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Selectivity of Trawl, Trap, Longline and Set-net Gears to Sablefish, *Anoplopoma fimbria*

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Selectivity of Trawl, Trap, Longline and Set-net

Gears to Sablefish, *Anoplopoma fimbria*

by

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Abstract

Sablefish resources off the Washington-Oregon-California coast are fully utilized (perhaps over-exploited) by trawl, trap, longline and set-net gears. This fishery is an expanding fishery where the gear mix changes rapidly. Management regulations that control fishing effort were explored.

Trawlers landed the smallest sized fish (73% < 60 cm off Washington in 1984), received the lowest ex-vessel prices, and trawls were the least selective gear for sablefish. Traps were the most selective gear for sablefish but only 29% of the Washington landings were graded large (>66 cm). Longline and set-net landings were 64% large sablefish.

Mesh size controlled the length at entry and mean length for trap and set-net gears. With trawl gear, sablefish size composition was apparently controlled by mesh size for directed, but not incidental, captures of sablefish. Longline length frequency samples exhibited a very broad selection range, but 84% of the sablefish measured at sea were greater than 60 cm in length.

Using a modified Beverton and Holt yield-per-recruit model, a size at entry of 60 cm appears to be optimal for maintaining yields and increasing ex-vessel revenues. Compared to the present minimum size limit of 52 cm, a 60 cm entry size would increase revenues by 19-46% for fishing mortality rates of 0.2-0.4. In 1984, large sablefish averaged $0.86/kg, mediums (60-66 cm) $0.62/kg, and smalls $0.34/kg; therfore, delaying harvest until sablefish grow into the medium size category increases revenues.

Minimum mesh sizes of 133 mm would result in a 60 cm size at entry for trap and set-net gears. For the longline and trawl fisheries, a minimum size limit coupled with an incidental catch allowance for undersized sablefish would be necessary. Information on trawl discards and discard mortality rates is required to determine if the full benefits of delayed harvest from 52 to 60 cm can be realized.

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Chapter 1

Introduction

Sablefish (*Anoplopoma fimbria*) resources are largely confined to the U.S. Fishery Conservation Zone (FCZ), from the Bering Sea through the Gulf of Alaska and southward to California. Within the U.S. FCZ, sablefish resources have been either over-exploited or are presently fully utilized (Stauffer and McDevitt, in prep.). Competition among users, whether between domestic and foreign fishermen or among different gear types, has characterized the fisheries.

The sablefish fishery off the Washington-Oregon-California (WOC) coast is a wholly domestic fishery in which four gear types figure prominently in the landings: trawl, trap, longline and set-nets. Sablefish resources are presently fully utilized and perhaps over-exploited. Uncertainties in stock condition have confronted an expanding WOC sablefish fleet since the implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) of 1976. As biologists and managers try to obtain a better understanding of the stock conditions and population dynamics, the fleet continues to expand, largely without restrictions.

As fishing effort continues to increase or the optimum yield (OY) is decreased to maximum sustainable yield (MSY) levels, management measures will be necessary to control fishing effort. Since trawl, trap, longline and set-net gears all have different selective properties, management measures will differentially affect the four gear types. As mandated in the MFCMA, however, management measures must not only conserve resources but also promote fair and equitable allocation of resources among users.

Regulations to limit the harvest of the WOC sablefish fishery and yet have equitable impacts on the various gears require an understanding of the different gear selectivities. The objectives of this study are to describe the fisheries of the four gear types, to quantify the recruitment and selection processes, and to assess the optimum size at entry. Based upon these results, the implications for fisheries management are discussed.

Chapter 2

Overview of the Washington-Oregon-California Sablefish Fishery

Introduction

The sablefish fishery is one of the oldest fisheries on the Pacific coast, originating as a longline fishery in the late 1800's (Bell and Gharrett, 1945). Trawl vessels entered the fishery during World War II, but domestic landings off the WOC coast never exceeded 5,000 mt until 1974 (Low et al., 1976). Foreign catches from the Vancouver-Conception International North Pacific Fisheries Commission (INPFC) areas (Fig. 1) first exceeded 2,000 mt in 1967 and increased to nearly 18,000 mt in 1976 (Table 1). With the implementation of the MFCMA in 1976, directed foreign fishing for sablefish was eliminated off the WOC coast in 1977.

U.S. landings have increased sporadically from 7,500 mt in 1977 to 14,000 mt in 1984 (McDevitt, in prep.). Sablefish landings soared to 24,000 mt[1/] in 1979 due to record ex-vessel prices and a large influx of troll salmon vessels into the fishery [Pacific Fishery Management Council (PFMC), 1982]. Landings declined to 8,000 mt in 1980 because of depressed prices but have averaged 14,000 mt the past four

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1/ McDevitt (in prep.) has compiled the best available landing statistics after reviewing all data sources. Her revised landings are similar to landings reported by the Pacific Fishery Management Council (1984a) except for 1979, where the landings reported by PFMC were 18,944 mt.

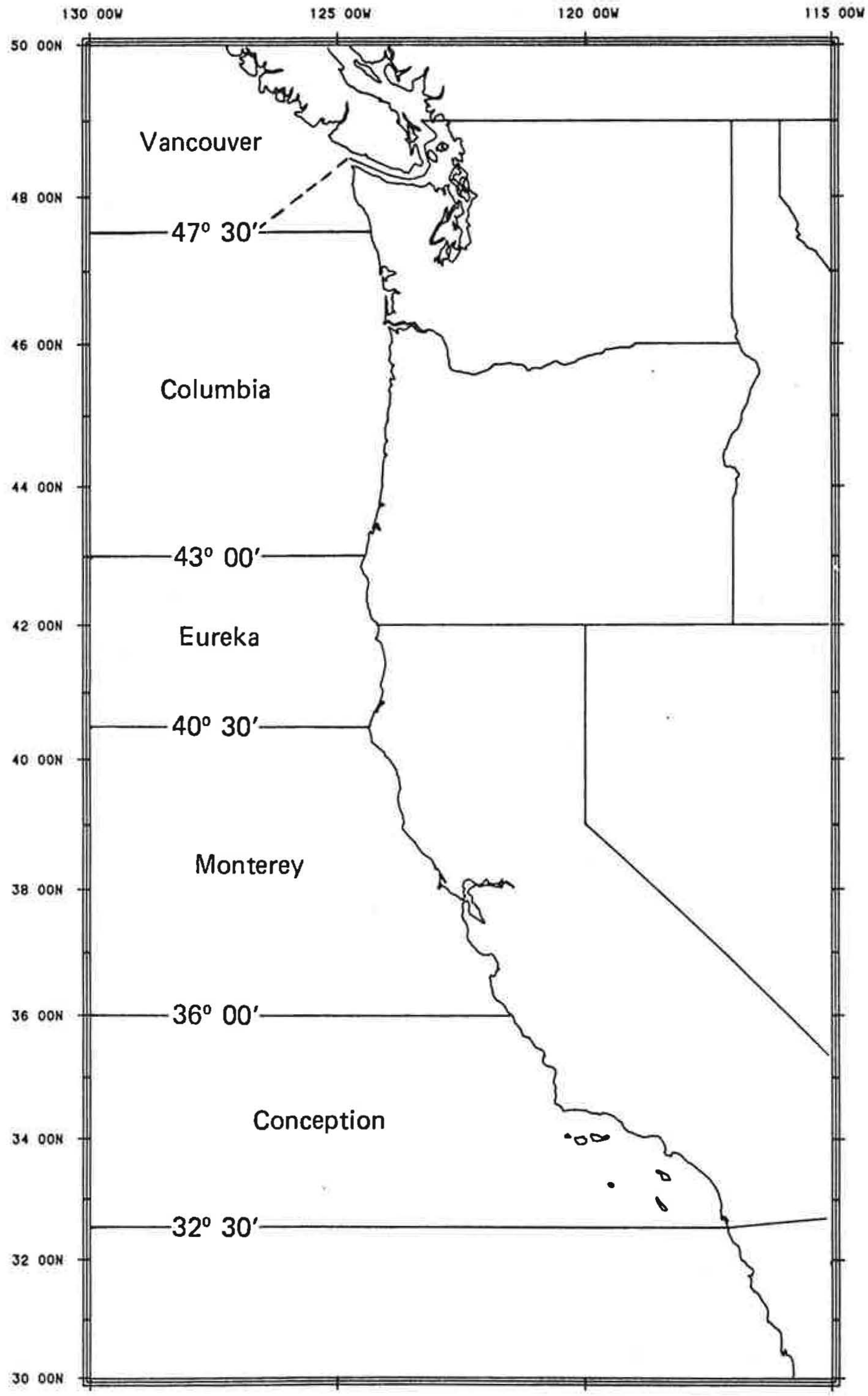


Fig. 1.--International North Pacific Fisheries Commission (INPFC) areas for the Washington-Oregon-California coast; dashed line divides U.S. and Canadian portions of the Vancouver area.

Table 1.--United States, foreign and all nation catch of sablefish (mt) from the Vancouver-Conception INPFC area, 1956-84.

Year	U.S.	Foreign[a]	All Nation
1956	3,283	79	3,363
1957	2,562	165	2,727
1958	1,573	191	1,764
1959	2,566	198	2,765
1960	3,348	258	3,606
1961	2,418	286	2,704
1962	3,017	237	3,254
1963	2,171	85	2,257
1964	2,183	152	2,335
1965	2,129	123	2,252
1966	1,848	238	2,086
1967	1,187	2,308	3,495
1968	1,138	1,133	2,271
1969	1,600	3,263	4,863
1970	1,708	2,343	4,051
1971	2,475	1,822	4,297
1972	4,178	3,243	7,421
1973	4,759	1,363	6,122
1974	6,231	2,685	8,916
1975	7,808	6,958	14,766
1976	7,230	17,594	24,824
1977	7,528	2,197	9,725
1978	11,341	1,216	12,557
1979	23,568	1,410	24,977
1980	8,007	2,340	10,347
1981	11,429	1,467	12,896
1982	18,588	1,327	19,914
1983	14,138	1,309	15,447
1984	13,550	2,336	15,886

[a] Prior to 1977, foreign catches are not partioned by nation. After 1977, foreign catches strictly represent Canadian landings from the Canadian Vancouver INPFC area.

Source: McDevitt (in prep.)

years. Norris (1984) attributes the general increase in WOC landings to the introduction of traps and improved markets for small trawl-caught sablefish; annual fluctuations arise from changes in the Japanese market, which largely controls the ex-vessel prices offered to U.S. fishermen.

Each gear type is characterized by different species compositions, size selectivities, ex-vessel prices and landing rates. This chapter represents a first attempt at describing these characteristics by gear, the objective being to obtain a better understanding of the multi-gear and multi-species interactions inherent in the WOC fishery. Since the Vancouver-Columbia area exhibits the greatest diversity in gears, the analysis is confined to this area.

Fisheries management

Management of the WOC sablefish fishery is complex because of the multi-gear, multi-species nature of the fishery, limited understanding of sablefish biology, suspect ageing methods, and a lack of reliable catch-per-unit-effort (CPUE) statistics. Estimates of MSY range from 7,000 mt (Low et al., 1976) to 20,000 mt (Hardwick, 1983)--a three-fold difference that reflects the uncertainty of biologists. These two estimates undoubtedly represent extreme differences in stock abundance and productivity.

Stauffer and McDevitt (in prep.) believe current catch rates off the WOC coast are excessive compared to more northern areas (e.g., Gulf of Alaska) and such catch rates are unlikely to be sustainable in the long-term. Based upon the work of Stauffer and McDevitt, Francis

(1984) derived a MSY range of 6,183-12,347 mt. The midpoint of this interval is 9,265 mt, and landings have exceeded this value in six of the past seven years.

The current management regime off the WOC coast consists of an OY quota, trip limits, a minimum size limit and mesh size regulations. The 1985 OY for sablefish is 13,600 mt coastwide, which is above the range of MSY values and nearly equal to the average 1977-84 landings of 13,500 mt. The PFMC has set OY above the levels recommended by biologists to accomodate the fishing industry (i.e., social and economic concerns).

For the purposes of reducing sablefish discards and allowing other groundfish trawl fisheries to continue (e.g., Dover sole, Microstomus pacificus), trip limits are implemented whenever 90% of the OY is caught (PFMC, 1984b). When 90% of the OY has been landed, fixed gears (i.e., traps, longlines and set-nets) and trawls are each allocated 5% of the remaining OY so that resources are equitably allocated.

A minimum size limit of 22 in. total length (52.4 cm fork length) with an incidental catch allowance of 5,000 lbs (2.3 mt) undersized sablefish per trip was implemented in 1983. The size limit applies to grounds north of Point Conception (excluding Monterey Bay). The size limit was intended to minimize targeting on small sablefish and was expected to impact the trawl fishery more than the fixed gear fisheries (PFMC, 1984b).

Mesh size regulations exist for trawl and set-net gears. Flatfish bottom trawls must have a minimum mesh size of 4.5 in. (114 mm) stretched measure between knots. Roller trawls, which are used to target on rockfish and sablefish, must have mesh sizes of 3.0 in. (76 mm) or greater. The set-net fishery is an experimental fishery by permit only: commercial mesh sizes must measure at least 5-7/8 in. (149 mm) and experimental mesh sizes of 5.5 in. (140 mm) or less must also be fished.

Fishery Description

The bathymetric and seasonal distributions of groundfish in general and sablefish in particular govern the times and areas of sablefish captures. Juvenile sablefish generally inhabit inshore and surface waters and are unavailable to commercial fishing gear. Alverson (1960) found that adult sablefish have an extensive bathymetric range from 50-1000 m. In the summer, sablefish are dispersed over both the continental shelf and slope, but sablefish are exclusively confined to slope waters (>200 m) during the winter (Phillips, 1954; Alverson, 1960).

