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Trends in Area-Weighted CPUE of Pacific Sleeper Sharks *Somniosus pacificus* in the Northeast Pacific Ocean Determined from Sablefish Longline Surveys

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Abstract: The deepwater Pacific sleeper shark *Somniosus pacificus* is an opportunistic predator in the northeast Pacific Ocean. Their life history and distribution are poorly understood, and changes in their relative abundance or distribution could have direct and indirect effects on the ecosystem. There are no directed fisheries or surveys for Pacific sleeper sharks in Alaskan marine waters; consequently, abundance estimation is limited to indirect methods. We analyzed Pacific sleeper shark incidental catch (bycatch) from sablefish longline surveys conducted on the upper continental slope of the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska between the years 1979 and 2003. Our objectives were to estimate trends in Pacific sleeper shark relative abundance and their statistical significance. A total of 1,565 Pacific sleeper sharks were captured by sablefish longline surveys between the years 1979 and 2003 with a sample effort of 19.7 million hooks. Area (km^2) weighted catch per unit effort (CPUE) of Pacific sleeper sharks was analyzed from standardized sablefish longline surveys between the years 1982 and 2003 with bootstrap 95% confidence intervals as an index of relative abundance in numbers. Within the limited time series available for hypothesis testing, area-weighted CPUE of Pacific sleeper sharks increased significantly in the eastern Bering Sea between the years 1988 and 1994 and in the Gulf of Alaska between the years 1989 and 2003, but also decreased significantly in the Gulf of Alaska in 1997. The increasing trend in the Gulf of Alaska was driven entirely by one region, Shelikof Trough, where most (54%) Pacific sleeper sharks were captured. Increasing trends in area-weighted CPUE of Pacific sleeper sharks in the eastern Bering Sea and Shelikof Trough are consistent with previous analyses of fishery-dependent and fishery-independent data from the northeast Pacific Ocean and with evidence of a climatic regime shift that began in 1976 and 1977. Whether increasing trends in area-weighted CPUE of Pacific sleeper sharks from sablefish longline surveys represent an increase in the relative abundance of Pacific sleeper sharks at the population level or just reflect changes in local densities is unknown because of caveats associated with computing area-weighted CPUE of Pacific sleeper sharks from sablefish longline surveys and because of a lack of information on the life history and distribution of Pacific sleeper sharks.

INTRODUCTION

Pacific sleeper sharks *Somniosus pacificus*, spiny dogfish *Squalus acanthias*, and salmon sharks *Lamna ditropis* are the 3 most abundant shark species in Alaskan marine waters (Mecklenburg et al. 2002). Of these, Pacific sleeper sharks are the least understood (e.g., Yano et al. 2004; 2007). Pacific sleeper sharks range in the North Pacific from Japan along the Siberian coast to the Bering Sea, and southward to southern California USA and Baja California, Mexico (Compagno 1984). Pacific sleeper sharks have also been identified on seamounts in the North Pacific (Borets 1986) and along the Pacific coasts as far south as Taiwan (Wang and Yang 2004) and Chile (Crovetto et al. 1992), although Yano et al. (2004) suggest that the range of Pacific sleeper sharks is limited to the northern hemisphere. In Alaskan marine waters, Pacific sleeper sharks occur on the continental shelf and slope of the Chukchi Sea, Bering Sea, Aleutian Islands, and Gulf of Alaska (Hart 1973; Mecklenburg et al. 2002; Benz et al. 2004; Courtney et al. 2006a, 2006b). Published observations suggest that mature female Pacific sleeper sharks are in excess of 365 cm TL (total length), mature male Pacific sleeper sharks are in excess of 397 cm TL, and size at birth is approximately 40 cm TL (Gotshall and Jow 1965; Yano et al. 2007). Pacific sleeper sharks are assumed to bear live young, although little is known about their reproduction or other aspects of their life history including age (Ebert et al. 1987; Yano et al. 2007). Virtually nothing is known about the space utilization or geographic movements of Pacific sleeper

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sharks within Alaskan marine waters. Tagging studies in Alaska have shown that at least some Pacific sleeper sharks reside in the Gulf of Alaska and Prince William Sound, where they exhibit relatively limited geographic movement (< 100 km) throughout the year (Hulbert et al. 2006).

Pacific sleeper sharks appear to be opportunistic predators, and changes in their relative abundance or distribution could have direct and indirect effects on the ecosystem. Direct effects result from predation. Pacific sleeper sharks are known to feed on a wide variety of mid-water and benthic prey (Bright 1959; Hart 1973; Compagno 1984; Sigler et al. 2006; Yano et al. 2007). Prey items found in Pacific sleeper shark stomachs include cetaceans, harbor seal *Phoca vitulina*, flatfishes *Pleuronectiformes*, Pacific salmon-*Oncorhynchus* spp., rockfishes *Sebastes* spp.,walleye pollock *Theragra chalcogramma*, and invertebrate species including Tanner crab *Chionoecetes bairdi*, cephalopods, gastropods, and occasionally even sponges (Compagno 1984; Orlov 1999; Yang and Page 1999; Sigler et al. 2006). Whales are probably consumed as carrion (Smith and Baco 2003; Sigler et al. 2006). Whether other cetaceans and harbor seals are consumed as living prey or as carrion is not known (Sigler et al. 2006). However, indirect effects on the ecosystem may occur even if predation is not evident. Frid et al. (2006, 2007a, 2007b, In press) modeled predation risk of harbor seals from Pacific sleeper sharks and predicted indirect effects of the removal of Pacific sleeper sharks on 2 species consumed by harbor seals, Pacific herring *Clupea pallasii* and walleye pollock, mediated by changes in harbor seal behavior in response to predation risk.

Although the trophic relationships of Pacific sleeper sharks in the ecosystem are still uncertain (e.g., McMeans et al. 2007), Pacific sleeper sharks have been implicated in the decline of Steller sea lions *Eumetopias jubatus* in western Alaska (NRC 2003) and in the decline of harbor seals in Glacier Bay, Alaska (Taggart et al. 2005). The NRC (2003) recommended research into potential predator feeding habits and population size, including 1) collection of sleeper shark incidental catch (bycatch) data from longline fisheries to assess shark abundance and 2) examination of shark stomach contents to determine diet. A subsequent study of Pacific sleeper shark predation on sea lions found no sea lion remains in the stomachs of nearly 200 sleeper sharks (130–284 cm TL) captured near sea lion rookeries (Sigler et al. 2006). Directed studies of Pacific sleeper shark predation on harbor seals have not been conducted. This study responds to the NRC (2003) recommendation to assess trends in sleeper shark abundance in the northeast Pacific Ocean.

There are no directed fisheries for Pacific sleeper sharks in Alaskan marine waters, length compositions are not available, and age determination is not currently possible (Courtney et al. 2006a, 2006b). Consequently, abundance estimation is limited to indirect methods. Pacific sleeper sharks are occasionally captured in longline surveys for sablefish *Anoplopoma fimbria* conducted by the National Marine Fisheries Service (NMFS) on the upper continental slope and deepwater gullies of the continental shelf of the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) within NMFS regulatory areas (Figure 1). Shark bycatch from sablefish longline surveys has not previously been analyzed.

For this report, historic data from sablefish longline surveys were tabulated, and area-(km^2) weighted CPUE of Pacific sleeper sharks was calculated with statistical methods previously implemented for the sablefish longline surveys (Gulland 1969; Quinn et al. 1982; Sasaki 1985; Sigler and Fujioka 1988; Sigler and Zenger 1989; Zenger and Sigler 1992). Trends in area-weighted catch per unit effort (CPUE) of Pacific sleeper sharks were tested for statistical significance by comparing 95% confidence intervals obtained from bootstrap resampling (Efron 1982; Efron and Tibshirani 1986). Bootstrap resampling has been implemented for the sablefish longline surveys (Sigler and Fujioka 1988) and for sablefish pot surveys (Kimura and Balsiger 1985), and is reviewed for use in survey sampling of marine fishes by Gunderson (1993) and Kimura and Somerton (2006). This is the first time that area-weighted CPUE and bootstrap resampling have been applied to shark bycatch from sablefish longline surveys.

MATERIALS AND METHODS

Survey methods

Since 1979, annual sablefish longline surveys have sampled the 201–1,000 m depths of the upper continental slope and shelf break in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska including some deepwater gullies (>200 m) in the Gulf of Alaska. The time series includes 2 surveys, the Japan-U.S. cooperative longline survey from 1979 to 1994 (cooperative survey) and the NMFS domestic longline survey from 1988 to present (domestic survey; Sasaki 1985; Sigler and Fujioka 1988; Sigler and Zenger 1989; and Zenger and Sigler 1992).

Surveys were conducted each year from May to September. Survey station locations were fixed, and the same station locations were fished each year. Survey stations were distributed as uniformly as possible within NMFS regulatory areas (Figure 1). The eastern Bering Sea slope stations sampled 5 geographic regions: Bering-V, Bering-IV, Bering-III, Bering-II, and Bering-I (Sasaki 1985). The Aleutian Islands slope stations sampled 4 geographic regions: Northwest (NW) Aleutians, southwest (SW) Aleutians, northeast (NE) Aleutians, and southeast (SE) Aleutians (Sasaki 1985). The Gulf of Alaska slope stations sampled 6 geographic regions: Shumagin, Chirikof, Kodiak, West Yakutat, East Yakutat, and Southeast Outside (Sasaki 1985; Sigler and Fujioka 1988; Sigler and Zenger 1989; Zenger and Sigler 1992). Gulf of Alaska gully stations were added in 1989 to index prerecruit sablefish (Sasaki 1985), but were not included in sablefish assessments (Sigler and Fujioka 1988; Sigler and Zenger 1989; Zenger and Sigler 1992). The Gulf of Alaska gully stations sampled 14 geographic regions: Shumagin Gully, West Semidi, Shelikof Trough, Chiniak Gully, Amatuli Gully, Western Grounds, Yakutat Valley, Alsek Strath, Spencer Gully, Southeastern Shelf, Southeastern, Omany Trench, Iphigenia Trench, and Dixon Entrance.

One station was fished per day, except in Gulf of Alaska gullies where 2 adjacent stations were fished per day. Each slope station in the Aleutian Islands and Gulf of Alaska fished 160 hachis (the Japanese word for "skate" or length of longline). Each slope station in the Bering Sea fished 180 hachis. Each gully station in the Gulf of Alaska fished 80 hachis. A standard longline survey hachi consisted of a 100 m groundline with 45 hooks spaced 2 m apart on 1.2 m gangions with 5 meters of groundline left bare on each end of the hachi. The hook was a type of J-hook called a tara hook or a circle hook. Ring-cut short-finned squid were used as bait. At slope stations, the longline was set at right angles to the isobaths in a manner to cover the

