collected from the drift gillnet fishery was 115.3 cm FL (± 29.4 SD), while smaller sizes were collected in the NOAA juvenile survey (mean size of 98.2 cm FL ± 32.7 SD). The range of blue shark lengths was similar across years relative to each survey and no significant differences in length occurred over time for either survey. Mean lengths of blue sharks were smaller from drift gillnet collections in the first two quarters (January through June) than collections in the latter two quarters (July through December). Quarterly juvenile surveys were dominated by blue sharks collected during summer months (66 % of all sharks) since this was the primary time period collections occurred. Lengths most abundant in our length frequencies overlapped with the lengths where previous age and growth studies in the North Pacific have resulted in similar size-at-age estimates. The primary size range of samples collected from the drift gillnet survey ranged between 75 and 160 cm FL corresponding to an estimated age range of one to seven years with a peak in size between 90-130 cm FL (~2-4 years of age) based on previous age and growth studies. Similarly, the majority of samples collected from the juvenile survey ranged in size from 60 to 125 cm FL, corresponding to an approximate age range of one to four years, with a peak in size of 75-110 cm FL (~1 to 3 years of age). Assuming an average size-at-maturity of 175 cm FL based on previous studies, over 96 % of the blue sharks collected in both surveys are juvenile and sub-adults and are likely sexually immature.

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INTRODUCTION

The blue shark, *Prionace glauca*, is the most abundant pelagic shark worldwide in tropical and subtropical seas, where it is found throughout oceanic and neritic waters (Nakano & Stevens 2008). Consequently, sound management of this valuable resource is important from both a single-species and ecosystem-based perspective given its role as a top level predator.

Accurate size-at-age determinations are necessary for both stock assessment and management of sharks because they form the basis for calculations of growth and mortality rates, age at maturity, age at recruitment, and estimates of longevity. Validation of annual band pair deposition for up to four years in age was performed using vertebrae from two oxytetracycline-injected blue sharks (Skomal & Natanson 2003). Their results suggested an annual spring deposition of growth zones within the vertebrae and used supporting migratory and life history information of this species as a plausible explanation of annulus formation. Blue shark growth rates are moderately fast with males and females reaching sexual maturity between 4-6 and 5-7 years, respectively (Nakano 1994). Age and growth studies of blue sharks in the North Pacific and Atlantic have been fairly well documented with size-at-maturity of about 200 cm total length (TL) (~170 cm fork length, FL) for both sexes in the North Pacific (Suda 1953, Nakano et al. 1985). In the western Atlantic, 50% sexual maturity of male blue sharks averaged 218 cm TL (~180 cm FL) and females were fully mature by 221 cm TL (~185 cm FL) (Pratt 1979). Maximum longevity of blue sharks is approximately 20 years with a maximum size of 383 cm TL (320 cm fork length, FL) reported from the northwest Atlantic Ocean (Bigelow and Schroeder 1953).

Two of most common methods to estimate size-at-age of blue sharks are vertebral band counts and length frequency modal analyses. However, in order to utilize length frequency analyses effectively, sufficient size data covering the size range of the species under investigation are needed. To date, most age and growth models are limited to a narrow size range, often missing the smallest and largest specimens which are the most influential in growth model calculations (Campana 2001). As such, the objective of this study was to investigate the length frequency data available from the U.S. west coast fisheries. Specifically, we provide a summary of blue shark lengths based on two fishery datasets: 1) California drift gillnet fishery and 2) a fishery-independent NOAA Southwest Fisheries Science Center (SWFSC) juvenile shark longline survey. The primary factors investigated were blue shark lengths relative to dataset (hereafter survey type), year, and quarter. Ultimately, these data will be used to represent survey-specific catch-at-size data and for modal length frequency analyses in order to estimate growth rates and compare to existing growth models that may be used for the upcoming ISC blue shark stock assessment.

MATERIALS AND METHODS

Data for blue shark lengths originated from two sources 1) fishery-dependent data from scientific observers of the California Drift Gillnet fishery (1990-2010), which operates between May and January, 2) fishery-independent data from juvenile shark longline research surveys conducted by the NOAA Southwest Fisheries Science Center (1993-2011) primarily between

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June and August of each year. A mixture of length measurements were taken across study years and surveys: TL, FL and alternate length (AL, straight line distance between the origin of the first and the second dorsal fins) and were therefore standardized to FL. The following length conversions were obtained based on data from fishery observer or researcher measured fish collected in these two surveys and used to standardize data for subsequent length frequency analyses:

FL=0.829*(TL) - 1.122, r^2=0.987, n=13,799

FL=2.746*(AL) + 11.803, r^2=0.941, n=9,504

These length conversions were similar to other studies: FL=0.820*(TL) - 1.061, r^2=0.999 (Castro and Mejuto 1995), FL=0.831*(TL) + 1.391, r^2=0.997 (Kohler et al. 1995).