The exploitable sablefish biomass is principally confined to the 150-800 m depth range (Low et al., 1976; Sasaki, 1985), and this is where the fisheries occur. Norris (1985) classified the major gear types as follows: directed trap, winter trawl, summer trawl, and summer longline and set-net fisheries. Seasonal availability of sablefish and smaller vessel sizes limit the directed longline and set-net fisheries to summer operations and depths shallower than 500 m. The directed trap fishery operates year-round at depths of 400 m and greater. The winter trawl fishery uses bottom trawls to target upon flatfish;

sablefish are primarily caught incidentally. Sablefish are captured both as a target species and incidentally to rockfish and sole in the summer trawl fishery. The trawl fleet operates at depths exceeding 400 m in the winter but generally less than 400 m in the summer.

Off the WOC coast, the mix of gear varies by INPFC area (Fig. 2). For the Vancouver-Columbia area, trawl and fixed gears are equally represented in the landings. Trawl landings predominate in the Eureka-Monterey area and trap landings in the Conception area. All four gears harvest significant amounts of sablefish in the Vancouver-Columbia area.

Materials and Methods

Two sources of landing data were used to describe the WOC sablefish fishery: Washington Department of Fisheries (WDF) fish ticket records and the Pacific Fisheries Information Network (PacFIN). PacFIN reports are published by INPFC area according to the area of landing. The WDF landing statistics reported here are solely for fish that were caught and landed off Washington state. Both data sources compile landings of fish--actual catches would be greater than the landings since unknown quantities of fish are discarded.

Species selectivity was examined by comparing the landing compositions of each gear type from the U.S. Vancouver INPFC area. The percentage of the landings that was sablefish indicates the selectivity of each gear towards sablefish. Since the landings are from the

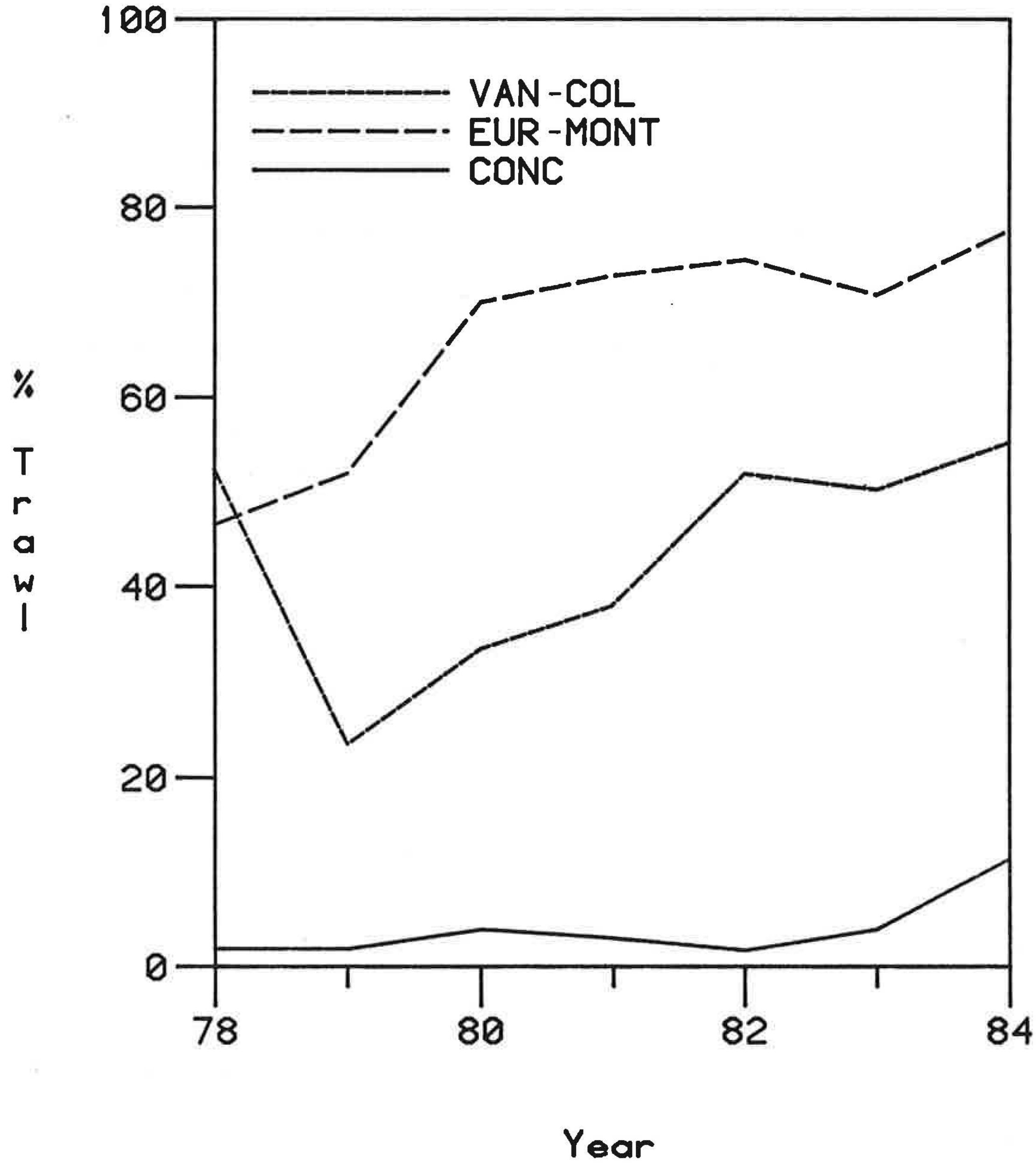


Figure 2.--Percentage of sablefish caught by trawl for the U.S. Vancouver-Columbia, Eureka-Monterey and Conception INPFC areas, 1978-84.

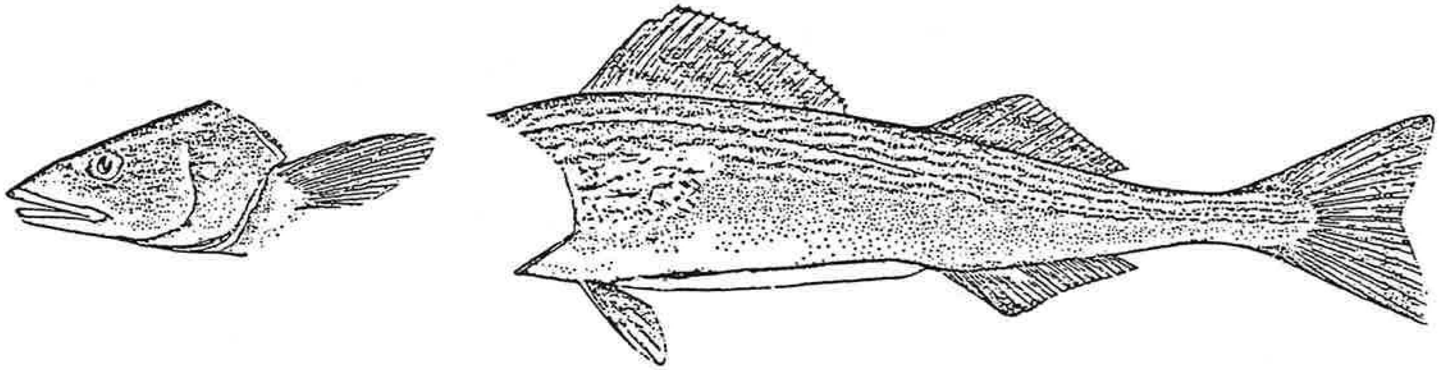
Source: McDevitt (in prep.)

commercial fisheries, selectivity is also influenced by market conditions, particularly for the multi-species trawl fishery.

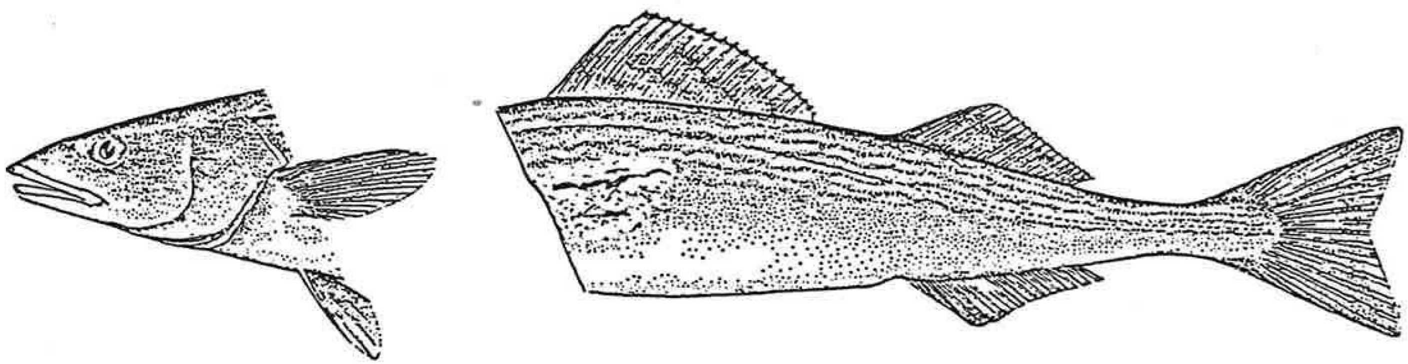
Sablefish catch and effort trends were examined by compiling the number of vessels and landings, by gear type, for the years 1976-84. Since only one set-net vessel fished from 1980-82, set-net landings were not reported for these years. The fleet was further examined by determining the number of vessels landing over 20 mt sablefish per year for each gear type, then describing these vessels in terms of vessel length, gross tonnage and net tonnage.

Sablefish CPUE of each gear type was calculated in terms of the landings per vessel and the landings per trip (i.e., landing rate). Since the number of days fished per trip varies by gear type and vessel size, it would be desirable to use days or hours fished as the unit of effort, but such data are either unavailable or unreliable.

The size composition of sablefish was calculated for each gear type. On WDF fish tickets, sablefish landings are graded into the following size categories (round weight): large, over 7 lbs (3.2 kg); medium, 5-7 lbs (2.3-3.2 kg); and small, under 5 lbs (2.3 kg). Dressed fish, whether eastern or western-cut (Fig. 3), are similarly graded with medium-sized sablefish weighing 3-5 lbs (1.4-2.3 kg) dressed. Since the pectoral girdle is removed in the eastern cut, a medium western-dressed sablefish could be graded as small when eastern-dressed. WDF converts dressed weights to round weights by multiplying the dressed weight by 1.75, regardless of how the fish is dressed. The



Western-dressed: Pectoral girdle on; belly open.



Eastern-dressed: Pectoral girdle off; belly closed.

Fig 3.--Western and eastern cuts for sablefish.

weights reported here equal the round weight landed plus the dressed landings multiplied by 1.75.

Ex-vessel prices were also acquired from WDF fish tickets, based upon the dealers' reported values. Average ex-vessel prices were calculated by summing the landed ex-vessel values of round and dressed fish for all size categories, and then dividing the total value by the total landings (round landings plus dressed landings converted to round weight).

Results

Species Selectivity

Different species are selected by the various gears. Within the U.S. Vancouver INPFC area, traps were the most selective gear for sablefish, followed by longline, set-net and trawl gear (Table 2). Over the past four years, trap-caught groundfish landings have exceeded 98% sablefish in each year. Coastwide, trap landings were 99% sablefish in 1984.

Longline groundfish landings ranged from 68-77% sablefish during 1981-84 in the U.S. Vancouver area. Sablefish composition in set-nets increased from 34% in 1981 to 65% in 1984 due to increased targeting upon sablefish and the greater depths fished. The major incidental species landed by longline and set-net gear were lingcod (*Ophiodon elongatus*) and rockfish (*Sebastes* spp.).

Sablefish composition from trawl landings has increased four-fold from 4% in 1981 to 16% in 1984. Rockfish and flatfish have comprised

Table 2.--Percentage of sablefish from each gear type as a fraction of each gear's landed groundfish catch from the U.S. Vancouver INPFC area, 1981-84.

Year	Trawl	Trap	Longline	Set-net
1981	4.1	98.8	76.5	34.1
1982	8.6	99.9	67.7	43.5
1983	8.8	99.9	74.4	49.5
1984	16.3	98.4	77.3	64.8

Source: PacFIN Rept. #124, June 25, 1985.

over 68% of the landed trawl catch during the past four years, but the relative importance of these two species groups has reversed. From 1981-84, flatfish composition has increased from 24 to 42%, whereas the rockfish composition has decreased from 54 to 27%.

Sablefish Landings and Fleet Composition

From 1976-79, fishing effort (measured by number of vessels landing sablefish) increased almost three-fold and sablefish landings increased over five-fold off the Washington coast (Table 3). In 1980, landings decreased 50% from 1979 levels due to greatly reduced ex-vessel prices. Sablefish landings in 1981 were nearly equal to the 1979 landings but with half the vessels. The number of vessels was relatively stable for all gears from 1982-84, but landings doubled for all gear types except traps over this three year period.

The fleet composition off the Washington coast changed rapidly over 1976-84. Three different gear types dominated the sablefish landings within a six year period (Fig. 4): longline landings comprised most of the catch in 1979, trap landings predominated in 1981, and most of the sablefish landings were caught by trawl in 1984.

Throughout the period 1976-84, a small proportion of the fleet has made the bulk of the sablefish landings. From 1976-81, less than 23% of the fleet landed over 59% of the sablefish catch (Table 3); less than 30% of the vessels landed over 89% of the catch from 1982-84. Approximately 40 vessels have landed 90% of the Washington sablefish catch during the past three years.

Table 3.--Number of vessels, landings, and fleet composition of trawl, trap, longline and set-net vessels operating off the Washington coast, 1976-84.

