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Estimated Impacts of Hypothetical Oil Spill Accidents off Port Moller, Port Heiden and Cape Newenham on Eastern Bering Sea Yellowfin Sole

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ESTIMATED IMPACTS OF HYPOTHETICAL OIL SPILL ACCIDENTS OFF PORT MOLLER, PORT HEIDEN AND CAPE NEWENHAM ON EASTERN BERING SEA YELLOWFIN SOLE

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INTRODUCTION

The yellowfin sole (Limanda aspera) is a flounder of the family Pleuronectidae and is the most abundant of the commercially important species of the eastern Bering Sea benthos. The species ranked first or second in abundance of all fish taken in the trawl surveys of the National Marine Fisheries Service (NMFS), Northwest and Alaska Fisheries Center (NWAFC) trawl surveys in 1975-80. Although information for more recent years was not available, their abundance ranking probably remains unchanged.

This large biomass is ubiquitously distributed over the eastern Bering Sea, therefore, any oil spill scenario in Bristol Bay will contaminate some of the species' habitat. The impact of such contamination on the productivity of the eastern Bering Sea yellowfin sole stock will depend upon the concentrations and duration of exposure as well as the physiological state and life history stage of the animals in the contaminated area. Considerable knowledge has been compiled on the life history, distribution, abundance and fishery of yellowfin sole in the eastern Bering Sea (Fadeev 1970a & b, Bakkala 1981, Wakabayashi 1985). The purpose of this report is to summarize information from these and other sources to provide relevant background information for estimating the impact of specific quantities and types of petroleum released at three sites in Bristol Bay on the productivity of the eastern Bering Sea yellowfin sole population.

DISTRIBUTION

Overall Distibution

Yellowfin sole (Limanda aspera) are widely distributed in the northern North Pacific Ocean and adjacent seas. They are typically found over sandy and sandy-silt bottom and never found in large numbers on gravel or purely silty sediments (Fadeev 1970a). In Asia, the species occurs on the shelf from the east coast of the Korean Peninsula northward in the Sea of Japan, Okhotsk Sea and along the Pacific coast of Siberia to Bering Strait. In the eastern North Pacific Ocean, yellowfin sole occur on the North American continental shelf from off central British Columbia and Alaska as far north as the Chukchi Sea (Fig. 1). The largest biomass of yellowfin sole occurs on the broad shelf of eastern Bering Sea with only minor centers of abundance found off the western coast of Kamchatka, off the southeastern coast of Sakhalin and in the northernmost parts of the Sea of Japan (Kasahara 1961). Eastern Pacific stocks other than those of eastern Bering Sea are also minor.

Distribution in the Eastern Bering Sea

Yellowfin sole are very broadly distributed over the continental shelf and slope of the eastern Bering Sea at depths of 5 m to 360 m (Fadeev 1970) although the most dense concentrations and the commercial fishery occur generally south of 60°N (Fig. 1). The distribution of yellowfin sole varies by stock, season and age.

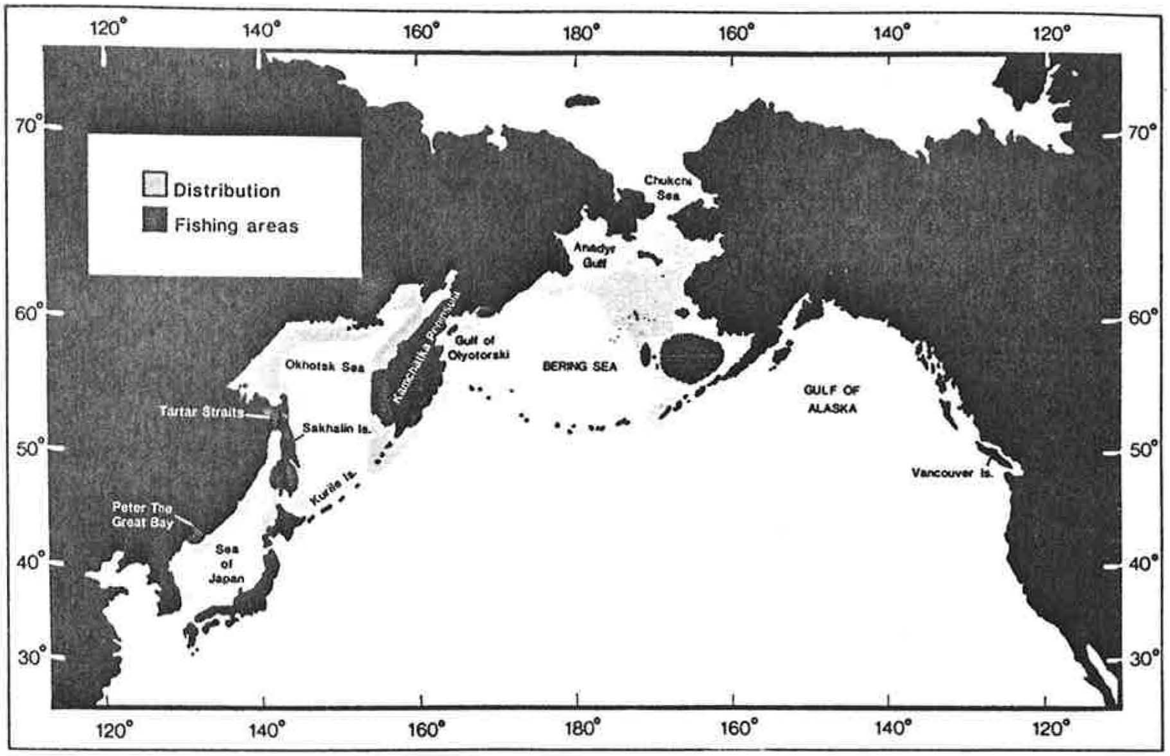


Figure 1. Overall distribution and areas of commercial fishing for yellowfin sole.

During the winter, adults aggregate in large dense schools on the outershelf and upper slope at depths of 100-270 m (max. depth, 360 m). Wintering adults are found in temperatures of 2° to 6°C (Fadeev 1970a). In April and May (sometimes as early as March), these aggregations of adult fish migrate generally northeastward to shallower waters of the eastern Bering Sea shelf (Fig. 2).

With the approach of summer, there is a progressive movement of the fish toward Bristol Bay and northward. By summer the main body of yellowfin sole is broadly distributed over the inner shelf of southeastern Bering Sea at bottom depths of 100 m and less (Fig. 3). Yellowfin occur in bottom temperatures of -1.0° to 13°C with highest catches at -1° to 7°C according to Bakkala (1981) and 1° to 6°C according to Fadeev (1970b). Distribution extends well into Bristol Bay with dense concentrations off Togiak, the Egegik River estuary and the northern Aleutian Shelf in some years (e.g., 1980).

Stimulus for spring migrations is apparently not temperature per se because sole move from relatively warm deep water (3.5°-4.0°C in April) to cooler shelf waters (0°C)in April and May (Fadeev 1970a). Maximum winter chilling of shelf water occurs in March-April. Large concentrations of sole may be aggregations of fish near the borders of cold water masses.

Bakkala (1981) has presented evidence that the distribution and spring migration of sole is associated with seasonal changes in the ice covering of the eastern Bering Sea.

Movements of the Japanese fishery also illustrate the seasonal changes in the distribution of eastern Bering Sea yellowfin sole (Fig. 4).

In addition to these seasonal movements, yellowfin sole are known to migrate vertically through the water column. They have been observed near the

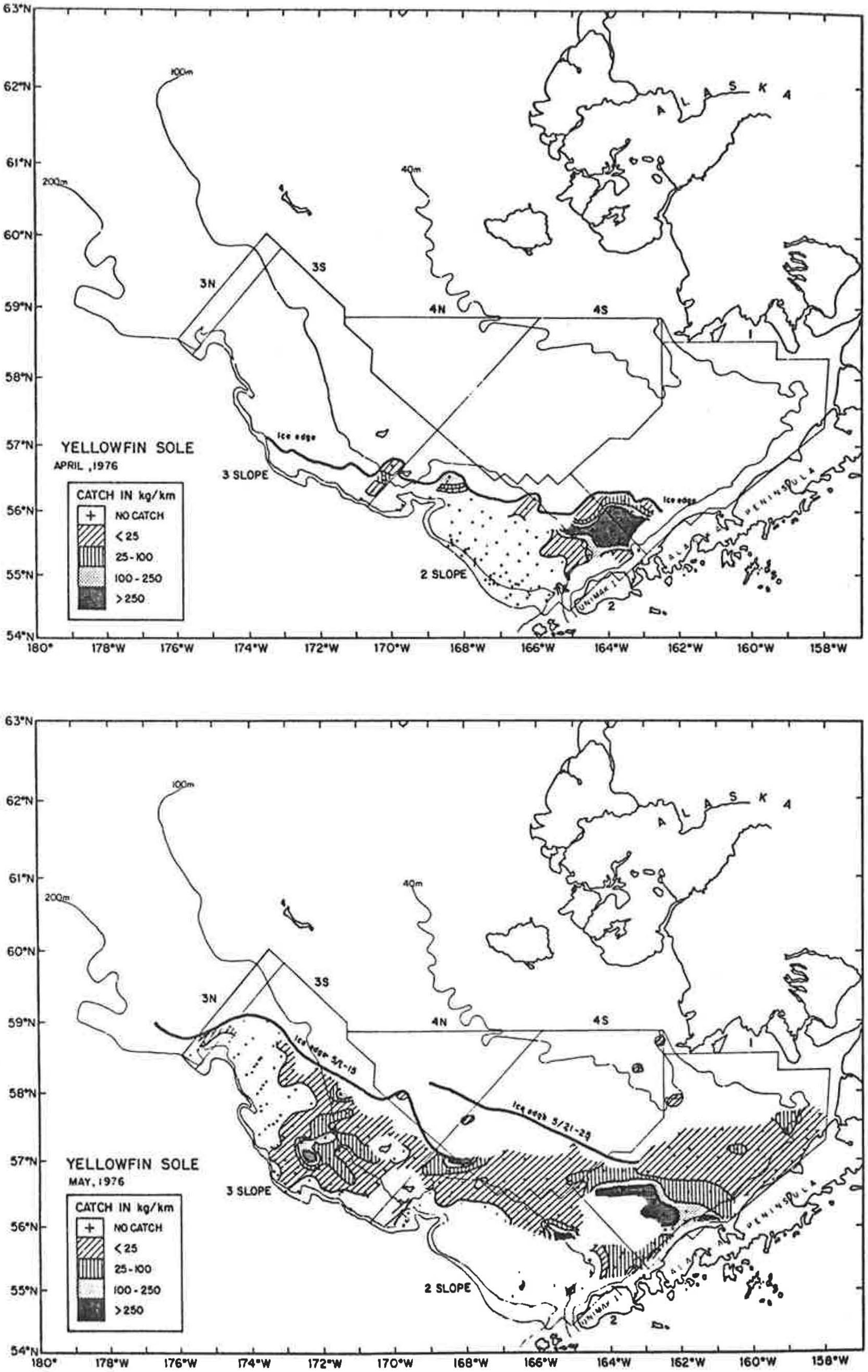
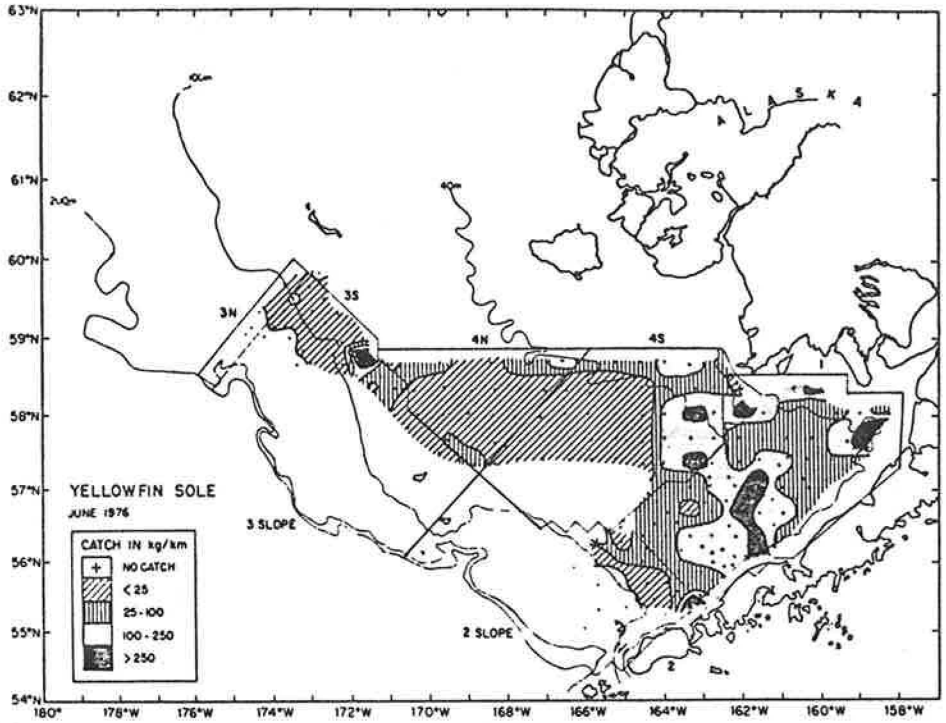
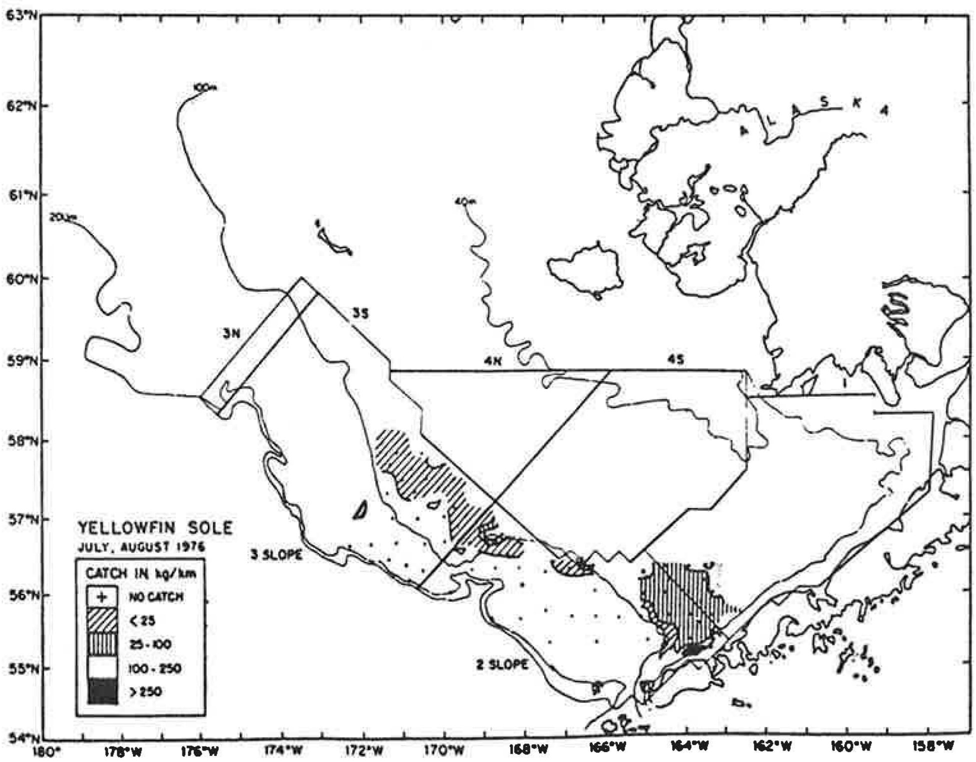


Figure 2. Seasonal changes in relative abundance of yellowfin sole as shown by NWAFC trawl surveys.