Size data were combined between sexes because no significant differences existed for either survey (t-test, $P > 0.05$). Blue shark size bins were grouped by 5 cm FL ranging from 40 to 275 cm FL. Six blue sharks ranging in size from 21-39 cm FL were removed from the drift gillnet dataset and nine sharks ranging from 23-38 cm FL were removed from the NOAA juvenile dataset. The literature varies slightly relative to size-at-birth; however, Pratt (1979) estimates 35-44 cm FL and Lessa et al. (2004) used 56.4 cm TL (~45 cm FL) as a birth size estimate. Further, Skomal & Natanson (2003) age and growth study of blue sharks used an average size-at-birth of 45 cm FL based on the work of Pratt (1979).

Length frequencies were analyzed according to survey type, year, and quarter. Quarters were defined as winter (January-March, quarter 1), spring (April-June, quarter 2), summer (July-September, quarter 3), and fall (October-December, quarter 4).

Lastly, a small number of blue shark lengths were also recorded from both set net and small mesh gillnet fisheries that are not analyzed in this study. A total of 43 blue sharks from the set net fishery had a mean size of 170.4 cm FL and 130 individuals with a mean size of 102.4 cm FL from the small mesh gillnet survey. Seven blue sharks were recorded in the California Department of Fish and Game (CDFG) port sampling database (1980-1989) with a mean size of 77.3 cm FL; there is no market for blue sharks in California, thus most blue sharks are discarded at sea.

RESULTS AND DISCUSSION

A total of 17,806 blue sharks ranging in size from 41 to 273 cm FL were used to investigate trends in size distributions. Median size of all blue sharks was 106.0 cm FL and mean size was 109.8 cm FL (± 31.5 standard deviation, SD). A total of 12,080 blue sharks collected from the drift gillnet fishery had a median size of 113.0 cm FL and mean of 115.3 cm FL (± 29.4 SD) (Figure 1). Smaller sizes were generally collected in the NOAA juvenile survey with a total of 5,726 measured individuals; median size of 88.0 cm FL and mean size of 98.2 cm FL (± 32.7 SD) (Figure 1).

The range of blue shark lengths appeared similar across years relative to each survey (Figures 2 & 3). Smaller blue sharks were collected in the NOAA juvenile survey during most years of the study; however, during three years (1994, 2002, 2003) smaller sharks were found in the drift gillnet survey (Figure 3). No significant differences in length occurred over time for either survey (drift gillnet: $P = 0.094$, $r^2 = 0.141$, juvenile survey: $P = 0.8155$, r^2=0.003) (Figure

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3). There was a slight decrease in mean length from 1994 to 2000, but then variability up and down since 2000 with a recent trend of increased lengths during the final years investigated.

Mean lengths of blue sharks were smaller from drift gillnet collections in the first two quarters (January through June) than collections in the latter two quarters (July through December) (Figure 4A). Specifically, mean sizes during quarters one and two were 102.2 cm FL (± 26.2 SD) and 106.6 cm FL (± 31.9 SD), respectively. Sample sizes were much smaller during these first two quarters representing only 5.5 % and 0.9 % of the total drift gillnet catch. In contrast, larger sample sizes comprising 17.5 % and 76.1% of the total catch occurred during quarters three and four, respectively. Mean length during quarter three was the largest at 124.7 cm FL (± 35.4 SD) followed by 114.2 cm FL (± 27.4 SD) during quarter four. Quarterly juvenile survey plots were dominated by blue sharks collected during summer months (66 % of all sharks) since this was the primary time period collections occurred. Mean spring and summer lengths were similar (spring=100.2 ± 33.0, summer=93.2 ± 31.6), but larger sizes of blue sharks were evident during the fall (118.6 ± 28.5) (Figure 4B). Quarterly plots of blue shark lengths relative to survey type and year are shown in Figures 5 & 6. The majority of blue sharks collected in the drift gillnet survey were during the fall, while most were collected during summer in the juvenile survey. Due to the dominance of one to two quarters in most years, length frequency modal analyses may prove difficult by quarter and survey type. Thus, collapsing across quarters or years (by survey) and investigating length frequencies by mode may prove the most reasonable method.

Age and growth of the blue shark has been described by several studies in the North Pacific using both vertebral band counts and length frequency modal analyses. Cailliet et al. (1983), Tanaka et al. (1990), and Blanco-Parra et al. (2008) used vertebral growth rings or band counts and Nakano (1994) used both vertebrae and length-frequency modes to establish growth curves for the blue shark. Differences in size-at-age existed among studies likely based on geography, methodology, sex, and range of lengths available. Generally, length modes most abundant in our length frequencies overlapped with the lengths where the aforementioned studies resulted in similar size-at-age estimates. The primary size range of samples collected from the drift gillnet survey ranged between 75 and 160 cm FL corresponding to an age range of one to seven years with a peak in size between 90-130 cm FL (~2-4 years of age) based on previous age and growth studies (Cailliet et al. 1983, Tanaka et al. 1990, Nakano 1994, Skomal & Natanson 2003, Blanco-Parra et al. 2008). Similarly, the majority of samples collected from the juvenile survey ranged in size from 60 to 125 cm FL, corresponding to an approximate age range of one to four years, with a peak in size of 75-110 cm FL (~1 to 3 years of age). These size-at-age estimates suggest the majority of samples collected in both surveys are juveniles and sub-adults. Assuming an average size-at-maturity of 175 cm FL based on previous studies (Suda 1953, Pratt 1979, Nakano et al. 1985), over 96 % of the blue sharks collected in both surveys would likely be sexually immature.

