Biological Characteristics and Fishery Assessment of Alaska Plaice, *Pleuronectes quadrituberculatus*, in the Eastern Bering Sea

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Introduction

The Alaska plaice, *Pleuronectes quadrituberculatus* (Fig. 1), is a right-eyed flounder, family Pleuronectidae, and one of four shallow-water flatfishes, along with the yellowfin sole, *Pleuronectes asper;* rock sole, *Pleuronectes bilineatus;* and flathead sole, *Hippoglossoides elassodon*, commonly found in the eastern Bering Sea. They inhabit continental shelf waters of the North Pacific Ocean ranging from the Gulf of Alaska to the Bering and Chukchi Seas and in Asian waters as far south as the Sea of Japan (Fig. 2) (Pertseva-Ostroumova, 1961; Quast and Hall, 1972).

The Alaska plaice is a relatively large flounder, with an average length taken in commercial catches of 32 cm (12.6 inches) while the average weight caught is 390 g (0.86 lb.). This corresponds to an age of 7 or 8 years. Moiseev (1953) reported a maximum length of 60 cm (23.6 inches), and ages in excess of 30 years have been determined for fish collected from NMFS Alaska Fisheries Science Center (AFSC) surveys (data on file, AFSC).

In this paper, we examine available information on Alaska plaice to provide 1) a detailed description of the life history characteristics of eastern Bering Sea Alaska plaice, including growth and mortality, age at maturation and spawning, and feeding habits and ecological interactions; 2) the history of its exploitation and trends in estimated abundance; 3) the current condition of the resource and 4) projections of future biomass under various harvest levels.

Materials and Methods

Information Sources

Information for this paper came from both a review of the available literature on the biology of Alaska plaice and from analyses of research and fishing data. Information from the literature was primarily used to describe the distribution and such life history parameters as age and growth, age at maturation and spawning, fecundity, feeding habits, and ecological interactions with other species. Data from AFSC trawl surveys and the fishery were analyzed to describe size composition, size and age at maturity, fecundity at length relationships, abundance and biomass by year and age, and annual recruitment.

Assessment Methods

Resource Assessment Surveys

Since 1971, the AFSC has conducted summer bottom-trawl surveys in the eastern Bering Sea to estimate abundance and study the biology of important fish and invertebrate species. In 1975, and annually since 1979, these surveys have covered the major portion

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ABSTRACT—Alaska plaice, Pleuronectes quadrituberculatus, *is one of the major flatfishes in the eastern Bering Sea ecosystem and is most highly concentrated in the shallow continental shelf of the eastern Bering Sea. Annual commercial catches have ranged from less than 1,000 metric tons (t) in 1963 to 62,000 t in 1988. Alaska plaice is a relatively large flatfish averaging about 32 cm in length and 390 g in weight in commercial catches. They are distributed from nearshore waters to a depth of about 100 m in the eastern Bering Sea during summer, but move to deeper continental shelf waters in winter to escape sea ice and cold water temperatures. Being a long-lived species (>30 years), they have a relatively low natural mortality rate estimated at 0.20.*

Maturing at about age 7, Alaska plaice spawn from April through June on hard sandy substrates of the shelf region, primarily around the 100 m isobath. Prey items primarily include polychaetes and other marine worms. In comparison with other flatfish, Alaska plaice and rock sole, Pleuronectes bilineatus, *have similar diets but different habitat preferences with separate areas of peak population density which may minimize interspecific competition. Yellowfin sole,* Pleuronectes asper, *while sharing similar habitat, differs from these two species because of the variety of prey items in its diet. Competition for food resources among the three species appears to be low.*

The resource has experienced light exploitation since 1963 and is currently in good condition. Based on the results of demersal trawl surveys and age-structured analyses, the exploitable biomass increased from 1971 through the mid-1980's before decreasing to the 1997 level of 500,000 t. The recommended 1998 harvest level, Allowable Biological Catch, was calculated from the Baranov catch equation based on the F_{MSY} *harvest level and the projected 1997 biomass, resulting in a commercial harvest of 69,000 t, or about 16% of the estimated exploitable biomass.*

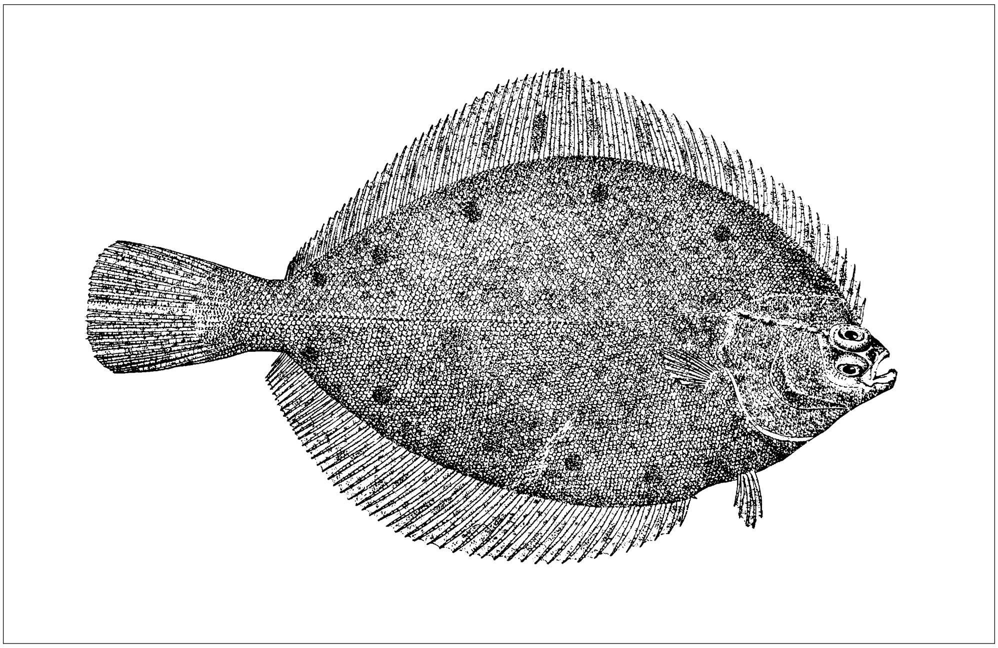

Figure 1.—The Alaska plaice, *Pleuronectes quadrituberculatus*.