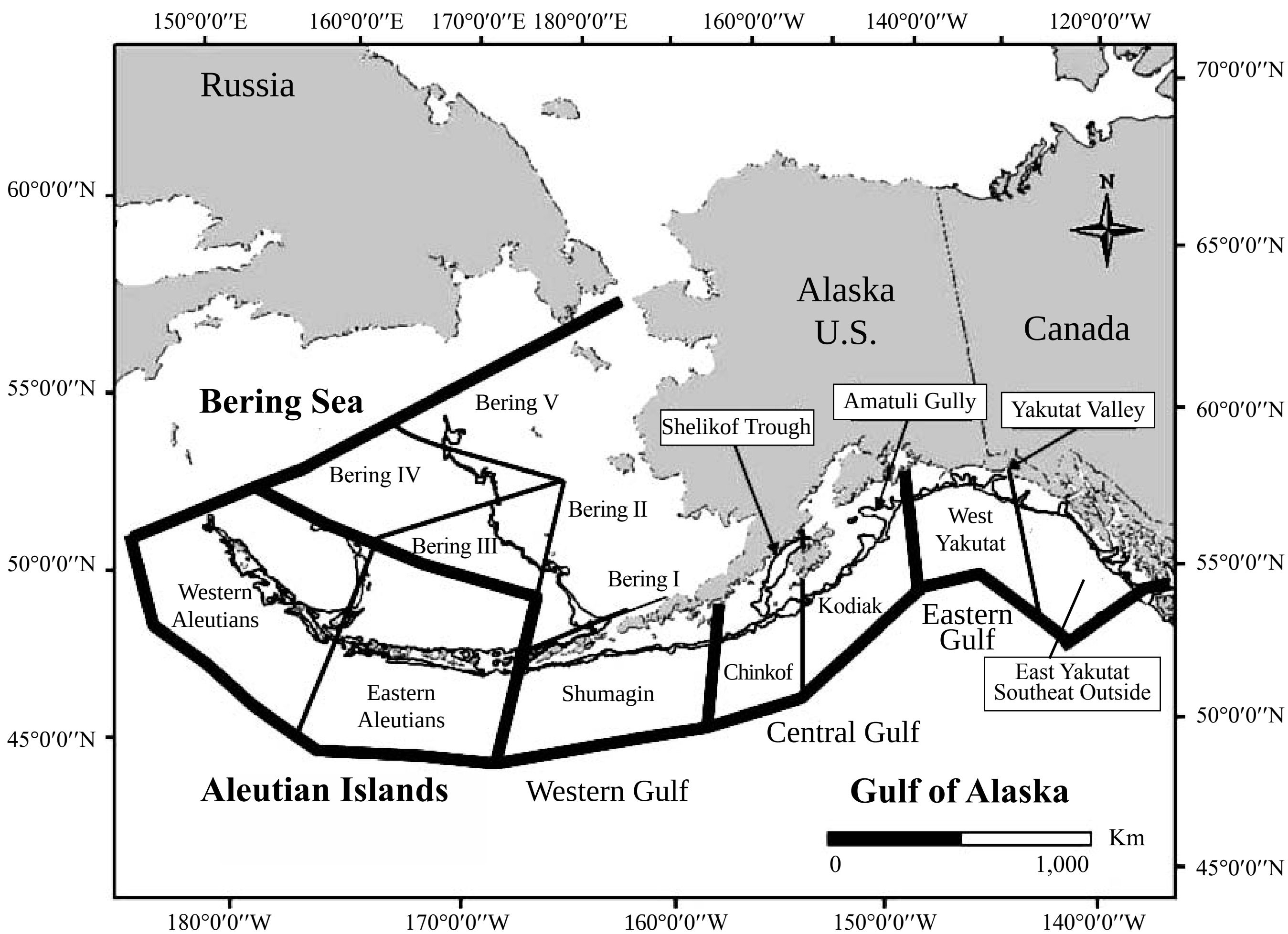

Figure 1. Sablefish longline surveys sampled the continental shelf break and upper continental slope of Alaskan marine waters in the northeast Pacific Ocean between the 200 and 1,000 m contour intervals outlined in black.

depth range of 201–1,000 m. However, the distance between 201 and 1,000 m varied at each station, and the complete depth range could not be covered at stations where this distance exceeded the length of the longline gear—16 km at slope stations in the Gulf of Alaska and Aleutian Islands, and 18 km at slope stations in the eastern Bering Sea. The longline was usually set from shallow to deep waters and was retrieved in the same direction. At gully stations in the Gulf of Alaska, the longline was set along the bottom of the gully where the maximum depth was generally between 300–400 m. Although some hooks landed in shallower (<200 m) and deeper (>1,000 m) depths, only depths between 201–1,000 m received full coverage with the sablefish longline survey gear.

Hauling the longline started 2 hours after the set was completed. The soak time averaged 5 to 6 hours, but varied by section of the longline. For the first section of the longline hauled, the soaking time was about 3 hours, but for the last section hauled it was about 7 to 9 hours. The depth at which fish were caught was estimated by measuring the depth of water under the vessel with an echo sounder for every fifth hachi. The catch in numbers was recorded by species or species group for each hachi. Large non-target species such as Pacific sleeper sharks were counted and released at the rail. As a result, length, weight, and sex were not recorded for Pacific sleeper sharks captured in sablefish longline surveys.

The domestic survey (1988–2003) was similar to the cooperative survey (1979–1994) with some exceptions: the domestic survey sampling design was expanded in 1989 to include more deepwater gullies (>200 m depth) of the Gulf of Alaska continental shelf; the domestic survey sampling design did not include the western Aleutians; the domestic survey sampling design did not include the eastern Bering Sea and eastern Aleutian Islands in all years; the domestic survey gear used stronger beckets and gangions than the cooperative survey; the domestic survey gear used circle hooks (Eagle Claw No. 7), whereas the cooperative survey used a J-hook 74 mm in length and 21 mm in width; the domestic survey chartered U.S. commercial longline vessels of 37–45 m, whereas cooperative survey chartered Japanese commercial longline vessels of approximately 500 gross tons, but otherwise with essentially the same structural characteristics.

Statistical methods

First, the CPUE of Pacific sleeper sharks was tabulated from the combined cooperative survey (1979–1994) and domestic survey (1988–2003) to identify trends over time (1979–2003) and to identify the distribution of CPUE by survey region and depth (Figure 1). The CPUE was tabulated for all stations fished, during all years, in all depths where hooks landed (0–1,200 m or greater), and in all survey regions. The CPUE was calculated as the number of Pacific sleeper sharks captured per hachi from each region (*r*), station (*j*), and depth (*k*) with equation (*1*):

$$CPUE_{rjk} = \frac{sleeper\ sharks_{rjk}}{hachi_{rjk}}. \qquad (1)$$

Second, area-weighted CPUE of Pacific sleeper sharks was calculated from sablefish longline surveys as an index of relative abundance in numbers. An attempt was made to control for factors unrelated to abundance by limiting the calculation of area-weighted CPUE to standard survey years, standard survey regions, standard survey stations, standard survey depths, and effective hachis, following methods in Sasaki (1985), Sigler and Zenger (1989), and Zenger and Sigler (1992). Standard survey years were defined as years with the same survey design each year: 1982–1994 for the cooperative survey, and 1989–2003 for the domestic survey. Standard survey regions were defined as geographically stratified regions within each regulatory area that were designed to be sampled by one or more fixed station locations each year (Figure 1). Standard survey stations were defined as fixed station locations designed to be fished each year and spread as uniformly as possible within standard survey regions along the upper continental slope, continental shelf break, and deepwater gullies (>200 m depth). Standard survey depths were defined as the following stratified depth ranges (depth strata) between 201–1,000 m designed to have full coverage by the longline gear: 201–300 m, 301–400 m, 401–600 m, 601–800 m, 801–1,000 m. Effective hachis were defined as hachis with 5 or fewer ineffective hooks. Ineffective hooks were identified during gear retrieval and generally included hooks tangled in a snarl, missing hooks or hooks straightened with bait removed, and hooks on a hachi associated with a parted ground line. Standard survey stations were also excluded from calculation of standardized area-weighted CPUE if they experienced whale predation on the gear, competition with other fishing vessels, or excessive loss of gear.

Trends in area-weighted CPUE were calculated separately for the standardized cooperative survey (1982–1994) and the standardized domestic survey (1989–2003). The standardized surveys differed in the design of their station locations and regions. In particular, the standardized domestic survey design included several deepwater gullies (>200 m depth) on the Gulf of Alaska continental shelf, including Shelikof Trough, where Pacific sleeper shark appeared to be relatively abundant. The standardized cooperative survey design had more limited sampling of deepwater gullies and did not include Shelikof Trough. The types of hooks and gangions also differed between the standardized cooperative and domestic surveys, which may have affected the catchability of sleeper sharks. Standardizing CPUE of Pacific sleeper sharks between the 2 sablefish surveys was not attempted here because of low Pacific sleeper shark sample sizes within geographic regions sampled by both surveys in the same years. The cooperative and domestic longline surveys have been standardized for sablefish CPUE (Kimura and Zenger 1997; Zenger 1997).

Area-weighted CPUE of Pacific sleeper sharks in sablefish longline surveys was calculated following methods previously implemented for sablefish longline surveys by Sasaki (1985), Sigler and Fujioka (1988), Sigler and Zenger (1989), and Zenger and Sigler (1992). The CPUE at each station was multiplied by the estimated bottom area (A_{rk}; km^2) within each standard survey region and depth stratum combination (Table 19 in Sasaki 1985; Table 2 in Sigler and Fujioka 1988; M. Sigler, unpublished data). Results for each station were summed across depth strata to obtain an independent estimate of Pacific sleeper shark relative population numbers (RPNs) for the standard survey region sampled by the station with equation (*2*):

$$RPN_{rj} = \sum_k A_{rk} * CPUE_{rjk} \ . \qquad (2)$$

Station RPNs were averaged within standard survey regions to obtain regional RPNs with equation (*3*):

$$RPN_r = \frac{\sum_j RPN_{rj}}{j} . \qquad (3)$$

Regional RPNs were summed within regulatory areas to obtain regulatory area RPNs with equation (*4*):

$$RPN = \sum_r RPN_r \ . \qquad (4)$$

Following Gulland (1969) and Quinn et al. (1982), regional RPNs from equation (*3*) were divided by the total bottom area (A_r; km^2) surveyed within each standard survey region to obtain area-weighted CPUEs for standard survey regions with equation (*5*):

$$Area\text{-}weighted\ CPUE_r = \frac{RPN_r}{A_r} . \qquad (5)$$

Similarly, area RPNs from equation (*4*) were divided by the total bottom area (A; km^2) surveyed within each regulatory area (Eastern Bering Sea, Aleutian Islands, Western Gulf of Alaska, Central Gulf of Alaska, Eastern Gulf of Alaska, and Gulf of Alaska total) to obtain area-weighted CPUEs for regulatory areas with equation (*6*):

$$Area\text{-}weighted\ CPUE = \frac{RPN}{A} . \qquad (6)$$

Third, bootstrap 95% confidence intervals were calculated for area-weighted CPUE of Pacific sleeper sharks from sablefish longline surveys with bootstrap resampling to determine if trends in Pacific sleeper shark area-weighted CPUE over time were statistically significant. Following Sigler and Fujioka (1988), each station was treated as an independent estimator of area-weighted CPUE for the standard survey region it sampled. Stations within each standard survey region were randomly resampled with replacement. A new RPN estimate was calculated for each standard survey region as the average of the randomly resampled station RPNs using equation 3 and termed the bootstrap replicate (RPN^*_r). Bootstrap replicates of RPNs for regulatory areas (RPN^*) were computed using equation 4. Bootstrap replicates of area-weighted CPUE for standard survey regions (area-weighted $CPUE^*_r$) were computed using equation 5. Bootstrap replicates of area-weighted CPUE for regulatory areas (area-weighted $CPUE^*$) were computed using equation 6. The bootstrap procedure was repeated 1,000 times. A bootstrap 95% confidence interval was obtained from the 1,000 bootstrap replicates of area-weighted CPUE by the percentile method (Efron and Tibshirani 1986).

There were insufficient data to conduct hypothesis testing for all survey regions during all survey years. The percentile method (Efron and Tibshirani 1986) requires approximately normally distributed bootstrap replicates. Histograms of bootstrap replicate distributions of area-weighted CPUE were graphed and visually inspected for selected standard survey regions and regulatory areas by year. Bootstrap 95% confidence intervals were computed for time series of area-weighted CPUE from standard survey regions and regulatory areas with approximately normally distributed bootstrap replicates.

