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ABSTRACT

Saffron cod, *Eleginus gracilis*, is a shallow water gadid that is found in coastal regions of the U.S.S.R. and Alaska. This report investigates the abundance and availability of the saffron cod resource of western Alaska. It incorporates life history information on Eleginus stocks in the western North Pacific Ocean and Soviet Arctic with data from U.S. research trawl surveys of Norton Sound and adjacent waters of the Bering Sea. Stock parameters, such as biomass, length-at-age, growth maturity, and natural mortality, are derived from the U.S. survey data, and harvest estimates in Norton Sound are determined through yield per recruit analyses on three fishing strategies. The analyses described in this report indicate that the estimated exploitable biomass of saffron cod may permit sustained annual yields of 3,600 to 18,800 metric tons (t), but individual fish size is insufficient to readily lend its substitution into most existing gadid fisheries and markets. A commercial potential, however, may exist in development of a local small boat fishery using vessels and gear already available in western Alaska and in the development of specific foreign markets.

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INTRODUCTION

The most abundant fish species with commercial potential in Norton Sound, according to a 1976 survey, is saffron cod, Eleginus gracilis. This report evaluates that resource: its nature, condition, and potential for exploitation. The conclusions suggest that if saffron cod becomes a higher valued fish, or yields a speciality product such as roe, it could become significant for the development of a small boat fishery in Norton Sound or adjacent western Alaska regions, using vessels and gear currently available.

This evaluation of the saffron cod resource of Norton Sound and adjacent western Alaska waters is somewhat unusual because very little information has been published concerning the biology and population characteristics of this species in U.S. waters. Since information on Eurasian Arctic and western Pacific stocks of members of the genus Eleginus is found almost solely in Soviet literature, I have provided a summary of these foreign sources, and have made translations as necessary for material not previously available in English. The Soviet life history information then serves as the basis for an analysis of saffron cod data gathered in U.S. waters in 1976 and 1979 by the National Marine Fisheries Service's Northwest and Alaska Fisheries Center (NMFS-NWAFC).

The NMFS studies in Norton Sound were part of an intensified effort to catalog all marine resources of the outer continental shelf in conjunction with extensive investigations of Alaskan continental shelf oil and gas reserves. One of the baseline biological studies involved identifying fish and shellfish resources of Norton Sound. Prior to that study, only Pacific salmon, genus Oncorhynchus, and Pacific herring, Clupea harengus pallasi, were harvested commercially in this western Alaska region.

Subsequently, a small commercial fishery for red king crab, *Paralithodes camtschatica,* started in 1977, prompted by study information that located and defined little known crab stocks with potential for commercial harvest. Crab harvests increased through 1979, when they approached 1,400 metric tons (t).

The inception of this new commercial venture spurred the region's native American corporations to investigate development of other new fisheries, and it stimulated state and federal fisheries research in western Alaska. One of the resources looked at as having commercial potential was saffron cod, the most abundant fish species encountered during the 1976 survey.

Saffron cod is a cold-water gadid (member of the family Gadidae) that has been fished commercially for nearly a century in nearshore Soviet regions of the western North Pacific Ocean. The saffron cod resource in Norton Sound is, by contrast, a virgin stock and prior to 1976 very little data had been gathered on the biology and population characteristics of this species in Alaskan waters. Information gathered during the 1976 baseline study and a subsequent survey in 1979 provides the first detailed data on this unfished stock. To analyze that data, this report does three things: 1) integrates knowledge concerning Soviet stocks with information on Alaskan stocks derived from surveys of Norton Sound and adjacent western Alaska regions; 2) develops a comprehensive view of the resource in northern U.S. waters; and 3) derives estimates of harvest yields for saffron cod in this region. The analysis of these data offers a unique opportunity to examine the harvest potential prior to initial exploitation of the species.

The primary objective of this report is to estimate the sustainable harvest from the western Alaska saffron cod stocks and to better define the magnitude of the fishery which might be based upon this resource. That potential is evaluated through various yield per recruit analyses to determine exploitation rates and minimum size limits that maximize yield per recruit. These analyses are based on various estimates of natural mortality and harvest strategies that take into account resource availability and pronounced seasonal changes in the sub-Arctic environment of Norton Sound.

LITERATURE REVIEW

Interest in saffron cod in the Soviet Union has exceeded its somewhat minor commercial significance. According to Romanov (1959) over 50 reports concerning this fish had been published by Soviet scientists; unfortunately, very few are available in the United States in either the translated or original form. The available reports describe life history and population characteristics for saffron cod stocks of the northwestern Pacific, as well as a very similar species in the Siberian Arctic.

Biological Information

Saffron cod, Eleginus gracilis, is a shallow water gadid, and according to Svetovidov (1948), is one of two species in the genus Eleginus. E. gracilis and E. navaga are both mostly endemic to waters of the U.S.S.R. Andriyashev (1954) noted the following characteristics by which eleginids can be distinguished from other gadids:

--size of barbel (equal to or shorter than diameter of pupil);

--location of anal opening relative to fins (ventral and positioned below posterior edge of first dorsal fin or under interspace between first and second dorsals; and

--inflated tips of most parapophyses, i.e., transverse processes on the ribs.

Both Eleginus species are very similar externally and according to Svetovidov (1948) can be differentiated only by the following morphometric characteristics:

	E. gracilis	E. navaga
gill rakers	14-23	24-28
inflated parapophyses tips	begin at 9th vertebra	begin at 6th vertebra
vertebra parapophyses shortened and without inflated tips	first 4 pairs	first pair only

However, Walters (1955) examined a few specimens of what he considered E. navaga from Point Barrow, Alaska, and from Coppermine and Bathurst Inlet in western Arctic Canada. He indicated a meristic variation for those specimens that overlapped counts of both E. navaga and E. gracilis.

Since the distinguishing taxonomic characteristics between E. navaga and E. gracilis are not externally obvious, possibly those differences are associated with geographic and environmental variability as well as with genetic segregation.. Geographic distribution is the most obvious difference between E. gracilis and E. navaga (Fig. 1). The former has a Pacific boreal distribution from the Korean Peninsula and southeastern Alaska northward along the Asian and North American coasts through Bering Strait across the Arctic Circle and into the Chukchi Sea. The latter is found in the European Arctic along the coast from the Kola Peninsula eastward beyond the Yamal Peninsula in Siberia, as well as apparently along the Alaskan coast of the Beaufort Sea eastward into the Coronation Gulf in Arctic Canada (Walters 1955).

While there are marked life history differences between the two species (e.g., growth, fecundity, and maturity), these differences are substantially reduced when information for E. navaga is compared to data

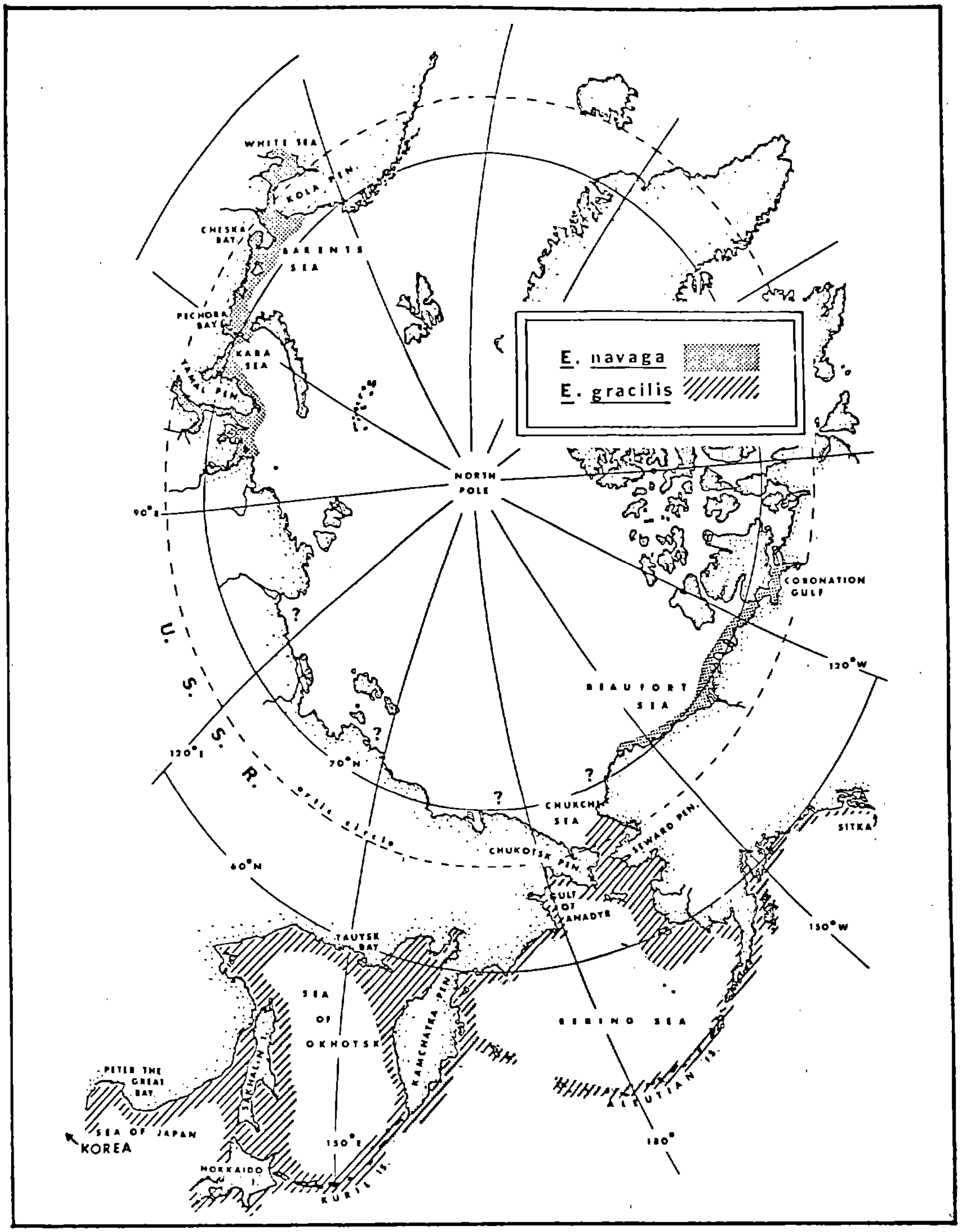


Figure 1. --Geographic distribution of Eleginus gracilis and E. navaga.

gathered from northern portions of the range of E. gracilis (see Pokrovskaya 1960, for extensive comparisons). Some Soviet investigators have discussed the two species as one when discussing biological characteristics. Soviet commercial catches are combined in fishery statistics of the Food and Agriculture Organization (FAO) of the United Nations, and the two species are sometimes referred to with the almost identical common names ("navaga" and "far eastern navaga"). Given the confusion in the literature regarding the taxonomic distinction of E. navaga and E. gracilis and gaps in knowledge for the latter species, I must treat both species as forms or varieties of saffron cod.

Within limits of their distribution in the Arctic and western Pacific, saffron cods are usually found in relatively cold water areas to depths of less than 60 m. One exception to shallow water distribution occurs off northern Japan where saffron cod have been found out to the continental shelf edge (200 m) (Tanaka 1939). Although typically marine, these gadids have been found infrequently in freshwater lakes (Grebnitskii 1897; Andriyashev 1954) and are often present in lower portions of coastal rivers to the extent of tidal influence. Presence in brackish water can occur for extended periods, especially for juveniles.

Seasonal migrations are not extensive and differ by stage of maturity. Juvenile saffron cod do not undertake seasonal migrations. They apparently can tolerate low salinity better than adults and remain in shallow water areas throughout the year (Pokrovskaya 1960).

Adults form relatively small, local, discrete concentrations whose seasonal movements are fairly restricted and associated with spawning, feeding, and changes in water temperature (Pokrovskaya 1960). According to several Soviet authorities, seasonal distribution of adults can generally be described as: winter-inshore; summer-offshore (or less inshore). During autumn when water masses start to cool, saffron cod move inshore into silty, shallow water areas along the coast or in estuaries and continue feeding. Movement into adjacent sandy-pebbly areas occurs at the start of spawning activity in early winter when feeding stops. After spawning, the fish return to silty bottom and/or estuarine areas and resume limited foraging. Throughout late fall-winter, saffron cod are primarily found under extensive ice cover. Seaward (offshore) movements occur during spring-early summer when nearshore waters warm and become diluted by ice breakup and the associated runoff of the thawing snowpack from adjacent land masses. Pokrovskaya (1960) and others report that from late spring until autumn, adult saffron cod distribution is primarily associated with cold, highly saline waters of the open sea.

Most saffron cod mature during their second or third year (Table 1). Spawning usually occurs during January but may vary from late December through early March, depending upon the region and severity of winter weather (Pokrovskaya 1960). In relatively mild weather, peak spawning occurs later and is often prolonged, while in cold years, spawning begins earlier and the period of peak activity is shorter. Demersal spawning occurs under coastal sea ice in very shallow areas (2-10 m) with sandy-pebbly substrate and highly saline waters under strong tidal influence. Optimum water temperatures were reported by Pokrovskaya (1960) as less than l°C in the laboratory; most spawning actually occurs at temperatures between -1.3° and -1.8°C.

Egg size and fecundity vary substantially by geographic region. Egg diameter increases and the number of eggs released decreases from east to west in the European Arctic and from south to north in western Pacific

Table 1.--Age at sexual maturity for *Eleginus* spp. in Arctic and Pacific regions of the U.S.S.R. (from Pokrovskaya 1960).

Area	Year	Sex of Fish	Percent sexually mature by age 1	2	3 (years)	4	5
Northern Arctic Ocean (i.e. Barents Sea):							
Onega Gulf	1951-52	Females	--	99	100	100	100
		Males	30	100	100	100	100
Upskaya Bay	1941-43	Females	--	90.2	94.5	90.1	100
		Males	--	89.1	93.9	100	100
North Mouth (estuary) Dvina R.	1941-42	Females	--	5	5	5	--
		Males	--	--	5	--	--
Mezen - Kamenka (mouth of Mezen R.)	1941-42	Females	--	*	87	97.1	100
		Males	--	50*	93.5	100	100
Pechora Sea:							
Cheska Bay	1936-38	Females & Males	1	42	100	100	100
Pechora Gulf	1940-44	Females & Males	--	2.7	62.5	98.1	100
Kara Sea	1945-46	Females & Males	--	**	92.5	98.5	100
Pacific Ocean:							
Peter the Great Bay	1927-31	Females	--	70-78	100	100	100
		Males	--	75-90	100	100	100
Terpenia Bay	1948-53		They had matured by 2nd year				
Northern Part of Tartar Strait	1944-54		They had matured by 3rd year				
Nagaeva Bay (Okhotsk Sea)	1949	Females	--	2.5	*	*	*
		Males		16.5	*	*	*

* Information for the age group was insufficient or absent.

** In the Kara Sea 2-year-olds in the spawning stage made up an insignificant part of spawning populations. In the years 1945-46, sexually mature and immature 2-year-olds represented less than 1% of all fish sampled from catches during the spawning period.

waters (Tables 2,3). For example, along the Pacific coast of the U.S.S.R., egg size (before fertilization) ranges from 0.84 mm to 0.94 mm in Peter the Great Bay off the Sea of Japan to sizes of 1.00-1.10 mm in Tatar Strait (Table 2). Estimates of fecundity for 20-35 cm fish in these same regions are 30,000-188,000 and 29,000-124,000 eggs, respectively (Table 3).

Saffron cod eggs swell after fertilization, are demersal (i.e., they are found at or near the bottom), may only be slightly adhesive, and can (continue to develop in sub-zero (°C) temperatures. The incubation period varies, although Mukhacheva (1957) determined the development period under normal environmental conditions in Pacific waters to be about 2 l/2 months. Khaldinova (1936) indicated a normal incubation period of 4 months for Arctic waters. Egg development is arrested when temperatures fall below -3.8°C and resumes when ambient temperatures increase to above that temperature (Mukhacheva 1957). Although the eggs can survive in a wide range of temperatures (<-3.8° to 8°C), they cannot tolerate brackish water and perish when salinity falls below 23.2 ppt (Pokrovskaya 1960).

Larvae hatch out in early spring, prior to the warming of coastal waters in the Arctic or northernmost portions of the western Pacific, and somewhat later (during warming) in waters farther south, such as the Sea of Japan. A general time is April-May. Embryonic and post-embryonic development of saffron cod is very similar throughout their Arctic and Pacific distributions. Larvae differ only in size; an example of size differences for newly hatched larvae was described by Mukhacheva (1957) as follows:

	Pacific waters (*E. gracilis*)	Arctic waters (*E. navaga*)
body length (mm)	3.5-3.9	4.5-5.3
ante-anal distance (% of total body length)	36.4-39.8	37.2-44.0

Table 2.--Diameter of eggs of Eleginus spp. in Arctic and Pacific regions of the U.S.S.R.

Region		Egg size before fertilization (mm)	Egg size after fertilization (mm)
	Arctic Waters		
West	Onega Bay[a]	0.99-1.11	1.45-2.08
↓	Onega Bay[b]	0.90-1.40	1.50-2.00
	Mezen Bay[c]	0.88-1.21	--
East	Kara Gulf[d]	1.00-1.60	--
	Pacific Waters		
South	Peter the Great Bay[e]	0.84-0.94	0.97-1.30
↓	Kunashir Island[g]	0.87-1.01	1.30-1.60
	Tatar Strait[f]	1.00-1.10	--
North	Paramushir Island[g]	0.87-1.11	--

[a] Source: Kuldinova 1936
[b] Source: Nikolaev 1957
[c] Source: Lanshin 1929
[d] Source: Fridlyand 1948
[e] Source: Kozlov 1951
[f] Source: Mukhacheva 1957
[g] Source: Pokrovskaya 1960

Table 3.--Fecundity of _Eleginus_ spp. in Arctic and Pacific regions of the U.S.S.R. (from Pokrovskaya 1960).

Length(cm)	Number of eggs (x1000) in ovaries by region				
	Arctic Waters (West to East)			Pacific Waters (South to North)	
	Onega Bay[a]	Mezen Bay[b]	Off W. Yamal Pen.[c]	Peter the Great Bay[d]	Tatar Strait[e]
15.5-17.5	-	7.5	-	-	-
17.6-20.0	11.8	12.7	-	-	-
20.1-22.5	19.0	21.0	16.7	30.3	28.9
22.6-25.0	24.9	29.8*	21.0	47.0	41.3
25.1-27.5	34.2	?	29.4	66.9	56.1
27.6-30.0	45.1	50.6	36.1	91.4	75.0
30.1-32.5	67.8	62.6	48.9	135.1	96.8
32.6-35.0	77.1	64.7	55.8	188.5	123.8
35.1-37.5	95.5*	71.6*	66.5	-	154.1
37.6-40.0	162.5	-	77.2	-	190.7

[a] Source: Nikolaev 1957
[b] Source: Lanshin 1929
[c] Source: Pokrovskaya 1960
[d] Source: Dubrovskaya 1953
[e] Source: Calculated from data provided by B. M. Kozlov in Pokrovskaya 1960

* Calculated from samples containing less than 5 individuals

The 2-3 month larval stage (Andriyashev 1954) is planktonic. By mid-summer the larvae reach 3.9-5.6 cm (Pacific) or 5.5-6.0 cm (Arctic) (Table 4) and descend to the bottom.

Planktonic feeding occurs only during the larval period; thereafter, saffron cod juveniles and adults are opportunistic epibenthic feeders. Primary food types throughout their range include: crustaceans, worms, and small or juvenile forms of several fish species (Fig. 2). Juvenile fishes are the principal prey item of Arctic stocks, primarily because of their increased availability relative to invertebrates. Saffron cod along the western Pacific coast usually feed on crustaceans, mostly amphipods. The high proportion of invertebrates in the diet of western Pacific fish (Fig. 2) is probably due to a much higher benthos biomass in that region as compared with the Arctic (Table 5). Intensive feeding in both major geographic regions starts during summer and continues until just prior to winter spawning. Feeding is then abruptly reduced and resumes somewhat in mid-winter after the period of sexual reproduction.

Despite resumed feeding in mid-winter, the growth of saffron cod is almost entirely arrested at this tine because the fishes are in an extremely stressed physiological condition after intense spawning activity. Pokrovskaya (1957) studied Arctic (Kara Sea) stocks through the winter and found that annual growth nearly ceased after October and did not resume until late the following spring. This may seen to- contradict an earlier reference by the sane authority indicating feeding until winter spawning; however, late fall-early winter feeding appears associated with a rapid increase in gonadal material. I assume that intensive gonad development occurs in both sexes, but unfortunately, the available foreign literature only describes changes in females. (This 'interpretation of the translated

Table 4.--Average size (mm) by month for young Eleginus spp. for 14 months after hatching in Arctic and Pacific regions of the U.S.S.R. (from Pokrovskaya 1960).

Region/Year of Study	Months													
	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V
Onega Bay, 1951/52	--	4.6	--	57*	60.0	90.0	109.0	--	126.0	128.0	125.0	131.0	119.0	132.0
Yugorski Region and Baydaratsk Gulf, 1945-46	--	5.3	6.1	8.0	--	58-64**	84.5	61.1	85.8	88.0	81.5	94.6	91.6	--
Peter the Great Bay, 1927, 1928, 1953	3.8	15.3	28.7	64.1	92.0	118.0	136.2	--	--	--	140.6	--	150.0	161.0

* Judging from data by Timakova (1957), young navaga measuring 50-60 mm were obtained in the final days of July in 1951. Consequently, this should be taken into account in the above table and in comparison to sizes identified for adjacent months and the 57 mm measurement may be too high.

** Three juveniles measured during September from work by Soldatov (1923).

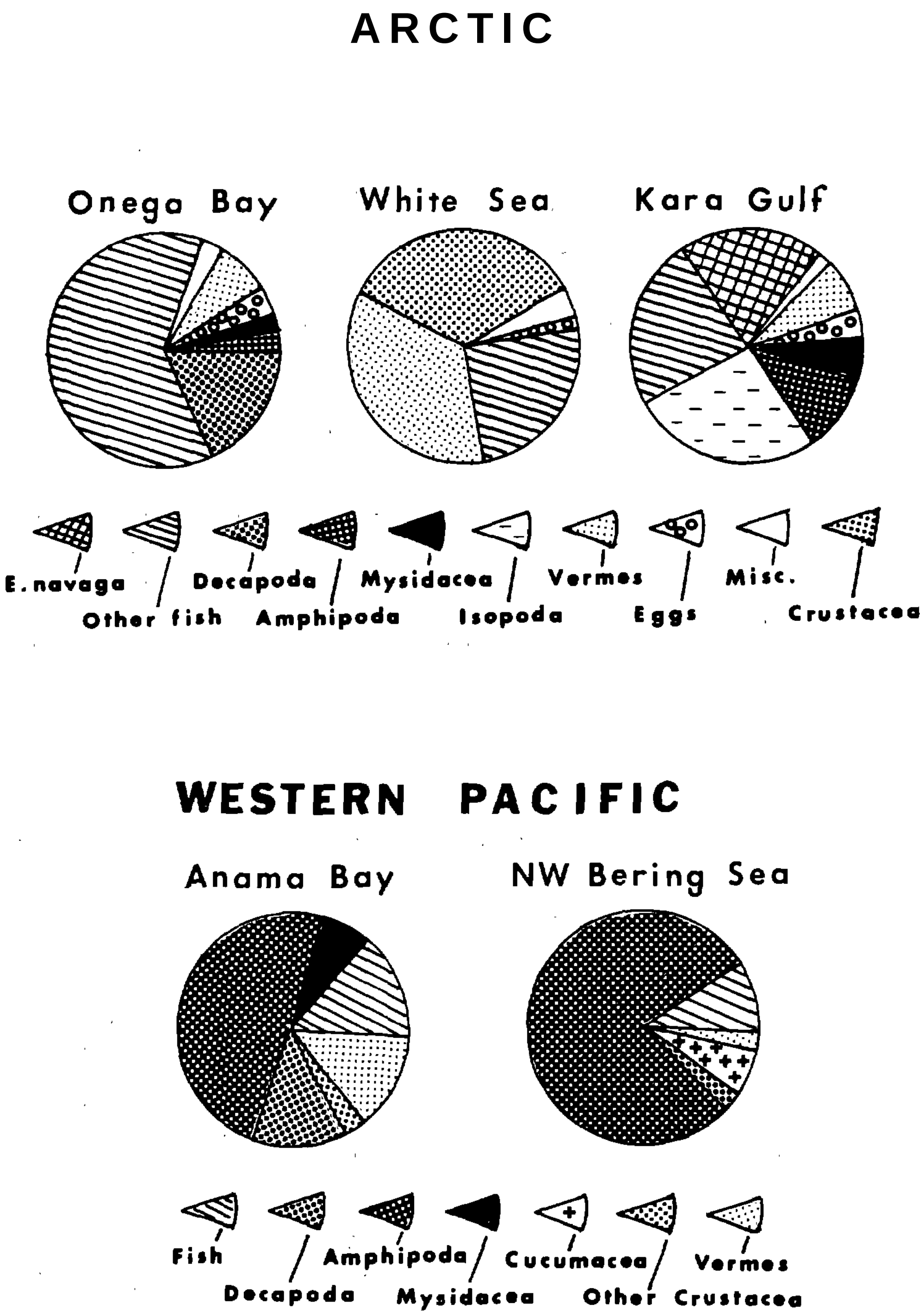


Figure 2. --Composition of food items for Eleginus spp. from various regions of the Arctic and Pacific coasts of the U.S.S.R. (from Pokrovskaya 1960).

Table 5.--Benthos biomass in Arctic and Pacific coastal regions of the U.S.S.R. (from Pokrovskaya 1960).

Region	Biomass by group in g/m²						Authority
	Molluscs	Worms	Crustaceans	Echinoderms	Other Animals	Combined Biomass g/m²	
Cheska Gulf	90.50	10.00	24.00	10.00	19.30	153.80	Zenkevh 1947
Baydaratsk Gulf (southwest coast)	62.33	0.12	--	7.62	4.32	74.38	Grishina and Filatova 1948
Baydaratsk Gulf (northeast coast)	131.16	2.64	0.20	0.44	2.08	136.52	Grishina and Filatova 1948
Anadyr Bay	121.03	53.68	17.06	32.75	3.33	227.50	Makarov (from Moiseev 1953)
Northwest Coast Kamchatka:							
Northern Part	213.25	275.40	78.20	14.71	76.89	668.50	Gordeeva (from Moiseev 1953)
Central Part	166.02	90.36	17.11	22.93	45.86	342.30	
Southern Part	240.97	74.15	97.87	18.80	43.30	675.00	
Tauyskaya Gulf	8.33	7.54	61.90	3.43	33.00	114.20	Usakov (from Moiseev 1953)
Central Region of northwestern part of Sea of Okhotsk	2.57	14.03	0.30	15.03	21.57	53.50	Ivanov, Volk (from Moiseev 1953)
Peter the Great Bay:							
10-15 m interval	35.20	38.40	7.70	12.10	6.60	264.00	Derugin and Somova (from Moiseev 1953)
50-80 m interval	27.10	25.60	45.70	1.60	--	340.10	
Southern Kuril I.	--	--	--	--	--	about 500	

material was verified by Dr. V. Pachenko of the Pacific Scientific Research Institute of Marine Fisheries and Oceanography (TINRO) during discussions at Kodiak, Alaska, on 20 April 1983.) Very intensive gonad development, especially ovaries, occurs during late fall (Table 6) and results in increased gonad weight as well as a much higher ratio of gonad to total body weight. In an Arctic (Kara Sea) population, Pokrovskaya (1960) indicated that ovaries for various sizes of fish averaged nearly 25% of body weight (Table 7).