				Vessels landing more than 20 mt		
Year	Gear	No. Vessels	Sablefish landings (mt)	No.	% of Vessels	% of Landings
1976	Trawl	38	228.8	4	10.5	56.6
	Trap	8	117.5	2	25.0	85.7
	Longline	25	183.1	2	8.0	66.6
		71	529.4	8	11.3	66.5
1977	Trawl	48	400.8	7	14.6	66.1
	Trap	9	358.1	3	33.3	96.5
	Longline	22	292.3	3	13.6	83.9
		79	1051.2	13	16.5	81.4
1978	Trawl	78	635.6	11	14.1	72.7
	Trap	21	486.5	9	42.9	90.5
	Longline	42	603.3	4	9.5	78.6
		141	1725.4	24	17.0	79.8
1979	Trawl	95	741.4	11	11.6	54.0
	Trap	22	416.8	2	9.1	69.2
	Longline	80	1534.5	21	26.3	78.7
		197	2692.7	34	17.3	70.4
1980	Trawl	69	402.4	5	7.2	52.6
	Trap	9	386.6	3	33.3	89.8
	Longline	40	538.1	7	17.5	42.9
	Set-net	1		1	100.0	100.0
		119	1327.1	16	13.4	59.5
1981	Trawl	55	568.2	9	16.4	47.3
	Trap	6	1277.4	5	83.3	99.2
	Longline	28	503.9	5	17.9	76.8
	Set-net	1		1	100.0	100.0
		90	2349.5	20	22.2	81.9
1982	Trawl	76	1681.8	20	26.3	89.5
	Trap	11	1616.4	6	54.5	97.1
	Longline	36	417.7	10	27.8	85.1
	Set-net	1		1	100.0	100.0
		124	3715.9	37	29.8	92.3
1983	Trawl	71	1285.4	18	25.4	88.5
	Trap	10	1471.9	8	80.0	97.7
	Longline	31	354.9	5	16.1	67.1
	Set-net	2	178.3	2	100.0	100.0
		114	3290.5	33	28.9	91.0
1984	Trawl	81	2200.0	27	33.3	89.0
	Trap	11	923.5	3	27.3	94.1
	Longline	49	771.5	8	16.3	81.0
	Set-net	3	376.6	3	100.0	100.0
		144	4271.6	41	28.5	89.6

Source: Washington Department of Fisheries/fish ticket records

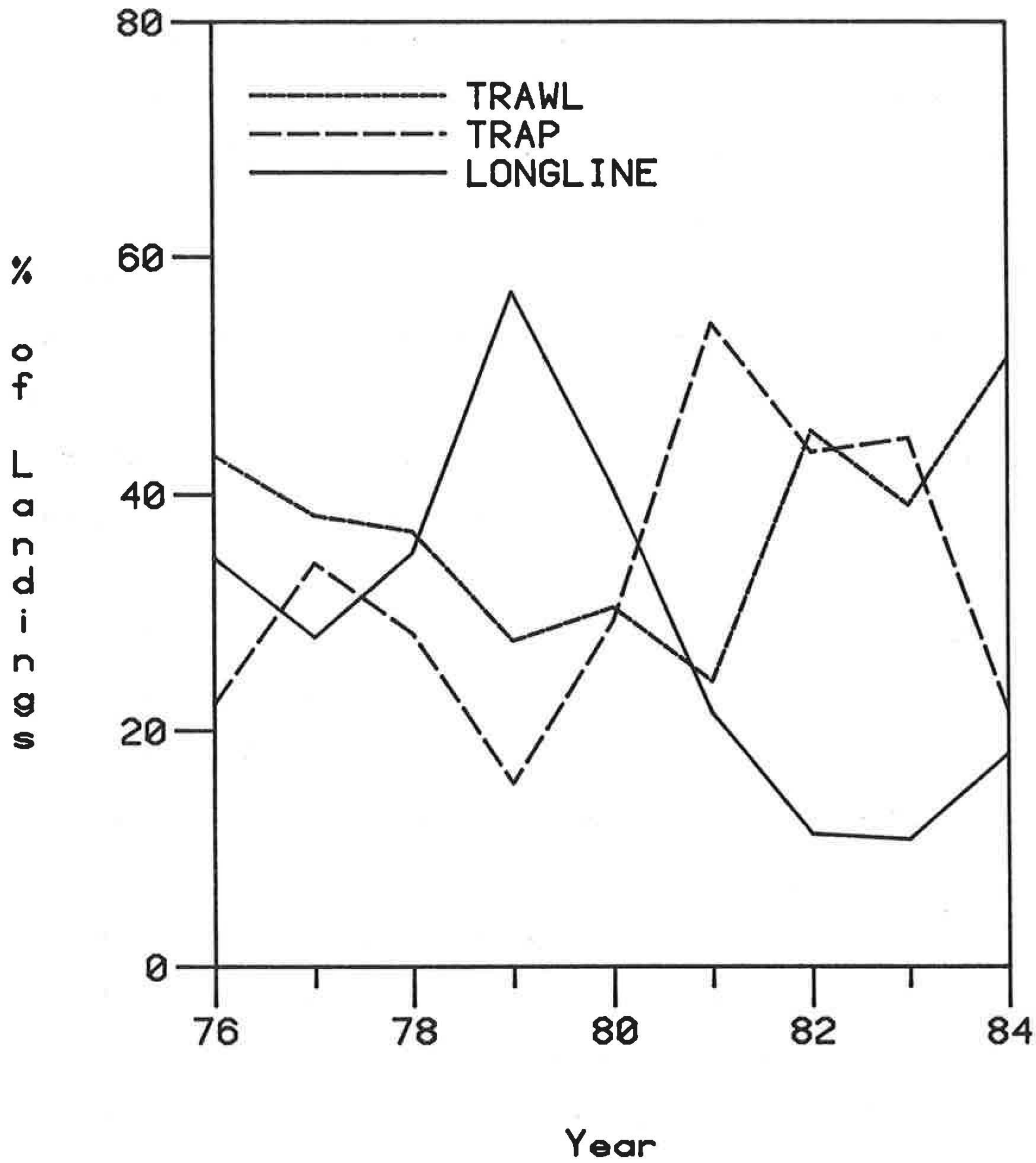


Fig. 4.--Percentage of Washington sablefish landings by trawl, trap and longline vessels, 1976-84.

Source: Washington Department of Fisheries/fish ticket records

The percentage of vessels landing over 20 mt of sablefish has constantly increased from 11% in 1976 to 29% in 1984, reflecting either greater CPUE, better targeting performance or improved markets. Set-net vessels have always landed at least 20 mt. Over 50% of trap vessels have landed over 20 mt three of the past four years, but less than one-third of the trawl or longline vessels have landed over 20 mt of sablefish during 1976-84.

For vessels landing over 20 mt of sablefish in Washington state during 1984, trap and trawl vessels were the largest (Table 4). Trap and trawl vessels averaged over 100 gross tons, whereas longline and set-net vessels averaged less than 50 gross tons. In terms of net tonnage, the majority of trap and trawl vessels were over 40 t, but most longline and set-net vessels were under 40 t.

Landing Rates

During 1983-84, the majority of Washington sablefish landings were made by trawlers, both in terms of the number of landings and tonnage landed (Table 5). Trawl landings (mt) and the number of trawl landings nearly doubled during 1983-84.

In terms of sablefish tonnage landed per trip, vessels fishing traps landed 7.9 mt per trip in 1983, compared to 4.5 mt/trip for set-nets and 2.2 mt/trip for trawl and longline vessels. Landing rates increased for all four gear types in 1984; longliners nearly doubled their sablefish tonnage per trip. The landing rate of all vessels combined, however, actually decreased from 3.4 to 3.2 mt/trip because

Table 4.--Vessel characteristics of vessels landing more than 20 mt sablefish in Washington state during 1984.

Gear	Vessel length (m)			Gross tonnage (t)			Net tonnage (t)		
	Mean	Range	25% & 75% Quartiles	Mean	Range	25% & 75% Quartiles	Mean	Range	25% & 75% Quartiles
Trawl	21.8	15-28	20-24	105.1	38-213	71-136	66.0	19-110	44-93
Trap	23.4	15-28	15-28	113.3	41-155	41-155	82.7	31-112	31-112
Longline	17.4	10-21	15-20	45.0	12-66	37-61	30.2	8-46	24-41
Set-net	14.5	13-16	13-16	31.7	21-50	21-50	19.0	11-30	11-30

Source: Washington Department of Fisheries

Table 5.--Sablefish landings, fishing effort, and catch/effort by gear type for the Washington coast, 1983-84.

Year	Gear	No. Vessels	No. Landings	Sablefish Landings (mt)	Sablefish Catch/Effort mt/vessel	Sablefish Catch/Effort mt/landing
1983	Trawl	71	592	1285.4	18.1	2.2
	Trap	10	187	1471.9	147.2	7.9
	Longline	31	162	354.9	11.4	2.2
	Set-net	2	40	178.3	89.1	4.5
		114	981	3290.5	28.9	3.4
1984	Trawl	81	953	2200.0	27.2	2.3
	Trap	11	108	923.5	84.0	8.5
	Longline	49	197	771.5	15.7	3.9
	Set-net	3	64	376.6	125.5	5.9
		144	1322	4271.6	29.7	3.2

Source: Washington Department of Fisheries/fish ticket records

the 1984 landings were weighted more heavily towards trawlers rather than trap vessels.

Size Composition and Ex-vessel Prices

Based upon the graded landings of sablefish recorded on WDF fish tickets, set-nets harvested the largest sablefish from 1980-84 (Table 6). Nearly two-thirds of the set-net and longline landings were graded large (over 7 lbs round weight) in 1984. Trap landings were divided evenly between the three size categories. The majority of trawl-caught sablefish was under 5 lbs--73% smalls in 1984.

For trap, longline and set-net gears, round ex-vessel prices were roughly equivalent for all three size categories in 1984 (Table 7). The ex-vessel price for large round sablefish averaged $0.47/lb ($1.04/kg) for these three gears, whereas trawlers only received $0.19/lb ($0.42/kg) for large sablefish. Longliners received the highest prices for dressed sablefish, followed by set-net, trap and trawl gear. In 1984, 81% of the longline catch was dressed; other gear types delivered less than 6% of their catch dressed (WDF/fish ticket records).

Accounting for the size composition of the landings and standardizing dressed weights to round weights, the average price per pound was as follows: trawl, $0.16/lb; trap, $0.28/lb; longline, $0.49/lb; and set-net, $0.41/lb. Longliners received over three times as much per pound as trawlers. The average prices for all gear types combined was $0.26/lb ($0.57/kg). Large sablefish averaged $0.39/lb ($0.86/kg), mediums $0.28/lb ($0.62/kg) and smalls $0.15/lb ($0.34/kg).

Table 6.--Washington sablefish landings (mt) by gear type and size category, 1980-84 (graded landings only).

Year	Size	Trawl mt	Trawl %	Trap mt	Trap %	Longline mt	Longline %	Set-net mt	Set-net %	Total mt	Total %
1980	large	137	35	130	37	446	83		91		57
	medium	49	12	99	28	37	7		0		14
	small	203	52	121	35	54	10		9		29
	total	389	100	350	100	538	100		100		100
1981	large	133	24	589	47	356	78		96		48
	medium	14	3	286	23	52	11		1		15
	small	415	74	367	30	48	10		3		36
	total	562	100	1241	100	456	100		100		100
1982	large	121	8	599	37	225	54		75		28
	medium	156	10	356	22	85	20		6		16
	small	1318	83	662	41	104	25		19		56
	total	1594	100	1616	100	413	100		100		100
1983	large	99	8	518	35	221	62	116	70	954	30
	medium	93	8	422	29	76	21	2	1	594	19
	small	987	84	532	36	58	16	48	29	1625	51
	total	1179	100	1472	100	355	100	166	100	3172	100
1984	large	541	25	275	29	456	63	57	64	1329	34
	medium	35	2	325	34	131	18	26	29	517	13
	small	1579	73	362	38	141	19	6	7	2088	53
	total	2154	100	962	100	729	100	89	100	3935	100

Source: Washington Department of Fisheries/fish ticket records

Table 7.--Average ex-vessel prices received for sablefish in the state of Washington during 1984.

			Average Ex-vessel Price ($/lb.)			
Product	Size	Category	Trawl	Trap	Longline	Set-Net
Round	Large	(>7 lb.)	.19	.47	.49	.46
	Medium	(5-7 lb.)	.16	.26	.29	.28
	Small	(<5 lb.)	.14	.15	.16	.20
Dressed[a]	Large	(>7 lb.)	.52	.57	.89	.85
	Medium	(5-7 lb.)	.33	.38	.57	.46
	Small	(<3 lb.)	.24	.36	.49	.42

[a]No distinction made between western and eastern-dressed sablefish on Washington Department of Fisheries fish tickets.

Source: Washington Department of Fisheries/fish ticket records

Discussion

The Washington sablefish fishery can be characterized as an expanding fishery: landings have increased from 500 mt in 1976 to 4300 mt in 1984. Most of this growth occurred during 1976-82. Washington sablefish landings have been fairly constant from 1982-84 and landings have actually decreased coastwide during this period.

Another characteristic of the Washington sablefish fishery is tremendous fluctuation in the gear mix--trawl, trap and longline gears have each predominated in the landings during the past five years. These fluctuations are believed to be responses to sablefish fisheries elsewhere (e.g., Gulf of Alaska), regulations within the rockfish, salmon and halibut fisheries, gear innovations, market conditions, and the abundance of small fish. Predicting even short-term changes for this complex fishery would be a difficult task.

The four gear types operating off the Washington coast are characterized by different species and size selectivities, gear efficiencies, and ex-vessel price structures. Although trawls are very effective for harvesting groundfish, particularly rockfish and flatfish, trawl gear appears to be the least desirable gear for harvesting sablefish--trawlers capture the smallest-sized fish, receive the lowest prices and trawls are the least selective gear for sablefish.

The remaining three gear types have distinct advantages and disadvantages. Traps are the most selective gear for sablefish and have the highest landing rates, but capture smaller fish than longlines or set-nets. Set-nets are an effective gear, harvesting the largest-sized sablefish, but landings have been less than 50% sablefish in three of the past four years. Longlines are fairly selective for sablefish, receive the highest prices per pound and capture primarily large fish.

Increased restrictions on Sebastes spp. have caused trawlers to target more upon sablefish and flatfish in recent years. From 1981-84, the percentage of sablefish in trawl landings has doubled in the U.S. Vancouver area and trawl landings of small sablefish have increased from 400 to 1,600 mt off the Washington coast (Table 6). Since the ex-vessel price of trawl-caught sablefish is only 33-57 percent that of other gears, this suggests that sablefish resources might be more efficiently utilized by curtailing trawl captures of small sablefish. Information on trawl discards and a breakdown of the size composition by gear (roller versus bottom trawl) would be required to fully assess the validity of this claim.