Finally, an additional bootstrap resampling step was used to test the null hypothesis that the difference (area-weighted $CPUE_{i'}$) − (area-weighted $CPUE_i$) = 0, where i = year and i' = any subsequent year (Sigler and Fujioka 1988). Hypothesis testing was limited to selected time series of area-weighted CPUE from standard survey regions and regulatory areas with non-zero catches and approximately normally distributed bootstrap replicates. A difference was computed from each pair of 1,000 bootstrap replicates (area-weighted $CPUE^*_{i'}$) – (area-weighted $CPUE^*_i$), producing a bootstrap distribution of 1,000 differences. The percentile method was used to compute bootstrap 95% confidence intervals for the difference (Efron and Tibshirani 1986). The statistical significance of the difference (area-weighted $CPUE_{i'}$) – (area-weighted $CPUE_i$) was evaluated by the following criteria. If the 95% confidence interval for the difference did not include zero, then the null hypothesis was rejected, and the annual change in the area-weighted CPUE was considered statistically significant. However, because of multiple testing, approximate *P* values for any individual year to year combination may be greater than 0.05.

RESULTS

CPUE of Pacific sleeper sharks

The CPUE of Pacific sleeper sharks was tabulated from the combined cooperative survey (1979–1994) and domestic survey (1988–2003) for all survey years (1979–2003), regions, stations, depths, and hachis fished. Pacific sleeper shark bycatch was distributed along the entire upper continental slope and shelf break sampled by the sablefish surveys, except for the western Aleutian Islands (Figures 1 and 2). Sleeper shark catches occurred at 419 of 3,100 stations fished, and sleeper shark catch per station from stations with sleeper shark catch ranged from 1 to 44 (Figure 3). A total of 1,565 Pacific sleeper sharks were captured during sablefish longline surveys from 1979 to 2003 (Table 1). Pacific sleeper shark bycatch increased almost every year of the sablefish longline surveys and ranged from a low of 0 in 1979 and 1983 to a high of 176 in 2001 (Table 1). Similarly, Pacific sleeper shark CPUE increased almost every year of the sablefish longline surveys and ranged from 0.0 in 1979 and 1983 to a high of 1.4 in 2002 (Table 1). Most (67%) of Pacific sleeper sharks were captured in the 201–300 m depth stratum (Table 2); 54% of Pacific sleeper sharks were captured in Shelikof Trough, another 11% were captured in Amatuli Gully and Yakutat Valley combined, and another 21% were captured in the eastern Bering Sea (Table 3; Figures 1 and 2).

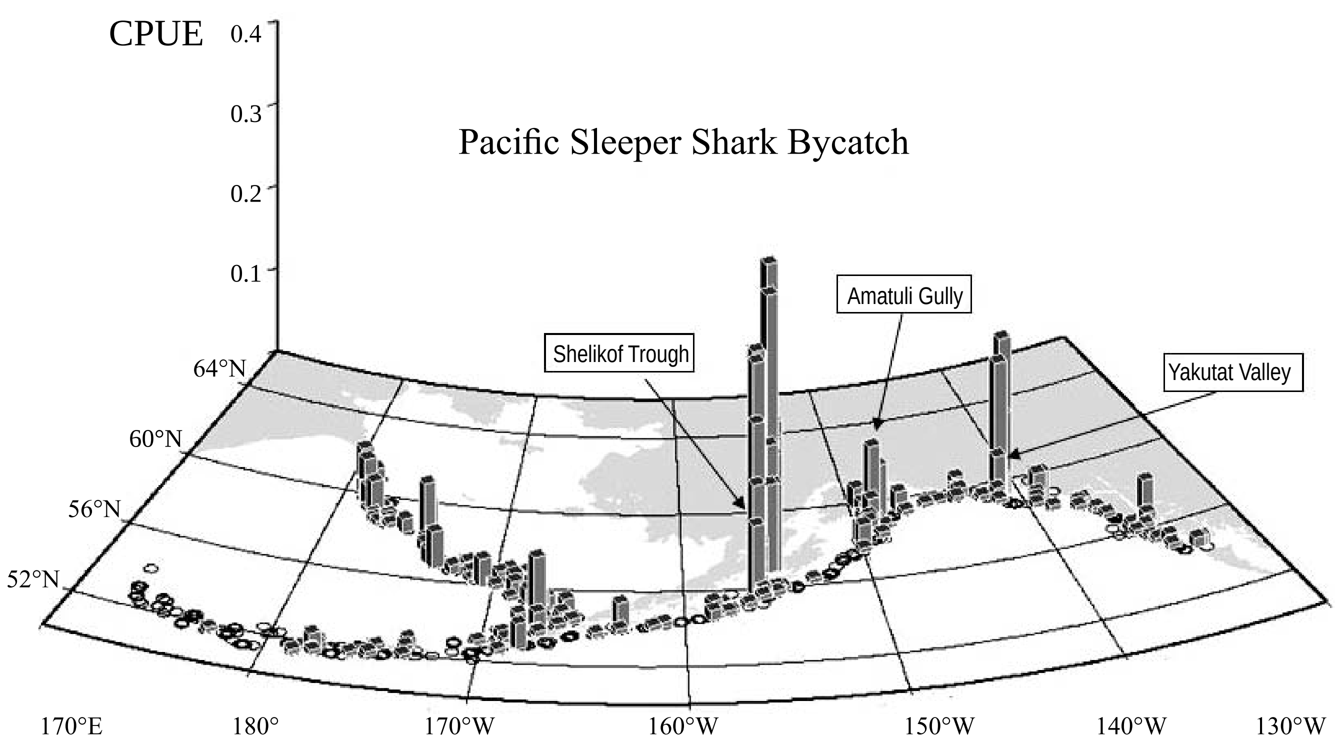

Figure 2. CPUE of Pacific sleeper sharks from sablefish longline surveys in the northeast Pacific Ocean between the years 1979 and 2003; Empty circles represent stations fished where no sharks were caught.

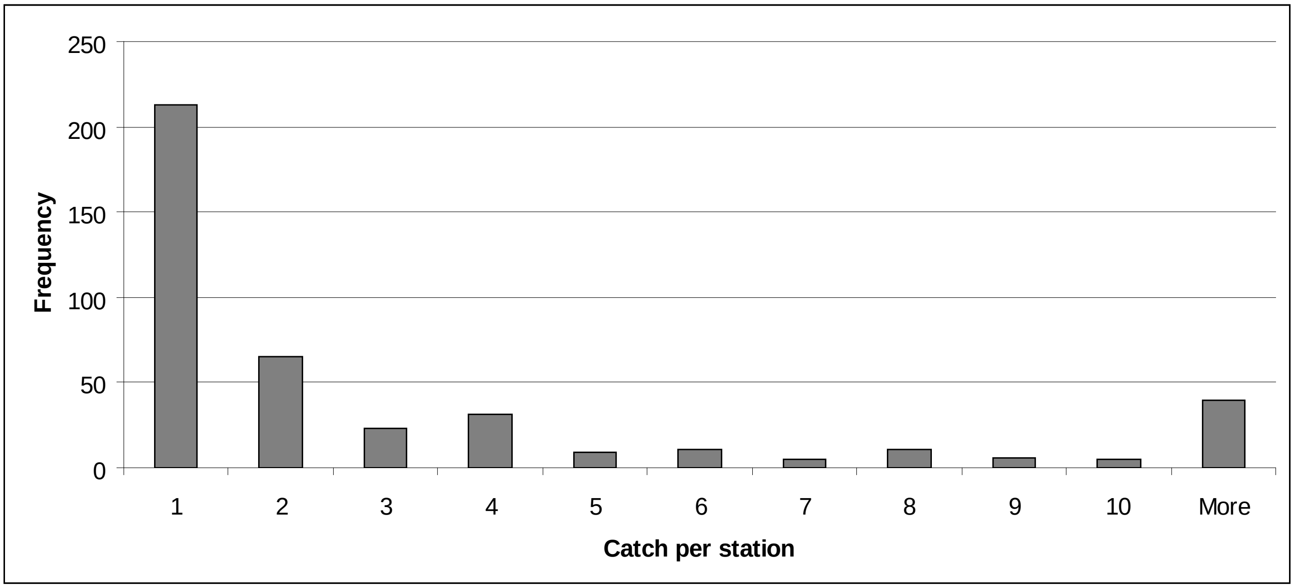

Figure 3. Pacific sleeper shark catch per station in sablefish longline surveys in the northeast Pacific Ocean between the years 1979 and 2003 from 419 stations with sleeper shark catches out of 3,001 stations fished.

Area-weighted CPUE of Pacific sleeper sharks

Analysis of area-weighted CPUE of Pacific sleeper sharks was conducted separately for the standardized cooperative survey (1982–1994) and the standardized domestic survey (1989–2003). The cooperative and domestic surveys differed in the design of their standard station locations (Table 4). Analysis of area-weighted CPUE within each survey was limited to standard survey regions, standard survey stations, standard survey depths, and effective hachis. The number of standardized fixed station locations fished successfully varied from year to year for each survey (Tables 5 and 6). Limiting the analysis to standardized surveys and to stations fished successfully reduced the sample size of Pacific sleeper shark bycatch to 147 in the cooperative survey and to 1,052 in the domestic survey (Tables 5 and 6). Total bottom area (km^2) surveyed within each standard survey region and depth stratum combination was used to weight Pacific sleeper shark CPUE from the cooperative and domestic surveys (Table 7). Weighting CPUE by the total bottom area (km^2) surveyed resulted in area-weighted CPUE with units of Pacific sleeper sharks captured per hachi. Area-weighted CPUEs were multiplied by 100 and reported as Pacific sleeper sharks captured per 100 hachis because of low sample sizes (Tables 8 and 9; Figures 4–6).

Area-weighted CPUE of Pacific sleeper sharks was higher in the Gulf of Alaska than in the eastern Bering Sea or the Aleutian Islands, and within the Gulf of Alaska was higher in the domestic survey than in the cooperative survey (Tables 8 and 9; Figure 4). In the eastern Bering Sea, area-weighted CPUE increased in 1993, 1994, and 1997, and then decreased. Area-weighed CPUE increased within each standard survey region of the Bering Sea between the years 1992 and 1994, with the largest increase in Bering IV in 1994 (Table 8; Figure 5). In the Aleutian Islands, area-weighted CPUE increased in the 1980s and decreased by 1990. In the Gulf of Alaska, there was no trend in the cooperative survey, but area-weighted CPUE in the domestic survey increased in 1993 and again in 2001. The increasing trend in area-weighted CPUE in the Gulf of Alaska was driven entirely by one standard survey region, Shelikof Trough (Table 9; Figure 6).

Bootstrapped 95% confidence intervals for area-weighted CPUE of Pacific sleeper sharks

Analysis of bootstrapped 95% confidence intervals for area-weighted CPUE was also limited to standard survey years (1982–2003), standard survey regions, standard survey stations, standard survey depths, and effective hachis. Bootstrapped 95% confidence intervals were also analyzed separately for the standardized cooperative survey (1982–1994) and the standardized domestic survey (1989–2003). There were insufficient data to calculate bootstrapped 95% confidence intervals for all standard survey regions and regulatory areas each survey year. As a result, analysis of bootstrapped 95% confidence intervals was further limited to the following standard survey regions and regulatory areas with non-zero catches and approximately normally distributed bootstrap replicates (Appendix A): Eastern Bering Sea cooperative survey 1988, 1992–1994; Gulf of Alaska total domestic survey 1989–2003; Gulf of Alaska domestic survey Shelikof Trough 1992–2003; and Gulf of Alaska total domestic survey without Shelikof Trough 1989, 1991, 1995, 1997–2000 (Tables 8 and 9; Figures 4 – 6). There were insufficient data to calculate bootstrapped 95% confidence intervals for the domestic survey in the eastern Bering Sea during the years 1999, 2001, and 2003; for the cooperative and domestic surveys in the Aleutian Islands from 1982 to 2002; and for the cooperative survey in the Gulf of Alaska from 1982 to 1994 (Tables 8 and 9; Figures 4 – 6).

Table 1. CPUE of Pacific sleeper sharks from sablefish longline surveys by year (1979 – 2003) for all survey stations, all survey regions, all survey depths, and all hachis fished.