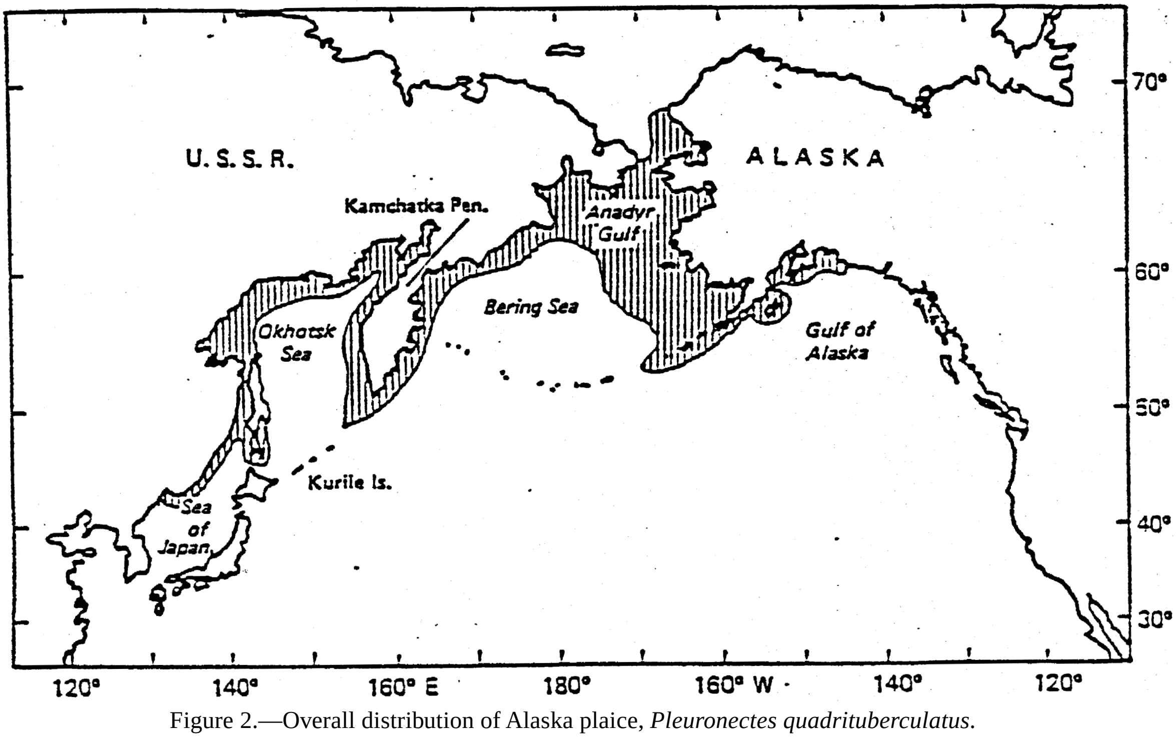

Figure 2.—Overall distribution of Alaska plaice, *Pleuronectes quadrituberculatus*.

of the continental shelf to lat. 61°N (465,000 km^2). The depth range covered by the standard survey extends from about 10 m near the mainland to about 200 m at the shelf break (subareas 1–6 in Fig. 3). Although the survey's primary role is to provide fishery-independent abundance estimates for management purposes, they also provide a wealth of biological information on the multispecies complex of fishes that inhabits the eastern Bering Sea.

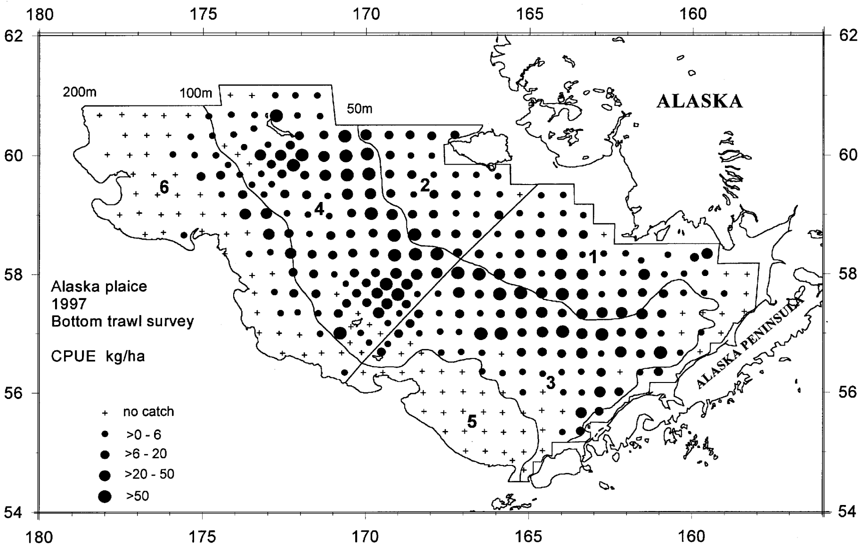

Figure 3.—Summer distribution and relative abundance in kg/ha of Alaska plaice from the 1997 eastern Bering Sea bottom trawl survey. Depth contours and statistical subareas are indicated.

The standard survey area on the shelf is divided into a grid with 37 × 37 km blocks (20 × 20 n.mi.) containing a sampling location at the center of each grid block. In areas of special interest, the corners of the blocks have also been sampled. The sampling gear is a standard AFSC eastern otter trawl with a 25.3 m headrope and 34.1 m footrope. Otter doors are 1.8 × 2.7 m and weigh about 800 kg each. At each sampling site the trawl is towed for 0.5 h at a speed of 5.6 km/h. The operating width between the wings varied from about 10 to 18 m as a function of the amount of trawl warp payed out and therefore indirectly as a function of depth. The operating trawl height varied from 2 to 3 m as determined from net mensuration. Due to the relatively flat, unobstructed bottom on the shelf, the trawl is operated without roller gear. To improve the catches of invertebrates, the trawl was rigged to dig slightly into the bottom.

Estimates of biomass and population are made using the "area swept" method described by Wakabayashi et al. (1985). The mean catch per unit of effort (CPUE) of a group of tows of known area swept is expanded to estimate the biomass within the total area of a stratum (Armistead and Nichol, 1993). The area swept is considered to be the product of the operating net width between the wings and the distance fished. The potential herding effect of the doors and dandylines is unknown for Alaska plaice, as is escapement under the footrope.

Age-structured Analyses

Biomass-based cohort analysis, after Zhang and Sullivan (1988), were applied to Alaska plaice catch at age data from 1971 to 1995 by Wilderbuer and Zhang (In press). This method assumes knife-edge recruitment with equal availability for all recruited ages and constant natural mortality over all ages and years. The input terminal fishing mortality values were estimated using the following formula:

$$F_{95} = \frac{C_{95}}{B_{95}},$$

where B_{95} is the 1995 trawl survey biomass estimate, and C_{95} is the 1995 catch in weight. The second run of the analysis was conducted using the tuned terminal fishing mortality values, which were tuned to different ratios of mean fishing mortalities by age and by year.

Wilderbuer and Zhang (In press) also incorporated age composition information from a variety of sources into a stock synthesis model (Methot, 1990) for Alaska plaice. Stock synthesis functions by simulating the dynamics of the population and the process by which the population is observed. The simulation incorporates bias and imprecision in the observations and is used to predict expected values for the observations. The expected values are compared to the actual observations (data) from the surveys and fisheries.

The biomass-based approach to the production model (Zhang, 1987; Zhang et al., 1991) was also utilized to analyze biomass and fishing mortality and to provide estimates of the important management parameters MSY, B_{MSY} and F_{MSY} . The model was used to project the future biomass of the Alaska plaice stock and catch under various F levels, including the current F level.

Optimal Fishing Mortality and Age at First Capture

Yield per recruit analysis was performed using the Beverton and Holt (1957) model to estimate the optimal fishing mortality and age at first capture. Age at first capture (t_c) was varied from 1.0 to 10.0 and the annual instantaneous rate of fishing mortality was varied from 0.01 to 0.30.

History of Exploitation

Groundfish species in the eastern Bering Sea were first exploited commercially by Japan, initially by exploratory vessels in 1930 and then by a mothership-catcher boat operation in Bristol Bay in 1933–37 and 1940–41 (Forrester et al., 1978). From 1933 to 1937, walleye pollock, *Theragara chalcogramma*, and various flounders (family Pleuronectidae) were reduced to fish meal, and annual Japanese catches peaked at 43,000 metric tons (t). During 1940–41, the fishery targeted on yellowfin sole, *Pleuronectes asper*, for human consumption, and catches ranged from 9,600 to 12,000 t (Forrester et al., 1978).

After World War II, Japanese distant-water fleets resumed operations in the eastern Bering Sea, with motherships and independent trawlers targeting yellowfin sole in 1954. In 1958 the U.S.S.R. also entered the fishery, followed by other nations in later years.