Reliable CPUE statistics are unavailable for the WOC sablefish fishery. Since only 40 vessels contributed 90% of the landings off the Washington coast, it is recommended that the logbooks of these highline vessels be analyzed to construct a CPUE series. Effort could be quantified in days or even hours fished (rather than trips), which would yield more reliable CPUE statistics and greatly improve our knowledge of stock conditions.

Chapter 3

Length-Weight-Girth Relations

Useful information can be derived from length-weight and length-girth relations, but these relations have not been published for sablefish inhabiting grounds off the Washington coast. In this chapter, length-weight and length-girth relations are derived from trap and set-net samples collected off the Washington coast. From these relations, a length-weight table is constructed and the relationship between mesh size and minimum retention length is determined.

Materials and Methods

Fork length was measured from the snout to the fork of the caudal fin. Length, weight and sex were determined for seventy-six sablefish from set-nets during the summer of 1984.[2/] Since set-nets primarily harvest large sablefish, length-weight relations were also derived from the 1981 National Marine Fisheries Service (NMFS) trap survey, which included 837 sexed sablefish. The trap sample was collected along the entire Washington coast, whereas the set-net sample was confined to the U.S. Vancouver INPFC area.

Length-girth samples were collected during the summer of 1984 from commercial set-net and trap vessels fishing the U.S. Vancouver area. Maximum body girth was measured with a girthometer, described by Hunter

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[2/] Additional samples were lost when a set-net vessel sank.

and Wheeler (1972), and usually occurred at the insertion of the pelvic fins. Constricted girths were measured with a force of approximately 2 kg. Sample sizes were 89 and 623 for the set-net and trap samples, respectively. Sex was determined for the set-net sample but not the commercial trap sample.

Separate regression lines of males versus females or trap versus set-net samples were tested for coincidence to determine whether sexes or gear types could be pooled. The multiple regression model

$$Y = B_0 + B_1X + B_2Z + B_3XZ + e$$

was used (Kleinbaum and Kupper, 1978), where Z is a dummy variable for sex or gear type. Separate regression equations are incorporated into the model:

$$Z = 0 \qquad Y_a = B_0 + B_1X + e \qquad \text{for a}$$

$$Z = 1 \qquad Y_b = (B_0 + B_2) + (B_1 + B_3)\, X + e \qquad \text{for b}$$

where a and b denote the sexes or gear types. The null hypothesis, H_0: $B_2 = B_3 = 0$, is the test for coincidence. The null hypothesis is rejected if $F > F_{2,n-3,1-\alpha}$, where n is the sample size and $\alpha = 5\%$.

For the length-weight relation, the natural logarithm (ln) of weight was regressed against ln length. A simple linear regression of girth against length was used for the length-girth relation. Because variability is inherent in both the dependent and independent variables, functional regression equations were derived for the final length-weight and length-girth relations (Ricker, 1973).

A length-weight table was constructed from the length-weight relation for round, western and eastern-dressed sablefish. Dressed recovery ratios of 0.691 and 0.567 were obtained for western and eastern-cut sablefish aboard set-net vessels, so these ratios were used to convert round to dressed weights.

The circumference of a mesh is equivalent to twice the stretched mesh size; therefore fish with maximum girths less than two times the mesh size should not be retained by the mesh. However, fish with girths smaller than the mesh size can become entangled in the meshes or, in the case of trawls, their passage through the meshes can be blocked by other fish. From the length-girth and length-weight relations, minimum retention lengths and weights were calculated for mesh sizes ranging from 76-165 m (3.5-6.5 in.).

Results and Discussion

Length-Weight Relation

The size of sablefish and the sex ratio differed among gears. Mean lengths were significantly larger for the set-net caught sablefish; 70.3 cm versus 54.6 cm in the trap sample. The 25% and 75% length quartiles were 67-73 cm for the set-net sample and 51-57 cm for the trap sample. Sex ratios were 51.3% female from set-nets and 42.5% female from traps.

The multiple regression model of ln weight (W) on ln length (L) did not differ significantly by sex (S). For the set-net sample ($n = 76$),

$$\ln W = -11.23 + 2.97 \ln L - 0.07\, S + 0.01\, (S \times \ln L) \qquad (r^2 = .92)$$

and for traps ($n = 623$),

$$\ln W = -11.94 + 3.10 \ln L - 0.27 S + 0.07 (S \times \ln L) \qquad (r^2 = .92)$$

Tests for coincidence yielded $F = 1.24$ ($P>0.25$) and $F = 0.95$ ($P>0.25$) for set-net and trap samples, respectively. Thus the lines are coincident for both samples and we can conclude that the length-weight equations are not significantly different for males and females at the 5% level.

Since the length-weight relation did not differ by sex for either the set-net or trap samples, I pooled the two samples. The multiple regression by gear type (T) was as follows:

$$\ln W = -12.06 + 3.13 \ln L + 1.05 T - 0.22 (T \times \ln L) \qquad (r^2 = .95)$$

However, the two lines were not coincident ($F = 41.29$, $P<0.001$) at the 5% level of significance.

Upon calculation of the functional regression coefficients and taking the exponential of both sides of the equation, the resulting relations were

$$W = (1.65 \times 10^{-5})L^{2.92} \qquad \text{for set-nets}$$

and $W = (5.79 \times 10^{-6})L^{3.13}$ for traps.

Over the length range of the samples (43-98 cm), predicted weights differed by less than 0.5 kg (4-18%) between the two gears. Differences were small because of the correlation between the slopes and intercepts: the set-net sample had a higher intercept value but smaller slope than the trap sample.

Although the regression lines were significantly different between the two gears, the two samples were pooled for two reasons:

1) I wanted the length-weight relation to be applicable over a

broad range of lengths. Recall 50% of the length measurements spanned 51-57 cm from traps and 67-73 cm in set-nets.

2) Predicted weights were similar between trap and set-net samples.

To give roughly equivalent weights to each sample, 76 length-weight observations were randomly selected from the trap sample, then pooled with the set-net observations. The functional relations resulting from the pooled sample of 152 sablefish were

$$\ln W = -13.1671 + 3.4184 \ln L \qquad (r^2 = 0.97)$$

$$W = (1.9126 \times 10^{-6})L^{3.4184}$$

The pooled length-weight curve followed the randomly selected trap sample for sablefish less than 60 cm and the set-net curve thereafter (Fig. 5).

Length-Weight Table

A length-weight table was derived for round, western and eastern-dressed sablefish from the pooled length-weight relation (Table 8). Round sablefish would be graded small (<5 lbs or 2.3 kg) when less than 60 cm, medium (5-7 lbs or 2.3-3.2 kg) when 60-66 cm, and large (>7 lbs or 3.2 kg) when over 66 cm.

Medium-sized sablefish would be 58-66 cm for western-dressed and 61-70 cm for eastern-dressed fish. Thus large sablefish are greater than 67 cm when graded as round or western-dressed, but for the eastern cut, sablefish would only be graded large when exceeding 70 cm in length.

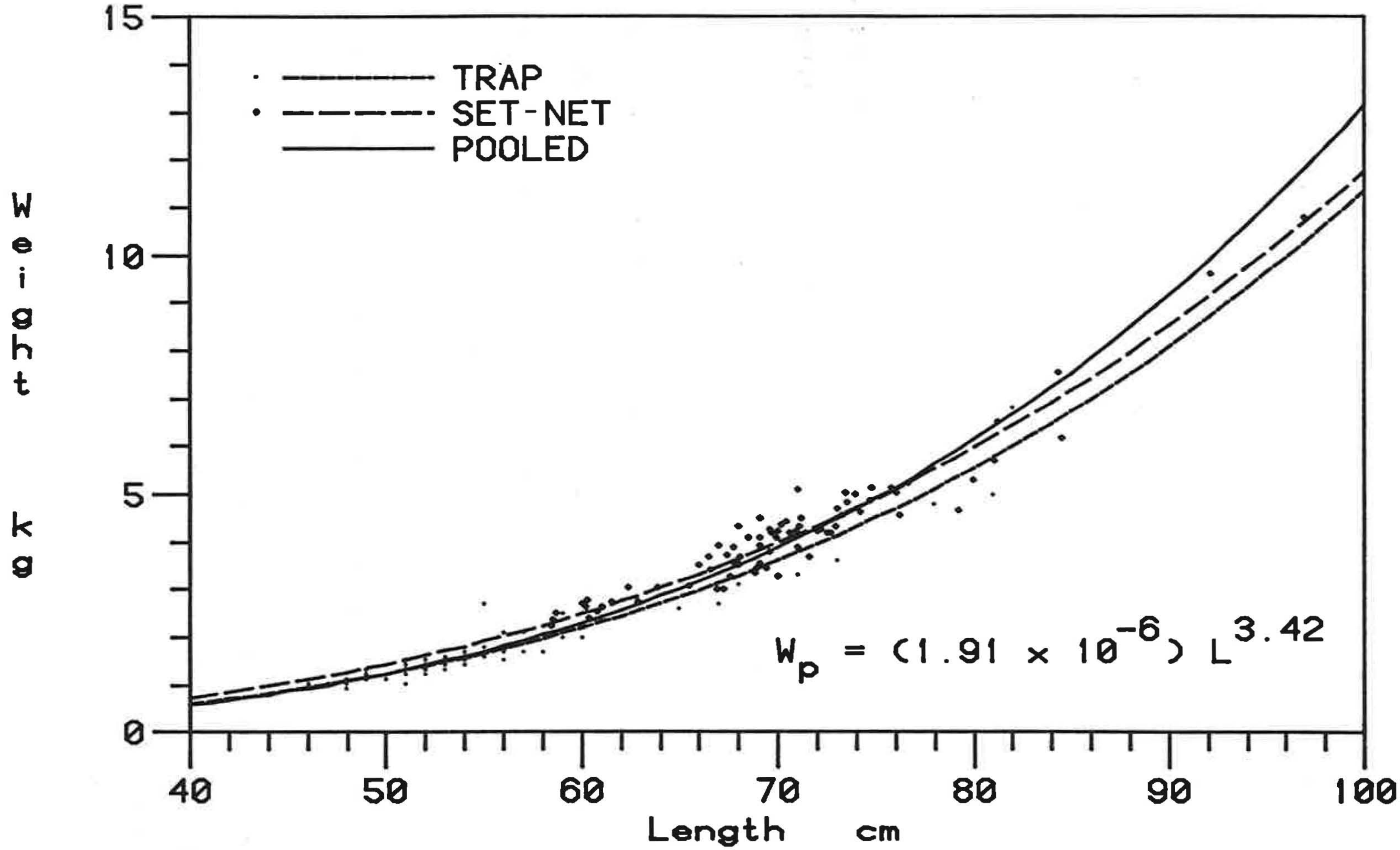

Fig 5.--Sablefish length-weight relations for trap, set-net and pooled samples collected off the Washington coast.

Table 8.--Length-weight table for round, western and eastern-dressed sablefish from the Washington coast.

Length	Weight					
	Round		Western-dressed		Eastern-dressed	
(cm)	(kg)	(lbs)	(kg)	(lbs)	(kg)	(lbs)
40	0.57	1.26	0.40	0.87	0.32	0.72
41	0.62	1.37	0.43	0.95	0.35	0.78
42	0.68	1.49	0.47	1.03	0.38	0.85
43	0.73	1.62	0.51	1.12	0.42	0.92
44	0.79	1.75	0.55	1.21	0.45	0.99
45	0.86	1.89	0.59	1.31	0.49	1.07
46	0.92	2.04	0.64	1.41	0.52	1.15
47	0.99	2.19	0.69	1.51	0.56	1.24
48	1.07	2.36	0.74	1.63	0.61	1.34
49	1.15	2.53	0.79	1.75	0.65	1.43
50	1.23	2.71	0.85	1.87	0.70	1.54
51	1.31	2.90	0.91	2.00	0.75	1.64
52	1.40	3.10	0.97	2.14	0.80	1.76
53	1.50	3.30	1.04	2.28	0.85	1.87
54	1.60	3.52	1.10	2.43	0.91	2.00
55	1.70	3.75	1.18	2.59	0.96	2.13
56	1.81	3.99	1.25	2.76	1.03	2.26
57	1.92	4.24	1.33	2.93	1.09	2.40
58	2.04	4.50	1.41	3.11	1.16	2.55
59	2.16	4.77	1.49	3.29	1.23	2.70
60	2.29	5.05	1.58	3.49	1.30	2.86
61	2.42	5.34	1.67	3.69	1.37	3.03
62	2.56	5.65	1.77	3.90	1.45	3.20
63	2.71	5.97	1.87	4.12	1.53	3.38
64	2.86	6.30	1.97	4.35	1.62	3.57
65	3.01	6.64	2.08	4.59	1.71	3.76
66	3.17	7.00	2.19	4.83	1.80	3.97
67	3.34	7.36	2.31	5.09	1.89	4.18
68	3.51	7.75	2.43	5.35	1.99	4.39
69	3.69	8.14	2.55	5.63	2.09	4.62
70	3.88	8.55	2.68	5.91	2.20	4.85
71	4.07	8.98	2.81	6.20	2.31	5.09
72	4.27	9.42	2.95	6.51	2.42	5.34
73	4.48	9.87	3.09	6.82	2.54	5.60
74	4.69	10.34	3.24	7.15	2.66	5.86
75	4.91	10.83	3.39	7.48	2.79	6.14
76	5.14	11.33	3.55	7.83	2.91	6.42
77	5.37	11.85	3.71	8.19	3.05	6.72
78	5.62	12.38	3.88	8.56	3.18	7.02
79	5.87	12.93	4.05	8.94	3.33	7.33
80	6.12	13.50	4.23	9.33	3.47	7.66
81	6.39	14.09	4.42	9.73	3.62	7.99
82	6.66	14.69	4.60	10.15	3.78	8.33
83	6.95	15.31	4.80	10.58	3.94	8.68
84	7.24	15.95	5.00	11.02	4.10	9.05
85	7.53	16.61	5.21	11.48	4.27	9.42

Length-Girth Relation

Mean lengths and standard errors were 71.0 and 0.72 cm for 89 set-net caught sablefish, and 60.1 and 0.36 cm for 623 sablefish measured from traps. The 25% and 75% quartiles were 68-74 cm for set-nets and 54-65 cm for the trap sample. Although fish were not sexed from trap samples, a sex ratio of 53.9% female was found in the set-net sample.