Year[a]	Number of sleeper sharks	Number of stations fished	Number of hachis[b] fished	Number of hooks fished	Catch per hachi (CPUE)×100
1979	0	57	8,069	363,105	0.00
1980	1	75	11,153	501,885	0.01
1981	1	75	11,469	516,105	0.01
1982	1	108	16,950	762,750	0.01
1983	0	104	16,344	735,480	0.00
1984	5	108	17,139	771,255	0.03
1985	10	107	17,062	767,790	0.06
1986	9	107	16,959	763,155	0.05
1987	27	107	16,844	757,980	0.16
1988	21	165	25,909	1,165,905	0.08
1989	45	184	26,980	1,214,100	0.17
1990	33	195	28,572	1,285,740	0.12
1991	34	190	28,192	1,268,640	0.12
1992	74	194	28,728	1,292,760	0.26
1993	110	195	28,749	1,293,705	0.38
1994	175	190	29,415	1,323,675	0.59
1995	61	81	11,176	502,920	0.55
1996	86	94	12,281	552,645	0.70
1997	103	137	13,920	626,400	0.74
1998	91	87	12,030	541,350	0.76
1999	93	89	12,475	561,375	0.75
2000	111	87	11,895	535,275	0.93
2001	176	89	12,423	559,035	1.42
2002	169	87	11,761	529,245	1.44
2003	129	89	12,403	558,135	1.04
Total	1,565	3,001	438,898	19,750,410	

[a]Sablefish longline survey time line:
1979: First year of Japan–U.S. cooperative sablefish longline survey.
1982: First year of Japan–U.S. cooperative survey in the eastern Bering Sea.
1982: First year of standardized Japan–U.S. cooperative survey in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska.
1987: Experimental domestic sablefish longline survey in the Gulf of Alaska (using herring as bait).
1988: First year of experimental domestic sablefish longline survey in the Gulf of Alaska (using squid as bait).
1989: First year of standardized domestic sablefish longline survey. Also, first year of additional gully stations in the Gulf of Alaska.
1994: Last year of standardized Japan–U.S. cooperative sablefish longline survey in the Gulf of Alaska.
1996: First year of standardized domestic sablefish longline survey in the Aleutian Islands (Aleutians sampled every other year thereafter).
1997: First year of standardized domestic sablefish longline survey in the eastern Bering Sea (eastern Bering Sea sampled every other year thereafter). Also, experimental fishing alongside a submersible in the Gulf of Alaska.
[b]A hachi is a standardized 100 m section of longline containing 45 hooks spaced 2 m apart with 5 m between each end of the line and the nearest hook. 160 hachis were tied together and deployed at each station on the Gulf of Alaska slope and Aleutian Island slope. 180 hachis were deployed per station on the eastern Bering Sea slope, and 80 hachis were deployed per station on Gulf of Alaska gullies. Upon retrieval of the gear, catch was recorded per hachi. The number of hooks listed here is extrapolated as 45 times the number of hachis retrieved.

Within the limited time series available to conduct hypothesis testing in the eastern Bering Sea, area-weighted CPUE of Pacific sleeper sharks increased significantly in the cooperative survey between the years 1998 and 1994 (Table 10A; Figure 4). There were insufficient data to conduct hypothesis testing for the cooperative survey within individual survey regions of the Bering Sea (Table 8; Figure 5).

Within the limited time series available to conduct hypothesis testing in the Gulf of Alaska, area-weighted CPUE of Pacific sleeper sharks increased significantly in the domestic survey between the years 1989 and 2003, but also decreased significantly between the years 1996 and 1997 (Table 10B; Figure 4). The largest increases occurred between the years 1992 and 1993 and between the years 2000 and 2001 (Figure 4C). As before, the increasing trend in the Gulf of Alaska was driven entirely by one standard survey region, Shelikof Trough. Area-weighted CPUE of Pacific sleeper sharks increased significantly in Shelikof Trough between the years 1992 and 2003, but also decreased significantly in 1997 and again in 2003 (Table 10C; Figure 6A). There was no trend in area-weighted CPUE of Pacific sleeper sharks in the Gulf of Alaska after Shelikof Trough was removed (Figure 6B). Area-weighted CPUE of Pacific sleeper sharks in the Gulf of Alaska after Shelikof Trough was removed increased significantly between the years 1989 and 2000 but also decreased significantly in 1999 (Table 10D).

DISCUSSION

Within the limited time series available for hypothesis testing, area-weighted CPUE of Pacific sleeper sharks increased significantly in the eastern Bering Sea between the years 1988 and 1994 and in the Gulf of Alaska between the years 1989 and 2003, but also decreased significantly in the Gulf of Alaska in 1997. The increasing trend in the Gulf of Alaska was driven entirely by one region, Shelikof Trough, where most (54%) Pacific sleeper sharks were captured.

The main obstacle to conducting hypothesis testing of trends in area-weighted CPUE was the small sample size of Pacific sleeper shark bycatch in sablefish longline surveys. The percentile method (Efron and Tibshirani 1986) requires approximately normally distributed bootstrap replicates. Therefore, we assumed that time series of area-weighted CPUE with approximately normally distributed bootstrap replicates had sufficient data to conduct hypothesis testing of differences in area-weighted CPUE from bootstrap 95% confidence intervals. Insufficient data existed to compute bootstrap 95% confidence intervals in some standard survey regions and regulatory areas, so hypothesis testing was limited to time series of area-weighted CPUE from selected standard survey regions and regulatory areas with non-zero catches and approximately normally distributed bootstrap replicates (Appendix A).

Increasing trends in area-weighted CPUE of Pacific sleeper sharks in the eastern Bering Sea and Shelikof

Table 2. CPUE of Pacific sleeper sharks from sablefish longline surveys by depth strata for all survey years (1979–2003), all survey stations, all survey regions, all survey depths, and all hachis fished.

Depth Strata[a]	Depth (meters) Min	Depth (meters) Max	Number of sleeper sharks	Percent of total number	Number of stations fished	Number of hachis fished	Number of hooks fished	Catch per hachi (CPUE)×100
Unknown	NA	NA	3	0.19%	NA	NA	NA	NA
1	0	100	0	0.00%	126	1,550	69,750	0.00
2	101	200	115	7.35%	1,835	84,704	3,811,680	0.14
3	201	300	1,042	66.58%	2,604	80,313	3,614,085	1.30
4	301	400	89	5.69%	2,354	50,833	2,287,485	0.18
5	401	600	152	9.71%	2,320	103,353	4,650,885	0.15
6	601	800	133	8.50%	2,059	90,053	4,052,385	0.15
7	801	1,000	31	1.98%	1,304	26,604	1,197,180	0.12
8	1,001	1,200	0	0.00%	144	1,429	64,305	0.00
9	1,200	Greater	0	0.00%	4	59	2,655	0.00
Total			1,565	100%	3,001[b]	438,898	19,750,410	

[a] Depth strata 1, 2, 8 and 9 are not effectively sampled by the sablefish longline surveys and are not included in standardized sablefish longline survey CPUE. The sablefish longline surveys (both cooperative and domestic) set gear from shallow to deep to cover the 201–1,000 m depths along the continental shelf break and upper continental slope of the northeast Pacific Ocean as well as some deepwater gullies (> 200 m) on the shelf break of the Gulf of Alaska. Some hooks landed in shallower and deeper depths (0–200 m, and > 1,000 m).

[b] A total of 3,001 stations were fished, but all depth strata were not fished at each station because of differences in the bottom contour.

Trough are consistent with previous analyses of fishery-dependent and fishery-independent data from the northeast Pacific Ocean. These analyses indicate that bycatch of Pacific sleeper sharks in commercial fisheries for groundfish and in fishery-independent bottom trawl surveys has been increasing in the Bering Sea and Gulf of Alaska (Courtney et al. 2006a, 2006b). Mueter and Norcross (2002) conducted a separate analysis of NMFS fishery-independent bottom trawl survey data from the Gulf of Alaska continental shelf and upper slope from 100 to 500 m depth. The CPUE of Pacific sleeper sharks in bottom trawl surveys increased significantly between the years 1984 and 1996 in 2 NMFS statistical areas, Chirikof (200–300 m depth), and Kodiak (100–200 m depth; Mueter and Norcross 2002). The Chirikof statistical area includes Shelikof Trough (Figure 1). Increasing trends in area-weighted CPUE of Pacific sleeper sharks in the eastern Bering Sea and Shelikof Trough are also consistent with evidence of oceanographic fluctuations or a change in

Table 3. CPUE of Pacific sleeper sharks from sablefish longline surveys by survey region for all survey years (1979–2003), all survey stations, all survey regions, all survey depths, and all hachis fished.

Survey region Regulatory area Slope stations Gully stations	Number of sleeper sharks	Percent of total number	Number of stations fished	Number of hachis fished	Number of hooks fished	Catch per hachi (CPUE)×100
NA	1	0.1%	NA	640	28,800	0.16
Eastern Bering Sea						
Bering V[a]	51	3.3%	45	7,400	333,000	0.69
Bering IV	77	4.9%	94	15,468	696,060	0.50
Bering III	61	3.9%	137	22,454	1,010,430	0.27
Bering II	75	4.8%	200	32,333	1,454,985	0.23
Bering I	62	4.0%	87	13,963	628,335	0.44
Aleutian Islands						
NW Aleutians	0	0.0%	61	9,687	435,915	0.00
SW Aleutians	1	0.1%	89	13,901	625,545	0.01
NE Aleutians	11	0.7%	142	20,941	942,345	0.05
SE Aleutians	12	0.8%	169	25,828	1,162,260	0.05
Western Gulf of Alaska						
Shumagin	35	2.2%	321	50,562	2,275,290	0.07
Shumagin Gully[a]	2	0.1%	16	1,453	65,385	0.14
Central Gulf of Alaska						
Chirikof	44	2.8%	222	35,551	1,599,795	0.12
West Semidi[a]	0	0.0%	1	160	7,200	0.00
Shelikof Trough	850	54%	124	10,313	464,085	8.24
Kodiak	6	0.4%	288	45,985	2,069,325	0.01
Chiniak Gully[a]	0	0.0%	1	159	7,155	0.00
Amatuli Gully	71	4.5%	116	11,994	539,730	0.59
Eastern Gulf of Alaska						
West Yakutat	13	0.8%	259	41,209	1,854,405	0.03
Western Grounds	5	0.3%	30	2,418	108,810	0.21
Yakutat Valley	104	6.6%	30	2,416	108,720	4.30
East Yakutat	20	1.3%	94	14,841	667,845	0.13
Alsek Strath[a]	13	0.8%	12	960	43,200	1.35
Southeast Alaska	19	1.2%	280	43,535	1,959,075	0.04
Spencer Gully	1	0.1%	31	2,578	116,010	0.04
Southeastern Shelf[a]	1	0.1%	32	4,910	220,950	0.02
Southeastern[a]	0	0.0%	48	1,440	64,800	0.00
Ommaney Trench	21	1.3%	30	2,417	108,765	0.87
Iphigenia Gully[a]	0	0.0%	12	966	43,470	0.00
Dixon Entrance	9	0.6%	30	2,416	108,720	0.37
Gulf of Alaska sub total, slope stations	137	8.8%	1,464	231,683	10,425,735	0.06
Gulf of Alaska sub total, gully stations	1,077	69%	513	44,600	2,007,000	2.41
Gulf of Alaska sub total	1,214	78%	1,977	276,283	12,432,735	0.44
Grand Total	1,565	100%	3,001	438,898	19,750,410	

[a]Experimental or discontinued survey regions.

prey composition that began with a climatic regime shift in 1976 and 1977. This regime shift triggered a substantial change in the northeast Pacific Ocean fish community (Hollowed and Wooster 1995). Sleeper shark abundance changes may have taken longer to become apparent than the abundance changes of other species due to sleeper shark's assumed long life, low fecundity, and slow growth rates.