Both male and female saffron cod are very emaciated after spawning (Table 8) with weight losses reported to average 15% of total body weight for Arctic (White Sea) populations (Mantiefel 1944); weight remains reduced throughout winter and early spring (Table 9). Limited data by Dubrovskaya (1953) from Pacific coast waters (Peter the Great Bay) suggest that weight loss after spawning is not so significant. Regardless of geographic location, changes in body size appear substantially influenced by winter spawning and food availability. It also seems likely that the physiological demands of winter spawning could result in spawning stress mortality, but this was not stated in the reviewed literature.

Saffron cod growth rates differ between the Arctic and western Pacific, and within each major geographic region (Tables 10,ll). According to Pokrovskaya (1960), greater amounts of forage are generally available in the western Pacific than in most areas of the Arctic. This usually results in faster growth for Pacific stocks; however, this relation is not always true.

Saffron cod growth in certain northwestern Pacific areas (e.g., portions of the Sea of Okhotsk) is slow in comparison to some Arctic stocks. A general ranking of growth rates by area, from fastest to

Table 6. --Stages of ovarian development (in percent of total females) by month for Eleginus spp. in various regions of the U.S.S.R. (from Pokrovskaya 1960). Pacific regions are marked with asterisks.

Region and year of investigation	Stage of Development[a]	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Southern portion of White Sea 1941-43	II, II-III	--	--	--	--	--	99.6	92.0	9.7	12.2	0.3	15.3
	III, III-IV	--	--	--	--	--	0.3	8.0	81.9	85.4	48.2	1.5
	IV, IV-V	--	--	--	--	--	--	--	17.0	2.4	51.5	40.1
	V, V-VI	--	--	--	--	--	--	--	--	--	--	35.9
	VI	--	--	--	--	--	0.1	--	--	--	--	7.2
Mezen-Kanin 1941-42	II, II-III	--	--	--	--	--	--	--	63.0	36.0	9.5	--
	III, III-IV	--	--	--	--	--	--	--	36.2	51.6	64.4	15.2
	IV, IV-V	--	--	--	--	--	--	--	0.8	11.6	26.0	81.4
	V, V-VI	--	--	--	--	--	--	--	--	--	0.1	2.8
	VI	--	--	--	--	--	--	--	--	--	--	0.6
Cheska Gulf 1936-38	II, II-III	--	--	--	--	--	--	96.5	--	--	9.5	--
	III, III-IV	--	--	--	--	--	--	3.5	--	--	1.0	1.2
	IV, IV-V	--	--	--	--	--	--	--	--	--	89.5	93.0
	V, V-VI	--	--	--	--	--	--	--	--	--	--	5.8
	VI	--	--	--	--	--	--	--	--	--	--	--
Pechora Sea 1942-43	II, II-III	--	--	--	--	--	98.8	72.3	27.9	--	1.6	--
	III, III-IV	--	--	--	--	--	--	24.6	48.2	56.8	73.9	--
	IV, IV-V	--	--	--	--	--	1.2	0.6	23.0	43.2	24.5	66.1
	V, V-VI	--	--	--	--	--	--	0.6	--	--	--	33.9
	VI	--	--	--	--	--	--	--	--	--	--	--
Kara Gulf 1945-46	II, II-III	1.5	26.7	32.2	12.4	16.6	92.1	84.0	53.9	--	--	--
	III, III-IV	--	2.2	0.3	0.2	--	7.9	16.0	45.4	90.5	28.0	3.1
	IV, IV-V	0.9	1.0	0.5	0.6	--	--	--	0.7	9.5	69.5	96.9
	V, V-VI	42.0	7.4	5.2	7.7	--	--	--	--	--	2.5	--
	VI	55.6	57.2	30.4	65.0	10.8	--	--	--	--	--	--
	VI-II	--	5.6	23.4	14.3	72.6	--	--	--	--	--	--
Ob Gulf 1946	II, II-III	--	--	--	--	--	81.5	54.6		--	--	--
	III, III-IV	--	--	--	--	--	--	9.1		--	--	--
	IV, IV-V	--	--	--	--	--	--	9.1		--	--	--
	V, V-VI	--	--	--	--	--	10.6	18.2		--	--	--
	VI	--	--	--	--	--	3.9	9.0		--	--	--
Southern Kuril I. 1949, 1951, 1953	II, II-III	--	+	+	+	+	+	+	+	--	--	--
	III, III-IV	--	--	--	--	--	--	--	--	+	--	--
	IV, IV-V	--	--	--	--	--	--	--	--	--	--	+
Northern part of Tatar Strait* 1944-49	II, II-III	--	--	--	+	+	+	78.5	+	+	--	--
	III, III-IV	--	--	--	--	--	--	22.5	Predominant		--	--
Nagaeva Bay* 1949	II, II-III	--	--	--	--	--	--	--	61.5	--	--	--
	III, III-IV	--	--	--	--	--	--	--	38.5	--	--	--
Korfa Bay* 1950	II, II-III	--	--	--	--	--	--	--	--	--	--	--
	III, III-IV	--	--	--	--	--	--	--	100.0	--	--	--
Shantar I.*	II, II-III	--	--	--	+	--	--	--	--	--	--	--
	VI	--	--	--	+	--	--	--	--	--	--	--

* The symbol "+" is placed in those cases where individuals with that stage of ripeness were present, rather than percentages.

[a] I - Immature; II - Adult or adult maturing; III - Adult mature; IV - Adult spawning, imminent or free flowing; V - Adult ripe; VI - Spent; and VII - Resting.

Table 7.--Ovary weight for Eleginus navaga from the Kara Sea, in percent with relation to body weight (from Pokrovskaya 1960).

Time of investigation	Length of fish, cm													Number examined	Mean % ovary wt/ body wt
	21	22	23	24	25	26	27	28	29	31	33	34	38		
January 1945	24.6	--	--	22.6	24.2	--	23.2	--	--	25.0	21.6	29.8	--	8	24.50
December 1945	--	11.0	16.8	13.3	13.4	14.5	14.6	13.1	15.5	--	15.8	--	11.0	26	13.25

Table 8.--Average body weight (gm) at length for Eleginus navaga in the Kara Sea (from Pokrovskaya 1960).

Time caught	Length of fish, cm									Coefficient of fatness[a]
	22	23	24	25	26	27	28	29	30	
January 1945	70.0	82.7	92.0	117.5	120	140	150	170	210	0.68
December 1945	95.0	110	118	138.8	150	170	190	203.3	223.3	0.85

[a]Ratio between the body weight in grams x 100 and the cube of body length in cm, i.e. $\frac{wt(gm)}{L^3(cm)} \times 100$

Table 9.--Average body weight for Eleginus navaga from the Kara Sea in the winter period 1945-46 (in gm) (from Pokrovskaya 1960).

Size (cm)	Weight in grams					Reduction of weight in % over fish weight in December			
	16 Dec.[a]	7 Feb.	March	April	May	7 Feb.	March	April	May
22	79.2	76.8	77.2	69.7	63.7	3.0	2.5	12.0	19.5
23	86.2	91.9	86.0	79.1	73.0	0	0.5	8.1	15.5
24	104.3	101.2	92.5	87.7	80.3	3.0	11.6	16.1	23.2
25	125.5	126.1	107.0	98.7	89.9	0	14.9	21.5	28.5
26	128.8	131.2	115.0	102.4	105.0	0	10.6	21.2	18.5
27	141.0	136.6	128.7	120.5	117.2	3.4	8.6	14.6	17.8
28	172.4	--	150.3	135.5	122.5	--	12.9	21.5	29.0
Average	--	--	--	--	--	1.5	8.8	16.4	21.7

[a]The weight of navaga cod in December is less or minus the weight of the ovaries.

Table 10.--Average size (cm) at-age for Eleginus navaga in Arctic waters of the U.S.S.R. (Data is from numerous sources and is summarized in Pokrovskaya 1960).

Region	Time of study	Age group (years)									
		1	2	3	4	5	6	7	8	9	10
Pechora Sea											
Cheska Gulf	Winter 1936-37	--	16.06	20.70	24.10	26.30	--	--	--	--	--
	Winter 1937-38	--	17.10	20.80	24.50	--	--	--	--	--	--
	Winter 1941-42	--	15.00	16.58	18.22	20.40	24.80	27.06	31.30	29.00	--
	Winter 1942-43	--	15.10	16.50	20.70	23.10	24.70	26.20	30.00	--	--
Pechora Bay	Winter 1940	--	--	17.90	20.00	21.60	23.80	27.00	--	--	--
	Winter 1941-42	--	14.00	17.30	19.60	20.90	22.60	23.10	29.00	--	--
	Winter 1942-43	--	14.40	18.80	20.10	21.50	22.10	24.00	26.00	--	--
	Winter 1943-44	11.70	16.20	18.60	21.80	23.40	24.30	26.10	29.00	--	--
	Winter 1955	--	--	17.73	19.47	--	--	--	--	--	--
White Sea											
Pomorski Coast	January 1926	--	18.50	22.50	--	--	--	--	--	--	--
	Jan.-Feb. 1933	13.40	19.00	22.00	24.60	26.00	27.70	--	--	--	--
	Winter 1942-43	--	15.00	17.20	19.70	22.60	--	--	--	--	--
	January 1950	--	19.60	23.10	26.30	--	--	--	--	--	--
	Winter 1950-51	--	21.12	23.61	24.08	27.80	--	--	--	--	--
	January 1952	12.80	20.40	24.15	27.00	29.10	35.80	--	--	--	--
	January 1953	--	20.51	26.00	28.25	30.20	--	--	--	--	--
	February 1954	--	19.51	24.33	28.00	--	36.40*	--	--	--	--
Unskaya Gulf	January 1926	--	18.30	21.60	31.40*	--	--	--	--	--	--
	Winter 1941-42	--	14.30	16.60	18.40	23.10	26.00	28.00	--	--	--
	Winter 1942-43	--	--	17.60	19.80	22.10	25.40	--	--	--	--
Pertominsk	Winter 1950-51	--	21.57	25.18	29.78	31.38	--	--	--	--	--
Dvina Bay	Winter 1941-42	--	13.70	15.30	16.30	16.40	--	--	--	--	--
Mezen Bay	Winter 1925	9.50	15.26	16.98	19.57	23.02	26.35	28.41	31.77	34.84	--
	Winter 1941-42	8.30	13.70	16.90	19.80	23.00	25.40	28.90	33.20	--	--
	Winter 1942-43	--	--	--	--	23.60	26.60	28.90	31.20	--	--
Chizha R.	Winter 1950-51	--	18.70	22.60	24.49	28.69	30.87	35.00	--	--	--
Shoina R.	Winter 1950-51	--	19.48	22.72	26.85	30.47	34.55	--	--	--	--
Semzha R.	Winter 1953-54	--	16.21	21.55	26.18	--	--	34.85*	--	--	--
Ness R.	June 1955	--	--	22.40	23.80*	--	--	--	--	--	--

* Number examined is less than 5.

Table 11.--Average size (cm) at-age for <u>Eleginus gracilis</u> in regions of the Pacific coast of the U.S.S.R. (Date is from several sources and summarized in Pokrovskaya 1960.)

Region	Time of study	Age groups (years)						
		1	2	3	4	5	6	7
Sea of Japan								
Amur Bay	1928-32	14.40	25.40	30.50	35.40	40.50	--	--
Tatar Strait-Sakhalin								
De-Kastri Bay	1928, 1932	14.10	24.20	30.20	33.40	36.10	37.30	--
Northwest part of Sakhalin Coast	?	--	23.80	28.70	32.60	36.20	38.50	40.50
Terpenia Bay	?	--	21.20	23.40	26.80	31.70	35.10	37.80
O-V Polonskaya	1955	14.20	--	--	--	--	--	--
Sea of Okhotsk								
Western Kamchatka	1927-32	16.90	28.40	35.40	39.90	42.80	46.90	52.00
Nagaev Bay	1949	13.30	17.44	--	--	--	--	--
Northeast part Sea of Okhotsk	1935	--	16.23	18.75	--	26.47	--	--
Western Bering Sea								
Anadyr Bay	1938	16.80	21.80	24.90	28.10	32.30	35.60	--

slowest, follows:

1. Western Kamchatka Peninsula coast
2. Northwest Sea of Japan
3. Sakhalin Island-Tatar Strait
4. Gulf of Anadyr
5. Kara Sea
6. White Sea
7. Northwest Sea of Okhotsk
8. Pechora (Barents) Sea.

As an example of size at age, average size at age 3 years in the Barents and Kara Seas ranges between 16.5 and 20.7 cm (Table 10) while Pacific coast populations display an average size at the same age of from 18.8-35.4 cm, mostly 29-35 cm (Table 11). Maximum sizes also differ. According to Andriyashev (1954) the largest specimen found in Arctic waters was 44 cm (weight - more than 700 g) while the largest specimens found in Pacific waters were about 53 cm (weight - 1,000 to 1,100 g). Maximum age in Arctic waters is 12 years (Pokrovskaya 1957) and apparently 8-9 years along the Pacific coast (Lestev et al. 1956). In other words, the Pacific form grows larger and dies younger than the Arctic form.

Foreign Catch Summaries and Methods

Saffron cod are taken, commercially in numerous areas (Fig. 3) and have been harvested for almost 100 years. Summaries of early catch statistics are unavailable; however, several authorities have mentioned historic catch levels for specific regions. Mantiefel (1945) stated that catches from the White Sea-Pechora Sea region of northwestern Russia ranged from 0.2 to 2,400 t between 1894 and 1944, and were perhaps as high as 4,000 t before that time. On the western Pacific coast of the

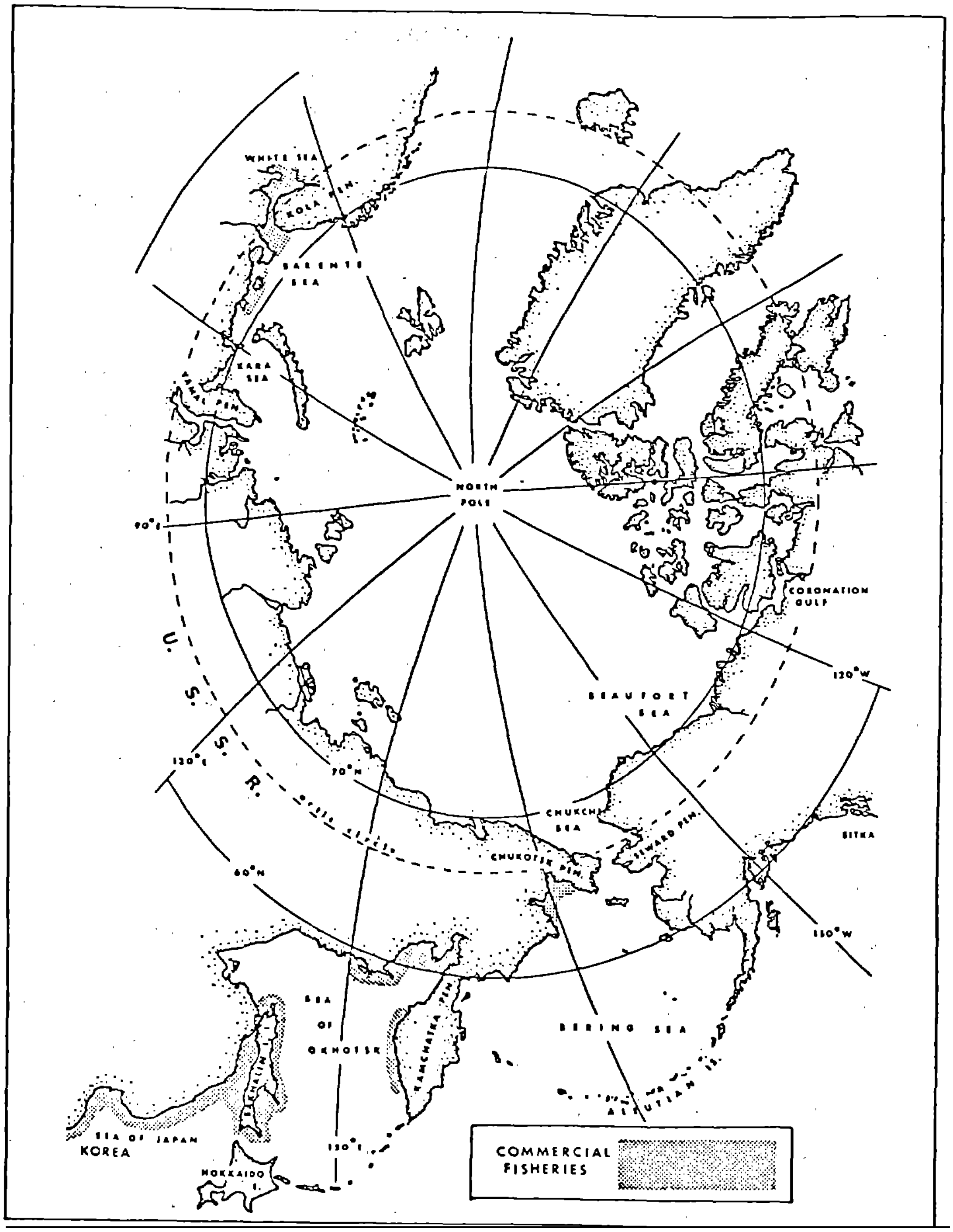


Figure 3 .---Locations of commercial fisheries for *Eleginus* spp. in waters of the U.S.S.R.

[U.S.S.R. early harvests from Peter the Great Ray ranged between 13 and 1,630 t from 1910 to 1930 (Svetovidov 1948). In other western Pacific coast regions harvests prior to the mid-1950s included 5,000 t in the Maritime Territory, primarily Tatar Strait and around Sakhalin Island (Lestev et al. 1956), and up to 15,000 t off the Kamchatka Peninsula, apparently off both the Okhotsk and Bering Sea coasts (Andriyashev 1954).

Annual catch statistics after 1955 are available through the FAO. Total catches (all areas combined) until 1973 fluctuated between 6,600 and 22,300 t and have risen almost continuously into the most recent periods reported (Table 12). Harvests for the latest 4 years available, 1977-80, have averaged over 39,000 t. Most of these recent harvests have come from the "northwest Pacific" reporting region and have averaged nearly 90% of the total annual landings since 1974 (Source: FAO Statistical Yearbooks). Different regional fisheries appeared to target on different age groups: e.g., 2- to 3-year-olds in Peter the Great Bay and other areas near Vladivostok (Svetovidov 1948; Berg 1949); 2- to 5-year-olds in the Sakhalin region (Lestev et al. 1956); and 3- to 4-year-olds in the Sea of Okhotsk and Kamchatka waters (Berg 1949; Semenenko 1973).

Saffron cod are usually fished in the Soviet Union during late fall-winter. Product quality may influence timing of harvests since feeding and pre-spawning fish have good flesh characteristics while spent individuals contain very low fat content and their flesh is very watery until several months after spawning (Lestev et al. 1956). The magnitude of recent harvests suggests a greater interest in harvesting these gadids, but current available information from the U.S.S.R. does not shed light on whether the saffron cod fishery is not a prime activity or merely an offseason venture.

Table 12.--Annual harvests (t) of saffron cod by area in the U.S.S.R.

	AREAS			
Year	U.S.S.R. inland waters (FAO area 7)	Northeast Atlantic (FAO area 27)[b]	Northwest Pacific (FAO area 61)[c]	TOTAL
1965	a	2,500	19,600	22,100
1966	a	2,500	7,000	9,500
1967	a	2,100	11,200	13,300
1968	a	3,400	18,900	22,300
1969	a	2,000	18,500	20,500
1970	a	2,500	19,500	22,000
1971	a	2,800	14,100	16,900
1972	a	2,100	19,900	22,000
1973	a	4,400	22,000	26,400
1974	a	6,649	26,700	33,349
1975	a	3,624	29,594	33,218
1976	a	NR	27,500	27,500
1977	a	4,140	36,885	41,025
1978	6,127	--	35,187	41,314
1979	86	2,866	35,183	38,135
1980	360	2,641	33,300	36,301

[a] Apparently included in FAO area 27

Source: 1965-73 -- FAO, 1974 Yearbook of Fishery Statistics Vol. 36
1974-77 -- FAO, 1977 Yearbook of Fishery Statistics Vol. 44
1978-80 -- FAO, 1980 Yearbook of Fishery Statistics Vol. 51

[b] Marine Atlantic waters north of lat. 36° N. from 68°30' E. to 42°00' W.

[c] Marine Pacific waters north from lat. 20° N. to the Gulf of Anadyr and west of long. 175° W.

Residents of each fishing region generally conduct the harvest since saffron cod do not form massive aggregations that would interest large fishing fleets. These "cottage industry" operations are not highly mechanized and fishing gear includes hook and line, trawls, beach and Danish seines, gillnets, hoop-nets, and fyke nets (Andriyashev 1954; Lestev et al. 1956; Andreev 1962; and Fridman 1969).

Stationary gear (i.e., fyke, hoop, and pound nets) is usually used for fishing, and is well suited to catch saffron cod which are often nearshore and in shallow water. The gear is set at nearshore locations before winter ice formation and the position of the catch bag or impoundment section is marked by a buoy. These nets are located in areas covered by shorefast ice so that the movement of adjacent ice floes will not damage the trap or distort it. Once ice forms, fishermen cut a hole over the impoundment section and periodically lift this part of the trap to the surface to remove the catch. Lestev et al. (1956) stated that fyke nets fished in the Sakhalin region could achieve average catches of 1.5-2.0 t per season. An example of stationary fishing devices used specifically for catching saffron cod is illustrated in Figure 4. Although several sources mention that trawls are used in saffron cod fisheries, the extent of trawling is not well documented.

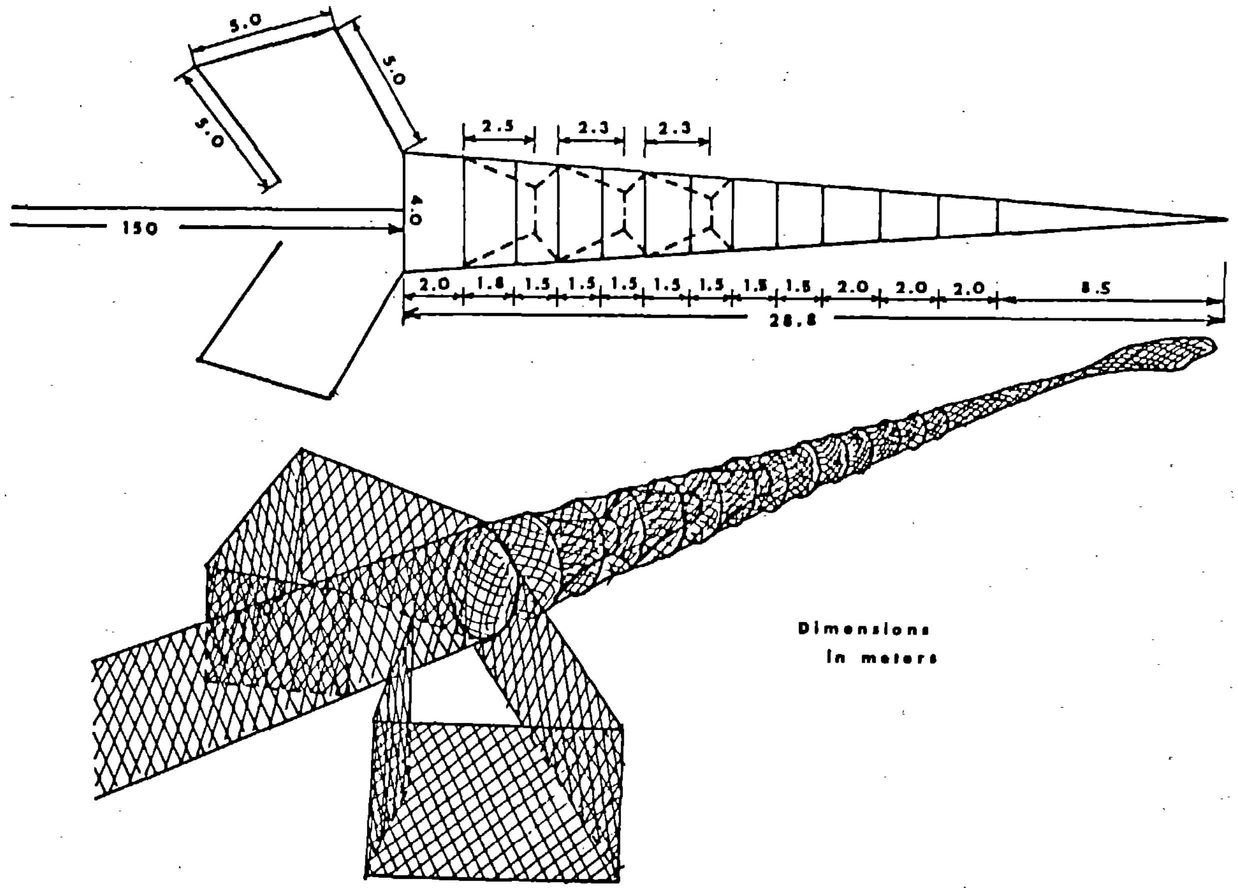


Figure 4.- Diagram of a traditional fishing device used for capturing saffron cod in Pacific waters of the U.S.S.R. (from Andreev 1962).

MATERIALS AND METHODS

Information Sources Other Than Foreign Literature

Aside from a few historic accounts regarding distribution (i.e., Turner 1886; Alverson and Wilimovsky 1966), the main body of information on saffron cod in western Alaska waters comes from three sources:

1) an intensive NMFS trawl survey of Norton Sound and the northern Bering Sea that was part of the 1976 Bureau of Land Management/ Outer Continental Shelf (BLM/OCS) baseline survey of western Alaska;

2) an extensive series of 1979 trawl surveys performed by NMFS as part of an annual assessment of king crab populations in the eastern Bering Sea; and

3) a brief trawl survey by NMFS in Norton Sound during 1982 to obtain biological information on marine resources of that region.

All 3 years of NMFS trawl surveys were initially designed to estimate the spatial distribution, abundance, and population characteristics of fish and shellfish of current or potential economic importance in western Alaska. Unfortunately, other marine resource priorities resulted in alterations to some of the surveys. The 1976 and 1979 studies were completed as anticipated but the 1982 work was substantially altered because of an urgent need for additional information on king crab in the eastern Bering Sea. Consequently, most data used in this paper were obtained from the 1976 and 1979 surveys.

Area Surveyed

The total area investigated during each of the yearly surveys differed substantially and ranged throughout the eastern Bering Sea and along the coast of western Alaska from Bristol Bay northward into the southeastern Chukchi Sea (Fig. 5). Portions of those survey areas selected for these analyses focused on Norton Sound and adjacent waters where saffron cod concentrations were assumed to occur. Specifically, the selected areas were:

1) Norton Sound and the northern Bering Sea including waters north of a line from the mouth of the Yukon River to St. Lawrence Island, east of the U.S.-U.S.S.R, Convention Line of l867, and south of Bering Strait; and

2) the northeastern Bering Sea including waters north of lat 58°N (approximately Cape Newenham), shoreward from about the 50 m isobath and/or the Convention Line, and south of St. Lawrence Island (Fig. 6).

The shoreward limit of the survey area was the 9 m isobath, the shallowest depth possible for safe survey vessel operations. The greatest depth found in any of the above mentioned areas was 65 m.

Survey Approach and Rationale

For sampling and analytical purposes, the survey areas were subdivided into subareas (Fig. 7). Demersal trawling stations were arranged in a systematic pattern within each subarea or stratum. Station density within each stratum was based on prior knowledge of distribution patterns of principal fish and shellfish species of the region (Table 13).