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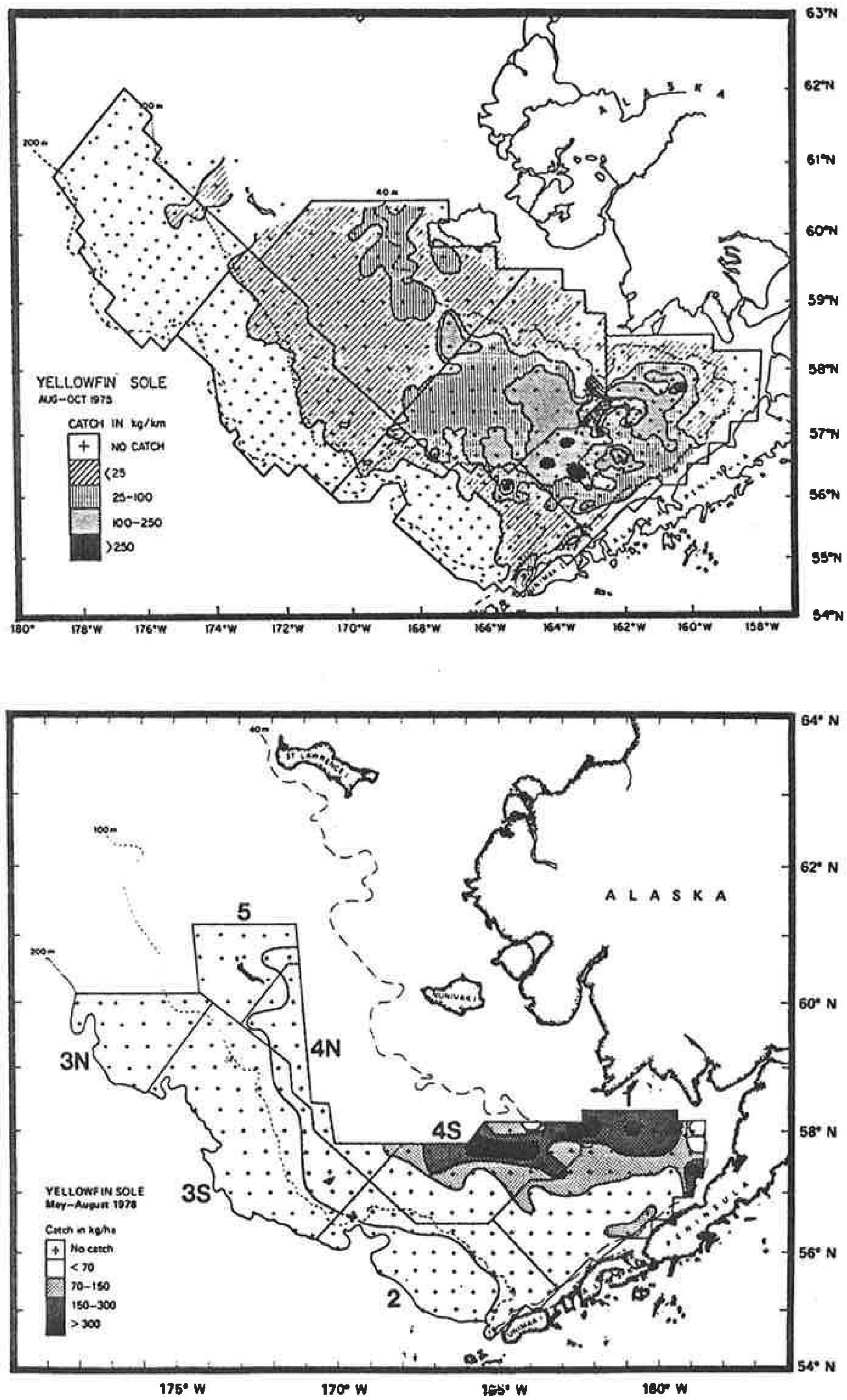


Figure 3. Distribution and relative abundance by weight of yellowfin sole in the eastern Bering Sea.

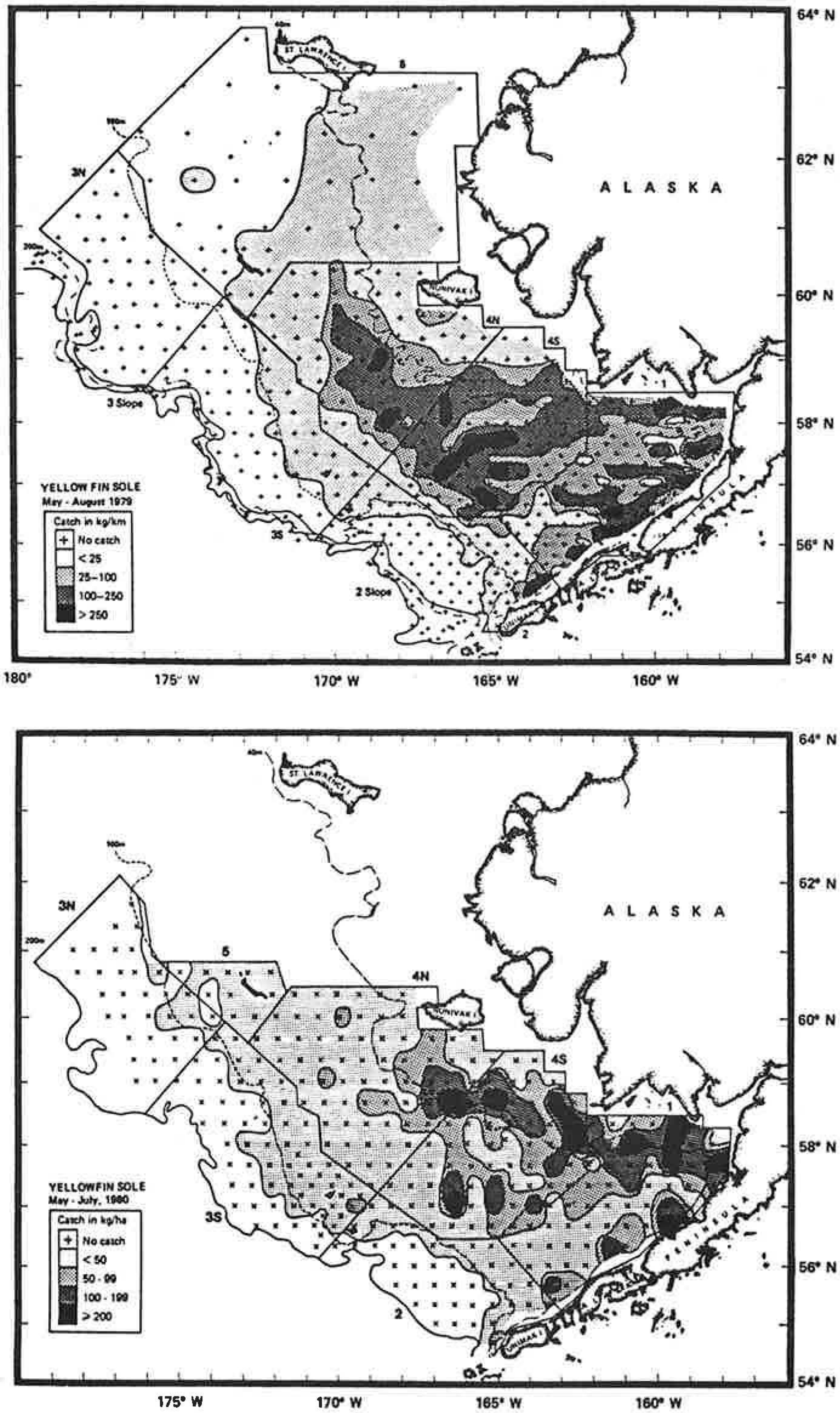


Figure 3. Continued.

surface in spawning areas and during the winter rising to the surface at night and descending to the bottom during daylight hours (Fadeev 1970a). Occurrence of yellowfin sole well off the bottom has been confirmed by Japanese and United States investigations (Salveson and Alton 1976).

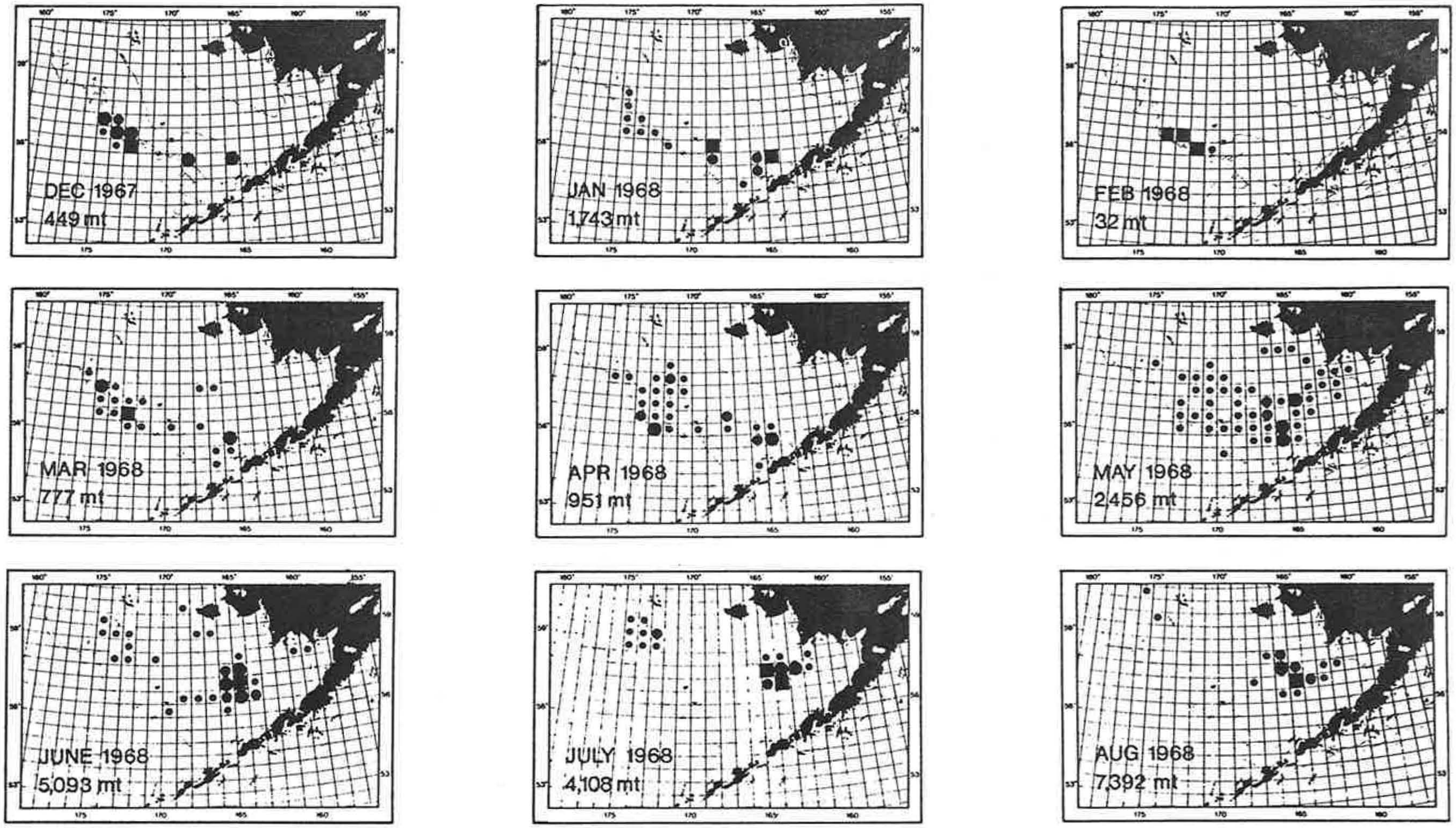
Available evidence indicates that juveniles are year round residents of the inner shelf. As juveniles mature, they move from shallower to deeper waters (Bakkala 1981).

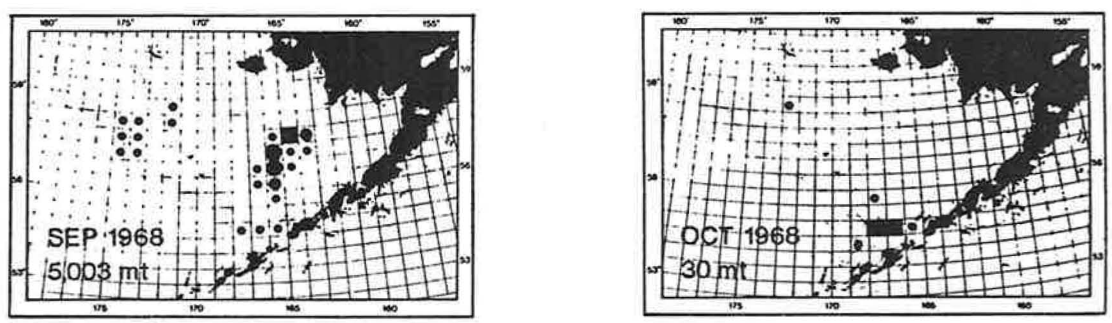
Stock Structure and Seasonal Migrations

There is evidence that the eastern Bering Sea yellowfin sole population is composed of more than one stock. As mentioned in the previous paragraph, adults aggregate in deeper water during the winter. Three such aggregations were reported by Soviet scientists, the largest off Unimak Island, another west of the St. Paul Island and a comparatively small and poorly defined concentration south or east of St George Island (Fadeev 1970a, Wakabayashi 1974). Tagging studies have shown that the Unimak and St. George Island wintering groups combine in spring before onshore migrations (Wakabayashi et al. 1977). The juvenile concentrations in Bristol Bay are thought to be a part of the Unimak-St. George group (Bakkala 1981).

The Unimak-St. George school moves to shallower water in April and May (as early as March) and with the approach of summer, there is progressive movement toward Bristol Bay and northward. By summer, most yellowfin sole are on the inner shelf of southeast Bering Sea at bottom depths of 100 m and less.

The St. Paul Island wintering group apparently remains relatively independent of the Unimak-St. George group. This group forms summer concentrations in shallow waters around Nunivak Island.





YELLOWFIN SOLE

• Less than 5%
● 5-10%
● 10-20%
■ More than 20%

Figure 4. Seasonal changes in Japanese fishing grounds for yellowfin sole, December 1967 to October 1968 (Wakabayashi 1974). Symbols represent the percentages of the total monthly catches (shown within the figure) taken in various ½° latitude and 1° longitude statistical blocks.

Tagging studies (Wakabayashi 1974, Wakabayashi et al. 1977) and differences in morphometric measurements (Kashkina 1965, Wakabayashi 1974) indicated that these populations constitute a northern (St. Paul) and southern (Unimak-St. George) stock of yellowfin sole. Other biological studies (Fadeev 1970a, Wakabayashi 1974, Grant et al. 1978) and more recent tagging studies, suggest that the eastern Bering Sea yellowfin sole constitute a single stock.

Distibution by Subareas in Northwest and Alaska Fisheries Center (NWAFC) Trawl Surveys

The history of resource surveys in the eastern Bering Sea was described by Alton (1976). Surveys have occurred since 1890, however, the most comprehensive in area and consistent in time are the trawl surveys of the NWAFC which have occurred annually and included demersal fish assessments since about 1971. Subareas of the NWAFC eastern Bering Sea trawl surveys in recent years (since 1975) are shown in Figure 5. As indicated in this figure, the Port Heiden and Port Moller spill scenario sites are located within Subarea 1 and the Cape Newenham spill site in Subarea 4S. The following discussion will, therefore, emphasize the population characteristics of the yellowfin sole within these two Subareas.

Distribution of Biomass By Subareas

The mean estimated biomass of yellowfin sole in the eastern Bering Sea is given in Table 1. The mean biomass almost doubled from 1 million t in 1975 to 1.9 million t in 1979. The biomass remained essentially the same through 1981. From 1981 to 1982, the biomass increased by 63% and again from 1982 and 1983 the biomass increased by almost 19%. The increase in biomass from 1981 to 1982 was far more than could be explained by population growth

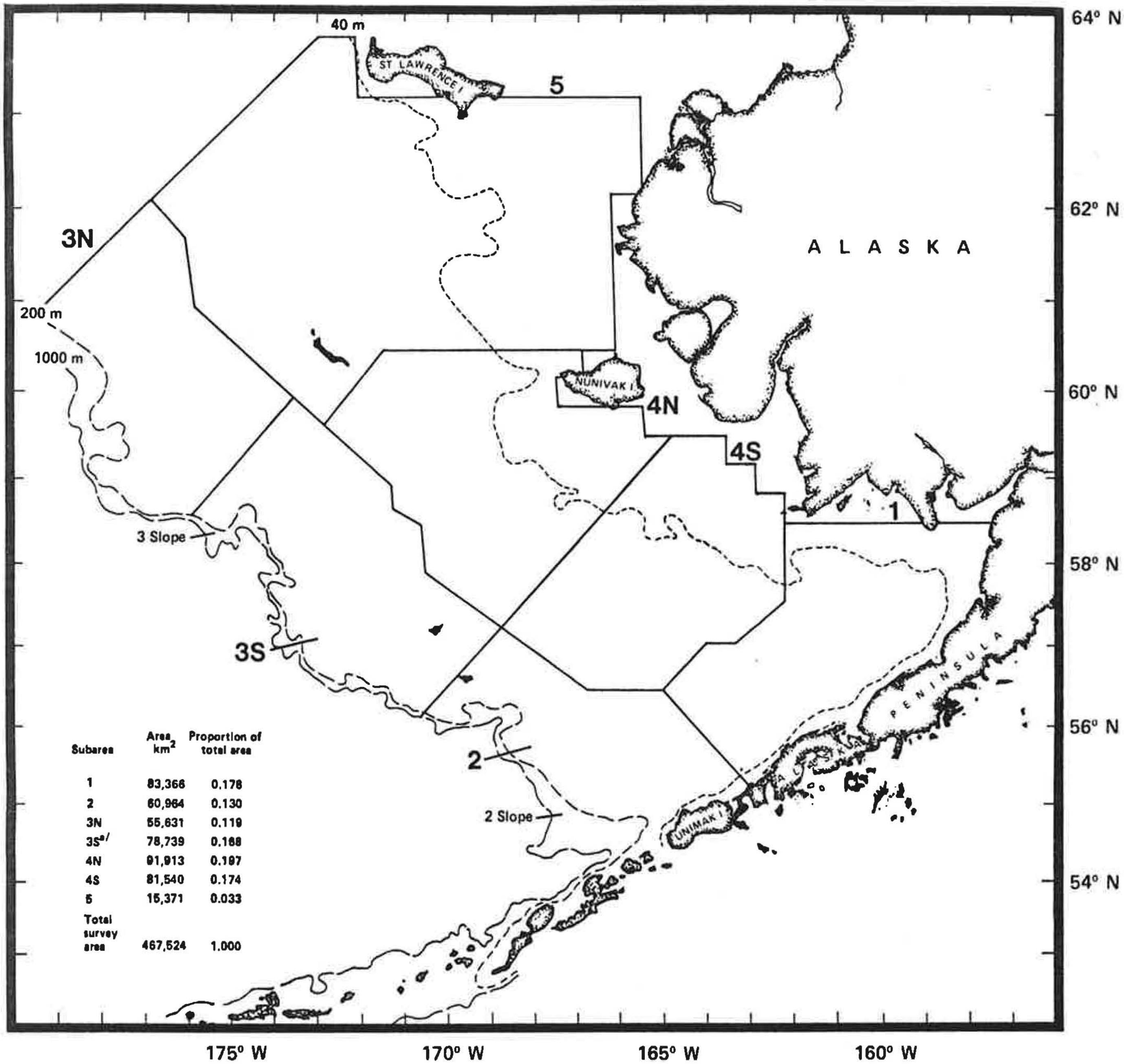


Figure 5. National Marine Fisheries Service trawl survey subareas showing locations of hypothetical oil spill sites off Port Moller, Port Heiden and Cape Newenham.

