

Abstract.—Annual and between-sex variations in yellowfin sole, *Pleuronectes asper*, distributions in the eastern Bering Sea during spring and summer were examined by analyzing research survey data, including a standard 15-year time series from 1982 to 1996, as well as exploratory nearshore samples. Yellowfin sole were most concentrated nearshore; abundance gradually decreased with increasing bottom depth to trace numbers beyond 100 m. Male yellowfin sole were distributed nearer to shore than females in all years. Proportions of males (no. males/no. both sexes), therefore, increased nearshore with decreasing bottom depth. Males outnumbered females by two to one in waters less than 30 m deep. Yellowfin sole during 1982–84 were distributed in deeper waters than during 1985–96. The shallower distributions after 1984 were attributed to greater percentages of mature fish that reside in nearshore spawning areas (< 30 m) during spring–summer. High biomass estimates (>3 million metric tons) during 1982–84 were attributed in part to increased availability of yellowfin sole within the standard survey area.

Annual and between-sex variability of yellowfin sole, *Pleuronectes asper*, spring–summer distributions in the eastern Bering Sea

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Yellowfin sole, *Pleuronectes asper*, of North America has a Pacific coast distribution from British Columbia (49°N) north to the Chukchi Sea (70°N) and a distribution along the Asian coast that ranges from the Sea of Japan (35°N) north to the Gulf of Anadyr (Fadeev, 1970; Hart, 1973; Bakkala, 1981; Wilderbuer et al., 1992). The eastern Bering Sea shelf has supported the largest concentration of yellowfin sole (Bakkala, 1993), with survey biomass estimates exceeding 2 million metric tons (t) since the early 1980s (Wilderbuer et al., 1992).

Spring–summer (June–August) distributions of yellowfin sole in the eastern Bering Sea are dependent upon the timing of their annual cross-shelf migration from overwintering grounds near the shelf-slope break (about 200 m bottom depth) to nearshore waters (<50 m bottom depth) of Bristol Bay north to Nunivak Island (Bakkala, 1981; Wakabayashi, 1989). This migration is thought to follow the ice edge as it recedes during spring (Bakkala, 1981). Many juvenile yellowfin sole are likely nonmigratory and remain nearshore under ice-cover during winter (Fadeev, 1970). Juvenile and adult distributions, therefore, overlap during spring–summer when adults enter nearshore waters to spawn (Nichol, 1995, 1997).

Past yellowfin sole abundance in the eastern Bering Sea has varied with the magnitude of fishery exploitation. A predominantly foreign-led commercial trawl effort (Japan and U.S.S.R.) accounted for annual landings in excess of 400,000 t from 1959 to 1962. This trawl effort led to a decline of the stock and to significantly lower annual catches (<100,000 t) through the 1970s (Wilderbuer et al., 1992). Lower exploitation rates during the late 1970s coincided with a major increase in stock abundance that appeared to peak in the early 1980s. Considering the high abundance, annual yellowfin sole catches have been moderate since 1982, averaging 147,433 t (Table 1). Commercial trawl catches of yellowfin in recent years have been limited by fishery management time and area closures owing to bycatch of species such as Pacific halibut (*Hippoglossus stenolepis*), Pacific herring (*Clupea pallasii*), Tanner crab (*Chionoecetes bairdi*), and red king crab (*Paralithodes camtschaticus*) (Witherell, 1995). Despite moderate exploitation, annual survey biomass estimates have fluctuated widely since the early 1980s (Wilderbuer¹). These fluctua-

¹ Wilderbuer, T. K. 1996. Yellowfin sole. Chapter 3 in Plan team for groundfish fisheries of the Bering Sea/Aleutian Islands (ed.), Stock assessment and fishery evaluation

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Table 1

Standard AFSC survey yellowfin sole (*Pleuronectes asper*) biomass and population estimates, percentage of male and female CPUE (kg/hectare) in nearshore (<30 m bottom depth) waters, sex-proportions, and mean CPUE-weighted bottom depths by sex, for years 1982–96. Commercial catch estimates for yellowfin sole in the eastern Bering Sea are also included.

Year	Survey biomass (metric tons)	% CPUE ¹ < 30 m		Population numbers (billions)	Proportion male (m/m+f) ²	Mean depth (m) ³		Commercial catch (metric tons) ⁴
		Males	Females			Males	Females	
1982	3,377,838	20.56	9.81	20.67	0.492	45.0	52.9	95,712
1983	3,535,269	22.04	5.41	16.94	0.486	46.3	58.5	108,385
1984	3,141,188	16.96	5.62	14.26	0.434	47.3	58.7	159,526
1985	2,443,666	29.63	11.39	10.60	0.437	43.3	55.2	227,107
1986	1,909,866	31.05	13.38	7.96	0.436	42.8	54.7	208,597
1987	2,613,067	27.47	13.18	10.35	0.438	44.6	53.6	181,428
1988	2,402,369	23.94	9.86	10.09	0.426	45.0	55.6	223,156
1989	2,316,249	28.83	20.05	9.66	0.454	42.3	48.3	153,165
1990	2,183,708	24.30	12.46	9.06	0.435	44.6	53.0	83,970
1991	2,393,268	19.22	5.94	9.54	0.453	44.5	53.8	115,842
1992	2,172,900	34.89	19.01	8.21	0.452	42.3	53.4	149,569
1993	2,465,443	31.64	11.59	10.03	0.442	43.8	54.2	106,101
1994	2,610,474	32.34	13.73	10.70	0.442	40.1	51.0	144,544
1995	2,009,671	33.02	13.66	8.24	0.445	40.2	51.3	124,740
1996	2,298,560	31.28	9.83	9.62	0.460	43.9	56.8	129,659

¹ %CPUE = $(\sum CPUE_{i,d=30} / \sum CPUE_{i,d=all}) \times 100$ where $CPUE_{i,d}$ = station CPUE of the i th sex within the d th depth range. Note that this estimate is derived from the AFSC survey which did not cover the entire nearshore area.

² Proportion male = population number of males divided by population number of males and females.

³ Mean depths are weighted by CPUE (kg/hectare) values at each tow location.

⁴ Total retained and discarded catch estimates for yellowfin sole from foreign (1982–87), joint-venture (1982–90), and domestic (1987–present) fisheries in the eastern Bering Sea (Wilderbuer¹).

tions are inconsistent with age-structured stock synthesis models (Methot, 1990) that predict relatively stable abundance levels after 1981 (Wilderbuer¹).

Large scale spring–summer Alaska Fisheries Science Center (AFSC) resource assessment surveys of the eastern Bering Sea shelf began with a baseline survey in 1975 (Pereyra et al.²) and have continued annually since 1979 with the primary purpose of estimating the abundance of important groundfish and crab species, including yellowfin sole (Gunderson, 1993). In 1982, a change in the standard survey trawl from a 400-mesh “eastern” trawl to a larger 83–112 “eastern,” increased the catch efficiency for most flatfish species including yellowfin sole (Bakkala, 1993). Survey gear has remained constant since 1982. Al-

though these surveys cover most of the shelf area north of the Alaska Peninsula and south of latitude 60°N (Fig. 1), nearshore waters have been excluded owing to shallow bottom depths and variable bottom substrate. Areas such as Togiak Bay (Fig. 1), where commercial trawlers have successfully targeted yellowfin sole in waters as shallow as 5–6 m (Low and Narita, 1990), have been excluded from resource assessment. Recognition that yellowfin sole spawn during the survey period (June–August) and that nearshore spawning grounds extend into these nonsurveyed areas (Nichol, 1995) has prompted speculation as to whether fluctuations in survey biomass may be due to annual variation in yellowfin sole distributions that overlap surveyed and nonsurveyed areas.