Because of the extensive amount of planned sampling and limited vessel time, it was necessary to deviate from usual daytime-only trawling protocol when the size of vessel crews and scientific field parties warranted. When possible, trawling operations were conducted on an around-the-clock schedule. Since 24-hour operations were often used,

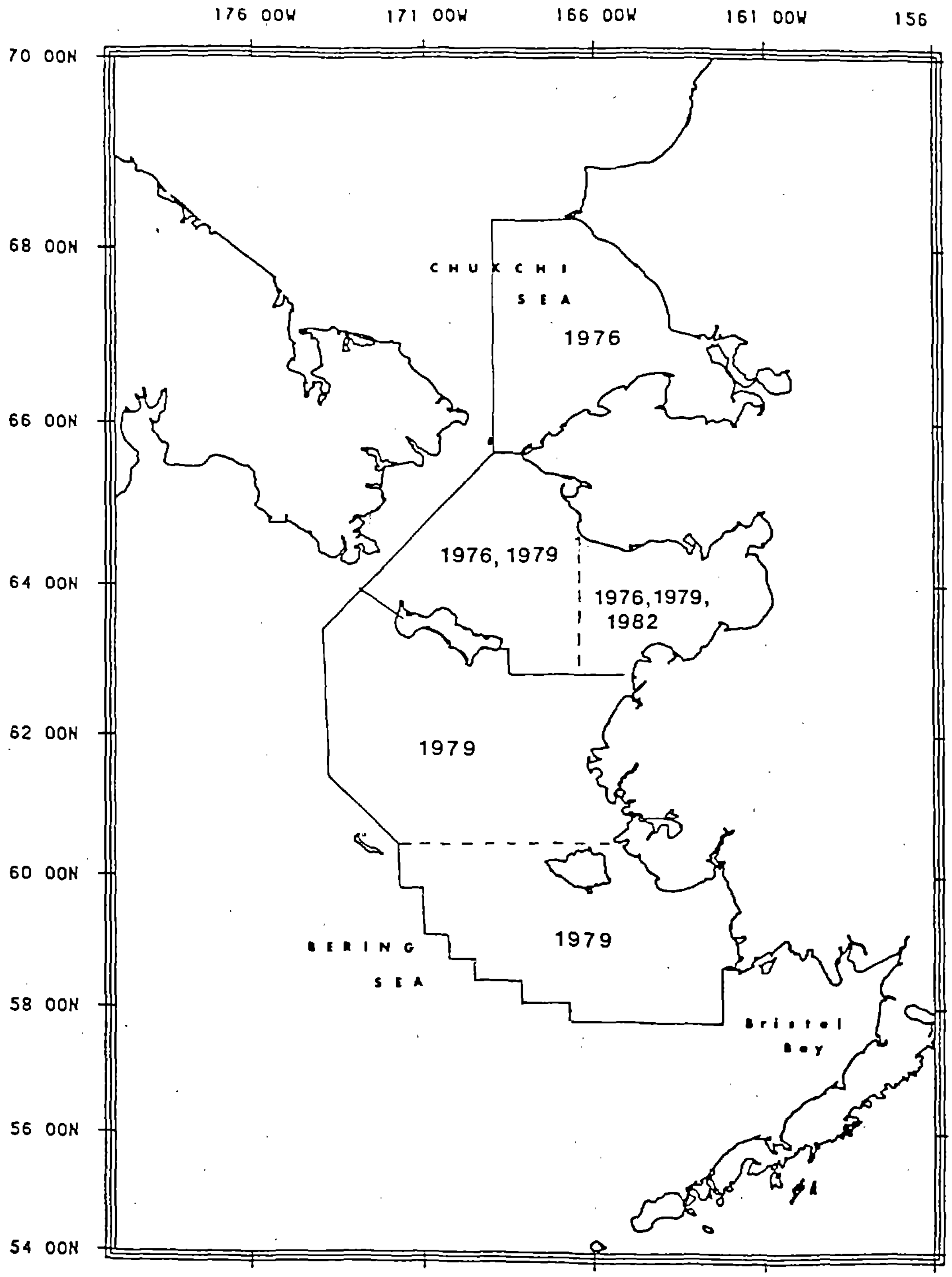


Figure 5. --Regions surveyed by the 1976-82 trawl surveys of the National Marine Fisheries Service that gathered data on saffron cod.

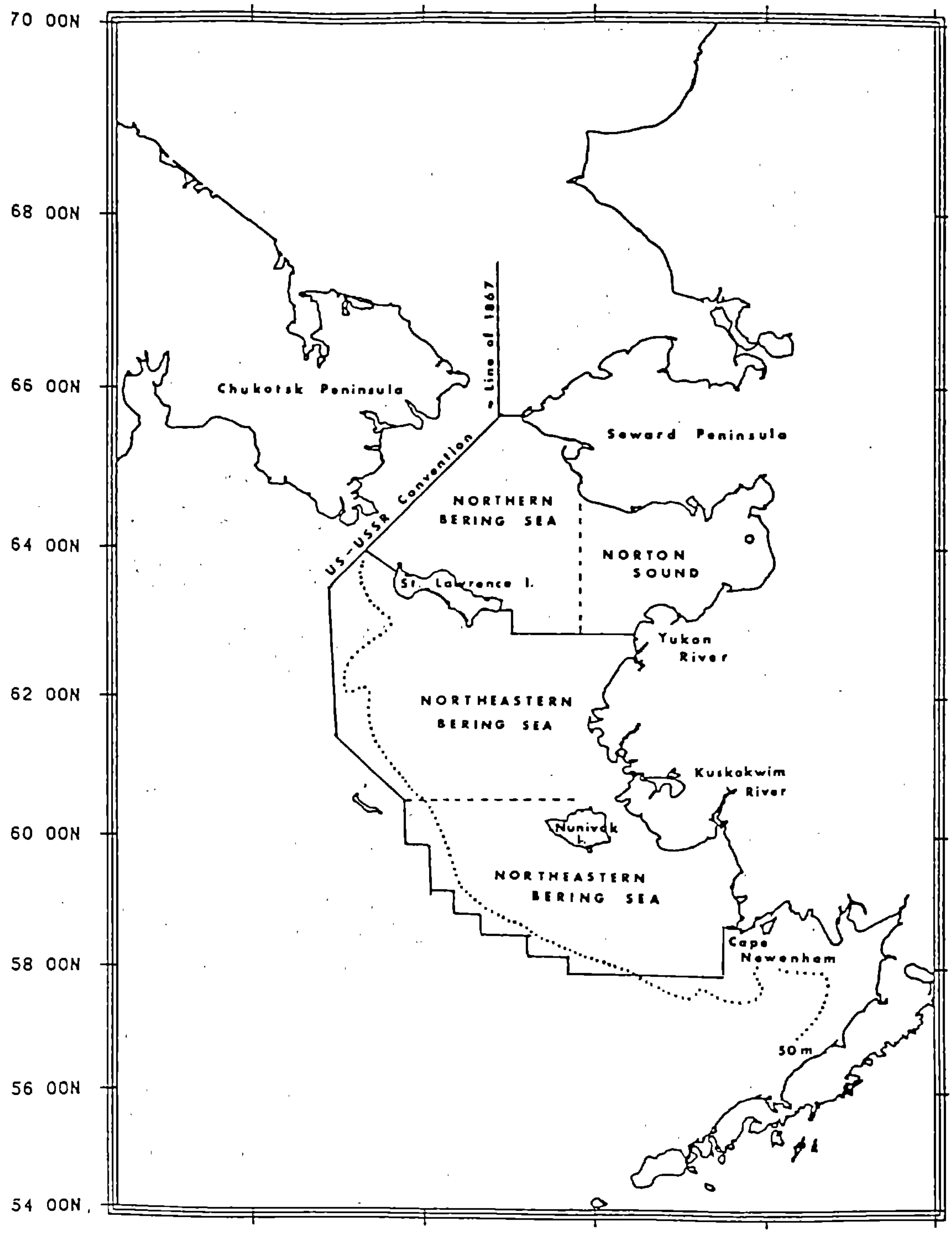


Figure 6. --Areas used for description of the saffron cod resource in western Alaska waters.

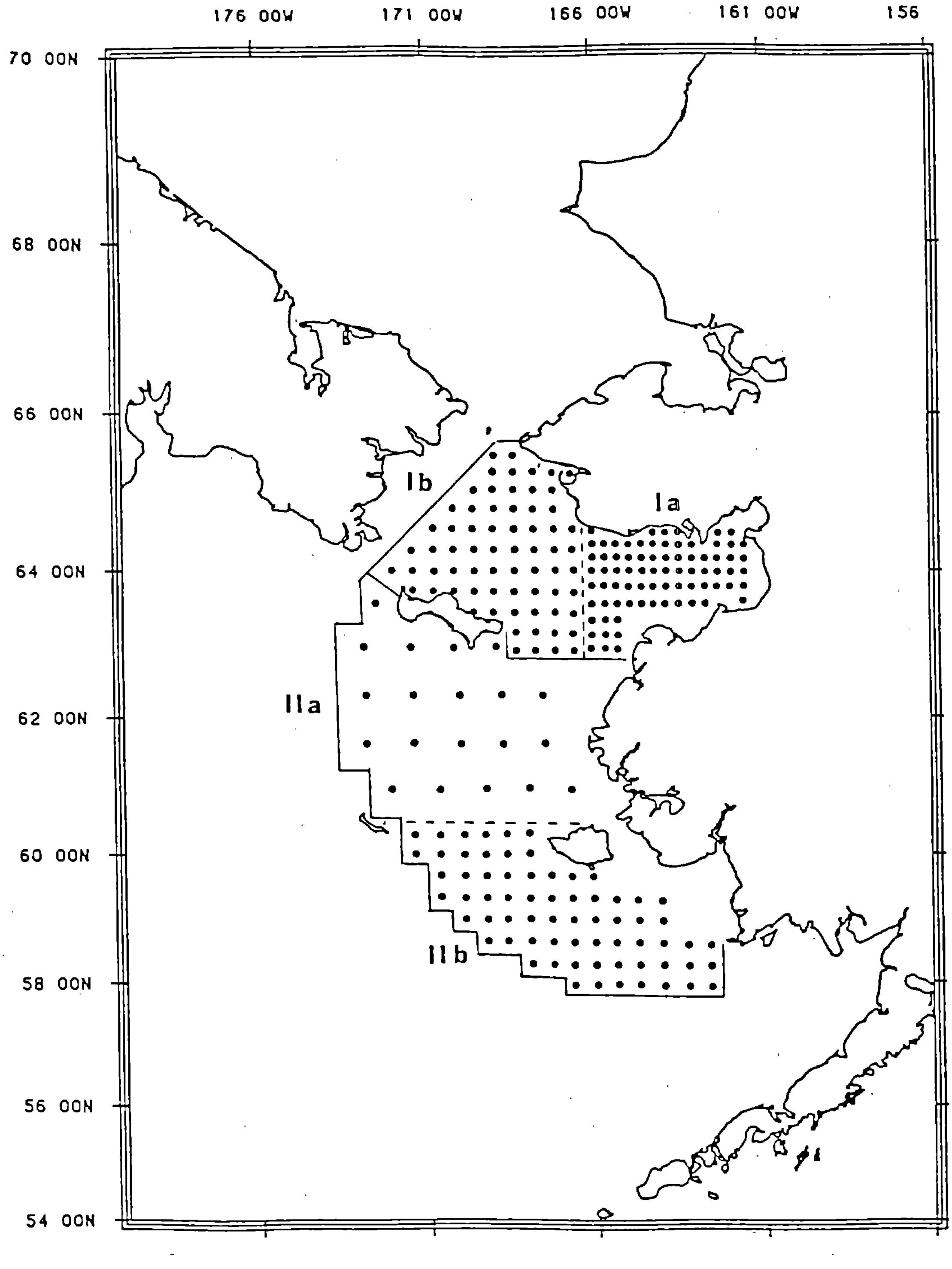


Figure 7.--Subareas used for analyzing the saffron cod resource and planned station sampling patterns within the subareas.

Table 13.--Station sampling density by subarea during the 1976 and 1979 National Marine Fisheries Service trawl surveys of Norton Sound and adjacent areas of western Alaska.

Year	Subarea	Subarea description	Stations planned for sampling	Planned sampling density (sq km/sta)	Stations successfully trawled
1976	Ia	Norton Sound	90	343	75
	Ib	Northern Bering Sea	64	772	46
1979	Ia	Norton Sound	90	343	79
	Ib	Northern Bering Sea	40	772	39
	IIa	Northeastern Bering Sea, Nunivak I. to St. Lawrence I.	20	5,488	14
	IIb	Northeastern Bering Sea, Cape Newenham to Nunivak I.	69	1,372	63

catches of saffron cod from nighttime trawling were adjusted according to day-night fishing power experiments conducted during the 1976 Norton Sound trawl survey.

Vessels and Fishing Gear

The two vessels used during the surveys were the NOAA research ship Miller Freeman and the fishing vessel Paragon II. The Miller Freeman is a 1500 gross ton, 2200 horsepower stern trawler with an overall length of 65.5 m equipped with a variable pitch propeller. The Paragon II is a 196 gross ton, 1125 horsepower combination trawler/crabber with an overall length of 33.8 m. The Miller Freeman was used during all surveys associated with these analyses while the Paragon II was used only during a portion of the 1979 surveys (Table 14).

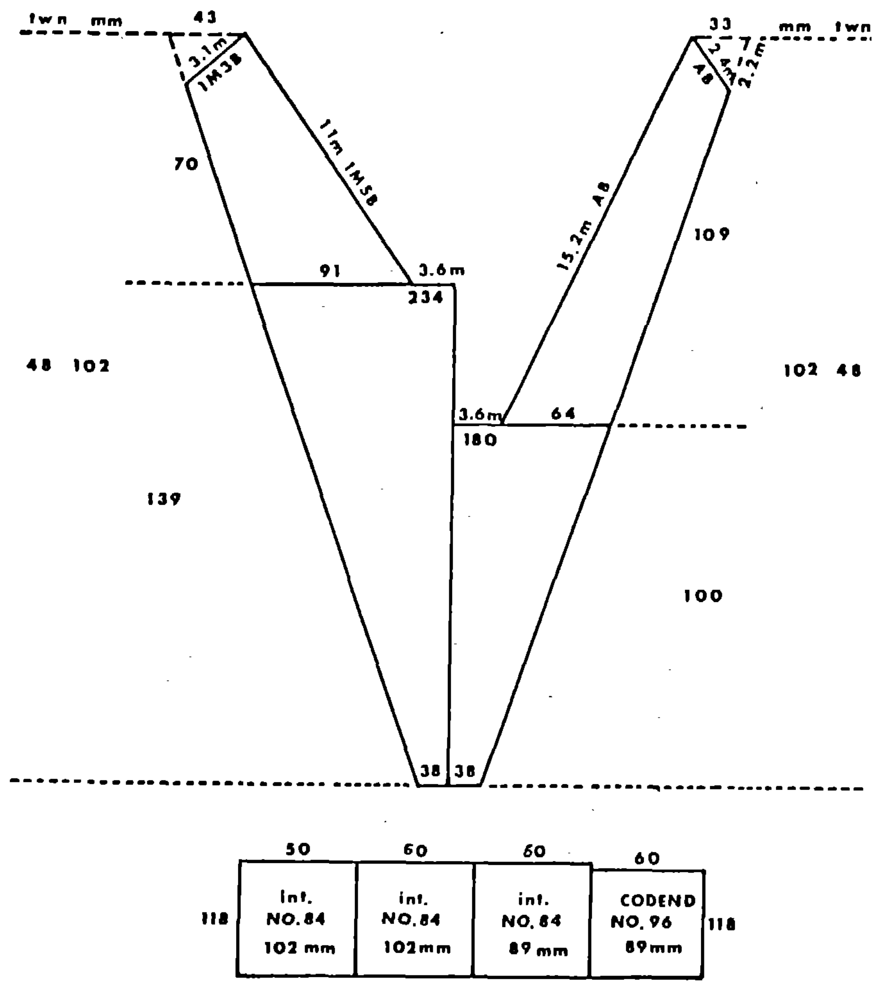
A modified eastern demersal trawl was the fishing gear used during all surveys (Fig. 8). It was fished with 2.1 m x 3.0 m steel V-design trawl doors and its codend was lined with 31.8 mm (1.25 in) mesh web for retention of small fish. A set of four 45.7 m dandylines were fished with the demersal trawl, two connected to each wing.

Sampling Procedures

Prior to actual demersal fishing operations, some stations were first surveyed by echosounder to establish the condition of the bottom. At inshore stations where highly uneven or muddy bottom might be encountered, a 4 km echosounder transect was run over the station to determine both its trawlability and a course that would provide a uniform depth throughout the length of the tow. If the echosounder trace indicated rough bottom, the vessel would proceed to the next station rather than spending additional time searching for a trawlable area. If the echosounder trace indicated

Table 14.--Numbers of stations surveyed by vessel in those portions of National Marine Fisheries Service surveys used in the analysis of the saffron cod resource off the coast of western Alaska.

Vessel	Year	Dates vessel used	Stations trawled
Miller Freeman	1976	Sept. 2-Oct. 10	121
Miller Freeman	1979	July 15-Aug. 5	118
Paragon II	1979	July 25-Aug. 21	77



Netting: Dacron polyester body and wings, nylon intermediate and codend.

Headrope: 25.3 m, 13 mm diam., 6x19 galv. wire rope wrapped with 8 mm polypropylene rope.

Footrope: 34.2 m, 16 mm diam., 6x19 galv. wire rope wrapped with 8 mm polypropylene rope.

Breastlines: 13 mm diam. braided nylon, 5.5 m Long.

Riblines: 13 mm diam. braided nylon, extending length of first intermediate (webbing hung-in).

Flotation: 31-20.3 cm and 3-25.4 cm aluminum floats.

Dandylines: Single - 20 m, 19 mm diam., double - 45.5 m, one 19 mm, one 14 mm.

Otterboards: 2.1 x 3.1 m Vee.

Figure 8. --Diagram and description of the demersal trawl used during the trawl surveys of the National Marine Fisheries Service.

muddy bottom, a test set of 5-10 minutes was attempted. If extensive mudding of the trawl resulted from the test set, the station was abandoned.

Station positioning was by Loran C with radar fixes used at nearshore locations. The direction of the trawl tows varied depending on prevailing wind and sea conditions. Tows generally were made into the wind. The trawl was set prior to reaching the station so that the actual station position was reached about midway through the trawl tow. Towing speed averaged about 6.5 km/hr. Demersal tow duration was 30 minutes. Timing of the tow was started after the vessel was slowed to allow the trawl to settle to the bottom and as the trawl winch brake was set. The average bottom distance trawled was 1.65 km (range: 0.7-3.2 km).

Initial Handling of Trawl Catches

The method of processing trawl catches depended on catch size. If the catch did not exceed the 1,150 kg capacity of the sorting table, it was dumped directly onto the table and completely processed. For larger catches, only a subsample of the catch was processed. The subsampling method used was based on a system developed by Hughes (1976). This system is described below.

Sorting and Weighing the Trawl Catch

After the catch was on the sorting table, it was sorted by species into bushel baskets and smaller plastic containers. For catches having a single dominant species, two or three baskets were filled simultaneously with that species and the baskets were removed from the table in a set, weighed, and placed on deck as a group. While the dominant species was being sorted, other species were sorted into single baskets or other containers. The procedure of filling single baskets or sets of baskets was repeated until the entire catch or subsample of the catch was sorted and weighed.

Baskets were placed on deck in processing sequence in order to identify baskets of fish that came from the top, middle, and bottom of the trawl sample. Baskets of fish were weighed to the nearest 0.5 kg on a 141 kg capacity platform scale or to the nearest 0.1 kg on a hand held spring scale when small catches occurred. Numbers of individuals by taxonomic group were determined by direct count or from subsample counts which were expanded to the total catch.

Subsampling for Biological Data

Catches of saffron cod were further processed for length composition, length-weight relationships, and samples of age structures. A random sample of from 200 to 300 individuals was taken for length frequency from each catch. The procedure used to obtain a random sample was. as follows: as the baskets were taken from the sorting table and weighed, they were aligned on the deck in the order by which they were filled. When two or more baskets were filled simultaneously, they were kept together as parallel rows. To arrive at the desired number of fish for the subsample, one row was picked at random to represent the catch. If there were still too many fish, the sample was further reduced by picking baskets from the front, middle, and end of the row. This procedure provided a subsample that would not be affected by any size stratification that might have existed on the sorting table. If an entire catch resulted in numerous baskets of very small individuals (400-1000 fish/basket), the sample was obtained by taking random portions of the picked baskets from the front, middle, and end of the row. When catches were equal to or less than the desired subsample size, all individuals were measured.

Length-frequencies were recorded onplastic length-frequency strips. The fish were first examined to determine their sex, then measured to the nearest centimeter from the tip of the snout to the middle of the caudal rays. The sex of small juvenile fish was not always determined because immature individuals could not be easily sexed by a cursory examination. Samples for obtaining age structures and length-weight information were selected so as to obtain representative length classes of fish for each sex. At times, otoliths or length and weight measurements were collected in conjunction with length-frequency samples, but at other times the aforementioned data were selected independently. Unfortunately, otoliths and length-weight data were not always collected on the same individual.

Separate samples for age and length-weight were obtained from specific geographic areas. Two areas were identified for the 1976 and 1979 surveys. The boundary between the two areas in 1976 was Bering Strait since that location was thought to be a point of separation between fish populations in the Norton Sound-northern Bering Sea region and in the southeastern Chukchi Sea. In 1979 the boundary between the two areas was St. Lawrence Island and the region between the island and the mouth of the Yukon River.

Otoliths were used for determining age of saffron cod. In 1976 up to six otoliths were obtained for each 1 cm size group by sex and geographic area (e.g., for 10 cm fish, otoliths were obtained from as many as six males and six females in each geographic area; for 11 cm fish, otoliths from six males and six females, etc.) In 1979 up to 20 otoliths were obtained for each 1 cm size group, without regard to sex. All otoliths were stored in 50% ethanol in glass vials. Otolith samples were obtained from both the southeastern Chukchi Sea and Norton Sound in 1976 but only from the Norton Sound area in 1979.

Length and corresponding weight was measured for six individual fish for each sex-centimeter group per area in both 1976 and 1979. Individual fish were weighed to the nearest gram on a triplebeam balance. In addition to observations of length to total weight, measurements of gonad weight were also obtained for all individuals in the six fish per sex-centimeter groups in 1979. The comparison of gonad weight to length was used as a measure of sexual maturity.

Analytical Procedures

Standardization of Catches

Catches were standardized to a trawling distance of 1 km. These standardized catches were calculated-as follows:

$$CPUE_{ijk} = \frac{C_{ijkt} \times Q_{tk}}{D_{ijt.}},$$

where $CPUE_{ijtk}$ refers to the catch per unit of effort (kg/km) for species k at the j^{th} station in the i^{th} subarea and the t^{th} time of day. Catch (kg) is designated by C_{ijtk}, D_{ijt}. equals the distance trawled (km) computed from beginning and ending Loran C readings at each station, and Q_{tk} is the relative fishing power correction factor for time-of sampling (day or night) t in respect to species k.

The relative fishing power correction factor, Q, was obtained from results of comparative day-night fishing trials performed during the 1976 survey. The comparative experiments were designed so an analysis of variance (ANOVA) with a balanced factorial design of five fishing areas by two time intervals with four replicates for each factor could be conducted on catch-per-kilometer data for saffron cod in two size groups: <15 cm and >15 cm. Since neither weights nor numbers caught per kilometer were normally distributed when untransformed, all analyses were carried out on the variable ln (catch in kg/km + 1). Robson (1966) concluded that a logarithmic transformation of plaice, *Hippoglossoides platessoides*, catch rates tended to normalize distributions and equalize variances. Results of the experiment indicated a significant catch rate difference by time of day for both size groups (Table 15), with no area x time interaction (i.e., regardless of area, catches of both sizes of saffron cod were greater during the day than during the night). The relative fishing power was then calculated from the ratio of the means of the transformed catch rates. Since Q for saffron cod <15 cm was nearly identical to that for fish >15 cm (1.52 and 1.50, respectively), the value for the latter size group was used for the entire nighttime catch (i.e., all saffron cod catches were multiplied by 1.50). A Kolomogrov-Smirnov nonparametric two-sample test as described by Seigel (1956) was used to compare size frequency data from day and night catches. This test failed to detect differences in sizes of saffron cod caught during the day and night at a = 0.001.

Catch Per Unit Effort (CPUE) by Stratum and Total Survey Area

The mean CPUE by stratum (or subarea) was computed as follows:

$$\overline{CPUE_i} = \frac{\sum_{j=1}^{n_i} CPUE_{ij}}{n_i}$$

Table 15.--Analysis of variance and f-ratios for catch rates of saffron cod in day-night fishing experiments during the 1976 survey (random variable, ln (kg/km + 1)).

Species	Design variable	Degrees of freedom	Mean square	F
Saffron cod < 15 cm	Area	4	5.55	24.77*
	Time	1	1.75	7.79*
	Area x Time	4	0.32	1.44
	Error	30	0.22	
Saffron cod ≥ 15 cm	Area	4	16.68	73.68*
	Time	1	1.65	7.30*
	Area x Time	4	0.45	1.98
	Error	30	0.23	

*Significant at a = 0.05

where n_i equals the number of successfully trawled stations in the i^{th} stratum.

The variance of this estimate was:

$$VAR(CPUE_i) = \frac{\sum_j (CPUE_{ij})^2 - n(\overline{CPUE}_i)^2}{N_i(n_i-1)} .$$

The overall mean CPUE for the entire survey area ($CPUE_t$) was determined as a weighted sum of the mean CPUE values by stratum:

$$\overline{CPUE}_t = \frac{\sum_i (CPUE_i \times A_i)}{A_t} ,$$

where A_i equals the area of the i^{th} stratum and A_t equals the area of all strata combined.

The variance of this estimate was determined as a weighted sum of the individual variances by strata:

$$VAR(\overline{CPUE}_t) = \sum_i ((A_i/A_t)^2 \times VAR(\overline{CPUE}_i)).$$

Standing Stock Estimates

Population weight--Biomass estimates by stratum followed the methods described by Alverson and Pereyra (1969):

$$\hat{B}_i = \overline{CPUE}_i/q,$$

where B_i equals the estimated standing stock by weight in the i^{th} stratum, and q is a coefficient of catchability:

$$q = C(\overline{W}/A_i),$$

where $\overline{W}$ is the average effective trawl width and C is the coefficient of vulnerability for those fish of sufficient size to be retained by the trawl during a standard tow. The coefficient of vulnerability consists of two components: 1) C_h, the vulnerability of those fish that actually come within the influence of the trawl; and 2) C_u, the proportion of the total fish in the volume of water above the seabed area swept by the trawl which would come within the trawl's influence. A coefficient of vulnerability for saffron cod is not known, but has been assumed to be constant and equal to 1.0. The estimated area covered by the trawl when towed 1 km (i.e., $\bar{a}$)is equal to 0.017 km^2, based on an estimated 17 m horizontal opening of the trawl while fishing. Therefore, the biomass within stratum i can be estimated:

$$\hat{B}_i = \frac{A_i}{w} \overline{CPUE_i},$$

having a variance of:

$$VAR\ \hat{B}_i = (A_i/\bar{a})^2 \times VAR(\overline{CPUE_i}),$$

where $\bar{a}$ is the mean bottom area sampled in 1 km trawl distance (km^2). Ninety-five percent confidence intervals of the estimated biomass are then computed:

$$\hat{B}_i \pm t_{(0.5)(n_e)} \sqrt{VAR\ \hat{B}_i}\ .$$

The biomass estimate for saffron cod for a total survey area was obtained by summing the subarea biomasses and variances, respectively:

$$\hat{B}_T = \sum_{i=1} \hat{B}_i;$$

$$VAR\ \hat{B}_T = \sum_{i=1} VAR(\hat{B}_i)$$

$$= \sum_{i=1} ((A_i/\bar{a})^2 \times VAR(\overline{CPUE_i}))\ .$$

Effective degrees of freedom (n_e) for the calculation of confidence limits for biomass estimates for a total survey area were determined according to Cochran (1963):

$$n_e = \frac{\left(\sum_{i-1} f_i \times VAR(CPUE_i)\right)^2}{\sum_{i=1} \frac{f_i^2 \times (VAR(CPUE_i))^2}{n_i - 1}}$$

where

$$f_i = \frac{N_i(N_i - n_i)}{n_i},$$

and N_i equals the total number of sampling units in the i^{th} stratum $(A_i/\bar{a})$ and n_i equals the number of stations in subarea i.