Catch statistics for Alaska plaice cannot be precise for the earlier years because the species was often included in the "other flatfish" category. Catch composition data improved in later years, particularly after implementation of the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA) which established the foreign fishery observer program. The Alaska plaice catch (Table 1) was low until the resumption of the U.S.S.R. fishery in 1978 and onset of the harvests by the Republic of Korea and other nations in 1980.

Table 1.—Annual catches of Alaska plaice in metric tons (t) by fishing nation in the eastern Bering Sea, 1963–97.

	Catch (t)						
Year	Japan	U.S.S.R.	ROK	Other	Joint Venture	Domestic U.S.	Total
1963	233	746	0	0	0	0	979
1964	808	1,085	0	0	0	0	1,893
1965	484	516	0	0	0	0	1,000
1966	2,054	2,579	0	0	0	0	4,633
1967	1,339	2,513	0	0	0	0	3,852
1968	1,233	1,396	0	0	0	0	2,629
1969	3,127	3,815	0	0	0	0	6,942
1970	1,356	2,125	0	0	0	0	3,481
1971	533	490	0	0	0	0	1,023
1972	191	139	0	0	0	0	330
1973	1,136	40	0	0	0	0	1,176
1974	2,168	220	0	0	0	0	2,388
1975	2,408	84	0	0	0	0	2,492
1976	3,518	102	0	0	0	0	3,620
1977	2,589	0	0	0	0	0	2,589
1978	5,204	5,216	0	0	0	0	10,420
1979	3,767	9,896	9	0	0	0	13,672
1980	3,810	0	2,978	120	0	0	6,908
1981	7,298	0	1,315	40	0	0	8,653
1982	5,451	0	1,144	216	0	0	6,811
1983	5,790	0	3,126	1,850	0	0	10,766
1984	10,405	1,573	4,012	2,992	0	0	18,982
1985	5,702	265	4,833	14,088	0	0	24,888
1986[1]	– – – – – – – – 46,519 – – – – – – – –				0	0	46,519
1987[1]	– – – – – – – – 18,567 – – – – – – – –				0	0	18,567
1988	0	0	0	0	61,638	0	61,638
1989	0	0	0	0	13,883	0	13,883
1990	0	0	0	0	6,080	0	6,080
1991	0	0	0	0	0	18,029	18,029
1992	0	0	0	0	0	18,895	18,895
1993	0	0	0	0	0	14,536	14,536
1994	0	0	0	0	0	9,277	9,277
1995	0	0	0	0	0	13,343	13,343
1996	0	0	0	0	0	16,106	16,106
1997	0	0	0	0	0	19,829	19,829

[1] Catch of Alaska plaice by nation is presently unavailable.

Alaska plaice share similar habitats and distributions with yellowfin sole and are taken as bycatch with that species. Yellowfin sole were intensely harvested by distant-water fleets from Japan and the U.S.S.R. in the early 1960's with a peak catch of 554,000 t in 1961. High exploitation during the 4-year period from 1959 to 1962 caused the population to decline which was reflected in the reduced harvest over the following two decades (Wilderbuer et al., 1992). From 1963 to 1971, however, yellowfin sole annual catches still averaged 117,800 t. Given the similarity of the distributions, the yellowfin sole fishery probably removed a significant portion of the Alaska plaice population through bycatch. Catches for the period 1963–71 in Table 1, therefore, are likely underestimated.

After the cessation of foreign fishing in 1987, the Alaska plaice harvest peaked at over 61,000 t during U.S. joint-venture fisheries in 1988. Catches therafter have been made by the U.S. domestic fishery, with an annual average of 14,800 t. Based on results of cohort analysis and stock synthesis analysis, the stock has been lightly harvested, with an average exploitation rate of less than 5% since 1971 (Wilderbuer and Zhang, In press).

Biological Characteristics

Distribution and Migration

The summer distribution of Alaska plaice in the eastern Bering Sea is almost entirely restricted to depths of less than 110 m, with major concentrations between 40 and 100 m on the central and northern Bering Sea shelf (Fig. 3). Fish >25 cm predominate in the sampled population between 20 and 110 m. Larger fish generally prefer such deeper waters (Bakkala et al., 1985), while juveniles (< 20 cm) occupy shallower coastal waters (Wakabayashi, 1972). This difference in depth preference provides a buffer between the juvenile and adult populations. Annual AFSC trawl surveys also indicate a summertime sexual segregation: female catch rates are greatest at depths > 60 m, while the highest catch rates for males occur at 45–55 m depths.

Fadeev (1965) suggests that Alaska plaice live year round on the shelf and move seasonally within its limits. Water temperatures may influence the seasonal movements and subsequent distribution on the shelf. Alaska plaice maintain a more westerly wintertime distribution (Fig. 4), possibly to avoid the cold bottom water temperatures that exist over the eastern Bering Sea shelf during winter. However, the extent of ice coverage may be limiting the distribution of fishing effort which is used to discern the wintertime distribution; restricting our knowledge of their seasonal distribution.

Alaska plaice are rarely encountered on the slope during the winter. They may reach the outer shelf in winter together with yellowfin sole, as was observed during spring 1976, but they generally prefer shallow water. Although this species distribution overlaps with rock sole, *Pleuronectes bilineata*, and yellowfin sole, the center of abundance of Alaska plaice is located to the north of the other species.

Early Life History

The eggs and larvae of Alaska plaice are pelagic and transparent, with egg diameter ranging from 1.9 to 2.05 mm (Musienko, 1963; Waldron, 1981; Matarese et al., 1989). Pertseva-Ostroumova (1961) described the embryonic and larval development of Alaska plaice from the west coast of Kamchatka and reported that artificially fertilized eggs, incubated at an average temperature of 6°C, hatched in 15.5–18 days. Eggs developing under natural conditions (–1.5°–6.7°C) may have a longer incubation period.

Little is known about the distribution of Alaska plaice eggs. The available data suggests the eggs are widely distributed

Table 2.—Summary of Alaska plaice egg distribution information from results of ichthyoplankton surveys conducted in the eastern Bering Sea.

Authority	Time period	Method	Findings
Waldron and Favorite (1977)	April–May 1976	Bongo and neuston nets	Eggs widely distributed with centers of abundance near the outer Alaska Peninsula, east of the Pribilof Islands, outer Bristol Bay and northwest of the Pribilof Islands
Waldron and Vinter[1] (1978)	May 1977	Bongo and neuston nets	Eggs comprised 28% of bongo samples and 72% of the neuston net samples at 64 locations. Eggs had a wide distribution over the Bering Sea shelf.
Waldron (1981)	1955–79	Bongo and neuston nets	Eggs were widely distributed from lat. 55°N off Unimak Island to lat. 59.5°N near Nunivak Island and from long. 159°W in Bristol Bay to long. 175°W near the shelf edge.

[1] Waldron, K. D., and B. M. Vinter. 1978. Ichthyoplankton of the eastern Bering Sea. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Seattle, Wash., NWFC Processed Rep., 88 p.

over the continental shelf of the Bering Sea and have been found in varying densities and spatial concentrations among the years sampled (Table 2). Spawning is believed to occur during March–April, and eggs are found from April to early summer.

Upon hatching, Alaska plaice larvae are apparently more developed than other flounders. The larvae are relatively large at hatching (5.85 mm) and have advanced body differentiation and eye pigmentation, which may be an adaptation to development at high latitudes and low temperatures (Pertseva-Ostroumova, 1961). Small larvae are mainly found in the surface layer, although they occasionally are caught as deep as 120 m. The yolk sac, ranging from 0.68 to 1.5 mm long and 0.32 to 0.60 mm high, is absorbed when the larvae are about 6.0–7.5 mm in length. Although the length at which metamorphosis occurs is unknown, young larvae of Alaska plaice appear to become demersal at a length of about 13–17 mm (Pertseva-Ostroumova 1961).