Similar to the length-weight analysis, a significant difference was found in the length-girth relationship between gears but not between sexes. The multiple regression model for the sexed set-net sample was

$$G = 1.37 + 0.44\ L + 2.81\ S - 0.05\ (L \times S) \qquad (r^2 = 0.71)$$

where G is girth (cm) and L is length (cm). Between gears, the model was

$$G = -3.98 + 0.51\ L + 7.92\ T - 0.11\ (L \times T) \qquad (r^2 = 0.90)$$

The coincidence test between sexes yielded $F = 0.84$ ($P>0.25$); between gears, $F = 9.62$ ($P<0.001$).

Comparison of the predicted girths from the set-net sample and 89 randomly selected trap-caught sablefish revealed that predicted girths differed by less than 1 cm (<4%) for sablefish ranging between 52 and 80 cm; therefore, the pooled regression line was chosen, both because of the small error and the desire to have the largest extrapolation range possible.

The functional regression equation for the 178 pooled fish was

$$G = -4.7388 + 0.5227\ L \qquad (r^2 = .88)$$

and this line bisected the set-net and trap regression lines throughout the length range (Fig. 6).

Minimum Retention Length

From the length-weight and length-girth relations, minimum retention lengths (and weights) were calculated for mesh sizes ranging from 76-165 cm (3.0-6.5 in.) (Table 9). A 127 mm mesh, for example, would not retain sablefish less than 58 cm or 2.0 kg unless the fish became entangled in the meshes (e.g., set-nets) or passage through the meshes was blocked (e.g., trawl). Small and medium-sized sablefish should pass through mesh sizes exceeding 148 mm.

A 32 mm mesh size (1.25 in.), which is used in trawl surveys by NMFS, would retain sablefish greater than 22 cm in length. However, this length is below the range of lengths measured for girth because the smallest fish measured was 43 cm. A minimum retention length of 25 cm is a safer estimate for a 32 mm mesh size.

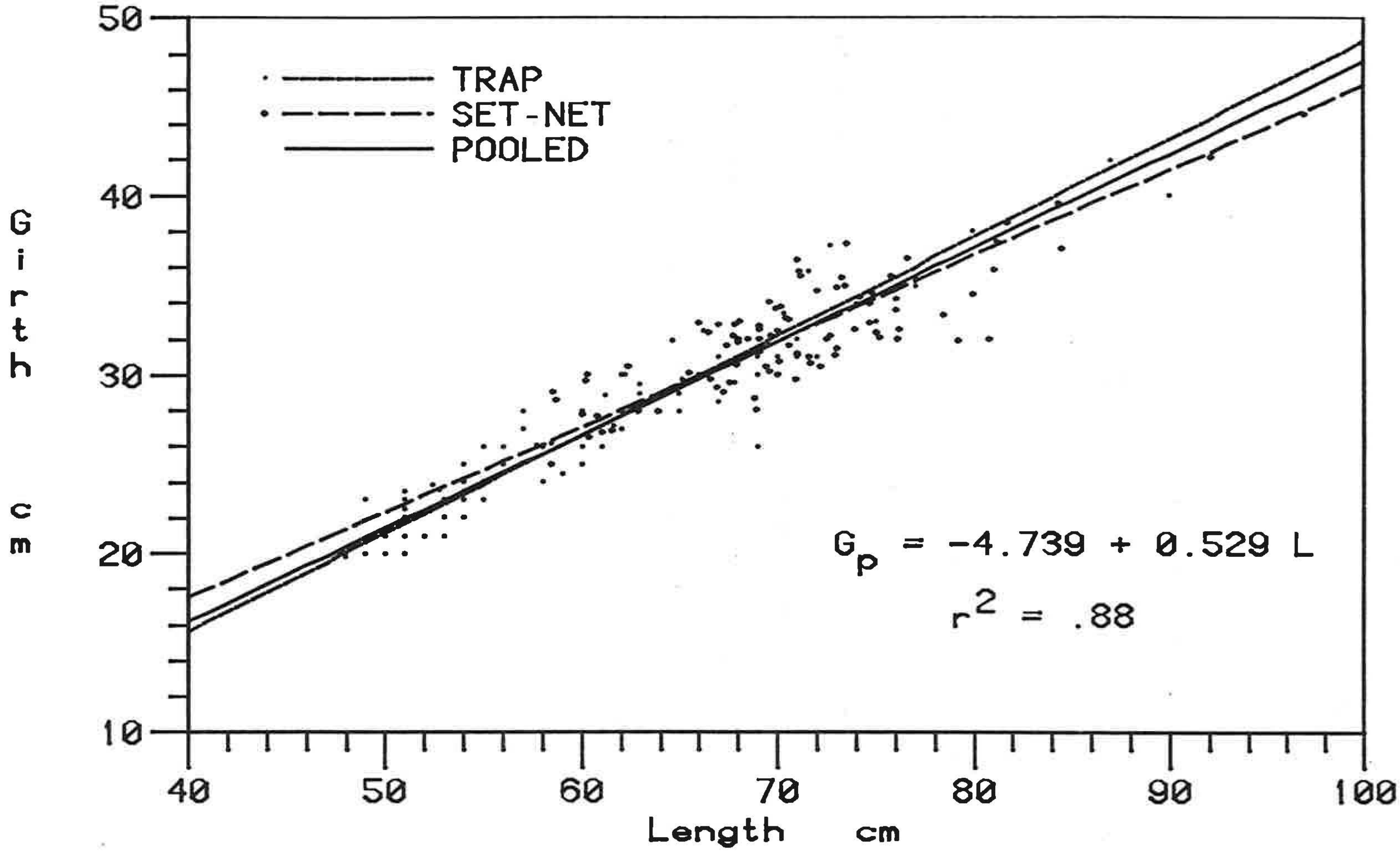

Fig. 6.--Sablefish length-girth relations for trap, set-net and pooled samples collected off the northern Washington coast.

Table 9.--Relationship of mesh size to length, weight and girth of sablefish.

Mesh size (mm)	Mesh size (in.)	Girth (cm)	Length (cm)	Weight (kg)	Weight (lbs)
76	3.00	15.2	38.2	0.5	1.1
89	3.50	17.8	43.1	0.7	1.6
102	4.00	20.3	47.9	1.1	2.3
114	4.50	22.9	52.8	1.5	3.3
127	5.00	25.4	57.7	2.0	4.4
133	5.25	26.7	60.1	2.3	5.1
140	5.50	27.9	62.5	2.6	5.8
149	5.88	29.8	66.2	3.2	7.1
152	6.00	30.5	67.4	3.4	7.5
165	6.50	33.0	72.2	4.3	9.5

Chapter 4

Recruitment and Selection

Recruitment and selection are the processes that govern when fish become liable to capture, and hence, the concomitant yield from the fishery. Recruitment is the process in which young fish enter the exploited area (Gulland, 1969). Whether or not newly recruited fish are retained by the fishing gear depends upon the selective properties of the gear, the size of fish, and the behavior of the fish. In general, fish enter the catch at some age later than the age at recruitment (Beverton and Holt, 1957).

For sablefish, recruitment results from a migration from shallow, inshore waters to the continental slope. Selectivity is controlled by mesh size for trawl, trap and set-net gear and by hook size (i.e., gape) for longlines. Mesh selection is a function of maximum girth and hook selection is controlled by mouth size (Hamley, 1975). For trawl and trap gear, fish with maximum girths less than the mesh perimeter should escape through the meshes, but larger fish should be retained. For longlines and set-nets, escapement occurs for fish smaller and larger than some optimum. The probability of capture decreases as size departs from this optimum. For trawls and traps, the probability of capture typically remains constant above some critical size. In the case of Pacific halibut (*Hippoglossus stenolepis*), however, trawl selectivity is dome shaped (Myhre, 1969).

Studies on sablefish recruitment are mostly limited to when the species enters the commercial fisheries. Since commercial fishing gear is selective, the separate processes of recruitment and selection cannot be quantified. For example, Balsiger and Alton (1981) derived a "recruitment" curve for sablefish entering the Japanese longline fishery for the Gulf of Alaska. Sablefish entered the fishery from 42 cm to 65 cm; 50% "recruitment" occurred at 55 cm. However, their "recruitment" curve is actually the resultant ogive of recruitment which is a behavioral process, and selection, which is a function of the physical properties of the gear and its mode of fishing. The ogive would differ for other gears.

Several studies have analyzed the emergence of the 1977 year class in the commercial fisheries (Sasaki, 1985; McFarlane and Beamish, 1983a; Umeda et al., 1983). These studies suggest that sablefish initiate recruitment to slope waters at age 2 but most recruitment occurs at ages 3-4 and even age 5. Umeda et al. (1983) employed nonselective trawl gear to assess recruitment processes in the Bering Sea, and found that the 1977 year class largely recruited to the continental slope at ages 3 and 4; recruitment spanned the length range 36-57 cm.

Although an abundance of literature exists on gear selectivity (Pope et al., 1975; Huson et al., 1984; Myhre, 1969; Hamley, 1975) selectivity studies on sablefish have not been conducted. In this chapter, the selectivities of trawl, trap, longline and set-net gear are described, then quantified in terms of mesh size. Recruitment is assessed by analyzing length and age frequency samples from research surveys.

Materials and Methods

Recruitment

Sablefish recruitment was assessed by analyzing the ascending limbs of length frequency histograms derived from NMFS trawl and trap surveys. All length frequency samples were collected from the continental slope, so the sablefish that were measured are assumed to be recruited to the fishing grounds. For a non-selective gear, the smallest length observed indicates the initiation of recruitment and the mode of the histogram is an approximation to the fully recruited length if year class strength is assumed constant. The 50% recruitment length was calculated by examining the area under the ascending limb.

Three trawl cruises from 1983-85 were used in the analysis. A cod end liner of 32 mm (1.25 in.) stretched mesh was used in all cruises, which presumably would retain all sablefish greater than 25 cm fork length. The 1983 and 1985 length frequency samples were confined to the U.S. Vancouver INPFC area. Collection depths ranged from 179-473 m and sample sizes were 322 and 541 sablefish for the 1983 and 1985 surveys, respectively. The 1983 samples were collected in September and the 1985 samples in April.

An April-May 1984 trawl cruise from the Oregon portion of the Columbia INPFC area was also included in the analysis because an age subsample was taken. A total of 2,437 fish were measured, of which 501 sablefish were sexed and aged. Sablefish otoliths were aged by the NMFS Northwest and Alaska Fisheries Center (NWAFC) ageing unit using the break-and-burn technique. Age composition was determined by extrapolating the age subsample to the length sample, by sex. Sex was determined for 1,836 of the 2,437 fish measured. Von Bertalanffy growth equations were derived for males and females using the Walford equation (Ricker, 1975).

An October 1983 trap survey off the Washington coast was also used in the length frequency analysis. Collection depths ranged from 274-823 m. Both 76 and 89 mm mesh traps were used in the survey, which correspond to minimum retention lengths of 38 and 43 cm, respectively. Such meshes may not include the smallest recruited ages, but the modes of the length-frequency histograms should reveal the fully recruited length. A total of 820 sablefish were measured from 76 mm mesh traps and 790 from the 89 mm mesh traps.

Selectivity

Over 4,500 sablefish were measured from commercial fishing vessels operating off the Washington-Oregon coast (Table 10). Most samples were collected during the summer of 1984 from continental slope waters. It was desired to only collect samples at sea to minimize the bias of discards; however, trawl samples were almost exclusively collected at port. Samples were also limited to the Washington coast except for two trawl samples (127 mm mesh) collected off Tillamook Head, Oregon. The longline samples were caught using a No. 6 circle hook.

The commercial samples were analyzed both by gear and mesh size. For the gear comparison, the two trawl mesh sizes (89 and 127 mm) were combined since both mesh sizes contribute significantly to the

Table 10.--Summary of sablefish length frequency samples collected from commercial vessels fishing off the Washington-Oregon coast, 1983-85.

Gear	Mesh size (mm)	Mesh size (in.)	Sample months	Collection depths (m)	No. Samples	No. at-sea Samples	No. fish Measured
Trawl	89	3.50	8/84, 9/84	128-183	3	0	447
	127	5.00	8/84, 2-3/85	123-604	6	4	431
Trap	102	4.00	8/84, 10/84	219-768	16	15	1061
Longline			9/84	211-403	6	6	282
Set-net	133	5.25	9/83, 8/84	174-375	3	3	192
	140	5.50	9/84	219-256	1	1	77
	149	5.88	7/84, 9/84	183-347	6	6	997
	152	6.00	9/83, 7-9/84	165-384	10	10	1021

landings; for set-nets, only the commercial mesh sizes of 149 and 152 mm were used. Length frequency histograms of each gear were constructed to quantify the selection ranges.

For each gear, the length frequency samples were graded into small, medium and large size categories. Total weight in each grade was calculated by multiplying the frequency at each length times the weight at length, and then summing the weight frequencies by size category (e.g., 60-66 cm for the medium size category). By dividing the weights of each size category by the sum of the weight-frequencies, the graded weight composition was obtained.

In the mesh size analysis, the length composition was compared to the minimum retention lengths computed in the last chapter. The effective opening of a mesh is assumed to be gear-independent. A linear regression of mean length versus mesh size was calculated to determine how well these two variables correlate, and secondly, to derive an equivalent mesh size for No. 6 circle hooks, based upon the mean length of sablefish in the longline samples. Finally, sex ratios and mean lengths by sex were determined for the various mesh sizes.