Population numbers--Estimates of population numbers within strata and for a total survey area were determined in the same manner as population weight, simply substituting numbers for weight in all calculations. Fishing power coefficients used to standardize catch rate by number and between day and nighttime trawling were identical to those used for catch rate by weight.

Size Composition

Size composition by numbers in the population was estimated for those strata where sufficient length-frequency data were collected. Length-frequency data for individual stations were expanded by a weighting factor to give an estimate of the total standard catch in numbers by size and sex:

$$\hat{N}_{ijlm} = n_{ijlm} \times P_{ij} / \sum_{m=1}^{3} \sum_{l=1}^{L} n_{ijlm},$$

where N_{ijlm} equals the estimated number of individuals of size category 1 and sex m at the j^{th} station of stratum i where length information was collected, and L is the total number of size categories. The independent variable n_{ijlm} is the number of fish in this category actually measured, and the weighting factor is the ratio of the total number of individuals per standard tow (P_{ij}) to the number of individuals measured in the length frequency sample. The number of fish by size-sex category for individual strata (P_{ilm}) was obtained by summing the size-sex categories for those stations where this information was available and expanding this sum to the total standing stock in each subarea:

$$\hat{P}_{ilm} = \frac{\sum_{j=1} N_{ijlm}}{\sum_{j=1} \sum_{l=1} N_{ijlm}} \times P_{i\cdot}$$

An overall estimate of the standing stock size composition for a total survey area (P) was obtained by summing the population numbers by size-sex category (P_{ilm}) for all strata.

Length and Weight

For most species of fish, the relationship between length and weight takes the form:

$$\text{weight} = a \times (\text{length})^b.$$

A least-squares linear regression procedure was used to fit saffron cod length-weight observations grouped by sex to the logarithmic transformation of this equation:

$$\log(\text{weight}) = \log a + b \times \log(\text{length}).$$

Estimates of the coefficients a and b, and a coefficient of correlation r were determined.

Age and Growth

Age-length tables were constructed by sex for the 1976 survey. These tables show the number of actual observations in each size-age class and estimates of mean length-at-age. These tables were used as keys to represent the age-length relationships for the entire survey area. The age-length table constructed from the 1979 survey data was not separated by sex.

From the above keys, expanded age-length tables were constructed by sex and area using the method of K. R. Allen (1966). This method applies the age-length relationship for a region to population estimates in numbers at length, resulting in a table of numbers at-age for each length for the area. To make this conversion, the proportion of ages within any length interval were calculated from the keys (e.g., 10% were age 2 and 90% were age 3) and then applied to the corresponding numbers in the length-frequency distribution data. The result is an age-length table in which actual observations have been expanded to estimates of total numbers of individuals in the population at age and length. Estimates of the age composition (numbers of fish in each age class) for the population were obtained by summing the values in the expanded age-length table over all lengths by age. (In applying size composition data to the age-length key, lengths outside the length range of the key were not assigned ages. This sometimes resulted in minor discrepancies between population estimates (numbers) for some strata and the sum total of numbers of individuals-at-age in those strata.)

Mean lengths-at-age from the expanded age-length tables were used to fit growth curves in the form:

$$l_t = L_\infty (1-e^{k(t-t_o)})$$

where l_t equals length in centimeters at time t (years), L_∞ is an asymptotic length (cm), k (per year) is a growth completion rate, and t_o (years) is the intercept of the curve with the t axis. Three methods were used that differ only in the data used for fitting the curve: 1) curves were fit to all mean lengths-at-age as calculated from the expanded age-length table by area; 2) mean lengths which might have been biased because the complete size range for an age was not fully recruited (vulnerable) to the fishing gear were deleted as were mean lengths derived from a relatively small number of observations at-age in the age-length key; and 3) the origin

(0,0) was added as a data point to the above selected data set (i.e., set NO. 2) in order to compensate for missing data points for young ages which were not fully vulnerable to the survey sampling gear. Age at "complete" recruitment or vulnerability was estimated using logarithmic catch curve analysis (Ricker 1975, p. 34). The parameters k, L_∞ and t_0 were estimated by the iterative method of Fabens (1965).

Natural Mortality

The saffron cod population in Norton Sound offers an ideal situation for estimating natural mortality since there is no fishing or other man-induced impacts upon the stock.

Estimates of natural mortality were derived from declining relative abundance of cohorts over time and from single season age frequency analysis. The data used were the estimated numbers in the population by age from the 1976 and 1979 surveys. Age groups older than 4 years were not used because their sample sizes were too small.

Chapman and Robson (1960) showed that unbiased estimates of annual survival and mortality rates could be derived from age class catch curves for a single season with the assumptions of constant year-class strength and survival rates. Furthermore, all fish beyond some minimal age had to be fully vulnerable to the sampling gear. Minimum age of full vulnerability to the sampling gear was determined through a chi-square test described by Robson and Chapman (1961). This test compares observed numbers-at-age with expected age group population sizes, using expected values determined by back calculation from the oldest tested age group in the population (i.e., age 4 years) with two estimates of survival rates. The estimated survival rates were: Chapman and Robson's (1960) estimate, T/n+T-1; and Heincke's (1913) estimate, $n-N_0/N$, where n equals the total population size (e.g., $N_o + N_1$ +....+ oldest age group), T denotes an arithmetic progression without the youngest age group (i.e., $1N_1, + 2N_2 + 3N_3 + \ldots$), and N_0 equals the population size of the youngest age group tested. A chi-square test statistic was then determined by the formula:

$$\text{Chi-square}_{df=1} = \frac{\left[\frac{T}{n+T-1} - \frac{(n-N)}{n}\right]^2}{\frac{T(T-1)(n-1)}{n(n+T-1)^2\ (n+T-2)}} \ .$$

Age groups 0-4 years, l-4 years, and 2-4 years were tested to determine if the minimum age group fully "recruited" was young of the year, 1-year-olds or 2-year-olds, respectively. If the test statistic value for the tested age group was less than 3.84 (chi-square value at a = 0.05 with 1 degree of freedom), then that group was assumed to include all ages of fish fully vulnerable to the sampling gear. Once the age group set was determined, a linear regression of the natural log of population size by age group over time (years) was used to estimate mortality (Z) with the equation:

$$\ln Nt = -Zt + \ln N_O,$$

where N_t is the number of an age group alive at time t (years) and N_0 is the number present in the youngest age group fully vulnerable to the sampling gear. In addition to performing these analyses on populations present during each survey year, other estimates of Z were derived by a linear regression of mean age-group sizes using a combination of the 1976 and 1979 data.

RESULTS

This section describes what is known about the saffron cod resource in Norton Sound and adjacent western Alaska regions. In addition to data from the NMFS trawl surveys, information presented here will draw material from the foreign literature treated previously to aid in describing specific aspects of saffron cod life history and distribution in these North American waters.

Distribution

Saffron cod occur along the coast of Alaska as far south as Sitka (Schultz and DeLacy 1936) but, with an exception of northern Cook Inlet (Blackburn et al. 1980), there is no mention of concentrations of this species anywhere in the northeast Pacific. Their presence becomes notable in areas of the eastern Bering Sea near the Kuskokwim River Delta and northward.

The 1979 NMFS trawl surveys resulted in the most extensive coverage ever of the eastern Bering Sea shelf and thoroughly delineated the main region of saffron cod distribution. Trawl catches from these surveys indicated a continuous presence of saffron cod along the western Alaskan coast from Cape Newenham north to the northernmost sites sampled near Port Clarence on the southwestern coast of the Seward Peninsula (Fig. 9). The earlier (1976) BLM/OCS baseline study sampled into the southeastern Chukchi Sea as well and noted the presence of this species continued as far north as Cape Seppings between Kotzebue Sound and Point Hope.

The 1976 and 1979 surveys were performed during September-October and July-August, respectively. From this information, the summer distribution of saffron cod appears ubiquitous in shallow water areas of western

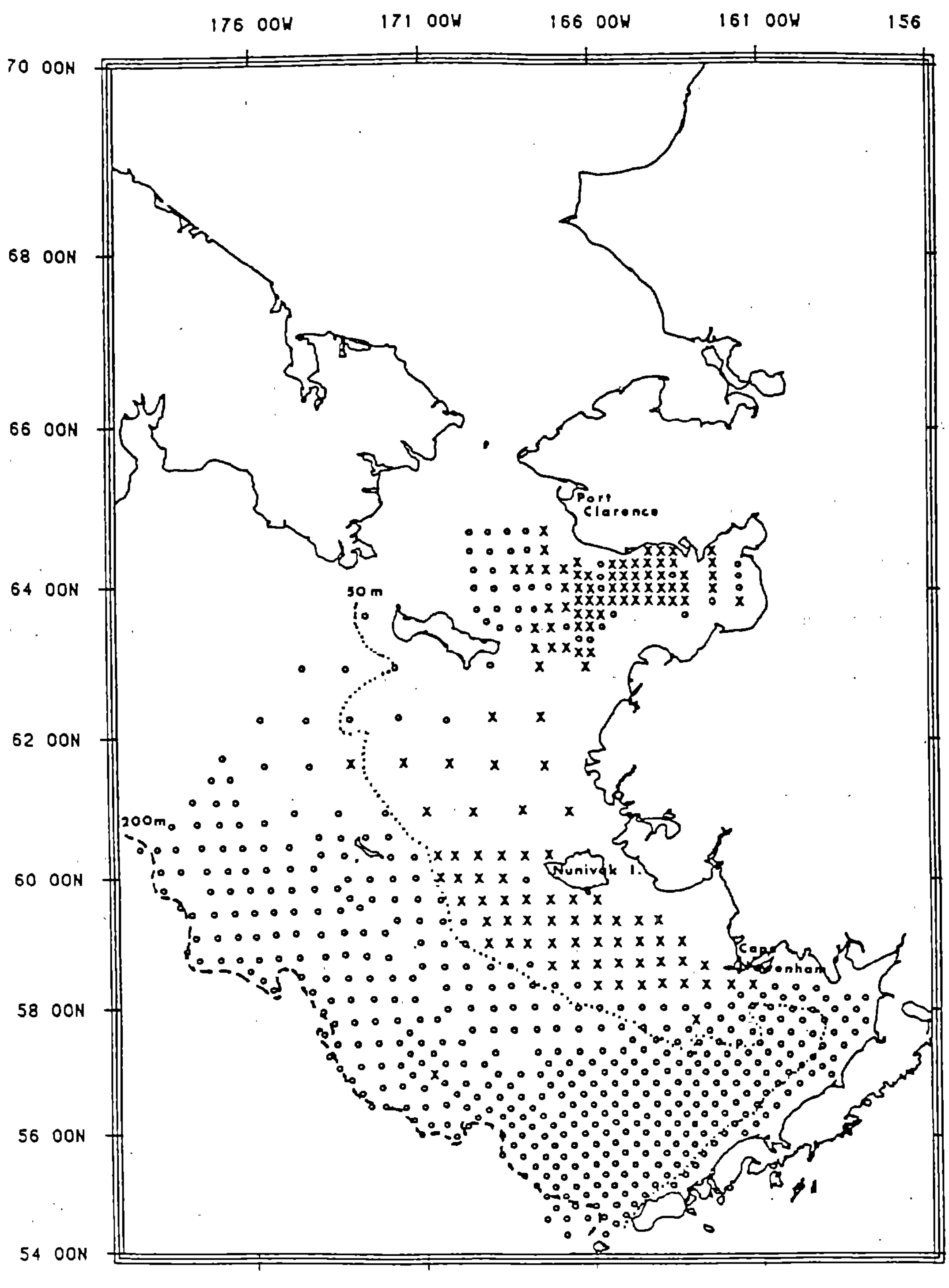


Figure 9.--Occurrence of saffron cod (marked by x's) at locations sampled during trawl surveys of the National Marine Fisheries Service in Norton Sound and the Bering Sea, July-August 1979.

Alaska. Nearly all fish of this species were found at depths less than 50 m throughout the northeastern Bering Sea and Norton Sound, and most occurred at less than 40 m. As with Soviet accounts for the western Pacific and Arctic, smaller individuals were found shallower and in more nearshore locations than larger fish. Most small fish (<19 cm) were in depths less than 30 m, along the coast from Cape Newenham past the mouth of the Yukon River and into Norton Sound to Golovin Bay (Fig. 10). Large saffron cod, i.e., individuals 19-35 cm, were found in patches somewhat more offshore in areas off Nunivak Island and in Norton Sound (Figs. 11,12). The 1976 study also found high concentrations of these larger fish in areas along the southern coast of the Seward Peninsula and in Port Clarence (Fig. 13). The size groups of <19 cm and 19-35 cm were chosen to describe saffron cod distribution because size-at-age data indicate that the former size group includes fish that are mostly less than 2 years old, while the latter represents individuals that are about 2 years old and older.

Nearshore assessment around the Yukon River Delta was not attempted during any of the survey-s because the Delta is very shallow with an extremely muddy bottom. These conditions precluded trawling.

Population Estimates

The NMFS trawl surveys identified a relatively large saffron cod population for western Alaska. In 1976 the Norton Sound region alone contained an estimated 750 million fish with an associated biomass of about 16,500 t (Table 16). This amount comprised over 90% of the total saffron cod biomass estimated for the entire 1976 survey region that included Norton Sound, the northern Bering Sea, Kotzebue Sound, and the southeastern Chukchi Sea. A 1979 survey reexamined Norton Sound and identified a

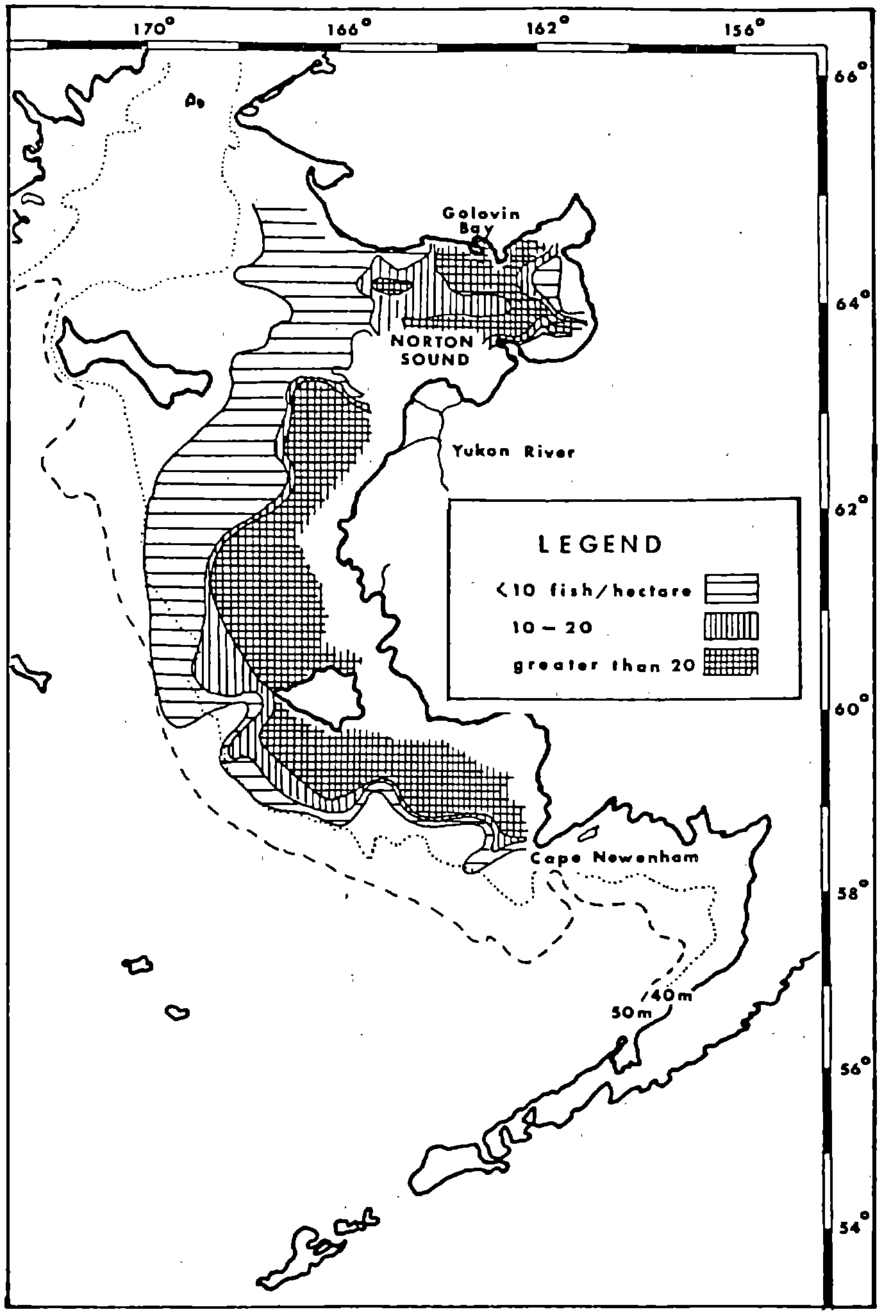


Figure 10.--Distribution and relative abundance (in numbers per hectare) of saffron cod smaller than 19 cm in length in Norton Sound and adjacent Bering Sea waters during July-August 1979. (Note: This size interval corresponds with fish that are mostly juveniles and less than 2 years old.)

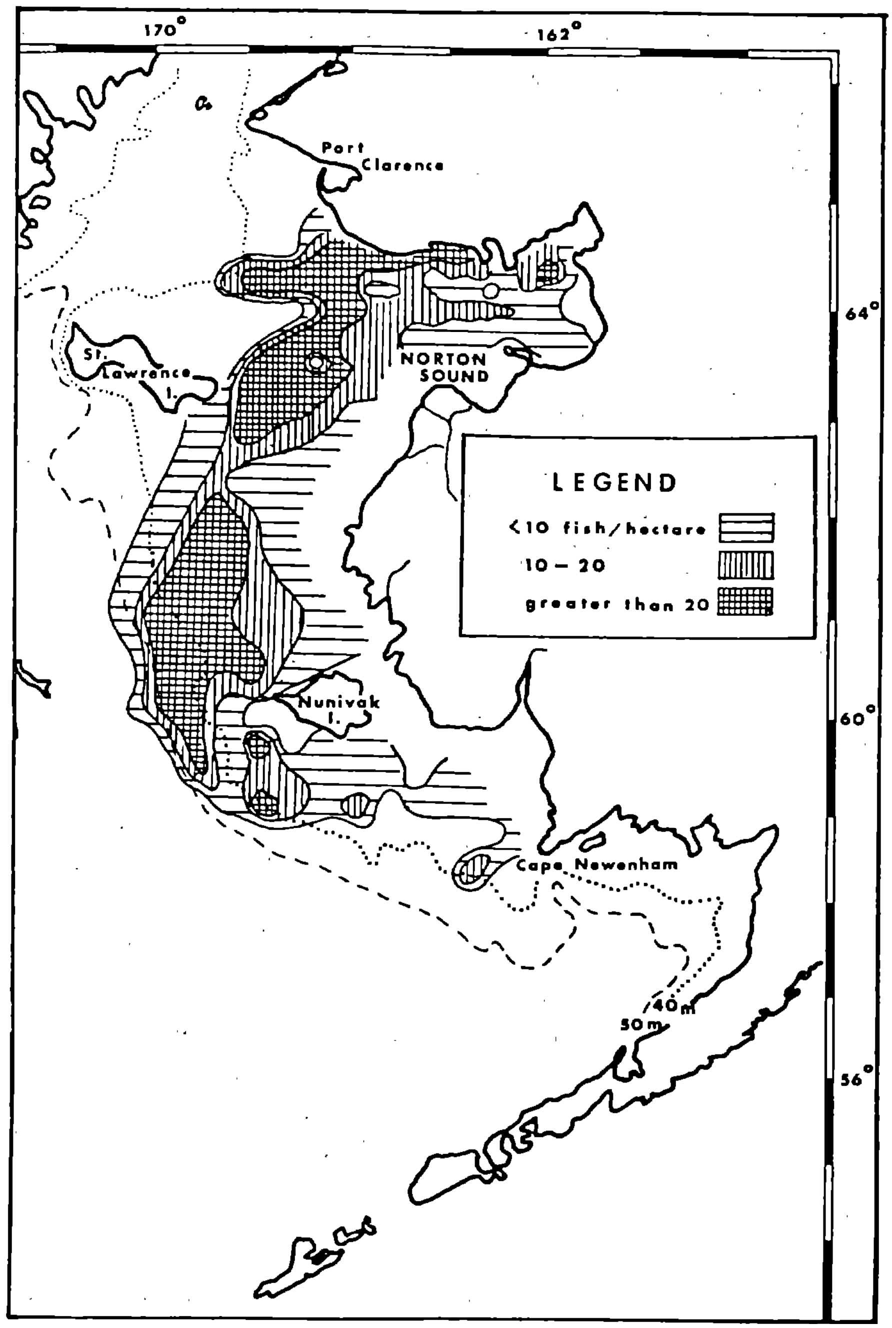


Figure 11.--Distribution and relative abundance (in numbers per hectare) of saffron cod 19-27 cm in length in Norton Sound and adjacent Bering Sea waters during July-August 1979. (Note: This size interval corresponds with fish that are 2 and 3 years old.)

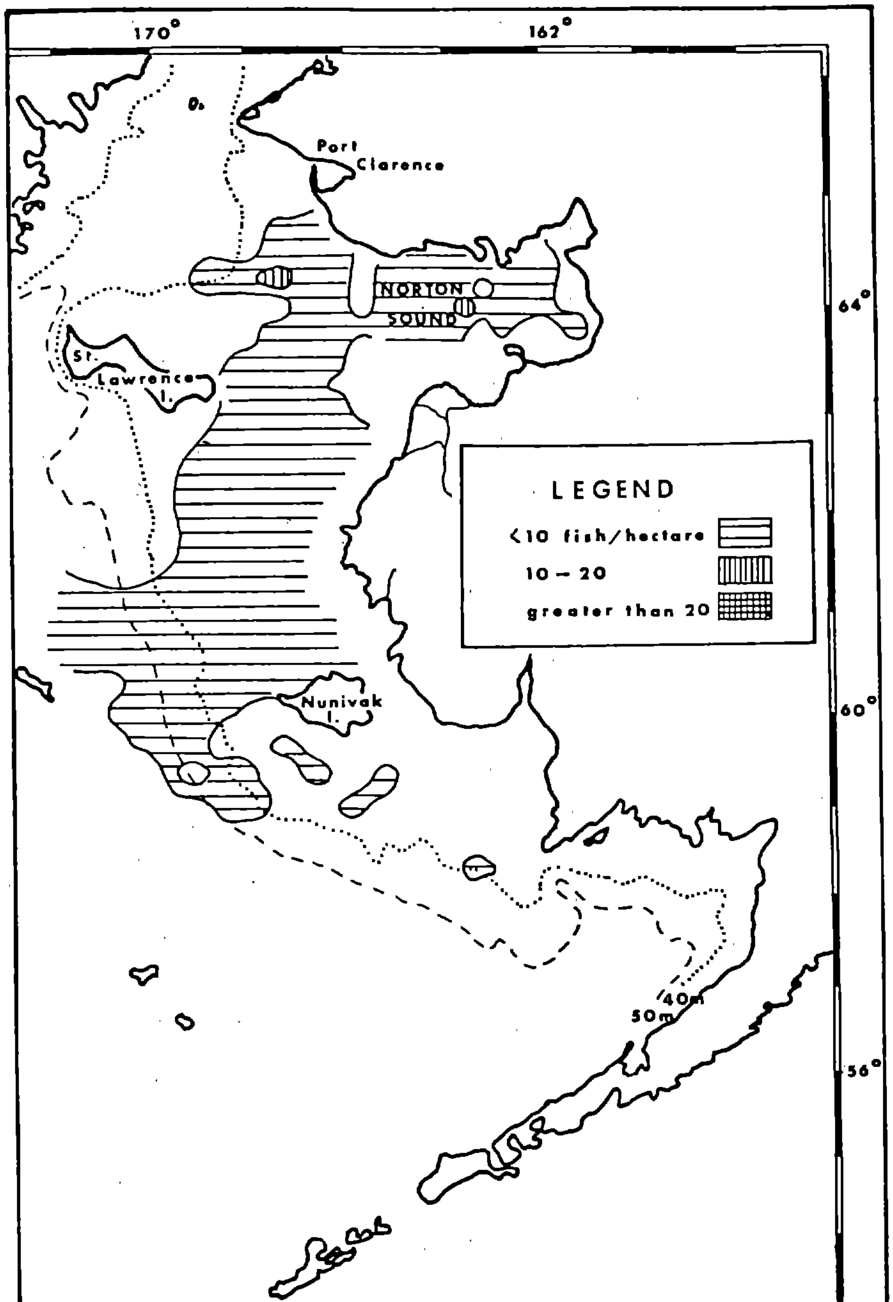


Figure 12. --Distribution and relative abundance (in numbers per hectare) of saffron cod greater than 27 cm in length in Norton Sound and adjacent Bering Sea waters during July-August 1979. (Note: This size interval corresponds with fish that are 3 years old and older.)

