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PRELIMINARY REPORT ON

BIO-ECONOMIC CONSIDERATIONS OF HARVESTING SABLEFISH BY LONGLINE AND TRAWL GEAR IN THE GULF OF ALASKA

April 1979

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PRELIMINARY REPORT ON

BIO-ECONOMIC CONSIDERATIONS OF HARVESTING SABLEFISH BY LONGLINE AND TRAWL GEAR IN THE GULF OF ALASKA

by

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April 1979

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PRELIMINARY REPORT ON

BIO-ECONOMIC CONSIDERATIONS OF HARVESTING SABLEFISH

BY LONGLINE AND TRAWL GEAR

IN THE GULF OF ALASKA

EXECUTIVE SUMMARY

Evaluation of the bio-economics of harvesting sablefish by trawls and longline gear includes the following considerations:

(1) Yield of sablefish,

(2) Size composition of catch,

(3) Effects on spawning potential of sablefish,

(4) Total groundfish production,

(5) Incidental halibut mortality, and

(6) Value of harvest to fishermen.

YIELD OF SABLEFISH

Yield-Per-Recruit

This analysis shows that the physical yield of sablefish will be obtained when recruitment to the fishery is delayed until the fish are about 6½ years old, then applying a rather high exploitation rate. Near-maximum yield (95%) can be achieved at lower fishing rates with an age at recruitment of 5½ years; however, yield falls off rapidly at ages younger than 5 years.

Instantaneous Fishing Mortality	Optimum Age at Entry into Fishery	Maximum Yield-Per-Recruit (gm)
0.2	3.1	1200
0.4	4.5	1450
0.6	5.3	1540
0.8	5.8	1580
1.0	6.1	1610
1.2	6.3	1630
1.4	6.5	1640
1.5	6.5	1650
1.6	6.6	1650

Yield-Per-Cohort

This analysis shows that a sablefish cohort has its maximum biomass at age 6 (average length = 25½ in; average weight = 6½ lbs).

Age	Percent of Maximum Biomass	Average Length (cm)	Average Length (in)	Average Weight (gm)	Average Weight (lbs)
1	42	34	13.5	416	0.9
2	63	42	16.6	766	1.7
3	80	49	19.3	1216	2.7
4	92	55	21.6	1745	3.8
5	98	60	23.7	2332	5.1
6	100	65	25.5	2952	6.5
7	98	69	27.1	3588	7.9
8	92	72	28.5	4222	9.3
9	85	75	29.7	4843	10.7
10	76	78	30.7	5440	12.0

Size Composition of Catch

The Japanese longline and trawl fisheries both take sablefish of an average size that is close to that which produces maximum yield-per-recruit and at which cohort biomass is maximized. If the domestic trawl fishery operates in shallower water or closer inshore than do the Japanese trawlers, the average size of sablefish in its catch is likely to be somewhere between that of research vessel and Japanese trawl catches, and well below the optimum.

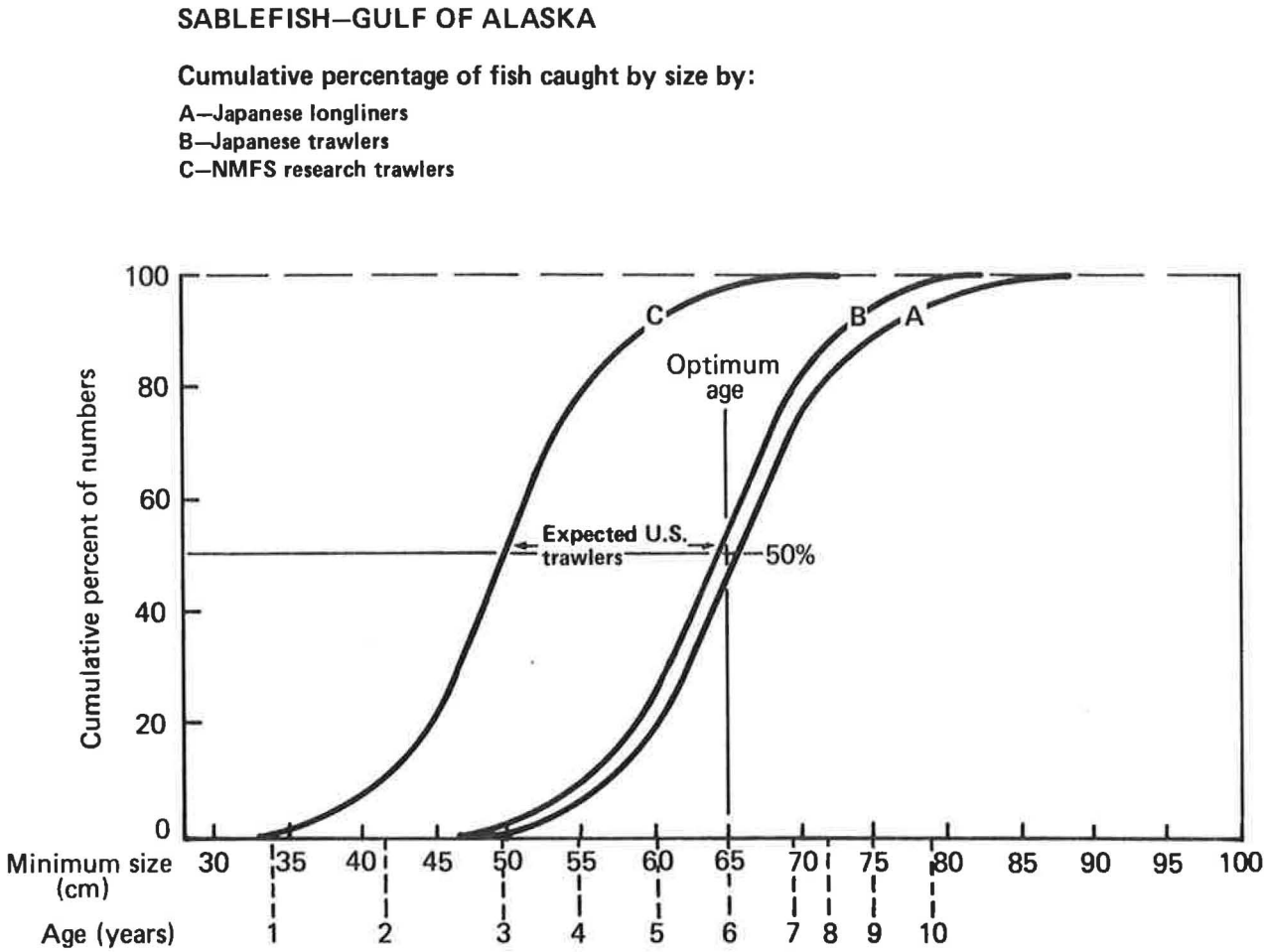

Figure --Comparison of sablefish size composition taken by Japanese longliners, Japanese trawlers, and U.S. research trawlers in 1977-78.

EFFECT ON SPAWNING POTENTIAL OF SABLEFISH

The catch of a Japanese-style longline fishery is composed of 45% mature fish, a Japanese-style trawl fishery 25% mature fish, and a U.S. trawl Fishery perhaps 10-20% mature fish. All other things being equal, a Japanese-style longline fishery would allow maintenance of the largest sablefish spawning potential.

TOTAL GROUNDFISH PRODUCTION

A broad range of fishing strategies is used to forecast total groundfish production by trawlers and longliners. These strategies are based on several assumptions as to fishery performances under different sablefish allocation schemes for longliners and trawlers. The extremes considered are:

- Exclusive longline fishery in the Gulf of Alaska (that is, no trawling for any species);
- Exclusive trawl fishery in the Gulf of Alaska (that is, no longlining for any species).

Between the extremes are coexistence fisheries with almost limitless combinations of sablefish allocations to trawlers and longliners, each having an array of possible species compositions in its catch. Two constraints are placed on the forecasting analyses: the 13,000 mt optimum yield (OY) of sablefish and the 285,900 mt combined OY for "other groundfish" cannot be exceeded.

In an exclusive longline fishery, all of the sablefish OY, but no more than 5% of the other groundfish OY, are taken. In an exclusive trawl fishery, 92% of the sablefish OY, while all of the other groundfish OY, are taken. Between these extremes are combinations of sablefish allocations among trawlers and longliners, several of which would allow the OY of both sablefish and other groundfish to be caught. One such situation determined in the coexistence fishery occurs when approximately 10,000 mt of sablefish is allocated to longliners with a catch containing 50% sablefish. The remaining 3,000 mt is allocated to trawlers whose catch is composed of 1% sablefish.

INCIDENTAL HALIBUT MORTALITY

The incidental catch of halibut in a Japanese-style trawl fishery is greater than in a Japanese-style sablefish longline fishery. On a relative scale, the

incidental mortality per metric ton of trawl catch is 4 times greater than the mortality in the longline catch.

On an absolute scale, each of the previous fishing strategies used to maximize sablefish and other groundfish production by an exclusive longline, an exclusive trawl, or a coexistence fishery has a unique impact on halibut. The amount of halibut killed is as follows:

	Metric Tons	Million Pounds
Exclusive longline fishery	194	0.4
Exclusive trawl fishery	4,848	10.7
Coexistence fishery	5,335	11.8

VALUE OF HARVEST TO FISHERMEN

Total and net values are derived for groundfish production forecasts to determine economic benefits associated with each fishing strategy mentioned previously. Total and net dollar values calculated indicate that an exclusive longline fishery produces the most valuable sablefish catch. However, the coexistence fishery described previously, which produces the largest catch of sablefish and other groundfish, also yields the highest total and net dollar value for all species caught.

RESULTS

A summary of the tonnage and dollar value of the catch for selected fishing strategies is given in the following table. The table summarizes the results of an exclusive longline fishery, 4 situations of a coexistence fishery, and an exclusive trawl fishery in the Gulf of Alaska. These fishing strategies are chosen on the basis of their ability to maximize sablefish and other groundfish catches, minimize halibut mortality, and maximize gross and net values from sablefish and other groundfish. The gross value of the Pacific halibut kill is given to show the potential economic loss to the Pacific halibut fishery.

Summary of tonnage and dollar value of the catch for several realistic fishery strategies by longline and trawl gear in the Gulf of Alaska.

Sablefish Allocation (Metric Tons)		Percent Sablefish in Catch		Amount of Catch (Metric Tons)			Gross Value of Catch (Million Dollars)				Net Value of Catch (Million Dollars)		
Longline	Trawl	Longline	Trawl	Sablefish	Other Groundfish	Halibut Kill	Sablefish	Groundfish	Sub-total	Halibut	Longline Fishery	Trawl Fishery	Total
13,000	0	50	0	13,000	13,000	194	19.4	7.2	26.6	0.5	17.0	0	17.0
12,000	1,000	50	1	13,000	111,000	2,038	18.8	32.8	51.6	5.7	15.6	7.6	23.2
10,112	2,888	50	1	13,000	285,900	5,335	17.6	78.5	96.1	15.0	13.2	20.9	34.1
9,000	4,000	50	1	11,797	285,900	5,338	15.9	78.2	94.1	15.0	11.7	21.1	32.8
1,087	11,913	50	4	12,954	285,900	5,538	12.7	75.9	88.6	15.5	1.5	25.4	26.9
0	13,000	0	4	11,956	285,900	5,554	11.0	75.6	86.6	15.6	0	25.4	25.4

Results are high-lighted as follows:

- The total groundfish catch (tonnage) is maximized in a coexistent longline-trawl fishery (if approximately 3,000 mt of sablefish are allocated to trawlers).
- The value of the total groundfish catch (dollars) is maximized in the same coexistence fishery.
- The value of sablefish catch (dollars) is maximized in an exclusive longline fishery.
- The halibut kill (tonnage) is greatest in an exclusive trawl fishery.
- The halibut kill (tonnage) will be high (>5,000 mt) for any fisheries that allow total groundfish catch to approach or reach its OY.
- A coexistent longline-trawl fishery, with 3,000 mt of sablefish allocated to trawlers and 10,000 mt of sablefish allocated to longliners provides the maximum total groundfish catch, the maximum value of the total groundfish catch, and a near-maximum (90%) value of the sablefish catch, but would result in a near-maximum halibut kill of 5,335 mt or 11.8 million lbs.

Preliminary Report on
Bio-Economic Considerations of Harvesting Sablefish
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INTRODUCTION

The sablefish, or blackcod, Anoplopoma fimbria, resource of the North Pacific Ocean is distributed from northern Mexico northward and westward to the western Bering Sea. The center of its distribution and the region of highest catches is in the Gulf of Alaska. The Gulf of Alaska fishery was not fully developed until the mid-1960s when Japan entered the fishery. Catches rose rapidly to a peak in 1972 and declined thereafter as a result of declining stock abundance and fishing regulations. The resource came under direct United States' management after March 1, 1977 with the passage of the Fishery Conservation and Management Act

Although catches have been declining, the price of sablefish has increased significantly and the species is now economically attractive to U.S. fishermen. Prior to 1976, U.S. catches in the Gulf of Alaska were less than 1,000 mt as compared to foreign catches which exceeded 25,000 mt. Domestic catches increased to 4,000 mt in 1978 and are expected to increase substantially again in coming years. Most of the domestic catches are taken by longliners, although some are taken by trap, troll, and trawl gear. Domestic trawl catches are minor, but the fishery is expected to undergo a rapid expansion. Trawlers, however, are not expected to target on sablefish and will only take sablefish incidentally while fishing for other species. The present foreign fishery is still dominated by Japanese longliners. Foreign trawlers are allowed only an incidental catch of the species.

The average size of sablefish in the catch varies with the type of gear used and depth of fishing. Since the size and life history stage when sablefish are caught varies by gear type, the harvesting technique will affect optimum yield and maintenance of the reproductive potential of the stock. The effects of harvesting sablefish on other species is also gear dependent. Further, since prices paid to fishermen are based on size and quality, the economic value of the catch will differ by type of gear.

Given the ability of both longliners and trawlers to harvest sablefish, there is a question over how the fishery ought to be conducted. The question of which is best can be answered only in the context of specific goals set for the Gulf of Alaska groundfish fishery. Some goals are identified in this paper and the effectiveness of different fishing strategies in maximizing biological yield, total value of the catch, and net value of the catch is determined. Alternative fishing strategies include but are not limited to exclusive longlining, exclusive trawling, and some combination of the two. Section I of the report describes the distribution of sablefish and the nature of its fishery. Biological and economic considerations of harvesting sablefish are the subjects of Sections II and III. An overall conclusion of the report is presented in Section IV.

SECTION I: THE SABLEFISH RESOURCE AND ITS FISHERY

RESOURCE DISTRIBUTION

Geographic

The geographic distribution of sablefish is very broad--extending along the entire Pacific Coast from off Mexico to the northern Gulf of Alaska and westward through the Aleutian Island chain and along the edge of the continental shelf in the Bering Sea. On the Asian coast it ranges from the northern Bering Sea to the northeastern coast of Japan.

Based on historical catch data, the center of abundance of the resource is in the Gulf of Alaska (north of 54°30'N and east of 170°W). Highest concentrations are found in the Southeast statistical area (Figure 1), but other areas of the Gulf are also very productive--the entire region having supported a large and profitable fishery for the Japanese since 1966. The distribution of the resource in the Gulf is best inferred from Japanese longline catch trends in the period 1970-76 (Low et al. 1976) when the fishery was well developed but prior to U.S. extended jurisdiction which forced some changes in the fishing pattern. Proportions of the catch taken in each area were: Shumagin (14%), Chirikof (9%), Kodiak (17%), Yakutat (27%), and Southeast (33%).

Bathymetric

Sablefish occupy a wide depth range--juveniles are distributed from shallow inshore waters to approximately 150 m and adults from 150 m to 1,200 m. Trawl survey data (Alverson et al. 1964), suggest that 3% of the exploitable biomass is found at depths less than 200 m, 16% between 200 and 400 m, 28% between 400 and 600 m, 29% between 600 and 800 m, 20% between 800 and 1,000 m, and the remaining 4% beyond 1,000 m (Figure 1).