Table 1. Biomass estimates from research vessel surveys, 1975-84.

Year	Mean estimate (t)	95% confidence interval (t)
1975	1,038,400	870,800 - 1,206,400
1976	1,192,600	661,700 - 1,723,600
1978	1,523,400	1,103,300 - 1,943,600
1979	1,932,600	1,669,000 - 2,196,100
1980	1,965,900	1,716,000 - 2,215,900
1981	2,039,900	1,791,000 - 2,288,800
1982	3,322,500	2,675,900 - 3,970,100
1983	3,951,500	3,459,200 - 4,443,900
1984	3,365,900	2,972,000 - 3,759,800

Source: Bakkala and Wespestad, 1984.

increments. This increase was attributed in part to improved bottom tending qualities of the trawl and an increase in the area sampled during the 1982 survey (Bakkala and Wespestad 1984a).

The distribution of yellowfin sole biomass by subareas of the eastern Bering Sea is summarized in Table 2 with the percentage of estimated biomass in each of the 7 subareas shown in Figure 6. During the period of the surveys (spring-fall), 90% (1976) to 98% (1978) of the biomass was estimated to be on the inner shelf (primarily Subareas 1, 4S and 4N). Subareas 1 and 4S combined accounted for 69% (1983) to 96% (1978) of the total biomass. Estimated biomass was generally largest in Subarea 1 which includes the Port Moller and Port Heiden hypothetical spill sites. Estimated biomass in Subarea 1 constituted 33% (1979) to 79% (1976) of the total, although the latter was considered to be an overestimate (Smith and Bakkala 1982). The average percentage of biomass in Subarea 1 for 1975-83 (excluding 1976 and 1977) was 43%.

Excluding 1976 and 1977, the percentage of the eastern Bering Sea yellowfin sole biomass occupying Subarea 4S (Cape Newenham spill site) ranged from 31% (1975) to 46% (1981) with the average 37% for the 7 years considered.

Distribution of Life History Groups

Spawning Populations and Eggs and Larvae

Knowledge concerning the timing and areas of spawning of yellowfin sole has been obtained primarily from observations of the distribution of their eggs and larvae. The distribution of yellowfin sole eggs and larvae taken in Soviet plankton surveys is shown in Figure 7. Spawning begins in early July and probably ends in September (Musienko 1963). Eggs are distributed over a

Table 2. Estimated biomass of yellowfin sole in the eastern Bering Sea, 1975-83.

Subarea/Year	1975[1]	1976[2]	1978[3]	1979[4]	1980[5]	1981[6]	1982[6]	1983[6]
Inner Shelf								
5			10	24,872	1,742	1,076	1,073	81,320
4N	105,800	44,249	30,367	414,050	343,291	154,746	591,547	976,568
4S	319,000	88,151	694,943	790,749	677,458	948,406	1,052,146	1,343,322
1	540,100	939,471	937,829	634,061	821,490	827,670	1,376,102	1,438,319
Total	964,900	1,071,871	1,663,149	1,863,732	1,843,981	1,931,898	3,020,868	3,839,529
	(93)	(90)	(98)	(96)	(96)	(94)	(91)	(95)
Outer Shelf								
3N	t	120,753	0	0	24	47	19	39
3S	5,800		4,555	11,476	21,649	18,072	16,615	47,546
2	67,700	-	37,006	57,349	47,321	114,492	285,295	163,150
Total	73,500	120,753	41,561	68,825	68,994	132,611	301,929	210,735
	(7)	(10)	(2)	(4)	(4)	(6)	(9)	(5)
All Areas Total	1,038,400	1,192,624	1,704,710	1,932,557	1,912,975	2,064,509	3,322,797	4,050,264

1/ Pereyra et al. 1976
2/ Smith and Bakkala 1982.
3/ Bohle and Bakkala 1978.
4/ Bakkala, et al. 1982
5/ Umeda and Bakkala 1983
6/ Unpublished data, RACE Division, NWAFC.

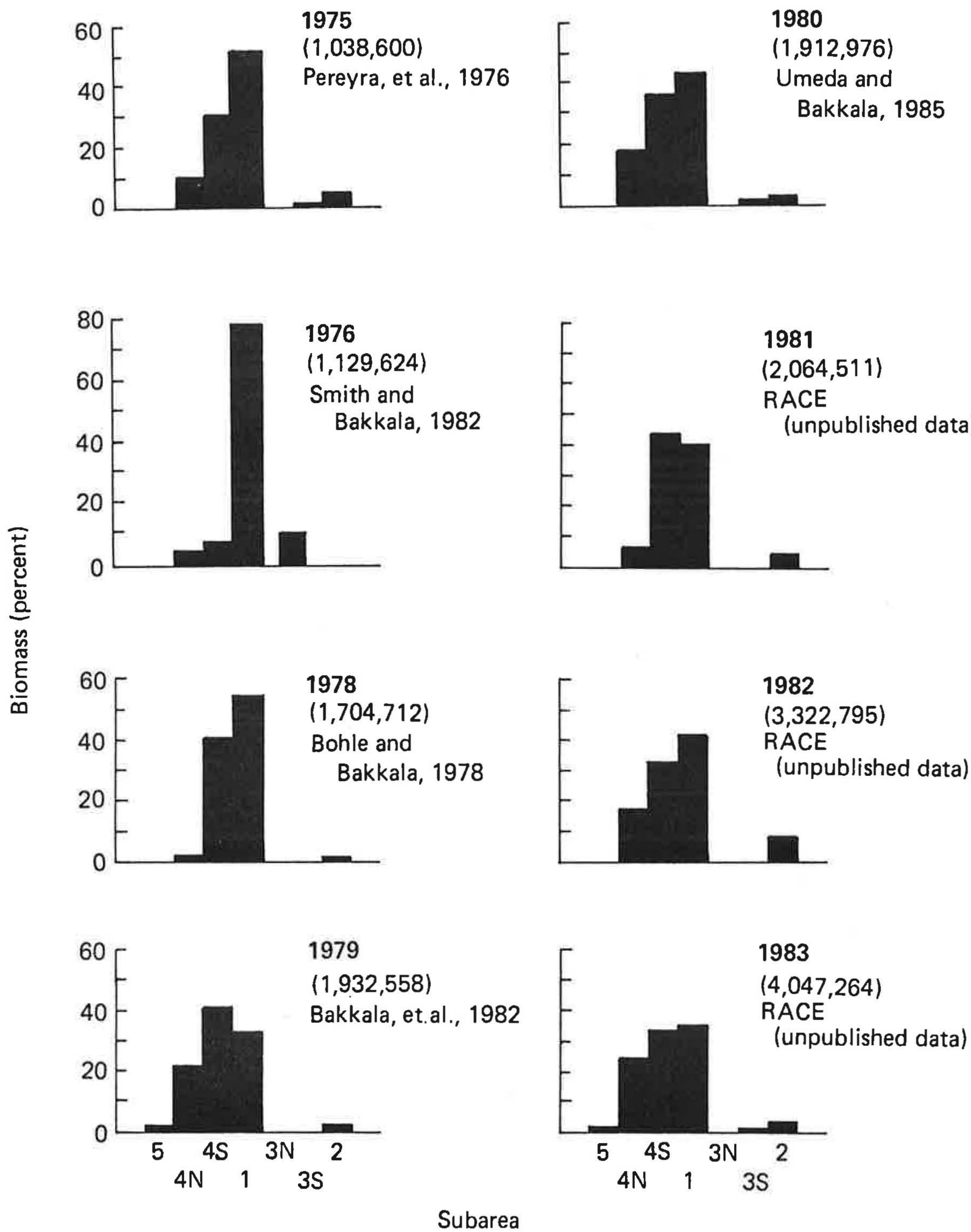


Figure 6. Percentage distribution of biomass of yellowfin sole in subareas of the NWAFC eastern Bering Sea trawl survey.

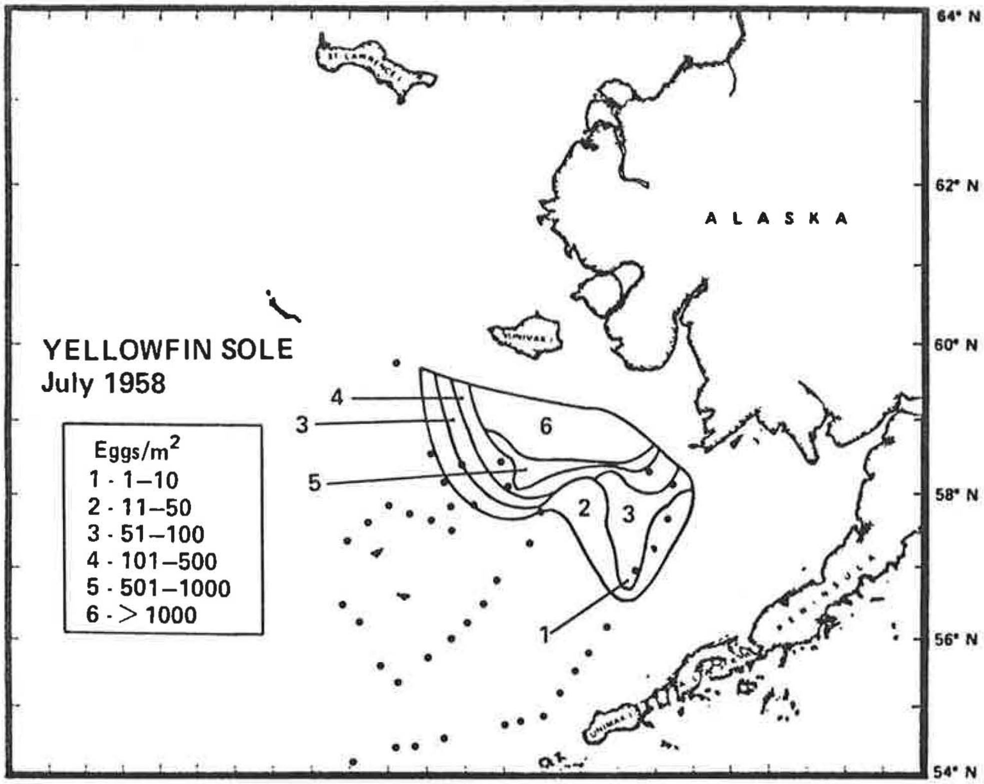


Figure 7. Distribution of yellowfin sole eggs as shown by plankton surveys.

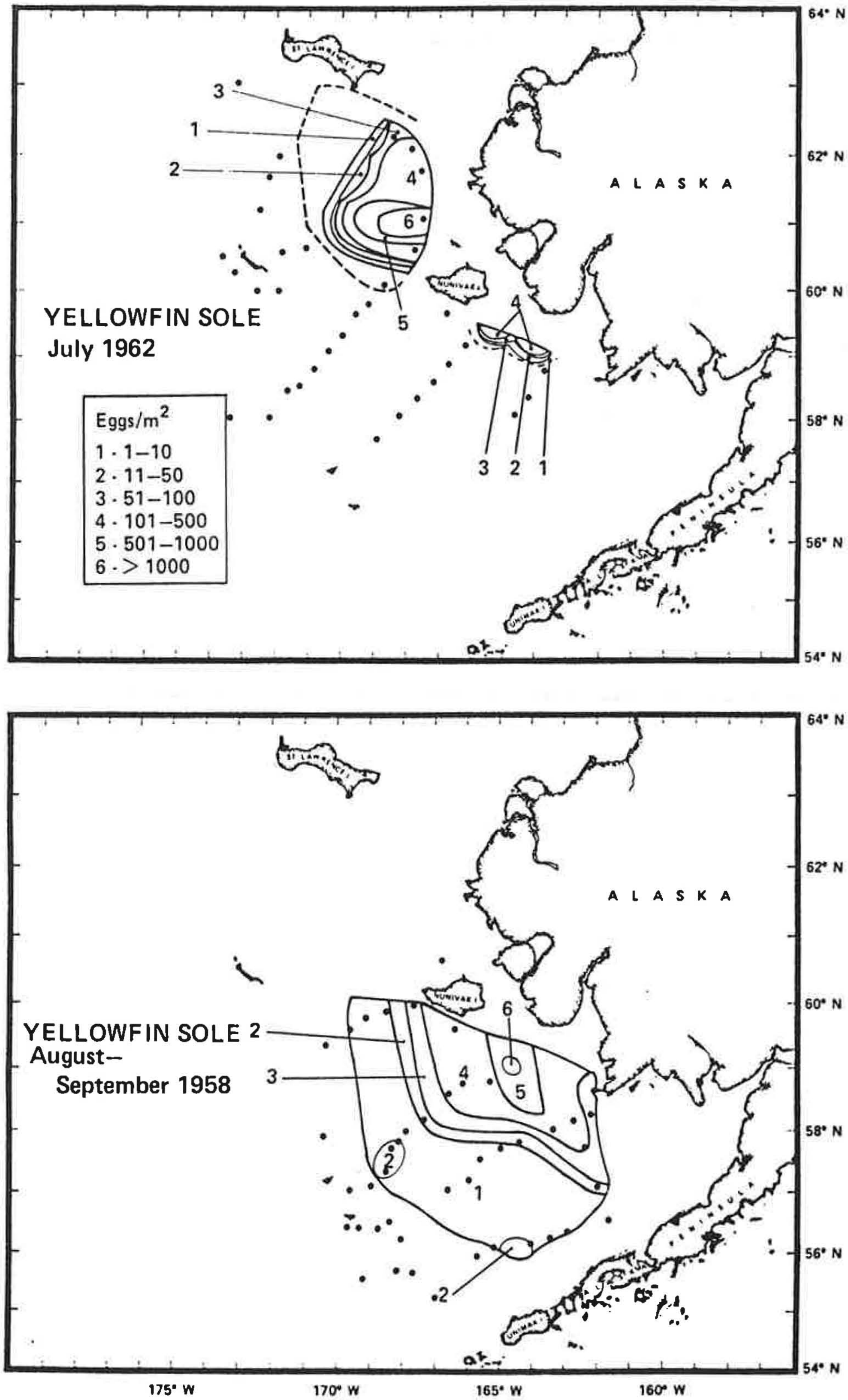


Figure 7. Continued

broad area of the eastern Bering Sea shelf from off Bristol Bay to Nunivak Island. Density of eggs was greatest south and southeast of Nunivak I. Depth of spawning ranged from 15-75 m (Bakkala 1981).

The eggs of yellowfin sole are pelagic, hatch in about 4 days at 13°C and larvae absorb their yolk sacs in about 3 day (Pertseva-Ostroumova 1961). The distribution of yolk-sac larvae is presumed to be similar to that of the eggs.

Young Juveniles (3 yrs and younger)

The time elapsed from hatching to metamorphosis is not known, although partially metamorphosed yellowfin sole have been taken in plankton hauls. Juvenile fish larger than this size are presumed to have begun a bottom existence even though metamorphosis may not be completed. Although there are no quantitative estimates of their relative abundance or numbers, 2 and 3 year old yellowfin sole have been taken in relatively small numbers in shallow waters of inner Bristol Bay (Fig. 8).