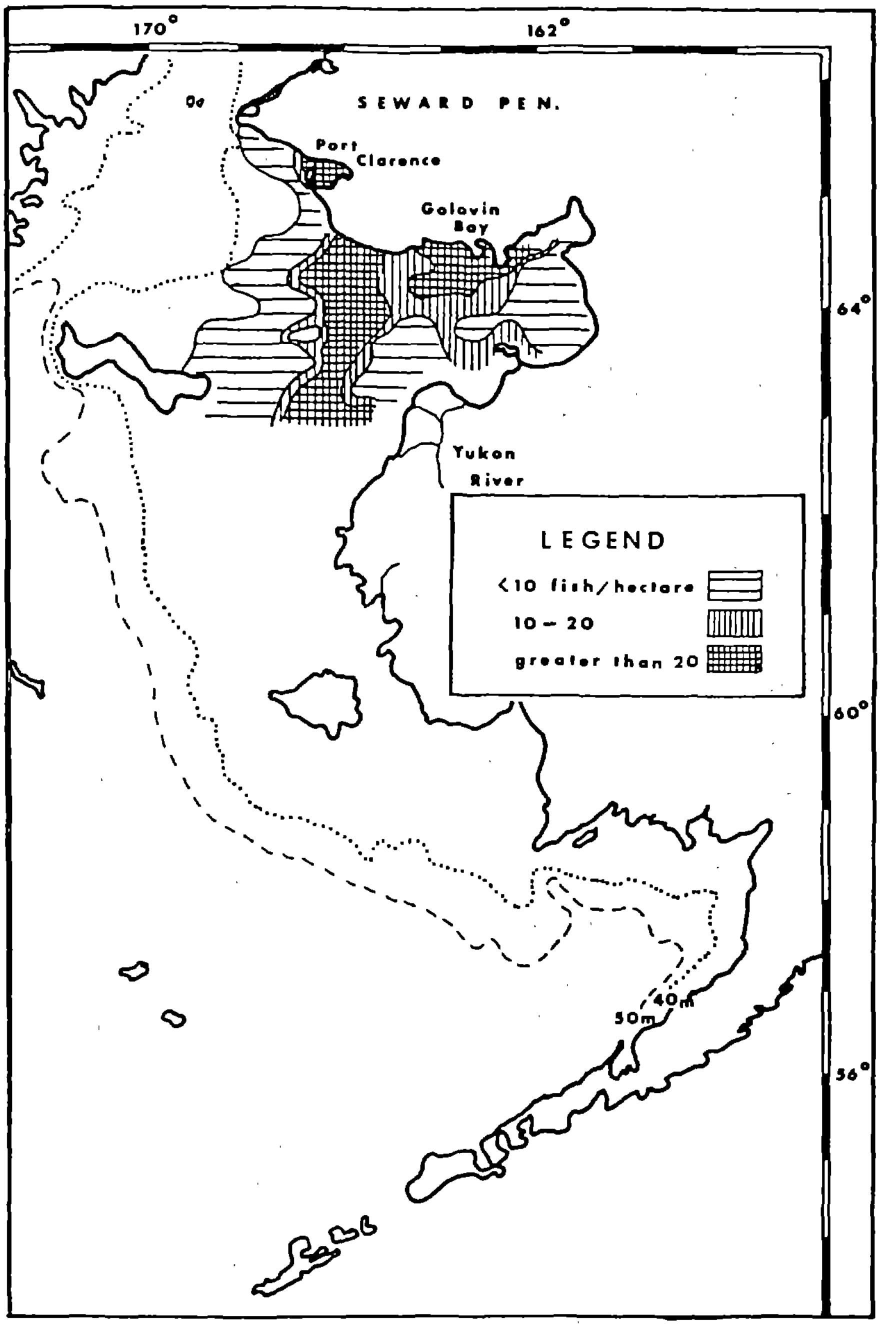


Figure 13. --Distribution and relative, abundance (in numbers per hectare) of saffron cod greater than 18 cm in length in Norton Sound during September-October 1976.

Table 16.--Estimated biomass and population size of the saffron cod resource in Norton Sound an adjacent regions of western Alaska. Information derived from 1977 and 1979 trawl surveys of the National Marine Fisheries Service.

Year of survey(s)	Region surveyed	Area surveyed (sq km)	Estimated biomass (95% confidence interval) (t)	Estimated population size (95% confidence interval) ($x10^6$)
1976	Norton Sound	41,444	16,570 (12,393 - 20,747)	757.71 (578.91 - 936.51)
1979	Norton Sound	57,471	50,621 (35,825 - 65,417)	632.99 (507.94 - 758.03)
1979	Nearshore from Kuskokwim Delta to Norton Sound	168,575	58,291 (38,378 - 78,204)	1,460.3 (753.58 - 2,167.08)

somewhat smaller population than that observed in 1976. Although the estimated population size of 630 million fish was slightly smaller than that present 3 years earlier, a substantially greater biomass of over 50,000 t was associated with the smaller population. This difference in population size related to biomass ratio from the two surveys results from substantially more small fish in Norton Sound in 1976 than in 1979.

A large population of saffron cod was also identified south of Norton Sound in a region sampled only during 1979. That portion of the northeastern Bering Sea shallower than 50 m and between Cape Newenham and the mouth of the Yukon River was estimated to contain nearly 1.5 billion fish with a biomass approaching 60,000 t (Table 16). For 1979, the entire western Alaska region had an estimated population of over 2 billion saffron cod and a biomass of about 110,000 t.

Size and Age Composition

The saffron cod population in Norton Sound and adjacent waters of western Alaska is composed of fish ranging in length from 5 to 35 cm.

The 1976 study encountered a stock that contained an exceptionally large proportion of very small individuals (Figs. 14a,b). The size group at about 7-10 cm comprised more than one-half of the entire estimated population and the numeric dominance of small-sized fish occurred in both major geographic areas surveyed that year. Two additional size groups were present in Norton Sound in 1976, at 14-17 cm and at about 19-24 cm. Although individuals as large as 35 cm were encountered, the samples contained very few large fish. For the 1976 survey, less than 2% of the saffron cod in the Norton Sound region exceeded 25 cm.

Length-frequency samples obtained during the 1979 trawl surveys of Norton Sound and adjacent waters to the south showed a substantially

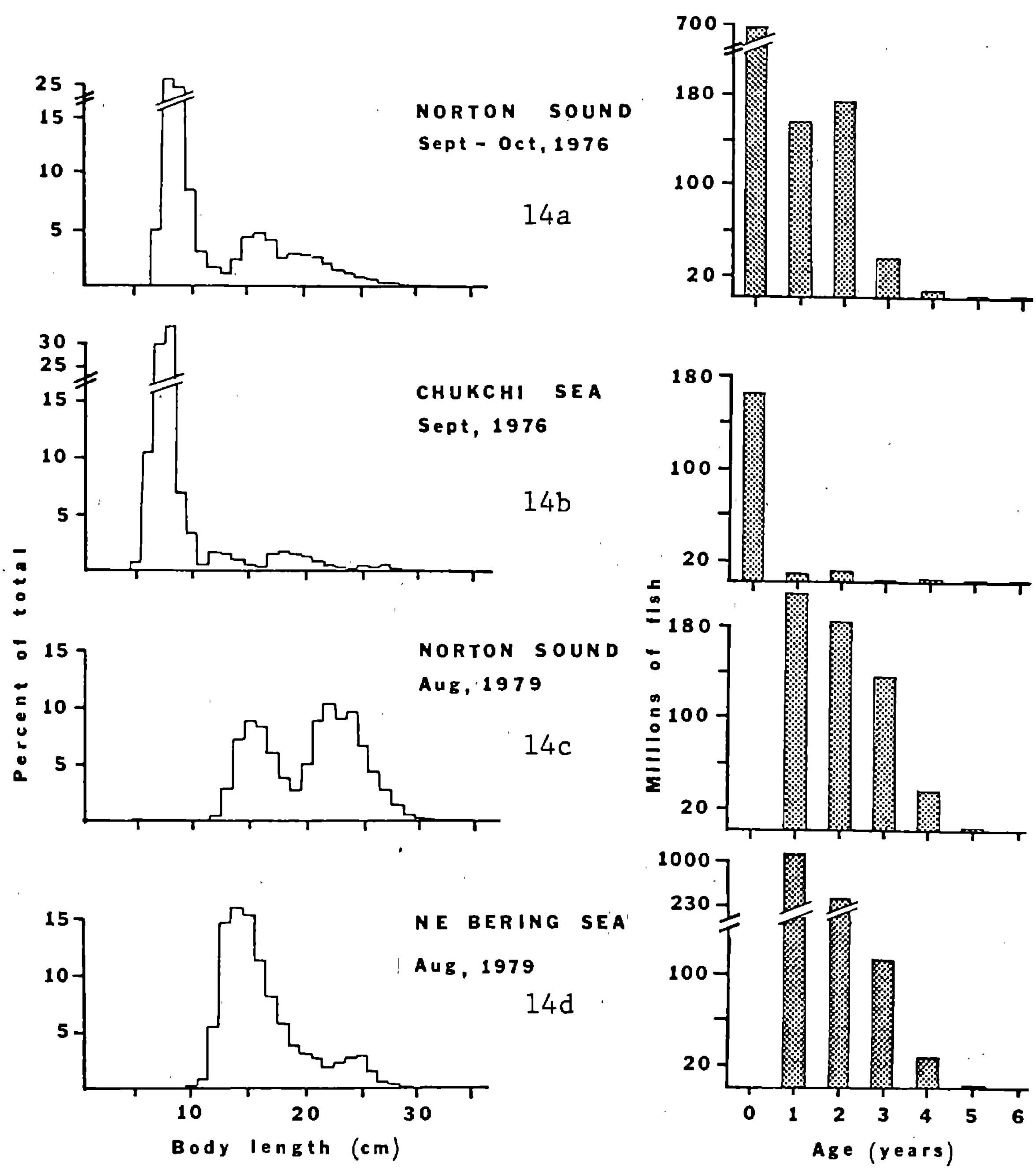


Figure 14. --Size and age composition of saffron cod in Norton Sound and adjacent western Alaska waters during late summer-early fall 1976 and 1979. Information is derived from data collected by the National Marine Fisheries Service.

different size composition than in 1976. Fish that year averaged larger than in 1976 and there were two predominant size groups, at 14-17 cm and 20-26 cm (Figs. 14c,d). The most obvious difference between size distributions of 1976 and 1979 was the almost total absence of small saffron cod in 1979. Less than 5% of the estimated population in Norton Sound in 1979 were smaller than 13 cm whereas in 1976, two-thirds of all fish measured were less than that size. It is not known whether a similar situation occurred in the southeastern Chukchi Sea since that area was surveyed only in 1976. However, the adjacent area south of Norton Sound was sampled in 1979, and this area, i.e., Cape Newenham to St. Lawrence Island, also appeared to contain relatively few small fish (Fig. 14d).

Age-length keys derived from otolith samples indicate most saffron cod in waters off western Alaska are less than 5 years old and maximum age is about 9 years (Table 17). The 7-10 cm size group in samples from the 1976 survey were young-of-the-year, while fish in the 14-17 cm and 19-24 cm size groups were 1-year-olds and mostly 2-year-olds, respectively. In 1979 the dominant size group at 14-17 cm again was 1-year-olds, and 20-26 cm fish were predominantly 2- and 3-year-old saffron cod.

Estimates of saffron cod numbers by age in Norton Sound were derived by applying the age-length keys to length-frequency information. These estimates indicate differences in age composition within the population between 1976 and 1979 and strongly suggest highly variable year-class strength as a cause for the differences. Of particular note is the 1976 year-class. This year-class was numerically dominant in 1976, and as 3-year-olds in 1979 it still comprised a sizable proportion of the population (Fig. 15). Indeed, 3-year-old fish in 1979 were nearly five times more abundant than that age group 3 years earlier. An additional indication

Table 17. --Age-length keys for saffron cod derived from otolith samples gathered during the 1976 and 1979 National Marine Fisheries Service trawl surveys of Norton Sound and adjacent regions.

1976, NORTON SOUND, MALES

LENGTH (CM)	FREQUENCY	AGE IN YEARS 0	1	2	3	4	5	6	7	8	9	10
***	****	***	***	***	***	***	***	***	***	***	***	***
7	--	--	--	--	--	--	--	--	--	--	--	--
8	5	5	--	--	--	--	--	--	--	--	--	--
9	6	6	--	--	--	--	--	--	--	--	--	--
10	7	6	1	--	--	--	--	--	--	--	--	--
11	8	7	1	--	--	--	--	--	--	--	--	--
12	6	--	6	--	--	--	--	--	--	--	--	--
13	8	1	7	--	--	--	--	--	--	--	--	--
14	7	--	7	--	--	--	--	--	--	--	--	--
15	6	--	6	--	--	--	--	--	--	--	--	--
16	7	--	6	1	--	--	--	--	--	--	--	--
17	6	--	2	4	--	--	--	--	--	--	--	--
18	9	--	--	9	--	--	--	--	--	--	--	--
19	7	--	--	7	--	--	--	--	--	--	--	--
20	6	--	--	5	1	--	--	--	--	--	--	--
21	6	--	--	5	--	--	--	--	--	--	--	--
22	6	--	--	4	2	--	--	--	--	--	--	--
23	5	--	--	2	2	1	--	--	--	--	--	--
24	7	--	--	4	3	--	--	--	--	--	--	--
25	5	--	--	1	3	1	--	--	--	--	--	--
26	7	--	--	--	5	2	--	--	--	--	--	--
27	6	--	--	1	1	4	--	--	--	--	--	--
28	3	--	--	--	1	2	--	--	--	--	--	--
29	1	--	--	--	1	--	--	--	--	--	--	--
30	1	--	--	--	--	1	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--	--	--	--
32	--	--	--	--	--	--	--	--	--	--	--	--
33	--	--	--	--	--	--	--	--	--	--	--	--
34	1	--	--	--	--	--	1	--	--	--	--	--
TOTAL	136	25	36	43	20	11	1	0	0	0	0	0

1976, NORTON SOUND, FEMALES

LENGTH (CM)	FREQUENCY	AGE IN YEARS 0	1	2	3	4	5	6	7	8	9	10
***	****	***	***	***	***	***	***	***	***	***	***	***
7	1	1	--	--	--	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--	--	--	--	--	--
9	1	1	--	--	--	--	--	--	--	--	--	--
10	7	7	--	--	--	--	--	--	--	--	--	--
11	7	5	2	--	--	--	--	--	--	--	--	--
12	6	4	2	--	--	--	--	--	--	--	--	--
13	7	2	5	--	--	--	--	--	--	--	--	--
14	9	--	9	--	--	--	--	--	--	--	--	--
15	7	--	6	1	--	--	--	--	--	--	--	--
16	8	--	8	--	--	--	--	--	--	--	--	--
17	6	--	2	3	1	--	--	--	--	--	--	--
18	8	--	--	8	--	--	--	--	--	--	--	--
19	8	--	--	8	--	--	--	--	--	--	--	--
20	6	--	--	6	--	--	--	--	--	--	--	--
21	6	--	--	6	--	--	--	--	--	--	--	--
22	6	--	--	5	1	--	--	--	--	--	--	--
23	7	--	--	5	2	--	--	--	--	--	--	--
24	8	--	--	3	5	--	--	--	--	--	--	--
25	9	--	--	6	3	--	--	--	--	--	--	--
26	7	--	--	1	5	1	--	--	--	--	--	--
27	7	--	--	1	3	3	--	--	--	--	--	--
28	6	--	--	--	1	5	--	--	--	--	--	--
29	8	--	--	--	1	6	1	--	--	--	--	--
30	5	--	--	--	1	3	1	--	--	--	--	--
31	6	--	--	--	1	3	--	2	--	--	--	--
32	1	--	--	--	--	--	--	1	--	--	--	--
33	2	--	--	--	--	2	--	--	--	--	--	--
34	1	--	--	--	--	--	1	--	--	--	--	--
TOTAL	160	20	34	53	24	23	3	3	0	0	0	0

Table 17.--(Continued).

1976, CHUKCHI SEA, MALES

LENGTH (CM)	FREQUENCY	AGE IN YEARS 0	1	2	3	4	5	6	7	8	9	10
***	****	***	***	***	***	***	***	***	***	***	***	***
6	3	3	--	--	--	--	--	--	--	--	--	--
7	3	3	--	--	--	--	--	--	--	--	--	--
8	3	3	--	--	--	--	--	--	--	--	--	--
9	2	2	--	--	--	--	--	--	--	--	--	--
10	1	--	1	--	--	--	--	--	--	--	--	--
11	6	--	6	--	--	--	--	--	--	--	--	--
12	7	--	7	--	--	--	--	--	--	--	--	--
13	7	--	7	--	--	--	--	--	--	--	--	--
14	7	--	7	--	--	--	--	--	--	--	--	--
15	6	--	1	5	--	--	--	--	--	--	--	--
16	7	--	1	6	--	--	--	--	--	--	--	--
17	6	--	1	5	--	--	--	--	--	--	--	--
18	7	--	--	7	--	--	--	--	--	--	--	--
19	7	--	--	5	2	--	--	--	--	--	--	--
20	7	--	--	6	1	--	--	--	--	--	--	--
21	7	--	--	7	--	--	--	--	--	--	--	--
22	6	--	--	4	2	--	--	--	--	--	--	--
23	7	--	--	2	4	1	--	--	--	--	--	--
24	6	--	--	1	3	2	--	--	--	--	--	--
25	3	--	--	--	1	1	1	--	--	--	--	--
26	5	--	--	--	1	3	1	--	--	--	--	--
27	6	--	--	--	1	5	--	--	--	--	--	--
28	4	--	--	--	1	2	1	--	--	--	--	--
29	4	--	--	--	--	2	2	--	--	--	--	--
30	1	--	--	--	--	--	--	--	--	--	1	--
31	--	--	--	--	--	--	--	--	--	--	--	--
32	1	--	--	--	--	--	1	--	--	--	--	--
33	--	--	--	--	--	--	--	--	--	--	--	--
34	--	--	--	--	--	--	--	--	--	--	--	--
35	1	--	--	--	--	--	--	--	--	1	--	--
TOTAL	130	11	31	48	16	16	6	0	0	1	1	0

1976, CHUKCHI SEA, FEMALES

LENGTH (CM)	FREQUENCY	AGE IN YEARS 0	1	2	3	4	5	6	7	8	9	10
***	***	***	***	***	***	***	***	***	***	***	***	***
6	1	1	--	--	--	--	--	--	--	--	--	--
7	1	1	--	--	--	--	--	--	--	--	--	--
8	1	1	--	--	--	--	--	--	--	--	--	--
9	--	--	--	--	--	--	--	--	--	--	--	--
10	3	1	2	--	--	--	--	--	--	--	--	--
11	7	--	7	--	--	--	--	--	--	--	--	--
12	6	--	6	--	--	--	--	--	--	--	--	--
13	7	--	7	--	--	--	--	--	--	--	--	--
14	6	--	6	--	--	--	--	--	--	--	--	--
15	5	--	--	5	--	--	--	--	--	--	--	--
16	7	--	1	6	--	--	--	--	--	--	--	--
17	5	--	--	5	--	--	--	--	--	--	--	--
18	8	--	--	8	--	--	--	--	--	--	--	--
19	6	--	--	6	--	--	--	--	--	--	--	--
20	7	--	--	7	--	--	--	--	--	--	--	--
21	7	--	--	7	--	--	--	--	--	--	--	--
22	8	--	--	8	--	--	--	--	--	--	--	--
23	3	--	--	3	--	--	--	--	--	--	--	--
24	7	--	--	4	3	--	--	--	--	--	--	--
25	5	--	--	--	4	1	--	--	--	--	--	--
26	2	--	--	--	--	2	--	--	--	--	--	--
27	6	--	--	--	1	4	1	--	--	--	--	--
28	6	--	--	--	--	5	1	--	--	--	--	--
29	4	--	--	--	--	3	1	--	--	--	--	--
30	6	--	--	--	--	6	--	--	--	--	--	--
31	6	--	--	--	--	1	3	2	--	--	--	--
32	2	--	--	--	--	1	--	--	1	--	--	--
33	1	--	--	--	--	--	1	--	--	--	--	--
34	1	--	--	--	--	--	1	--	--	--	--	--
35	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	134	4	29	59	8	23	8	2	1	0	0	0

Table 17.--(Continued).

1979, NORTON SOUND AND NORTHEASTERN BERING SEA, UNSEXED

LENGTH (CM)	FREQUENCY	AGE IN YEARS 0	1	2	3	4	5	6	7	8	9	10
***	***	***	***	***	***	***	***	***	***	***	***	***
6	--	--	--	--	--	--	--	--	--	--	--	--
7	--	--	--	--	--	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--	--	--	--	--	--
9	--	--	--	--	--	--	--	--	--	--	--	--
10	4	--	4	--	--	--	--	--	--	--	--	--
11	13	--	13	--	--	--	--	--	--	--	--	--
12	19	--	19	--	--	--	--	--	--	--	--	--
13	21	--	21	--	--	--	--	--	--	--	--	--
14	19	--	18	1	--	--	--	--	--	--	--	--
15	19	--	19	--	--	--	--	--	--	--	--	--
16	20	--	20	--	--	--	--	--	--	--	--	--
17	18	--	15	3	--	--	--	--	--	--	--	--
18	18	--	13	5	--	--	--	--	--	--	--	--
19	19	--	6	12	1	--	--	--	--	--	--	--
20	20	--	1	17	2	--	--	--	--	--	--	--
21	16	--	--	10	6	--	--	--	--	--	--	--
22	15	--	--	13	2	--	--	--	--	--	--	--
23	21	--	--	10	8	3	--	--	--	--	--	--
24	17	--	--	6	10	1	--	--	--	--	--	--
25	18	--	--	2	12	4	--	--	--	--	--	--
26	11	--	--	2	7	2	--	--	--	--	--	--
27	18	--	--	1	11	6	--	--	--	--	--	--
28	13	--	--	--	5	7	1	--	--	--	--	--
29	7	--	--	--	3	4	--	--	--	--	--	--
30	8	--	--	1	3	3	1	--	--	--	--	--
31	5	--	--	--	--	5	--	--	--	--	--	--
32	2	--	--	--	--	--	2	--	--	--	--	--
33	2	--	--	--	--	2	--	--	--	--	--	--
34	--	--	--	--	--	--	--	--	--	--	--	--
35	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	343	0	149	83	70	37	4	0	0	0	0	0

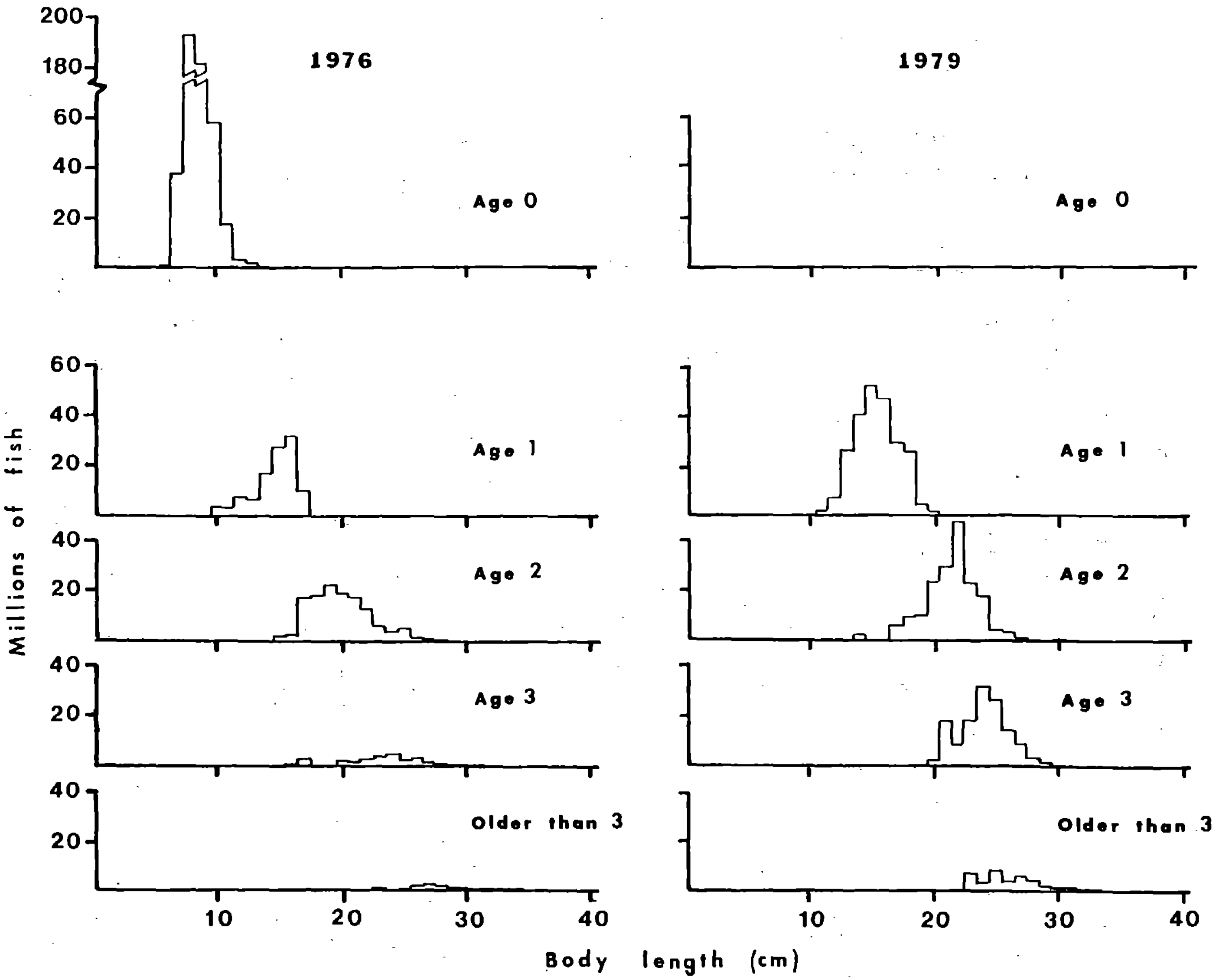


Figure 15.--Size composition by age for saffron cod in Norton Sound during 1976 and 1979.

of variable year-class strength is the absence of measurable amounts of young-of-the-year in samples obtained from Norton Sound (and the north-eastern Bering Sea) in 1979.

Length-at-age and Growth

Age and length data collected for saffron cod were as follows:

Year	Region	Sex	Number of readable otoliths	Range in age (yrs)	Range in length (cm)
1976	Chukchi Sea	male	130	0-9	6-35
		female	134	0-7	6-34
1976	Norton Sound	male	136	0-6	8-34
		female	160	0-6	7-34
1979	Norton	unsexed	343	1-5	10-33

Since Wolotira et al. (1977) determined that saffron cod growth differs by sex, growth rates presented here are derived solely from the 1976 sex-segregated data.

Mean lengths-at-age from the expanded age-length data were plotted against time (years) to estimate the growth parameters L_∞, k, and t_0. The inclusion of young of the year (age group 0) in the data sets required an adjustment to the independent variable of time since these fish (as well as all other age groups) had already achieved a portion of their annual growth at the time the samples were collected. A time adjustment of 0.5 years was used since it appears that annual growth commences in the spring, and on the basis of seasonal growth information from other saffron cod stocks (Andriyashev 1954; Pokrovskaya 1957) it is reasonable to assume that half of a year's growth had been completed by the time the 1976 survey had commenced.

In determining estimates of the various parameters of the growth there was a substantial reduction in residual variation when mean lengths-at-age for age groups not fully vulnerable to the survey gear were eliminated from the data sets (i.e., the "selected data" in Table 18) and when the curve was fitted through the origin (i.e., 0,0; shown as "selected data with origin"). Using the selected data sets also improved fits for the Norton Sound data where meaningless values of some parameters (k<0 and L_∞ <0) were estimated before data set selection (Table 18).

Analysis of the 1976 age-growth information indicates that saffron cod in Norton Sound grow differently than individuals to the north in the Chukchi Sea. Populations of both sexes in Norton Sound average larger sizes at ages up to about 4 years than populations further north (Fig. 16). However, this difference in size at age decreases with time. After age 4 years, a reversed trend is noted: Chukchi Sea fish average larger than equal-aged individuals in Norton sound. As a result, saffron cod in Norton Sound attain a smaller maximum size (L_∞) than members of the same species found further north. This is apparent for both males and females. Asymptotic length is achieved at a more rapid rate by fish in Norton Sound.

This examination of saffron cod growth, combined with a regression analysis of length and weight (see next section) suggests that separate stocks may occur in Norton Sound and the southeastern Chukchi Sea. This stock separation may simply be the result of geographic influence since the Seward and Chukotsk Peninsulas substantially restrict movement, between the regions.

A similar analysis of growth differences in Norton Sound and the northeastern Bering Sea was not made because age samples from the latter

Table 18. --Parameters for von Bertalanffy growth curves for saffron cod in Norton Sound and the southeastern Chukchi Sea (from Wolotira et al. 1977).