In the summer of 1978, Japanese scientists conducted a research program aboard a commercial longline vessel to define the bathymetric distribution of

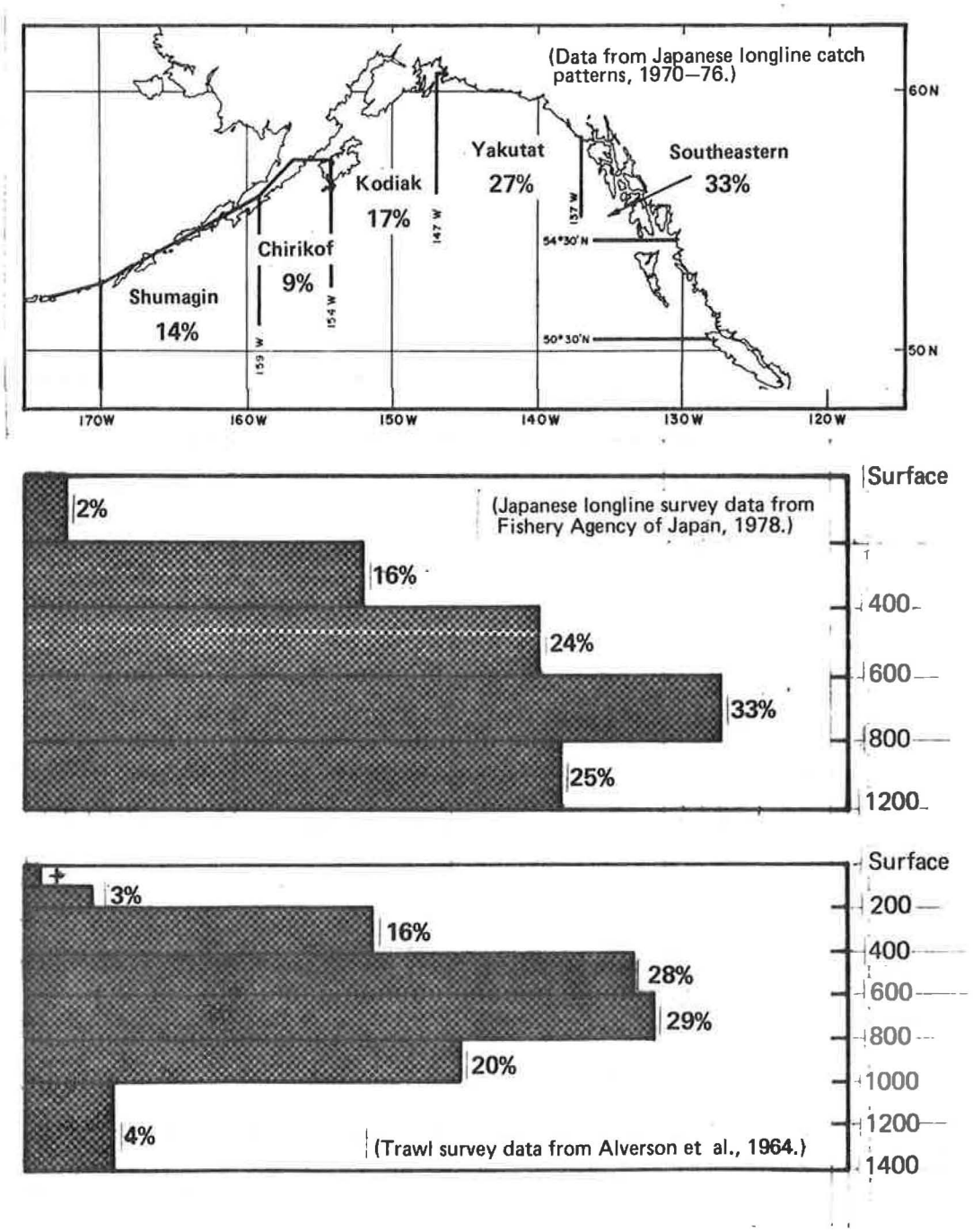


Figure 1.--Geographic and bathymetric distribution of sablefish in the Gulf of Alaska.

sablefish (Fishery Agency of Japan 1978). Highest catch rates were found between 200 and 600 m in the Shumagin area, between 400 and 600 m in the Chirikof area, and between 600 and 800 m in the Kodiak-Southeast region (Table 1). Overall, the distribution was 2% in depths less than 200 m, 16% between 200 and 400 m, 24% between 400 and 600 m, 33% between 600 and 800 m, and 25% between 800 and 1,000 m. The bathymetric distribution of sablefish shown by the trawl survey in the 1960s is similar to that shown by the 1978 longline survey.

THE SABLEFISH FISHERY

Catch History

Although small quantities of sablefish have been taken from the Gulf of Alaska by U.S. fishermen for many years, the resource was underutilized until Japan began their fishery in the early 1960s. Catches rose rapidly from less than 3,000 mt in 1963 to a peak of 36,500 mt in 1972 (Table 2). Since 1972 catches have ranged from about 17,000 to 30,000 mt. Japan accounted for 91% of the total catch during 1970-77, the Republic of Korea 5%, United States 3%, Union of Soviet Socialist Republics <1%, and Canada <1%. Catches by the U.S. fishery are expected to increase. The projected U.S. harvest in 1979 is greater than 4,000 mt.

Gear

The major gear used to fish for sablefish in the Gulf of Alaska is longlines or setlines, which accounts for more than 95% of the total catch. A small part of the catch is taken by foreign stern trawlers which take sablefish incidentally in fisheries for other species. Foreign trawlers are not prohibited from targeting on sablefish, but as a practical matter they do not. According to Alaskan regulations, U.S. domestic trawlers are prohibited from targetting on sablefish in the Southeast statistical area (Figure 1).

Table 1.--Sablefish catch rates (number of fish per hachi by longline gear) by area and depth zones in the Gulf of Alaska by the Japanese vessel Hatsue Maru No. 55 during a research operation in the summer of 1978.

Depth (m)	Shumagin	Chirikof	Kodiak	Yakutat	Southeast	All Areas
0-200	0.4	0.1	2.4	0.0	-	0.4
200-400	2.4	0.9	4.2	2.3	4.6	3.0
400-600	2.1	3.7	4.2	3.8	7.5	4.5
600-800	1.5	2.5	5.7	5.7	8.2	6.1
800-1,000	0.5	1.6	-	4.5	5.6	4.7

Table 2.--Historical catch of sablefish in metric tons in the Gulf of Alaska 1959-77.

Year	U.S.	CANADA	JAPAN	USSR	ROK A/	TOTAL
1959	967	B/	---	---	---	---
1960	1,348	B/	---	---	---	---
1961	606	B/	---	---	---	---
1962	684	B/	---	---	---	---
1963	617	B/	1,681	---	---	2,298
1964	1,173	B/	1,041	---	---	2,214
1965	1,048	B/	2,107	---	---	3,155
1966	1,051	B/	3,514	---	---	4,565
1967	947	B/	4,217	---	---	5,164
1968	112	B/	13,886	---	---	13,998
1969	302	B/	19,587	---	---	19,889
1970	369	B/	21,397	---	---	21,766
1971	270	15	25,636	---	---	25,921
1972	1,387	16	34,259	535	308	36,505
1973	867	16	29,246	109	58	30,296
1974	771	10	23,300	38	2,431	26,550
1975	1,088	16	21,561	33	3,000	25,698
1976	803	23	22,947	41	3,700	27,514
1977	823	3	14,367	4	1,594	16,791

A/ Includes catches from other areas in the northeastern Pacific.

B/ Data not available.

C/ Trawl gear only.

Some sablefish are also taken by U.S. troll and pot-like trap gear. Traps are especially effective for producing "pure" catches of sablefish and also take larger fish than other types of gear.

The Foreign Sablefish Fishery

Foreign Longline Fishery

The Japanese longline fishery has traditionally accounted for more than 85% of the all-nation sablefish catch and has taken a larger share of foreign sablefish allocations since extended jurisdiction. In 1979, 22 Japanese longliners are licensed to operate in the Gulf while the ROK is licensed one longline vessel (Table 3). Since 1972 the Japanese fishery has been restricted from taking sablefish in depths less than 500 m. In 1978 and 1979 this restriction was partially lifted to allow Japanese longliners to fish Pacific cod landward of the 500 m isobath in the area west of 157°W longitude. The Japanese longline fishery is conducted year-round but only a few of the 22 vessels will operate in any one month.

A Japanese longline vessel is typically less than 500 gross tons with a length of 50 m, breadth of 10 m and fish-hold capacity of 850 mt. It carries ten officers, four processors, and a fishing crew of fourteen for a complement of 28. The standard unit of the fishing gear is the "hachi." One hachi is about 75 m long with 36 to 38 hooks. A single set numbers 390 to 420 hachis. Starting early in the morning the vessel spends about 2½ hours baiting and setting the gear. Squid is the preferred bait and about 600 kg of bait is required for each set. When the last hachi is set after 2 hours, the vessel returns to the first hachi and begins to haul the gear. It takes 10 to 15 hours to retrieve the gear, remove the fish, and repair and coil the gear for re-use. The sablefish are headed, gutted, cleaned, and placed in flash freezers before conveyance to the hold. Some of the incidentally caught species such

Table 3.--Number of foreign fishing vessels issued permits to fish in the Gulf of Alaska, 1979

Type of Fishing Vessel	Japan	USSR	ROK
Stern trawlers (small)	16	0	0
Stern trawlers (large)	21	50	12
Factory vessel	1	0	0
Longliners	22	0	1

as skates, octopi, and rockfishes are also processed and frozen.

The daily catch rate of all species by Japanese longliners in 1977 ranged from 5 to 6 mt per day. The average daily catch rate of the ROK longliner was about 3.5 mt. Typically, about 67% of the catch by Japanese longliners was sablefish when the vessel fished in deep waters exceeding 500 m (Table 4). Most of the remainder of the catch was rattails (25%) and shortspine thornyhead (6%). When the vessel fished in shallow waters (150-350 m), the species composition was usually Pacific cod (56%), sablefish (0.2%), turbot (14%), sculpin (10%), skate (4%), octopus (3%), rockfish (1%), and others (10%).

Foreign Trawl Fishery

The foreign trawl fishery in the Gulf of Alaska is dominated by large trawlers. Japan and the USSR have trawled for groundfish, mostly rockfish, flounders, and pollock, in the region since the early 1960s. The ROK entered the fishery in the early 1970s. In 1979, 16 small Japanese stern trawlers (<1,500 GRT) and 83 large independent foreign stern trawlers (>1,500 GRT) are licensed to fish in the Gulf of Alaska (Table 3). Japan has licensed 21 large trawlers, the USSR 50, and the ROK 12. Some of the small Japanese trawlers are catcher boats for the single factory vessel that Japan is licensed to fish in the Gulf.

Any incidental catch of sablefish in the trawl fishery is counted towards the sablefish quota for each nation. The incidental catch rate of sablefish depends on the area and depth of operation and size of trawler. In 1977, the catch of sablefish represented 1.6% of the total catch by small Japanese trawlers (Table 4). The catch rate by large trawlers was 1.3% for Japan and 0.07% for the USSR. The daily catch rate of groundfish was 8-10 mt for small trawlers, 29-52 mt for large Japanese trawlers, and 19-27 mt for large Soviet trawlers. The foreign trawlers normally tend to operate in depths shallower

Table 4.--Percent species composition of Japanese catches in the Gulf of Alaska during 1977 by vessel-gear types reported by U.S. observers.

	Small Trawler					Large Trawler					Longline				
Species Group	Shum	Chir	Kod	Yat	SE	Shum	Chir	Kod	Yat	SE	Shum	Chir	Kod	Yat	SE
Pollock	36	30	44	9	T	--	63	82	7	2	0	--	0	0	0
POP	49	23	15	27	33	--	18	5	33	29	T	--	T	T	T
Other rockfish	10	T	6	33	47	--	1	T	43	51	T	--	T	3	1
Pacific cod	3	2	1	1	T	--	4	1	1	T	0	--	0	0	0
Flounders	1	32	22	16	9	--	11	8	12	14	.13	--	0.09	0.5	0.13
Sablefish	.03	1.9	2.1	2.8	1	--	4.3	0.2	0.5	1.6	57	--	59	68	84
Other species	1	3	7	4.2	2	--	T	4	3	1	1	--	1	T	3
Rattail	T	6	1	T	3	--	T	T	0	T	32	--	34	25	10
Shortspine thornyhead	T	2	2	7	5	--	1	T	1	1	10	--	6	4	3

Notations

Vessels = Small trawler (<1,500 GRT), large trawler (>1,500 GRT)

Areas = Shumagin, Chirikof, Kodiak, Yakutat, and Southeast

T denotes trace catches

than 500 m where their target species are concentrated. Therefore, gear conflict with foreign longliners is minimized. Based on bathymetric distribution of sablefish, the trawlers are generally fishing in areas where sablefish are less concentrated and where the fish are smaller in size.

The Domestic Sablefish Fishery

Domestic Longline Fishery

The U.S. longline fishery for sablefish in the Gulf of Alaska is conducted almost exclusively in the Southeast statistical area and usually in deep channels like Chatham Strait. Many of the traditional halibut fishing vessels make at least a couple of trips to fish for sablefish during the year; once before the halibut season begins and again after the halibut season closes. Pacific halibut is still the preferred species for the longliners but sablefish has become a good additional source of income.

Since a large longliner fleet exists for the Pacific halibut fishery which is also effective for catching sablefish and there are few domestic trawlers operating in the Gulf of Alaska, it is not surprising that the domestic sablefish fishery is dominated by longliners. The number of U.S. longline vessels licensed to fish halibut in International Pacific Halibut Commission (IPHC) regulatory area 3 (mostly the Gulf of Alaska) in 1977 was 378 (IPHC 1978). There is, therefore, a large physical capacity for possible expansion to the sablefish fishery in the Alaska region. In 1976, the State of Alaska issued 101 sablefish fishing permits to domestic longliners but many more longliners are capable of entering the fishery (Table 5).

It is difficult to describe a typical domestic sablefish longliner. Of the larger vessels, a typical longliner may be said to be about 20 m long with a fish-hold capacity of 25 mt and a crew of 3-5. A typical fishing trip is from 9-15 days, each set consists of about 12-18 skates, and a skate

Table 5.--Number of domestic vessels licensed to enter and capable of entering the sablefish fishery in the Gulf of Alaska.

(A) Vessels licensed for sablefish by the Alaska Department of Fish and Game in 1976

Number	Vessel-Gear Type
4	Hand troll
8	Longline to 9.4 m (26 feet) keel length
93	Longline over 9.4 m (26 feet) keel length
19	Pots to 18 m (50 feet) keel length
6	Pots over 18 m (50 feet) keel length

(B) Number of vessels capable of entering the sablefish fishery in 1975

Keel Length Feet (m)	Southeast			Cook Inlet	Kodiak
	Troll	Pot	Longline	Longline	Longline
1-33 (1-12)	3	1	45	0	4
34-45 (12-16)	3	5	78	0	4
46-60 (16-22)	0	4	35	0	4
61-81 (22-29)	0	2	5	1	0
Total	6	12	163	1	12

Source: Fishery Management Plan for 1979 Gulf of Alaska Groundfish (DOC 1978)

ranges from 200-1200 m long with 100-150 hooks per skate. Depths frequently fished are 300-600 m. These vessels are capable of venturing into offshore waters where the Japanese longliners operate.

The trend in the domestic sablefish fishery is towards automated fishing systems which reduces gear handling during all stages of longlining--setting, hauling, baiting, bait cutting, and gear storage. These automated longliners will be typical of the fleet in the near future.