Results and Discussion

Recruitment

Sablefish less than 27 cm were not observed in any of the four research surveys. Since the minimum retention length for a 32 mm mesh is approximately 25 cm, the research trawls were nonselective, at least for small fish.

Based upon the 1983 trap survey, sablefish were fully recruited at 49-53 cm (Fig. 7). Recruitment patterns differed among the 1983-85 trawl surveys (Fig. 8). Recruitment spanned 38-49 cm for the 1983 trawl survey, 27-50 cm for the 1984 survey and 27-44 cm during the 1985 survey. The absence of sablefish less than 38 cm during the 1983 trawl survey may have resulted from the month of capture--the 1983 survey was conducted 4-5 months later than the 1984-85 surveys.

Based upon these results, it appears that sablefish gradually recruit to the continental slope beginning at 27 cm and continuing until the fully recruited length of 50 cm; the length at 50% recruitment is approximately 45 cm. This pattern of recruitment corresponds most closely with the 1984 trawl survey; an age sub-sample derived from this survey indicates that sablefish begin to recruit to the slope after their first year of life (Fig. 9). Sablefish are fully recruited at age 4.

Of the 501 sablefish subsampled for age, 491 otoliths were readable. The following von Bertalanffy growth curves were obtained (Fig. 10):

$$L = 70.5750\ (1 - e^{-.1609(t\ +\ 2.5773)}) \quad \text{for males}$$

$$L = 82.5542\ (1 - e^{-.1476(t\ +\ 2.1352)}) \quad \text{for females}$$

where L = length and t = age. Approximately 50% of the sablefish stock off Washington-Oregon recruit at 45-50 cm, which corresponds to ages of 3.7-5.0 for males and 3.2-4.2 for females. This implies that most sablefish off the Washington-Oregon coast recruit to the continental slope during their third and fourth years of life, which agrees with

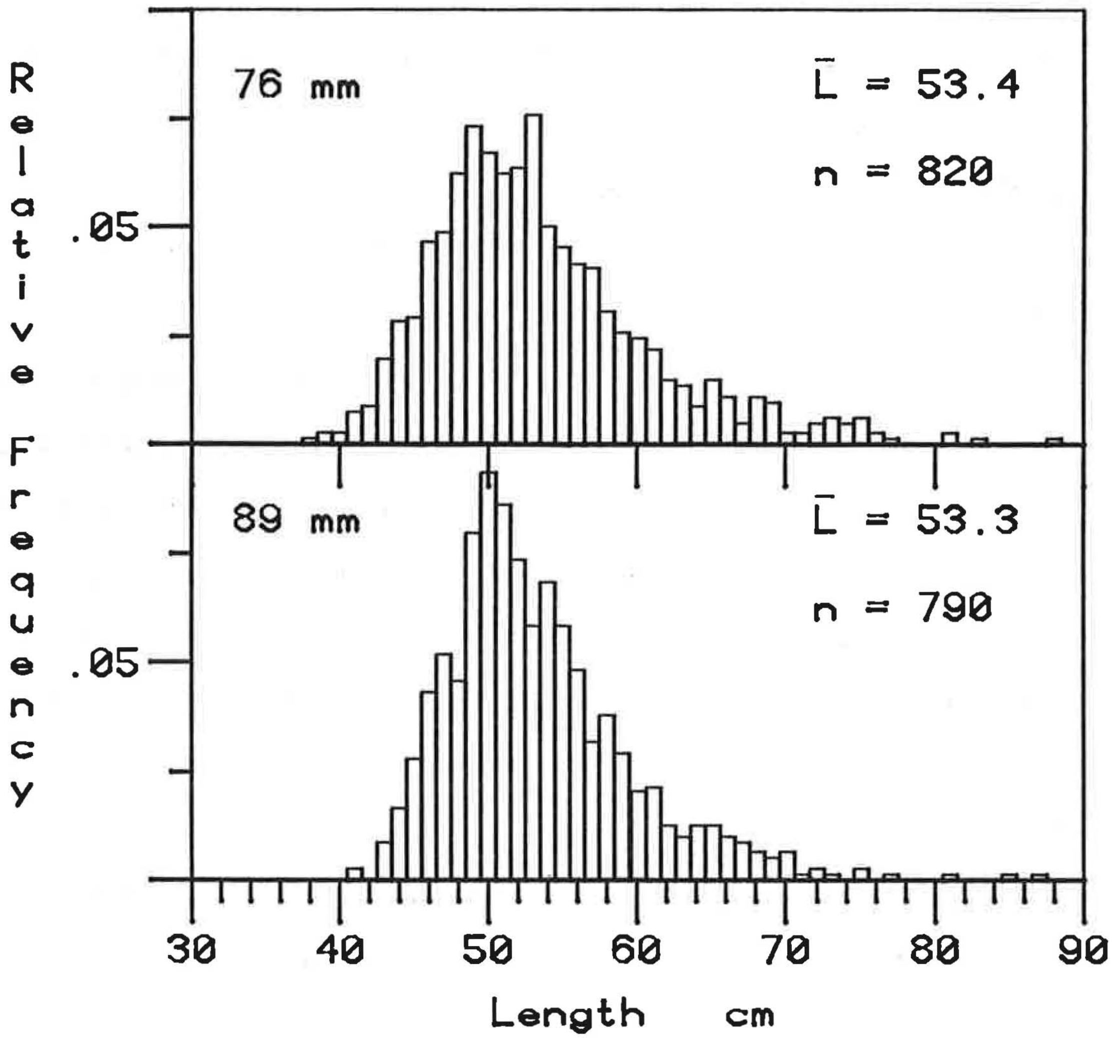

Fig. 7.--Length frequency histograms of sablefish collected during the 1983 NMFS trap survey off the Washington coast, by mesh size.

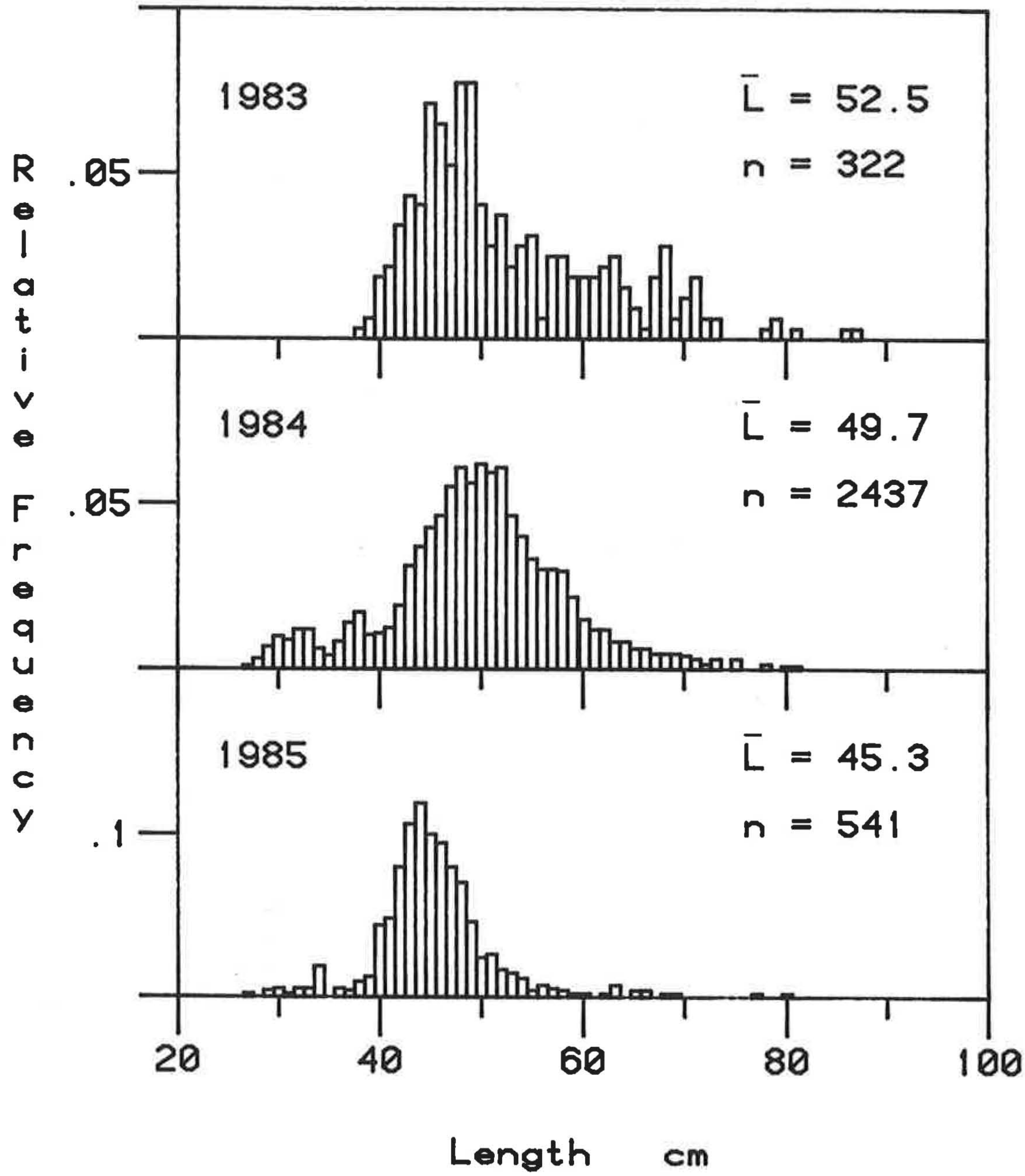

Fig. 8.--Length frequency histograms of sablefish collected off the Washington-Oregon coast during the 1983-85 NMFS trawl surveys.

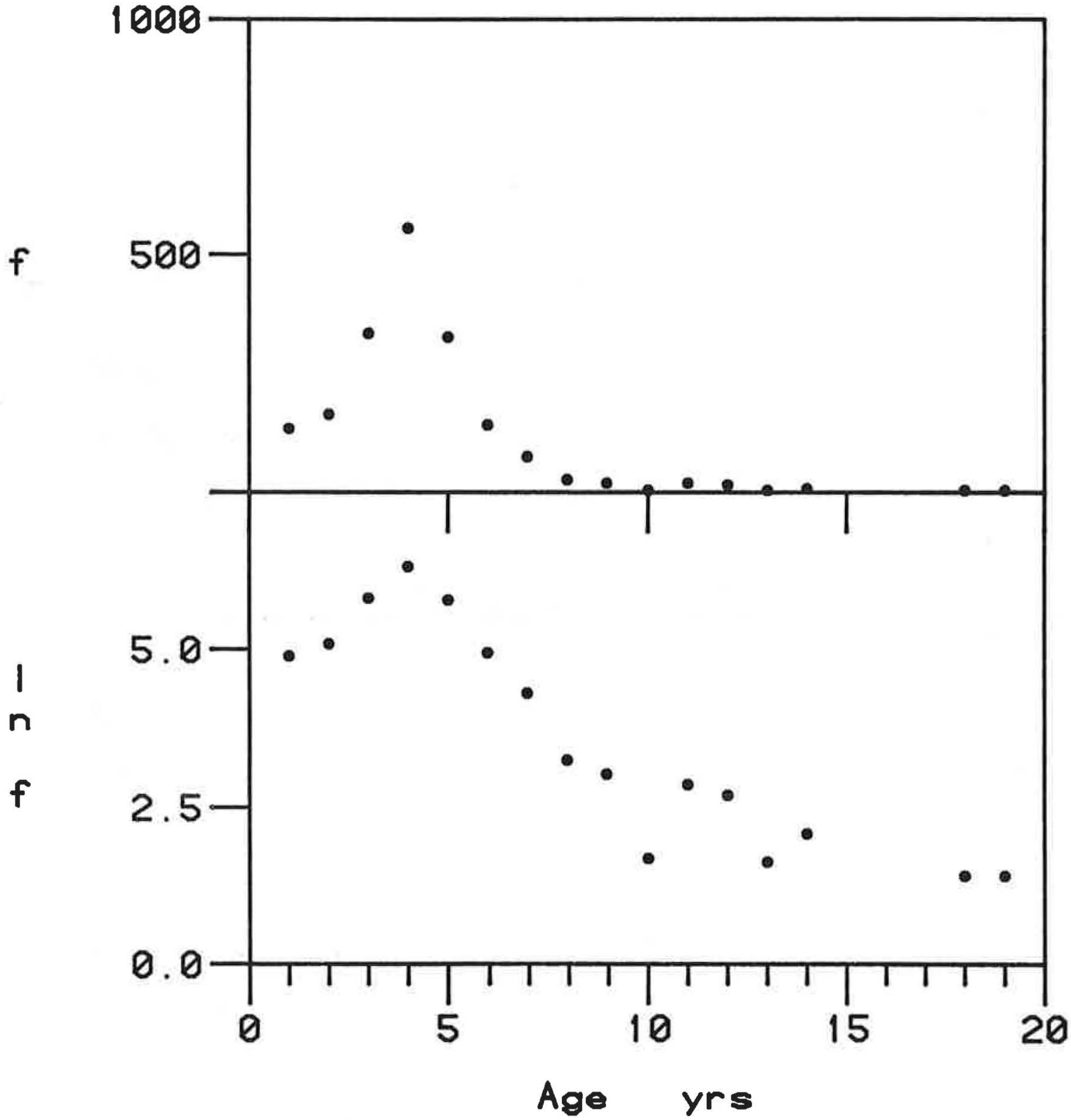

Fig. 9.--Age-frequency and ln frequency versus age plots of sablefish collected in the Columbia INPFC area during the 1984 trawl survey.