Areas	Sex	Range in age and length of analyzed data: age (yr)	Range in age and length of analyzed data: length (cm)	Original data set: δ	Original data set: L_∞	Original data set: K	Original data set: t_o	Selected data: δ	Selected data: L_∞	Selected data: K	Selected data: t_o	Selected data with origin: δ	Selected data with origin: L_∞	Selected data with origin: K	Selected data with origin: t_o
Chukchi Sea	Males	0.5-9.5 (1.5-5.5)	(10-32)	2.08	35.83	-0.27	-0.35	0.87	30.35	-0.42	0.18	0.79	31.57	-0.36	-0.01
	Females	0.5-7.5 (1.5-4.5)	(10-32)	1.51	37.32	-0.26	-0.32	0.99	36.26	-0.36	0.34	0.95	43.61	-0.23	-0.01
Norton Sound	Males	0.5-5.5 (0.5-4.5)	(8-30)	2.35	-618.18	0.01	-1.13	0.15	30.86	-0.34	-0.47	1.27	25.76	-0.63	-0.02
	Females	0.5-6.5 (1.5-4.5)	(11-33)	1.10	46.18	-0.14	-1.58	0.77	102.93	-0.05	-1.71	1.29	32.16	-0.42	0.02

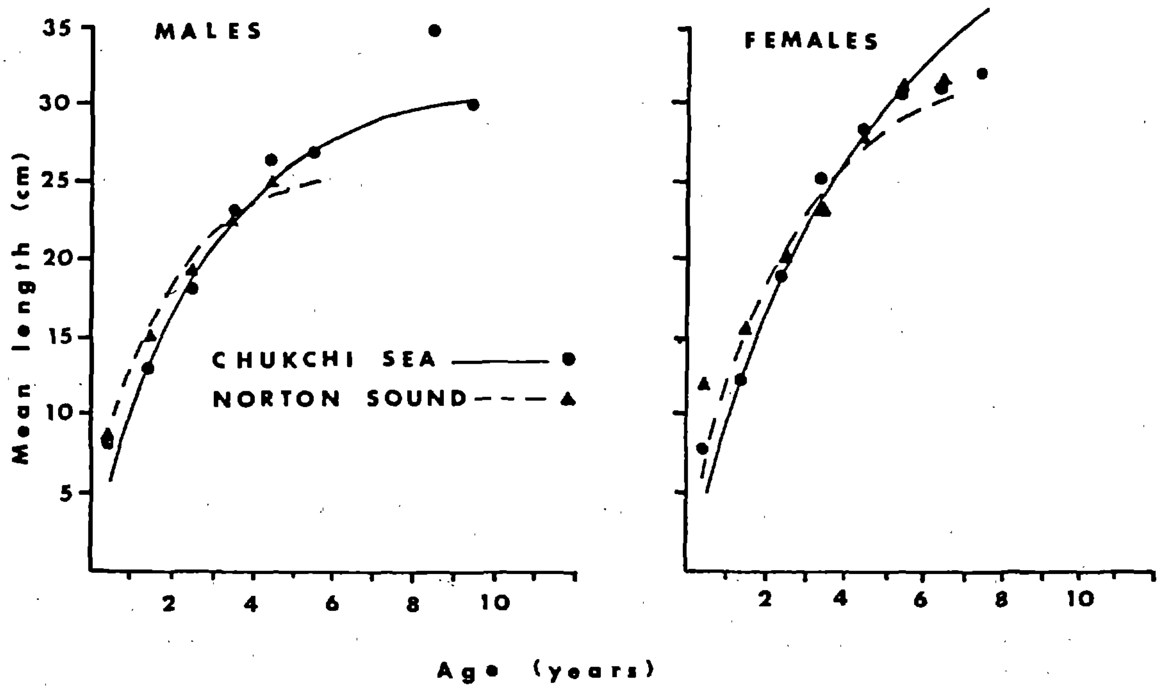


Figure 16. --Mean lengths-at-age and growth curves fit to the origin for saffron cod by sex fn Norton Sound and the southeastern Chukchi Sea (from Wolqtira et al. 1977).

region are not available. However, the 1979 surveys identified a near continuous presence of relatively sizable numbers of fish from Nunivak Island into Norton Sound and there are no geographic factors that separate these two regions. This implies that saffron cod within the northeastern Bering Sea and Norton Sound could comprise a single population.

Other comparisons can be made between Norton Sound length-at-age data and information from several Eleginus stocks in waters off the U.S.S.R. A comparison with mean lengths-at-age (sexes combined) for E. gracilis populations from four selected areas of the western Pacific suggests that saffron cod in Norton Sound are smaller at age than fish in populations throughout the western Pacific (Fig. 17). Differences are most pronounced at young ages. Norton Sound fish are roughly 30-50% smaller in length than western Pacific fish at 1 year, but the size difference is somewhat less than this by age 4. It is interesting to note that two comparative areas geographically closest to Norton Sound (i.e., the Sea of Okhotsk and Gulf of Anadyr) represent extremes in the ranges of size at age. Fish from the Gulf of Anadyr in the northwest Bering Sea seem to have the smallest sizes at age of any western Pacific stocks and, consequently, are the most similar in size to saffron cod in Norton Sound.

Although Eleginus representatives in Arctic Ocean regions are considered a different species, their sizes-at-age appear to more closely resemble Norton Sound fish than any western Pacific stocks. A comparison with representative data from Arctic Ocean populations (Fig. 17) indicates that after age 1 year, saffron cod (E. gracilis) in Norton Sound are only slightly smaller or the same length as equal aged fish in the Kara and White Seas. Fish from Norton Sound are actually l0-20% larger than similar aged E. navaga in the Pechora Gulf region of the Barents Sea after age 2 years.

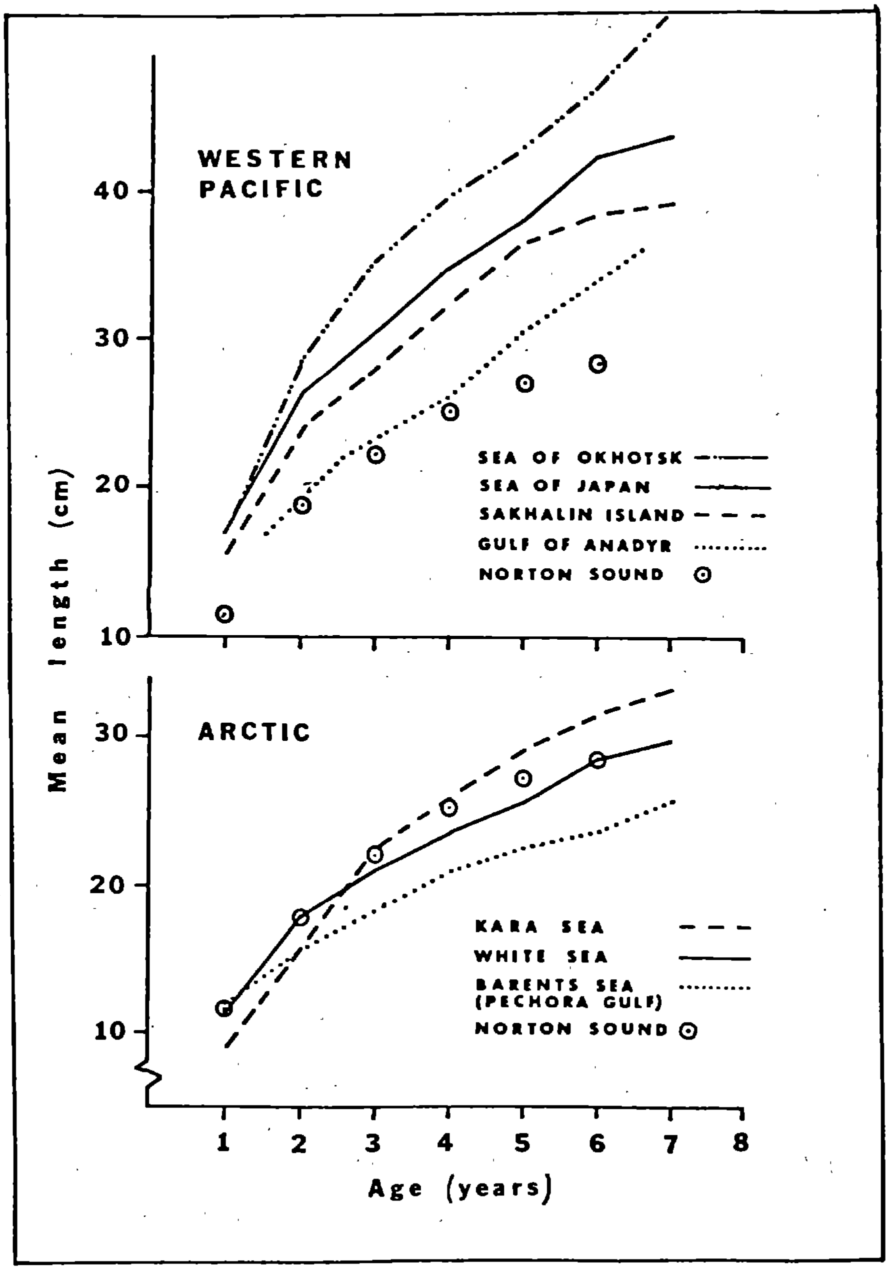


Figure 17. --Mean sizes-at-age for <u>Eleginus</u> spp. from several Arctic and western Pacific regions of the U.S.S.R. and for saffron cod from Norton Sound.

Length-weight Relationships

The relationship of body weight to total length of saffron cod in Norton Sound and the southeastern Chukchi Sea was examined from length-weight data obtained during the 1976 and 1979 surveys. On the basis of weights predicted by the regression coefficients determined from regression analysis of the 1976 data (Table 19), males generally weighed more at given lengths than females. Saffron cod of either sex in the southeastern Chukchi Sea were heavier at given lengths than fish of corresponding length and sex in Norton Sound. Differences in weight at length, however, were only 3-5%; thus, an overall length-weight relationship could be described by the equation:

$$w = 0.00431l^{3.1926},$$

where w equals the predicted weight in grams for a fish l cm in length (Fig. 18).

Sexual Maturity

There are no samples available from which to develop a precise relationship between size or age and sexual maturity for saffron cod in Alaskan waters. Such a relationship can be inferred, however, by the comparison of gonad weight to body length and length-age from data obtained during the 1979 surveys. Unfortunately, data on these two relationships were obtained concurrently, but from different fish.

Drawing conclusions about sexual maturity from a comparison of gonad weight to body length (or age) requires the following assumptions: 1) growth varies between individual fish; 2) not all individuals mature at the same exact body length (or age): and 3) gonad weight does not begin to substantially increase until the onset of sexual maturity. If these assumptions are correct, then the relationship between gonad weight

Table 19.--Parameters for the length-weight relationship (weight (gm) = a x length^b) for saffron cod from Norton Sound and the southeastern Chukchi Sea and results from the analysis of covariance for between-area and between-sex differences in this relationship (from Wolotira et al. 1977).

Sex	Otolith area	Number of fish measured	Range in length (cm)	Parameters a	Parameters b
Males	Chukchi Sea	122	10-35	.0033	3.3018
	Norton Sound	128	8-30	.0045	3.1765
Females	Chukchi Sea	141	10-34	.0041	3.2071
	Norton Sound	151	9-32	.0032	3.2750

Differences between	F slope df	F slope F	F intercept df	F intercept F	H_b 1/	H_a 1/	Pooled regression a	Pooled regression b
Areas for males	1;246	5.20*	1;247	6.18*	+	+	.0038	3.2425
Areas for females	1;288	2.91	1;289	11.50**	-	+	.0036	3.2478
Areas for sexes combined 2/	1;561	17.10**	1;562	6.52*	+	+	.0043	3.1926
Sexes for Norton Sound	1;275	4.11	1;276	7.69**	+	+	.0039	3.2218
Sexes for the Chukchi Sea	1;259	4.58*	1;260	10.10**	+	+	.0038	3.2399
Sexes for areas combined	1;538	.03	1;539	17.50**	-	+	.0038	3.2355

* Significant at the .05 level.
** Significant at the .01 level.
1/ Plus (+) indicates that the common slope (H_b) hypothesis or common intercept (H_a) hypothesis cannot be rejected on the basis of the values of F obtained.
2/ Includes unsexed fish.

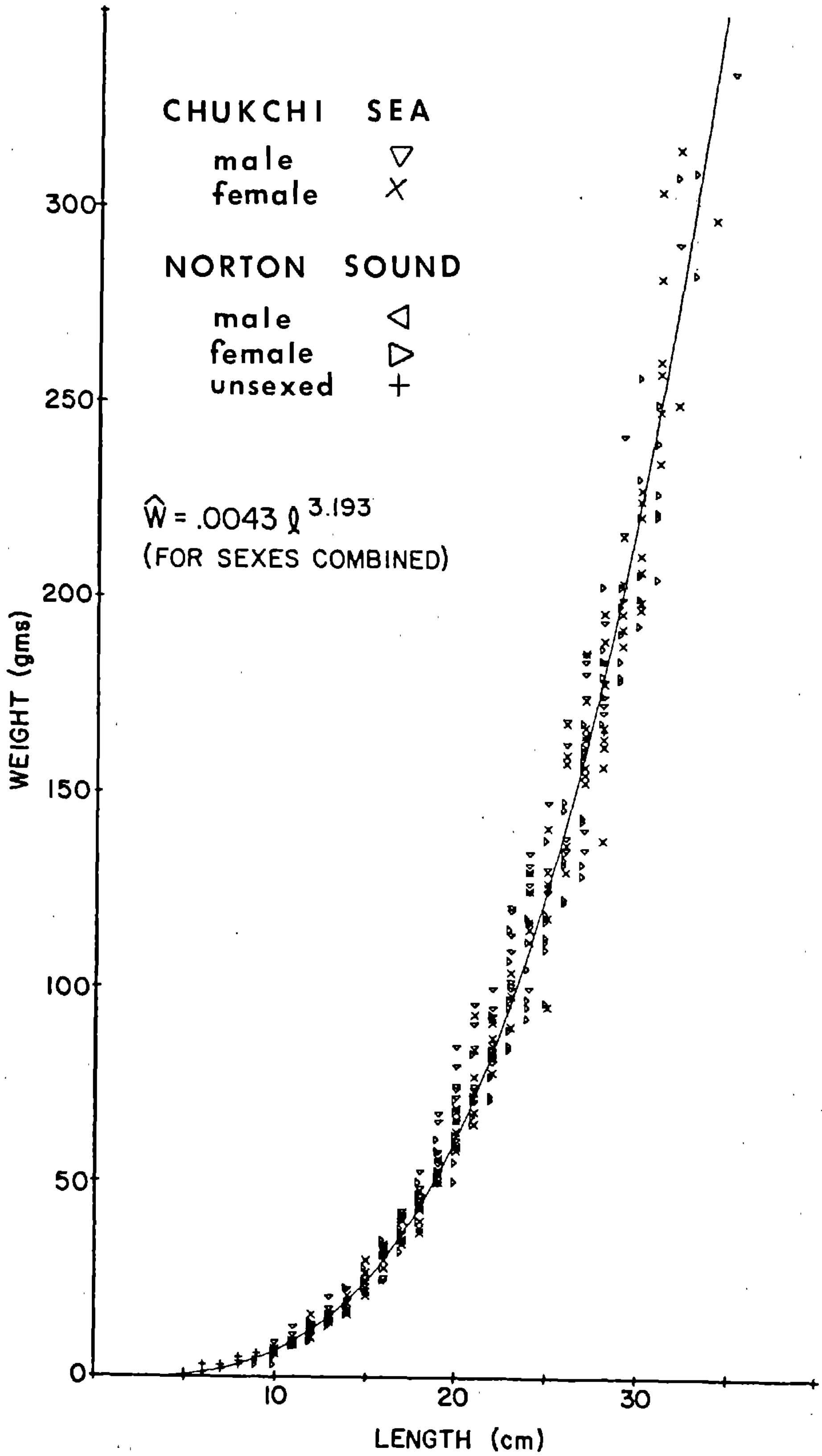


Figure 18. --Weight-at-length observations by sex for saffron cod in Norton Sound and the southeastern Chukchi Sea (from Wolotira et al. 1977).

and body length should be fairly uniform for individuals of equal length at small sizes. As fish grow older and larger and some begin to mature, the gonad weights for these maturing individuals should become relatively heavier than those of fish of the same length that have not yet started to mature. At this point the variability in body length-gonad weight should increase for fish of equal length but different stages of maturity. In other words, fish of identical length may have a wide variance in gonad weights brought on by varying stages of maturation.

A comparison by sex of the mean, range, and variation (represented by ± 2 standard deviations) of gonad weights for equal-sized saffron cod shows that variability increases noticeably at lengths starting at about 19-20 cm in both sexes (Fig. 19). This length primarily corresponds to fish in the 1979 age-length key that are 2+ years old (i.e., in the third year of life). My conclusion is that saffron cod in Norton Sound begin to mature during their third year. This is corroborated by observations on western Pacific saffron cod populations in northern Tatar Strait (Kozlov 1949) and the northern Sea of Okhotsk (Pokrovskaya 1960; Semenenko 1973).

Estimates of Natural Mortality

Chi-square analyses of age groups within the 1976 and 1979 populations and a test of mean age group values for the 2 years combined suggest that Z-year-old saffron cod were the youngest age group fully vulnerable to the sampling gear (Table 20). Because of this, age groups 2-4 years were used for estimating mortality rates. The resulting estimates of Z ranged from 0.82 to 1.59 (Table 21) and suggest that in the Norton Sound region about 20-44% of a year-class of saffron cod survives each year.

Similar estimates were made on Sea of Okhotsk saffron cod data presented by Semenenko (1973) for comparison with the Norton Sound

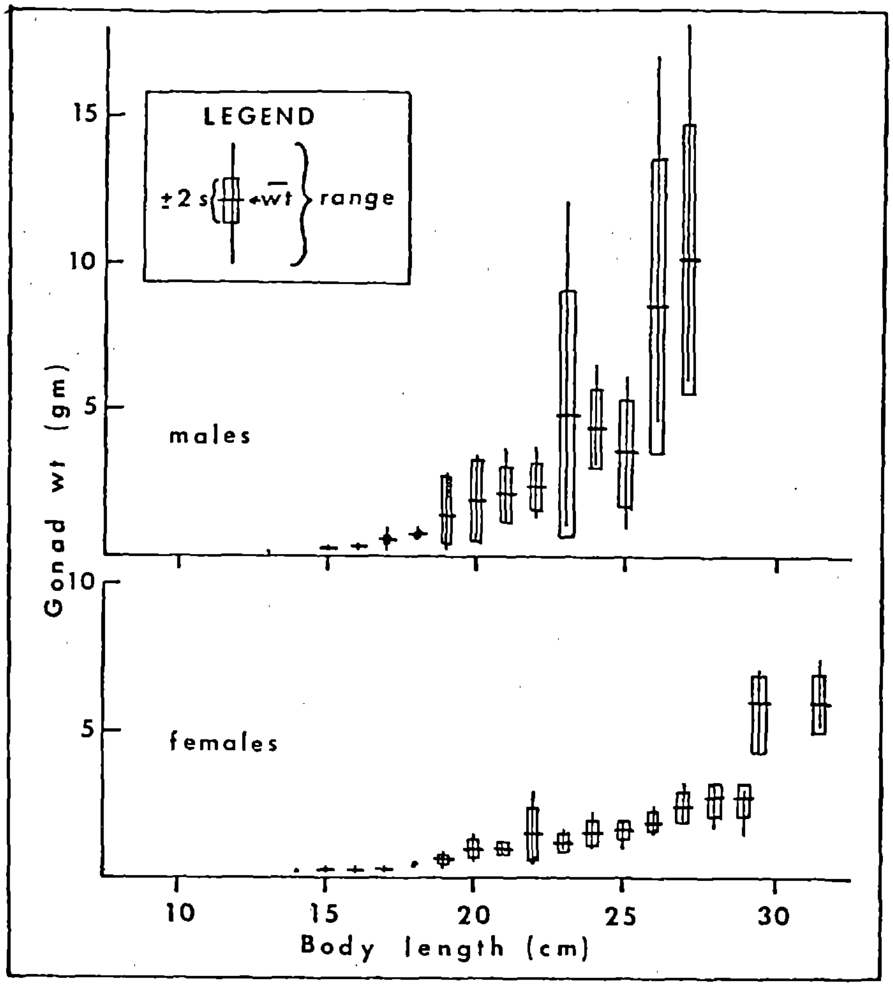


Figure 19. --Mean and range of gonad weights-at-length by sex of saffron cod in Norton Sound from data gathered during National Marine Fisheries Service trawl surveys in August 1979.

Table 20. --Summary of information used to estimate minimum age of full recruitment (i.e., vulnerability) for saffron cod to trawl sampling gear of the National Marine Fisheries Service in 1976 and 1979.

Survey year	1976			1979			Mean of 1976 and 1979		
Age tested for full recruitment	Young of yr	1-yr old	2-yr old	Young of yr	1-yr old	2-yr old	Young of yr	1-yr old	2-yr old
Age groups used in test	0-4	1-4	2-4	0-4	1-4	2-4	0-4	1-4	2-4
N_0	118.92[a]	27.24	29.38	0[b]	40.53	35.65	59.46[c]	33.88	32.00
N_1	27.24	29.38	5.77	40.53	35.65	26.66	33.88	32.00	16.20
N_2	29.38	5.77	1.21	35.65	26.66	7.06	32.00	16.20	4.14
N_3	5.77	1.21	--	26.66	7.06	--	16.20	4.14	--
N_4	1.21	--	--	7.06	--	--	4.14	--	--
T[d]	108.17	44.58	8.20	219.95	110.09	40.75	163.04	76.81	24.47
n[e]	182.53	63.61	36.36	109.86	109.86	69.34	145.68	86.22	59.34
Chapman and Robson's estimate of survival[f]	0.37	0.42	0.19	0.67	0.50	0.37	0.53	0.47	0.32
Heinke's estimate of survival[g]	0.35	0.57	0.19	1.00	0.63	0.49	0.59	0.63	0.39
Chi-square value[h]	1.30*	15.51	0.02*	81.41	14.46	10.16	4.26	17.60	3.30*

[a] Estimated number/hectare based on the 1976 survey area of 41,444 sq km

[b] Estimated number/hectare based on the 1979 survey area of 57,471 sq km

[c] Estimated $\text{number/hectare}_{1976}$ + estimated $\text{number/hectare}_{1979}$ - 2

[d] $T = N_1 + 2N_2 + 3N_3 \ldots$

[e] $n = N_0 + N_1 + N_2 \ldots$

[f] $T/n + T - 1$

[g] $n = N_0/n$

[h] $\chi^2_{df=1} = \frac{(\text{Chapman \& Robson est} - \text{Heinke est})^2}{T(T-1)(n-1)} \Big/ n(n+T-1)^2(n+T-2)$

* Significant at $a = 0.05$

Table 21.--Estimates of the natural mortality rate M for saffron cod in the Norton Sound region based on catch curve analyses on age-groups 2-4 years from the 1976 and 1979 trawl surveys.

Trawl survey	Estimate of M	Correlation coefficient
1976	1.59	0.99
1979	0.82	0.88
1976 & 1979 combined[a]	1.02	0.96

[a] $\text{Number/hectare}_{\text{age } i} = \sum_{j=1976}^{1979} \text{number/hectare}_{\text{age } i}/2$

where i = ages 2, 3, and 4 years; and j = 1976 and 1979 information. This sea of Okhotsk data was from a winter fishery where substantial numbers of fish up to age 7 years were caught. A chi-square analysis of age groups indicated that saffron cod 4 years old and older were fully vulnerable to the Soviet fishing gear and a regression analysis on catch rate data for ages 4-7 years resulted in an estimate of Z = 1.08. Since the age group data presented by Semenenko were from a commercial fishery, the resulting estimate of Z included both natural (M) and fishing mortality (F).

YIELD PER RECRUIT ANALYSIS

The previous section of this report described various population characteristics of the saffron cod resource in Norton Sound and adjacent waters. This section will use this information to investigate the potential harvest that could be expected from a commercial fishery on saffron-cod under various fishing regimes. Harvest potential will be examined through yield per recruit analysis.

Yield per recruit is the level of catch (in weight) that can theoretically be obtained under some particular fishery management regime from a year-class or cohort over its lifespan, divided by the initial number in the cohort. Typically, it is calculated using a yield model (Ricker 1975; Beverton and Holt 1957) that incorporates intrinsic features of the population such as growth and mortality with extrinsic factors such as age or size at recruitment, harvest rates, and fishing seasons. By varying the extrinsic factors, a manager may determine an optimal management regime to maximize the yield per individual recruited into the exploitable population.

Model Selection and Parameters

Several factors influenced my selection of an appropriate yield model. These included seasonal differences in saffron cod growth, the climate of Norton Sound, and potential fishing strategies.

The growth rate of saffron cod apparently varies seasonally. Pokrovskaya (1957) studied the growth of saffron cod in Soviet waters and found that nearly all annual growth occurred during ice-free periods when active feeding took place. This information excludes the possible use of the Beverton and Holt yield model because that yield analysis requires the assumption of constant growth throughout a year.

Climatological features of the Norton Sound region necessitated use of a model which allowed for varying extrinsic population factors. Norton Sound and adjacent nearshore regions of western Alaska are ice covered during a large portion of each year. Ice typically starts forming during October-November and remains present until late spring, usually early June (Ahlnas and Wendler 1979; Pease et al. 1982; and others). Therefore, it is highly likely that ice cover would dictate seasonally restricted fishing that would vary substantially from season to season, resulting in variable fishing mortality.

Variable growth and fishing mortality factors resulted in selection of the Ricker model for my yield analyses. Estimates of yield per recruit were determined following procedures described by Ricker (1975) using the model:

$$\text{Yield} = W_o e^{\sum_{t=t_o}^{t=t_\lambda} \int_i^{i+t} G-Z}$$

where t_o and t_λ are the initial and final times (dates) included in the yield period; i is some finite time increment in which growth and mortality remain approximately constant; G-Z is a stock "change factor" based on the growth in weight (G) of an individual during a time increment (i) and a rate of all mortality (Z) during the same time; and W_o is the initial stock weight derived from the equation:

$$W_o = N_o \times a \left[L_\infty \left(1-e^{K(t-t_o)}\right)\right]^b.$$

Parameters used in this equation include an arbitrary initial stock size (N_o); asymptotic length (L_∞) growth completion rate (k) and theoretical time at zero length (t_o) from the von Bertalanffy growth equation; and the parameters a and b from the allometric growth equation where weight = a x length^b.

values for all the above-mentioned parameters (including the natural mortality component of Z) were obtained from analyses presented in the previous section of this report. Since growth of-saffron cod was noticeably different by sex (See Fig. 16. p.70) yield estimates were derived separately for an identical number of males and females (500) and then combined for a final estimate of yield per recruit from a cohort. A list of all values used in these analyses is presented in Table 22. Total yield was actually determined by a stepwise calculation of changes in weight of a cohort during the finite time intervals (i) when Z included either natural and fishing mortality or only natural mortality. The latter occurred prior to initial fishing effort or during those time periods between fishing seasons. Yield to the fishery was then determined by multiplying the average cohort weight during a time increment by the fishing mortality exerted on the cohort during that time. An example of these calculations will follow.

Yield estimates from the Ricker model were obtained through an interactive computer program developed on a Hewett-Packard 97 portable computer-calculator. The program, RICKER YIELD, permits the segmentation of a yearly cycle into as many as three parts. Each segment can vary from 0 to 1 full year and requires the input of percentage of annual growth, natural mortality, and fishing mortality during the time segment.

Different values of M and F were used for comparative purposes. Two estimates of natural mortality were used: M = 1.02, the value derived from the catch curve analysis of age groups 2-4 years from the combined 1976-79 population data; and M = 0.82, the value derived from age groups

Table 22.--Values for various parameters used in the yield per recruit analyses of saffron cod in the Norton Sound region.