Increasing trends in area-weighted CPUE of Pacific sleeper sharks from sablefish longline surveys may also simply reflect changes in local densities resulting from a shift in distribution. Assumptions required for area-weighted CPUE to represent trends in relative abundance at the population level are that survey effort and the relative area occupied by Pacific sleeper sharks are proportional to the bottom area (km^2) surveyed, that catchability of Pacific sleeper sharks in sablefish longline surveys is constant, and that the area inhabited by Pacific sleeper sharks is constant (Gulland 1969; Quinn et al. 1982). However, the distribution of Pacific sleeper sharks in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska relative to the area sampled by NMFS sablefish longline surveys is unknown. The catchability of Pacific sleeper sharks with sablefish longline gear is also unknown and may vary depending on factors not accounted for in this study. In particular, the sablefish longline survey is not designed to capture Pacific sleeper sharks, and they have not

Table 4. Number of fixed station locations in the survey designs of the standardized cooperative sablefish longline survey (1982–1994) and the standardized domestic sablefish longline survey (1989–2003).

Survey region	Number of standard survey stations		Longitude	
Regulatory area Slope stations Gully stations	Cooperative survey 1982–1994	Domestic survey 1989–2003	Maximum	Minimum
Eastern Bering Sea				
Bering V[a]	–	–	178°51.3'W	177°22.8'W
Bering IV	6	4	177°34.9'W	174°18.0'W
Bering III	8	5	174°13.9'W	170°34.3'W
Bering II	12	4	169°57.0'W	166°01.8'W
Bering I	5	3	169°15.0'W	165°40.0'W
Aleutian Islands				
Northwest Aleutians	4	–	179°55.0'E	172°43.0'E
Southwest Aleutians	6	–	179°34.0'E	172°57.4'E
Northeast Aleutians	8	6	177°35.0'W	170°08.5'W
Southeast Aleutians	9	8	178°36.6'W	173°30.3'W
Western Gulf of Alaska				
Shumagin	10	10	169°05.9'W	159°52.7'W
Shumagin Gully[a]	–	–	158°30.4'W	158°0.4'W
Central Gulf of Alaska				
Chirikof	7	7	158°33.4'W	154°47.8'W
West Semidi[a]	–	–	157°30.3'W	157°30.3'W
Shelikof Trough	–	8	156°13.7'W	155°02.4'W
Kodiak	9	9	153°04.9'W	148°20.4'W
Chiniak Gully[a]	–	–	151°41.9'W	151°41.9'W
Amatuli Gully	1	9	149°54.7'W	146°58.6'W
Eastern Gulf of Alaska				
West Yakutat	8	8	146°51.3'W	141°20.0'W
Western Grounds	–	2	143°35.7'W	143°23.3'W
Yakutat Valley	–	2	141°16.2'W	140°56.2'W
East Yakutat	3	3	139°29.0'W	137°22.4'W
lsek Strath[a]	–	–	139°20.1'W	139°05.0'W
Southeast Outside	8	8	136°32.4'W	133°55.1'W
Spencer Gully	–	2	137°5.32'W	137°05.3'W
Southeastern Shelf [a]	–	–	135°24.0'W	135°24.0'W
Southeastern[a]	–	–	136°17.8'W	136°06.6'W
Ommaney Trench	–	2	134°58.6'W	134°54.2'W
Iphigenia Gully[a]	–	–	134°40.2'W	134°24.4'W
Dixon Entrance	–	2	133°09.2'W	132°50.6'W

[a]Experimental or discontinued survey regions.

Table 5. Number of fixed station locations fished successfully (number of stations with sleeper shark catches: and number of sleeper sharks captured) during the standardized cooperative sablefish longline survey (1982 – 1994). Stations were excluded from computation of area-weighted CPUE for the standardized sablefish longline surveys if they had whale predation on the gear, competition with other fishing vessels, or excessive loss of gear.

Survey region / Regulatory area / Slope stations / Gully stations	Year													
	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Total
Bering Sea														
Bering IV	6(0:0)	4(0:0)	4(0:0)	6(0:0)	6(0:0)	5(1:1)	5(1:1)	4(1:1)	4(0:0)	4(0:0)	4(2:2)	4(0:0)	4(4:24)	60(9:29)
Bering III	8(0:0)	7(0:0)	5(0:0)	8(0:0)	7(0:0)	7(2:3)	7(1:2)	7(2:2)	3(0:0)	4(0:0)	6(4:5)	6(3:7)	6(4:15)	81(16:34)
Bering II	12(0:0)	8(0:0)	9(1:1)	10(0:0)	10(1:1)	11(2:5)	12(2:3)	12(0:0)	9(0:0)	6(0:0)	12(3:3)	12(2:4)	12(3:7)	135(14:24)
Bering I	5(1:1)	5(0:0)	5(1:1)	5(0:0)	5(0:0)	5(0:0)	5(1:1)	5(1:1)	5(0:0)	4(0:0)	5(2:2)	5(2:6)	5(2:2)	64(10:14)
Aleutian Islands														
Northwest Aleutians	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	4(0:0)	52(0:0)
Southwest Aleutians	6(0:0)	5(0:0)	6(0:0)	6(1:1)	6(0:0)	6(0:0)	6(0:0)	6(0:0)	6(0:0)	6(0:0)	6(0:0)	6(0:0)	6(0:0)	77(1:1)
Northeast Aleutians	8(0:0)	7(0:0)	8(1:1)	8(1:1)	8(1:2)	8(1:1)	8(2:2)	6(1:1)	7(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	100(7:8)
Southeast Aleutians	9(0:0)	8(0:0)	9(1:1)	9(1:3)	8(0:0)	8(1:1)	9(2:2)	9(0:0)	9(0:0)	9(1:1)	9(0:0)	9(0:0)	9(0:0)	114(6:8)
Western Gulf of Alaska														
Shumagin	10(0:0)	10(0:0)	10(0:0)	10(1:1)	10(1:1)	10(3:8)	10(0:0)	9(0:0)	10(0:0)	10(0:0)	10(0:0)	10(0:0)	10(0:0)	129(5:10)
Central Gulf of Alaska														
Chirikof	7(0:0)	7(0:0)	7(1:1)	7(0:0)	7(0:0)	7(1:2)	7(1:1)	7(0:0)	7(0:0)	7(0:0)	7(1:1)	7(0:0)	7(1:1)	91(5:6)
Kodiak	9(0:0)	9(0:0)	9(0:0)	8(0:0)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	116(0:0)
Amatuli Gully	1(0:0)	1(0:0)	1(0:0)	1(0:0)	1(1:1)	1(0:0)	1(0:0)	1(1:1)	1(0:0)	1(0:0)	1(0:0)	1(0:0)	1(0:0)	13(2:2)
Eastern Gulf of Alaska														
West Yakutat	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(2:2)	8(0:0)	8(1:1)	8(0:0)	8(0:0)	8(1:1)	8(0:0)	8(0:0)	104(4:4)
East Yakutat	3(0:0)	3(0:0)	3(0:0)	3(0:0)	3(0:0)	3(2:2)	3(0:0)	3(1:1)	3(1:1)	3(0:0)	3(0:0)	3(2:2)	3(1:1)	39(7:7)
Southeast Outside	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	104(0:0)
Grand Total	104 (1:1)	94 (0:0)	96 (5:5)	101 (4:6)	100 (4:5)	100 (15:25)	102 (10:12)	98 (8:8)	93 (1:1)	91 (1:1)	100 (13:14)	100 (9:19)	100 (15:50)	1,279 (86:147)

Table 6. Number of fixed station locations fished successfully (number of stations with sleeper shark catches:and number of sleeper sharks captured) during the standardized domestic sablefish longline survey (1989–2003). Stations were excluded from computation of area-weighted CPUE for the standardized sablefish longline surveys if they had whale predation on the gear, competition with other fishing vessels, or excessive loss of gear.

Survey region / Regulatory area / Slope stations / Gully stations	Year														
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
Bering Sea																
Bering IV									4(4:12)		4(1:6)		2(1:1)		3(1:1)	13(7:20)
Bering III									5(4:9)		3(1:1)		3(1:1)		3(1:1)	14(7:12)
Bering III									4(4:11)		3(1:1)		4(0:0)		3(1:2)	14(6:14)
Bering I									3(3:17)		2(1:1)		3(1:2)		2(1:5)	10(6:25)
Aleutian Islands																
Northeast Aleutians										6(0:0)		6(0:0)		6(0:0)		18(0:0)
Southeast Aleutians								8(0:0)		8(0:0)		8(0:0)		8(0:0)		32(0:0)
Western Gulf of Alaska																
Shumagin	10(0:0)	10(1:6)	10(1:4)	10(0:0)	10(3:4)	10(1:1)	10(0:0)	10(0:0)	10(0:0)	10(2:2)	10(0:0)	10(0:0)	10(0:0)	8(0:0)	7(0:0)	145(8:17)
Central Gulf of Alaska																
Chirikof	7(1:2)	7(0:0)	7(1:1)	7(0:0)	7(0:0)	7(1:1)	7(0:0)	7(1:1)	7(1:1)	7(1:2)	7(1:1)	7(1:1)	7(1:3)	7(2:4)	7(0:0)	105(11:17)
Shelikof Trough	8(3:3)	8(1:5)	8(6:11)	8(5:17)	8(7:53)	8(6:43)	8(7:40)	8(7:64)	8(5:18)	8(8:53)	8(8:61)	8(7:77)	8(8:125)	8(8:101)	8(8:49)	120(94:720)
Kodiak	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(1:1)	9(0:0)	9(0:0)	9(0:0)	9(0:0)	9(2:2)	9(2:2)	9(0:0)	9(0:0)	135(5:5)
Amatuli Gully	3(0:0)	3(3:5)	3(2:3)	3(1:2)	3(1:4)	3(3:18)	9(4:7)	9(0:0)	9(3:4)	9(6:10)	9(3:4)	9(1:1)	9(0:0)	9(0:0)	9(0:0)	99(27:58)
Eastern Gulf of Alaska																
West Yakutat	8(2:2)	8(0:0)	8(1:1)	8(0:0)	8(0:0)	8(0:0)	8(1:1)	8(1:1)	8(1:1)	8(0:0)	8(0:0)	8(2:2)	8(0:0)	8(0:0)	8(0:0)	120(8:8)
Western Grounds	2(0:0)	2(0:0)	2(0:0)	2(1:1)	2(1:1)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(1:1)	2(0:0)	2(0:0)	2(0:0)	30(3:3)
Yakutat Valley	2(2:6)	2(1:8)	2(1:4)	2(1:1)	2(1:2)	2(0:0)	2(2:2)	2(1:16)	2(2:12)	2(2:6)	2(1:1)	2(2:7)	2(1:7)	2(2:10)	2(2:14)	30(21:96)
East Yakutat	3(0:0)	3(0:0)	3(1:2)	3(1:1)	3(1:1)	3(0:0)	3(0:0)	3(0:0)	3(1:1)	3(1:1)	3(0:0)	3(2:5)	3(0:0)	3(1:1)	3(0:0)	45(8:12)
Southeast Outside	8(1:1)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(1:1)	8(0:0)	8(0:0)	8(1:1)	8(2:2)	8(0:0)	8(0:0)	8(0:0)	8(0:0)	8(4:11)	120(9:16)
Spencer Gully	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(1:1)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	30(1:1)
Ommaney Trench	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(1:1)	2(0:0)	2(0:0)	2(0:0)	2(1:2)	2(1:2)	2(2:6)	2(1:1)	2(2:3)	2(1:6)	30(9:21)
Dixon Entrance	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(0:0)	2(1:1)	2(1:1)	2(1:1)	2(1:1)	2(0:0)	2(1:1)	2(0:0)	2(1:1)	2(1:1)	30(7:7)
Grand Total	66	66	66	66	66	66	72	80	88	86	84	86	84	84	80	1,140
	(9:14)	(6:24)	(13:6)	(9:22)	(14:65)	(13:65)	(17:53)	(11:83)	(30:88)	(24:79)	(18:78)	(21:103)	(16:142)	(16:120)	(20:90)	(237:1,052)

Table 7. Area (km^2) of each standard survey region and depth stratum combination used to weight Pacific sleeper shark CPUE from standardized sablefish longline surveys (1982–2003).