Growth and Mortality

Alaska plaice is a slow-growing long-lived species, typical of eastern Bering Sea shelf flatfish. Age and growth studies have been conducted by Mosher (1954), Weber and Shippen (1975), Bakkala et al. (1985), and Zhang (1987), based on an examination of otoliths. Male and female fish have been aged up to 31 years, and ages greater than 25 are not uncommon for fish in trawl survey catches. Length-at-age is similar for males and females until about ages 8–10 (30–32 cm) when male growth slows with the onset of sexual maturity (Fig. 5). It is not known whether differential growth by geographic region occurs on the eastern Bering Sea shelf. Parameters for the von Bertalanffy equation from age structures collected in 1988 are as follows:

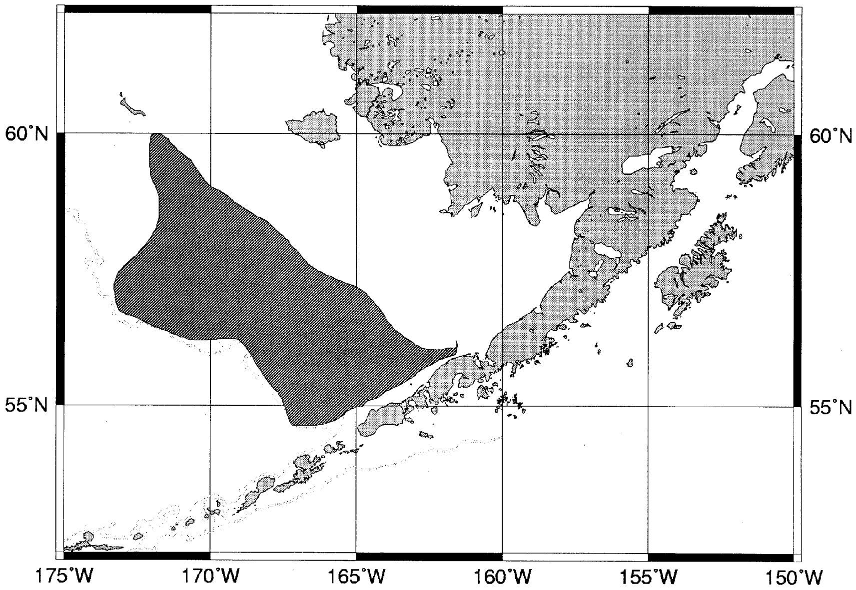

Figure 4.—Winter distribution of Alaska plaice determined from fishery sampling, 1978–96.

	L_∞ (mm)	t_0	K
Males	379.2	1.83	0.204
Females	501.7	2.09	0.156

Values of K are low for both sexes, indicative of slow growth. It is expected that the natural mortality rate (M) of such a slow-growing, long-lived species would also be relatively low. Estimates of M range from 0.195 to 0.22 for Alaska plaice (Wilderbuer and Zhang, In press). Natural mortality is likely close to 0.2, which is the value used in age-structured modeling of the eastern Bering Sea population (Wilderbuer and Walters, 1997).

The length-weight relationships for males and females from the 1990 survey are shown in Figure 6. The parameters for the relationship, weight in grams = a(length in cm)^b are:

	a	b
Males	.05677	2.576
Females	.006148	3.217

Although the length-weight relationships for males and females are similar, Zhang (1987), using data collected during the 1975 AFSC survey, reported that large females (> 26 cm) were up to 7% heavier than males of the same size.

Maturation and Spawning

During 1986–87, female Alaska plaice taken by the commercial fishery were classified as to maturity state by U.S. observers using the criteria presented in Table 3. Most of the females examined were in the developing stage (Code 2) in March, in the spawning stage (Code 3) in

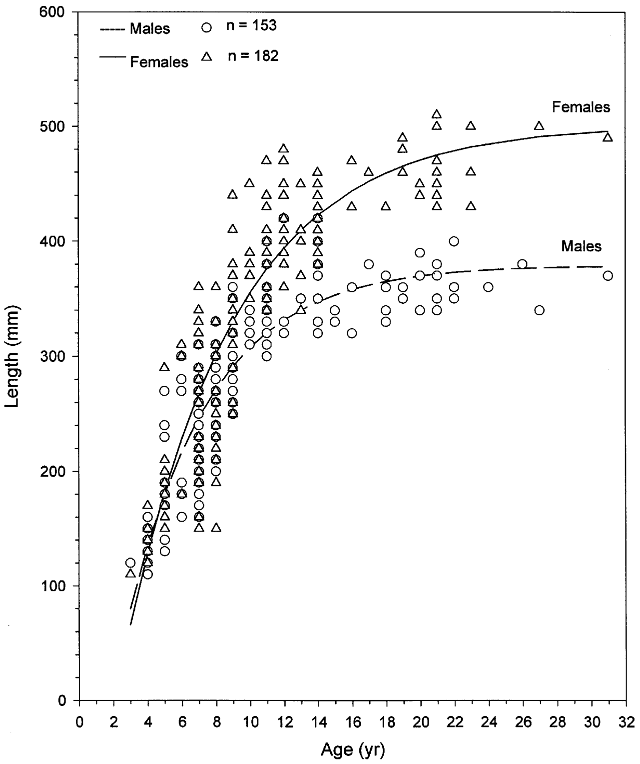

Figure 5.—Age-length distribution of Alaska plaice as determined by samples collected during the 1988 eastern Bering Sea bottom trawl survey. Curves are from nonlinear regression of the von Bertalanffy equation.

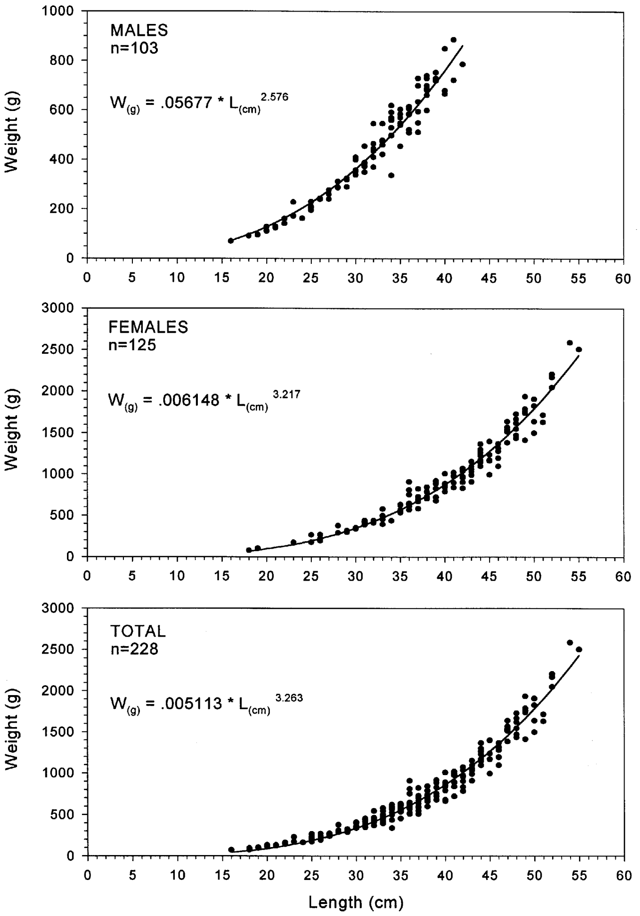

Figure 6.—Length versus weight relationships for Alaska plaice sampled during the 1990 eastern Bering Sea bottom trawl survey. Lines and equations are the result of nonlinear regression of the function, $\text{weight}_{(g)}$=a $(\text{length}_{(cm)}{}^{b})$.