Domestic Troll and Trap Fisheries

Only a few small vessels troll for sablefish and catches are small. Trolling effort is not expected to increase significantly. The trap fishery for sablefish, however, is capable of catching increasing quantities of sablefish. In 1975, 12 vessels were equipped with pot-like trap gear and the number of vessels has increased since then (DOC 1978a). In the California region, traps are more popular than longlines for catching sablefish but longlines are currently preferred in the Gulf of Alaska. Most of the fishermen entering the sablefish fishery in the Gulf are experienced halibut longliners and they will likely continue to use this type of gear.

Domestic Trawl Fishery

The size and number of domestic trawlers currently in operation in the Gulf are small. In 1975, 33 trawlers were registered with the Alaska Department of Fish and Game. Most of these vessels were 16-30 m (46-84 feet) otter and beam trawlers that fish for shrimp in the Kodiak and Unimak Island areas (DOC 1978a).

The domestic trawl fleet is expanding both in size and number of vessels with many large combination crabber-trawlers being built. Many of the existing vessels that operate for king and Tanner crabs in the Bering Sea and Gulf of Alaska are also capable of trawling. The physical potential for a substantial expansion of the U.S. trawl fishery therefore exists.

SECTION II: BIOLOGICAL CONSIDERATIONS OF HARVESTING SABLEFISH

SIZE COMPOSITION OF CATCH

The average size of sablefish in catches varies with the selective fishing characteristics of the gear and the depth of fishing. These variations in the size and life history stage when sablefish are caught have certain implications to the yield and reproductive potential that may be realized from the stock. The size composition of sablefish taken by longline, trap, and trawl gear in the Gulf of Alaska is compared to consider the impact of the various gear types on the yield of the stock. Troll caught fish are not considered because size information from this fishery is lacking and the amount landed is negligible.

Sablefish size data from Japanese longline and trawl catches were collected by U.S. observers in the Gulf of Alaska during 1977-78. Since Japanese longliners fish mainly at depths exceeding 500 m, they tend to catch more larger fish than taken at shallower depths. Size frequency distribution on recent domestic longline catches is generally lacking but based on information provided by domestic fishermen through their sablefish logbooks for 1977-78, the fish caught were generally large--about 55-70% were over 3.2 kg or 7 lbs round weight. Since most of these fish were caught in inside waters of Southeast Alaska, their average size was probably slightly smaller than that of Japanese longline caught fish in offshore waters. Edson (1954) reported that sablefish in inside waters were generally smaller than in outside waters.

The fish taken by U.S. longliners in certain outside waters (Middleton Island, Cape Spencer, and Chatham Strait) in 1952 were much larger than fish taken in similar areas by Japanese longliners in 1977-78 (Figure 2). Fifty percent of the total number of fish taken in 1952

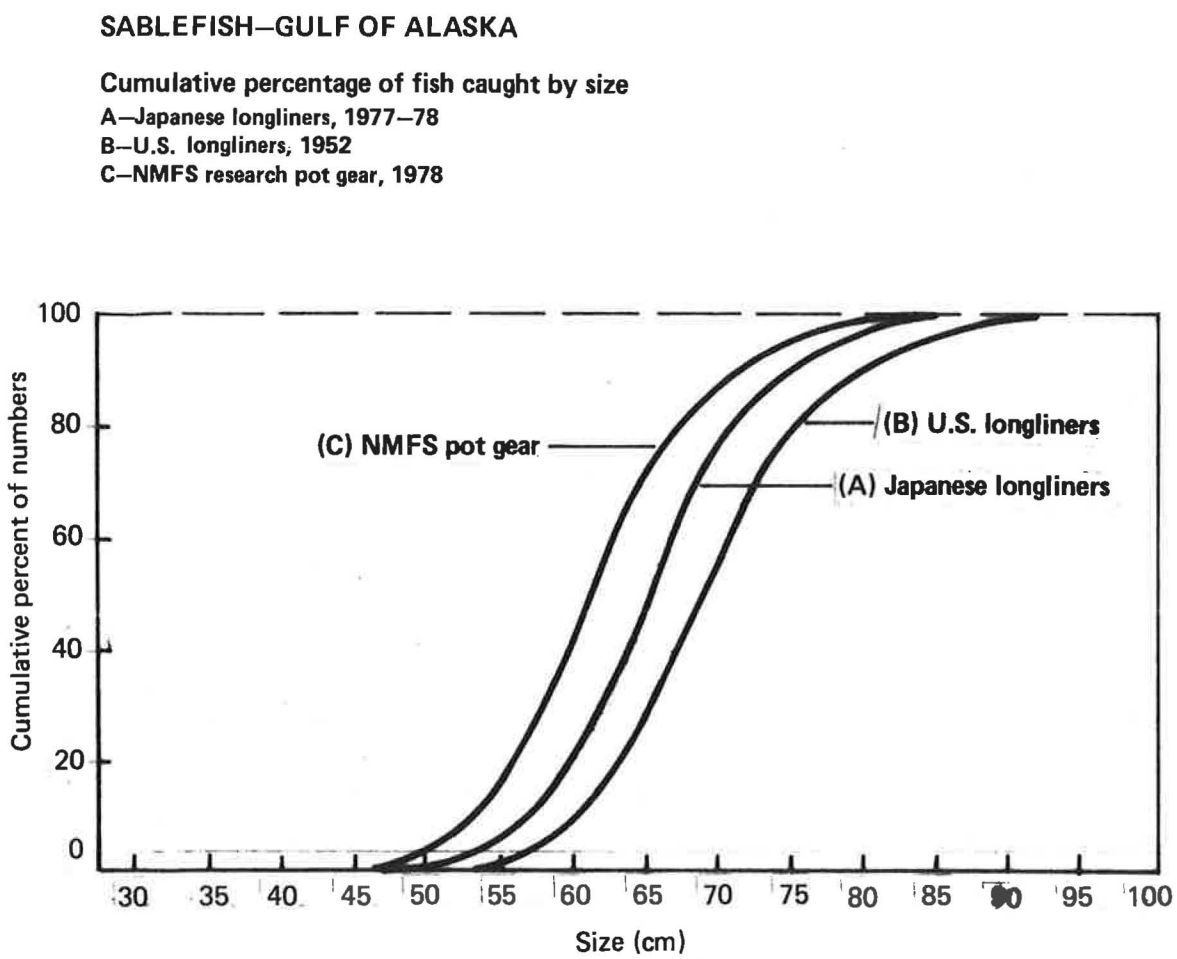


Figure 2.--Comparison of sablefish size composition taken by Japanese longliners in 1977-78, U.S. longliners in 1952, and U.S. research vessel using pot-like trap gear in 1978.

were larger than 70 cm (28 inches) as compared to 65 cm (26 inches) twenty-five years later. For the present developing domestic longline fishery, it may be assumed that their catch will likely follow the size composition of Japanese longline catches.

Information on size composition of the small U.S. trap catch of sablefish is not available. Based on information gathered by NMFS R/V John N. Cobb fishing with trap gear in the summer of 1978 in outside waters of Southeast Alaska (at Cape Ommaney, Cape Addington, and Cape Cross), the size of fish caught was smaller than those caught by Japanese longliners (Figure 2).

In order to evaluate biological implications of harvesting different sized sablefish, it is necessary only to consider the size composition of fish taken by 3 major gear types: Japanese longline, Japanese trawl, and U.S.-type trawl (Table 6). Implications of harvesting sablefish by the other gear types may be inferred from these three. The curves on cumulative percentage of total number of fish taken according to size are compared in Figure 3. The numbers plotted in Figure 3 are summarized in Table 7. For example, in terms of catch by number, 50% of the catch by Japanese longliners are larger than 65 cm while the catch by Japanese trawlers and NMFS trawlers are larger than 63 cm and 50 cm, respectively. In terms of catch by weight, 50% of the catch by Japanese longliners, Japanese trawlers, and NMFS trawlers are larger than 68 cm, 66 cm, and 52 cm, respectively.

It is surprising to note that sablefish taken by Japanese trawlers during 1977-78 were only slightly smaller than fish taken by Japanese longliners (Figure 3). The small difference is probably due to the depths (200-400 m) where the trawlers mainly operated. At such depths, many large sablefish are apparently present. Information on size composition of sablefish by domestic trawlers is not available but based on NMFS research trawl operations, the size of sablefish caught are substantially smaller. These trawlers fished mainly in depths

Table 6.--Size frequency distribution of sablefish caught by Japanese longliners and trawlers in 1978, U.S. research trawlers in 1977-78 and a U.S. research vessel using trap gear in 1978.

Length Range in cm	Percentage Distribution of Catch by Numbers				Percentage Distribution of Catch by Weight		
	Japanese Longliners	Japanese Trawlers	NMFS Trawlers	NMFS Trap Gear	Japanese Longliners	Japanese Trawlers	NMFS Research Trawlers
30-32	0	0	T	0	0	0	T
33-34	0	0	1	0	0	0	T
35-36	0	0	1	0	0	0	T
37-38	T	0	2	0	0	0	1
39-40	T	0	2	0	0	0	1
41-42	T	0	4	0	T	0	2
43-44	T	T	7	T	T	T	4
45-46	T	T	10	T	T	T	7
47-48	T	1	14	T	T	T	11
49-50	T	1	12	1	T	T	11
51-52	1	2	11	2	T	1	12
53-54	2	2	11	4	1	1	13
55-56	3	4	7	6	2	3	9
57-58	6	7	5	10	3	4	7
59-60	8	10	3	12	5	7	5
61-62	11	14	3	12	8	12	5
63-64	11	12	2	13	10	11	4
65-66	12	11	1	10	11	12	1
67-68	10	11	2	7	10	13	4
69-70	9	7	T	6	10	9	1
71-72	7	5	T	4	9	7	T
73-74	4	3	0	3	7	5	0
75-76	4	3	0	3	6	5	0
77-78	3	2	0	2	5	3	0
79-80	2	1	0	1	3	1	0
81-82	1	2	0	1	3	4	0
83-84	1	0	0	1	1	0	0
85-86	T	T	0	T	1	T	0
87-88	T	0	0	T	T	0	0
89-100	T	T	0	T	T	T	0

Table 7.--Comparison of size frequency distribution of sablefish caught by Japanese longliners and trawlers during 1978 and U.S. research trawlers during 1977 and 1978.

Percent of Fish Caught	Size (cm) above which indicated percentage of fish by number is caught			Size (cm) above which indicated percentage of fish by weight is caught		
	Japanese Longliner	Japanese Trawler	NMFS Trawlers	Japanese Longliner	Japanese Trawler	NMFS Trawlers
10	75	73	61	78	76	62
20	71	69	57	75	72	58
30	69	67	53	72	69	56
40	67	65	51	70	67	54
50	65	63	50	68	66	52
60	63	62	48	66	64	50
70	62	61	46	64	62	49
80	60	58	44	62	60	47
90	57	56	42	60	58	46

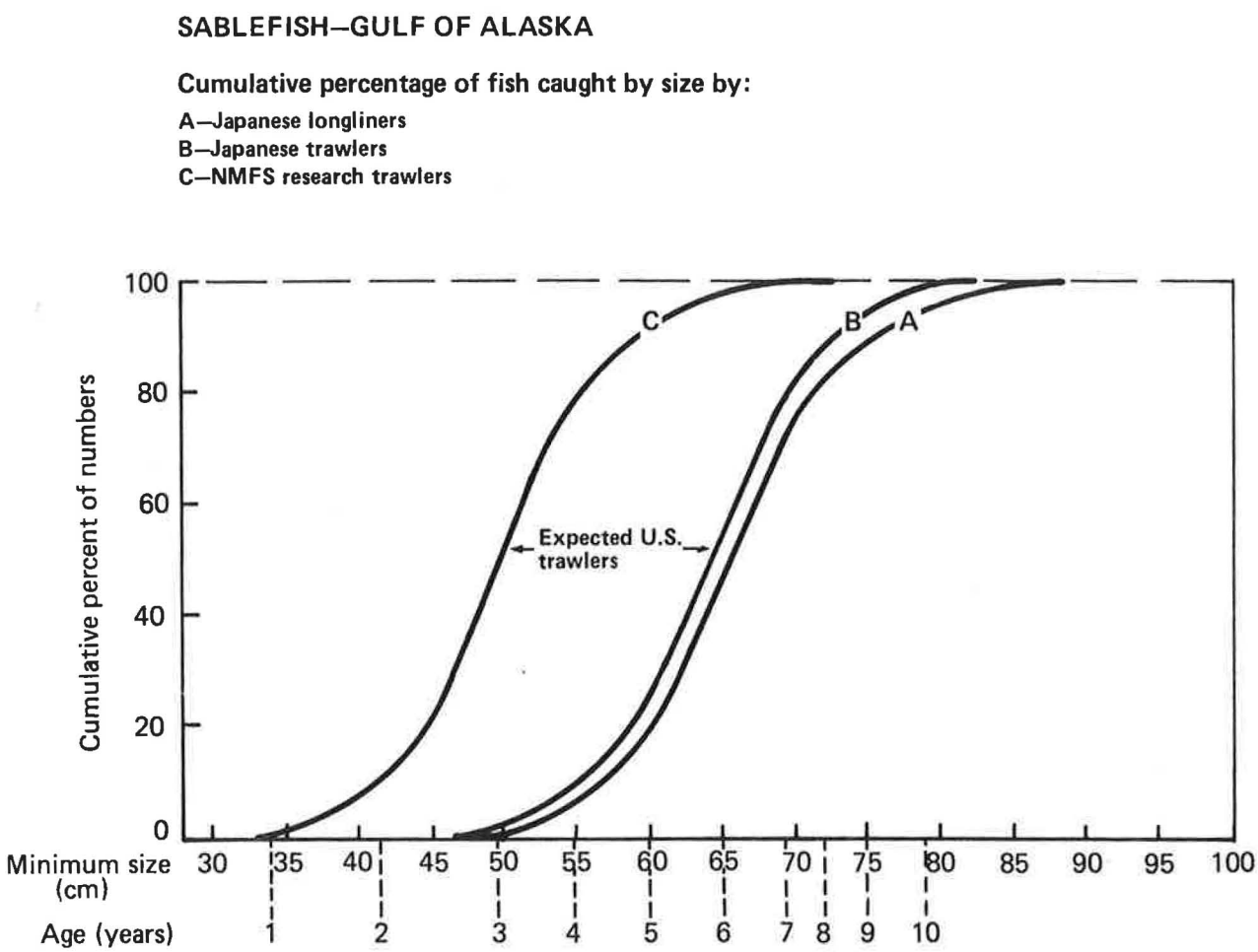


Figure 3.--Comparison of sablefish size composition taken by Japanese longliners, Japanese trawlers, and U.S. research trawlers in 1977-78.

below 200 m where the smaller sablefish are found. Commercial domestic trawlers are expected to fish in deeper waters, and therefore are expected to catch larger fish than taken by research vessels. They are, however, expected to be smaller than those caught by Japanese trawlers because some domestic trawling will probably take place inshore where foreign trawlers have not been permitted to operate. In such shallow waters, many juvenile sablefish are expected to be encountered.

Overall, the largest fish are taken by Japanese longliners, followed closely behind by Japanese trawlers, and the smallest fish are taken by NMFS trawlers. These differences in average size of fish taken have some significance to the biological potential that may be realized from the stock.

MAXIMIZATION OF YIELD FROM COHORT

Yield-Per-Recruit

The concept of yield-per-recruit by Beverton and Holt (1957) may be used to determine the optimum size or age of exploitation to ensure the maximum yield corresponding to a desired level of fishing intensity. The biomass, over time, of a known number of recruited fish is determined at various life history stages by its mortality and growth characteristics. The potential yield from this biomass is calculated according to the age or size of entry into the fishery and the intensity of fishing. Since the number of recruits that is expected to enter the fishery is variable, the results are presented on a yield-per-recruit basis. The data used in the Beverton and Holt yield expression for sablefish in the Gulf of Alaska are given in Table 8. Data on length-age-weight relationships were collected by NMFS in Southeast Alaska during the summer of 1978.