Survey region / Regulatory area / Slope stations / Gully stations	Depth 201–300 m	301–400 m	401–600 m	601–800 m	801–1,000 m
Eastern Bering Sea					
Bering IV[a]	1,030	840	960	920	1,050
Bering III[a]	600	520	890	1,160	900
Bering II[a]	2,440	2,090	3,010	3,150	1,700
Bering I[a]	770	730	1,270	1,160	1,130
Aleutian Islands					
Northwest Aleutians[a]	1,130	1,300	3,100	2,640	2,210
Southwest Aleutians[a]	1,440	1,570	3,480	2,820	2,130
Northeast Aleutians[b]	2,141	2,085	3,800	3,250	2,786
Southeast Aleutians[b]	2,530	2,096	2,396	1,978	1,570
Western Gulf of Alaska					
Shumagin[c]	2,737	1,264	2,269	1,629	1,248
Central Gulf of Alaska					
Chirikof[c]	1,533	817	1,766	1,955	2,012
Shelikof Trough[c]	13,076				
Kodiak[c]	1,626	1,480	2,255	1,923	2,296
Amatuli Gully[c]	6,346				
Eastern Gulf of Alaska					
West Yakutat[c]	992	992	1,271	1,245	1,282
Western Grounds[c]	1,008	302			
Yakutat Valley[c]	1,268	768			
East Yakutat[c]	502	502	395	225	207
Southeast Outside[c]	891	891	822	1,006	1,165
Spencer Gully[c]	189	189	301	50	
Ommaney Trench[c]	521	610	122		
Dixon Entrance[c]	1,130	793	58		

[a]Sasaki (1985).
[b]M. Sigler, unpublished data.
[c]Zenger and Sigler (1992).

Table 8. Area–weighted CPUE and bootstrap 95% confidence intervals (lower:upper) of Pacific sleeper sharks from the standardized cooperative sablefish longline survey (1982–1994). Bootstrap 95% confidence intervals from the percentile method for selected time series with sufficient sample size to produce approximately normally distributed bootstrap replicates (Appendix A).

Survey region / Regulatory area / Slope stations / Gully stations	Year 1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Eastern Bering Sea													
Slope	0.02	0.00	0.07	0.00	0.11	0.22	0.20	0.21	0.00	0.00	0.23	0.55	1.2
							(0.03:0.41)				(0.1:0.38)	(0.14:1.06)	(0.58:1.93)
Aleutian Islands													
Slope	0.00	0.00	0.06	0.19	0.06	0.07	0.10	0.02	0.00	0.01	0.00	0.00	0.00
Western Gulf of Alaska													
Slope	0.00	0.00	0.00	0.07	0.08	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Central Gulf of Alaska													
Slope	0.00	0.00	0.01	0.00	0.00	0.08	0.02	0.00	0.00	0.00	0.03	0.00	0.01
Gully[a]	0.00	0.00	0.00	0.00	2.22	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.00
Eastern Gulf of Alaska													
Slope	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.04	0.04	0.00	0.17	0.04	0.27
Gulf of Alaska sub totals													
Slope	0.00	0.00	0.00	0.02	0.02	0.25	0.01	0.01	0.01	0.00	0.06	0.01	0.09
Slope and gully[a]	0.00	0.00	0.00	0.01	0.33	0.21	0.01	0.21	0.01	0.00	0.06	0.01	0.08

[a]Amatuli Gully.

Table 9. Area-weighted CPUE and bootstrap 95% confidence intervals (lower:upper) of Pacific sleeper sharks from the standardized domestic sablefish longline survey (1989–2003). Bootstrap 95% confidence intervals from the percentile method for selected time series with sufficient sample size to produce approximately normally distributed bootstrap replicates (Appendix A).

Survey region / Regulatory area / Slope stations / Gully stations	Year														
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Eastern Bering Sea															
Slope									1.41						
									(0.81:2.06)		0.25		0.16		0.48
Eastern Aleutian Islands															
Slope								0.00		0.00		0.00		0.00	
Western GOA															
Slope	0.00	0.37	0.42	0.00	0.19	0.06	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00
Central GOA															
Slope	0.05	0.00	0.03	0.00	0.00	0.03	0.03	0.03	0.01	0.02	0.01	0.17	0.16	0.10	0.00
Gullies[a]	0.32	1.33	1.58	2.18	6.72	7.75	4.52	6.76	2.18	6.63	7.01	8.50	14.66	12.82	7.16
Shelikof Trough	0.47	0.78	1.74	2.84	9.04	7.44	6.19	10.05	2.96	9.0	10.09	12.51	21.78	19.04	10.64
				(0.94:4.57)	(3.79:13.9)	(2.76:12.7)	(2.38:9.73)	(4.91:16.7)	(0.92:5.36)	(5.66:12.5)	(4.13:18.0)	(5.23:21.4)	(13.7:32.7)	(13.3:24.5)	(4.52:18.8)
Eastern GOA															
Slope	0.14	0.00	0.12	0.01	0.01	0.02	0.02	0.04	0.54	0.04	0.00	0.17	0.00	0.01	0.24
Gullies[b]	0.59	0.89	0.48	0.28	0.38	0.09	0.30	1.66	0.90	1.26	0.17	1.05	0.85	2.09	2.00
GOA Subtotals															
Slope	0.06	0.09	0.15	0.00	0.05	0.04	0.02	0.03	0.18	0.07	0.01	0.13	0.07	0.05	0.08
Gullies[a,b]	0.39	1.21	1.28	1.66	4.99	5.65	3.37	5.37	1.83	5.16	5.14	6.46	10.89	9.88	5.75
GOA Grand Total															
Slope and gullies[a,b]	0.20	0.54	0.61	0.68	2.05	2.31	1.38	2.19	0.85	2.13	2.09	2.7	4.46	4.04	2.38
	(0.10:0.30)	(0.24:0.92)	(0.34:0.87)	(0.3:1.04)	(1.04:3.07)	(1.28:3.39)	(0.6:2.09)	(1.17:3.47)	(0.43:1.34)	(1.44:2.8)	(0.89:3.68)	(1.25:4.49)	(2.84:6.54)	(2.87:5.16)	(1.17:4.03)
GOA Grand Total w/o Shelikof Trough															
Slope and gullies[c]	0.13		0.33				0.19		0.32	0.43	0.11	0.27			
	(0.06:0.20)	0.48	(0.11:0.54)	0.14	0.32	1.05	(0.08:0.31)	0.25	(0.17:0.51)	(0.24:0.62)	(0.04:0.2)	(0.17:0.39)	0.17	0.32	0.33

[a] Shelikof Trough and Amatuli Gully.
[b] Western Grounds, Yakutat Valley, Spencer Gully, Omany Trench, and Dixon Entrance.
[c] Amatuli Gully, Western Grounds, Yakutat Valley, Spencer Gully, Omany Trench, and Dixon Entrance.

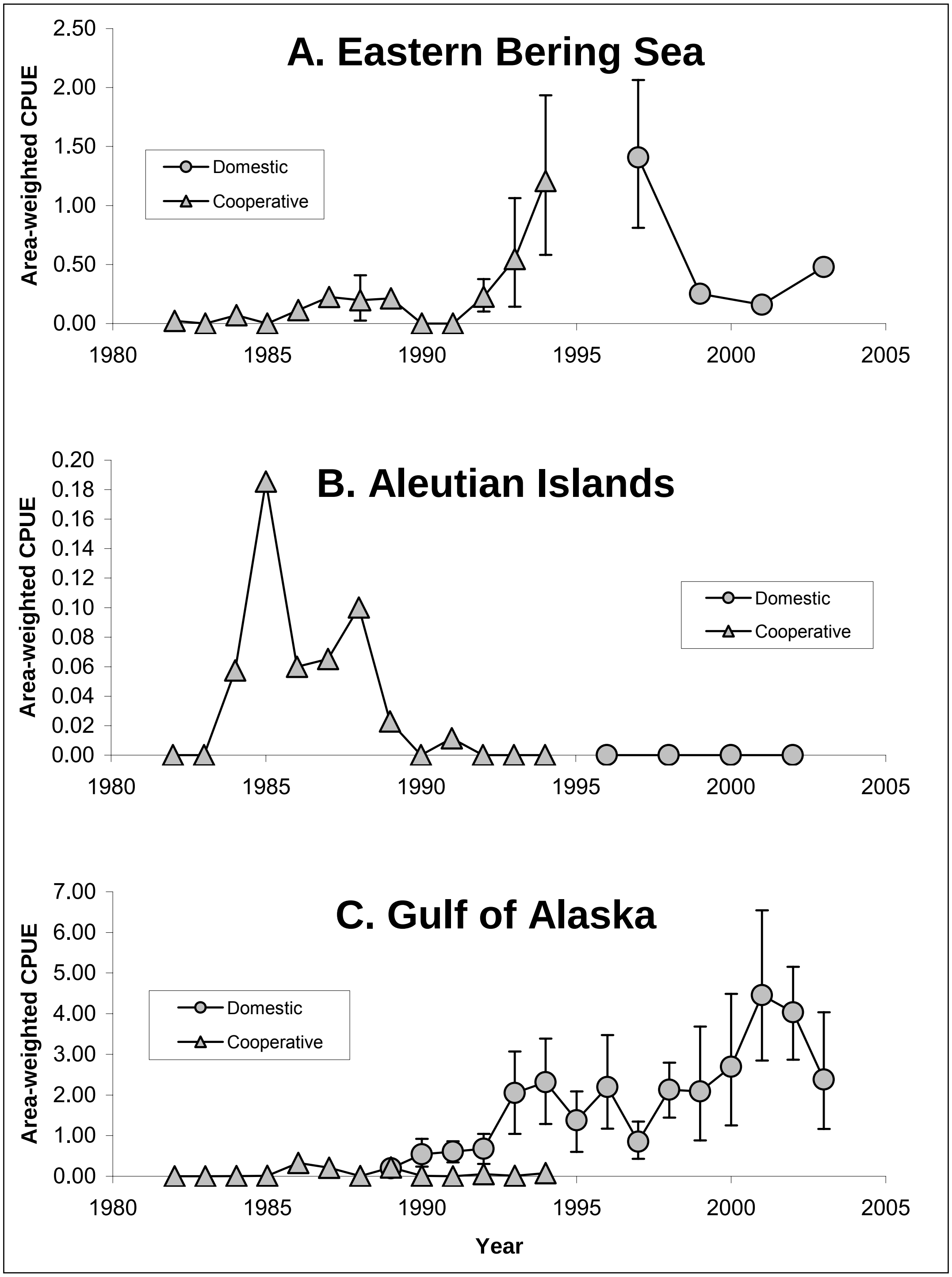

Figure 4. Area-weighted CPUE of Pacific sleeper sharks from standardized sablefish longline surveys (cooperative survey 1982–1994, and domestic survey 1989–2003) in the eastern Bering Sea (A), Aleutian Islands (B), and Gulf of Alaska (C) with bootstrap 95% confidence intervals for time series with sufficient data.