This study investigates two potential sources of variation in yellowfin sole distribution during spring–summer, which may partially account for fluctuations in survey biomass estimates. In this paper, I describe variations in yellowfin sole distribution patterns between sexes and among years. Data from exploratory nearshore samples are included to demonstrate problems associated with the exclusion of nearshore areas from resource assessments.

¹ (continued from previous page) report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 1997. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

² Pereyra, W. T., J. E. Reeves, and R. G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Northwest and Alaska Fisheries Center Proc. Rep. NOAA-NMFS, 619 p. Alaska Fisheries Science Center, Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-0070.

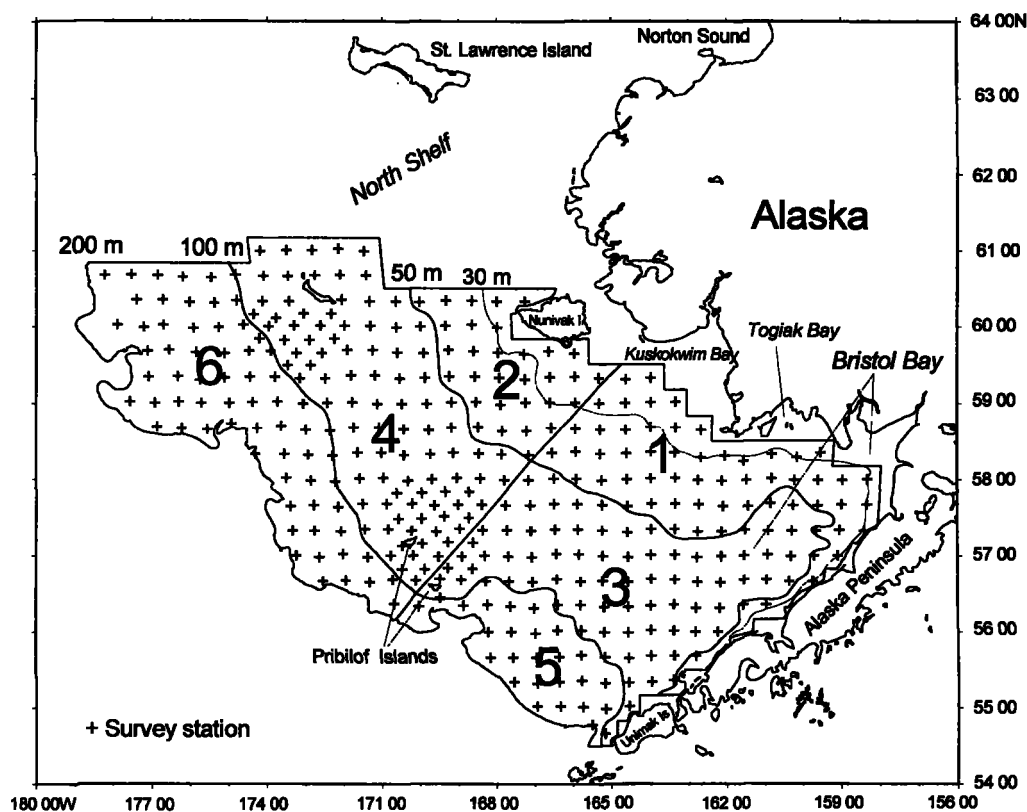


Figure 1

Standard Alaska Fisheries Science Center eastern Bering Sea survey stations. Large numerals (1–6) indicate strata areas: strata 1–2, <50 m; strata 3–4, 50–100 m; strata 5–6, 100–200 m.

Materials and methods

Surveys and gear

Standard AFSC Owing to differences in standard trawl gear used prior to 1982, only the 1982–96 standard surveys are considered here. About 350 standard stations, ranging in depth from 16 m to 230 m, were sampled annually for each of the 1982–96 AFSC surveys (Fig. 1; Table 2). Survey stations were spaced 37 km (20 nautical miles) apart, following a 37×37 km grid pattern. Surveys generally began in inner Bristol Bay, followed transects directed north and south, and progressed east to west with each finished transect. Trawls were towed for about 30 min at a speed of 5.6 km/h (3 knots) at each station during daylight hours. The standard AFSC sampling gear, an 83–112 “eastern” trawl, was characterized by average vertical and horizontal wing openings of 2.6 m and 16.5 m, respectively. Effective net spread and height measurements were obtained by means of a commercial trawl net-mensuration system (Scanmar) that was used during most tows. Footrope and headrope lengths were 25.3 m and 34.1 m, respec-

tively. Paired 55-m dandylines (bridles) were attached to each wing and to 1.8 m \times 2.7 m steel V-doors. Chain extensions measuring 61 cm in length were attached from each end of the footrope to the lower dandyline to improve bottom contact of the footrope. Two chartered commercial trawl vessels were employed each year to complete the standard survey. A total of 9 vessels ranging from 30.0 to 39.6 m in length have been used since 1982.

Total yellowfin sole catch weights (kg) as well as random sex-specific length-frequency samples (total length in cm) were collected at each station (haul) where the species was captured. Haul positions, bottom depths, and surface and bottom temperatures were also recorded at each station.

AFSC exploratory tows Additional 30-minute tows in waters nearer shore than the standard survey area were made during the course of the AFSC surveys with the same trawl gear and sampling procedures. Sampling depths ranged from 9.0 m nearshore to 29.3 m offshore. A total of twenty-five nearshore tows, 13 in the Togiak Bay area and 12 in the Kuskokwim Bay area, were made during the 1988–91 standard

Table 2

Summary of AFSC groundfish surveys on the eastern Bering Sea shelf. Tows in which yellowfin sole (YFS, *Pleuronectes asper*) were captured are noted parenthetically.

Survey	Area ¹	Gear ²	Date	Bottom depth (m)	Number of tows ³	Number of YFS measured
Standard	EBS	83-112	June–Aug 1982	18–137	329 (251)	37,023
			June–Aug 1983	20–134	354 (270)	33,924
			June–Aug 1984	18–134	355 (279)	33,894
			June–Aug 1985	18–154	353 (270)	33,824
			June–Aug 1986	18–148	354 (251)	30,470
			June–Aug 1987	18–112	342 (235)	31,241
			June–Aug 1988	18–130	353 (249)	27,121
			June–Aug 1989	18–110	354 (236)	29,510
			June–Aug 1990	16–126	352 (247)	30,491
			June–Aug 1991	18–119	351 (248)	27,985
			June–Aug 1992	16–152	336 (231)	23,626
			June–Aug 1993	18–163	355 (243)	26,647
			June–Aug 1994	16–113	355 (257)	24,420
			June–Aug 1995	16–154	356 (249)	22,111
			June–Aug 1996	20–114	355 (247)	27,190
Exploratory	Kuskokwim Bay area	83–112	June 1988	13–27	4 (4)	786
			June 1989	9–20	4 (4)	734
			June 1990	13–29	2 (2)	408
			June 1991	13–29	2 (2)	293
	Togiak Bay area		June 1988	13–29	5 (5)	1264
			June 1989	16–27	5 (5)	1438
			June 1990	11–26	2 (2)	515
			June 1991	15	1 (1)	107
Nearshore beam trawl	Togiak Bay area	PSB	May, 1995	2–30	28 (28)	4134

¹ EBS = eastern Bering Sea shelf area from the Alaska Peninsula north to latitude 62° N.