Prerecuits (4 & 5 yrs) and Adults

Yellowfin sole of sizes equivalent to ages 3-5 years have been found to be broadly distributed in inner Bristol Bay from off Port Moller to waters north of northern Bristol Bay (Fig. 8). At these ages, yellowfin sole begin to disperse to offshore waters. By 5 to 8 years of age which is roughly the age at sexual maturity, they join the adult population (Fig. 8). This group winters in the the deeper waters of the outer shelf and upper slope and migrates to the inner shelf in the spring with spawning occurring in midsummer to early autumn (Bakkala 1981).

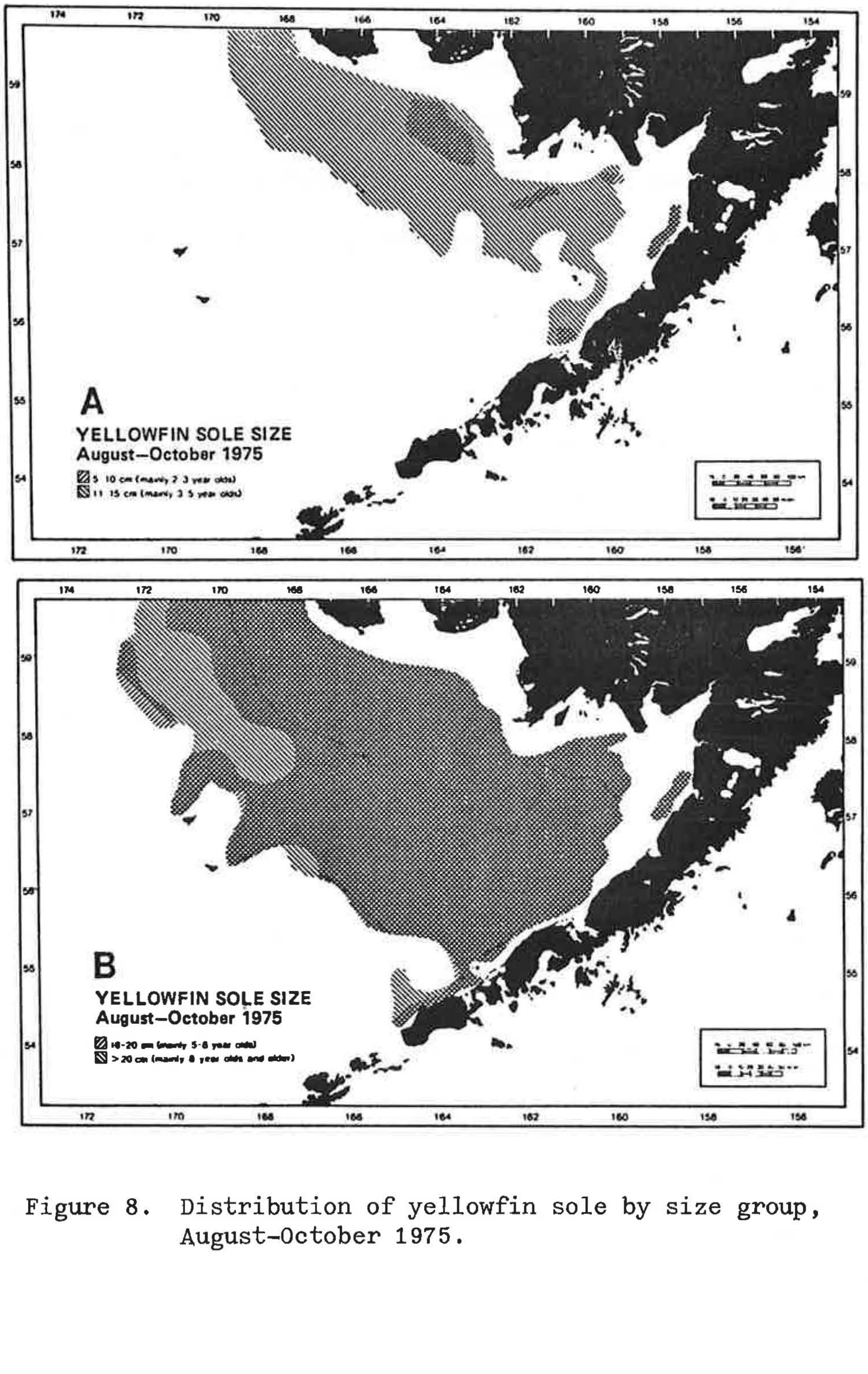


Figure 8. Distribution of yellowfin sole by size group, August-October 1975.

BIOLOGICAL CHARACTERISTICS

Sex Ratios

From data averaged over all areas of eastern Bering Sea, in summer hauls, females dominated males by 2.8 in 1958 to 1.1 in 1959. The sexes were more equally represented in 1961-63 and males were somewhat more numerous in all winter hauls (Fadeev 1970a). The ratio of females to males by regions and seasons is shown in Table 3. In Bristol Bay, the area of primary interest to these studies, and where fish are small, males were subordinate in numbers in the winter but dominant in spring. The ratio of females to males for All Areas, Subarea 1 and Subarea 4S are given in Table 4.

Table 4. Sex ratios (F/M) in All Subareas, Subarea 1 and Subarea 4S, 1981-83.

Year	All Areas	Subarea 1	Subarea 4S
1981	1.1	0.7	1.2
1982	1.0	0.6	1.1
1983	1.0	0.7	0.9

Source: Data on file in RACE Div., Northwest and Alaska Fisheries Center.

For these recent 3 years the sexes have been about equally represented in catches in the entire survey. Males have dominated the catch in Subarea 1 and females outnumber males slightly in Subarea 4S (excepting 1983).

The fecundity of yellowfin sole increases with size (Table 5).

Table 3. Ratio of yellowfin sole females and males by regions and seasons.

Region and time of catch	1958		1959-1961		1962-1964	
	Ratio of females to males	Average number of fish	Ratio of females to males	Average number of fish	Ratio of females to males	Average number of fish
Unimak bank	-	-	1.2	1464	0.7	1454
Slope west of the Pribilof Islands						
winter and spring. . . .	-	-	1.1	437	1.5	769
Bristol Bay						
winter	-	-	0.6	273	1.4	392
spring	-	-	0.8	693	0.6	398
North bank						
May.	-	-	1.4	783	-	-
February	-	-	-	-	3.1	200
Central shallows						
June	-	-	1.9	1098	1.3	295
July	2.8	905	0.5	388	2.9	323
September.	-	-	1.5	400	-	-

Source: Fadeev 1970a.

Table 5. Fecundity of yellowfin sole in the eastern Bering Sea (10^3).

Length (cm)	Fecundity ($X10^3$ eggs)
15 - 20	--
20 - 25	--
25 - 30	1293.7
30 - 35	1707.6
35 - 40	2413.4
40 - 45	3319.2
45 - 50	--

The relationship of fecundity to total length was estimated by Wakabayashi(1974) to be:

$$\text{Fecundity (in 1000 egggs)} = 0.0747565 \text{ (total length in cm)}^{2.86517}$$

An estimate of the potential number of eggs which might be produced by yellowfin sole in Subareas 1 and 4S was calculated from data on the female yellowfin sole population estimated from the 1983 NWAFC trawl survey (Table 6). From these data, about a third of the total female population occurred in both Subareas 1 and 4S during the period of the survey. This would indicate that about one third of the estimated potential number of 8.6×10^{15} eggs were produced in each of Subareas 1, 4S and 4N. As discussed earlier, however, there is little evidence from ichthyoplankton surveys that any spawning occurs in Subarea 1.

Eggs, Larvae and Juveniles

Fertilization of eggs is external. Fertilized eggs are pelagic with diameters ranging from 0.68 to 0.90 mm (Kashkina 1965).

Table 6. Estimated number of eggs produced by eastern Bering Sea yellowfin sole in 1983[1].

Length (cm)	Average fecundity $(X10^3)$[2]	Est. no. of females $(X10^6)$ Subareas 1	Est. no. of females $(X10^6)$ Subareas 4S	Est. no. of females $(X10^6)$ All subareas	Est. no. of eggs $(X10^9)$ Subareas 1	Est. no. of eggs $(X10^9)$ Subareas 4S	Est. no. of eggs $(X10^9)$ All subareas
<25	-	1,047.70	1,493.53	3,677.21			
25-30	1293.7	1,454.75	1,396.55	4,235.21	1,882,010	1,806,716	5,479,091
30-35	1707.6	466.36	428.13	1,659.29	796,356	731,075	2,833,404
35-40	2413.4	39.01	39.20	123.18	94,147	96,605	297,283
40-45	3319.2	0.00	0.48	2.06	-	1,593	6,837
Total		3,007.82	3,357.89	9,686.95	2,772,513	2,635,989	8,616,615

1/ Based on trawl survey population estimate (data on file at NWAFC, NMFS, NOAA).
2/ From Fadeev (1970).

Eggs of yellowfin sole from Peter the Great Bay were fertilized and observed under experimental conditions by Pertseva-Ostroumova (1961). Incubation time was about 4 days at an average water temperature of 13°C. The lower temperature threshhold for egg hatching was 4°C. Newly hatched larvae ranged in size from 2.25 to 2.80 mm (ave. = 2.55 mm). These larvae were transparent, had large yolk sacs and were capable of swimming. After about 3 days, larvae attained lengths of 3.29 to 3.84 mm, absorbed their yolk sacs and were actively feeding.

In the eastern Bering Sea, yellowfin sole eggs were encountered at surface temperatures of 6.4° to 11.4°C (Kashkina 1965, Musienko 1970). Prolarvae collected in Bering Sea ranged from 2.2 to 3.1 mm (Musienko 1963).

Details regarding the metamorphosis of yellowfin sole from pelagic larvae to bottom dwelling juveniles are not known. Partially metamorphosed juveniles 16.5 to 17.4 mm in length have been captured in plankton hauls. Juveniles larger than this (until about 5 cm in length) have not been captured in plankton hauls and are assumed to have begun a benthic existence in shallow, nearshore waters.

Juvenile yellowfin sole 5-10 cm in length (2 and 3 yrs) are first observed in research vessel bottom trawls in inshore waters (Fig. 8). They occur in low abundance off Kuskokwim Bay, in Bristol Bay and along the Alaska Peninsula. At lengths of 16-20 cm (5-8 yrs), they occupy the same waters as larger fish.

Growth

Von Bertalanffy growth curves (Fig. 9) and parameters (Table 7) from Bakkala (1981) show the similarity in growth of males and females. Mean

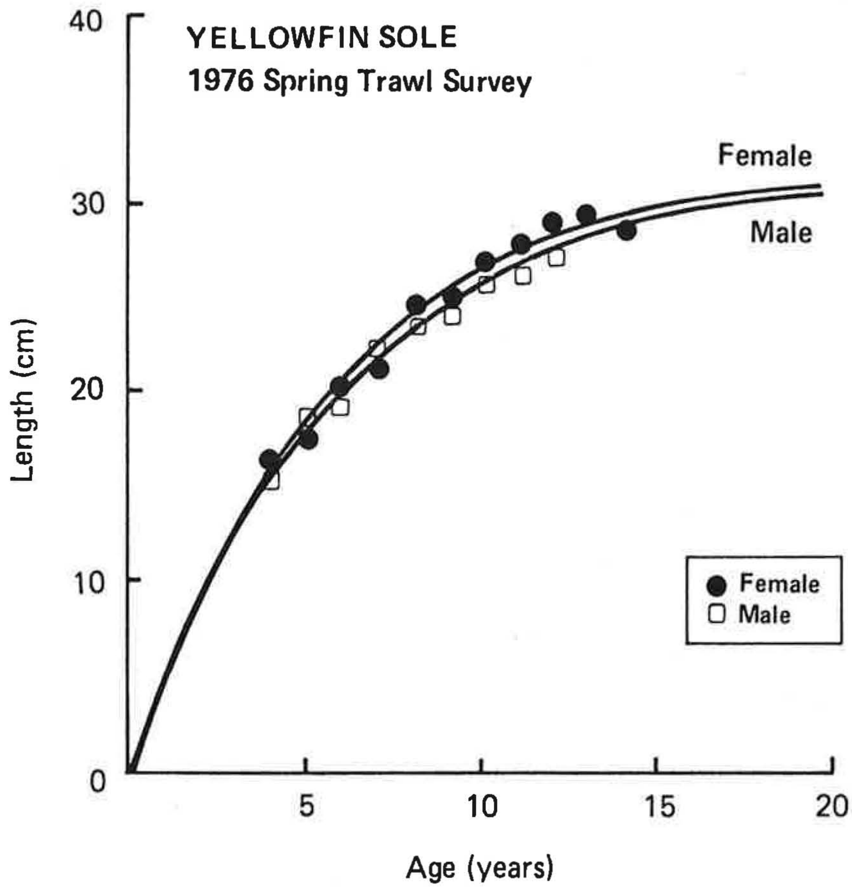


Figure 9. Von Bertalanffy growth curves for yellowfin sole taken during spring 1976 (Bakkala and Smith 1978).

Table 7. Parameters of the von Bertalanffy growth curve for yellowfin sole of the eastern Bering Sea (data of Pereyra et al. 1976, Bakkala and Smith 1978).

Sex	Year	Number of age readings	Age range	Length range (cm)	Standard error of curve fit	Parameter		
						L_∞	K	t_0
Male	1975	609	0,8-15	0,17-30	1.50	40.79	0.11	0.22
	1976	507	0,4-12	0,13-33	0.31	31.88	0.17	-0.02
Female	1975	707	0,8-15	0,19-39	0.80	40.28	0.11	-0.09
	1976	600	0,4-14	0,13-36	0.66	32.23	0.18	0.10

Source: Bakkala 1981.

lengths and weights of yellowfin sole sampled from catches of the NWAFC trawl surveys of 1973-78 were also given by Bakkala (Table 8). The annual growth increment in length decreases to less than 2.0 cm after age 6 and to less than 1.0 cm after age 13. Annual weight increment increases rapidly from ages 4 to 6, ranges from 22.4 to 34.9 gm from ages 7 through 13 and declines, thereafter. Laevastu and Livingston (1978) have shown growth rate to decline between ages 7 and 8 which they attributed to the diversion of energy for growth to the production of sex products.

The oldest yellowfin sole captured in eastern Bering Sea were a 17 year old male and a 19 year old female (Salveson and Alton 1976).

Size and Age at Maturity and Recruitment to the Fishery

Male yellowfin sole attain sexual maturity at a smaller size and earlier age than females. Males begin to mature at 11 cm and females at 19 cm (Wakabayashi 1974). About half the males at a length of about 13 cm and half the females at 26-27 cm are mature (Wakabayashi 1974). These lengths correspond to ages of less than 4 for males (Fadeev 1970a) and 9 years for females.

Yellowfin sole first enter the fishery at 13-14 cm which corresponds to ages 4 or 5. They are fully recruited to the fishery at age 7 (Laevastu and Favorite 1978) when the the biomass of the exploitable stock is at its maximum (Wakabayashi 1975).

Natural Mortality

Instantaneous natural mortality of yellowfin sole 4 years and older was estimated by Fadeev (1970) as 0.29 (25% annual mortality rate) for the population in 1958, prior to the intensive exploitation of the stock(s).

Table 8. Six-year means of observed lengths and calculated weights at age for yellowfin sole of the eastern Bering Sea from NWAFC survey data of 1973-78.

Age	Mean length (cm)	Annual increment (cm)	Mean weight (g)	Annual increment (g)
3	12.0		19.5	
4	14.1	2.1	32.3	12.8
5	16.6	2.5	51.7	19.4
6	19.3	2.7	81.5	29.8
7	21.0	1.7	103.9	22.4
8	22.4	1.4	126.4	22.5
9	23.9	1.5	154.2	27.8
10	25.2	1.3	181.0	26.8
11	26.4	1.2	206.3	25.3
12	27.4	1.0	230.3	24.0
13	28.7	1.3	265.2	34.9
14	29.1	0.4	278.3	13.1
15	29.4	0.3	286.6	8.3

Source: Bakkala 1981.

Subsequently, Wakabayashi (1975) estimated instantaneous natural mortality for fish 4 years and older as 0.25 which corresponds to an annual mortality rate of about 22 %. If these estimates are reliable, the decrease in natural mortality may be a consequence of the intense fishery for yellowfin sole since 1958-59 (Pereyra et al. 1976).

Predators, Prey and Associated Species

Predators

Novikov (1964) found the distribution of Pacific halibut (*Hippoglossus stenolepis*) closely associated with yellowfin sole in spring and autumn. Yellowfin sole occurred in 33 to 70 percent of the halibut stomachs and constituted 30 to 55 percent of the weight of the stomach contents in fish examined by Novikov. Although there are no doubt other predators on yellowfin sole, particularly during the egg, larval and juvenile stages, they have not been documented (Bakkala 1981).