Yield-per-recruit curves for various ages of entry into the fishery and at increasing levels of fishing mortality are shown in Figure 4. An optimum

Table 8.--Optimal fishing strategies for maximization of yield-per-recruit for sablefish in the Gulf of Alaska

A. Data used for Beverton and Holt yield-per-recruit analysis

$L_t = 100\ (1 - e^{-0.12\ (t + 2.0)})$

$W = 0.005005\ L^{3.183305}$

R = 1000 = number of recruits

t_c = 4 years = age at first capture

W_m = 11,642 gm = maximum weight

M = 0.22 = instantaneous natural mortality

F = 0.2, 0.3, ..., 1.6 = instantaneous fishing mortality

L = length in cm

t = time in years

e = exponent

W = weight in gm

B. Results of Eumetric fishing curves for maximization of yield-per-recruit

Instantaneous Fishing Mortality	Optimum Age at Entry	Maximum Yield-Per-Recruit (gm)
.20	3.1	1200
.30	3.9	1360
.40	4.5	1450
.50	4.9	1500
.60	5.3	1540
.70	5.5	1560
.80	5.8	1580
.90	5.9	1600
1.00	6.1	1610
1.10	6.2	1620
1.20	6.3	1630
1.30	6.4	1640
1.40	6.5	1640
1.50	6.5	1650
1.60	6.6	1650

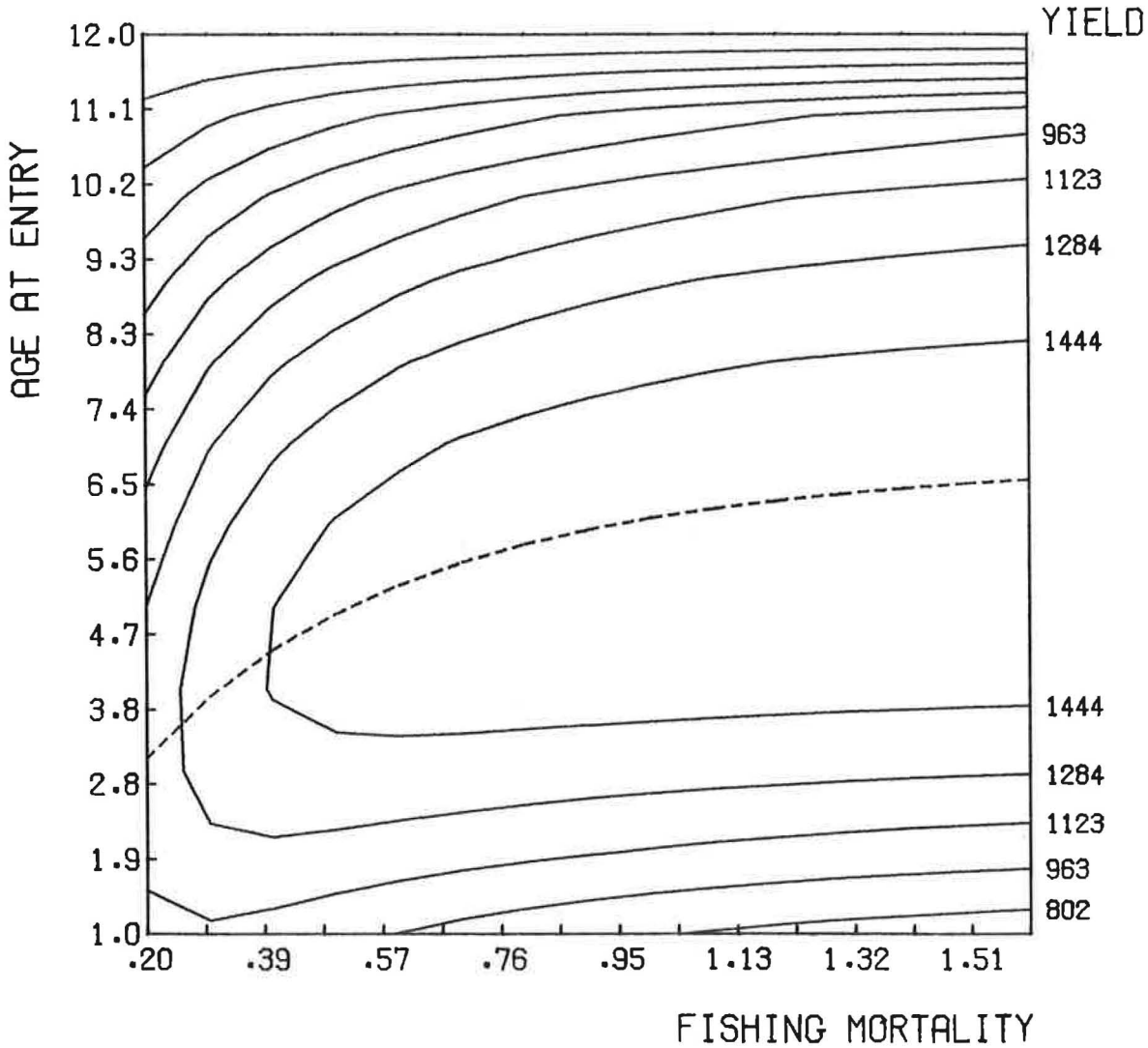


Figure 4.--Sablefish yield-per-recruit curves with eumetric fishing line (dotted line) when optimum yield-per-recruit is derived at selected ages of entry and fishing mortality.

age or size of entry into the fishery may be determined from a selected level of fishing mortality in order to maximize yield-per-recruit. With medium fishing mortality (F = 0.7), the optimum age of exploitation is 5.5 years when a yield of 1.56 kg-per-recruit may be realized. At this age the sablefish average 62 cm or 24 inches in length and 2.5 kg or about 6 lbs in weight (Table 8). At a higher level of fishing mortality (F = 1.0), the optimum age of exploitation is increased to 6.1 years (65 cm or 26 inches in length and 3.0 kg or 6.5 lbs in weight) in order to realize a yield of 1.61 kg-per-recruit.

From results of the yield-per-recruit analysis it is apparent that the Japanese longliners and Japanese trawlers are both catching fish close to the optimum age/size of capture. As shown in Table 7, 80% of the total number of fish caught by Japanese longliners were larger than 60 cm while the Japanese trawl-caught fish were larger than 58 cm. NMFS research trawlers fishing at depths less than 200 m caught fish that were substantially smaller than the optimum size of exploitation for the levels of fishing mortality stated above. On the average, U.S. commercial trawlers will probably catch sablefish larger than those caught by NMFS research trawlers but still smaller than the optimum size of exploitation.

Yield-Per-Cohort-Biomass

Another procedure used to determine the optimum age and size of exploitation is that by the yield-per-cohort-biomass theory (Alverson and Carney 1975). There comes a time in the life history of the population when the cohort is expected to maximize its biomass. In theory, a year-class of sablefish is subject to natural death (which reduces the number) and growth (which increases individual weight). The combined effect of these factors is that the cohort biomass will increase to a maximum and decrease thereafter.

The data used in the cohort analysis are the same as used in the yield-per-recruit analysis. The cohort analysis shows that yield-per-cohort-biomass

is maximized at age 6, corresponding to fish 65 cm or 25.5 inches in length and 2.9 kg or 6.5 lbs in weight (Table 9). The actual maximum falls between ages 5 and 6 and essentially is similar to that derived from the yield-per-recruit analysis. Sablefish found off Washington-California apparently also maximize its yield-per-cohort-biomass between ages 5 and 6 according to the draft Fishery Management Plan for Groundfish off Washington, Oregon, and California (DOC 1978b).

From results of the yield-per-cohort-biomass analysis it is again apparent that Japanese longliners and trawlers catch fish close to the age/size when the sablefish cohort is expected to maximize its biomass (Figure 5). NMFS research trawlers are catching fish when only 70% of the maximum biomass is achieved. As mentioned, U.S. commercial trawlers on the average will probably catch fish larger than those by research trawlers but smaller than Japanese trawlers when only 90% of the maximum biomass would be reached.

EFFECT ON SPAWNING POPULATION

It is difficult to evaluate the impact of harvesting different sized sablefish on the spawning potential and subsequent recruitment to the stock. An empirical inference, however, may be drawn by comparing the size of fish harvested and the proportion of the fish that are mature. Ninety percent of the catch by Japanese longliners are older than age 5 or larger than 58 cm (23 inches). At this size and age, 45% of the fish are mature (Figure 6). Japanese trawlers tend to catch smaller fish--90% are older than age 4 or larger than 56 cm (22 inches). At this size and age, only 25% of the fish are mature. NMFS research trawlers tend to catch the youngest fish. Most of them are too small and immature to spawn.

The impact of the fishery on the spawning potential of the stock also depends on the amount of fish taken from the stock. If the same amount of fish is taken by each of the 3 gear types discussed above, the practice of

Table 9.--Yield-per-cohort biomass for sablefish with an instantaneous natural mortality of 0.22 for the Gulf of Alaska

Age	Percent of Maximum Biomass	Average Length (cm)	Average Length (in)	Average Weight (gm)	Average Weight (lbs)
1	42	34	13.5	416	0.9
2	63	42	16.6	766	1.7
3	80	49	19.3	1216	2.7
4	92	55	21.6	1745	3.8
5	98	60	23.7	2332	5.1
6	100	65	25.5	2952	6.5
7	98	69	27.1	3588	7.9
8	92	72	28.5	4222	9.3
9	85	75	29.7	4843	10.7
10	76	78	30.7	5440	12.0
11	68	80	31.6	6008	13.2
12	59	82	32.4	6543	14.4
13	51	84	33.1	7041	15.5
14	44	86	33.8	7502	16.5
15	37	87	34.3	7926	17.5
16	31	88	34.8	8313	18.3
17	26	89	35.2	8666	19.1
18	22	90	35.5	8987	19.8
19	18	91	35.9	9276	20.4
20	15	92	36.1	9537	21.0

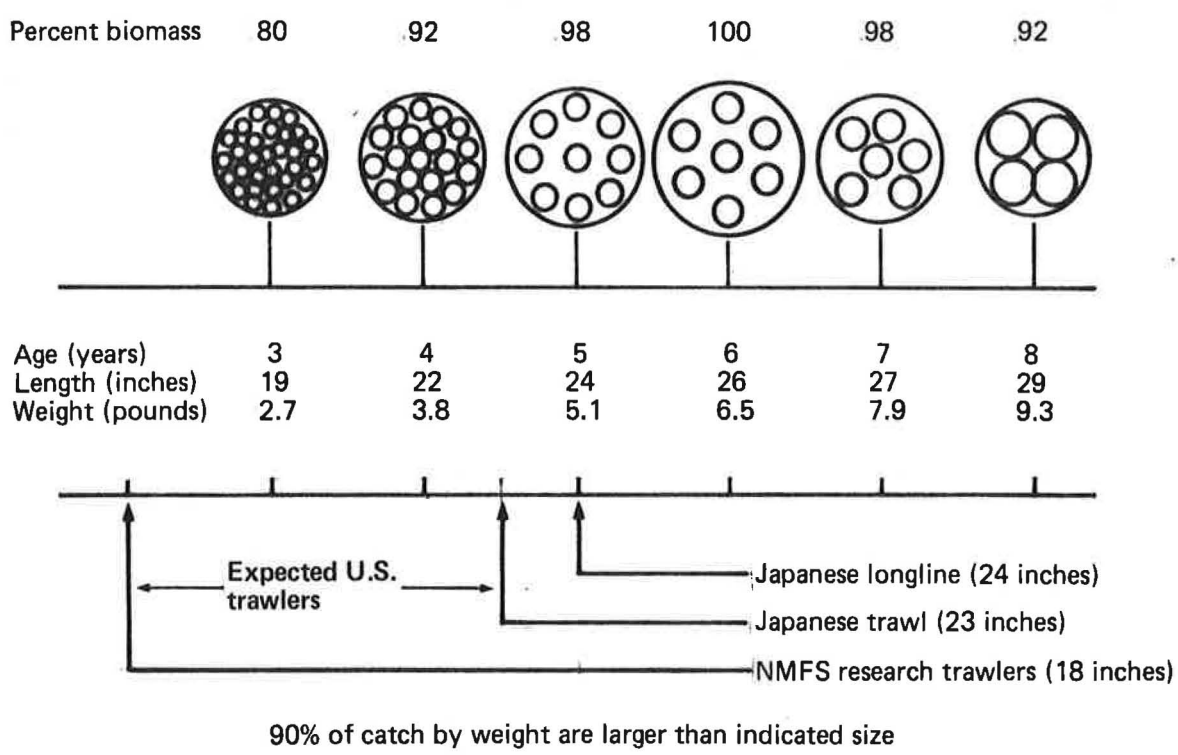
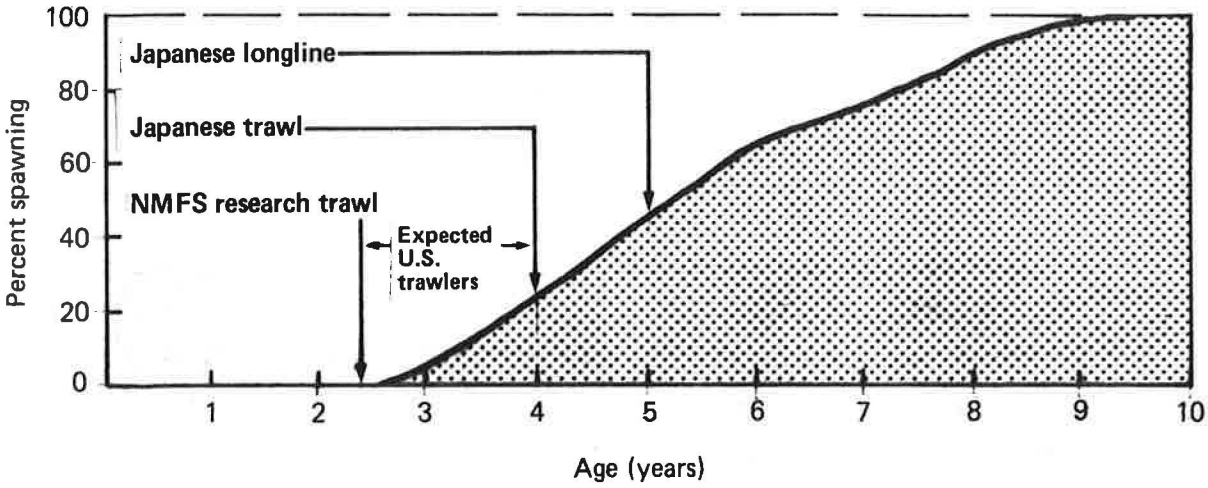


Figure 5.--Yield-per-cohort biomass for sablefish during its life stages from age 3 through age 8 and references to life stages when sablefish is harvested by various gear types.

SABLEFISH—TRAWL VERSUS LONGLINE FISHERY

Effect on spawning population



90% catch by Japanese longliners > 23 inches (age 5) **45% spawning**
90% catch by Japanese trawlers > 22 inches (age 4) **25% spawning**
90% catch by NMFS research trawlers > 17 inches (ages 2–3) **3% spawning**

Figure 6.--Sablefish population maturity schedule and references to stages along the schedule when sablefish is harvested by various gear types.

taking larger fishes by longlines means that fewer immature fish are harvested. Since a spawner-recruit relationship has not been established for sablefish, the minimum spawning population that is needed to ensure an adequate supply of recruits to the stock cannot be determined. Therefore, it is not known whether the spawning potential of the stock will or will not be impaired if all the OY for sablefish is taken by trawl gear. In any case, taking the fish by longlines means a lower probability of impairing this spawning potential when compared to taking them by trawl gear.

EFFECT ON CATCH OF OTHER SPECIES

During longline and trawl fishing operations for sablefish, a number of other species are also caught. The impact of these catches must be considered in management of the fisheries. To evaluate the impact of harvesting sablefish by longliners versus trawlers, the catch of other groundfish and Pacific halibut taken by the two gear types are compared. Although the incidental catch of Pacific halibut is small, it is considered separate from other groundfish because of its high social and economic value to U.S. fishermen. Under a selected number of fishing strategies, the catch of these 3 species groups are calculated for comparison. These strategies are realistic fishing situations built around exclusive fisheries for longliners versus trawlers and the situation when both fisheries coexist. To simplify identification of these selected strategies, they are classified in Table 10.