² 83-112 = Eastern otter trawl with 25.3 m (83 ft) headrope and 34.2 m (112 ft) footrope. PSB = plumb-staff beam trawl with a 3.1 m (10 ft) aluminum beam.

³ Number in parentheses indicates number of tows in which yellowfin sole were captured.

surveys (Fig. 2; Table 2). These tows were conducted to collect preliminary data on spawning yellowfin sole, which were known from commercial trawl reports to occur in these nearshore areas. Extensive survey coverage of this area has been limited owing to the shallow bottom depths.

Nearshore beam-trawl survey A 3.1-m plumb staff beam trawl with specifications detailed in Gunderson and Ellis (1986) was used aboard a chartered 9.7-m (32-ft) purse-seine or gillnet vessel. This survey successfully sampled a total of 28 stations in the shallow waters of the Togiak Bay area, from 18 May to 28 May 1995 (Fig. 2; Table 2). Sampling depths ranged from 1.8 m nearshore to 30.2 m offshore. Tows were made during daylight hours and were less than 10 min in duration. All yellowfin sole were sexed, measured, and assigned a maturity code. For the

purpose of this examination, maturity was classified as either mature or immature. Females were considered mature if ovaries were yolked or recently spent. Males were considered mature if testes were swollen, opaque colored, running with sperm, or recently spent.

Analysis

Yellowfin sole distributions were described in terms of catch per unit of effort (CPUE; kg/hectare) for each of the 1982–96 AFSC standard surveys. Calculation of CPUE followed area-swept methods described by Alverson and Pereyra (1969), whereby catch is the total weight (kg) of yellowfin sole within a station tow and effort is the area (hectare) swept by the path of the trawl. Area swept was computed as the product of the distance fished and the effective net-spread

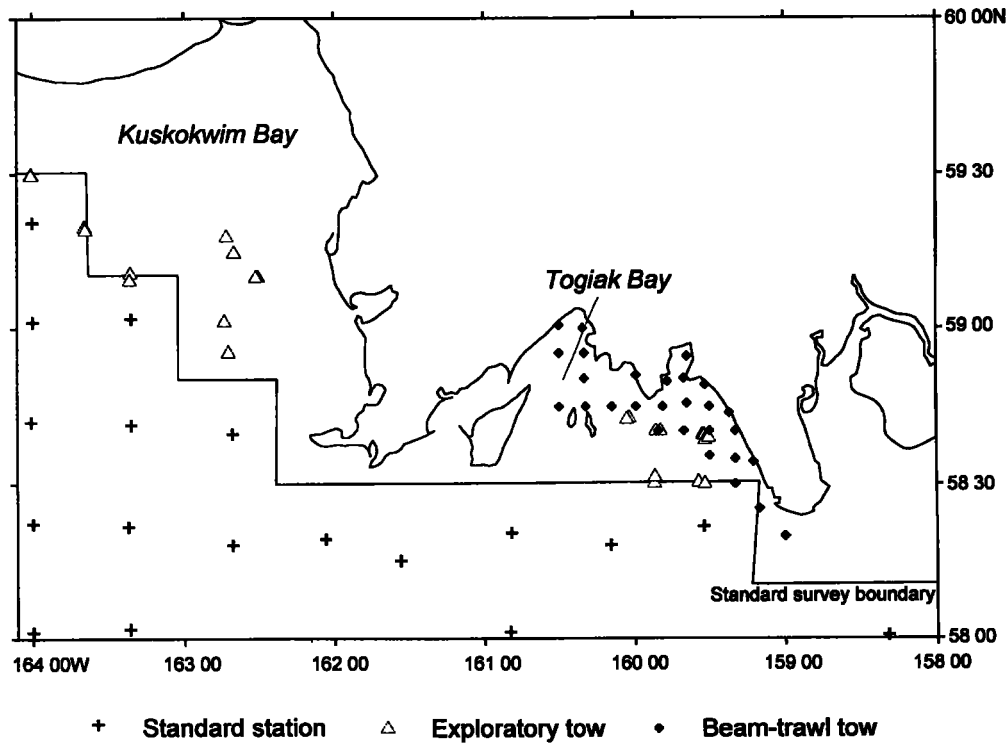


Figure 2

Geographic location of exploratory (1988–91) and beam-trawl tows (1995) made inshore of the standard AFSC survey stations.

for each tow. All fish within the path of the trawl were assumed captured. Male and female catch rates at each station were calculated as follows:

$$CPUE_i = CPUE \cdot (\text{Weight Proportion of } i\text{th sex}) =$$

$$CPUE \cdot \left(\frac{\sum_{j=1}^{n_i} aL_{ij}^b}{\sum_{j=1}^n aL_j^b} \right), \quad (1)$$

where *CPUE* = catch per unit of effort (kg/hectare) of all yellowfin sole at a station;

CPUE_i = catch per unit of effort (kg/hectare) of the *i*th sex;

n = total number of fish;

n_i = number of fish of the *i*th sex;

L = total length (cm) of the *j*th fish, males and females included;

L_i = total length (cm) of the *j*th fish and *i*th sex;

a = 0.007441; and

b = 3.130.

Constants *a* and *b* were calculated with nonlinear regression (nlin procedure; SAS Institute, 1989) with the equation: $W = aL^b$ ($n=796$, $r^2=0.99$), where *W*=individual yellowfin sole weights (g) measured during the 1987 standard AFSC survey. Prior to estimating *a* and *b*, a test comparing the length-weight relations between males and females was performed. A test of the null hypothesis of no difference between male and female linear log(length)-log(weight) revealed no significant difference in either slopes (analysis of covariance; $F=2.46$; $df=1,792$; $P=0.12$) or intercepts ($F=2.05$; $df=1,793$; $P=0.15$). Sexes were therefore combined to estimate constants *a* and *b* above.

Annual yellowfin sole “survey biomass” was estimated as:

$$\text{Biomass} = \sum_{k=1}^n (\overline{CPUE}_k \cdot A_k), \quad (2)$$

where \overline{CPUE}_k = the mean of station *CPUE* values (Eq. 1) within the *k*th stratum (Fig. 1); and

A_k = the area (hectares) of the *k*th stratum.

Proportions of males (no. males/no. both sexes) at each station were averaged across stations by depth

group (10–19 m, 20–29 m, etc.), weighted by the station CPUE (no. fish/hectare). For nearshore beam-trawl samples, variance surrounding mean male-proportions was estimated following Cochran (1977) for estimation of proportions in cluster sampling. For standard and exploratory surveys, the error structure of proportion means was approximated by the boot-strap method (Efron and Tibshirani, 1993). The station-specific data were randomly resampled and the mean estimated 1000 times. Twenty-fifth and 975th quantiles were chosen for the 95% confidence bounds.

Results

Between-sex variation

Male yellowfin sole within the standard survey area were distributed closer to shore than were females in all years, 1982–96 (Fig. 3; Table 1). In addition to having an overall distribution in deeper water, females also appeared to have a more extended north-westerly distribution than males (Fig. 3). Males outnumbered females near shore, whereas farther off shore (>60 m bottom depth), females outnumbered males (Fig. 4). The proportion of males (no. males/no. both sexes) and CPUE increased with decreasing depth (Fig. 4). Togiak and Kuskokwim Bay area samples from exploratory trawls were also characterized by a higher proportion of males as well as greater overall yellowfin sole concentrations. The proportion of males from Togiak and Kuskowim Bay areas averaged 0.60 and 0.67, respectively (Fig. 4).