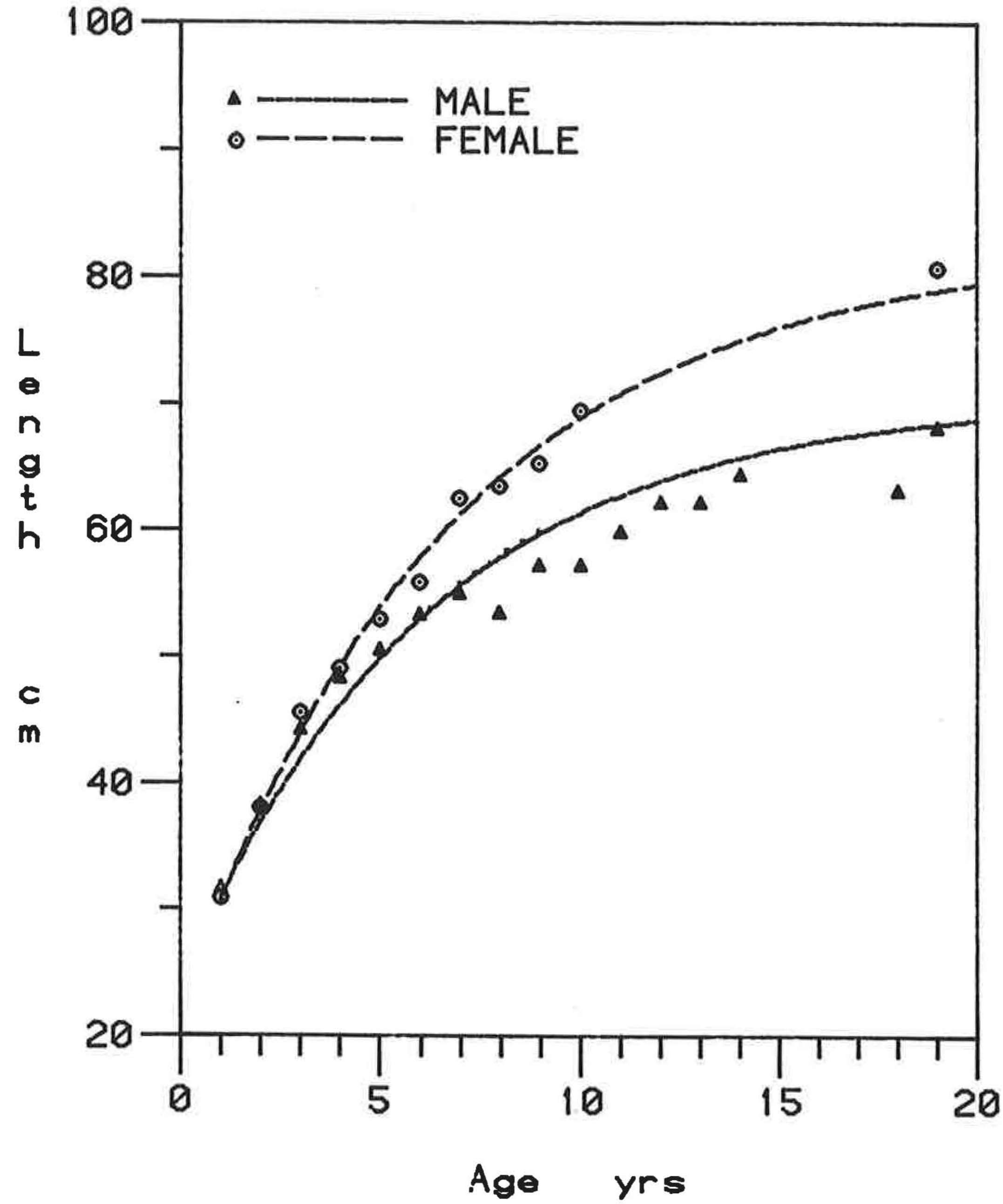

Fig. 10.--Von Bertalanffy growth curves of sablefish collected in the Columbia INPFC area.

previous studies by McFarlane and Beamish (1983a), Sasaki (1985) and Umeda et al. (1983).

Gear Comparison

With commercial fishing gears, mean lengths of sablefish ranged from 57.3 cm in trawls to 72.5 cm in set-nets (Fig. 11). For set-nets, the two commercial mesh sizes (149 and 152 mm) were pooled since the mean lengths did not differ significantly: $t = 1.03$ ($P>0.25$). Set-nets not only caught the largest fish but also proved to be the most selective gear. Set-net caught sablefish spanned a 30 cm selection range, primarily from 60-90 cm. Trawl-caught sablefish generally measured 40-80 cm, whereas traps and longlines caught sablefish that ranged from 45-90 cm--a 45 cm range.

Modal lengths were 53 cm for trawls, 54 cm for traps, 69 cm for longlines, and 71 cm for set-nets. Since longline-caught fish were symmetrically distributed the mean of 66 cm is a better measure of central tendency given the small sample size. Therefore, optimum selection lengths were 66 cm for longlines and 71 cm for set-nets. The modes for trawl and trap gear closely correspond to the fully recruited length of 50 cm.

The length distributions of longlines and set-nets were symmetrical, but negative skewness was exhibited in the trawl and trap samples. The negatively skewed distributions from trawl and trap samples occurred because of the selective properties of these gears: (1) all fish with girths larger than the mesh perimeters should be retained by the gear, thus expanding the right limbs of the distributions, and (2)

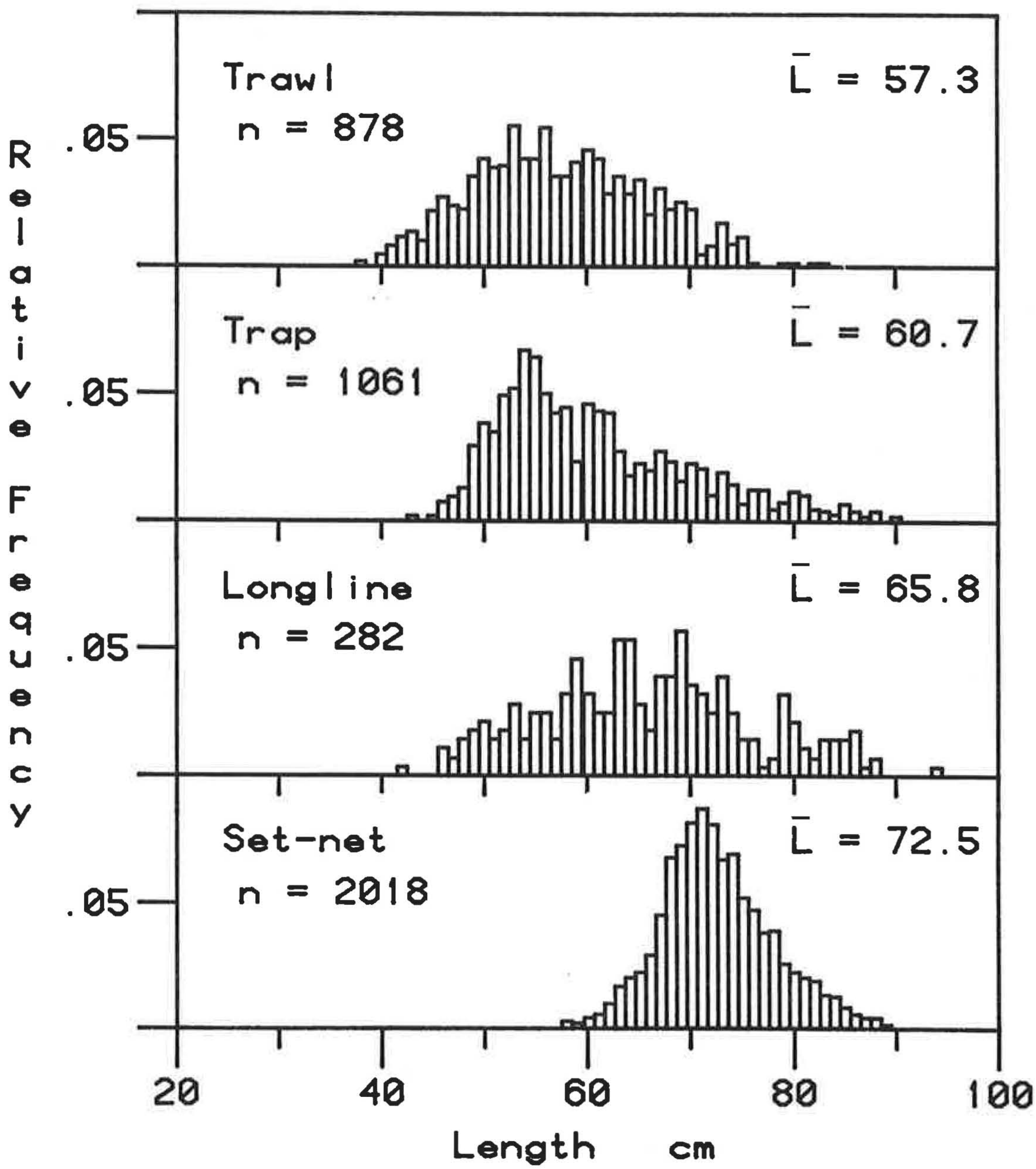

Fig. 11.--Length frequency histograms of commercial sablefish gears operating off the Washington-Oregon coast, 1983-85.

mesh sizes of 89 and 102 mm operate on partially recruited sablefish, thus contracting the left limbs.

Commercial set-nets were the only gear that operated entirely on fully recruited sablefish. Trawl gear, in particular, harvested a significant portion of smaller fish: 18% of the sample was less than 50 cm. Only five trawl-caught sablefish exceeded 75 cm in length (1% of sample), compared to 97 in traps (9%), 48 in longlines (17%) and 533 in set-nets (26%). Therefore, sablefish exceeding 75 cm are present on the fishing grounds but under-represented in both commercial and research trawl samples (Figs. 8 and 11). This indicates that large sablefish are able to avoid trawl gear, which has been shown by Parks (1973) for sablefish, halibut and lingcod. Myhre (1969) obtained symmetrical, rather than sigmoid selection curves for trawl-caught halibut.

Based upon a comparison of research and commercial captures of sablefish, we can conclude:

1) Trawl, trap and longline gear capture sablefish before the fully recruited length of 50 cm.
2) For sablefish exceeding 53 cm in length, trawls and traps harvest sablefish in proportion to their abundance, but trawl avoidance was evident for large sablefish (>75 cm). Therefore, even trawls equipped with small-meshed cod ends are selective.
3) Longlines exhibit a broader selection range than set-nets, which implies that hooks are less selective than mesh.
4) Longlines selectively capture sablefish ranging from 45-90 cm.

5) Commercial set-nets were the most selective gear, targeting upon a narrow size range of 60-90 cm sablefish.

6) Recruitment onto the fishing grounds and recruitment into the fishery (i.e., selection) are different processes for longlines and set-nets since the optimum selection lengths for these two gears were 66 and 71 cm, respectively.

7) The strong 1977 year class (8 year-old fish) noted in the Bering Sea, Gulf of Alaska, and off Canada is not present in the Vancouver-Columbia area. In fact, NMFS trap surveys off the Washington-Oregon coast never detected a strong year class from 1977, but a strong 1980 year class may be emerging (Parks, 1984).

Size Composition

Ranking the gear types according to the graded size composition of the length frequency samples, set-nets caught the largest sablefish, followed by longline, trap and trawl gear (Table 11). The experimental set-net mesh sizes of 133 and 140 mm would have been graded 57 and 75% large (round weight), respectively. Therefore, 133 mm mesh set-nets would produce a graded size composition smaller than longlines but larger than trawl or trap gear.

Trawl-caught sablefish averaged 2.1 kg (4.7 lbs) round weight, which corresponds to the small size category. In traps, the average weight was 2.6 kg (5.8 lbs) or a medium-sized sablefish. Longlines and set-nets selected large sablefish averaging 3.4 kg (7.6 lbs) in longlines and 4.5 kg (9.9 lbs) in commercial set-nets. Multiplying the

Table 11.--Size composition of commercial length frequency samples when graded as round, western or eastern-dressed sablefish.

Type/size	Trawl mt	Trawl %	Trap mt	Trap %	Longline mt	Longline %	Set-net mt	Set-net %
Round								
large	0.55	29.5	1.30	46.5	0.66	68.0	8.40	92.8
medium	0.55	29.4	0.61	21.8	0.18	18.4	0.62	6.9
small	0.77	41.1	0.89	31.7	0.13	13.6	0.03	0.3
	1.87		2.80		0.97		9.05	
Western-Dr.								
large	0.38	29.5	0.90	46.5	0.46	68.1	5.80	92.8
medium	0.48	36.9	0.53	27.2	0.16	23.1	0.44	7.1
small	0.43	33.6	0.51	26.3	0.06	8.8	0.01	0.1
	1.29		1.94		0.68		6.25	
Eastern-Dr.								
large	0.13	12.4	0.54	34.3	0.28	50.2	3.65	71.2
medium	0.44	41.6	0.48	30.0	0.19	34.1	1.45	28.3
small	0.49	46.0	0.57	35.7	0.09	15.7	0.03	0.5
	1.06		1.59		0.56		5.13	

1984 ex-vessel prices for these size categories times the mean weight, the average trawl-caught sablefish was worth $0.66. The average trap, longline and set-net caught sablefish were worth $1.51, $4.44 and $4.59, respectively. This implies that it takes 7 trawl-caught sablefish to receive the same value as a single sablefish caught by longline or set-net gear.

The size composition of the length frequency samples depended upon when the fish are graded. Trawl-caught sablefish, for example, would be graded 30% large when graded round or western-dressed but only 12% large when eastern-dressed. Since conversion factors differ between the western and eastern cuts, extrapolation of dressed weight to round weight is also dependent upon the type of cut. Because the sablefish market changes rapidly, the method of grading the catch must be taken into account to accurately estimate the landings and size composition. This requires either modifications in state fish tickets or port sampling of the landings. All state agencies should incorporate these changes into their data collection systems.

Mean Length and Mesh Size

Mean lengths of sablefish increased linearly with mesh size (Fig. 12), but the 127 mm trawl sample was an outlier. With the 127 mm sample included, the correlation coefficient (r) was 0.81, but if omitted, r = 0.95. Thus, mean length correlates very strongly with mesh size when this outlier is removed.