Table 3.—Criteria used to classify Alaska plaice by maturity stage.

Maturity		
Code	Stage	Description of gonads
1	Immature	Gonad small, situated close to vertebral column. Difficult to determine sex. Ovaries orangish to translucent, testes translucent. Apparently has not spawned for the first time.
2	Developing	Gonad small, to about ½ length of ventral cavity. Transparent and/or opaque ova visible to naked eye, testes more opaque and swelling.
3	Spawning	Ova and sperm run under slight pressure. Most eggs translucent with few opaque eggs left in pale orange ovary.
4	Spent	Ovaries and testes flaccid and empty. Ovaries may contain remnants of disintegrating ova, testes bloodshot.
5	Inactive	Adults with gonads firm and shaped, but showing no development of ova or sperm.

April, and in the post-spawning stage in May and June (Code 4). These observations suggest that spawning occurs during April through June.

The length at maturity for female Alaska plaice was also determined from a sample of fish examined during March and April by fitting a logistic equation to the relationship between length and the proportion of mature females (Fig. 7), as follows:

$$P_L = \frac{1}{1+\exp\frac{(-(L-L_{0.50}))}{c}},$$

where L = length in centimeters, P_L = proportion mature at length L, $L_{0.50}$ = length where: P_L =0.50 = maturation length and c is a constant. The above equation can be linearized to: $\ln(1/P_L - L) = L_{0.50}/c - 1/c$.

The equation is then of the form $Y = a + bX$, and a weighted linear regression of $\ln(1/P_L - L)$ on L can be applied. The weights used for Y observations were $1/\mathrm{Var}(Y) = nP_L\,(1-P_L)$ (Gunderson, 1977). Regression coefficients obtained were then used to estimate $L_{0.50} = (-a/b)$ and $c = (-1/b)$.

The variance of $L_{0.50}$ was approximated by using the delta method:

$$Var(L_{0.50}) = \frac{1}{b^2}Var(a) + \left(\frac{a}{b^2}\right)^2 - 2\left(\frac{1}{b^3}\right)Cov(a,b)$$

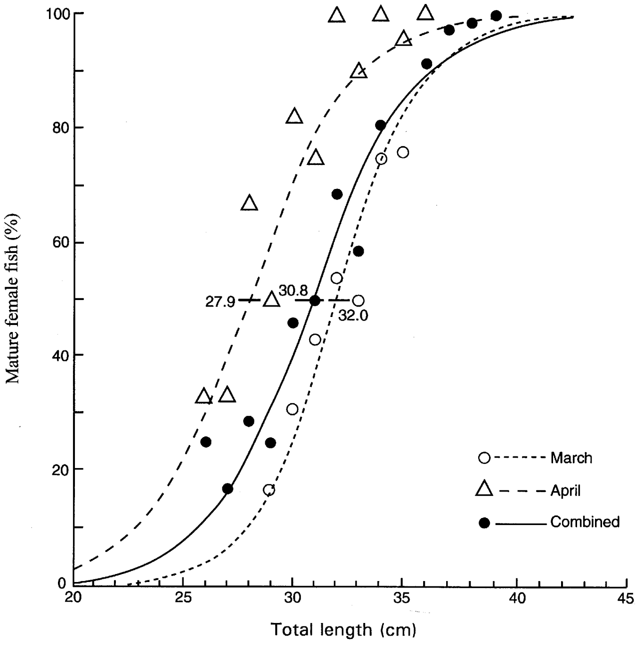

Figure 7.—Length-maturity relationship of Alaska plaice in the eastern Bering Sea, based on data collected by U.S. observers from the fishery.

Table 4.—Estimates of parameters for the logistic equation of the relationship between length and the proportion of mature female Alaska plaice in the eastern Bering Sea. Predicted length at maturity ($L_{0.50}$) and the standard error for $L_{0.50}$ are also shown.

Sample month	Proportion mature	$L_{0.50}$ (cm)	S.E. $L_{0.50}$ (cm)
March	0.5379	31.9985	0.2827
April	0.4418	27.9005	7.3571
Combined	0.4300	30.8013	0.3012

Table 5.—Fecundity of Alaska plaice in the southeastern Bering Sea from a sample of 47 fish (Fadeev, 1965).

Length (cm)	Fecundity (× 1,000)
28.1–30.0	56.3
30.1–32.0	93.2
34.1–36.0	127.2
36.1–38.0	159.5
38.1–40.0	161.8
40.1–42.0	183.0
42.1–44.0	268.5
44.1–46.0	280.8
46.1–48.0	289.3
48.1–50.0	312.6

The parameter estimates for the proportion mature at length, predicted length at 50% maturity $L(0.50)$ and standard errors for $L_{0.50}$ are presented in Table 4. The estimated $L_{0.50}$ was 32 cm from collections made in March and 28 cm from April. The combined value was 31 cm, which corresponds to an age of 6 to 7 years. Pertseva-Ostroumova (1961) reports that Alaska plaice from Asian waters reach sexual maturity at 4–6 years corresponding to a length of 20–21 cm. This may indicate a smaller size at maturity in Asian waters than in the eastern Bering Sea. However, it is difficult to suggest the existence of differences in age at maturity by area, since there is a large temporal difference in the collection times of the two samples.

Fecundity estimates (Fadeev, 1965) from the southeastern Bering Sea indicate female fish produce an average of 56,000 eggs at lengths of 28–30 cm, and 313,000 eggs at lengths of 48–50 cm (Table 5). Fertilization is external. Spawning of Alaska plaice is reported to occur over a 2–3 month period during the spring on hard sandy substrates of the shelf region, primarily around the 100 m isobath within a range of 75–150 m (Pertseva-Ostroumova, 1961). The annual spawning period may vary both temporally and spatially due to the variations in hydrological conditions. In the Bering Sea, Musienko (1970) reported that spawning apparently starts in early spring immediately after the ice melts (early May) and continues until mid-June. He also found that peak spawning in this region occurs at water temperatures ranging from –1.53° to 4.11°C and salinities ranging from 29.8‰ to 34‰ on the seafloor and 32‰ to 32.8‰ at the surface. Alaska Fisheries Science Center observations on the duration and timing of spawning generally agree with those of Pertseva-Ostroumova (1961) and Musienko (1970), although the AFSC data suggest that peak spawning may occur in April.

Observations from egg and larval surveys, however, indicate spawning may occur as late as June (Waldron and Vinter[1]). This variation in the time of spawning may result from variations in hydrographic conditions as suggested by Pertseva-Ostroumova (1961).

Alaska plaice do not aggregate for spawning but spawn over a wide area of the middle shelf. Northeasterly surface currents move the eggs to shallower waters of Bristol Bay and other coastal areas of the Alaska mainland where young plaice apparently live until they grow to about 20 cm in length. Eggs may also drift from the eastern Bering Sea to the Chukchi Sea through the Bering Strait. A strong current runs northward from the Bering Sea through the Bering Strait and into the southeastern Chukchi Sea (Pruter and Alverson, 1962). Current speeds of 0.25–0.50 m/sec have been reported from the surface to within a few meters of the bottom in the eastern Chukchi Sea and along the Alaska coast during summer (Fleming et al.[2]). Alaska plaice length frequency distributions collected from the Chukchi Sea in 1977, were comprised mostly of juveniles ranging from 10 to 20 cm in length although some were as large as 40 cm (12 years) (Wolotira et al.[3]).

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[1] Waldron, K. D., and B. M. Vinter. 1978. Ichthyoplankton of the eastern Bering Sea. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Seattle, Wash., NWAFC Processed Rep. (unnumbered: Final Rep. (RU 380)), 88 p.