Sex proportions also varied between mature and immature yellowfin sole. Among beam-trawl samples from the Togiak Bay area (Fig. 2), the overall mean proportion of males was 0.54 (SE=0.0033). Among mature fish, however, the proportion of males averaged 0.65 (SE=0.0067) and among immature fish, mostly small <20 cm fish, the proportion of males averaged 0.50 (SE=0.0024). Within the spawning area (<30 m), the proportion of males among mature fish averaged 0.68 (SE=0.0056) (Fig. 5).

Among-year variation

Yellowfin sole spring–summer distributions varied from year to year, although the most notable difference was for years 1982–84 when distributions of males in particular within the standard AFSC survey area were shifted off shore (deeper waters) relative to subsequent years (1985–96) (Fig. 3). A greater mean CPUE-weighted bottom depth in conjunction with a decreased percentage of nearshore (<30 m)

CPUE (kg/hectare) during 1982–84 confirmed a bathymetric shift to deeper waters for both male and female distributions in relation to subsequent years (Table 1). Interestingly, yellowfin sole biomass levels, as well as the overall proportion of males within the standard AFSC survey, were considerably higher during 1982–83 than in subsequent years (Table 1).

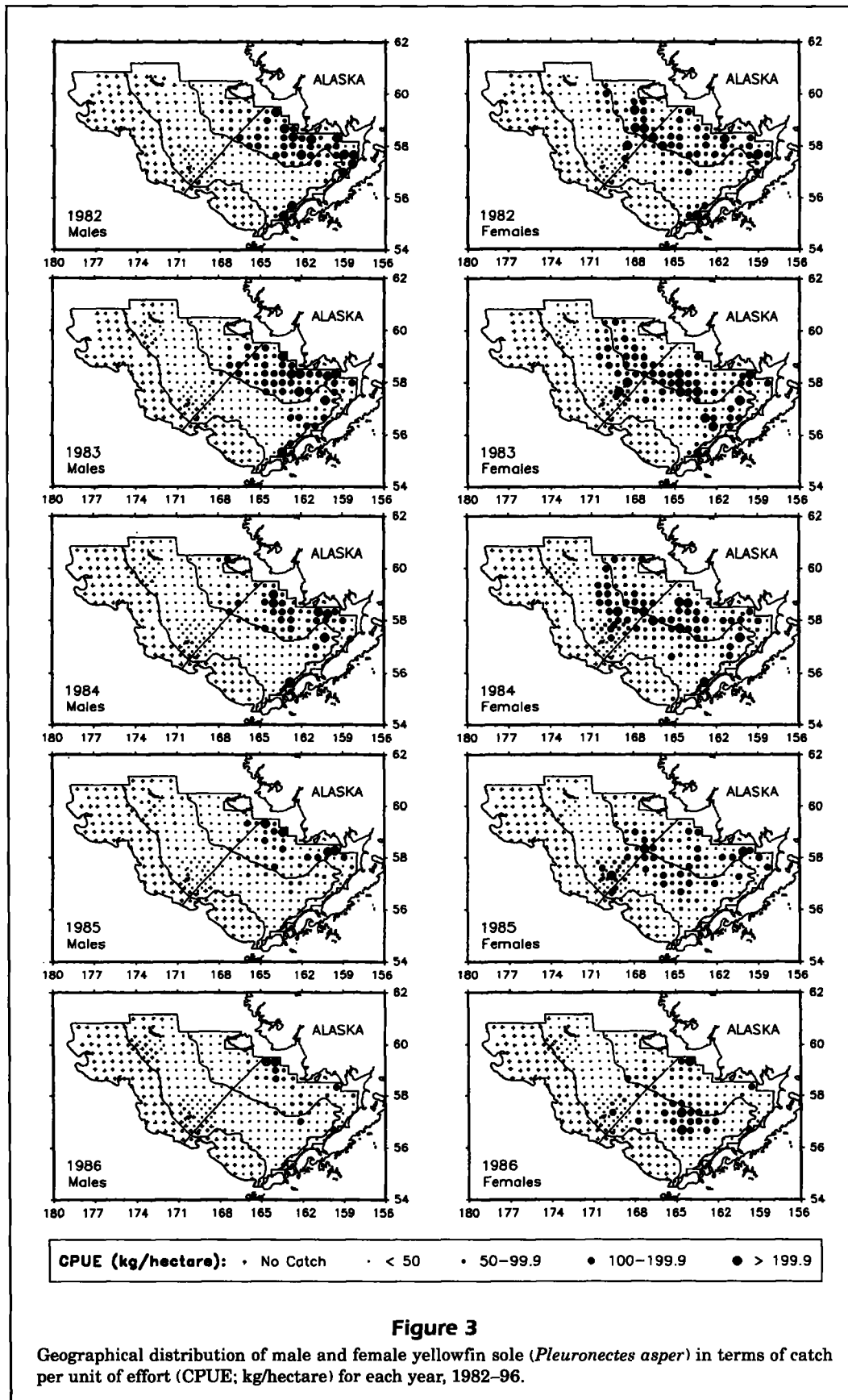
Discussion

Between-sex variation

Distributional differences between male and female yellowfin sole exist primarily because males mature earlier than females. Standard AFSC surveys, exploratory nearshore samples, and Togiak area beam-trawl samples have shown conclusively that male yellowfin sole outnumber females in the nearshore areas (<30 m bottom depth) of the eastern Bering Sea during spring–summer. Given that males mature approximately 4 years earlier than females (Wilderbuer et al., 1992), spawning males should considerably outnumber spawning females. Because yellowfin sole spawn primarily in nearshore areas (<30 m) during spring–summer (Nichol, 1995), mature males outnumber mature females by nearly 2:1 in this region. In deeper waters, females outnumber males because of the abundance of larger (25–32 cm TL) immature females that generally do not move into the spawning area (Nichol, 1997).

Factors such as differential life-spans and differential catchability between sexes have been shown to cause similar sex-ratio patterns in other species (Beverton, 1964). Such factors were assumed negligible in this case. Since 1982, maximum ages for yellowfin sole males and females averaged 25.7 and 26.1 years,³ respectively, and have not differed significantly (paired *t*-test; *P*-value=0.7758, *df*=28), suggesting similar life-spans for males and females. Beverton (1964) discussed the potential effects of differential natural mortality, fishing mortality, and catchability on sex-ratios of plaice (*Pleuronectes platessa* L.) in the North Sea. The possibility that male yellowfin sole may be more readily captured by trawl gear, at least among immature fish, is unlikely given that the sex proportion among immature fish in the spawning area was near 0.5 (Fig. 5). The possibility that spawning males are more catchable than females owing to differential spawning behavior, as Beverton (1964) reported for plaice, is not known for

³ Ages were determined by the Age and Growth Unit of the Alaska Fisheries Science Center (AFSC) from annual otolith collections made during the standard AFSC groundfish trawl surveys in the eastern Bering Sea.