Prey

Yellowfin sole feed on a broad range of organisms from the benthos (bivalves and worms), in the water column (amphipods, euphausids and mysids) to the pelagia (smelt and capelin). About 50 different taxa were found in the stomachs of yellowfin sole by Skalkin (1963).

Feeding generally stops in winter although some instances of intense winter feeding have been recorded (Fadeev 1970a). Feeding is more intense as they migrate onto the central shelf.

Primary food of yellowfin sole are bivalves, echurid and polychaete worms and amphipods (Table 9).

Table 9. Stomach contents (in grams) by size group of yellowfin sole collected in the eastern Bering Sea in 1970 (Wakabayashi 1974).

Food	Size group			Total
	101-200 mm	201-300 mm	>300 mm	
Gadidae	-	60.3	26.8	87.1
Osmeridae	-	12.7	-	12.7
Ammodytidae	-	12.5	56.4	68.9
Other Pisces	-	36.4	18.4	54.8
Amphipoda	22.6	180.2	45.3	248.1
Euphausiacea	1.6	61.7	38.1	101.4
Macrura	3.7	22.8	24.1	50.6
Mysidacea	0.4	-	0.2	0.6
Brachyura	-	39.4	7.8	47.2
Anomura	1.7	51.5	18.3	71.5
Crangonidae	0.3	10.0	0.8	11.1
Polychaeta	31.4	360.9	63.1	455.4
Cephalopoda	-	-	1.7	1.7
Bivalvia	6.5	403.6	553.1	963.2
Gastropoda	-	1.3	10.4	11.7
Ophiuroidea	2.3	36.1	1.4	39.8
Scutellidae	6.4	33.2	17.2	56.8
Echiurida	9.2	245.4	398.4	653.0
Ascidia	0.2	13.7	4.2	18.1
Holothuroidea	-	34.8	3.5	38.3
Sand[1]	7.2	91.9	13.7	112.8
Others	12.8	108.2	163.6	284.6
Indistinct	12.9	64.2	27.7	104.8
Total	119.2	1,878.3	1,496.7	3,494.2
No. of stomachs	275	1,708	374	2,357

[1]Possibly tubes of Polychaeta.

Associated Species

Species closely associated with yellowfin sole are shown in Table 10. Alaska plaice (Pleuronectes quadrituberculatus) is the only species which showed affinity to yellowfin sole in all studies. Pacific halibut, which were indicated to be closely associated with yellowfin sole by Novikov (1964), was not mentioned by any of the authors in Table 10.

ABUNDANCE BY YEAR, SUBAREAS, AGE AND YEAR CLASSES

Annual Biomass Estimates

The biomass of the exploitable stock (6 yrs and older) of eastern Bering Sea yellowfin sole prior to the intensive post World War II trawl fisheries of the late 1950s and early 1960s was estimated to be 1.3 to 2.0 million t (Alverson et al. 1964, Wakabayashi 1975). The stock declined in abundance, presumably as a consequence of excessive removals in 1960-62 and fluctuated at relatively low levels of abundance until recently.

Biomass of eastern Bering Sea yellowfin sole in 1975 through 1984 was estimated from annual trawl surveys of the NWAFC (discussed previously and given in Table 1). The subareal distribution of yellowfin for 1975-83 was also discussed in the same section and shown in Table 2.

The age composition of the yellowfin sole as estimated from sampling the catches of the annual trawl surveys and commercial landings is given in Fig. 10. The strong year classes of 1966-70 have dominated the catches of both the research vessels and commercial fisheries. These year classes have ranged from 13 to 17 years in the 1983 commercial catch and constituted 45% of the commercial catch of 1982 (Bakkala and Wespestad 1984a). The 1973-77 year classes were well represented in the 1982 trawl survey catches. These year

Table 10. Species showing close association with yellowfin sole as indicated by recurrent group analysis.

Authority	Season	Years of study	Species showing affinity with yellowfin sole
Kihara (1976)	Summer	1966-71, 1974	Alaska plaice (*Pleuronectes quadrituberculatus*) Rock sole (*Lepidopsetta bilineata*) Flathead sole (*Hippoglossoides elassodon*) Pacific cod (*Gadus macrocephalus*) Walley pollock (*Theragra chalcogramma*) Cottidae Agonidae
Mito (1977)	Winter	1972, 1974-75	Alaska plaice (*P. quadrituberculatus*) Rock sole (*L. bilineata*) Yellow Irish Lord (*Hemilepidotus jordani*) Plain sculpin (*Myoxocephalus jaok*)
Pereyra et al. (1976)	Summer	1975	Alaska plaice (*P. quadrituberculatus*) Pacific herring (*Clupea pallasi*)
Bakkala and Smith (1978)	Spring	1976	Alaska plaice (*P. quadrituberculatus*) Pacific herring (*C. pallasi*) Sturgeon poacher (*Podothecus acipenserinus*) Capelin (*Mallotus villosus*)

Source: Bakkala 1981.

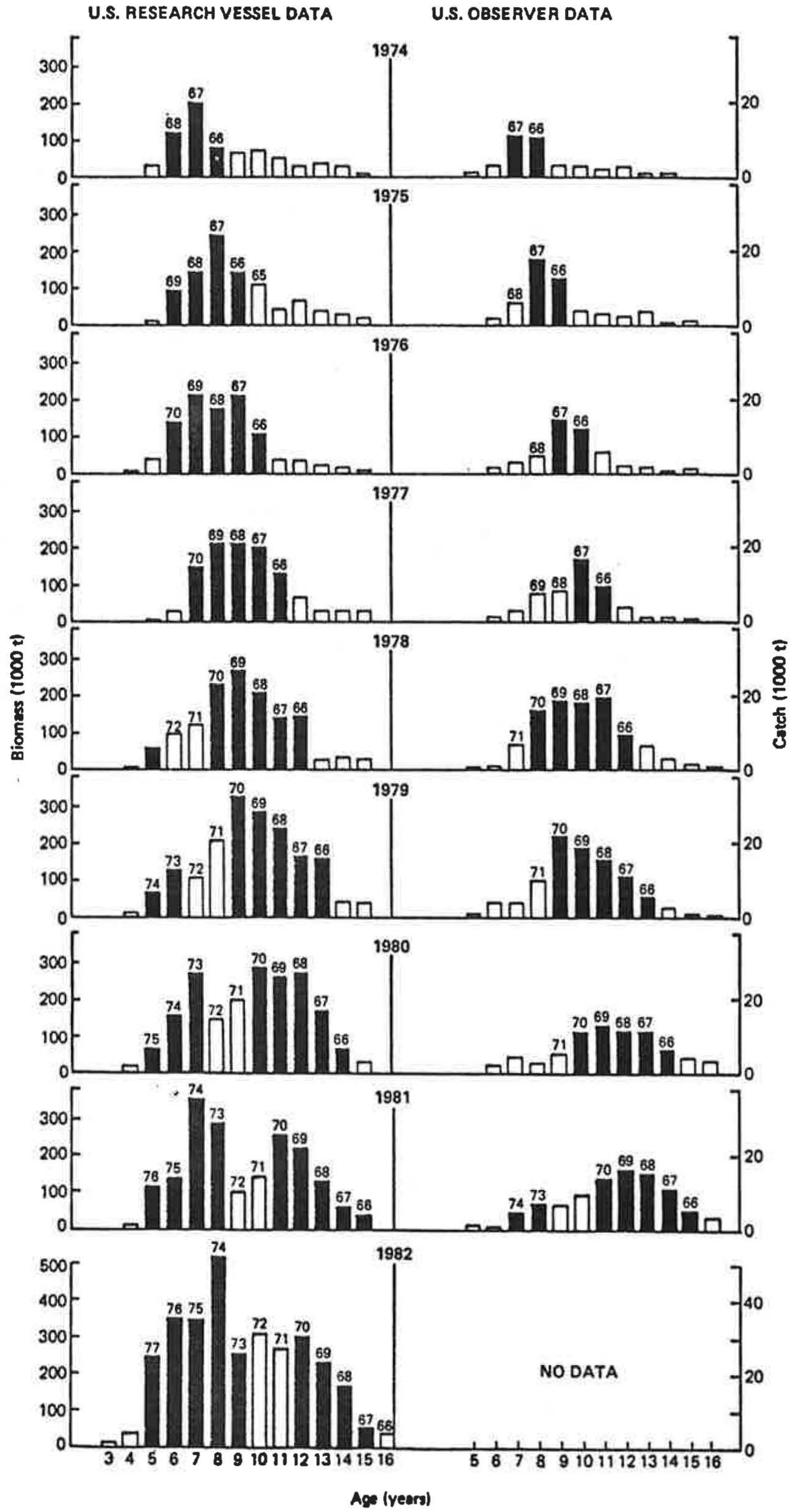


Figure 10. Age composition of yellowfin sole of the eastern Bering Sea as shown by data from trawl surveys of the Northwest and Alaska Fisheries Center and by U.S. observer data from the commercial fishery.

classes appear to be even more abundant than the 1966-70 year classes and contributed substantially to the increase in population abundance in 1981-83.

There is evidence that the strong year classes of 1966-70 were associated with warm bottom temperatures (2.5°-4°C) whereas the weaker year classes were associated with cooler bottom temperatures (Bakkala 1981).

Population Estimates from Cohort Analyses

Estimates of the eastern Bering Sea yellowfin sole in numbers and weight are given in Tables 11 and 12, respectively. According to these analyses, yellowfin sole were most numerous in 1977 due to the large contributions of the 1974-77 year classes (Table 11). Total estimated biomass was lowest in 1970 and highest in 1981, the last year included in the analysis (Table 12). Biomass of the exploitable population (7 years and older) was also largest in 1981.

Relative Abundance (Catch per Unit Effort)

The catch per unit effort (CPUE) of Japanese pair trawlers and NWAFC trawl surveys is shown in Fig. 11. The CPUE of pair trawlers in the September-December fishery peaked at over 50 t/1000 hp-hrs in 1980 and dropped rather sharply to less than 20 t/1000 hp-hrs in 1983. CPUE in the July-October fishery peaked in 1979 at about 30 t/1000 hp-hrs and declined to about 15 t/1000 hp-hrs in 1983.

The CPUE of the NWAFC trawl survey increased to about 80 kg/ha in 1983 with a modest decline in 1984. There has been no evaluation of the inconsistency in the two measures of relative abundance. Bakkala and Wespestad (1984b) do not believe the CPUE of the pair trawlers accurately represent the abundance of yellowfin sole. These authors have, however,

Table 11. Estimated numbers of yellowfin sole (billions of fish) in the eastern Bering Sea, 1959-81, based on cohort analysis.

Age (yr)	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
1	2.040	1.620	0.931	1.407	1.108	1.047	1.320	1.519	2.394	2.779	3.693	5.662
2	2.308	1.810	1.437	0.826	1.248	0.983	0.928	1.171	1.347	2.123	2.465	3.275
3	2.826	2.047	1.605	1.275	0.733	1.107	0.871	0.823	1.039	1.195	1.883	2.186
4	1.029	2.506	1.815	1.424	1.130	0.650	0.976	0.773	0.730	0.921	1.060	1.670
5	1.382	0.912	2.223	1.599	1.263	1.003	0.565	0.865	0.685	0.648	0.817	0.940
6	1.856	1.226	0.809	1.947	1.406	1.119	0.871	0.501	0.767	0.608	0.574	0.724
7	1.865	1.640	1.063	0.696	1.596	1.223	0.945	0.771	0.444	0.668	0.538	0.501
8	1.565	1.632	1.342	0.793	0.376	1.383	0.959	0.832	0.670	0.358	0.565	0.471
9	1.234	1.336	1.282	0.792	0.363	0.273	1.006	0.809	0.697	0.501	0.289	0.410
10	0.923	0.989	0.950	0.579	0.366	0.233	0.190	0.809	0.624	0.480	0.379	0.166
11	0.625	0.670	0.588	0.324	0.256	0.241	0.148	0.147	0.570	0.401	0.353	0.172
12	0.377	0.419	0.320	0.174	0.114	0.168	0.151	0.104	0.097	0.308	0.283	0.160
13	0.213	0.245	0.165	0.098	0.045	0.063	0.105	0.104	0.058	0.059	0.210	0.111
14	0.118	0.138	0.084	0.059	0.021	0.016	0.042	0.074	0.056	0.028	0.034	0.113
15	0.063	0.079	0.044	0.036	0.013	0.004	0.009	0.031	0.045	0.021	0.014	0.006
16	0.038	0.042	0.025	0.022	0.008	0.002	0.002	0.006	0.022	0.021	0.009	0.004
17	0.019	0.026	0.012	0.014	0.005	0.000	0.002	0.002	0.003	0.012	0.012	0.000
	18.482	17.337	14.695	12.064	10.051	9.513	9.089	9.343	10.250	11.130	13.177	16.571

Age (yr)	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	6.117	3.542	2.390	5.964	6.791	5.461	7.389	2.674	0.000	0.000	0.000
2	5.022	5.425	3.141	2.120	5.289	6.023	4.843	6.554	2.372	0.000	0.000
3	2.905	4.454	4.812	2.786	1.880	4.691	5.342	4.196	5.813	2.104	0.000
4	1.939	2.576	3.950	4.268	2.471	1.668	4.161	4.738	3.810	5.155	1.866
5	1.481	1.719	2.285	3.504	3.785	2.192	1.479	3.690	4.201	3.379	4.572
6	0.833	1.313	1.521	2.024	3.107	3.356	1.940	1.308	3.261	3.720	2.993
7	0.629	0.715	1.134	1.336	1.787	2.753	2.963	1.711	1.147	2.870	3.283
8	0.380	0.402	0.572	0.921	1.157	1.562	2.418	2.610	1.455	0.998	2.514
9	0.323	0.240	0.336	0.425	0.751	0.986	1.358	2.105	2.191	1.244	0.867
10	0.254	0.190	0.177	0.242	0.332	0.560	0.799	1.171	1.759	1.859	1.064
11	0.116	0.127	0.145	0.120	0.195	0.215	0.444	0.642	0.946	1.482	1.588
12	0.101	0.077	0.092	0.091	0.086	0.141	0.167	0.349	0.472	0.782	1.258
13	0.071	0.044	0.056	0.046	0.069	0.064	0.118	0.133	0.273	0.376	0.648
14	0.055	0.021	0.029	0.022	0.030	0.046	0.049	0.100	0.098	0.220	0.293
15	0.050	0.002	0.012	0.013	0.012	0.016	0.039	0.041	0.077	0.080	0.174
16	0.002	0.007	0.002	0.004	0.006	0.006	0.010	0.033	0.032	0.064	0.064
17	0.000	0.000	0.006	0.001	0.002	0.002	0.004	0.008	0.027	0.027	0.048
	20.276	20.856	20.659	23.885	27.751	29.743	33.524	32.163	27.932	24.359	21.232

Source: Bakkala and Wespestad 1984.

Table 12. Estimated biomass (in 1,000 t) of yellowfin sole in the eastern Bering Sea by age (with totals for all ages and ages 7 and above), 1959-81, based on cohort analysis.

Age (yr)	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
1	10	8	5	7	6	5	7	8	12	14	18	28
2	21	16	13	7	11	9	8	11	12	19	22	29
3	51	37	29	23	13	20	16	15	19	22	34	39
4	34	83	60	47	37	21	32	26	24	30	35	55
5	77	51	124	90	71	56	32	48	38	36	46	53
6	163	108	71	171	124	98	77	44	68	53	51	64
7	209	184	119	78	179	137	106	86	50	75	60	56
8	211	220	181	107	51	187	129	112	90	48	76	64
9	196	212	204	126	58	43	160	129	111	80	46	65
10	171	183	176	107	68	43	35	150	115	89	70	31
11	131	141	124	68	54	51	31	31	120	84	74	36
12	88	97	74	40	26	39	35	24	23	71	66	37
13	56	65	43	26	12	17	28	28	15	16	55	29
14	33	39	24	16	6	5	12	21	16	8	9	32
15	19	23	13	11	4	1	3	9	13	6	4	2
16	13	15	9	8	3	1	1	2	8	8	3	1
17	7	10	4	5	2	0	1	1	1	4	5	0
	1491	1492	1273	938	723	733	711	744	735	664	675	622
7+	1135	1189	971	592	461	523	540	593	562	489	469	353

Age (yr)	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	31	18	12	30	34	27	37	13	0	0	0
2	45	49	28	19	48	54	44	59	21	0	0
3	52	80	87	50	34	84	96	77	105	38	0
4	64	85	130	141	82	55	137	156	126	170	62
5	83	96	128	196	212	123	83	207	235	189	256
6	73	116	134	178	273	295	171	115	287	327	263
7	70	80	127	150	200	308	332	192	128	321	368
8	51	54	77	124	156	211	326	352	196	135	339
9	51	38	53	68	119	157	216	335	348	198	138
10	47	35	33	45	61	104	148	217	326	344	197
11	24	27	30	25	41	45	93	135	199	311	334
12	24	18	21	21	20	33	39	81	109	181	292
13	19	12	15	12	18	17	31	35	72	99	171
14	15	6	8	6	8	13	14	28	27	62	82
15	15	1	3	4	4	5	12	12	23	24	51
16	1	3	1	1	2	2	4	12	11	23	23
17	0	0	2	0	1	1	2	3	10	10	17
	666	717	890	1071	1314	1534	1783	2029	2224	2432	2593
	317	273	371	456	631	895	1216	1401	1450	1708	2012

Source: Bakkala and Wespestad 1984.