[2] Fleming, R. H. 1959. Oceanographic survey of the Chukchi Sea 1 August to 2 September 1959. Preliminary report of Brown Bear cruise No. 268. Univ. Wash., Dep. Oceanogr., Seattle, Mimeogr. Rep. 59-30:1-14.

[3] Wolotira, R. J., Jr., T. M. Sample, and M. Morin, Jr. 1977. Demersal fish and shellfish resources of Norton Sound, the southeastern Chukchi Sea, and adjacent waters in the baseline year 1976. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., NWAFC Processed Rep. (unnumbered), 292 p.

Table 6.—Prey diets of Alaska plaice in the Bering Sea.

Authority	Bering Sea area	Major food items
Skalkin (1963)	Southeastern	Benthic crustaceans, mollusks, polychaetes
Mineva (1964)	Eastern	Bivalves, gastropods, polychaetes
Feder (1977, 1978)	Eastern	Polychaetes, bivalves, amphipods, nemerteans
Allen[1] (1984)	Southeastern	Benthopelagic, epifaunal, sessil infaunal preys
Zhang (1987)	Eastern	Polychaetes, amphipods, Echiura, Sipuncula
Lang (1992)	Eastern	Polychaetes, amphipods, bivalves, decapods

[1] Text footnote 4.

Table 7.—Polled prey diet and Index of Relative Importance (IRI) of Alaska plaice in the eastern Bering Sea (Lang 1992).

Prey taxa	Frequency of occurrence (%)	Numbers (%)	Weight (%)	IRI
Polychaeta	90.4	25.6	60.9	78.2
Bivalvia	37.0	5.5	5.8	4.2
Amphipoda (Gammarida)	70.2	50.0	3.1	37.2
Decapoda	4.7	0.3	0.2	0.02
Marine worms	47.7	11.3	29.0	19.2
Echinodermata	12.7	1.0	0.2	0.2
Fish	1.1	0.05	0.1	0.002
Miscellaneous	25.4	6.3	0.7	1.8

Table 8.—Results of Schoener's index of diet overlap (Schoener, 1970) between Alaska plaice, yellowfin sole, and rock sole of the eastern Bering Sea. Values were calculated for the lowest possible prey taxonomic level and at the phylum level.

Species	Yellowfin sole	Rock sole
Lowest taxonomic level		
Alaska plaice	0.127	0.299
Yellowfin sole		0.154
Phylum level		
Alaska plaice	0.313	0.787
Yellowfin sole		0.517

Feeding and Ecological Interactions

Food habits of Alaska plaice in the eastern Bering Sea have been studied by Moiseev (1953), Skalkin (1963), Mineva (1964), Feder (1977, 1978), Zhang (1987, 1988), Lang (1992), Lang et al. (1995), and Allen (1984[4,5]). Skalkin (1963), Zhang (1987, 1988), Lang (1992), Lang et al. (1995), and Allen[4] also studied trophic interactions among Alaska plaice, yellowfin sole, and rock sole which share a similar habitat and have overlapping distributions.

According to Zhang (1987), the stomach fullness of Alaska plaice was lowest after midnight (0300 to 0600 h), suggesting that feeding does not occur at night. Stomach fullness was greatest in the afternoon (1500 to 1800 h) indicating that feeding seems to be active during daytime, primarily on polychaetes and amphipods regardless of sex and size.

Table 6 shows prey items of Alaska plaice in the Bering Sea. Skalkin (1963) found that the major food items of Alaska plaice in the southeastern Bering Sea were benthic crustaceans, mollusks, and polychaetes. All three major food types were not found to occur in stomach contents at the same time. Rather, the diet often consisted of polychaetes and mollusks or only one of the three groups.

Mineva (1964) examined 190 stomachs of Alaska plaice in the eastern Bering Sea and found the following important prey items: bivalves such as *Yoldia hyperborea*, *Y. johanni*, and *Macoma calcarea*; gastropods such as *Cylichna alba*; polychaetes such as *Sternaspia scutata*, and *Scalibregma* sp.; Nephtydae; Terebellidae; amphipods; and ophiuroids. Other Bering Sea studies (Feder, 1977, 1978) also found polychaetes, bivalves, amphipods, and nemerteans to be major food items for Alaska plaice. Allen[4] examined the stomach contents of Alaska plaice on the southeastern Bering Sea shelf in 1982, and found benthopelagic, epifaunal, and sessil infaunal prey in the stomachs.

Lang (1992) intensively studied the food habits of Alaska plaice from a sample of 513 stomachs, 64 of which were empty and 449 contained food. He found that polychaeta prey was the most commonly occurring prey group, however, gammarid amphipods were also quite common. The other prey items were bivalves, marine worms, decapods and echinoderms (Table 7).

Zhang (1987) found that the pattern of food consumption by size group was very similar, with the most important prey being polychaetes (75.2% for fish >30 cm and 63.3% for fish <30 cm). The next most important items were amphipods (6.7%) and Echiura (5.7%) for the >30 cm group, and Sipuncula (21.7%) and amphipods (11.6%) for the <30 cm group. Fish were only found in the stomachs of the >30 cm group, usually in small amounts.

To examine diet overlap among Alaska plaice, yellowfin sole, and rock sole, Zhang (1987) used Schoener's (1970) index of dietary overlap to compare the similarity of their diets for two taxonomic levels of prey (the lowest taxonomic level and the phylum level, Table 8). The analysis indicated that diet overlap between the three species was less than 0.3 for the lowest taxonomic level but as high as 0.8 at the phylum level. The highest values were obtained in comparisons between Alaska plaice and rock sole ($C(x,y) = 0.299$ at the lowest possible taxonomic level but was relatively high ($C(x,y) = 0.787$) at the phylum level). The most important common prey of the two species was polychaetes but the prey species of secondary importance differed; Echiura for Alaska plaice and amphipods, Echiura and Echinodermata for rock sole. The diet of yellowfin sole was different from these two species with amphipods and Echinodermata as the most important prey item. Overall, there was less overlap in the diet between Alaska plaice and yellowfin sole than between rock sole and yellowfin sole.

Skalkin (1963) stated that the degree of food similarity between Alaska plaice and yellowfin sole caught in the same trawl was more than 50%. He also found an unusually high degree of food similarity between Alaska plaice and rock sole due to the consumption of polychaetes. Allen[5] hypothesized that, on the ecological segregation among species of fish, competitive species have the same spatial distribution (habitat)

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[4] Allen, M. J. 1984. Functional organization of demersal fish communities of the eastern Bering Sea. Unpubl. manuscr. on file at U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northwest Alaska Fish. Cent., 7600 Sand Point Way, N.E. Seattle, WA 98115.

[5] Allen, M. J. 1984. Niche segregation of nearshore soft-bottom fishes in a subarctic, warm-temperature, and tropical environment. Unpubl. manuscr. On file at U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northwest Alaska Fish. Cent., 7600 Sand Point Way, N.E. Seattle, WA 98115.

and foraging behavior (niche), while noncompetitive species have either different feeding behavior or spatial distribution. Evidence presented for the three flatfish species considered here would tend to support the hypothesis that these species are not competitive. Schoener's index of diet overlap was highest between Alaska plaice and rock sole which have the most dissimilar distribution and lowest for Alaska plaice and yellowfin sole which have similar distributions.