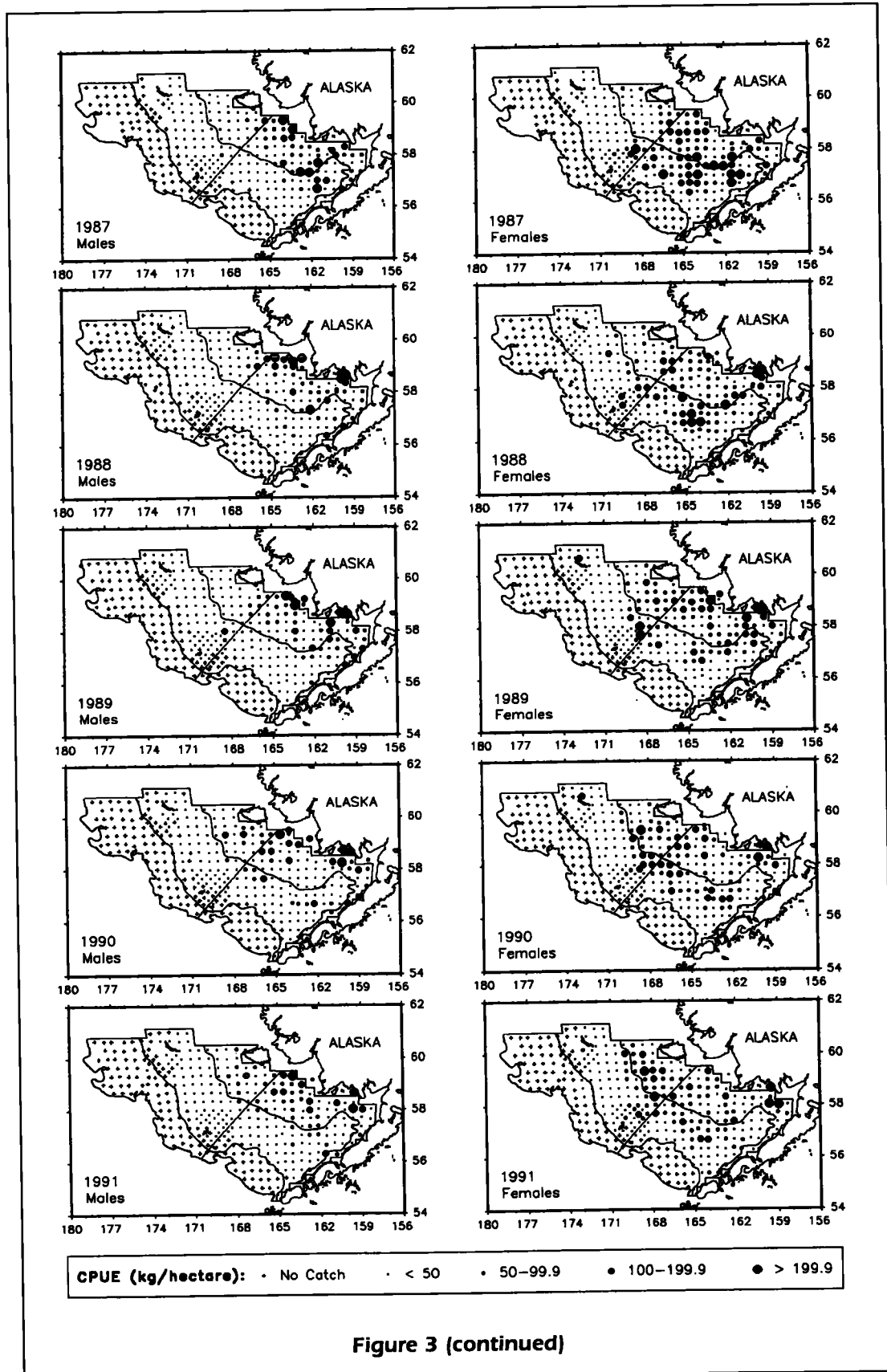


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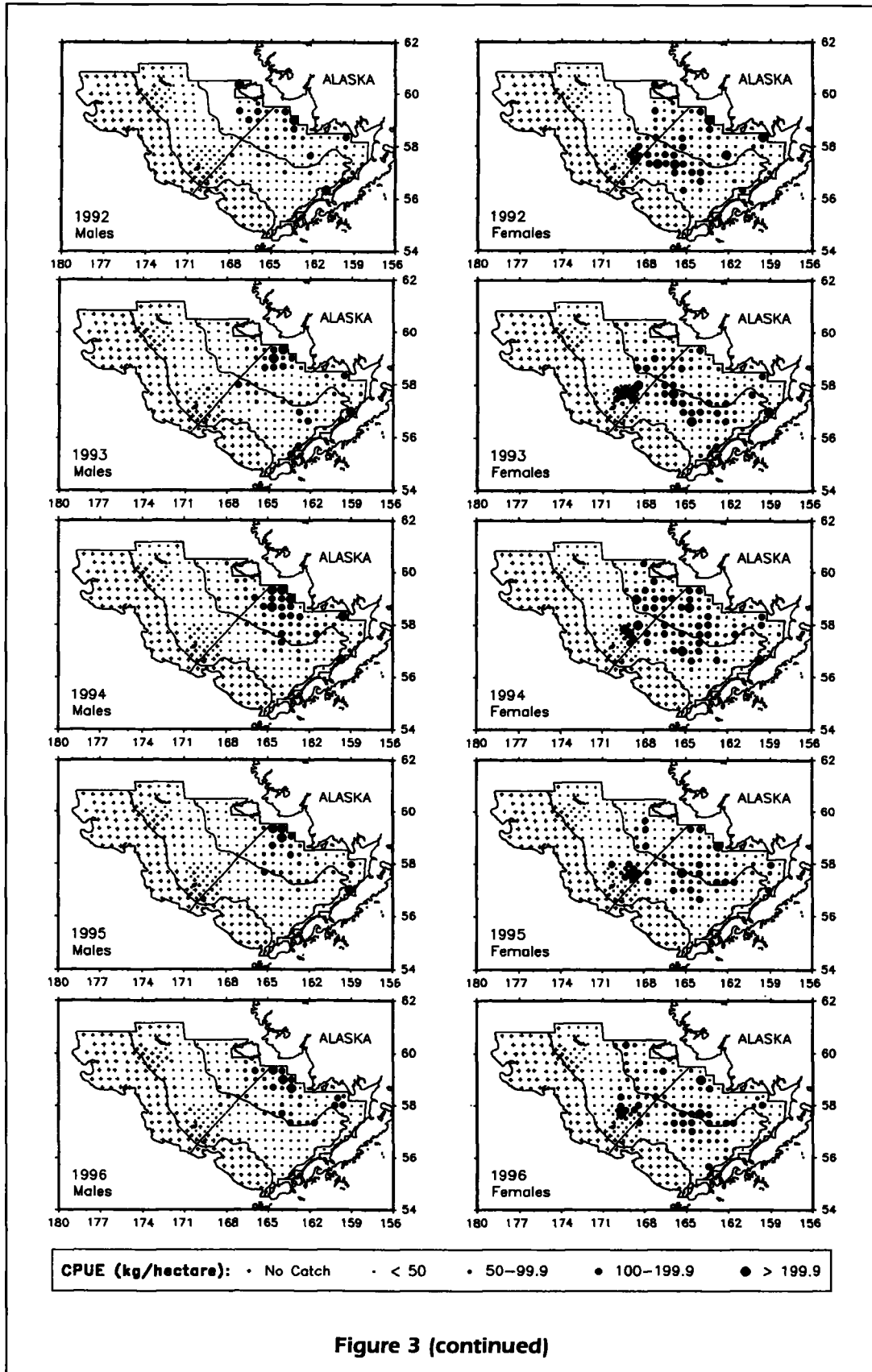


Figure 3 (continued)

yellowfin sole. However, because yellowfin sole males were dominant inshore and females were dominant offshore, the more likely cause for the sex-proportion patterns observed here was the differential distribution patterns between sexes.