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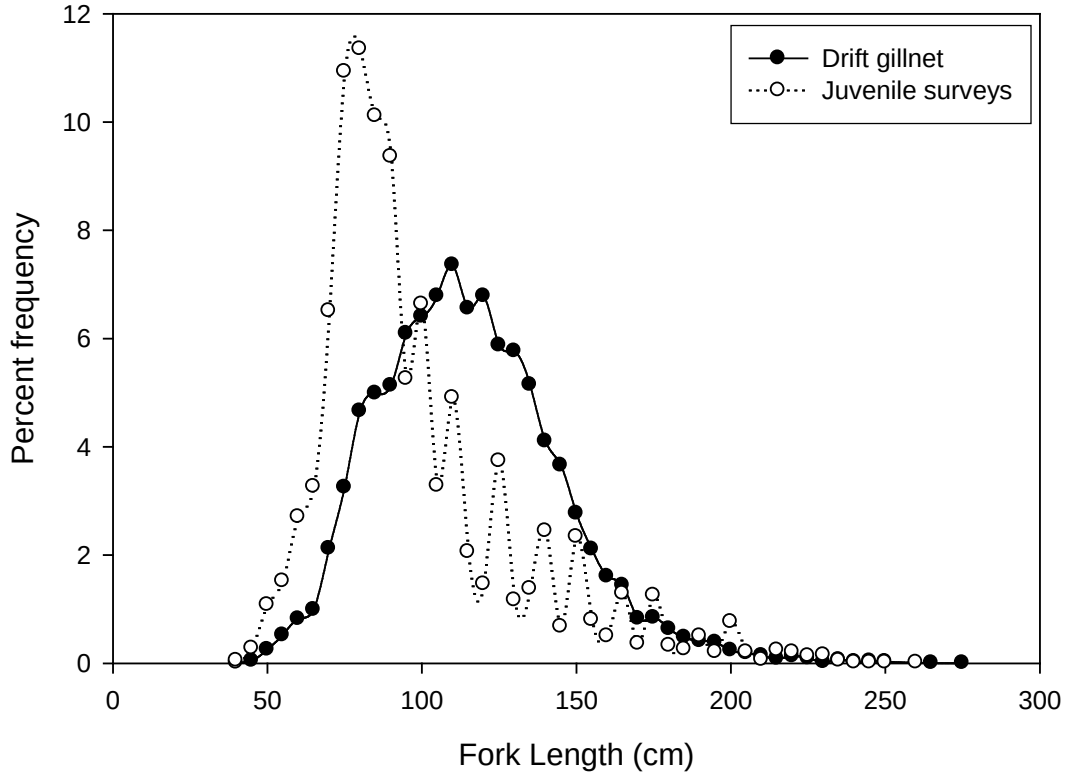

Figure 1. Size frequency distributions of blue sharks according to survey type (drift gillnet and NOAA juvenile surveys). Data are binned by 5 cm length increments.

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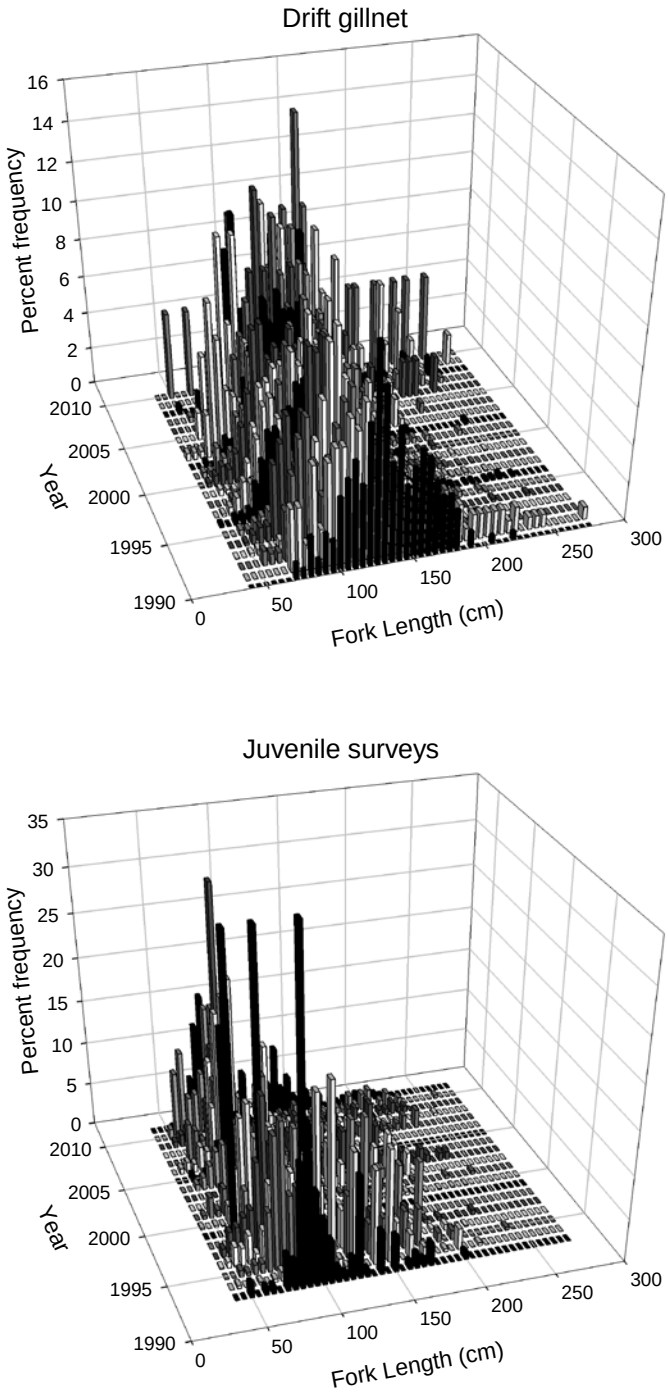