Lang et al. (1995) also examined food habits of the three congeneric flatfishes in the eastern Bering Sea and determined that Alaska plaice exhibited the narrowest diet selection, consisting primarily of polychaetes and other worms. This supports Zhang's hypothesis (Zhang, 1987) that the diets of Alaska plaice and rock sole are similar due to their reliance upon polychaetes, while yellowfin sole differed from the two species due to the variety of prey items, and their areas of highest abundance are spatially separate (Fig. 8). Thus, com-

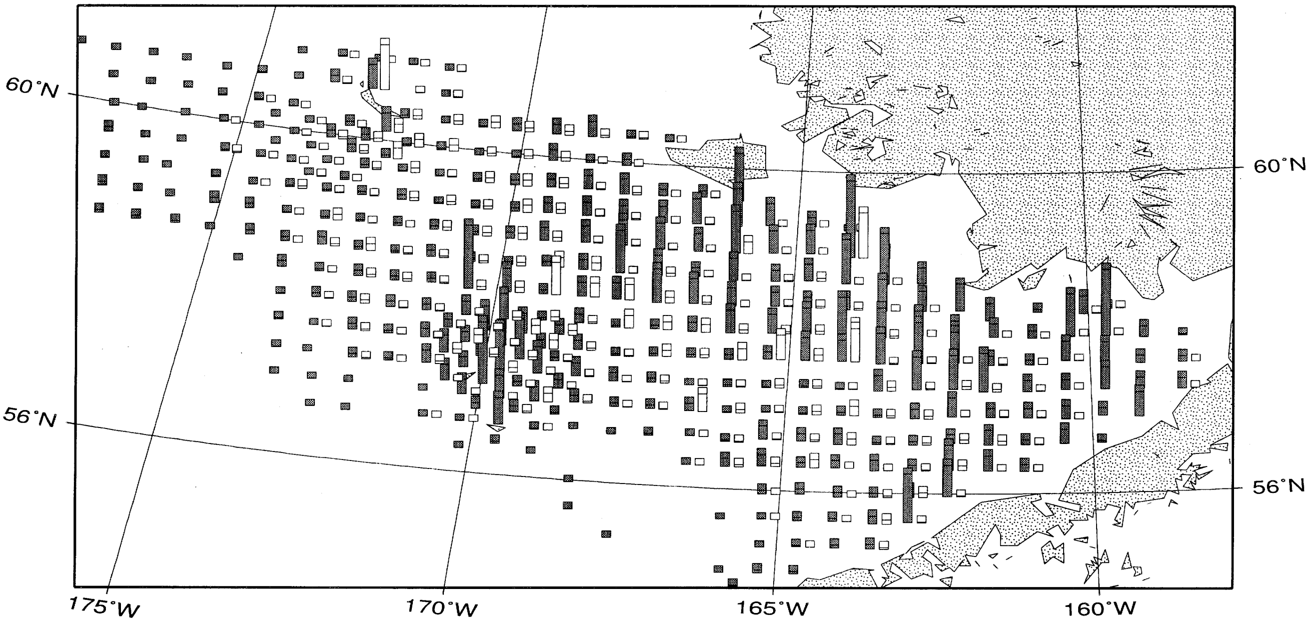

Figure 8a.—Comparison of the distribution and abundance for Alaska plaice (white) and rock sole (dark) from the 1996 trawl survey.

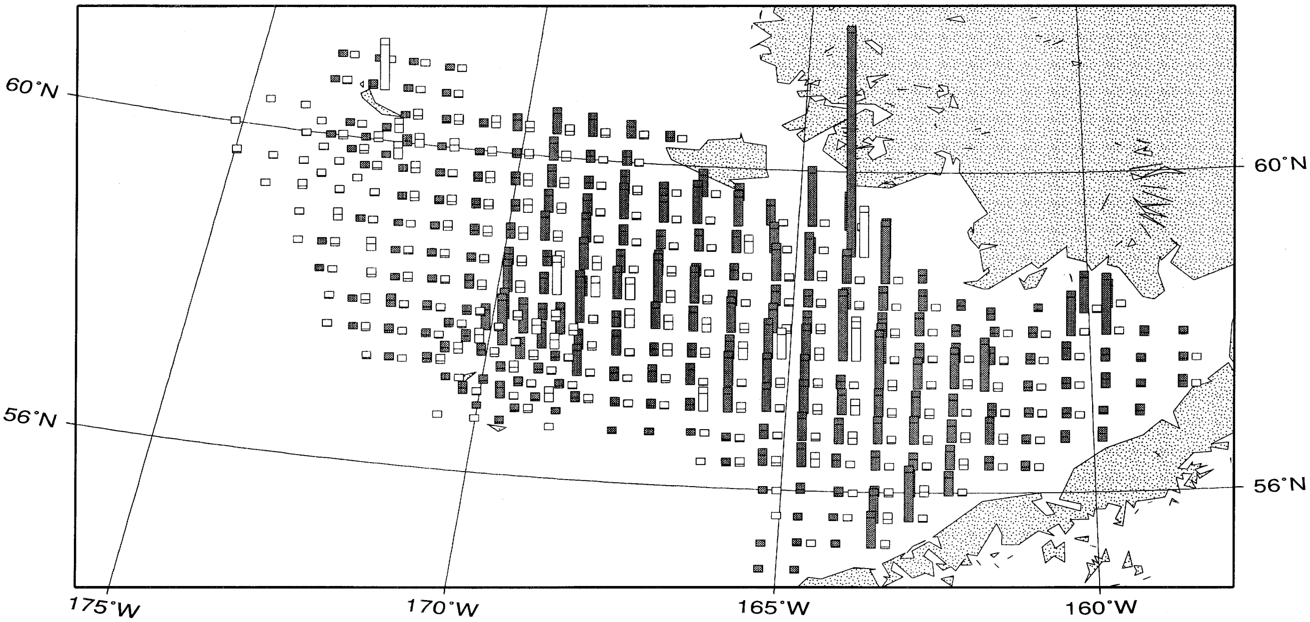

Figure 8b.—Comparison of the distribution and abundance for Alaska plaice (white) and yellowfin sole (dark) from the 1996 trawl survey.

petition for similar prey items among species appeared low. In conclusion, food competition seems to be negligible among the shallow-water flatfish species inhabiting the eastern Bering Sea due to differences in food spectra or spatial distribution. We hypothesize that the abundance and distribution of Alaska plaice may be less than that of yellowfin sole, because Alaska plaice are more specialized in terms of their food habits.

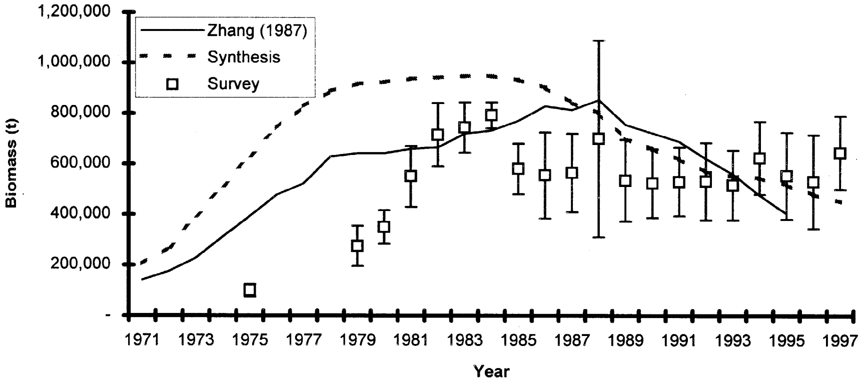

Figure 9.—Biomass estimates for eastern Bering Sea Alaska plaice from biomass-based cohort analysis, stock synthesis, and annual bottom trawl surveys.