Exclusive Longline versus Trawl Fishery when Species Composition Remains the same as in 1977 and 1978.

The impact of conducting an exclusive longline fishery for sablefish is compared to that of an exclusive trawl fishery for sablefish. According to the 1979 FMP for Gulf of Alaska Groundfish (DOC 1978a), the OY's for sablefish and other groundfish are 13,000 mt and 285,900 mt respectively. In evaluating

Table 10.--Selected fishing strategies to study effect of sablefish fishery by longline and trawl gear on catch of other species.

Exclusive Fisheries: Fishery conducted exclusively by longliners (identified by letter A) or trawlers (identified by letter B) under some assumptions on percentage of sablefish in the catch (identified by numbers 1 to 5).

Fishing Pattern	Gear-type	% Sablefish in Catch
A1	Longline	67
A2	Longline	20
A3	Longline	30
A4	Longline	40
A5	Longline	50
B1	Trawl	5
B2	Trawl	1
B3	Trawl	4
B4	Trawl	10

Coexistence Fishery: Fishery conducted by both longline and trawl gear under five sablefish allocation schemes (identified by letters C to G) and four assumptions on percentage of sablefish in longline and trawl catch (identified by numbers 1 to 4).

Fishing Pattern	Catch Allocation (mt)		% Sablefish in Catch	
	Longline	Trawl	Longline	Trawl
C1	12,000	1,000	50	1
C2	12,000	1,000	50	4
C3	12,000	1,000	67	1
C4	12,000	1,000	67	4
D1	10,112	2,888	50	1
D2	10,112	2,888	50	4
D3	10,112	2,888	67	1
D4	10,112	2,888	67	4
E1	9,000	4,000	50	1
E2	9,000	4,000	50	4
E3	9,000	4,000	67	1
E4	9,000	4,000	67	4
F1	1,087	11,913	50	1
F2	1,087	11,913	50	4
F3	1,087	11,913	67	1
F4	1,087	11,913	67	4

the impact of these two fisheries, the OY for any of the two species groups is not allowed to be exceeded. It is assumed that each fishery experiences the same species composition and incidental halibut catch rates as in 1977-78.

Specific assumptions are noted as follows:

(1) Species composition in the longline fishery is 67% sablefish and 33% other groundfish.

(2) Species composition in the trawl fishery is 5% sablefish and 95% other groundfish. In the Japanese trawl fishery, sablefish was less than 1.5% of 1977-78 catches but this percentage was kept low because of sablefish limitations imposed on trawlers. If an exclusive fishery for sablefish is permitted to trawlers, the percentage is assumed to increase to 5% of the catch.

(3) Incidental catch rate of halibut in the longline fishery is 2.47 halibut per ton of total catch. Mortality on halibut is about 30-50%. Longline-caught halibut are generally 2-years-old and average 3.36 kg.

(4) Incidental catch rate of halibut in the trawl fishery is 3.35 halibut per ton of total catch. Mortality on halibut is about 50-100%. The halibut is generally 4 years old and average 7.4 kg.

(5) The mortality on halibut by longline is standardized to the age and size of halibut taken by trawl gear. If the fish caught by longline gear is not caught until it grows to age 4, its number would have been reduced by natural mortality (M = 0.2) but individual fish would have grown from 3.36 kg to 7.4 kg. The total weight of halibut killed is therefore standardized to the age and size of halibut taken by trawl gear.

Based on these 5 sets of assumptions, the catch of sablefish, other groundfish, and halibut are calculated for fishing patterns A1 and B1 (identified in Table 10). The calculations are shown in Table 11. Under these fishing patterns when exclusive fisheries are conducted, the OY of sablefish

Table 11--Total incidental mortality on Pacific halibut assuming the entire optimum yield of sablefish is taken by longline or trawl gear based on incidental catch rates and mortality on halibut reported by U.S. observers aboard Japanese vessels during 1977 and 1978.

	Longline		Trawl	
	30% Mortality	50% Mortality	50% Mortality	100% Mortality
No. of halibut per mt of total catch	2.47	2.47	3.35	3.35
No. of halibut killed per mt of total catch	0.74	1.23	1.68	3.35
Average weight of halibut (kg)	3.36	3.36	7.40	7.40
No. of halibut killed per mt of total catch adjusted to 7.4 kg fish 1/	0.50	0.83	1.68	3.35
Incidental kill ratio	0.60	1.00	2.02	4.04
Sablefish catch (mt)	13,000	13,000	13,000	13,000
Percent sablefish in total catch 2/	67	67	5	5
Estimate total groundfish catch (mt)	19,400	19,400	260,000	260,000
Total number of halibut killed	9,700	16,102	436,800	873,600
Total weight of halibut killed--				
metric tons	72	119	3,232	6,464
millions of pounds	.158	.263	7.126	14.252

1/ Approximate age of recruitment into the longline fishery and trawl fishery is 2 and 4 years, respectively. The longline caught fish is adjusted for growth and mortality to age 4 fish of 7.4 kg using a natural mortality of M = 0.20.

2/ Longline sablefish catch percentage based on Japanese longliners fishing deeper than 500 m;
Trawl sablefish catch percentage assumed to be 3 times higher than present Japanese trawl percentage.

is attainable in both instances without exceeding the OY for other groundfish. The total catch of all species by longliners is 19,400 mt as compared to 260,000 mt (more than 13 times greater) by trawlers. Under such exclusive fisheries, the OY for other groundfish is not attainable.

Under an exclusive fishery by longliners, the incidental mortality on halibut average 96 mt (0.2 million lbs). This mortality is substantially lower than average halibut mortality of 4,848 (10.7 million lbs) that would be caused by an exclusive trawl fishery. Mortality on halibut caused by an exclusive trawl fishery will therefore be 51 times greater than that caused by an exclusive longline fishery. Considering that the 1979 catch quota for Pacific halibut in IPHC Area 3 (most of which is the Gulf of Alaska) is only 4,536 mt (10 million lbs), it is clear that a trawl fishery has a potentially devastating effect on halibut.

Exclusive Longline and Trawl Fisheries when Species Composition Varies from 1977 and 1978

The previous section describes fishing patterns A1 and B1 when both longline and trawl fisheries are assumed to continue fishing in their usual and accustomed manner. Actually, the fishing pattern will probably change when the fishery is exclusive and the species composition altered. Such changes, however, are unpredictable but it may be assumed that sablefish would make up 20-50% of the longline catch and 1-10% of the trawl catch. Comparisons of the 2 fisheries are then made under the following assumptions:

(1) In the longline fishery, sablefish makes up 20%, 30%, 40%, or 50% of the catch which identify fishing patterns A2-A5 in Table 10.

(2) In the trawl fishery, sablefish makes up 1%, 4%, or 10% of the catch which identify fishing patterns B2-B4.

(3) Average incidental mortality on halibut remains the same as described in the last section and Table 11 for the trawl fishery.

(4) Average incidental mortality on halibut caused by the longline fishery is increased as the percentage composition of sablefish is decreased. As the percentage is decreased below 67% in the longline catch, the vessels are assumed to be fishing in areas where Pacific cod and halibut are expected to be taken in larger quantities. When sablefish is 67% of the catch, the average incidental mortality rate on halibut is about 0.67 halibut per mt of catch. It is assumed that the average incidental mortality will be increased by 50% (to 1.0 halibut per mt of catch) when sablefish makes up 50% of the catch. When sablefish makes up 40% of the catch, the incidental mortality rate is doubled (to about 1.3 halibut per mt of catch). This rate is tripled and quadrupled as sablefish makes up 30% and 20% of the catch, respectively.

Based on these 4 sets of assumptions, the catch of sablefish, other groundfish, and halibut are calculated for the longline fishery (fishing patterns A2-A5) as shown in Table 12, and for the trawl fishery (fishing patterns B2-B4) as shown in Table 13. In all cases of the longline fishery, the OY for sablefish is attainable, but the OY for other groundfish is not. As the percentage of sablefish in the catch decreases below 67%, the amount of other groundfish taken in the longline fishery increases. This situation is likely if longliners are permitted to fish in depths shallower than 500 m. Under the assumption that sablefish makes up 20% of the total catch (fishing pattern A2), the incidental mortality on halibut is increased to 1,275 mt or 2.8 million lbs. The most likely situation of an exclusive longline fishery is when sablefish makes up 50% of the catch (fishing pattern A5). In this situation, the incidental mortality on halibut is expected to be about 7 times lower or 193 mt, or 0.4 million lbs by the time OY for sablefish is reached.

In the case of an exclusive trawl fishery, the OY for sablefish is attained before the OY for other groundfish is reached under the assumption that sablefish makes up 10% of the catch (fishing pattern B4, Table 13). If the percentage

Table 12.--Effect of a longline fishery on sablefish, other groundfish and Pacific halibut at selected percentage levels of sablefish in the longline catch assuming that the fishery is able to operate in all depths outside the territorial sea.

Percent of Sablefish in Longline Catch	20%	30%	40%	50%
Optimum Yield (mt):				
Sablefish	13,000	13,000	13,000	13,000
Other groundfish[1/]	285,900	285,900	285,900	285,900
Total groundfish[1/]	298,900	298,900	298,900	298,900
Estimated Catch (mt):				
Sablefish	13,000	13,000	13,000	13,000
Other groundfish[1/]	52,000	30,330	19,500	13,000
Total groundfish[1/]	65,000	43,330	32,500	26,000
Under Catch of OY (mt):				
Sablefish	0	0	0	0
Other groundfish[1/]	233,900	255,570	266,400	272,900
Total groundfish[1/]	233,900	255,570	266,400	272,900
Average no. halibut killed per mt of groundfish	2.7	2.0	1.3	1.0
Total Kill of Halibut:				
Metric tons	1,275	642	313	193
Million pounds	2.8	1.4	0.7	0.4

1/ Excludes Atka mackerel and squid because incidental catches of sablefish and halibut are negligible in fisheries for these species.

Table 13.--Effect of trawl fisheries on sablefish, other groundfish and Pacific halibut at selected percentage levels of sablefish in the total trawl catch.

Percent of Sablefish in Trawl Catch	1%	4%	10%
Optimum Yield (mt):			
Sablefish	13,000	13,000	13,000
Other groundfish[1/]	285,900	285,900	285,900
Total groundfish[1/]	298,900	298,900	298,900
Estimated Catch (mt):			
Sablefish	2,989	11,956	13,000
Other groundfish[1/]	285,900	285,900	117,000
Total groundfish[1/]	288,889	297,856	130,000
Under Catch of OY (mt):			
Sablefish	10,011	1,044	0
Other groundfish[1/]	0	0	168,900
Total groundfish[1/]	10,011	1,044	168,900
Average no. halibut killed per mt of all groundfish	2.8	2.8	2.8
Total Kill of Halibut:			
Metric tons	5,387	5,554	2,424
Million pounds	11.9	12.2	5.3

1/ Excludes Atka mackerel and squid because incidental catches of sablefish and halibut are negligible in fisheries for these species.

composition of sablefish is reduced to 4% or 1% (fishing patterns B3 or B2, respectively), which will more likely be closer to actual situations, the OY of other groundfish is attained before the OY of sablefish. Therefore, this binding constraint will stop the sablefish fishery before its OY is fully utilized. It appears that to maximize total catch, the percentage composition of sablefish would have to be about 4% of the total catch (fishing pattern B3). Under this condition, the total groundfish catch is 297,856 mt of which 11,956 mt (4%) is sablefish. However, the incidental mortality on halibut is also the highest at about 5,554 mt or 12.2 million lbs.

Again it is shown that an exclusive trawl fishery conducted to take the OY of sablefish will have a more severe impact on halibut than one by longliners. On the other hand, longliners can only catch a small fraction of the groundfish OY while the trawl fishery is able to utilize most of these groundfishes.

Coexistence of Longline and Trawl Fisheries

The longline and trawl fisheries in the Gulf of Alaska have coexisted for some time with longliners targetting on sablefish in waters deeper than 500 m and trawlers taking sablefish incidentally in depths shallower. For comparison, the effect on catches by such joint fisheries is examined under selected assumptions on species composition and catch allocation schemes noted as follows:

(1) Four sequences of catch allocations in metric tons are assumed for longliners versus trawlers--12,000 v. 1,000; 10,112 v. 2,888; 9,000 v. 4,000; and 1,087 v. 11,913.

(2) Sablefish makes up 50% or 67% of the longline catch.

(3) Sablefish makes up 1% or 4% of the trawl catch.

(4) Incidental mortality on halibut is assumed the same as previously described in Tables 11-13.

Based on these four sets of assumptions, 16 different fishing strategies (fishing patterns C1-F4, Table 10) are possible. In the present coexistence fishery, the percentage of sablefish is 67% in the longline fishery and 1% in the trawl fishery. Given the four sequences of allocation schemes, the maximum groundfish catch is realized in fishing pattern D3 under an allocation scheme of 10,000 mt to longliners and 3,000 mt to trawlers (Table 14). If the percentage of sablefish is 50% in the longline fishery and 1% in the trawl fishery, the maximum groundfish catch is realized in fishing pattern D1 under an allocation scheme of 10,000 mt to longliners and 3,000 mt to trawlers. In either case, the mortality on halibut is near its peak level expected under any coexistence fishery and is estimated to be about 5,335 mt or 11.8 million lbs. Therefore, if the management objective is to maximize the catch of all groundfishes in a coexistence fishery, the mortality on halibut will likely be about 12 million lbs when 3,000 mt of sablefish is allocated to trawlers and the rest (10,000 mt) allocated to longliners.

DISTRIBUTION OF FISHING EFFORT ON STOCK

The current manner in which the sablefish fishing effort is distributed over the Gulf of Alaska is desirable to spread the effect of fishing over the entire stock. Throughout the recent history of the fishery, the Japanese longline fleet has distributed its fishing effort throughout the Gulf in depths greater than 500 m. Foreign trawlers generally have not been taking too many sablefish to offset the distribution of fishing pressure on sablefish. Under the 1979 FMP, such a distribution of effort is ensured by limiting catches by area.

Since foreign longlining activities have been phased out in the Southeast statistical area, the void is being filled by U.S. longliners. Although these domestic fishermen tend to fish more in inside waters such as in Chatham Strait,

Table 14.--Catch in metric tons of sablefish, other groundfish and Pacific halibut under selected catch allocations and species composition by a co-existing longline and trawl fishery.

			Percent Sablefish in Catch				Percent Sablefish in Catch			
			Longline	Trawl			Longline	Trawl		
Sablefish	Allocation	Species Category	50%	1%	4%		67%	1%	4%	
12,000	1,000	Sablefish	12,000	1,000	1,000	*	12,000	1,000	1,000	*
		Other groundfish	12,000	99,000	24,000		5,910	99,000	24,000	
		Total	24,000	100,000	25,000		17,910	100,000	25,000	
		Halibut	177	1,861	465		89	1,861	465	
10,112	2,888	Sablefish	10,112	2,786	2,888		10,112	2,838	2,888	
		Other groundfish	10,112	275,788	69,312		4,981	280,919	69,312	
		Total	20,224	278,574	72,200		15,093	283,757	72,200	
		Halibut	150	5,185	1,344		75	5,281	1,344	
9,000	4,000	Sablefish	9,000	2,797	4,000		9,000	2,843	4,000	
		Other groundfish	9,000	276,900	96,000		4,433	281,467	96,000	
		Total	18,000	279,697	100,000		13,433	284,310	100,000	
		Halibut	133	5,205	1,861		67	5,291	1,861	
1,087	11,913	Sablefish	1,087	2,877	11,867		1,087	2,882	11,890	
		Other groundfish	1,087	284,813	284,813		535	285,365	285,365	
		Total	2,174	287,690	296,680		1,622	288,247	297,255	
		Halibut	16	5,354	5,522		8	5,365	5,532	

*These 6 situations delineated by boxes are not likely to happen because the 4% sablefish composition in the trawl catch under low sablefish allocations will probably not become a binding constraint to prevent more groundfish from being taken. The trawlers are able to avoid catching lots of sablefish if they have to, while fishing for other groundfish. Therefore, catches of sablefish, other groundfish and halibut will probably be quite similar to the corresponding 6 situations when sablefish makes up 1% of the catch.

they are believed to be catching the same stock of fish as foreign fishermen used to do in outside waters. Low et al. (1976) showed that the stock conducts inshore and offshore migration. In view of such inshore-offshore relationship of the stock, it does not matter biologically where the fish is caught although it is desirable to catch larger fish in order to maximize the yield potential and reduce the catch of immature fish.