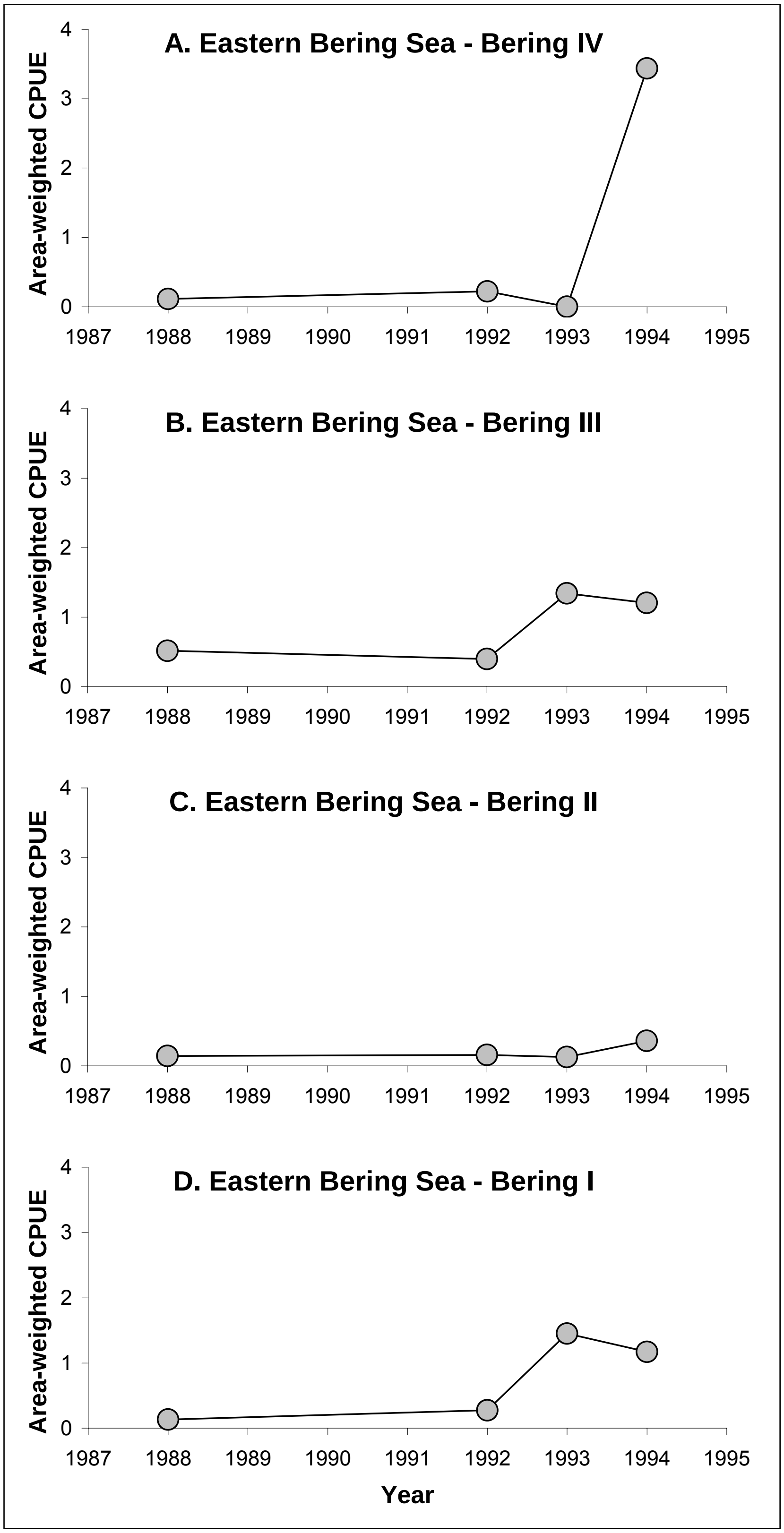

Figure 5. Area-weighted CPUE of Pacific sleeper sharks from the standardized cooperative sablefish longline survey (1988, 1992–1994) in the eastern Bering Sea by standard survey region; Bering IV (A), Bering III (B), Bering II (C), and Bering I (D).

been captured in large numbers during the history of the survey (Table 1). Pacific sleeper sharks are large animals and can be stripped from the gear before being tallied at the surface if the weather is rough or if the gear is hauled too fast. Pacific sleeper sharks may also interact with other species captured on sablefish longline gear through predation or competition for bait. These caveats may explain some of the between-year variability in area-weighted CPUE of Pacific sleeper sharks estimated from Shelikof Trough (Figure 6) and the Gulf of Alaska (Figure 4C).

Length compositions, age determination, and size and age at maturity of Pacific sleeper sharks are needed to determine if increasing trends in area-weighted CPUE of Pacific sleeper sharks from sablefish longline surveys represent a change in abundance of Pacific sleeper sharks associated with recruitment of a strong year-class. Pacific sleeper sharks are large animals and can not easily be brought on board commercial fishing and survey vessels for length measurements and specimen collections. As a result, length measurements and collections for age and maturity were not collected during sablefish longline surveys. Length of Pacific sleeper sharks from a directed study in the Gulf of Alaska with longline gear similar to that used in sablefish longline surveys ranged from 130 to 284 cm TL (n = 198; 40% female; years 2001 and 2002; Sigler et al. 2006). Maturity was not reported, but based on the observations of Yano et al. (2007), Pacific sleeper sharks less than 300 cm TL are probably immature. We recommend collection of basic life history information on Pacific sleeper sharks captured in commercial

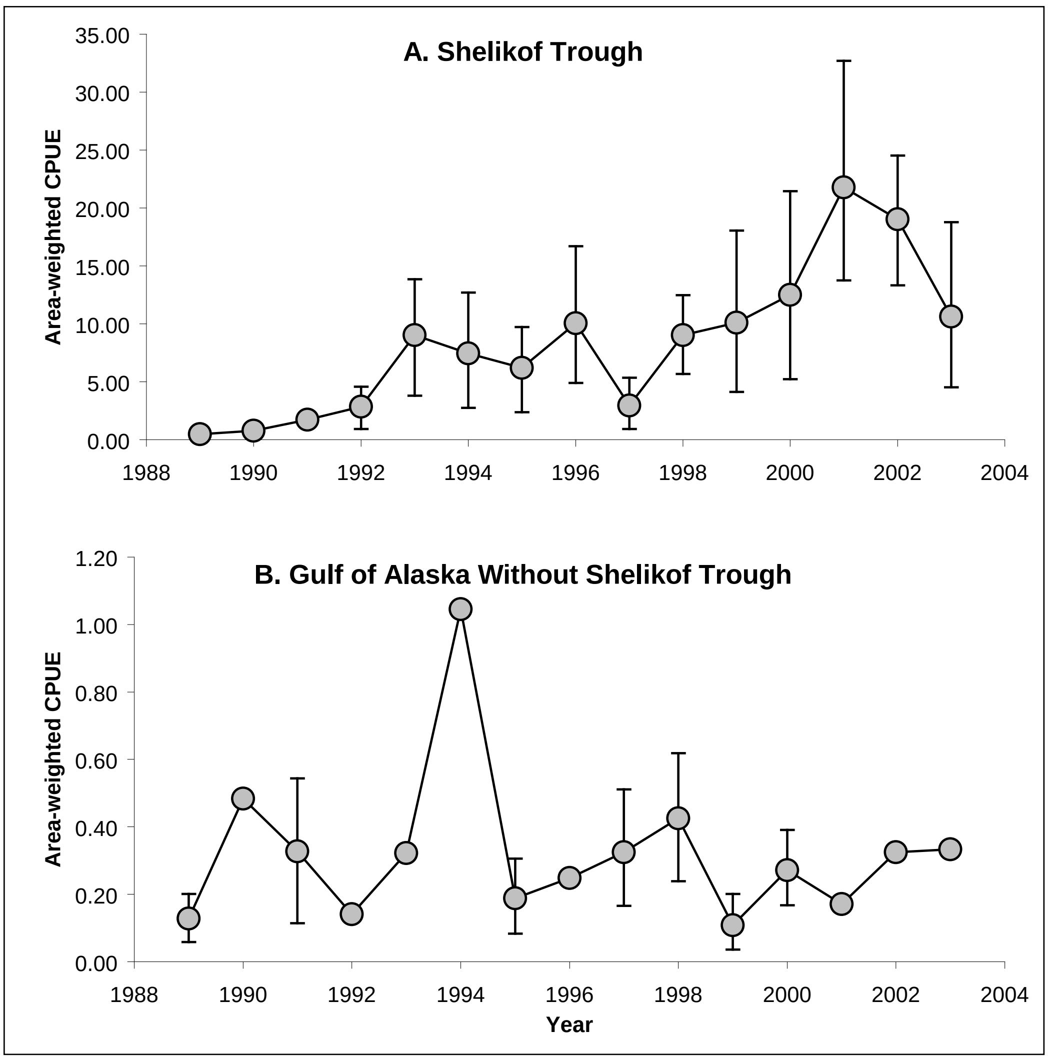

Figure 6. Area-weighted CPUE of Pacific sleeper sharks from the standardized domestic sablefish longline survey (1989–2003) in Shelikof Trough (A) and in the combined Gulf of Alaska (Western, Central, and Eastern) with Shelikof Trough removed (B) with bootstrap 95% confidence intervals for time series with sufficient data.

Table 10. Statistical significance of annual changes in area-weighted CPUE of Pacific sleeper sharks from standardized sablefish longline surveys (1982–2003) for the eastern Bering Sea (A), Gulf of Alaska total (B), Shelikof Trough (C) and Gulf of Alaska total without Shelikof Trough (D). The symbols used are defined as follows: "+" indicates a significant increase (95%): "-" indicates a significant decrease (95%): "o" indicates no significant change.

A. Eastern Bering Sea

Year	1992	1993	1994
1988	o	o	+
1992		o	+
1993			o

B. Gulf of Alaska total

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1989	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1990		o	o	+	+	o	+	o	+	+	+	+	+	+
1991			o	+	+	+	+	o	+	+	+	+	+	+
1992				+	+	o	+	o	+	+	+	+	+	+
1993					o	o	o	-	o	o	o	+	+	o
1994						o	o	-	o	o	o	+	+	o
1995							o	o	o	o	o	+	+	o
1996								-	o	o	o	+	+	o
1997									+	o	+	+	+	+
1998										o	o	+	+	o
1999											o	+	o	o
2000												o	o	o
2001													o	o
2002														o

C. Shelikof Trough

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1992	+	o	o	+	o	+	+	+	+	+	+
1993		o	o	o	-	o	o	o	+	+	o
1994			o	o	o	o	o	o	+	+	o
1995				o	o	o	o	o	+	+	o
1996					-	o	o	o	+	+	o
1997						+	+	+	+	+	+
1998							o	o	+	+	o
1999								o	o	o	o
2000									o	o	o
2001										o	-
2002											o

D. Gulf of Alaska total without Shelikof Trough

Year	1991	1995	1997	1998	1999	2000
1989	o	o	+	+	o	+
1991		o	o	o	o	o
1995			o	o	o	o
1997				o	-	o
1998					-	o
1999						o

fisheries and longline surveys in the northeast Pacific Ocean to determine if trends in CPUE reflect trends in relative abundance of Pacific sleeper shark at the population level.

Despite these caveats, development of Pacific sleeper shark relative abundance time series along with estimates of uncertainty will foster the determination of sustainable bycatch limits for sharks in the northeast Pacific Ocean. The NMFS Alaska Fisheries Science Center has formed a non-target species working group to improve assessment of non-target species including sharks within NMFS regulatory areas of the BSAI and GOA. The determination of sustainable bycatch limits for non-target species such as sharks is a priority for the non-target species working group (Courtney et al. 2006a, 2006b). Additionally, the calls for the incorporation of ecosystem considerations into stock assessments of commercial fisheries managed by the NMFS (NRC 1999; Witherell 1999; Witherell et al. 2000; Pikitch et al. 2004). Time series of Pacific sleeper shark relative abundance may prove useful as an ecosystem consideration in the determination of sustainable catch limits for commercial groundfish fisheries managed by the NMFS within the BSAI and GOA (Courtney and Sigler 2002; 2003).