Among-year variation

Spring-summer distributions during 1982-84 may have been deeper than those in subsequent years, in part, because the population was younger and less mature. Wilderbuer et al. (1992) indicated that older (>17 years) yellowfin sole were an insignificant part of the population prior to the mid-1980s compared with later years and indeed, length distributions were

skewed toward smaller length groups during the 1982-84 surveys compared with later years (Fig. 6). Given estimated lengths at 50% maturity of 20.3 and 28.8 cm TL for male and female yellowfin sole, respectively (Wilderbuer et al., 1992), many of the fish constituting the strong modes from 1982 to 1984 were sexually immature. Certainly there was a progression from immaturity to maturity for many of these fish. Nichol (1997) showed that larger (25-32 cm) immature females nearing maturity maintain a deeper bathymetric distribution than mature spawning fish during spring-summer. With increasing maturity of the population, therefore, we would expect to see a distribution shift to shallower spawning waters in years after 1984. Smaller males (22-27 cm TL) and females (25-32 cm TL) constituted a large proportion of the yellowfin sole biomass from 1982 to 1984 (Fig. 7). High concentrations of 22-27 cm males that resided at 40-49 m bottom depth during 1982-84 were not apparent from 1985 to 1996. Similarly, prominent modes of 25-32 cm females at 30-39 m and 70-79 m depths during 1982-84 were not nearly as apparent during 1985-96 (Fig. 7).

Why then was the proportion of males within the standard area higher during 1982-83 than other years? The most plausible explanation is that the deeper overall yellowfin sole distributions during these years rendered the population more available to the survey. Nearshore areas not

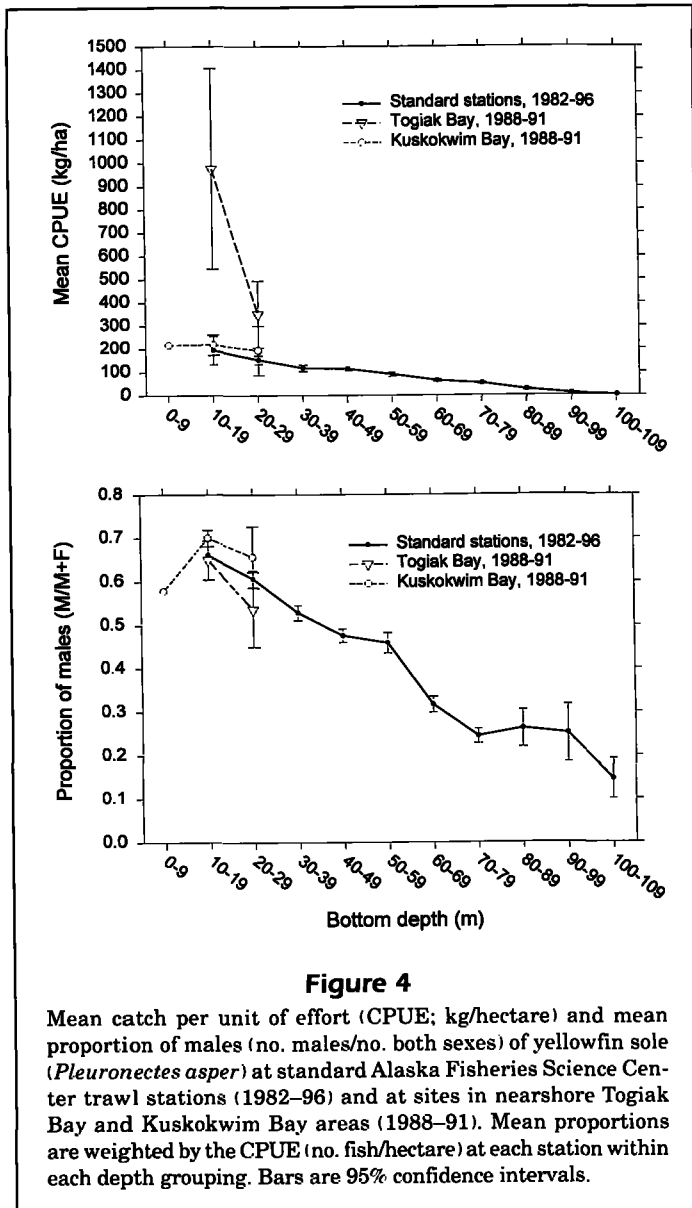


Figure 4

Mean catch per unit of effort (CPUE; kg/hectare) and mean proportion of males (no. males/no. both sexes) of yellowfin sole (*Pleuronectes asper*) at standard Alaska Fisheries Science Center trawl stations (1982-96) and at sites in nearshore Togiak Bay and Kuskokwim Bay areas (1988-91). Mean proportions are weighted by the CPUE (no. fish/hectare) at each station within each depth grouping. Bars are 95% confidence intervals.

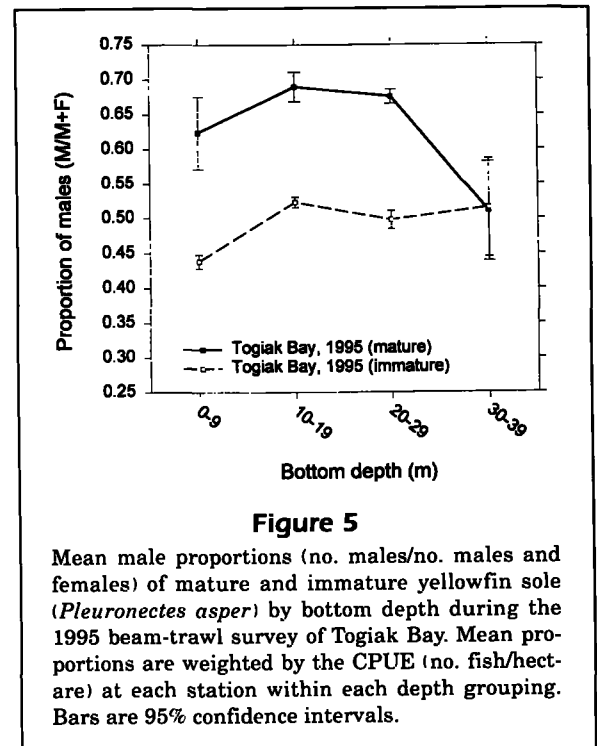


Figure 5

Mean male proportions (no. males/no. males and females) of mature and immature yellowfin sole (*Pleuronectes asper*) by bottom depth during the 1995 beam-trawl survey of Togiak Bay. Mean proportions are weighted by the CPUE (no. fish/hectare) at each station within each depth grouping. Bars are 95% confidence intervals.