In considering the developing domestic fishery for sablefish, it should be noted that fishing effort should be distributed throughout the Gulf to prevent overfishing in one area. Although sablefish in the Gulf of Alaska are known to migrate between areas, the rate of migration is not rapid and natural re-distribution of the population may be slow.

DISCUSSION ON BIOLOGICAL CONSIDERATIONS

The Gulf of Alaska sablefish fishery has been successfully conducted for many years in waters deeper than 500 m. At such depths, sablefish are found in abundant quantities. The highest concentrations and the largest fish are found at depths between 400 and 800 m. The average size of sablefish taken by gear types varies according to the depths they are caught in and the selective fishing characteristics of the gear. Such a difference in utilization of sablefish at a different size and time in its life history affects the biological production of the stock.

In order to consider some of these biological implications, the size composition of sablefish taken by 3 gear types that play important roles in catching sablefish are compared. These gear types are Japanese-type longliners, Japanese-type trawlers, and U.S.-type trawlers. Longline-caught fish are usually at a size near or at the point when the maximum yield potential is achieved by the stock. Fish caught by Japanese trawlers are slightly

smaller but also near the size when maximum yield potential is realized. Compared to these 2 gear types, U.S.-type trawlers are expected to catch the smallest fish at the time when only 90% of the maximum yield is expected to be reached.

Although the relation between abundance of sablefish spawners and subsequent recruitment to the fishery cannot be quantified at this time, the catch of a Japanese-style longline fishery is composed of 45% mature fish, a Japanese-style trawl fishery 25% mature fish, and a U.S. trawl fishery perhaps 10-20% mature fish. All other things being equal, a Japanese-style longline fishery would allow maintenance of the largest sablefish spawning potential.

Since sablefish stocks in the Gulf of Alaska are part of an ecological system where species are interrelated biologically, the effects of harvesting sablefish by longline versus trawl gear should be considered for other species as well. In evaluating these effects, the amount of sablefish, other groundfish and Pacific halibut taken are compared under a selected number of realistic fishing strategies.

On a relative scale, the incidental mortality on halibut per mt of trawl catch is 4 times greater than the mortality rate caused by longliners. However, if exclusive fisheries on sablefish are to be conducted by longliners versus trawlers, the absolute amount of groundfish and halibut catch will be far greater by trawlers.

The effect on the catch of sablefish and other groundfish, and incidental mortality on halibut is compared under the assumption that the species composition remains the same as in 1977-78 and also when the species composition is different. Under the first assumption, total catch of all groundfish by longliners is only 19,400 mt as compared to 260,000 mt (more than 13 times greater) by trawlers. Although the OY of sablefish (13,000 mt) is achievable

by either an exclusive longline or trawl fishery, the OY of other groundfish (285,900 mt) is attained by neither. The mortality on halibut caused by these fisheries is 51 times greater by trawls (averaging 4,848 mt or 10.7 million lbs of halibut) than by longlines (averaging 96 mt or 0.2 million lbs of halibut).

Under an exclusive longline versus a trawl fishery for sablefish and the assumption that species composition of the catch is different from 1977-78, it is also shown that the trawl fishery has a more severe impact on halibut than one by longliners. In the longline fishery when sablefish is likely to be 50% of the catch, the incidental mortality on halibut is 193 mt or 0.4 million lbs while an exclusive trawl fishery with 4% sablefish in the catch is expected to kill 5,554 mt or 12.2 million lbs of halibut. When considering the catch of sablefish and all groundfish, the OY of sablefish is attainable by longliners but the OY of other groundfish is not. For the exclusive trawl fishery, it is more likely that the OY of other groundfish is reached before the OY of sablefish. Therefore, the trawl fishery is able to utilize most of the OY of all groundfishes.

If the harvesting strategy is to take the OY of sablefish alone, then it does not matter which gear is used under an exclusive fishery. However, if this objective is coupled with the objective of reducing mortality on halibut, then the longline gear is preferred. This longline fishery is advantageous also because it is best able to take advantage of the yield potential from the stock while maintaining the largest spawning potential of the population. However, the longline fishery is not able to utilize the OY of other species in the way a trawl fishery can. An exclusive longline fishery with 50% of the catch being sablefish can harvest a total of 26,000 mt of all groundfish and kill 193 mt or 0.4 million lbs of halibut. An exclusive trawl fishery, on the other hand, with 4% of the catch being sablefish, can harvest 297,900 mt of all groundfish but kill 5,554 mt or 12.2 million lbs of halibut.

If the harvesting strategy is to fully utilize all groundfish species while keeping incidental catch of halibut as low as possible, then a coexistence longline and trawl fishery is also feasible. The highest combined catch of sablefish and other groundfish is derived under an allocation scheme when 10,000 mt of sablefish is allocated to longliners and the rest (3,000 mt) to trawlers. The percentage of sablefish is 50% in the longline fishery and 1% in the trawl fishery as presently encountered. Under this allocation scheme, the mortality on halibut is estimated to be at least 5,335 mt or 11.8 million lbs. Under any other allocation scheme, the OY of sablefish and/or other groundfish may not be realized. Therefore, this coexistence fishery is best suited to catch the entire OY for sablefish, other groundfish, and minimize halibut mortality to 11.8 million lbs.

Given these biological considerations of catching sablefish, longlines should be the preferred gear for harvesting sablefish if the harvesting strategy is to maximize its catch while reducing incidental halibut mortality. Catches of some sablefish are unavoidable in the trawl fishery and under a proper allocation scheme, the longline and trawl fishery can coexist. It also appears that in order for a longline fishery for sablefish and a trawl fishery for other groundfish to coexist with minimum conflict, longliners should continue fishing in waters deeper than 500 m. At these depths, the maximum biological advantage of utilizing the sablefish stock is realized while incidental mortality on halibut is kept lower than the situation when sablefish are taken in shallower depths. For such a coexistence fishery, the trawlers will also be able to utilize the abundant groundfish resource in the Gulf of Alaska, although high incidental mortality on halibut is unavoidable since they operate in shallower waters where halibut are abundant.

SECTION III: ECONOMIC CONSIDERATIONS OF HARVESTING SABLEFISH

The Gulf of Alaska currently supports numerous commercial fisheries. Alaska pollock, Pacific ocean perch, halibut, and sablefish provide examples of species harvested in the Gulf of Alaska. In a setting characterized by the existence of a complex of commercially valuable species, selection of a harvesting method for any one species must be made to facilitate realization of potential economic benefits derivable from all fishery resources.

The selection process used to determine the best harvesting method for sablefish in the Gulf of Alaska must recognize the existence of other commercially important species in the same geographical area. Further, price variation due to fish size requires that differences in the size composition of sablefish caught with various gear types also be taken into account.

This section focuses on identifying the harvesting approach which produces the highest total and net values of the catch.

Specific objectives are:

(1) Determination of the total value (price multiplied by quantity of fish) of sablefish and other groundfish accruing to fishermen from an exclusive longline sablefish fishery;

(2) Determination of the total value of sablefish and other groundfish accruing to fishermen from an exclusive trawl sablefish fishery; and

(3) Determination of the total value of sablefish and other groundfish accruing to fishermen when the OY for sablefish, 13,000 mt, is allocated to longliners and trawlers in the following ways:

(a) 12,000 mt to longliners and 1,000 to trawlers;

(b) 10,112 mt to longliners and 2,888 to trawlers;

(c) 9,000 mt to longliners and 4,000 to trawlers; and

(d) 1,087 mt to longliners and 11,913 to trawlers.

In addition to total values, net values of the catch are calculated for each harvesting alternative. Net value is defined as total value of fish less harvesting costs.

TOTAL VALUE OF HARVEST TO FISHERMAN

The following assumptions are used in the development of the total value of fish harvested in longline and trawl fisheries for sablefish.

(1) Fish less than 5 lbs dressed weight make up 46% and fish 5 lbs or larger dressed weight account for 54% of the Japanese-type trawl catch;

(2) Fish less than 5 lbs dressed weight make up 94% and fish 5 lbs or larger account for 6% of the U.S.-type trawl catch; and

(3) The longline catch is made up of 3% small (fish less than 3 lbs dressed weight), 34% medium (fish 3 to 5 lbs dressed weight), and 63% large (fish larger than 5 lbs) fish.

Prices used to determine the total value of sablefish caught with longlines are 78, 52, and 26¢/lb dressed weight for large, medium, and small fish, respectively. These prices were obtained from the Alaska Department of Fish and Game, and represent averages for sablefish landed in the State of Alaska during 1978. Prices calculated for trawl-caught sablefish were 50 and 32¢/lb dressed weight for fish 5 lbs or larger, and less than 5 lbs dressed weight, respectively. Estimation of trawl prices was necessary because of the lack of landings of trawl-caught sablefish in Alaska. Sablefish prices reported by the Fisherman's Marketing Association's October 1978 price sheet for Winchester Bay, Oregon to Monterey, California (Figure 7) in combination with 1978 prices of longline-caught sablefish landed in Alaska were used in the derivation process. The weighted price per pound of groundfish other than sablefish taken by trawlers is assumed to be 12¢/lb. Further, it is assumed that groundfish other than sablefish caught in a longline fishery would be worth 25¢/lb. The price per lb for halibut is taken to be $1.70.

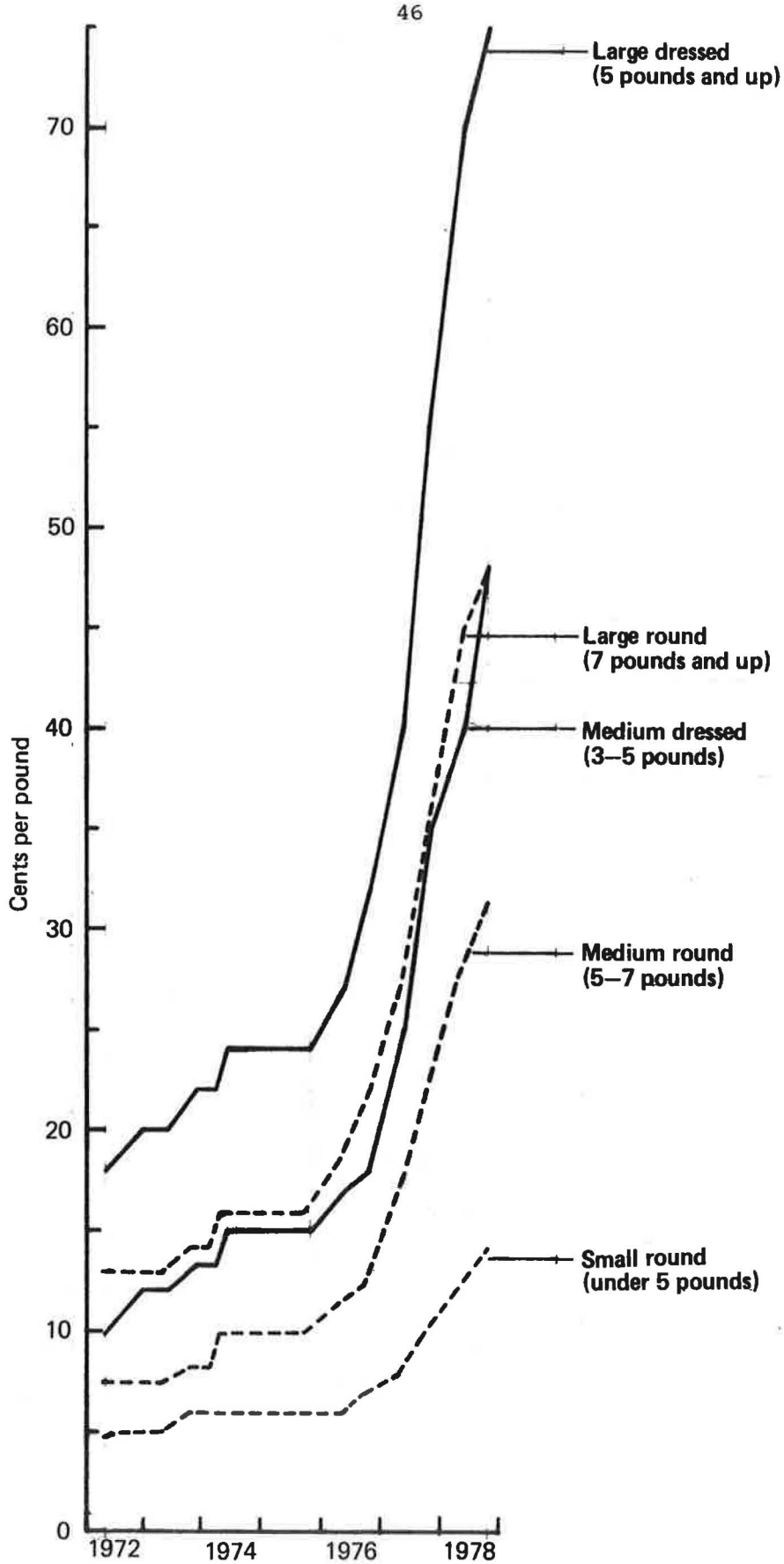


Figure 7.--Ex-vessel sablefish prices for Winchester Bay, Oregon to Monterey, California. (Source: Fishermen's Marketing Association's price sheets).

Total Value: Exclusive Longline versus Trawl Fishery

Total values of sablefish harvested in exclusive longline and trawl fisheries for sablefish are given in Tables 15 and 16. Values in Table 15 indicate that if the entire OY for sablefish is caught by an exclusive longline fishery, the catch would be worth $19.4 million. Further, the value of sablefish in the catch is shown to be unresponsive to changes in catch composition.

Total values of sablefish caught in exclusive Japanese and U.S.-type trawl fisheries are reported in Table 16 for four different assumptions about the percent of sablefish in the catch. The percentages selected are 1, 4, 5, and 10. The value of sablefish taken by a Japanese-type trawl fishery characterized by a total catch composed of 1% sablefish is $2,6 million. Catches made up of 4, 5, and 10% sablefish produce $11.0, $12.0, and $12.0 million worth of sablefish, respectively. The low relative values of sablefish for trawl catches composed of less than 5% sablefish result from exhaustion of OY for other groundfish prior to depletion of the OY for sablefish. Catches made up of 5 to 10% sablefish exhaust the sablefish OY before the constraint imposed on the catch by the OY for other groundfish is reached. Total values of sablefish taken in an exclusive U.S.-type trawl fishery range from $2.1 million for a catch containing 1% sablefish to $9.5 million for catches with from 5 to 10% sablefish. Exhaustion of the OY for other groundfish before the OY for sablefish is harvested also characterizes the U.S.-type trawl fishery when sablefish account for less than 5% of the total catch. The converse holds true when the quantity of sablefish in the catch is greater than or equal to 5%.