Figure 2. Length frequency plots by survey A) drift gillnet (1990-2010), B) NOAA juvenile surveys (1993-2011) across all years. Data are binned by 5 cm length increments.

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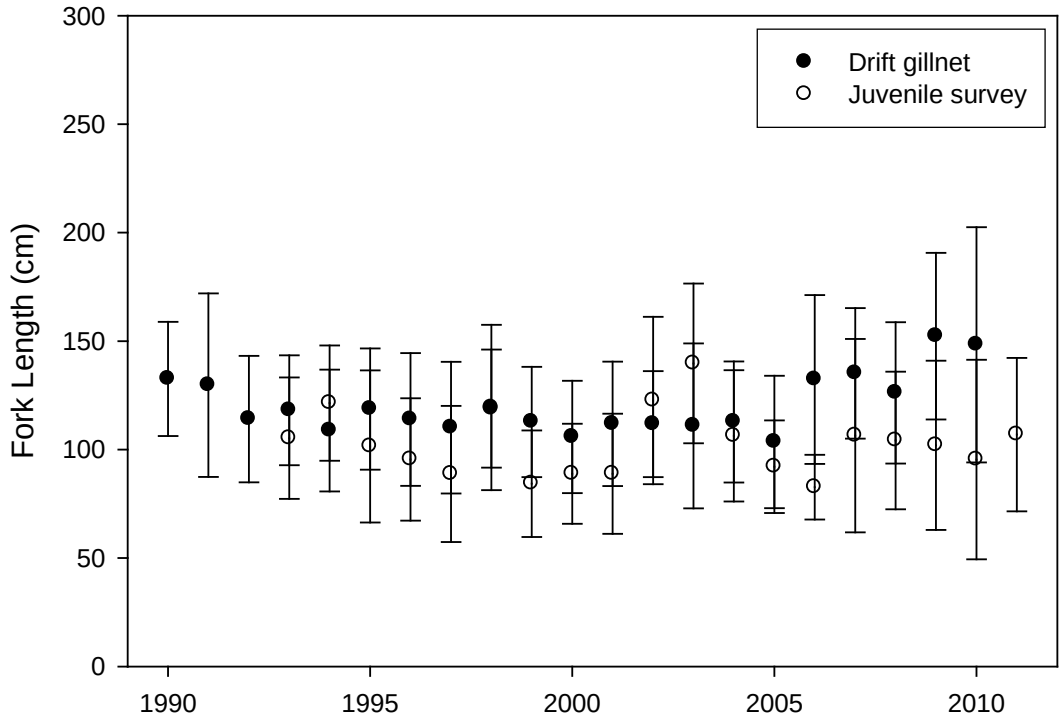

Figure 3. Mean size (cm FL) by year relative to each survey type: drift gillnet (solid circles) and NOAA juvenile survey (open circles). Bars represent 1 standard deviation (SD) about the mean.