Parameter	Values for males	Values for females
L_∞	30.86	32.16
t_0	-0.34	0.02
k	-0.47	-0.42
a	4.5×10^{-3}	3.2×10^{-3}
B	3.1765	3.2750
t	7 years	7 years
N_0	500	500

2-4 years in 1979. The latter rate was used, despite failure of the chi-square test for full recruitment to the fishing gear for 2-year-olds in the 1979 data, to provide a range of mortality values to theoretically examine changes in yield.

In addition to using two levels of natural mortality, three harvest strategies (i.e., fishing mortalities) were examined: 1) an intensive fishery only during ice-free months (i.e., June-October); 2) variable effort year-round fisheries including intensive ice-free season effort and a casual (low effort). winter fishery; and 3) an intensive winter fishery only (i.e., November-May). Based upon information from Soviet references, the yield analyses for all these strategies used the following assumptions: 90% of annual growth occurs during ice-free months; natural mortality remains constant throughout the year; and the start of life in adult (postlarval) form occurs about June 1. Also for these analyses, t_λ was assumed to be 7 years.

Results of Yield Per Recruit Analyses

The yield equation was numerically evaluated over a grid of age at recruitment (t_r) and F values for both levels of M and the three harvest strategies. The manner in which yield per recruit varied with fishing mortality rate and age at recruitment for M = 0.82 and 1.02 with each harvest strategy is shown as follows:

--variable year-round fishery (Figs. 20a, b)

--winter fishery only (Figs. 21a, b)

--ice-free or "summer only" fishery (Figs. 22a, b).

Yield isopleth diagrams (Figs. 20-22) portray yield the way that topographic maps portray elevations, where solid lines represent different

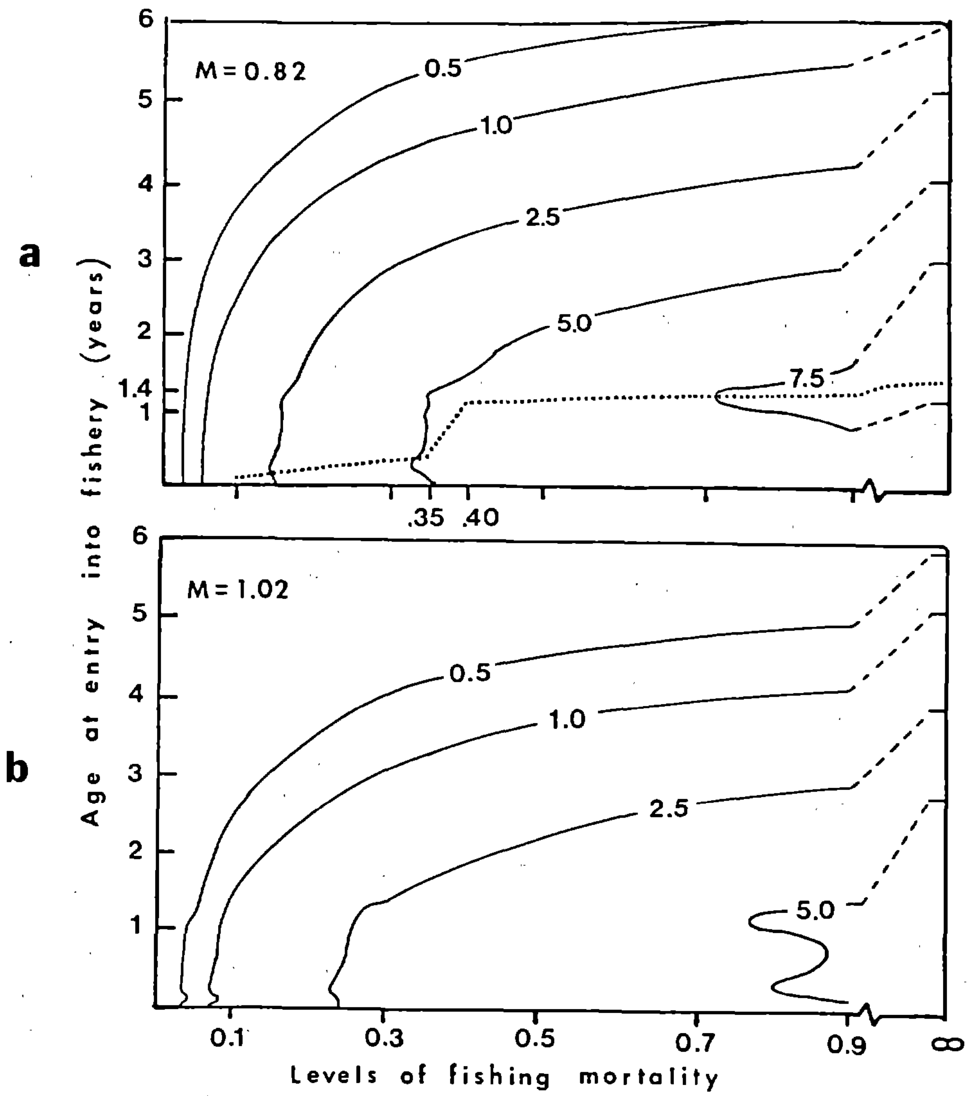


Figure 20. --Yield per recruit (gm) as a function of age at entry into the fishery and rates of instantaneous fishing mortality for saffron cod from a fishing strategy combining an intensive fishery during ice-free months (June-October) and a less intensive fishery (i.e., one-half the ice-free level) during months of ice cover (November-May). The eumetric fishing curve is shown as the dotted line in the figure using M = 0.82.

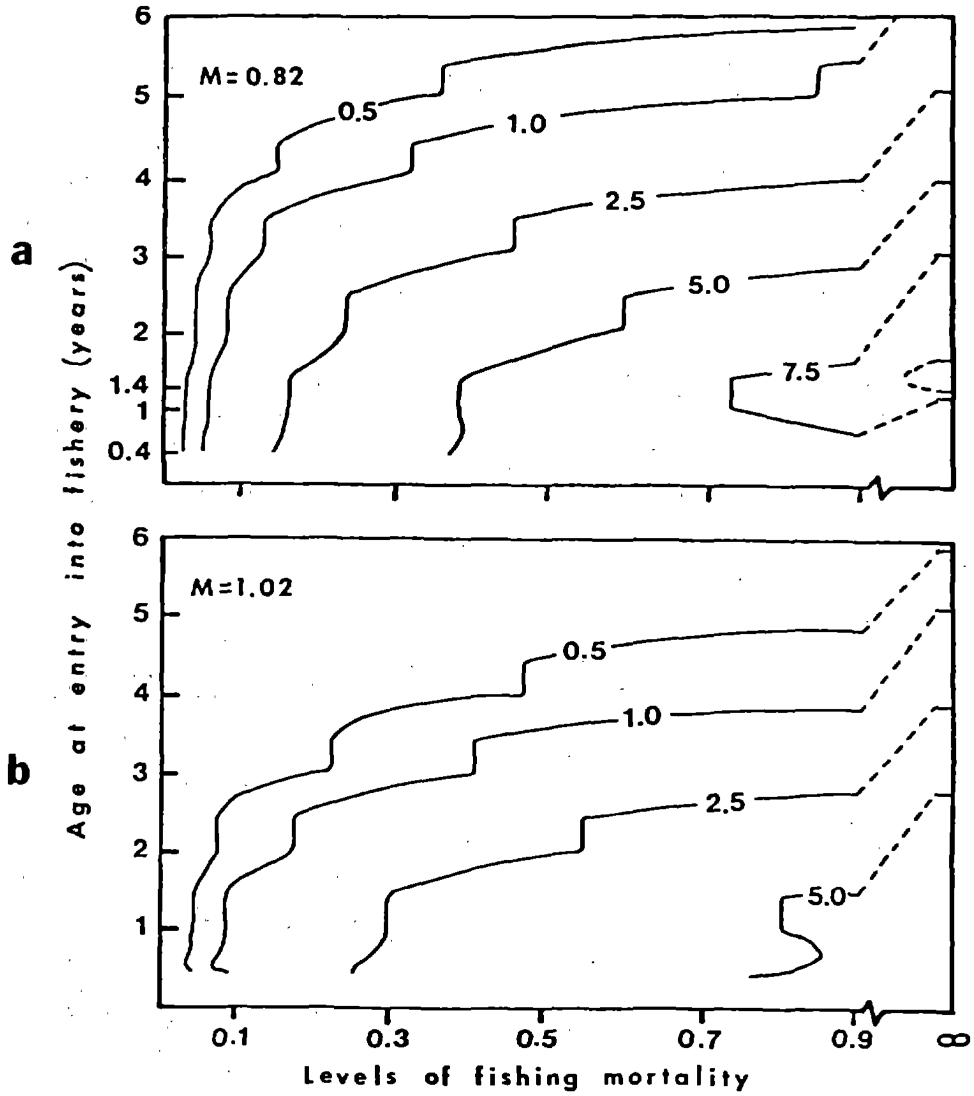


Figure 21. --Yield per recruit (gm) as a function of age at entry into the fishery and rates of instantaneous fishing mortality for saffron cod from a fishery that only occurs during the time of ice cover (i.e., "winter fishery", November-May).

a

b

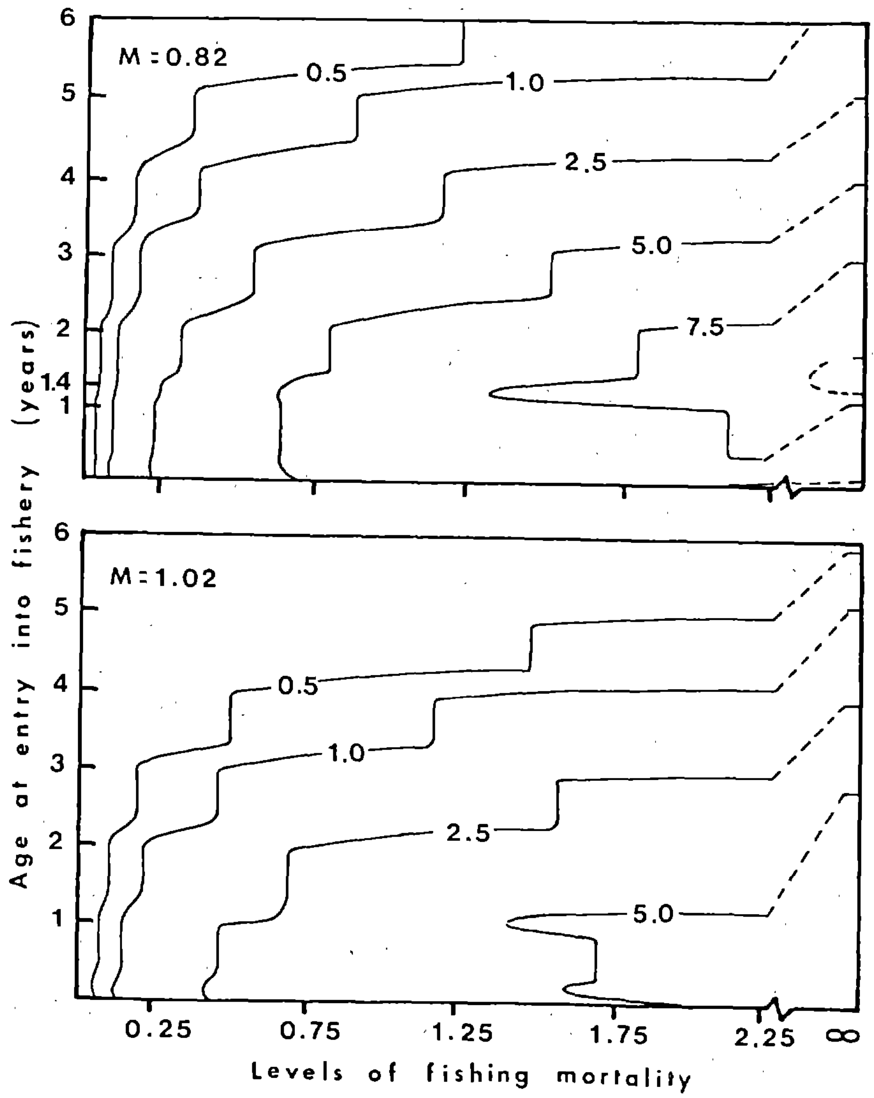


Figure 22. --Yield per recruit (gm) as a function of age at entry into the fishery and rates of instantaneous fishing mortality for saffron cod from a fishery that only occurs during the time that is ice free (i.e., summer fishery", June-October).

levels of -constant yield within the grid of fishing mortalities and age at recruitment values. Yield values used to construct the yield isopleths are presented in tabular form to indicate yield per recruit per mortality and fishing strategies (Tables 23-25). I should note that the values of F used with the "summer only" strategy had a somewhat larger range than those used for the other fisheries (i.e., 0.25-2.25 vs. 0.10-0.90). This was done to examine yields at slightly higher levels of fishing effort.

In yield per recruit analyses, the eumetric fishing curve or eumetric fishing line represents points in a yield isopleth diagram where yield at an age (or size) at recruitment is the maximum at each level of F. In analyses where year-class or cohort growth (in weight), and mortality are constant the eumetric fishing line forms a smooth curve which ascends to an asymptotic value at some infinite level of fishing mortality. The age or size which maximizes yield per recruit can be considered the critical age (or size) of individuals in the cohort and corresponds to the maximum biomass of the cohort. Ricker (1975) defined critical size as the average size of a fish in a year-class at the time when instantaneous rate of natural mortality equals the instantaneous rate of growth in weight for the year-class as a whole.

The various fishing strategies examined in this paper incorporate variable growth and fishing mortality and the eumetric fishing line determined from these analyses does not form a smooth curve. Rather, it forms line segments with very little positive slope that are connected by vertical lines.

An example of an eumetric fishing line formed from the fishing strategies discussed here is shown in Figure 20 in the yield isopleth diagram for variable effort summer and winter fisheries with M = 0.82.

Table 23.--Yield per recruit (gm) by age at recruitment into the fishery and levels of fishing mortality for saffron cod in Norton Sound. Yields are from a fishing strategy that combines an intensive fishery during ice-free months (June-October) and a less intensive one (i.e., one-half the ice-free level) during months with ice cover (November-May) with M = 0.82 and 1.02.

M = 0.82

Age at Recruitment (years)	Time (Date)	Levels of Fishing Mortality 0.1	0.3	0.5	0.7	0.9
0.0	(June 1)	1.84	4.35	5.60	5.94	5.96
0.1	(July 6)	1.85	4.69	5.95	6.38	6.55
0.2	(Aug. 12)	1.85	4.75	6.10	6.69	6.92
0.3	(Sept. 18)	1.82	4.85	6.13	6.82	7.17
0.4	(Oct. 24)	1.79	4.73	6.14	6.88	7.27
0.5	(Nov. 30)	1.77	4.70	6.12	6.88	7.29
0.6	(Jan. 5)	1.75	4.68	6.12	6.90	7.34
0.7	(Feb. 11)	1.73	4.66	6.13	6.94	7.41
0.8	(Mar. 19)	1.72	4.66	6.16	7.02	7.52
0.9	(Apr. 26)	1.70	4.65	6.16	7.07	7.65
1.0		1.69	4.65	6.18	7.16	7.77
1.1		1.67	4.61	6.21	7.39	8.14
1.2		1.63	4.55	6.20	7.44	8.27
1.3		1.55	4.40	6.11	7.25	8.11
1.4		1.49	4.21	5.83	6.94	7.79
2.0		1.25	3.64	5.12	6.15	6.94
3.0		0.76	2.31	3.33	4.10	4.73
4.0		0.40	1.25	1.85	2.32	2.71
5.0		0.18	0.58	0.89	1.14	1.36
6.0		0.13	0.21	0.33	0.44	0.54

M = 1.02

Age at Recruitment (years)	Time (Date)	Levels of Fishing Mortality 0.1	0.3	0.5	0.7	0.9
0.0	(June 1)	1.36	3.04	3.89	4.28	4.42
0.1	(July 6)	1.19	3.13	4.09	4.60	4.87
0.2	(Aug. 12)	1.36	3.15	4.18	4.77	5.11
0.3	(Sept. 18)	1.33	3.12	4.18	4.81	5.19
0.4	(Oct. 24)	1.29	3.04	4.10	4.75	5.16
0.5	(Nov. 30)	1.26	2.99	4.05	4.69	5.10
0.6	(Jan. 5)	1.24	2.95	4.00	4.66	5.08
0.7	(Feb. 11)	1.22	2.92	3.98	4.64	5.06
0.8	(Mar. 19)	1.20	2.89	3.96	4.64	5.08
0.9	(Apr. 26)	1.19	2.87	3.95	4.65	5.12
1.0		1.17	2.86	3.96	4.84	5.18
1.1		1.15	2.85	4.00	4.80	5.38
1.2		1.11	2.76	3.91	4.74	5.36
1.3		1.04	2.61	3.72	4.35	5.15
1.4		0.96	2.43	3.47	4.23	4.88
2.0		0.66	1.96	2.82	3.47	3.96
2.4		--	--	--	--	--
3.0		0.33	1.06	1.56	1.95	2.26
3.4		--	--	--	--	--
4.0		0.18	0.48	0.72	0.92	1.08
4.4		--	--	--	--	--
5.0		0.07	0.18	0.296.0	0.38	0.45
5.4		--	--	--	--	--
6.0		0.02	0.06	0.09	0.13	0.15

Table 24.--Yield per recruit (gm) by age at recruitment into the fishery and levels of fishing mortality for saffron cod in Norton Sound/ Yields are from a fishery that occurs only during the time of ice cover (i.e., "winter. fishery", November-May) with M = 0.82 and 1.02.

M = 0.82

Age at Recruitment (years)	Time (Date)	Levels of Fishing Mortality 0.1	0.3	0.5	0.7	0.9
0.0	(June 1)	--	--	--	--	--
0.4	(Oct. 24)	1.93	4.48	5.95	6.81	7.34
0.5	(Nov. 30)	1.85	4.41	5.90	6.79	7.38
0.6	(Jan. 5)	1.84	4.35	5.87	6.81	7.41
0.7	(Feb. 11)	1.80	4.31	5.87	6.88	7.54
0.8	(Mar. 19)	1.76	4.28	5.91	7.00	7.75
0.9	(Apr. 26)	1.73	4.25	5.94	7.13	7.99
1.0	(June 1)	1.70	4.24	6.01	7.31	8.31
1.4		1.70	4.24	6.01	7.31	8.31
1.5		1.60	3.99	5.67	6.89	7.82
1.6		1.50	3.76	5.36	6.53	7.42
1.7		1.40	3.56	5.09	6.23	7.09
1.8		1.33	3.38	4.86	5.98	6.84
1.9		1.25	3.13	4.64	5.75	6.62
2.0		1.18	3.04	4.45	5.56	6.46
2.4		1.18	3.04	4.45	5.56	6.46
3.0		0.79	1.81	2.70	3.42	4.02
3.4		0.79	1.81	2.70	3.42	4.02
4.0		0.35	0.94	1.42	1.83	2.18
4.4		0.35	0.94	1.42	1.83	2.18
5.0		0.15	0.43	0.66	0.87	1.05
5.4		0.15	0.43	0.66	0.87	1.05
6.0		0.05	0.15	0.24	0.32	0.40

M = 1.02

Age at Recruitment (years)	Time (Date)	Levels of Fishing Mortality 0.1	0.3	0.5	0.7	0.9
0.0	(June 1)	--	--	--	--	--
0.4	(Oct. 24)	1.51	2.95	4.08	4.84	5.37
0.5	(Nov. 30)	1.43	2.85	3.95	4.70	5.23
0.6	(Jan. 5)	1.37	2.76	3.86	4.61	5.15
0.7	(Feb. 11)	1.31	2.69	3.79	4.57	5.13
0.8	(Mar. 19)	1.26	2.63	3.74	4.56	5.17
0.9	(Apr. 26)	1.22	2.56	3.72	4.58	5.25
1.0	(June 1)	1.17	2.54	3.71	4.63	5.38
1.4		1.17	2.54	3.71	4.63	5.38
1.5		--	--	--	4.24	4.92
1.6		--	--	--	--	--
1.7		--	--	--	--	--
1.8		--	--	--	--	--
1.9		--	--	--	--	--
2.0		0.68	1.57	2.35	2.99	3.54
2.4		0.68	1.57	2.35	2.99	3.54
3.0		0.32	0.79	1.19	1.53	1.83
3.4		0.32	0.79	1.19	1.53	1.83
4.0		0.13	0.34	0.53	0.68	0.82
4.4		0.13	0.34	0.53	0.68	0.82
5.0		0.05	0.13	0.24	0.27	0.33
5.4		0.05	0.13	0.24	0.27	0.33
6.0		0.01	0.04	0.06	0.09	0.11

Table 25.--Yield per recruit (gm) by age at recruitment into the fishery and levels of fishing mortality for saffron cod in Norton Sound. Yields are from a fishery that occurs only during the time that is ice-free (i.e., "summer fishery", June-October) with M = 0.82 and 1.02.

M = 0.82

Age at Recruitment (years)	Time (Date)	Levels of Fishing Mortality 0.25	0.75	1.25	1.75	2.25
0.0	(June 1)	2.76	4.94	5.23	4.91	4.40
0.1	(July 6)	2.82	5.34	5.76	5.98	5.76
0.2	(Aug. 12)	2.84	5.58	6.51	6.73	6.67
0.3	(Sept. 18)	2.80	5.65	6.76	7.14	7.23
0.4	(Oct. 24)	2.70	5.62	6.86	7.36	7.54
1.0	(June 1)	2.70	5.62	6.86	7.36	7.54
1.1	(July 6)	2.50	5.75	7.28	8.10	8.57
1.2	(Aug. 12)	2.50	5.66	7.34	8.33	8.98
1.3	(Sept. 18)	2.36	5.26	6.96	8.05	8.78
1.4	(Oct. 24)	2.13	4.85	6.42	7.41	8.11
2.0	(June 1)	2.13	4.85	6.42	7.41	8.11
2.4	(Oct. 24)	1.36	3.26	4.50	5.39	6.07
3.0	(June 1)	1.36	3.26	4.50	5.39	6.07
3.4	(Oct. 24)	0.74	1.84	2.62	3.70	3.87
4.0	(June 1)	0.74	1.84	2.62	3.70	3.87
4.4	(Oct. 24)	0.41	0.89	1.31	1.65	1.93
5.0	(June 1)	0.41	0.89	1.31	1.65	1.93
5.4	(Oct. 24)	0.12	0.33	0.51	0.67	0.82
6.0	(June 1)	0.12	0.33	0.51	0.67	0.82

M = 1.02

Age at Recruitment (years)	Levels of Fishing Mortality 0.25	0.75	1.25	1.75	2.25
0.0	1.77	3.38	3.77	3.68	3.41
0.1	1.85	3.67	4.36	4.55	4.53
0.2	1.80	3.77	4.64	5.01	5.15
0.3	1.74	3.73	4.69	5.16	5.39
0.4	1.64	3.59	4.57	5.07	5.34
1.0	1.64	3.59	4.57	5.07	5.34
1.1	--	--	4.79	5.51	5.98
1.2	--	--	4.68	5.49	6.06
1.3	--	--	--	5.10	5.69
1.4	1.15	2.72	3.72	4.41	4.93
2.0	1.15	2.72	3.72	4.41	4.93
2.4	0.64	1.55	2.20	2.69	3.08
3.0	0.64	1.55	2.20	2.69	3.08
3.4	0.29	0.74	1.07	1.33	1.55
4.0	0.29	0.74	1.07	1.33	1.55
4.4	0.11	0.31	0.45	0.57	0.68
5.0	0.11	0.31	0.45	0.57	0.68
5.4	0.03	0.10	0.15	0.20	0.24
6.0	0.03	0.10	0.15	0.20	0.24

The combined efforts of high natural mortality and low levels of fishing effort (fishing mortality) result in relatively slight changes in a, (i.e., the age at maximum yield or eumetric yield at age) up to F = 0.35. Between F = 0.35 and 0.40, however, a_e jumps from 0.4 years up to about 1.1 years. For any increases in effort over F = 0.4, a_e again increases very slightly, only about 25% to 1.4 years by F = ∞. This very young age at maximum yield per recruit even at F = ∞ results from very high natural mortality. According to Ricker (1975, Appendix I, pages 337-338) M = 0.82 corresponds to an annual die-off of about 56% of a cohort and M = 1.02 equals an annual natural mortality of nearly 64%. The rapid change in a_e between F = 0.35 and 0.40 is caused by very slow winter growth (defined in these analyses) and a constant high M. These factors result in declining weight of a cohort during winter that is followed by a spurt of increased weight from the onset of rapid growth the following summer (Fig. 23).

Obviously, for each fishing strategy higher yields per recruit were achieved in analyses using the lower natural mortality rate. Yield differences between analyses using M = 0.82 and 1.02 were least at low F levels and increased as fishing mortality increased (Figs. 24-26). A comparison of yields by fishing strategies indicates that at either level of M and at various ages at recruitment, differences between the fisheries were least at low levels of fishing mortality.

In general, greatest yield per recruit with either value of M was achieved with the fishing strategy what combined summer and winter fisheries (Figs. 27,28). At very young ages at recruitment (i.e., <2 years), however, the "winter only" fishing strategy produced yields similar or larger than those obtained in the year-round combination. In most instances,

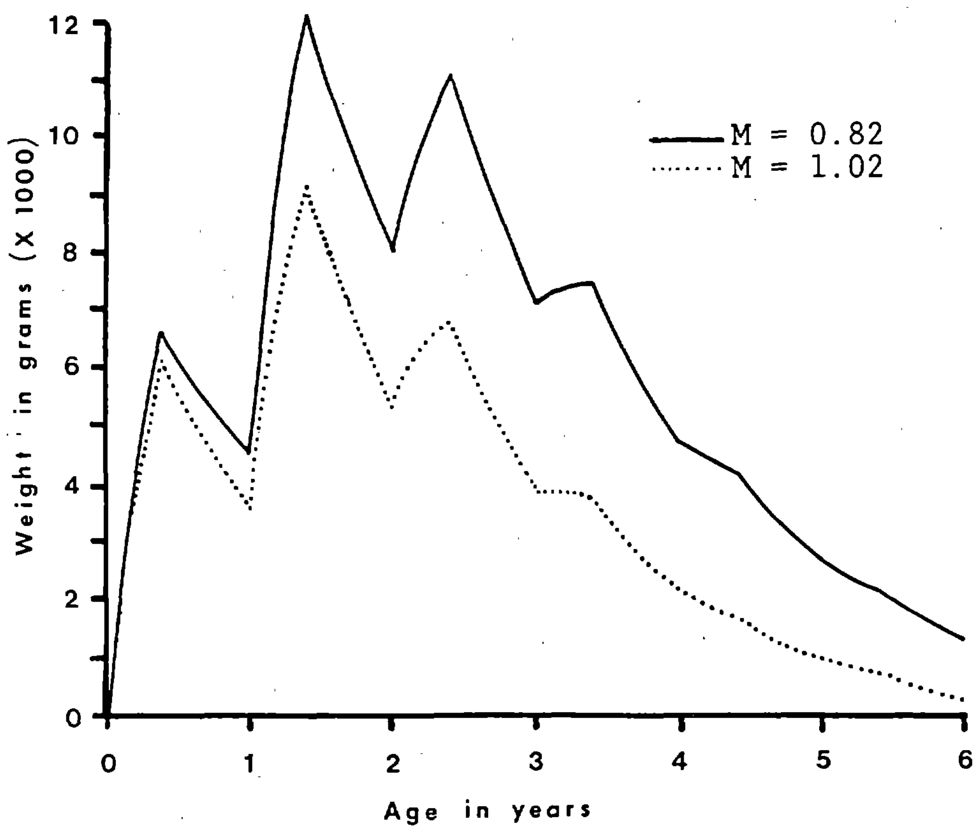


Figure 23. --Weight-at-age for a cohort of saffron cod with an initial population size of l,000 fish (500 males and 500 females).