Summarizing, the highest total value of the sablefish catch is obtained by harvesting the resource exclusively with longlines. The largest value of

Table 15.--Total value of fish harvested in an exclusive longline fishery*

Species Category	TOTAL VALUE OF CATCH (Million $)				
	Percent of Sablefish in Catch				
	20	30	40	50	67
Sablefish	19.4	19.4	19.4	19.4	19.4
Other groundfish	28.7	16.7	10.7	7.2	3.5
TOTAL	48.1	36.1	30.1	26.6	22.9
Incidental halibut a/	3.6	1.8	0.9	0.5	0.3

*Quantities of fish harvested with longlines are taken from Tables 11 and 12.

a/ The incidental halibut catch is taken from Tables 11 and 12.

Table 16.--Total value of fish harvested in an exclusive trawl fishery*

Species Category	TOTAL VALUE OF CATCH (Million $)							
	Japanese Type Trawl Fishery				U.S. Type Trawl Fishery			
	Percent of Sablefish in Catch				Percent of Sablefish in Catch			
	1	4	5	10	1	4	5	10
Sablefish	2.6	11.0	12.0	12.0	2.1	8.7	9.5	9.5
Other groundfish	75.6	75.6	65.3	30.9	75.6	75.6	65.3	30.9
TOTAL	78.2	86.6	77.3	42.9	77.7	84.3	74.8	40.4
Incidental halibut[a]	15.1	15.6	13.6	6.8	15.1	15.6	13.6	6.8

*Quantities of fish harvested with trawl gear are taken from Tables 11 and 13.

a/ The incidental halibut catch is taken from Tables 11 and 13.

sablefish harvested by an exclusive trawl fishery given assumed prices and size compositions of the catch is $12.0 million, while the value of the same quantity of fish caught by longliners is $19.4 million. The difference in the total value of sablefish caught in exclusive longline and trawl fisheries is due to the presence of larger quantities of big, more valuable fish in the longline catch.

Marketable species of fish other than sablefish will be taken in both longline and trawl fisheries. Rows in Tables 15 and 16 with the heading "Other groundfish" give the value of these species for the various fisheries. The value of other groundfish taken in a longline fishery is developed given five different assumptions concerning the species composition of the catch. The quantity of sablefish in the catch is allowed to be 20, 30, 40, 50, and 67%. Given catch compositions implied by these percentages and assuming a price of 25¢/lb, values of other groundfish taken in an exclusive longline fishery range from $3.5 to $28.7 million (Table 15). The highest value is associated with a catch composed of 20% sablefish, while the lowest value is obtained from a catch containing 67% sablefish. The weighted price for other groundfish caught by trawlers is taken to be 12¢/lb. Given this assumption, the total value of other groundfish caught by trawlers ranges from $30.9 million for a catch composed of 10% sablefish to $75.6 million for catches containing up to 4% sablefish (Table 16). Depletion of the OY for sablefish prior to harvesting the OY of other groundfish is responsible for the difference in the total value of groundfish in catches made up of from 5 to 10% sablefish and those containing less.

The values of sablefish and other groundfish are summed to determine the total value of all fish caught in the various types of fisheries. These values are presented in Tables 15 and 16 in the rows with the heading "Total." The highest value of the total catch, $86.6 million, is associated with an exclusive

Japanese-type trawl fishery where sablefish accounts for 4% of the catch. An exclusive U.S.-type trawl fishery, with a similar catch composition, is valued at $84.3 million. The lowest value, $22.9 million, is associated with the total catch of a longline fishery composed of 67% sablefish. The highest value of the total catch of all species for longlines, $48.1 million, is obtained when the quantity of sablefish in the catch is fixed at 20%.

Comparisons of the values of the total catches taken in exclusive longline and trawl fisheries for sablefish must include consideration of the incidental halibut catch issue. Values of the incidental halibut catches in Tables 11-13 appear in the last row of both Tables 15 and 16. Information in Table 16 indicates that the value of halibut caught in a trawl fishery could reach approximately $15.6 million. Results in Table 15 indicate that the value of halibut caught in a longline fishery could approach $3.6 million. These values represent losses to the halibut setline fishery.

Total Value: Coexistence of Longline and Trawl Fisheries

The high relative value of sablefish calculated for a longline fishery coupled with the high relative value of other groundfish derived for a trawl fishery suggest the possibility that coexistence of trawl and longline fisheries could produce a catch whose value would exceed the value of catches associated with either an exclusive longline or trawl fishery. To explore the likelihood of this outcome, values of the catch are derived for five alternative allocations of the sablefish OY between longliners and trawlers. Results of the calculations are summarized in Tables 17 and 18. Longline and trawl combinations whose total catches produce the largest total value for a given sablefish allocation appear in Table 19. Examination of information in Table 19 indicates that the highest total value of the catch, $96.1 million, is associated with an allotment of 10,112 mt of sablefish to longliners, whose catches are composed of 50% sablefish, and 2,888 mt to trawlers, whose catches

Table 17.--Values accruing given coexistence of trawl and longline fisheries when sablefish is 50% of the longline catch.

Sablefish Allocation (Metric Tons)		Species Category	VALUE OF THE CATCH (Million $)				
			Longline	Japanese Type Trawl		U.S. Type Trawl	
			Percent of Sablefish in Catch	Percent of Sablefish in Catch		Percent of Sablefish in Catch	
Longline	Trawl		50	1	4	1	4
13,000	0	Sablefish	19.4	0	0	0	0
		Other groundfish	7.2	0	0	0	0
		Total	26.6	0	0	0	0
12,000	1,000	Sablefish	17.9	0.9	0.9	0.7	0.7
		Other groundfish	6.6	26.2	6.3	26.2	6.3
		Total	24.5	27.1	7.2	26.9	7.0
10,112	2,888	Sablefish	15.1	2.5	2.6	2.0	2.1
		Other groundfish	5.6	72.9	18.3	72.9	18.3
		Total	20.7	75.4	20.9	74.9	20.4
9,000	4,000	Sablefish	13.4	2.5	3.7	2.0	2.9
		Other groundfish	5.0	73.2	25.4	73.2	25.4
		Total	18.4	75.7	29.1	75.2	28.3
1,087	11,913	Sablefish	1.7	2.6	11.0	2.1	8.7
		Other groundfish	0.6	75.3	75.3	75.3	75.3
		Total	2.3	77.9	86.3	77.4	84.0

Table 18.--Values accruing given coexistence of trawl and longline fisheries when sablefish is 67% of the longline catch.

Sablefish Allocation (Metric Tons)		Species Category	VALUE OF CATCH (Million $)				
			Longline	Japanese Type Trawl		U.S. Type Trawl	
			Percent of Sablefish in Catch	Percent of Sablefish in Catch		Percent of Sablefish in Catch	
Longline	Trawl		67	1	4	1	4
13,000	0	Sablefish	19.4	0	0	0	0
		Other groundfish	3.5	0	0	0	0
		Total	22.9	0	0	0	0
12,000	1,000	Sablefish	17.9	0.9	0.9	0.7	0.7
		Other groundfish	3.3	26.2	6.3	26.2	6.3
		Total	21.2	27.1	7.2	26.9	7.0
10,112	2,888	Sablefish	15.1	2.6	2.6	2.1	2.1
		Other groundfish	2.7	74.3	18.3	74.3	18.3
		Total	17.8	76.9	20,9	76.4	20.4
9,000	4,000	Sablefish	13.4	2.6	3.7	2.1	2.9
		Other groundfish	2.4	74.4	25.4	74.4	25.4
		Total	15.8	77.0	29.1	76.5	28.3
1,087	11,913	Sablefish	1.7	2.6	11.0	2.1	8.7
		Other groundfish	0.3	75.5	75.5	75.5	75.5
		Total	2.1	78.1	86.5	77.6	84.2

Table 19.--Total values accruing to a coexistence fishery for selected longline-trawl combinations

Gear Combination*	Sablefish Allocation		Value of Catch			Value of Incidental Halibut Catch **
	Longline	Trawl	Sablefish	Other Groundfish	Total	
	---metric tons--		---------- million $ ----------			
Type A5 Longline - No Trawl	13,000	0	19.4	7.2	26.6	0.5
Type A5 Longline - Type B2 Trawl	12,000	1,000	18.8	32.8	51.6	5.7
Type A5 Longline - Type B2 Trawl	10,112	2,888	17.6	78.5	96.1	15.0
Type A5 Longline - Type B2 Trawl	9,000	4,000	15.9	78.2	94.1	15.0
Type A5 Longline - Type B3 Trawl	1,087	11,913	12.7	75.9	88.6	15.5
No Longline - Type B3 Trawl	0	13,000	11.0	75.6	86.6	15.6

*Type A5 longline = longline with 50 percent of sablefish in catch.

Type B2 trawl = Japanese type trawl with sablefish accounting for 1 percent of the catch.

Type B3 trawl = Japanese type trawl with sablefish accounting for 4 percent of the catch.

**These values represent losses to the halibut setline fishery.

Table 20.--Value of incidental halibut catch in a coexistence fishery*

Sablefish Allocation (Metric Tons)		Value of Incidental Halibut Catch (Million $)			
		Longline		Trawl	
		Percent of Sablefish in Catch		Percent of Sablefish in Catch	
Longline	Trawl	50	67	1	4
13,000	0	0.5	0.3	0	0
12,000	1,000	0.5	0.2	5.2	1.3
10,112	2,888	0.4	0.2	14.6	3.8
9,000	4,000	0.4	0.2	14.6	5.2
1,087	11,913	0.04	0.02	15.0	15.5

*Mid-points in the incidental catch ranges were used to determine values.

contain 1% sablefish. Contrasting this result with the total value of an exclusive longline fishery with 50% sablefish indicates that a coexistence fishery increases the total value of the catch by $69.5 million. The value of sablefish in the coexistence fishery is $17.6 million, $1.8 million less than the value of the sablefish in the exclusive longline fishery. However, this $1.8 million loss is offset by a $71.3 million increase in other groundfish.

Values of the incidental halibut catch resulting from a coexistence fishery appear in the last column of Table 19. As indicated, the value of halibut captured in a coexistence fishery could reach $15.5 million. Alternatively, the incidental catch of halibut in an exclusive longline fishery with a catch composed of 50% sablefish could approach $0.5 million.

Values in Tables 17 and 18 also indicate how trawlers are affected by variations in the sablefish allocation. Results summarized in Table 17 for a Japanese-type trawl fishery with a catch composed of 1% sablefish indicate that an increase in the sablefish allotment from 1,000 to 2,888 mt has a dramatic impact upon the total value of the catch. The allocation change increases the value of the catch from $27.1 to $75.4 million, an increase of $48.3 million. Additional expansions in the trawlers' sablefish allotment increase the total value of the catch further. Although, incremental increases are relatively small. The binding nature of the OY for other groundfish is responsible for the small changes in total value once the quota exceeds 2,888 mt. That is, the OY for other groundfish is reached before the sablefish allotment is exhausted for trawl allocations in excess of 2,888 mt.

In a Japanese-type trawl fishery characterized by a catch composed of 4% sablefish, the incremental increases in the value of the catch are found to be more sensitive to allocation changes for quotas in excess of 2,888 mt. For example, the total value of the catch increases from $0 to $7.2 million when

the sablefish allocation is increased from 0 to 1,000 mt. Increases of from 1,000 to 2,888, 2,888 to 4,000, and 4,000 to 11,913 mt produce changes in the total value of catch of $13.7, $8.2, and $57.2 million respectively. Comparing Table 17 with Table 18 indicates that an increase in the quantity of sablefish in the longline catch does not substantially alter the impact of varying the sablefish allotment on the total value of the trawl catch.

Summarizing, comparisons of the total value of catches for various types of fisheries indicate that an exclusive longline fishery will produce the most valuable sablefish catch. In addition, it is demonstrated that a coexistence fishery is capable of producing a catch whose total value exceeds the value of catches associated with either exclusive longline or trawl fisheries. If the trawl catch contains 1% sablefish, allocations to longliners and trawlers, respectively, of either 10,112 and 2,888, 9,000 and 4,000, or 1,087 and 11,913 mt of sablefish will produce catches whose total values exceed those associated with either exclusive longline or trawl fisheries. The allocation of 12,000 mt to longliners and 1,000 mt to trawlers produces a total value which is greater than the total value of an exclusive longline fishery, but less than the total value of an exclusive trawl fishery. Values of the catch derived for a coexistence fishery, where the trawl catch is composed of 4% sablefish, exceed total values associated with an exclusive trawl fishery only when the trawl quota in a coexistence fishery approaches approximately 12,000 mt. However, total values of the catch for the four sablefish allocations exceed the total value of the exclusive longline catch.

NET VALUE OF HARVEST TO FISHERMEN

Making comparisons of different harvesting methods solely on the basis of total value of the harvest can be misleading. Harvesting costs frequently vary between fishing techniques. Valid comparisons, therefore, require that

costs be taken into account. To facilitate comparison of alternative harvesting methods for sablefish, returns to management and capital are calculated for longline and Japanese trawl-type fisheries. Returns to management and capital in the analysis is defined as total value of the harvest less operating expenses (including crew and skipper shares), gear replacement and maintenance, insurance and depreciation. Costs in the analysis are based on the assumption of a uniform fleet of longline vessels with lengths in excess of 36 feet. The trawl fleet is assumed to be composed of 108 foot crabber/trawler type steel vessels with 850 hp main engines. An itemized breakdown of costs by type of harvesting method appears in Table 21. It is important to emphasize that the validity of the returns to management and capital reported in this section are critically dependent upon cost information reported in Table 21. At present, domestic trawling for sablefish in the Gulf of Alaska is nonexistent. Therefore, it was necessary to modify vessel cost data reported in Hughes and Nelson (Oct. 1978). Harvesting costs for the longline fleet were obtained from industry sources. Time constraints prevented a thorough verification of cost data used in this analysis. Considerable uncertainty, therefore, surrounds the validity of reported harvesting costs.

Net Value: Exclusive Longline versus Trawl Fishery

Returns to management and capital, net value, for exclusive longline and trawl fisheries, are summarized in Tables 22 through 25. Results in Table 22 indicate that returns accruing to management and capital in an exclusive longline fishery could range from $10.8 to $17.0 million depending upon the daily catch rate and quantity of sablefish in the catch. The highest return is associated with a catch composed of 50% sablefish and a daily catch rate of 6 mt. Examination of the impact of catch composition on returns indicates that increasing the quantity of sablefish in the catch from 50 to 67% decreases

Table 21.--Harvesting costs.

Cost Item	Gear Type (Dollars) Longline	Trawl
Fuel and lube	264/day	887/day
Food	123/day	7.50/man/day
Bait	440/day	---
Crew share	11% of gross stock	5.5% per man of gross stock-food costs
Skipper share	2% of gross stock	11% of gross stock-food costs
Miscellaneous	1% of gross stock	
Vessel and gear maintenance	25,000 per year	41,000 per year
Hull Insurance	7,500 per year	33,000 per year
Injury Insurance	12,045 per year	12,045 per year
Depreciation	25,600 per year*	110,000 per year**
Crew size	5 men	5 men

*Initial value of vessel and gear assumed to be $512,000. Straight line depreciation was assumed to take place over a 20-year time period.

**Initial value of vessel and gear was assumed to be $2.2 million.

Table 22.--Returns accruing to management and capital from an exclusive longline fishery

Daily Catch Rate of Sablefish (metric tons)	Returns to Management and Capital (Million $)	
	Percent of Sablefish in Catch	
	50	67
2	14.9	10.8
3	17.0	13.8

Table 23.--Returns accruing to management and capital from an exclusive trawl fishery with sablefish accounting for 1 percent of the total catch*

Price of Other Groundfish (¢/lb)	Returns to Management and Capital (Million $) Daily Catch Rate (Metric Tons)		
	10.5	12	15
12	-17.4	- 9.1	2.3
13	-13.5	- 5.2	6.2
14	- 9.6	- 1.4	10.1
15	- 5.8	2.5	14.0
16	- 1.8	6.4	17.8
17	2.0	10.3	21.7

*Japanese type trawl assumed

Table 24.--Returns accruing to management and capital from an exclusive trawl fishery with sablefish accounting for 4 percent of the total catch*

Price of Other Groundfish (¢/lb)	Returns to Management and Capital (Million $)		
	Daily Catch Rate (Metric Tons)		
	10.5	12	15
12	-14.1	- 5.8	6.0
13	-10.3	- 1.9	9.9
14	- 6.4	2.0	13.8
15	- 2.5	5.9	17.6
16	1.4	9.7	21.5
17	5.2	13.6	25.4

*Japanese type trawl assumed

Table 25.--Returns accruing to management and capital from an exclusive trawl fishery with sablefish accounting for 5 percent of the total catch*

Price of Other Groundfish (¢/lb)	Returns to Management and Capital (Million $) Daily Catch Rate (Metric Tons)		
	10.5	12	15
12	-11.4	- 4.0	- 0.3
13	- 8.1	- 0.7	3.1
14	- 4.7	2.7	6.4
15	- 1.3	6.0	9.8
16	2.0	9.4	13.1
17	5.3	12.7	16.5

*Japanese type trawl assumed

returns to management and capital by $3.2 million. The larger returns associated with a catch composed of 50% sablefish are due to the increased catch of other groundfish.