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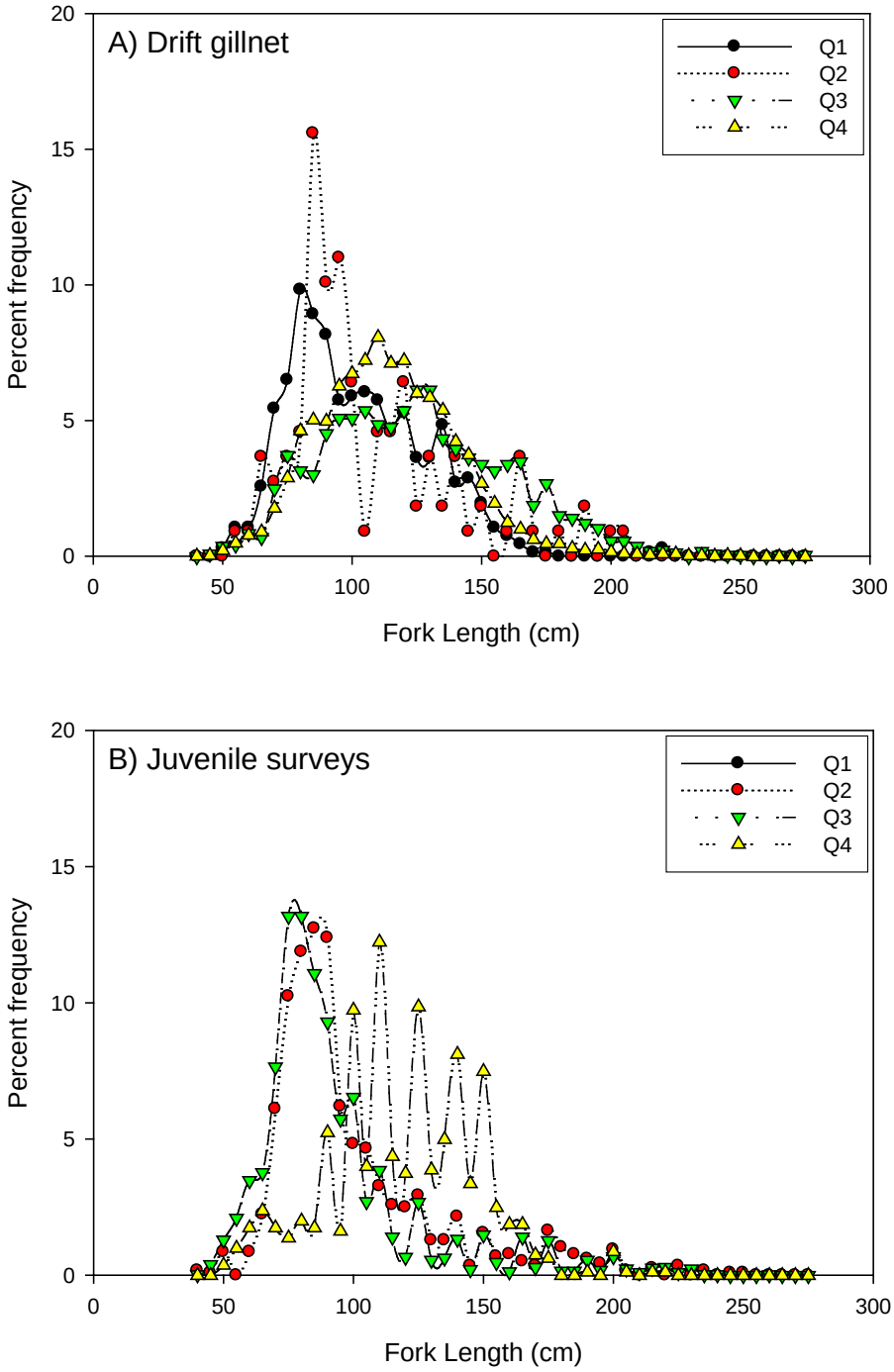

Figure 4. Quarterly length frequency plots by survey: A) drift gillnet, B) NOAA juvenile survey. Total percent frequencies by quarter are relative to each quarter. Data are binned by 5 cm length increments. Years are collapsed across quarters.

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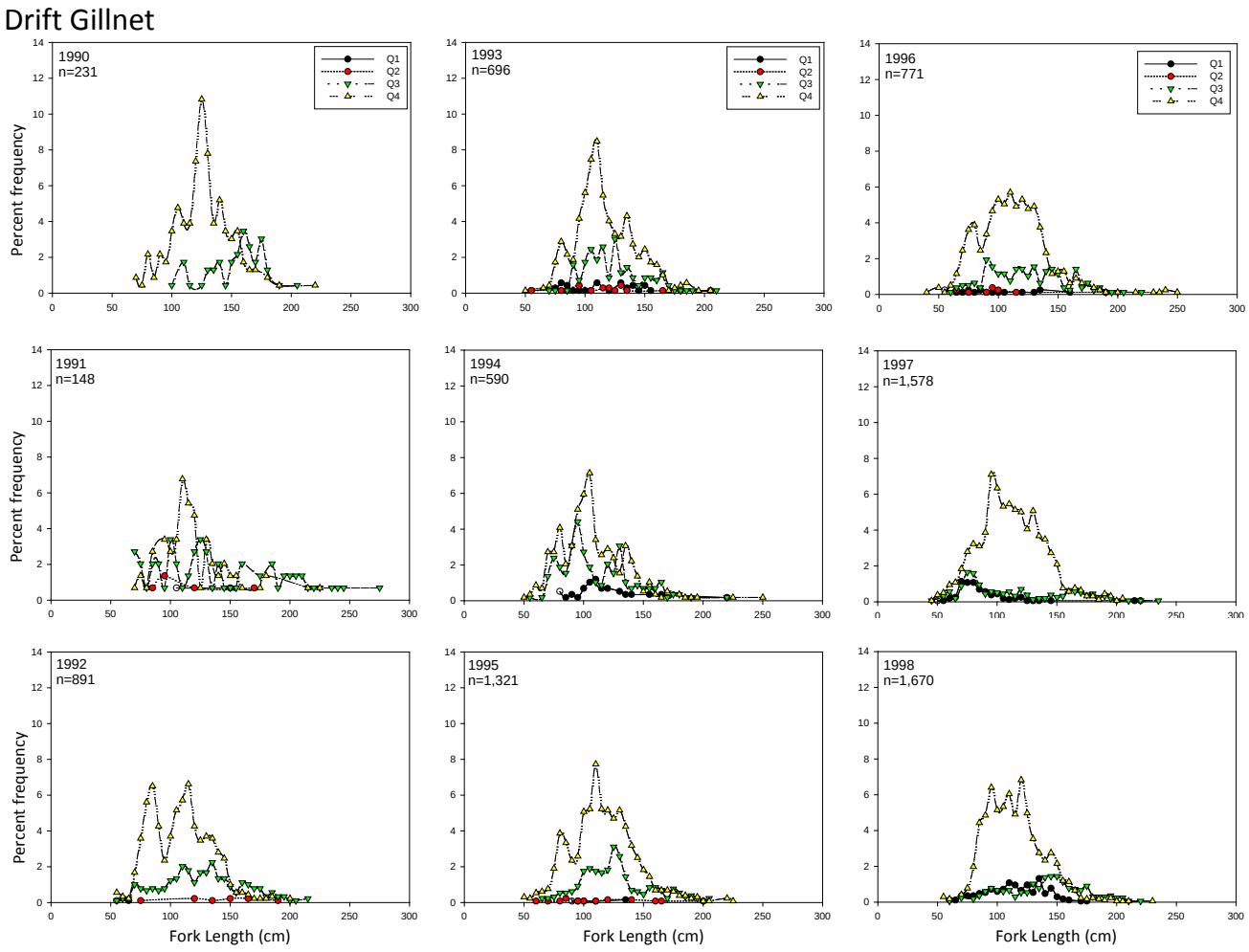