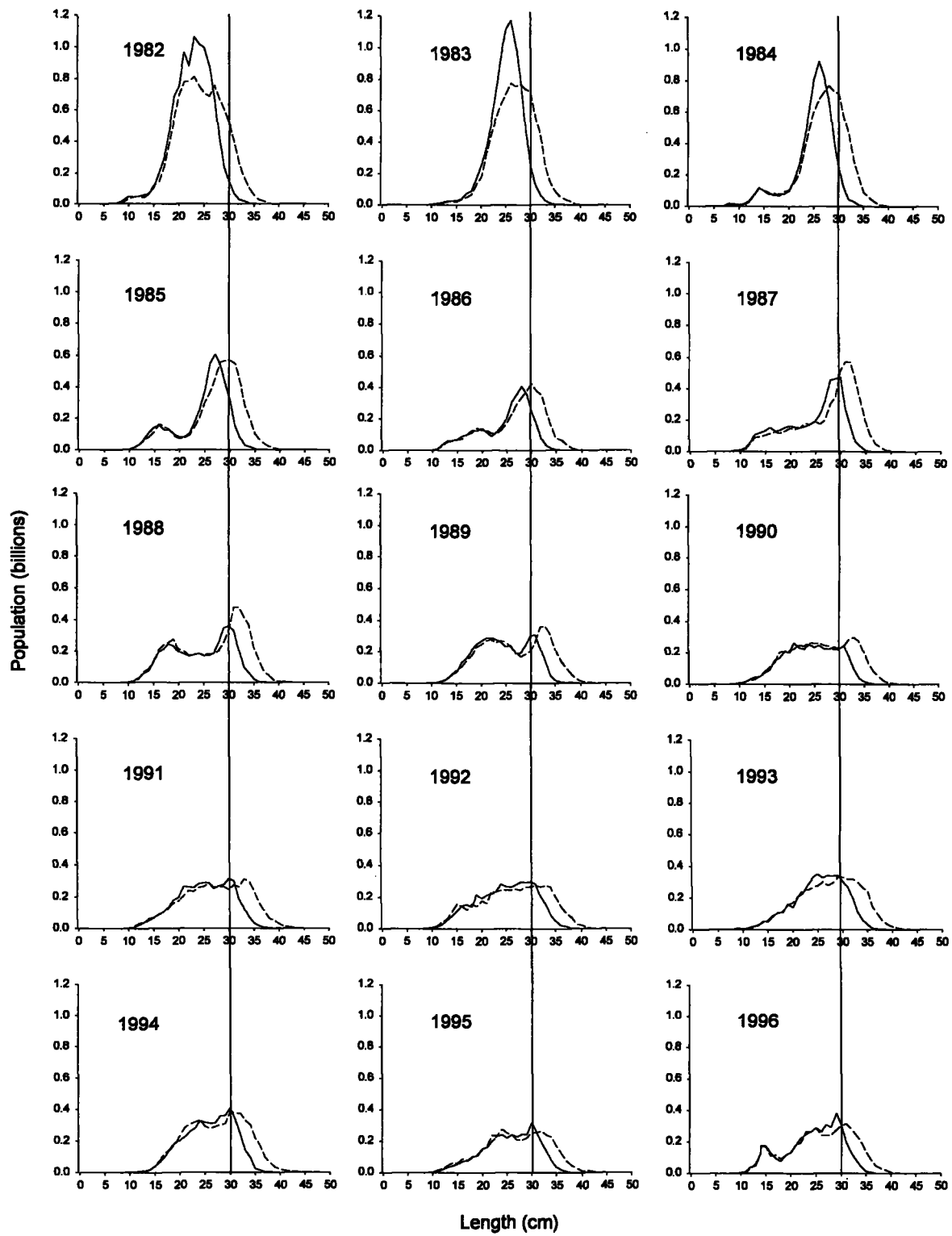
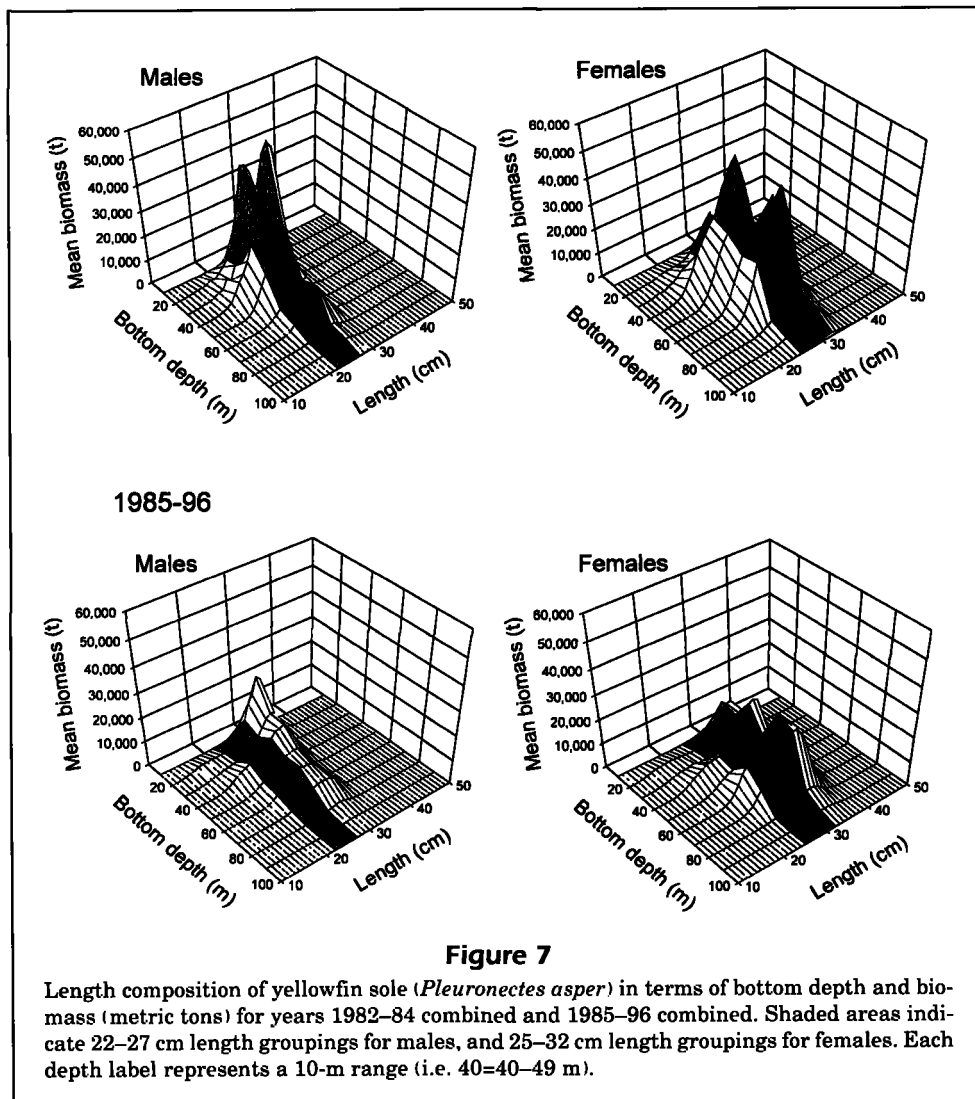


Figure 6

Length composition of male (solid line) and female (dashed line) yellowfin sole (*Pleuronectes asper*) in terms of population numbers for years 1982–96. The vertical lines provide a reference for fish length at 30 cm TL.



sampled during the standard AFSC surveys likely contained more males than females. Hence, a shift of the population to deeper waters possibly exposed a higher proportion of males to the survey gear than during subsequent years.