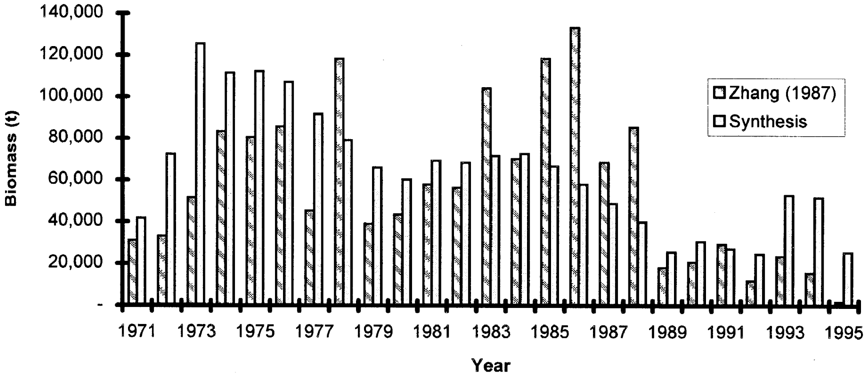

Figure 10.—Year-class strength at age 6 for Alaska plaice as estimated by biomass-based cohort analysis and stock synthesis.

Fluctuations in Abundance

Annual Changes in Population Biomass

The annual estimates of biomass from two age-structured models (Fig. 9) indicate a continuous increase in abundance from 1971 through the mid-1980's and a declining level of abundance thereafter (Wilderbuer and Zhang, In press). The stock synthesis model estimates indicate that the population biomass increased steadily from 1971, peaking in 1984 at over 947,000 t. The population has been in decline since, and the biomass is currently estimated to be only 50% of the peak level. The biomass-based approach to cohort analysis similarly estimates a prolonged period of increasing biomass since 1971 peaking in 1988 at 850,000 t and declining thereafter to 50% of the maximum level by 1995. Compared to the biomass-based cohort analysis model, synthesis estimates suggest a higher biomass from 1971 to 1987. The two models show close agreement for 1987–93.

The annual bottom trawl survey estimates indicate an increase in biomass from 1975 through 1984 and a stable trend during 1985–97 at levels ranging from 515,000 t to 700,000 t (Table 9). Due to the large amount of variability associated with the trawl survey point estimates, the trawl surveys do not detect the declining trend in the population biomass since the mid-1980's estimated by the two age-structured models.

Table 9.—Estimated biomass and 95% confidence intervals of Alaska plaice from U.S. bottom trawl surveys in 1975 and 1979–97.

Year	Biomass (t)	95% Confidence intervals
1975	103,500	82,989–124,105
1979	277,200	191,893–362,504
1980	354,000	288,224–423,706
1981	535,800	409,912–661,742
1982	715,400	587,034–843,783
1983	743,000	614,060–871,887
1984	789,200	560,625–1,017,735
1985	580,000	457,966–701,990
1986	553,900	383,587–724,212
1987	564,400	409,133–719,572
1988	699,400	309,641–1,089,139
1989	534,000	372,787–695,183
1990	522,800	386,807–658,775
1991	529,100	393,436–664,703
1992	530,400	378,004–682,871
1993	515,200	377,428–652,954
1994	623,100	479,130–767,028
1995	552,300	380,524–724,060
1996	529,300	344,200–714,400
1997	643,400	498,000–788,300

Recruitment Strengths

Estimates of age 6 recruitment from the two age-structured models corroborate the observed population increase and subsequent decline during a period of light exploitation (Fig. 10). Estimates since 1989 suggest a lack of good recruitment relative to the consistently strong recruitment estimated from the 1970's and 1980's which provided the population increase. Synthesis model recruitment estimates from the 1971–77 period were higher than those from the biomass-based model, resulting in the higher biomass estimates observed in the 1970's and early 1980's (Fig. 9). The population has declined as the large year classes, which recruited at age 6 prior to 1988, are now older than the age where they maximize their cohort biomass. The lack of recruitment to the fishable biomass in subsequent years has contributed to the population decline.

Current Management and Estimation of Yield

Maximum Sustainable Yield

Estimates of MSY are 54,300 t based on the biomass-based production model. The stock biomass that would provide this long-term yield (B_{MSY}) is

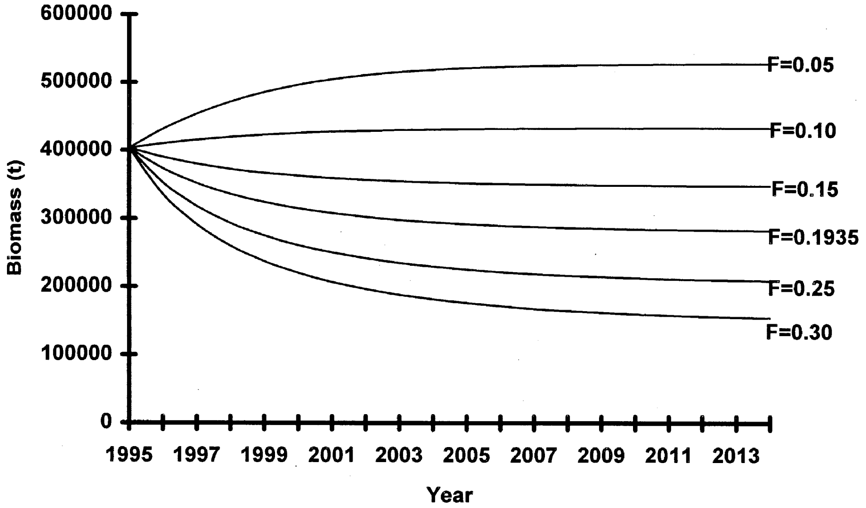

Figure 11.—Projections of estimated biomass for Alaska plaice from 1995 to 2014 using Zhang's difference equation under different harvest strategies.

estimated at 280,000 t, well below the current biomass estimate of over 400,000 t. The instantaneous rate of fishing mortality for MSY (F_{MSY}) was estimated at 0.194, much higher than the average F of less than 0.05 since 1971.

ABC for 1998

Alaska plaice of the eastern Bering Sea are managed under the jurisdiction of the North Pacific Fishery Management Council (NPFMC). Each year the NPFMC determines the total allowable catch (catch quota) for each management species derived from the Acceptable Biological Catch (ABC). The ABC currently used is based on Amendment 44 to the fisheries management plans for the Bering Sea/Aleutian Islands region and the Gulf of Alaska. These regulations set ABC commensurate upon the amount of reliable information available for the current biomass, the management parameters B_{MSY}, F_{MSY}, $F_{0.30}$, and $F_{0.40}$ and the relationship between the current biomass and B_{MSY} (Clark, 1991).

The ABC for the 1998 fishing season, according to present management guidelines, can be calculated with the following considerations. Since reliable estimates of initial 1998 biomass, B_{MSY}, F_{MSY}, $F_{0.35}$, and $F_{0.40}$ exist and the stock size at the beginning of 1998 is projected to be about 430,000 t (which is above B_{MSY}) using F levels for 1996 and 1997 of 0.05, ABC can be calculated as follows:

$$ABC = F_{MSY} B_{98} \frac{1}{Z}(1 - e^{-z}),$$

where B_{98} is the initial 1998 biomass estimated by the projection of the biomass-based approach to the production model, F_{MSY} = 0.194, and natural mortality = 0.2. This results in an ABC = 68,900 t which is higher than MSY (54,300 t) since the stock condition is presently above B_{MSY}.

Biomass Projections

Alaska plaice biomass through the year 2025 was projected using the biomass-based approach to the production model for six different F regimes ranging from 0.05–0.30 (Fig. 11). Under the optimum F level (F_{MSY} = 0.194) the biomass was projected to remain stable at 280,000 t (B_{MSY}). Biomass levels as low as 200,000 t could be reached within 7 years at a fishing mortality of 0.30 in the projection. If future harvest levels remain at current levels, the stock biomass should vary with recruitment success, as in past years.

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