Figure 5. Quarterly length frequency plots (total percent frequency by year) of blue sharks collected in the drift gillnet fishery (1990-2010). Data are binned by 5 cm length increments.

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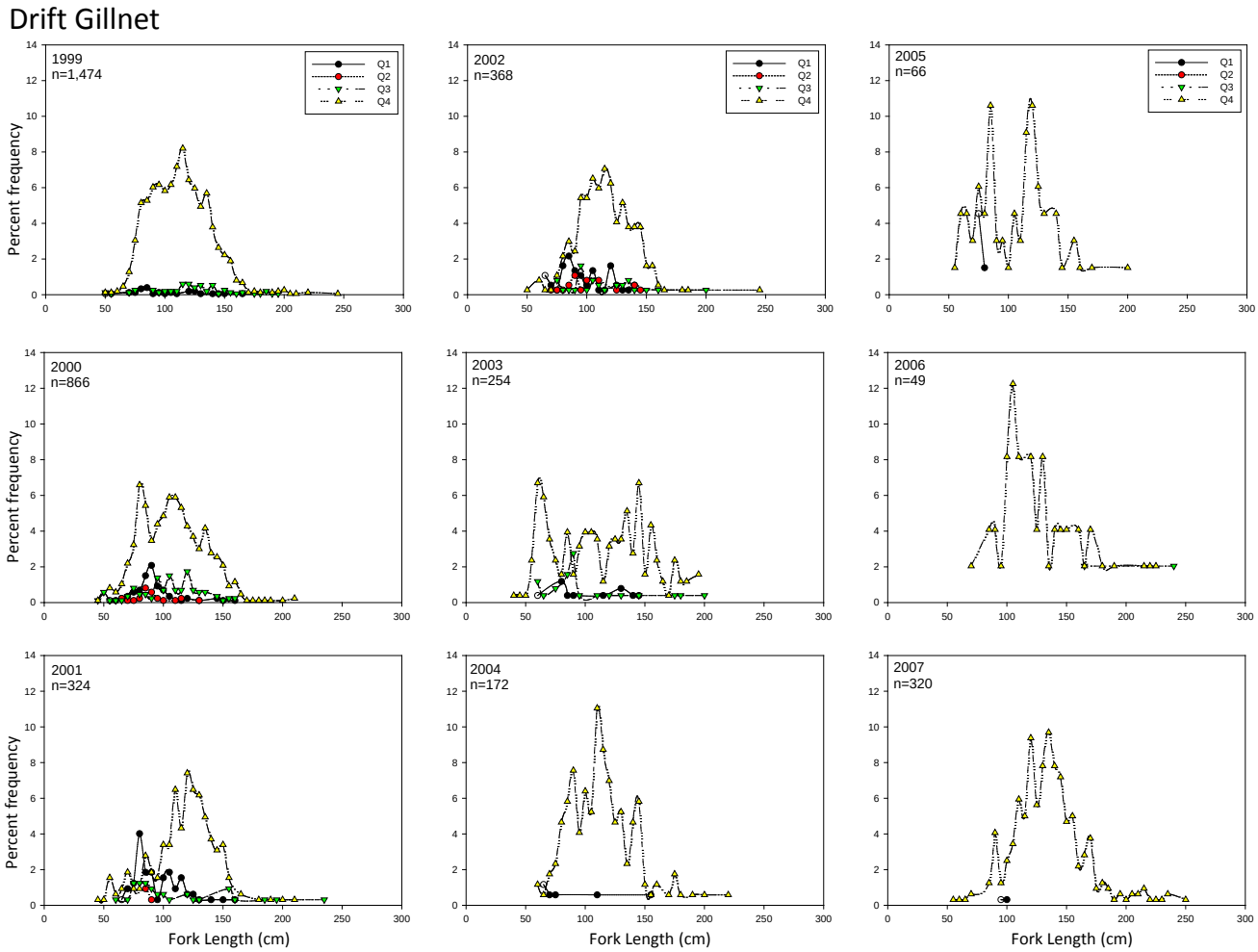