Effects of distribution on survey biomass

Given that the standard AFSC survey area does not encompass the entire yellowfin sole distribution, annual distributional shifts between surveyed and nonsurveyed areas may explain the annual biomass fluctuations observed within the standard AFSC survey area. Yellowfin sole biomass estimates within the standard AFSC survey area have fluctuated from a high of 3.5 million t in 1983 down to 1.9 million t in 1986 (Table 1). These fluctuations are not possible according to yellowfin sole life history and the relatively light fishing exploitation of this species since

the late 1970s (Wilderbuer et al., 1992). Stock synthesis models based on catch-at-age data (Methot, 1990) predict much more stable changes in yellowfin sole biomass (Fig. 8). Even though these models incorporate survey biomass estimates as auxiliary information (Wilderbuer¹), predicted biomass estimates from 1982 to 1984 were much lower than what survey estimates indicated. I propose that the deeper overall spring–summer distributions from 1982 to 1984 contributed to an inflation of survey biomass estimates in contrast with subsequent years, owing to increased availability of yellowfin sole to the AFSC survey. Strong year classes that were present in the survey area during 1982–84 may have become less accessible to the survey gear during later years owing to their sexual maturation and subsequent migration into shallower nearshore spawning waters.

Nearshore areas from the standard survey boundary to the coastline (excluding river systems and in-

ner bays) totaled approximately 40,184 km² (Fig. 1). In contrast, the two nearest shore strata within the AFSC survey area total 77,871 km² (stratum 1) and 41,027 km² (stratum 2), respectively. The coastline areas, thus, offered yellowfin sole a considerable refuge from the AFSC bottom trawl survey. According to past samples from Togiak Bay and Kuskokwim Bay areas (Table 2), yellowfin sole are more concentrated in the coastline areas than within the standard AFSC survey area (Fig. 4). Considering the vast unsampled areas near shore, as well as the large yellowfin sole concentrations that inhabit these areas, annual fluctuations in biomass within the standard AFSC area should be expected.

Biomass estimates generated from standard AFSC eastern Bering Sea trawl surveys are considered a relative measure of population abundance. However, because nonsurveyed nearshore areas contain higher concentrations of yellowfin sole and because males outnumber females there, standard area biomass estimates underestimate male abundance. Distribution plots suggest a more extended northwesterly distribution of females compared with males. Within the northwest area (subareas 2, 4, and 6) the average proportion of males from 1982 to 1996 was 0.33 ± 0.016 (95% confidence) compared with 0.50 ± 0.010 in the southeast area (subareas 1, 3, and 5). The lack of males in the northwest area may be an indication that a large percentage of males missed by the survey inhabit nearshore waters of Kuskokwim Bay and waters east of Nunivak Island (Fig. 1).

Bottom temperature may be one factor that has influenced the availability of yellowfin sole to the standard AFSC survey. Except for the years 1982–84, when fish availability was affected more by population structure, biomass estimates were generally lower during colder years (Fig. 9). Midshelf bottom temperatures were chosen to represent annual temperature regimes because water exchange is minimal when compared with the inner shelf (< 50 m) and outer shelf (>100 m) waters (Coachman, 1986; Wilderbuer et al., 1992). Distribution patterns, as well as timing of the annual yellowfin sole cross-shelf migration, may in part be dependent upon the annual temperature regime. Fadeev (1965) indicated that spring yellowfin sole migrations occurred one month earlier than usual during years when warm water developed earlier on the eastern Bering Sea shelf. Pola et al. (1985) also demonstrated, using simulation models, that summer yellowfin and rock sole distributions could be established two months earlier in a warm year than in a cold year. If ice-edge

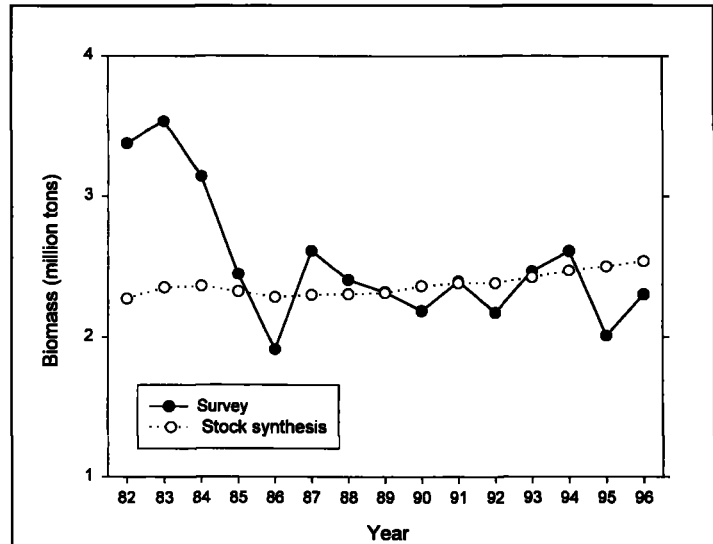


Figure 8

Comparison of yellowfin sole (*Pleuronectes asper*) biomass estimates from the AFSC survey and from stock synthesis analysis. Stock synthesis estimates incorporate the selectivity of the survey sampling gear and use survey biomass estimates as auxiliary data, but they are based on catch-at-age data.

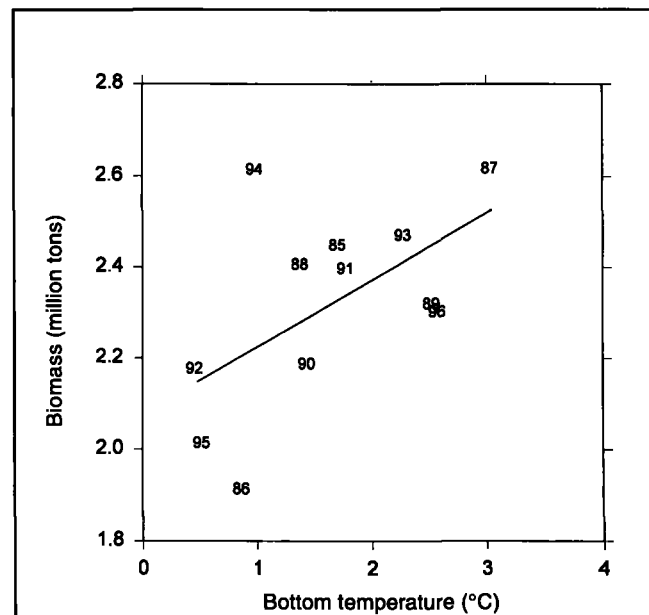


Figure 9

Increase in estimates of yellowfin sole (*Pleuronectes asper*) biomass as related to mean midshelf (50–100 m) bottom temperatures for years 1985–1995. Line represents the linear regression of biomass (dependent variable) against bottom temperature (independent variable); $r^2 = 0.32$, $n = 12$, slope = 0.15 (two-tailed $P = 0.054$), intercept = 2.08. Note that 1982–84 data were excluded because the population structure was unique during those years.

retreat determines the timing of inshore yellowfin sole migration (Bakkala, 1981), and subsequently the timing of spawning, distribution patterns at the time of the survey could be affected. Increasing percentages of spent yellowfin sole during the June 1993 AFSC survey (Nichol, 1995) indicated that spawning activity progresses within the duration of the survey. Spring–summer surveys conducted in warmer years may intercept higher proportions of spent individuals that no longer inhabit the unavailable nearshore spawning areas.

Interannual variation of yellowfin sole biomass estimates within the eastern Bering Sea may be reduced under alternative survey designs (McAllister, 1995). I recommend the incorporation of additional standard stations in nearshore areas, such as the exploratory tows made in Togiak and Kuskokwim Bays (Fig. 2), and east of Nunivak Island. The addition of such stations would likely reduce interannual variation of survey biomass estimates as well as provide a more accurate representation of the population sex-composition.

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