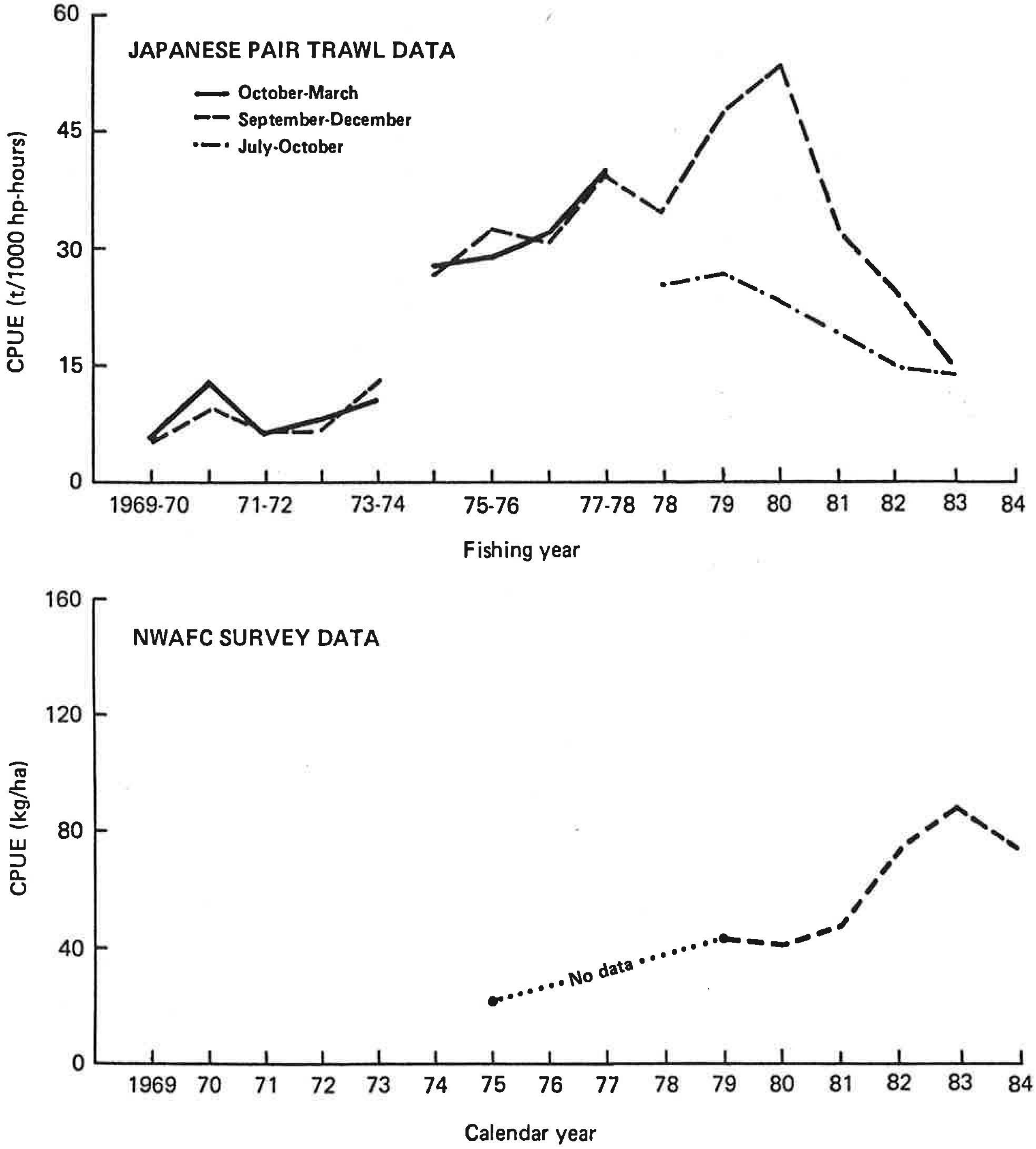


Figure 11. Relative abundance (CPUE) for Japanese pair trawlers and NWAFC trawl surveys.

presented evidence which suggests that the apparent increase in abundance reflected by the NWAFC trawl surveys after 1981 may be attributable to the better bottom tending qualities of the sampling gear (Bakkala and Wespestad 1984a and 1984b). This probably resulted in better estimates of the population since 1981, however, the siginificance of the abundance trend is questionable due to underestimation of the yellowfin sole population prior to 1982.

THE COMMERCIAL FISHERY

Yellowfin sole were first taken by Japanese trawlers which fished for flounders in the eastern Bering Sea beginning in 1929 (Kibesaki 1965). From 1933 through 1937, one factory ship (fish and meal) and accompanying trawlers were involved in a full scale reduction fishery. Japanese trawling in eastern Bering Sea was interrupted during World War II.

In 1954, the trawl fishery in eastern Bering Sea was resumed when Japanese trawlers caught about 12,500 t of yellowfin sole (Table 13). Until 1958 the Japanese fishery occurred on the eastern Bering Sea shelf during a short period during the summer and the fish were frozen for human consumption.

In 1958 the fishery was intensified and the catch reduced to meal as well as frozen for food. The Soviet Union also commenced fishing yellowfin sole in this year.

From 1960 through 1962, the combined catch of Japan and the Soviet Union exceeded 420,000 t (max. > 550,000 t). In 1963, however, the total catch of yellowfin sole dropped to 85,810 t (about 20% of the catch in 1962). Since then, total annual catches have been between 167,000 t (1969) and 42,000 t

Table 13. Annual catches of yellowfin sole in the eastern Bering Sea (east of long. 180° and north of lat. 54°N) in metric tons.[a]

Year	Japan	USSR	ROK[b]	Others	Joint venture	Total
1954	12,562					12,562
1955	14,690					14,690
1956	24,697					24,697
1957	24,145					24,145
1958	39,153	5,000				44,153
1959	123,121	62,200				185,321
1960	360,103	96,000				456,103
1961	399,542	154,200				553,742
1962	281,103	139,600				420,703
1963	20,504	65,306				85,810
1964	48,880	62,297				111,177
1965	26,039	27,771				53,810
1966	45,423	56,930				102,353
1967	60,429	101,799				162,228
1968	40,834	43,355	-			84,189
1969	81,449	85,685	-			167,134
1970	59,851	73,228	-			133,079
1971	82,179	78,220	-			160,399
1972	34,846	13,010	-			47,856
1973	75,724	2,516	-			78,240
1974	37,947	4,288	-			42,235
1975	59,715	4,975	-			64,690
1976	52,688	2,908	625			56,201
1977	58,090	283	-			58,373
1978	62,064	76,300	69			138,433
1979	56,824	40,271	1,919	3		99,017
1980	61,295	6	16,198	269	9,623	87,391
1981	63,961		17,179	115	16,046	97,301
1982	68,009		10,277	45	17,381	95,712
1983	64,824		21,050		22,511	108,385

[a]Source of catch data: 1954-76, Wakabayashi and Bakkala 1978; 1977-79, data submitted to the United States by fishing nations; 1980-82, French et al. 1981, 1982; Nelson et al. 1983, 1984.
[b]Republic of Korea.

(1974). Except for a token catch in 1980, the Soviet fishery for yellowfin sole was essentially terminated in 1979.

The Republic of Korea (R.O.K.) began fishing for yellowfin sole in the eastern Bering Sea in 1976, however, catches were very modest through 1979 and have remained at less than 22,000 t, thereafter.

The combined annual catches of foreign countries other than the three mentioned above have ranged from 3 to 269 t.

United States fishing vessels involved in joint-ventures with foreign fishing companies have fished yellowfin sole since 1980. Annual landings by these vessels has increased from 9600 t in 1980 to 22,500 t in 1983.

Monthly distribution of Catch

In the recent six years 1979-84, most of the yellowfin sole catches were made after June (Table 14). More than 75% of the annual catch in all three years was taken in the last two quarters of the calendar year (Table 14).

Fishery Management

Prior to enactment of the Fishery Management and Conservation Act of 1976 (FCMA), the domestic and foreign fisheries for groundfish in the eastern Bering Sea were subject to regulations which included gear restrictions, licensing of vessels and gear, time-area closures, requirements for reporting catches or landings and quotas on the catch for some species in some years. The Fishery Management Plan (FMP) for the Groundfish Fishery in the Bering Sea/Aleutian Islands Area (October 1983) prepared by the North Pacific Fisheries Management Council (NPFMC) contains a detailed summary of historical regulations. The FMP also describes the rationale and management of current foreign and domestic fisheries in the 3 to 200 mile economic zone.

Table 14. Yellowfin sole catch by month, 1979-84

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Q-1	Q-2	Q-3	Q-4	Total
								Foreign reported catch									
1979	3152	3344	1412	2295	282	1341	10686	15293	20141	22265	10217	1889	7908	3918	46120	34370	92316
1980	3699	3567	3250	2090	2005	3102	13801	11007	11826	10461	4736	4843	10516	7197	36633	20039	74385
1981	1819	2506	2943	3923	2548	4333	8597	9374	11248	10472	9970	9364	7268	10805	29219	29806	77097
1982	3795	1504	2947	1708	1676	2933	8727	8551	9540	10313	12113	7887	8246	6316	26819	30313	71695
1983	718	1451	2816	3371	3561	2974	10360	13366	10328	10148	9107	15139	4986	9906	34054	34394	83339
1984	783	1134	3353	7927	4887	2269	11854	21476	13339	21389	15589	15342	5270	15083	46669	52320	119342
1985	8530	2315	6192	4643													
NOTE: 1984 and 1985 are from "Observer" estimate file.																	
							Joint-venture: best blend estimate of catch										
1979	No observer data file																
1980	+	0	2	12	254	2084	2868	2546	1857	0	0	0	2	2350	2019	0	4371
1981	0	0	0	+	2702	1546	4153	3679	3966	+	0	0	0	4248	11798	+	16046
1982	0	0	6	1098	1431	7077	4073	2791	904	1	+	0	6	9606	7768	1	17381
1983	0	+	1893	1742	4353	6153	3566	4401	338	0	0	0	1893	12252	8304	0	22449
1984	+	12	107	2289	6426	8895	4168	5282	5199	338	0	0	119	17610	14648	338	32715
1985	+	21	195	4885													
				Bering Sea Area I - Catch of yellowfin sole (Total directed and joint-venture)													
1979	3152	3344	1412	2295	282	1341	10686	15293	20141	22265	10217	1889	7908	3918	46120	34370	92316
1980	3699	3567	3252	2102	2259	5186	16669	13553	13683	10461	4736	4843	10518	9547	38652	20039	78756
1981	1819	2506	2943	3923	5250	5879	12750	13053	15214	10472	9970	9364	7268	15053	41017	29806	93143
1982	3795	1504	2953	2806	3107	10010	12800	11342	10444	10314	12113	7887	8252	15922	34587	30314	89076
1983	718	1451	4709	5113	7914	9127	13926	17767	10666	10148	9107	15139	6879	22158	42358	34394	105788
1984	783	1146	3460	10216	11313	11164	16022	26758	18538	21727	15589	15342	5389	32693	61317	52658	152057
1985	8530	2336	6387	9528													

Source: Data on file, Observer Program, NWAFC, Seattle, WA.

Priority objectives of the FMP for the management of groundfish fisheries of eastern Bering Sea are to:

1. Provide for the rational and optimal use, in a biological and socio-economic sense, of the region's fisheries resources as a whole;

2. Minimize the impact of groundfish fisheries on prohibited species (including halibut, herring salmonids, shrimps, scallops, snails, king crab, Tanner crab, Dungeness crab, corals surf clams, horsehair crab and lyre crab) and continue the rebuilding of the Pacific halibut resources;

3. Provide for the opportunity and orderly development of domestic groundfish fisheries, consistent with 1. and 2. above and;

4. Provide for foreign participation in the groundfish fishery, consistent with all three objectives above, to take the portion of the total allowable catch (TAC) not utilized by domestic fishermen.

The following management actions pertain specifically to the yellowfin sole fishery of the eastern Bering Sea.

Total Allowable Catch (TAC)

The TAC of yellowfin sole in the Bering Sea/Aleutian region and its allocation to foreign and domestic fisheries under the FCMA is shown in Table 15. Except in 1978 (when the catch exceeded TAC by 12,000 t), annual catches have been less than the TAC. Most of the TAC has been allocated to foreign fisheries, although catches have been less than allocations for all years except 1978. Until 1980, the total allocation was to foreign fisheries. Since 1980, domestic production and the joint venture fisheries have taken a comparatively small but increasing proportion of the TAC.

Table 15. Total allowable catch of yellowfin sole and its allocation under the FCMA.

Year	Total Allowable Catch (OY)	Total Catch	U.S. Allocation DAP	U.S. Allocation JVP	J-V Catch	Foreign Fisheries Allocation	Foreign Catch	Reserves
1977	106,000	58,373	0	0	-	102,900	58,373	3,100
1978	126,000	138,433	0	0	-	126,000	138,433	0
1979	106,000	99,017	0	0	-	106,000	99,017	0
1980	117,000	87,391	100	15,614	9,623	101,286	77,768	0
1981	117,000	97,301	200	17,000	16,046	99,800	81,255	0
1982	117,000	95,712	1,200	18,000	17,381	96,400	78,331	1,400 (non-allocated)
1983		108,385			22,511		85,874	

Source: Data on file, NWAFC.

Annual catches in the years 1981-83 has been less than both the "most likely" maximum sustainable yield (MSY) of 150,000 to 175,000 t and the equilibrium yield of 310,000 t for the 1984 standing stock suggested by Bakkala and Wespestad (1984).

Fishing is terminated when the allocation of target species is taken or when the allocation of bycatch species is exceeded.

Time and Area Restrictions

Time and area closures for trawl fisheries and, therefore, to yellowfin sole fishing are shown in Fig. 12. A large sector of the North Aleutian Shelf has been designated as the Bristol Bay Pot Sanctuary which is closed year-round to foreign trawl fisheries. The waters north of the eastern Aleutians, eastward of 170°W is closed to foreign trawling from December 1 to May 31 for the protection of juvenile halibut.

STATUS OF THE EASTERN BERING SEA YELLOWFIN SOLE STOCK

The available evidence indicates that the eastern Bering Sea yellowfin sole stock is presently in excellent condition. The average total biomass for 1981-83 of 3.1 million t is the highest of recorded biomass estimates. The present population has an exploitable biomass which is equal to and perhaps greater than the exploitable biomass of the virgin stock. Furthermore, the age structure of the population indicates that yields may remain stable at high levels for at least the next few years. The strong year classes of 1966-70 still contribute substantially to the catch and a new series of year classes (1973-77) which may be even stronger are now entering the fishery. Catches in recent years have been less than TAC (117,000 t in 1982) and

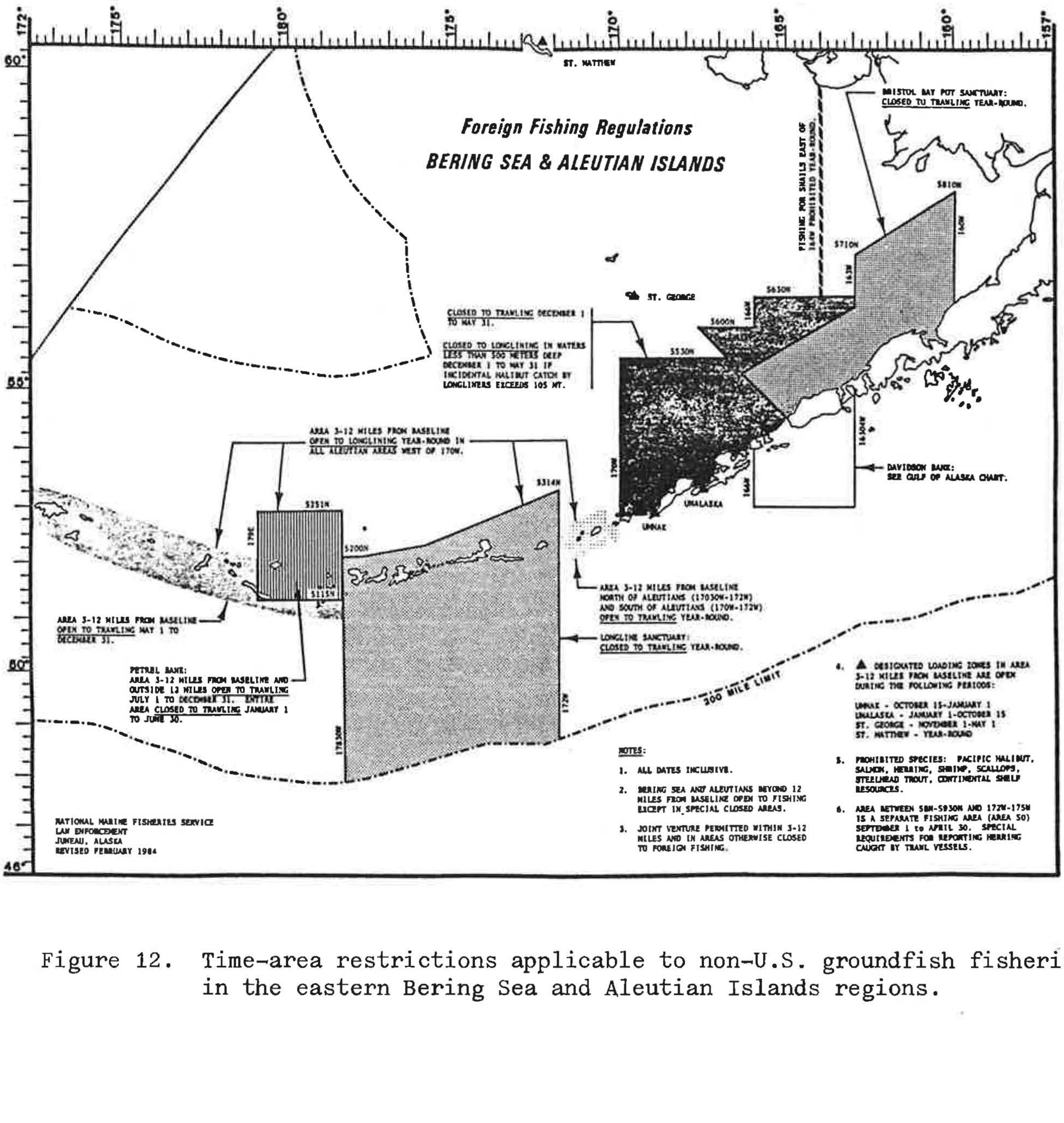


Figure 12. Time-area restrictions applicable to non-U.S. groundfish fisheries in the eastern Bering Sea and Aleutian Islands regions.

considerably below estimated MSY (150,000-175,000 t) and present equilibrium yield of 310,000 t.