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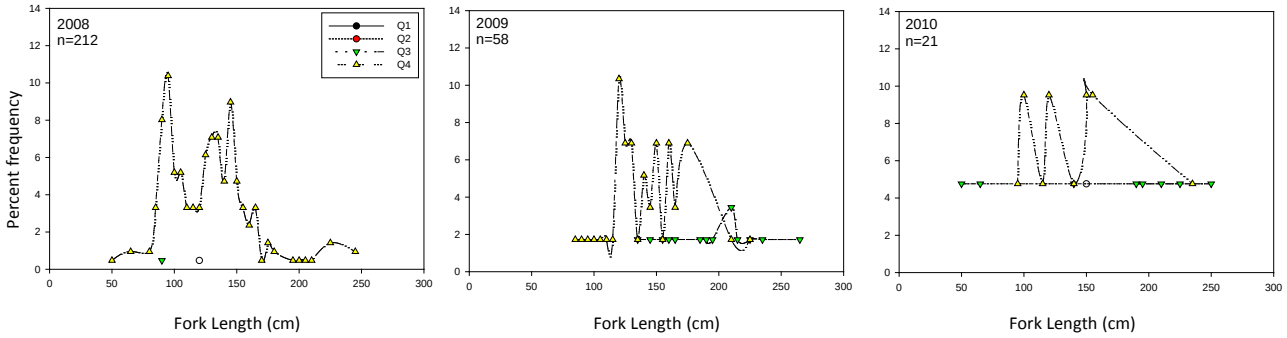
Drift Gillnet



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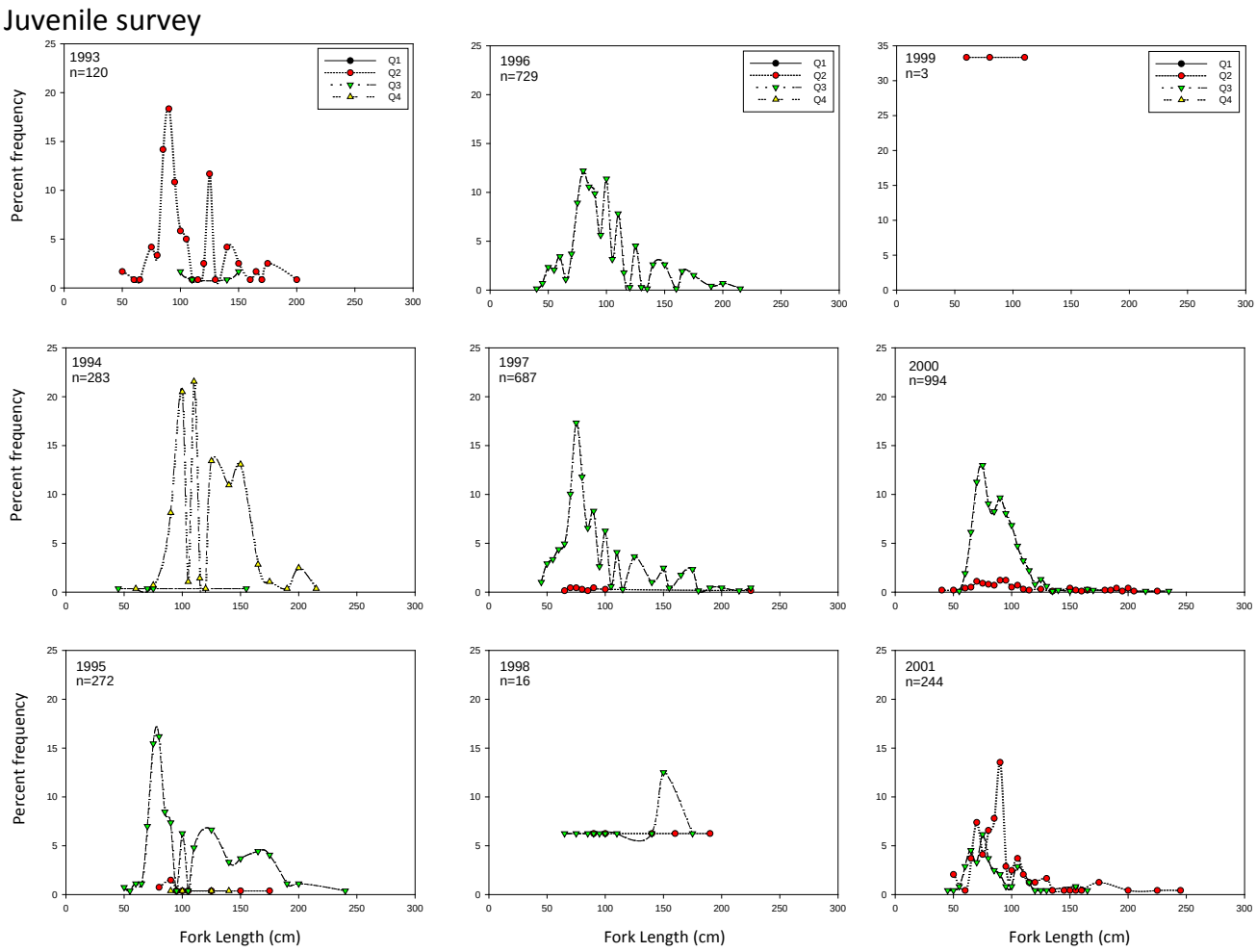