Returns to management and capital for an exclusive Japanese-type trawl fishery characterized by a catch composed of 1% sablefish appear in Table 23. Given total daily catch rates of 10.5, 12, and 15 mt and a price for other groundfish of 12¢/lb, returns are $-17.4, $-9.1, and $2.3 million, respectively. Returns to management and capital for the same set of daily catch rates increase to $2.0, $10.3, and $21.7 million, respectively, when the price of other groundfish is raised to 17¢/lb. When these results are compared with returns calculated for the exclusive longline fishery, it is shown that a trawl fleet would have to experience a daily catch rate of 15 mt and receive 16¢/lb for groundfish other than sablefish to out-perform an exclusive longline fishery experiencing daily catch rates of 6 metric tons which contain 50% sablefish. Further, an exclusive longline fishery, given daily catch rates and catch compositions considered in Table 22, will produce returns to management and capital which exceed those for a trawl fishery receiving 12¢/lb for other groundfish and experiencing daily catch rates of either 10.5, 12, or 15 mt. This same phenomenon also holds true for trawl catches composed of 4 and 5% sablefish (Tables 24 and 25). However, returns summarized in Tables 23 and 24 indicate that an increase in the quantity of sablefish in the catch from 1 to 4% reduces the price of other groundfish, where returns associated with a trawl fishery experiencing a daily catch rate of 15 mt exceed the highest return from a longline fishery with 50% of the catch sablefish from 16 to about 15¢/lb. In addition, returns for all daily catch rate-price combinations presented in Table 25 for a trawl fishery with a catch containing 5% sablefish are less than the highest return determined for an exclusive longline fishery.

Briefly summarizing, Tables 22 through 25 indicate that the dominance of an exclusive trawl over an exclusive longline fishery suggested by comparisons of total values of the aggregate catch is diminished when net values are used as the basis for making comparisons. Results obtained for both types of fisheries indicate that, given the ex-vessel price of other groundfish of 12¢/lb, returns to management and capital for all the hypothetical longline fisheries exceed returns calculated for the various trawl fisheries. Further, net values associated with a trawl fishery do not dominate net values derived for an exclusive longline fishery until the daily catch rate for trawlers and price of other groundfish reach 15 mt and 17¢/lb, respectively.

Net Value: Coexistence of Longline and Trawl Fisheries

Returns to management and capital for a coexistence fishery appear in Tables 26 and 27 for longline and trawl combinations which produce the catch with the highest total value for several sablefish allocations (Table 19). Returns summarized in Table 26 are derived given an assumed daily catch rate of 15 mt and a price of 12¢/lb for other groundfish for trawlers. Results reported in Table 27 are developed given an assumed price of 17¢/lb for other groundfish caught by trawlers.

Information summarized in Table 26 indicates that returns to management and capital accruing to an exclusive longline fishery exceed those derived from a coexistence fishery where trawlers experience daily catch rates of 15 mt and receive 12¢/lb for other groundfish. A coexistence fishery, however, performs better when the price received by trawlers for other groundfish is increased to 17¢/lb. Specifically, for the four coexistence fisheries considered in Table 27 returns to management and capital range from $23.2 to $34.1 million. The lowest return is associated with an allocation of 12,000 mt of sablefish to longliners and 1,000 mt to trawlers. An allocation of 10,112

Table 26.--Returns accruing to management and capital in a coexistence fishery for selected longline-trawl combinations given a price of 12 cents per pound for other groundfish and a daily catch rate of 15 metric ton for trawlers.

Gear Combination*	Sablefish Allocations (metric tons)		Returns to Management and Capital (million $)		
	Longline	Trawl	Longline	Trawl	Total
Type A5 Longline - No Trawl	13,000	0	17.0	0	17.0
Type A5 Longline - Type B2 Trawl	12,000	1,000	15.6	0.9	16.5
Type A5 Longline - Type B2 Trawl	10,112	2,888	13.2	2.2	15.4
Type A5 Longline - Type B2 Trawl	9,000	4,000	11.7	2.3	14.0
Type A5 Longline - Type B3 Trawl	1,087	11,913	1.5	6.0	7.5
No Longline - Type B3 Trawl	0	13,000	0	6.0	6.0

*Type A5 longline = longline with 50% of sablefish in catch, and a daily catch rate of 3 mt.
Type B2 trawl = Japanese-type trawl with sablefish accounting for 1% of the catch.
Type B3 trawl = Japanese-type trawl with sablefish accounting for 4% of the catch.

Table 27.--Returns accruing to management and capital in a coexistence fishery for selected longline-trawl combinations, given a price of 17 cents per pound for other groundfish and a daily catch rate of 15 metric tons for trawlers.

Gear Combination*	Sablefish Allocation (metric tons)		Returns to Management and Capital (million $)		
	Longline	Trawl	Longline	Trawl	Total
Type A5 Longline - No Trawl	13,000	0	17.0	0	17.0
Type A5 Longline - Type B2 Trawl	12,000	1,000	15.6	7.6	23.2
Type A5 Longline - Type B2 Trawl	10,112	2,888	13.2	20.9	34.1
Type A5 Longline - Type B2 Trawl	9,000	4,000	11.7	21.1	32.8
Type A5 Longline - Type B3 Trawl	1,087	11,913	1.5	25.4	26.9
No Longline - Type B3 Trawl	0	13,000	0	25.4	25.4

*Type A5 longline = longline with 50% of sablefish in catch, and a daily catch rate of 3 mt.
Type B2 trawl = Japanese-type trawl with sablefish accounting for 1% of the catch.
Type B3 trawl = Japanese-type trawl with sablefish accounting for 4% of the catch.

and 2,888 mt of sablefish to longliners and trawlers, respectively, produces the highest return. Further, the highest return to management and capital associated with a coexistence fishery is approximately twice as large as the return associated with an exclusive longline fishery.

Summarizing, net values indicate that prices received for other groundfish and daily catch rates experienced by trawlers play important roles in determining the harvesting method which generates the highest returns to management and capital. If an attempt is being made to produce the highest returns to management and capital, this analysis indicates that if trawlers experience daily catch rates of up to 15 mt per day and receive 12¢/lb for other groundfish, the fishery should be exploited solely by longliners. However, a coexistence fishery, where 10,112 and 2,888 mt of sablefish is allocated to longliners and trawlers with a catch containing 50% and 1% sablefish respectively, is the method which generates the highest net value when the price of other groundfish in the trawl catch approaches 17¢/lb and the daily catch rates reach 15 mt.

DISCUSSION OF ECONOMIC CONSIDERATIONS

Sablefish stocks in the Gulf of Alaska are part of an ecological system where species are related both biologically and economically. Attainment of the greatest economic benefits derivable from all fishery resources in the region should play an important role in the selection of the harvesting method for individual species which are part of this multiple-species complex. In an attempt to develop information which could be used to determine the harvesting method for sablefish, total and net values of the catch were developed for several alternative fishing methods. Total and net values are determined for catches resulting from exclusive longline and trawl fisheries. Also assessed is the economic performance of a coexistence fishery, where portions of the

sablefish OY are allocated to longliners and trawlers. Total values of the catches for these three harvesting methods indicate that an exclusive longline fishery would produce the most valuable sablefish catch. A coexistence fishery where 10,112 mt of the sablefish OY is allocated to longliners with a catch composed of 50% sablefish and 2,888 mt of sablefish allocated to trawlers with a catch containing 1% sablefish produces the largest total value for the aggregate catch, $96.1 million.

Sensitivity of the total value of the trawl catch to variations in the sablefish allocation is also explored. Total values of the catch calculated for sablefish quotas between 0 and 2,888 mt for a trawl fishery with a catch composed of 1% sablefish are determined to be very responsive to variations in the size of the quota. Variations in the size of the allocation for quotas in excess of 2,888 mt increase returns only slightly, due to the OY for other groundfish being reached prior to exhaustion of the sablefish allocation. However, returns associated with a trawl fishery experiencing catches with 4% sablefish are responsive over a broader range of allocations. Specifically, increases in the trawl allocation of from 0 to 1,000; 1,000 to 2,888; 2,888 to 4,000; and 4,000 to 11,913 mt produce changes in the value of the total catch of $7.12, $13.7, $8.2, and $57.2 million, respectively.

Net values, returns to management and capital, are also calculated for coexistence, exclusive longline, and exclusive trawl fisheries. Comparison of returns to management and capital for these three alternative fisheries arrangements indicates that a coexistence fishery where 10,112 and 2,888 mt of the sablefish OY is allocated to longliners whose catch contained 50% sablefish and trawlers with 1% of sablefish in their catch would produce the highest returns, $34.1 million, as opposed to $17.0 million for longline and $25.4 million for trawl fisheries

Comparisons of total and net values for the various fishing methods indicate that longline gear should be used if interest is centered solely in maximizing the value of the sablefish catch. The comparisons also indicate that in the proper setting a coexistence fishery could be employed to realize the greatest economic benefits associated with both sablefish and other groundfish resources of the Gulf of Alaska. Results of the analysis show that success of a coexistence fishery is critically dependent upon the price received for other groundfish contained in the trawl catch. Daily catch rates and catch composition are also important determinants of the comparative advantage of a coexistence fishery. When the price of other groundfish contained in the trawl catch is 12¢/lb, the returns to management and capital for the four types of coexistence fisheries are all less than the return associated with an exclusive longline fishery. The performance of a coexistence fishery improves significantly when the price of other groundfish in the trawl catch is 17¢/lb.

SECTION IV: CONCLUSION

Fish abundance, the Fisheries Conservation and Management Act of 1976, and increasing fish prices have fostered a surge in domestic interest in Gulf of Alaska fishery resources. Walleye pollock, halibut, Pacific ocean perch and sablefish are examples of species harvested commercially in the Gulf. Recent price increases have stimulated interest among U.S. fishermen, particularly in sablefish.

The sablefish resource in the Gulf of Alaska has traditionally been harvested by two dominant gear types--longlines and trawls--each with unique biological and economic ramifications. Therefore, there is a question over how the fishery ought to be conducted. The question of which is best can be answered only in the context of specific goals for the Gulf of Alaska groundfish fishery.

Since the size and life history stage when sablefish are caught is different between gear types, the harvesting technique would affect the optimum yield, maintenance of reproductive potential of the stock, and monetary value of the catch. Longliners, typically operating in depths which exceed 500 m, tend to catch larger, more valuable fish. Further, longline-caught fish are at the size and age when the maximum yield potential is derivable from the stock. Trawlers fishing in the shallower depths tend to catch smaller, lower value fish at the stage in their life history where only 90% of the maximum yield potential will be realized.

The practice of catching larger fish also means that fewer immature fish are harvested. Most of the fish taken by longlines are above the size when 45% are mature. Alternatively, trawlers catch fish at the size when less than 25% are mature. Therefore, the probability of impairing the spawning potential of the stock is lower if the fish are taken by longlines.

The effects of harvesting sablefish by longline versus trawl gear on other species should also be considered since sablefish stocks in the Gulf of Alaska are part of an ecological system where species are interrelated. These effects are evaluated by comparing the amount of sablefish, other groundfish, and Pacific halibut taken under a selected number of fishing strategies. These strategies are realistic fishing situations built around exclusive fisheries on sablefish by longliners and by trawlers, and several situations where both fisheries coexist.

A summary of the tonnage and dollar value of the catch for selected fishing strategies is given in Table 28. It summarizes the results of an exclusive longline fishery, 4 situations of a coexistence fishery, and an exclusive trawl fishery in the Gulf of Alaska. These fishing strategies are selected from various alternatives examined in the paper. They are chosen on the basis of their ability to maximize sablefish and other groundfish catches, minimize halibut mortality, and maximize gross and net dollar values from sablefish and other groundfish. The gross value of the Pacific halibut kill is given to show the potential economic loss to the Pacific halibut fishery.

If an exclusive longline fishery is conducted in the Gulf of Alaska, the OY of sablefish (13,000 mt) can be attained with the minimum impact on halibut (194 mt). However, the catch of other groundfish is very small (13,000 mt) in relation to its OY (285,900 mt). Of the 6 fishing situations in Table 28, the exclusive longline fishery produces the highest gross value ($19.4 million) and net value ($17.0 million) of the sablefish catch. Trawlers do not derive any economic benefits since they are excluded from the fishery.

In the case of an exclusive trawl fishery, the OY of other groundfish is fully utilized while the OY of sablefish is almost reached (11,956 mt). The size and gross value of the incidental halibut kill, however, are higher than those calculated for all other fishing strategies. The gross value of the

Table 28.--Summary of tonnage and dollar value of the catch for several realistic fishery strategies by longline and trawl gear in the Gulf of Alaska.

Sablefish Allocation (Metric Tons)		Percent Sablefish in Catch		Amount of Catch (Metric Tons)			Gross Value of Catch (Million Dollars)				Net Value of Catch (Million Dollars)		
Longline	Trawl	Longline	Trawl	Sablefish	Other Groundfish	Halibut Kill	Sablefish	Groundfish	Sub-total	Halibut	Longline Fishery	Trawl Fishery	Total
13,000	0	50	0	13,000	13,000	194	19.4	7.2	26.6	0.5	17.0	0	17.0
12,000	1,000	50	1	13,000	111,000	2,038	18.8	32.8	51.6	5.7	15.6	7.6	23.2
10,112	2,888	50	1	13,000	285,900	5,335	17.6	78.5	96.1	15.0	13.2	20.9	34.1
9,000	4,000	50	1	11,797	285,900	5,338	15.9	78.2	94.1	15.0	11.7	21.1	32.8
1,087	11,913	50	4	12,954	285,900	5,538	12.7	75.9	88.6	15.5	1.5	25.4	26.9
0	13,000	0	4	11,956	285,900	5,554	11.0	75.6	86.6	15.6	0	25.4	25.4

exclusive trawl catch is $86.6 million ($11 million sablefish and $75.6 million other groundfish).

The largest catch, gross and net value of sablefish and other groundfish combined, is derived in a coexistence fishery. This outcome occurs when approximately 10,000 mt of sablefish is allocated to longliners with a catch containing 50% sablefish. The remaining 3,000 mt is allocated to trawlers whose catch is composed of 1% sablefish. Both the optimum yields for sablefish and other groundfish are attainable in this situation. The gross value of the catch is $96.1 million ($17.6 million sablefish and $78.5 million other groundfish), while the net value is $34.1 million with $13.2 million accruing to longliners and $20.9 million to trawlers. Halibut mortality is 5,335 mt (11.8 million lbs) valued at $15 million, the lowest for fishing strategies that attempt to maximize the combined catch.

The size and value of the catch for other coexistence allocation schemes are substantially lower than those associated with the 2 situations previously discussed. It should be noted that all the above fishing situations reflect average catch, catch rate, price and operating costs that are constructed from data for 1977 and 1978. Actual situations will no doubt be different since fishing patterns and economic outlook of the fishery may change. The optimal fishing strategy will therefore depend on the nature of these changes and goals set for the fishery.

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