Forecasts of yellowfin sole abundance in the eastern Bering Sea are given in Table 16. The assumed catch of 214,500 t is considerably greater than the actual catch of recent years and both assumed recruitment levels are less than the estimated average recruitment of 2.1 billion fish for the 1973-80 period (Bakkala and Wespestad 1984a).

SENSITIVITY OF FLATFISH TO PETROLEUM AND DISTILLATES

The effects of oil on fish have been observed after some past oil spills and studied in the laboratory, however, I found no studies relating specifically to yellowfin sole. There have, however, been studies on other flatfish, the results of which may be applicable to assessing the impact of oil on yellowfin sole.

As a general rule, eggs and larvae of both fish and shellfish have been found to be more sensitive to petroleum hydrocarbons than adults.

Sensitivity of Eggs and Larvae

The 1978 year class of flatfish originating in the year of the spill of the Amoco Cadiz (March 16-17, 1978) was totally absent in subsequent years (Desaunay 1979, Conan & Friha 1979, Laubier 1980). Although there was no direct supporting evidence, this was indicative of total mortality to eggs and larvae as a consequence of oil contamination from the spill of the Amoco Cadiz.

Malins et al. (1981) exposed flatfish eggs to saltwater soluble fraction (SWSF) of slightly weathered Prudhoe Bay crude oil (PBCO) with renewal of SWSF

Table 16. Forecast of yellowfin sole abundance in the eastern Bering Sea, 1982-89, with constant catches of 214,500 t, natural mortality = 0.12, assuming lower (upper table) and higher recruitment estimates for 1959-81. Projections are made for ages 7-17 (ages fully recruited to research vessel catches) and ages 8-17 (principal ages in commercial trawl catches).

	Estimated biomass						
Year	Ages 7-17 (1,000 t)	Ages 8-17 (1,000 t)	Recruits (millions)	Catch (1,000 t)	E[a]	F[b]	Mean individual fish weight (kg)
1981	2,012.1	1,644.5	3,282.0	97.3	0.059	0.060	0.193
1982	2,048.8	1,928.5	1,074.0	214.5	0.111	0.120	0.193
1983	1,944.5	1,824.3	1,074.0	214.5	0.118	0.128	0.207
1984	1,808.7	1,688.4	1,074.0	214.5	0.127	0.139	0.217
1985	1,658.4	1,538.1	1,074.0	214.5	0.139	0.154	0.223
1986	1,478.5	1,358.2	1,074.0	214.5	0.158	0.177	0.222
1987	1,258.6	1,138.3	1,074.0	214.5	0.188	0.216	0.213
1988	1,048.2	927.9	1,074.0	214.5	0.231	0.274	0.203
1989	906.3	786.0	1,074.0	214.5	0.273	0.334	0.203
1981	2,012.1	1,644.5	3,282.0	97.3	0.059	0.060	0.193
1982	2,085.6	1,928.5	1,403.0	214.5	0.111	0.120	0.192
1983	2,020.8	1,863.6	1,403.0	214.5	0.115	0.125	0.205
1984	1,925.9	1,768.8	1,403.0	214.5	0.121	0.132	0.212
1985	1,817.4	1,660.2	1,403.0	214.5	0.129	0.142	0.217
1986	1,677.3	1,520.1	1,403.0	214.5	0.141	0.156	0.216
1987	1,494.0	1,336.8	1,403.0	214.5	0.160	0.180	0.208
1988	1,316.2	1,159.0	1,403.0	214.5	0.185	0.212	0.200
1989	1,208.2	1,051.1	1,403.0	214.5	0.204	0.237	0.202

[a]E = Exploitation rate for fished population (ages 8-17).
[b]F = Fishing mortality.

Source: Bakkala and Wespestad 1984

at mid-incubation. High embryo and larval mortality, gross abnormalities or pathological changes occurred at 100-500 ppb. At average concentrations of 130-165 ppb, percent hatching was high but all hatched larvae were either abnormal or dead. Test fish were similar to control fish only at concentrations of 80 ppb and less. Sandsole (Psettichthys melanostictus) embryos exposed to 164 ppb SWSF of weathered PBCO showed retinal and brain pathological changes.

Mazmanidi and Bazhashvili (1975) exposed Black Sea flounder (Platichthys luscus) at various stages to Water Soluble Fraction (WSF) of crude oil at concentrations of 2.5 to 0.025 ppm. All concentrations greater than 0.025 ppm were found to be toxic. Eggs exposed in the gastrulation stage died immediately. Embryos in more advanced stages hatched but died soon after. Surviving larvae exhibited scoliosis, reduced activity and rate of yolk absorption as well as abnormalities in heart rate and pigment configuration.

Similar experiments were done by Kanter et al. 1983 in which eggs, larvae and adults of California halibut (Paralichthys californicus) were exposed to 3 concentrations, of Santa Barbara crude oil (Table 17) which has a chemical composition very similar to Middle Eastern and Alaskan (Cook Inlet (CICO) and Prudhoe Bay) crude oils.

After 72 hours of exposure, halibut embryo showed a marked accumulation of petroleum hydrocarbons, particularly at the medium (91.3 ppb) and high (761 ppb) concentrations. Embryo mortality was directly related, and hatching success inversely related, to oil concentration. Size of hatched larvae was significantly smaller at the highest concentrations. The frequency of malformed larvae was significantly higher than controls at all concentrations of oil exposure and markedly higher at the highest concentration.

Table 17. Petroleum hydrocarbon uptake expressed as counts per minute (cpm) of radioactive tracer, embryo mortality, hatching success, total length of newly-hatched (mm), and malformed newly-hatched California halibut larvae following 72 hours of embryonic test solution exposure. All stared (*) elements were statistically significantly different from control values.

Concentration	Petroleum hydrocarbon uptake	Mean % embryo mortality	Mean % hatching success	Mean length mm) of newly-hatched larvae	Mean % malformed newly-hatched larvae
Control	2.8	13.3	86.7	2.29	1.9
Low	16.0	16.4	83.2	2.34	5.7*
Medium	85.2*	22.0*	78.0*	2.33	6.7*
High	267.7*	29.0*	71.0*	1.99*	20.6*

Source: Kanter et al. 1983

Larvae of California halibut were exposed to petroleum hydrocarbon concentrations of 10.5, 69.5 and 606 ppb. Survival of larvae was inversely proportional to concentration and duration of exposure. Halibut survived less than 7 days in the high regime and less than 14 days in medium concentrations. Some halibut survived the entire 18 days of the experiment in the low concentration regime, however, survival was significantly less than in the controls. Larvae exposed to the high concentration were smaller and less well developed. Larvae exposed to the medium concentration regime for 7 days had reduced growth and higher incidence of structural abnormalities. Larvae in the low concentration regime had significantly reduced growth rate but no evidence of delayed or abnormal development. Reduced growth of halibut larvae exposed to the medium concentration was closely associated with reduced or delayed development, abnormal swimming behavior and failure to feed. These observations indicate that a combination of reduced development and abnormal feeding behavior resulted in reduced growth rates. All medium concentration larvae died soon after yolk absorption, suggesting that impaired feeding due to petroleum hydrocarbon exposure was the primary cause.

Plaice (Pleuronectes platessa) and flounder (Platichthys flesus) exposed to crude oil for even short periods (1-15 hrs) developed deformed notochords and severe abnormalities in the head region (Lonning 1977).

Sensitivity of Juvenile Flatfish

The effect of the Amoco Cadiz spill was reported to be greatest among young sole (Solea vulgaris) and adult plaice. Up to 80% of the fish examined showed fin rot up to 9 months after the spill (Conan and Friha 1981). Growth rate was also reduced in adults as well as younger flatfish. It is not known whether or how much these factors contribute to the mortality of flatfish. Other evidence such as the absence of the 1978 year class in catches indicate oil-imposed mortality to the flatfish populations in some areas of the Amoco Cadiz accident. Although reduced growth rates were observed, there was no verifiable evidence of large mortalities to either juvenile or adult flatfish.

The available experimental evidence indicates that juvenile flatfish have far greater tolerance to petroleum than do eggs and larvae and are comparable to adults in that respect. Juvenile English sole (Parophrys vetulus) exposed for up to 7 days to sediments impacted with CICO and juvenile starry flounder (Platichthys stellatus) exposed to PBCO impacted sediments up to 6 weeks caused no change in disease resistance.

Sensitivity of Adults

Acute Toxicity

Rice et al. 1979 estimated the 96TLm for starry flounder to be 5.34 ppm of total aromatics CICO.

Sublethal Effects

Sublethal effects of petroleum hydrocarbons on flatfish include reduction in feeding, vitality and resistance to disease, alterations in behavior (including spawning) and tainting. Animals are known to accumulate and biomagnify hydrocarbons as well as to convert certain compounds to carcinogenic and mutagenic metabolites.

McCain et al. (1978) exposed three species of flatfish to sediments mixed with 0.2% (v/v) Prudhoe Bay crude oil. Adult rock sole and starry flounder showed no petroleum-related adverse effects. During the first month, half the English sole developed cellular abnormalities in the liver. Fish exposed to oil-sediment weighed significantly less than control fish. During the 4 month duration of the experiment, no control fish died whereas 18% of the oil-exposed fish died or were moribund and emaciated. Poor feeding and weight loss was greatest in the first 30 days when the total extractable petroleum hydrocarbon (TEPH) was between 400-700 µg/g (dry weight). Winter flounder (Pseudopleuronectes americanus) exposed to freshly oiled sediments were also observed to have reduced feeding rates (Fletcher et al. 1981).

Growth was almost arrested for a year in plaice (P. platessa) and reduced in dab (Limanda limanda) after the Amoco Cadiz spill. The reductions in observed growth were partially due to a scarcity of benthic prey and partly to a state of physiological deterioration (Desaunay 1979).

Prespawning, female starry flounder, exposed to WSF of monoaromatic hydrocarbons (ave. conc. = 117 ppb) for one week had an average concentration of monocyclic aromatics of 5.26 ppm in mature ovaries. The ripest female had an accumulation 236 times the water concentration of monoaromatics. Monocyclics were low or undectable in testes and immature ovaries (Whipple et al. 1978). There were no mortalities among females but they appeared to be stressed and had faster and more irregular ventilation rates. Eggs were pale and dead and opaque ovaries were observed after 4 days. There were no apparent effects on testes or on sperm motility. Flounders were thought to accumulate low boiling point compounds much more rapidly through the water column than through molluscan food items.

In the experiment with California halibut by Kanter et al. (1983), petrogenic hydrocarbons were accumulated in the gill, liver, digestive tract, muscle, gonad and eye from exposure to the high exposure (417 ppb) level. Only gill (7000 ng/g dry weight) and liver (about 5500 ng/g dry weight) tissue were damaged by petroleum hydrocarbon exposure.

ESTIMATED IMPACT OF HYPOTHETICAL OIL SPILL SCENARIOS OFF PORT MOLLER, PORT HEIDEN AND CAPE NEWENHAM ON EASTERN BERING SEA YELLOWFIN SOLE

In previous sections we have presented the available knowledge concerning distribution, life history and fishery of yellowfin sole. Although no information was available on the effects of oil on yellowfin sole, results of some studies on the sensitivity of other flatfish to different kinds and concentrations of petroleum hydrocarbons was discussed. By collating this information with estimates of the areas and concentrations of contamination expected from the hypothetical spill scenarios off Port Moller, Port Heiden and Cape Newenham, we can obtain provisional estimates of the impact of these spills on the productivity of yellowfin sole in eastern Bering Sea.

At this point, it may be useful to summarize and reiterate some factors relevant to such an assessment.

1. The Port Moller and Port Heiden hypothetical spill sites are located in the southerly portions of the NWAFC trawl Subarea 1 and the Cape Newenham site is slightly east of the middle of Subarea 4S. No other subareas will be impacted by these spill scenarios and, as will be shown later, only very small proportions of Subareas 1 and 4S are expected to be contaminated.

2. The yellowfin sole stock of eastern Bering Sea is very abundant (biomass greater than 3 million t) and broadly distributed over the shelf and upper slope. The stock is presently in excellent condition, the catch in recent years has been less than the allowable catch and the exploitation rate below the level for estimated equilibrium and maximum sustainable yields.

3. Adults inhabit deeper waters of the outer shelf and upper slope during late fall through early spring (November-March) and then migrate toward the inner shelf occupying these waters through summer and early autumn (May-September). Adults, therefore, are not in the area contaminated by the spill during the late autumn to early spring months when the liklihood of severe storms and tanker accidents is greatest. The average biomass percentage of the total eastern Bering Sea yellowfin sole in Subareas 1 and 4S as estimated by the NWAFC trawl surveys during May-October (1975, 1978-83) was 43% and 37%, respectively.

4. Yellowfin sole are found on sandy bottom and never on muddy or silty bottom. Longer term pollution is known to persist for longer periods over muddy and silty bottoms.

5. Spawning occurs from July-September, primarily in waters of northern Bristol Bay and northward (Subareas 4S, 4N and 5).

6. There is little knowledge regarding the distribution and life history of younger juveniles (<3 yrs). The available evidence indicates they are in bays and the shallower waters of Bristol Bay throughout the year, however, there are no estimates of their numbers or temporal-spatial distribution.

7. Yellowfin sole have high fecundity with estimates of the number of eggs per female ranging from 1.3 million (body length 25-30 cm) to 3.3 million (body length 40-45 cm). Although no estimates are available, natural mortality to eggs and larvae must be extremely high. Both eggs and larvae are pelagic.

8. Most foreign fishing for yellowfin sole has occurred after June with about 75% to 80% of the catch taken in the last two quarters of the calendar year (1981-84). In May-September, the fishery on the inner shelf is primarily

in Subarea 4S. Little or no foreign fishing has occurred in thode portions of Subarea 1 which might be impacted by spills, either at Port Moller or Port Heiden because a large part of Subarea 1 has been designated a pot sanctuary and is closed to foreign fishing year round. The domestic fishery, however, can and does operate in that area. Domestic catches (joint-venture fisheries) have been highest during the second and third quarters.

Fishing in October-April occurs mainly on the outer shelf and inner slope, well outside the areas which can reasonably be expected to be contaminated by the hypothetical spill scenarios.