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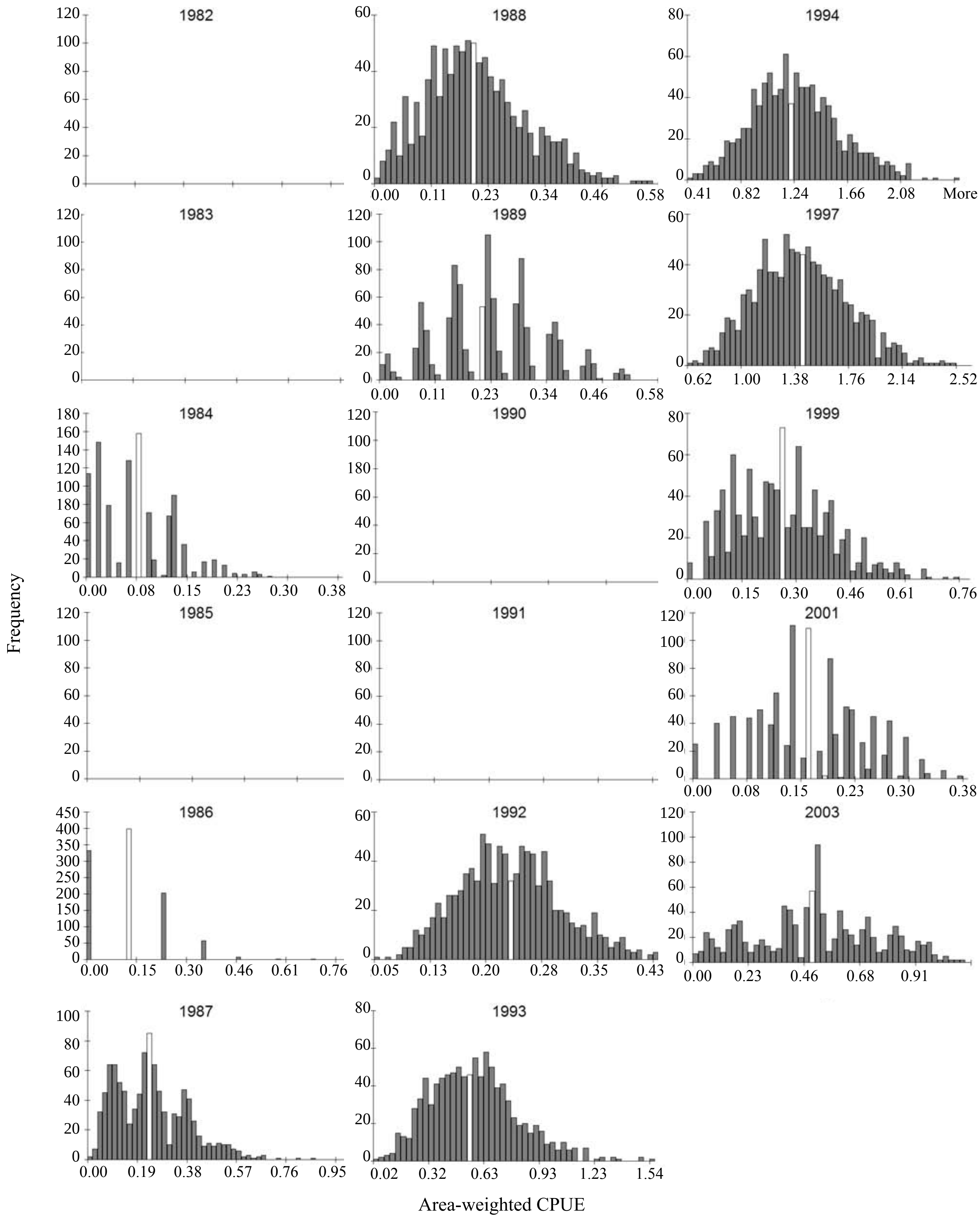
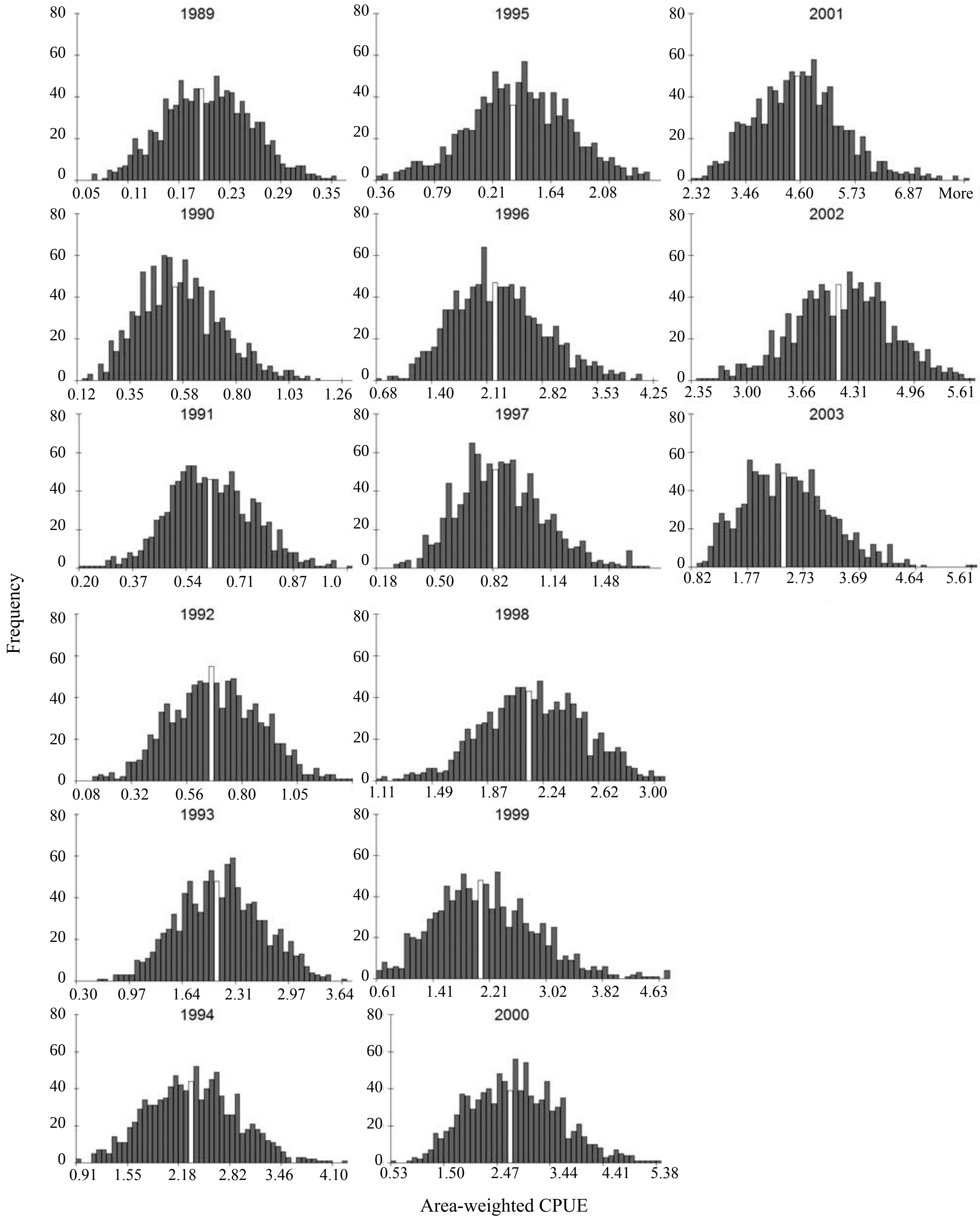
APPENDIX

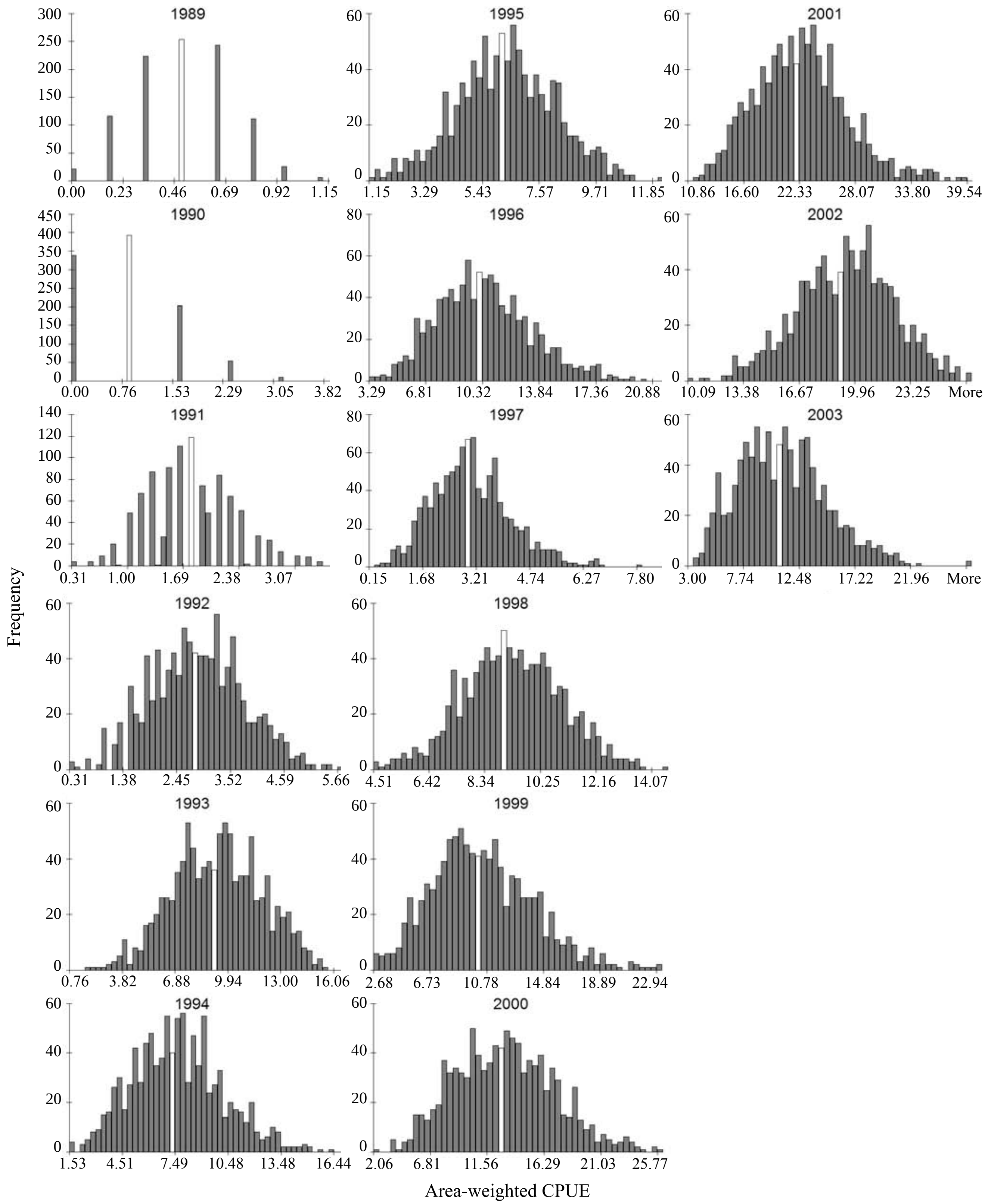
Appendix A. Eastern Bering Sea total. Pacific sleeper shark area-weighted CPUE estimates 1982–2003, from 1,000 bootstrap replicates. Unshaded bars indicate original CPUE estimate.



Appendix A. Gulf of Alaska total. Pacific sleeper shark area-weighted CPUE estimates 1989–2003, from 1,000 bootstrap replicates. Unshaded bars indicate original CPUE estimate.



Appendix A. Shelikof Trough total. Pacific sleeper shark area-weighted CPUE estimates 1989–2003, from 1,000 bootstrap replicates. Unshaded bars indicate original CPUE estimate.



Appendix A. Gulf of Alaska without Shelikof Trough. Pacific sleeper shark area-weighted CPUE estimates 1989–2003, from 1,000 bootstrap replicates. Unshaded bars indicate original CPUE estimate.