Figure 6. Quarterly length frequency plots (total percent frequency by year) of blue sharks collected from NOAA juvenile surveys (1993-2011). Data are binned by 5 cm length increments.

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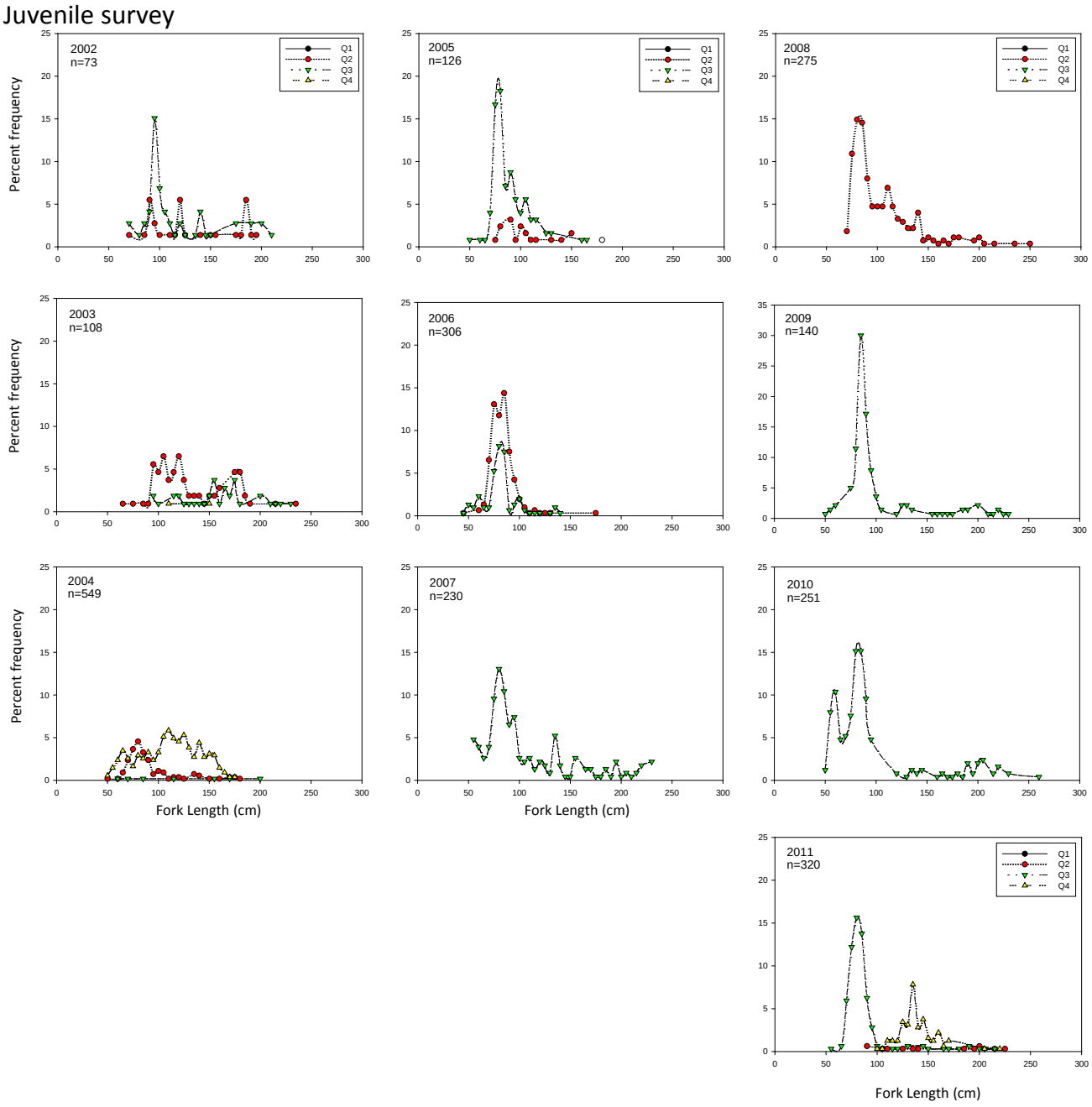

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