Information regarding the effect of oil on flatfish is summarized in Table 18. Acute toxicity in flatfish eggs occurred at concentrations as low as 25 ppb (Black Sea flounder, Mazmanidi & Bazhashvili 1975) to greater than 606 ppb (California halibut, Kanter et al. 1983). The variation is undoubtedly attributable to differences in the species, petroleum and conditions of the experiments. Whether any of the results apply to yellowfin sole in eastern Bering Sea is uncertain. For purposes of this discussion, the results of Malins et al. (1981) will be considered to be most applicable for no other reason than their experiment subjected subarctic North Pacific species of flatfish of the same family as yellowfin sole to weathered PBCO. Based on their results and for the sake of simplicity, the lethal concentration of WSF of PBCO is assumed to be 100 ppb or 0.1 ppm. Although there is some evidence that larvae may be more sensitive than certain egg stages, the same concentration will be assumed to be lethal to 100% of the larvae in the contaminated area.

Rice et al. (1979) have estimated the 96TLm for adult starry flounder to be 5.34 ppm (total aromatics, CICO). For these discussions, it will be

Table 18. Summary of effects of petroleum hydrocarbons on flatfish.

Stage	Oil/conc.	Effect	Authority
Embryo	WSF crude/25 ppb	Immediate mortality in gastrulation stage. Latent death of later stages. Surviving larvae deformed or physiologically defective.	Mazmanidi & Bazhashvili (1975)
	SWSF PBCO/80 ppb	Similar to controls	
	SWSF PBCO/130-165 ppb	Percent hatching high but all larvae abnormal or dead.	Malins et al. (1981)
	SBCO/10.2 & 91.3 ppb	Embryo mort = 16.4-22%, malformed larvae signif. greater than in controls (5.7-6.7%).	Kanter et al. (1983)
	SBCO/606 ppb	Signif. smaller larvae. Mean mortality = 29%. Mean % malformed larvae = 20.6%	
Larvae	SBCO/10.5 ppb	Survival signif. less than in controls. Reduced growth but no abnormal development.	Kanter et al. (1983)
	SBCO/69.5 ppb	Reduced growth rate after 7 day exposure. All died in less than 14 days after yolk absorption.	
	SBCO/606 ppb	Significantly smaller, less developed and all died after 7 days.	
Adults	SBCO/7.5-46.6 ppb	Little or no accumulation in tissues. Some mortality after 4-5 weeks of exposure.	Kanter et al. (1983)
	SBCO/417 ppb	Significant accumulation in gills (6900 ng/g), liver (5400 ng/g) and digestive tract (1250 ng/g). Marked mortality after 4 weeks of exposure with total mortality in 7 weeks.	
	CICO/>5.34 ppm (total aromatics)	50% mortality in 96 hrs.	Rice et al. (1979)

assumed that 50% of the yellowfin sole in WSF and TARS concentrations greater than 5.0 ppm will die of acute oil toxicity.

The spill scenarios involve Prudhoe Bay crude oil and automotive diesel fuel. Prudhoe Bay crude oil is much more viscous than Cook Inlet crude oil and automotive diesel fuel a much less viscous and volatile petroleum product. The scenarios are summarized in Table 19.

The areas contaminated by various concentrations of water soluble fractions (WSF) from these oil spill scenarios were estimated by the Rand Corporation. Using this and certain biological information, the contamination, uptake and depuration of hydrocarbons by various commercially valuable species or species groups in eastern Bering Sea were simulated by Gallagher and Pola (1985) and Pola, Miyahara and Gallagher (1985). Estimated concentrations and areas contaminated in the hypothetical spills as given by Gallagher and Pola are summarized in Table 20. The proportions of Subareas 1 and 4S (which are approximately the same size, i.e., 83,366 km^2 and 81,540 km^2, respectively) contaminated by the blowout and accident scenarios is also given in this table.

The biomass of yellowfin sole has been estimated from trawl hauls made at a number of stations broadly distributed over 467,000 km^2 and several months. Although estimates of biomass are available by subareas, the distribution of that biomass in smaller time and space intervals is not available. For purposes of making first approximations of the impacts of these oil spill scenarios, I will assume that eggs and larvae, juveniles and adult yellowfin sole are uniformaly distributed in time and space throughout Subareas 1 and 4S. Given this assumption, the proportion of the subarea

Table 19. Hypothetical oil spill scenarios.

Scenario	Oil Type	Volume	Duration	Temperature	Grid	Bristol Bay
Well blowout	Prudhoe Bay crude	20,000 bbl/day	15 days	9.3°C	(50 x 50)	Port Moller Port Heiden Cape Newenham
Tanker accident	Automotive diesel	200,000 bbl (instantaneous)	10 days	9.3°C	(32 x 34)	Port Moller Port Heiden Cape Newenham

Source: Gallagher & Pola (1985)

contaminated by the spill approximates the proportion of the total yellowfin sole population within each area impacted by the spill.

Acute Toxic Mortality

Blowout Scenario

In the blowout scenario, WSF and TAR concentrations never exceeded 0.34 ppm. At this level, all contaminated eggs and larvae will be killed, but no acute toxic mortality would be expected to juveniles and adults. Since eggs and larvae are pelagic, only the WSF is pertinent. In the areas of spill impact, spawning occurs only in Subarea 4S and only during the third quarter. WSF of 0.34 ppm is estimated to persist for 17 days in 0.4% of the waters in Subarea 4S. Assuming their uniform distribution, mortality of eggs and larvae in subarea 4S from the blowout off Cape Newenham would also be 0.4%. This estimated mortality rate applies only to the eggs and larvae in the area during the 17 day interval of the blowout. Considering that spawning can occur over a period of 3 months, the total mortality to eggs and larvae produced in subarea 4S would probably be considerably less than 0.4%. Also, because as much or more spawning occurs north of Subarea 4S, a blowout off Cape Newenham would kill a considerably smaller proportion of the total eggs and larvae produced by eastern Bering Sea yellowfin sole.

Accident Scenario

The area contaminated was estimated to be similar in accident scenarios off Port Moller, Port Heiden and Cape Newenham. Since the total areas of the potentially impacted Subareas 1 and 4S were also quite similar (83,366 km^2 and 81,540 km^2, respectively), the proportion of each of these subareas that would becontaminated by spills at any one site is also approximately the same

(Table 20). There are, however, differences in the quantity and life history groups of yellowfin sole inhabiting the two subareas.

An accident at any of the hypothetical spill sites is expected to result in concentrations of WSF greater than 0.1 ppm over an area of 1000 km^2 for 15 days, contaminating 1.2% of subarea 1 or 4S. Since eggs and larvae are pelagic, only WSF and not TARS is of concern. Also, as noted above, there is little or no spawning in Subarea 1 and spawning in Subarea 4S occurs only during the third quarter. Assuming uniform distribution of eggs and larvae throughout Subarea 4S during the 15 day period of contamination from a tanker accident off Cape Newenham, a mortality of 1.2% can be expected (Table 21). Except for the remote possibility that all yellowfin sole spawning coincided exactly with the time of the spill, actual mortality within Subarea 4S would be expected to be substantially less than 1.2% because the normal duration of spawning (3 months) is 6 times the duration of WSF concentrations lethal to eggs and larvae. Also, because much spawning occurs to the north of Subarea 4S, an accident off Cape Newenham would be expected to inflict mortalities on far less than 1.0% of the total egg and larvae produced by the eastern Bering Sea yellowfin sole stock.

Natural mortality of eggs and larvae for species of flatfish other than yellowfin sole has been estimated to equal or exceed 99% (Cushing 1974, Bannister et al. 1974). Considering their very high fecundity, natural mortality in yellowfin sole can be expected to be as great. Thus, it is highly improbable that an oil imposed mortality of less than 1.0% can be isolated from the huge background of ongoing natural mortality. Even if detectable and measurable, the impact of oil imposed mortality on yellow fin

Table 20. Estimated concentrations and area contaminated by simulated oil spills at Port Heiden, Port Moller and off Cape Newenham

Scenario	Conc./days[1/]	Area contaminated[1/] km^2	Proportion of Subareas 1 & 2 contaminated[2/]
Blowout			
WSF	max. 0.34 ppm/17	300	0.004
TARS	max. 0.34 ppm/8	300	0.004
Accident			
WSF	max. >5 ppm/4	50	0.0006
	1 - 5 ppm/12	450	0.005
	0.1 - 1 ppm/15	1000	0.012
TARS	5 ppm/15	225	0.003
	1 - 5 ppm/28	825	0.010
	0.1 - 1 ppm/30	1200	0.014

1/ Source: Summarized from Gallagher & Pola (1985).

2/ Subarea 1 = 83,366 km^2, Subarea 4s = 81,540 km^2

sole eggs and larvae to recruitment and stock productivity would be virtually impossible to assess, considering variations in survival rate.

Juvenile and adult yellowfin sole are known to migrate vertically through the water column from the bottom to the surface, and they can therefore be contaminated by both WSF and tars. The area contaminated by concentrations (>5.0 ppm) which are assumed to kill 50% of juvenile and adult yellowfin sole is 50 km^2 for WSF and 225 km^2 for TARS (Table 20). These spill fields represent 0.06% and 0.3%, respectively, of Subareas 1 and 4S. Assuming they are uniformly distributed, .03% (one-half of 0.06%) of the juvenile and adult yellowfin sole inhabiting Subareas 1 or 4S during the 4 day duration of lethal WSF concentrations would perish from acute hydrocarbon toxicity (Table 21). An additional mortality of 0.15% (1/2 of 0.3%) would be attributable to TARS concentrations exceeding 5.0 ppm. As a first approximation, it is estimated that an accident at any one of the three hypothetical spill sites would inflict acute toxic mortality to 0.18% of the juvenile and or adult yellowfin sole inhabiting Subareas 1 or 4S during the period of contamination.

Juveniles are year round residents of Subareas 1 and 4S and could therefore be impacted during any quarter but adults winter on the outer shelf and upper slope and would be imapcted by an accident in Subarea 1 or 4S only during the second and third quarters. An accident during either of these quarters will then result in an estimated mortality of 0.18% of the adults in the impacted subarea (Table 21). The current exploitable biomass of yellowfin sole in eastern Bering Sea is estimated to be about 3.3 million t. The average percentage of the total biomass occupying Subareas 1 and 4S during the late spring-early autumn months is 43% and 37% or a biomass of 1,419,000 t and

Table 21. Estimated percentage of mortality from acute toxicity in yellowfin sole in the accident scenarios at Port Moller, Port Heiden and Cape Newenham by life history group and quarter.

	A. Percentage Mortality at Port Moller or Port Heiden Spill Sites							
QUARTERS	1		2		3		4	
STAGE	WSF	TARS	WSF	TARS	WSF	TARS	WSF	TARS
EGGS & LARVAE	0	0	0	0	0	0	0	0
JUVENILES	.03	.15	.03	.15	.03	.15	.03	.15
ADULTS	0	0	.03	.15	.03	.15	0	0
	B. Percentage Mortality at Cape Newenham Spill Site							
EGGS & LARVAE	0	0	0	0	1.2	0	0	0
JUVENILES	.03	.15	.03	.15	.03	.15	.03	.15
ADULTS	0	0	.03	.15	.03	.15	0	0

1,221,000 t, respectively. The estimated loss of adults from an accident would be about 2,554 t in subarea 1 and 2,198 t in Subarea 4S.

The estimated oil-related mortality rate of 0.18% is a small fraction of the total annual mortality rate which is estimated to be 22% (Wakabayashi 1975). A loss of 2,554 t would be about 2% of the estimated total catch in 1984, perhaps less than the error in estimating the catch. Considering the very large number of fish in the eastern Bering Sea yellowfin sole population, their broad distribution and the relatively small area impacted by any one of the hypothetical spills, the estimated kill of adults probably would be of very small consequence as far as the productivity of the yellowfin sole stock is concerned.

Summary of Estimated Impacts of Oil Imposed Lethality to Eastern Bering Sea Yellowfin Sole

Only accidents at the Cape Newenham site are expected to impact eggs and larvae. The accident scenario was estimated to impose a mortality of about 1% to the eggs and larvae within Subarea 4S during the 15 day duration of WSF concentration greater than 100 ppb. As much or more spawning occurs north of the subarea, therefore, the percentage mortality imposed upon the total eggs and larvae of yellowfin sole in the eastern Bering Sea is expected to be far less than 1%. This a very small fraction, indeed, of total natural mortality which in marine eggs and larvae has been estimated to equal or exceed 99%.

The impact of spill scenarios at Port Moller, Port Heiden and Cape Newenham on juveniles cannot be estimated because there is little reliable information on the distribution or quantity of juveniles three years old and younger. An accident at any one of the three sites may kill about 2,500 t of the exploitable juveniles within either Subareas 1 or 4S. This is about 2% of the total catch in 1984 and a small fraction of the estimated biomass of the exploitable stock eastern Bering Sea yellowfin sole.

Considering the magnitude and variability of natural mortality mortality and its subsequent impacts on recruitment variability in marine fishes, it is doubtful that mortalities of these magnitudes can be detected, let alone evaluated for their effects on the productivity of the yellowfin sole stock. The difficulties and impracticalities of isolating the effects of oil imposed mortality from ongoing natural mortality has been discussed by Ware (1982).

The foregoing estimates of acute mortality to yellowfin sole were based on assumptions concerning the applicability of laboratory and field observations on the toxicity of oil to other flatfish to eastern Bering Sea yellowfin sole. It is generally recognized that the transferring of laboratory results for the assessment of oil on commercially imporatant fish and shellfish in the field is extremely difficult. In addition, the estimates carried additional assumptions regarding the abundance and time-space distribution of eggs and larvae, juvenile and exploitable yellowfin sole. As previously mentioned, quantitative information on eggs, larvae and young juveniles is almost totally lacking, estimates of the exploitable population are not without uncertainties. Available knowledge will not permit rigorous evaluation of assumptions relating to the quantitative estimation of the various components of the eastern Bering Sea yellowfin sole in time and space. For these reasons, the foregoing estimates must be considered first approximations which do, however, indicate that acute mortality and projected impact on the productivity of yellowfin sole from accident scenarios considered in these studies is of a magnitude which cannot be measured or evaluated.

Sublethal Effects of Oil on Flatfish

In the previous section (Sensitivity of Flatfish to Petroleum and Distillates), examples of some sublethal effects of petroleum hydrocarbons which have been observed in the field and in laboratory studies were briefly discussed. Observations on some short term effects such as tainting may be of some use in evaluating the possible impact of oil on the marketability of yellowfin sole concaminated by oil spills in Bristol Bay. In most cases, however, due to differences in experimental animals, oils and experimental procedures, field observations or the results of laboratory experiments cannot be directly extrapolated to reliably estimate the impacts of oil to assess either acute or sublethal effects of oil on yellowfin sole in eastern Bering Sea (see Rice et al. 1976, National Research Council 1985). Although the consequences of sublethal effects on the productivity and welfare of eastern Bering Sea yellowfin sole cannot be predicted with any reliability, they are briefly mentioned here because of the possibility that under some spill conditions and ecological circumstances, sublethal effects may have some long term consequences to the eastern Bering Sea resources.

After the Amoco Cadiz spill (March 16-17, 1978), a pronounced reduction was observed in the growth rate of the 1977 year class of plaice in the stock impacted by the spill. In addition, there was a marked increase in the incidence of fin rot, hemorrhagic fins and bent or scarred fin rays (Desaunay 1979) as well as some alterations of gonadal tissues (Laubier 1980).

Flounders (P. flesus) in the deeper soft bottom areas showed concentrations of 50 ppm in liver and muscle tissue even a year after the Tsesis spill. Flounders are known to feed very heavily on Macoma which were very heavily contaminated by oil. Chromatographic profiles of flounder flesh closely resembled that of Macoma (Linden et al. 1979).

The results of studies on the sublethal effects of petroleum hydrocarbons on a number of organisms has been summarized by Connell and Miller (1981), Malins (1981), Rice (1981) and most recently by the National Research Council (1985). Among these sublethal effects are alterations in behavior, physiological and pathological effects and tainting of flesh from bioaccumulation of petroleum hydrocarbons. Other effects which are external to the fish are the temporary or longer term destruction of habitat or the reduction or elimination of prey.

Malins et al. (1981) have summarized results of several experiments on the effects of Prudhoe Bay crude oil on some subarctic North Pacific species of flatfish. Roubal et al. (1978) showed that large amounts of low molecular weight hydrocarbons were acumulated in the muscle of starry flounder. Certain hydrocarbons have been found to accumulate in the skin and muscles of English sole (P. vetulus). The bioaccumulation of hydrocarbons was also observed in California halibut (Kanter et al. 1983) and in starry flounder (Whipple et al. 1977). The significance of such bioaccumulation to the welfare of the flatfish, its applicability to the condition and productivity of contaminated yellowfin sole stock is not known.

The metabolism of petroleum hydrocarbons in English sole (P. vetulus) was discussed by Varanasi and Gmur (1981). Relating hydrocarbons in the fish is complicated by the metabolic conversion of hydrocarbons in the environment by organs such as the liver. These hydrocarbons were taken up from oil-contaminated sediments and entensively metabolized to a number of compounds which are known to be carcinogenic and mutagenic to mammals.

The tainting of fish from the hypothetical spill scenarios is discussed in a report on the simulation of oil uptake and depuration (see Pola et al. 1985).

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