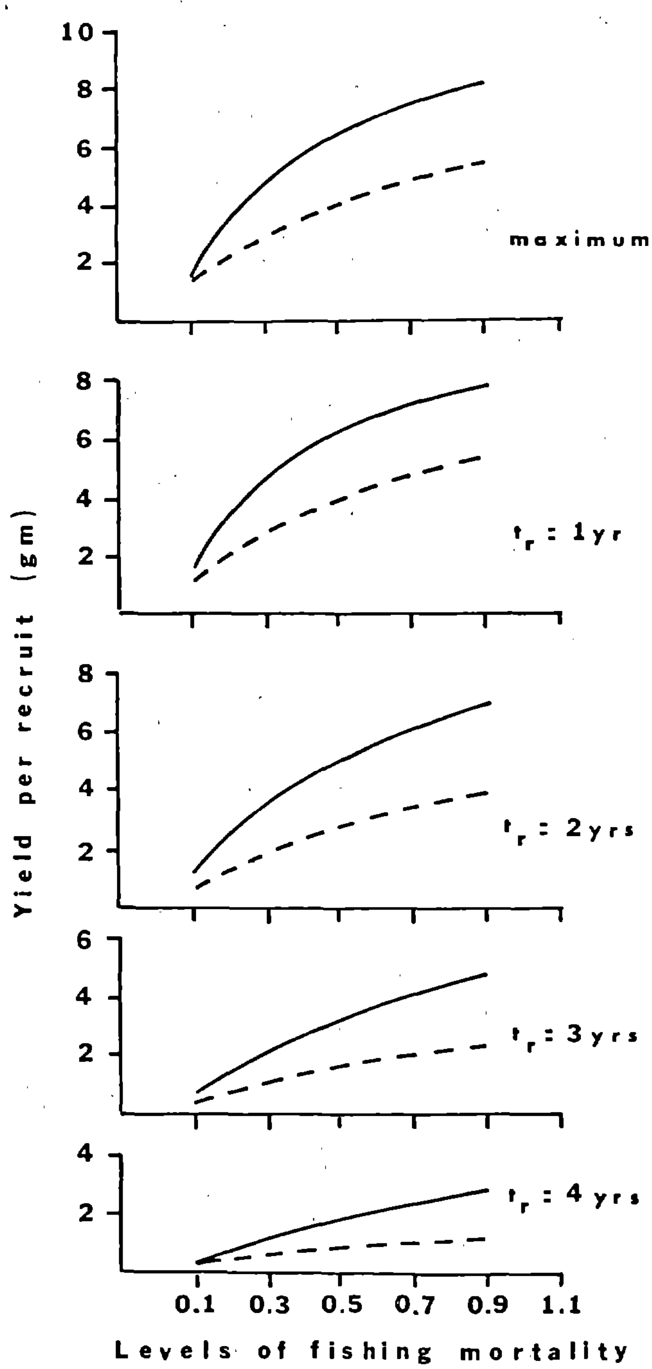


Figure 24. --Comparisons of yields per recruit for saffron cod at various levels of fishing mortality and ages at entry by two rates of natural mortality in a fishery that occurs year-round.

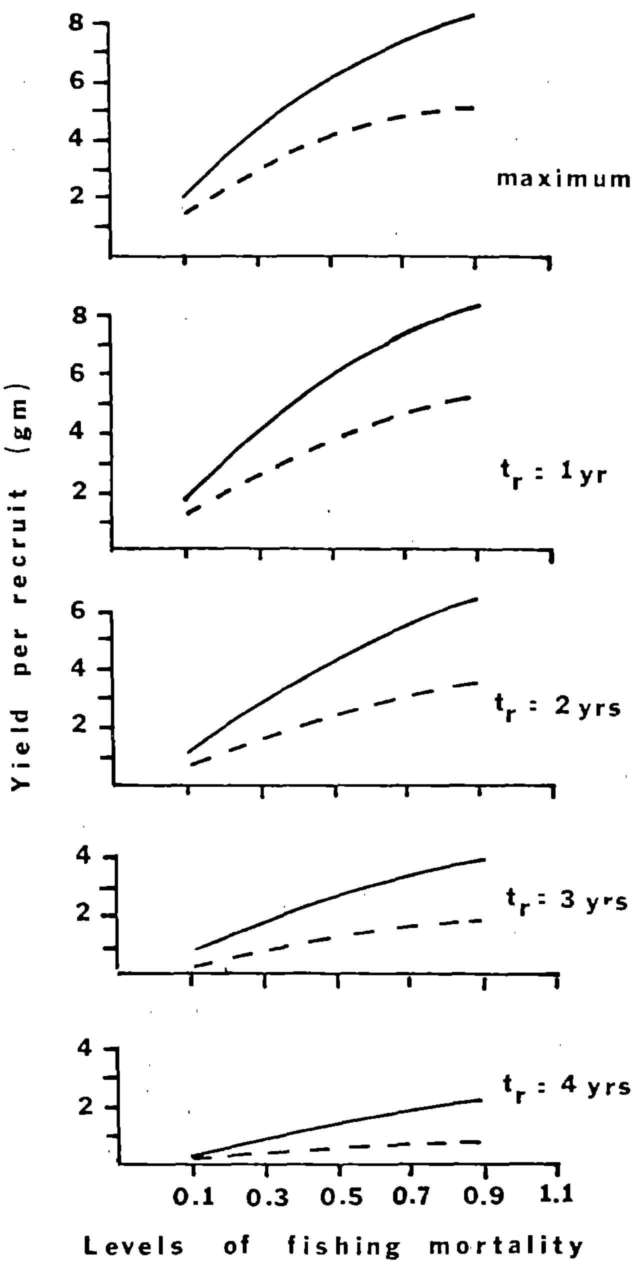


Figure 25.--Comparisons of yields per recruit for saffron cod at various levels of fishing mortality and ages at entry by two rates of natural mortality in a fishery that occurs during time periods with ice cover (i.e., "winter fishery").

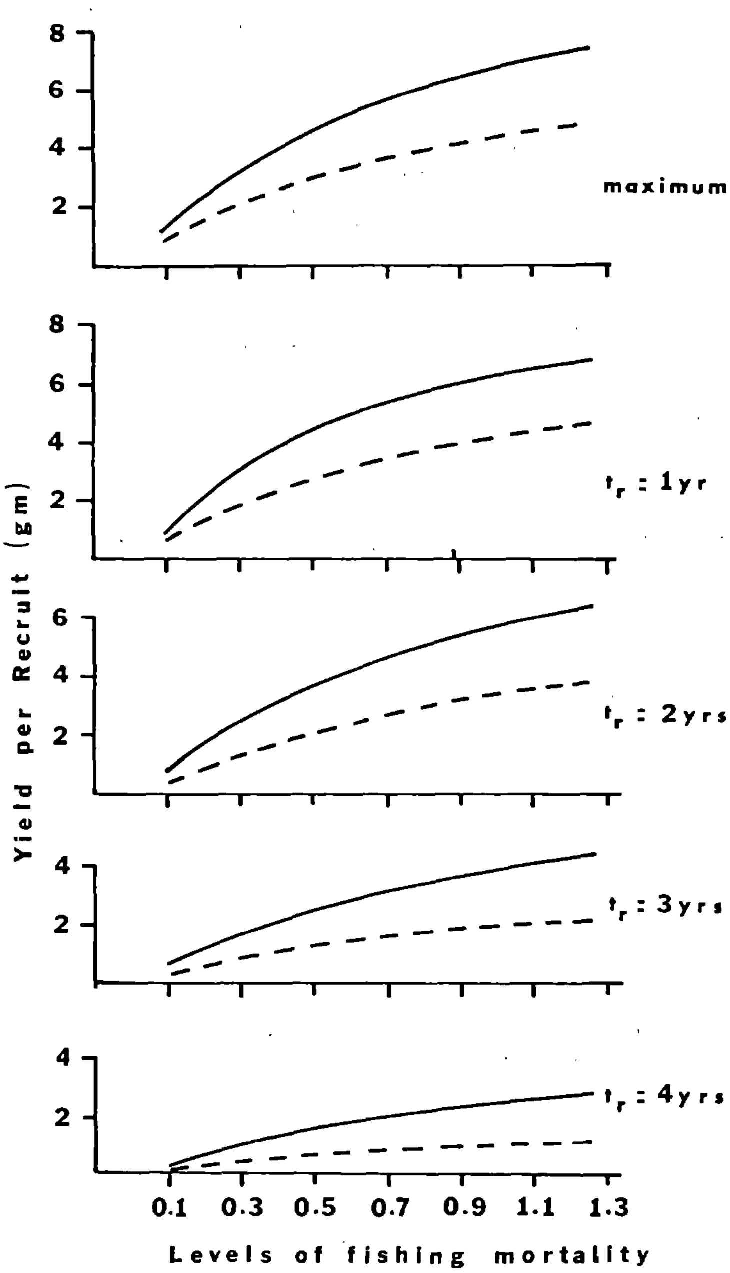


Figure 26.--Comparisons of yields per recruit for saffron cod at various levels of fishing mortality and ages at entry by two rates of natural mortality in a fishery that occurs during time periods that are ice-free (i.e., "summer fishery").

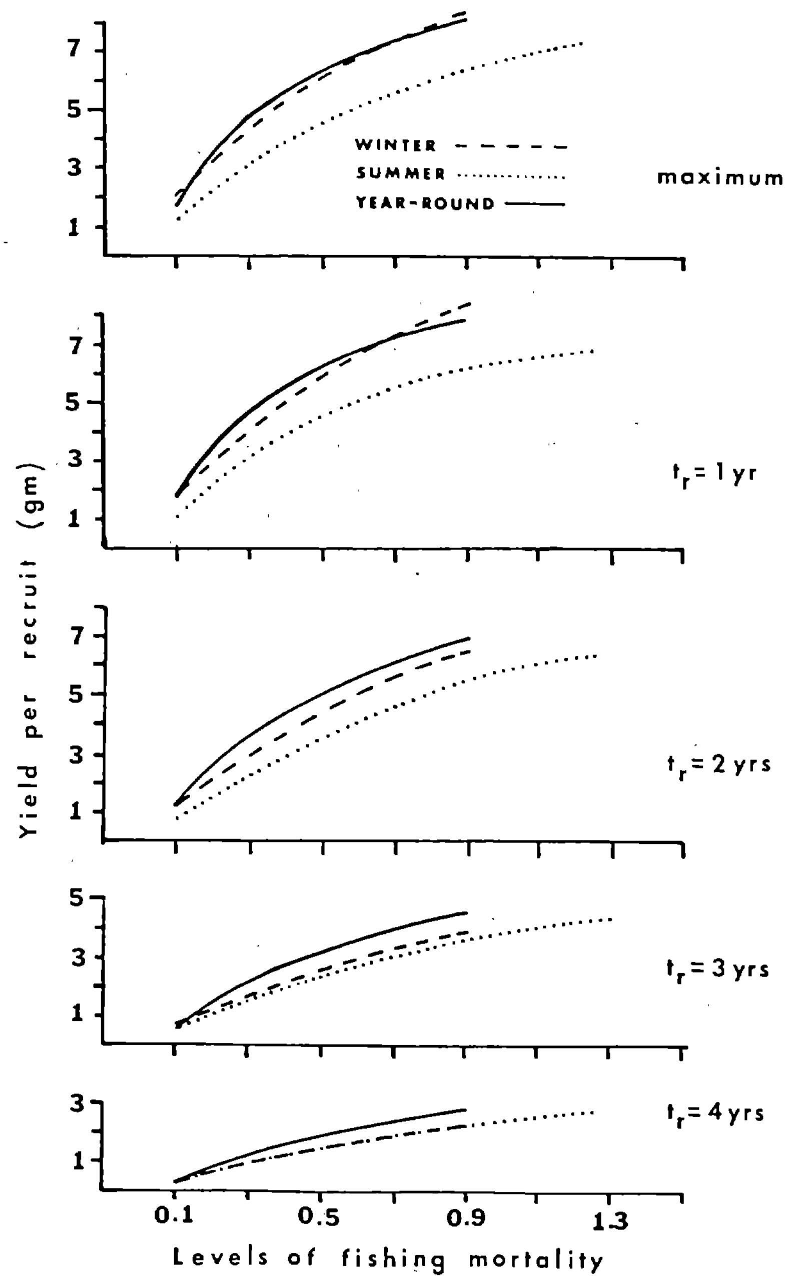


Figure 27. --Comparisons of yields per recruit for saffron cod by various levels of fishing mortality and ages at entry into "winter", "summer", and year-round fisheries with M = 0.82.

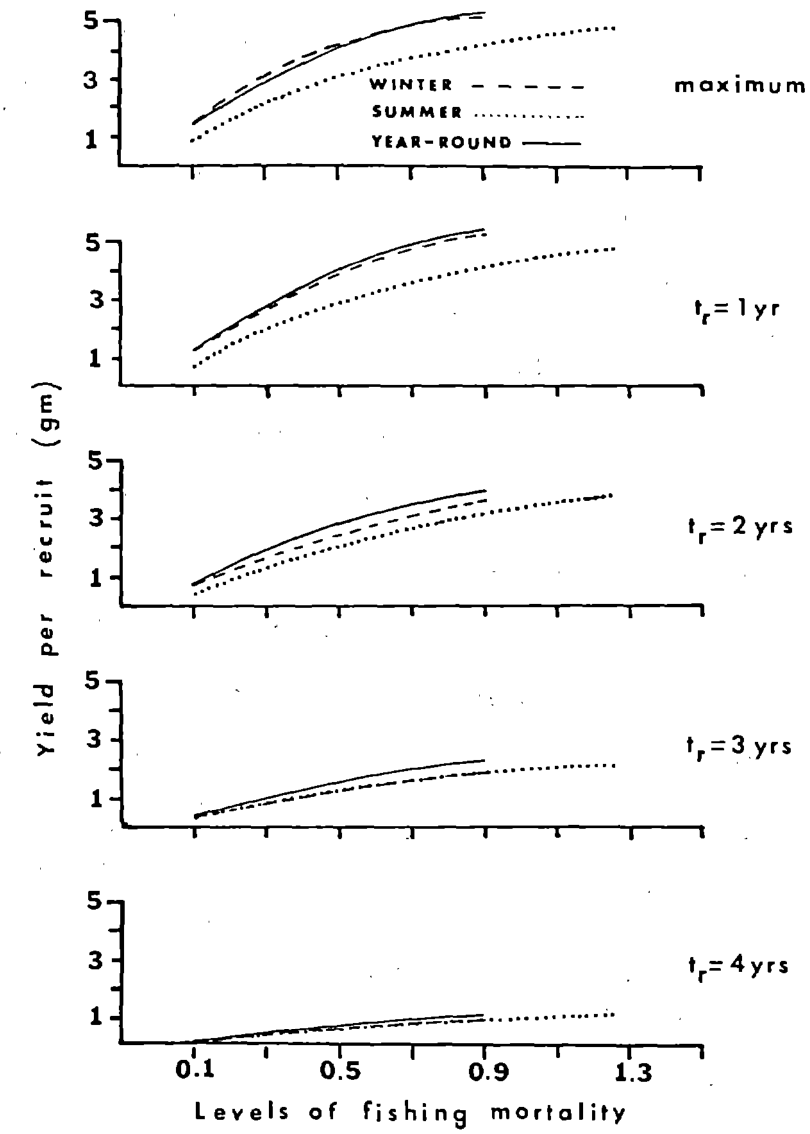


Figure 28. --Comparisons of yields per recruit for saffron cod by various levels of fishing mortality and ages at entry into "winter", "summer", and year-round fisheries with M = 1.02.

yields per recruit for the "summer only" fishing strategy were noticeably lower than the other strategies analyzed. The few instances where similar yields were produced by all three strategies were at the older ages of recruitment.

It appears, then, that the year-round combination fishery was the optimum strategy examined, regardless of which value of M was used. However, within this strategy the different rates of natural mortality changed expected yields. As stated previously, yields per recruit at M = 0.82 were greater than at M = 1.02 for equal F values, but the differences changed with increased fishing effort. At F = 0.1, yield per recruit with the lower value of M was about 35% greater than with the higher value. At F = 0.3, the difference had increased to about 50% (i.e., yield with M = 0.82 was 1.5 times that at M = 1.02) and it remained at about 50-54% with any further increases in F. In other words, differences were least at low F levels, increased substantially between F = 0.1 and 0.3, and then remained relatively constant for any further increases in F. Another notable difference between yields at the two levels of mortality was that at the lower value, age at recruitment could be substantially raised yet the fishery would still produce yields that were greater than amounts from the higher M with a younger t_r. For example, if t_r with M = 0.82 was at age 3 years, yields produced throughout the range of F values would be 15-19% higher than those attained at equal F levels with t_r = 2 years at M = 1.02.

It is very important to note that for both levels of M and in all fishing strategies analyzed, maximum yield per recruit was always obtained with t_r at very young ages, never older than age 1.4 years. The maturity data examined earlier suggest that both sexes of saffron cod start to mature during their third year (age 2+). Thus, if any of the fisheries examined in this paper were managed to maximize yield per recruit, a substantial harvest of a cohort or year class could occur before the age of sexual maturity, impacting the reproductive potential of the stock. Conversely, if the age at recruitment is set at some time after sexual maturity, yield per recruit could be substantially reduced from maximum levels determined in the analyses.

DISCUSSION

Federal trawl surveys during the late 1970s identified a population of saffron cod in sub-Arctic western Alaska waters that is estimated to be about 2 billion fish and comprises a standing stock of approximately 110,000 t. The size of this resource is only a fraction of the magnitude of gadid populations in the eastern Bering Sea. Yet, a commercial potential could exist for this resource.

There are problems associated with a commercial harvest of saffron cod. Their apparent high rate of natural mortality, small individual size, variable year-class strength, yield constraints, and other factors must be carefully considered before a fishery is attempted;

Analyses presented in this paper indicate that in western Alaskan waters saffron cod have a high rate of natural mortality. Apparently 60-80% of the population dies annually and less than 1% of the stock survives past the age of 5 years. This fact, coupled with a relatively slow growth rate, means that a very small portion of the population is larger than 25 cm (in length) or 125 gm (in weight). Most of the population then is composed of young and small sized individuals. It should be mentioned that saffron cod in Soviet waters appear to have a lower mortality. Semenenko (1973) provides the only known reference in the literature and states that about 5% of a year-class survives to an age of 6+ years in the Yamsk Bay region of the Sea of Okhotsk.

Yield analyses preformed in the previous section imply that even at very high levels of fishing effort, maximum yield per recruit is achieved at a very young age (with the critical age of a year-class at about 1.4 years). This corresponds to a fish that is only about 17 cm in length and weighs about 36-37 gm.

Delaying age at entry into a fishery would result in a substantial reduction in yield per recruit. With high natural mortality, delaying entry until an age of 3 years results in about a 45-80% decrease in yield per recruit depending on which fishery (and F level) is used. Age 3 years is mentioned because sexual maturity of saffron cod off western Alaska does not apparently begin until their third summer (age 2+). Delaying a harvest until a fish was 3 years old would then allow for one mating season, which, while it would lower yield per recruit dramatically below maximum levels, would be desirable until data relating stock size to recruitment were available. A number of fishing seasons might be needed to gain such information.

Other problems associated with developing a commercial harvest of saffron cod are the apparent variability of year-class strength and changes in condition of flesh during the year. Soviet literature suggests up to a sevenfold difference between weak and strong year classes in western Pacific waters (Semenenko 1973) and up to lo-fold differences in Eleginus populations in the Soviet Arctic (Anukina 1968). The Norton Sound data analyzed in this paper suggests even greater differences since over 400 million age 0 fish were estimated present in 1976 but no young of the year were found during the surveys in 1979. Such indicated variability in recruitment certainly needs consideration in management of the resource.

Soviet sources also indicate that the flesh of saffron cod is of very low quality after spawning in early winter and its condition does not improve until intensive feeding resumes the following late spring. If this is so for present stocks, it may preclude a winter fishery.

It should be mentioned, however, that the U.S.S.R. has maintained a fishery for saffron cod in the face of year-class fluctuations and changes in flesh quality.

Yet another set of problems lies in product forms and-marketing. Saffron cod are too small to be extensively used as an alternate or supplemental source of fillets and fish blocks to walleye pollock and Pacific cod from the Bering Sea and northeast Pacific Ocean. Also, using saffron cod as a substitute protein source in pet food does not seem likely. A Norwegian fisheries consultant group investigated the potential for using Alaskan saffron cod as an alternate to blue whiting, *Micromesistius poutasssou*, in the European pet food industry (Barlindhaug 1980). This analysis concluded that transportation expenses, coupled with processing costs, would be excessive; and the Alaskan fish would not be competitive with the existing European product.

Lastly, there could be problems with certain fishing strategies. In my yield analyses, the fishing strategy which resulted in the best yields per recruit included summer and winter fisheries. Using stationary fishing gear under the ice is a somewhat novel technique in U.S. waters. Some types of gear are fished during the winter in freshwater lakes in the midwestern United States (Dumont and Sundstrom 1961), but there are no apparent similar marine applications. This, coupled with an unfamiliarity of locations for safe and effective areas to set these nets, could impede development of a winter fishery.

Successful development of a major saffron cod fishery is therefore questionable. However, a potential exists for a less extensive fishery if the resource is considered in a proper perspective. The saffron cod population of Norton Sound (or western Alaska as a whole) is not sufficiently large to be targeted by a large distant-water fleet. Rather, a potential lies in a local small volume fishery with low overhead. This type of operation could be compatible with and supplemental to existing commercial fisheries.

Consider, for example, the coastal gill-net fishery by the local small boat fleet. There are approximately 175-200 commercial fishermen in coastal villages from Nunivak Island to Bering Strait (Alaska Department of Fish and Game 1982). They currently engage in gill-net and/or beach seine fisheries for Pacific herring in early to mid-June and a gill-net fishery for salmon from June through mid-August. Vessels used in these operations are small (4.5-6-0 m) open skiffs powered by outboard motors. A fishery for saffron cod that occurred after salmon fishing would not interfere with existing operations and would provide supplemental use of the fishing vessels and, probably, some herring fishing gear.

The western Alaska herring fishery uses small mesh (50-63.5 mm, stretched mesh measure) gill nets and fine mesh (32 mm) beach seines. These web sizes are similar to those used for saffron cod fisheries in the U.S.S.R. Information provided by Andreev (1962) suggests that herring gill nets currently used in western Alaska would be effective for catching 25 cm or larger saffron cod. This is based upon the formula provided by Baranov (1960) for optimal gill-net size, $a = kl$, where a is the optimum mesh size (bar measure) in millimeters, l is the average length (mm) of the fish for which the net is designed, and k is an empirically determined coefficient, specific for a fish species (0.10 for *Eleginus* spp. according to Andreev).

While fishing gear for a summer or ice-free fishery is probably available, winter fishing through the ice with pound or fyke nets is not currently performed in the region. However, another type of stationary gear is used in Norton Sound during winter so ice fishing is not totally foreign to the area. Residents of Nome annually participate in a subsistence fishery for red king crab. This operation ranges out several miles offshore and continues throughout the winter until the sea ice deteriorates in the spring. Additionally, residents along the western Alaska coast already fish for saffron cod through the ice with hook and line for subsistence purposes. As a result, local residents are familiar with some forms of ice fishing and already have some idea where saffron cod are found during winter. This familiarity enhances prospects for a winter fishery, and the use of snowmobiles to tend fyke nets would provide fishermen an extensive range of fishing locations along most of the coastline.

A problem still to be considered is resource availability associated with variable year-class strength and high natural mortality. While there appears to be substantial variation in year-class strength for the saffron cod population in the region, the 2 years' surveys indicate that so&older, larger fish are always present. The 1976 and 1979 data suggest that there are 40-172 million fish in Norton Sound 3 years old or older. A substantial portion of the population appears to occur south of Norton Sound but it is not certain whether the proportion of these older fish region-wide remains constant from year to year. If it remains relatively constant, then the total 3 years old and older segment of the saffron cod population for western Alaska would be about 73 to 300 million fish. (Note: this is based on the 1979 data which indicated that about 45% of the 3 years old and older fish in western Alaska were found south of Norton Sound.)

Seventy-three million fish seems adequate for a commercial fishery. This amount-corresponds to a standing biomass of about 7,000 t for the entire western Alaska region in 1976. The 1979 biomass would be nearly

36,000 t. While data for 1976 and 1979 may represent population extremes, they are the only numbers available.

Consequently, following procedures described by Alverson and Pereyra (1969), approximations of maximum sustainable yield (MSY) for harvest of 3 years old and older saffron cod would be about 3,600 t based on the 1976 population estimate and about 18,800 t using the 1979 data. These figures are derived from the formula determining a rough approximation of MSY: $MSY = 0.5\ M(B_o)$, where $M = 1.02$ and the virgin biomass B, is my estimate of the standing biomass of fish 3 years old and older. Fishing mortality F is assumed to equal natural mortality M. Since the value of M determined in my analysis is quite high, for the formula to be correct the corresponding F would likewise be very high.

The harvest levels are relevant only if the catches can be sold., While marketing requires knowledge beyond the scope in this paper, there may be some provocative possibilities. As mentioned earlier, the individual size of saffron cod does not readily lend to its substitution into existing Pacific cod and walleye pollock markets and transportation costs would not permit this species to be profitably used in the pet food industry. A viable market option, however, might exist in the U.S.S.R. That country apparently has utilized 30,000-40,000 t of saffron cod for human consumption during recent years. Fish from western Alaska could possibly be exported to the U.S.S.R., especially since ports on the Kamchatka Peninsula are closer to western Alaska than any port on the west coast of the United States. For example, the distances from Norton Sound to Petropavlosk and Seattle are about 3,000 km and 3,900 km, respectively. My assumptions regarding this potential market include favorable international trade conditions.

Another potential market option might be saffron cod roe if its quality is comparable to that of other gadids. There presently exists a Japanese market for roe of Pacific cod and walleye pollock. The wholesale price for pollock roe from Alaska has been as high as $4.40 per kilogram in past years and the most recent export (1983) brought a price of $2.27 per kilogram (NMFS Fishery Market News 1983). My study of saffron cod in Norton Sound did not identify roe content at the time of spawning, but an approximation can be determined from amounts identified for Arctic stocks in Soviet waters. Pokrovskaya (1960) indicated roe weight for E. navaga can be 22.6-24.6% of total body weight for fish 21-27 cm long. Using the value of 23% of total body weight of females, the estimated volume of roe present in the western Alaska saffron cod population is between about 700 t and 3,300 t for 3 years old and older females. A rough approximation of its value at $2.27/kg is $1.9 to $9.2 million. Even at an estimated ex-vessel price of $110 per metric ton for saffron cod in the round, the MSY could produce between $396,000 and $2 million. An MSY divided between flesh and roe products would substantially exceed the entire current value of this region's coastal commercial fisheries. The total value of commercial harvests by Norton Sound-western Alaska residents in 1982 was $2 million ($1 million, herring; $1 million, salmon) and for 1981 was about $2.3 million (source: Alaska Department of Fish and Game 1983).

It appears then, that the saffron cod resource along the coast of western Alaska has some commercial potential. The estimated exploitable biomass may permit sustained yields of 3,600-18,000 t per year. Harvesting of this resource can be done by local communities without major modifications of conventional fishing equipment and methodologies, or interference with existing herring and salmon fisheries. The development of a saffron cod fishery will, however, depend on economic considerations that go beyond the scope of this paper, which assesses only resource abundance and availability. Potential markets for western Alaska saffron cod, particularly in Japanese roe or Soviet frozen fish markets, should be investigated.

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