For commercial trawl gear, the mean length from 89 mm cod ends was 10 cm greater than 127 mm cod ends (Table 12). Since sablefish from

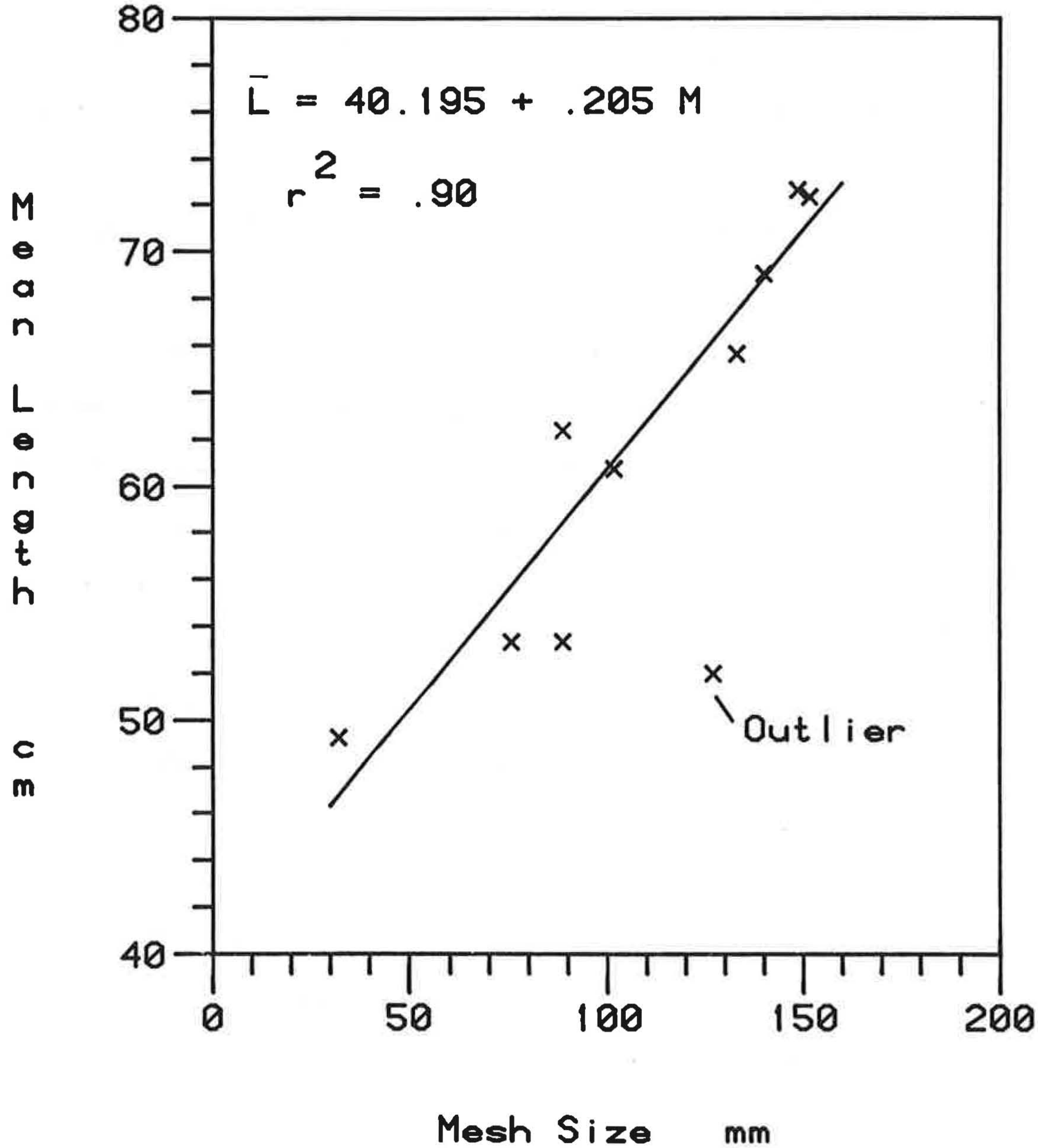

Fig. 12.--Regression line for mean length ($\bar{L}$) versus mesh size (M), outlier removed.

Table 12.--Sample statistics of sablefish length frequency samples collected from commercial and research vessels off the Washington-Oregon coast, 1983-85.

Gear	Mesh size (mm)	Mesh size (in.)	n	Mean (cm)	SE of Mean (cm)
Trawl	32	1.25	3300	49.22	0.15
	89	3.50	447	62.38	0.30
	127	5.00	431	52.01	0.32
Trap	76	3.00	820	53.36	0.25
	89	3.50	790	53.31	0.22
	102	4.00	1061	60.70	0.29
Longline			282	65.77	0.61
Set-net	133	5.25	192	65.66	0.39
	140	5.50	77	69.05	0.59
	149	5.88	997	72.62	0.18
	152	6.00	1021	72.36	0.18

the 89 mm trawl samples were measured at port, this discrepancy could have been caused by the discard of small sablefish at sea. Alternatively, the 127 mm codend, which was used to target on sole, may have had its meshes blocked by sole, reducing the effective mesh opening. Since the 127 mm mesh was an outlier in the regression analysis, the second hypothesis seems more plausible. The discrepancy in trawl samples is further discussed in the next section.

Although the size composition of longline gear is governed by hook size, an equivalent mesh size was derived from the regression equation

$$\bar{L} = 40.195 + 0.205\ M$$

where M is the mesh size in mm and $\bar{L}$ is the mean length in cm. Solving for M given $\bar{L}$, a No. 6 circle hook equates to a 125 mm (4.9 in.) mesh size. Since the mean length and size composition of longline-caught fish exceeded that for 127 mm trawls and 133 mm set-nets, hook size is less selective than mesh size (i.e., a broader size range of fish is caught than would be predicted by the mesh size relation).

Length at Entry

A distinct relationship existed between mesh size and length at entry for mesh sizes less than 127 mm (Table 13). For example, traps with an 89 mm mesh size should not retain sablefish less than 44 cm; only 9 sablefish less than this minimum retention length were observed (1% of the sample). For mesh sizes of 102 mm and less, less than 3% of each sample contained sablefish smaller than the minimum retention length. However, sablefish are not fully recruited until 50 cm, so

Table 13.--Minimum retention lengths of sablefish, by mesh size, related to length frequency samples.

Mesh size (mm)	Mesh size (in.)	Gear	Minimum retention length (cm)	No. fish measured	Length range (cm)	Fish <minimum retention length No.	Fish <minimum retention length %
32	1.25	Trawl	25	3300	27-87	0	0.0
76	3.00	Trap	39	820	38-88	1	0.1
89	3.50	Trap	44	790	41-87	9	1.1
89	3.50	Trawl	44	447	49-82	0	0.0
102	4.00	Trap	48	1061	43-94	22	2.1
127	5.00	Trawl	58	431	38-83	357	82.8
133	5.25	Set-net	61	192	53-84	29	15.1
140	5.50	Set-net	63	77	58-82	7	9.1
149	5.88	Set-net	67	997	53-93	112	11.2
152	6.00	Set-net	68	1021	46-98	165	16.2

mesh sizes less than 107 cm are selectively operating on partially recruited sablefish.

Set-nets measured at least 133 mm in mesh size, so sablefish are fully recruited onto the fishing grounds for this gear. For the four mesh sizes though, 9-16% of the fish measured were less than the minimum retention lengths. Some small sablefish were wedged and entangled in set-nets, rather than gilled, which partially explains the retention of undersized sablefish. Another factor is the variation in length with girth. When allowing for a +2 cm deviation in length with girth, the percentage of undersized sablefish decreases to 3-8% for the four mesh sizes considered.

The greatest discrepancies for the mesh size-length at entry relation occurred for trawls. First, the trawl with an 89 mm cod end should have retained sablefish 44 cm in length but the smallest sablefish measured was 49 cm from a total of 447 fish. The absence of sablefish from 44-48 cm could have been due to truncation of the length range by sub-sampling, the discarding of small sablefish at sea, or simply the absence of small sablefish on the fishing grounds.

The second discrepancy for the mesh size relation occurred for the 127 mm trawl samples. Sablefish less than 58 cm should not have been retained by the 127 mm mesh, but 83% of the sablefish measured at sea were less than the minimum retention length (Table 13). Since the sablefish were caught incidentally to directed flatfish (e.g., dover sole) tows, mesh size apparently does not control the size at entry of sablefish for the dover sole fishery. Since flatfish have a lot of surface area per unit volume, the passage of sablefish through the cod end meshes is evidently blocked by the accumulated catch. Flatfish bottom trawls sampled in this study had single-walled cod ends. Retention of undersized sablefish from double-walled cod ends, which are permissible in bottom trawls, may even be higher than the 83% figure found in this study.

The two trawl mesh sizes sampled in this study represent two distinct gears: roller trawls (minimum mesh size of 76 mm), which commonly target on rockfish and sablefish, and flatfish bottom trawls (minimum mesh size of 114 mm). Sablefish landings from the roller trawl samples averaged 11 mt whereas the flatfish bottom trawl samples averaged 3 mt. Unless small sablefish were discarded from the 89 mm roller trawls, directed tows by the roller trawl fishery are controlled by mesh size.

In summary, a mesh size of 107 cm corresponds to the fully recruited length of 50 cm for sablefish--traps and roller trawls typically use mesh sizes smaller than 107 cm. Mesh size controls the length at entry (and mean length) for trap, longline and set-net gear. With trawl gear, the method of capture (i.e., incidental or directed) and discarding of small sablefish must be considered. The results of this study suggest that mesh size controls length at entry for directed roller trawl tows but not the flatfish bottom trawl fishery. The collection of at-sea samples for both types of trawls is highly recommended.

Sex Ratio by Mesh Size

Sexual dimorphism was common to all samples--females ranged from

2.2-5.9 cm larger than males for the various mesh sizes (Table 14). In general, the disparity between males and females increased with mesh size. Mean lengths of both males and females increased with mesh size.

The sex ratios were approximately 50% female for most mesh sizes under 149 mm, but for the two largest mesh sizes, 149 and 152 mm, the samples averaged 66% female. Sablefish averaged 72 cm in the 149 and 152 mm set-nets; since few male sablefish exceed 70 cm in length, a 2:1 female to male ratio resulted. The 127 mm trawl mesh had a sex ratio of 22% female, which was derived from two samples of 9 and 34% female (100 fish each). The reason for such low sex ratios is not known, but sample sizes were small. The sex ratio for 282 longline-caught sablefish was 53.5% female.

The 2:1 female to male ratio in commercial set-nets is a disturbing statistic, particularly since smaller mesh sizes harvest males and females in equal proportions. The use of mesh sizes exceeding 148 mm could have serious consequences for sablefish recruitment since females presumably have a higher reproductive value than males. The establishment of maximum mesh sizes should be considered to prevent the selective harvest of female sablefish. Set-net mesh sizes of 133 and 140 mm reduce sex ratios to 56% female, compared to 65-68% female in 149 and 152 mm set-nets.

Table 14.--Sex ratio and sample statistics of sablefish length frequency samples, by sex and mesh size.

Mesh size (mm)	Mesh size (in.)	Male n	Male $\bar{L}$	Male SE of Mean	Female n	Female $\bar{L}$	Female SE of Mean	Sex Ratio (% female)
32	1.25	1253	46.69	0.21	1320	49.34	0.23	51.3
76	3.00	65	52.26	0.53	79	55.47	0.83	54.9
89	3.50	87	52.03	0.43	63	57.92	0.83	42.0
127	5.00	157	55.71	0.43	43	57.84	1.22	21.5
133	5.25	84	63.75	0.52	108	67.15	0.53	56.3
140	5.50	34	67.03	0.79	43	70.65	0.77	55.8
149	5.88	227	69.79	0.29	488	73.14	0.23	68.3
152	6.00	362	69.70	0.23	659	73.83	0.22	64.5

Chapter 5

Yield-per-Recruit Analysis

Determination of the optimal size at entry is necessary for protecting juvenile fish and maximizing the yield from the fishery. Optimal, in this sense, refers to the size that maximizes the yield per recruit for a fixed fishing mortality. In theory, this optimum is the size at which a cohort maximizes its biomass; yield would be maximized if all fish were harvested at this size. This is impractical because a fishery intensive enough to instantaneously harvest all fish above a given size would cost more than the catch is worth, and secondly, an adequate spawning stock would not be insured (Myhre, 1969). In practice, minimum retention lengths can be established such that yield is maximized for a fixed (rather than infinite) fishing intensity. Off the WOC coast, a minimum size limit of 52.4 cm fork length has been implemented to achieve this purpose. In this chapter, the optimal size at entry is quantified for the WOC coast by yield-per-recruit analysis and the variability in growth and natural mortality parameters is assessed.

Materials and Methods

A modified Beverton and Holt (1957) yield-per-recruit model was constructed to determine the sizes at entry that maximize yield for fixed fishing mortalities. The yield (Y) of a cohort from the age at entry (t_c) to the oldest exploited age (t_x) is described by:

$$Y = F \int_{t_c}^{t_x} N(t)\ W(t)\ dt \qquad (1)$$

where F is the instantaneous fishing mortality rate, and N(t) and W(t) are functions describing the numbers and weight of fish at age t. By assuming constant recruitment and constant fishing and natural mortalities between t_c and t_x, the annual yield from all cohorts in the population is also given by (1).

The yield equation was integrated numerically with a time step (T) of 0.1 years using the midpoint approximation of each interval. Setting the number or recruits entering the population to one, the annual yield per recruit (Y/R) is given by

$$\frac{Y}{R} = F\ e^{-M(t_c - t_r)} \sum_{i=t_c}^{t_x} e^{-Z(i+\frac{T}{2}-t_c)}\ A\ [L_\infty (1.0 - e^{-K(i+\frac{T}{2}-t_o)})]^B\ T \qquad (2)$$

where M = instantanous natural mortality rate

Z = instantaneous total mortality rate = M + F

t_r = age at recruitment

A,B = length-weight parameters

L_∞, K, t_0 = von Bertalanffy growth parameters

A FORTRAN program was written to perform the numerical integration for values of F ranging from 0.1-0.7 (Appendix). For each value of F, yield-per-recruit was calculated for entry ages corresponding to fork lengths of 45-70 cm. The yield-per-recruit was summed for males and females since separate von Bertalanffy curves were used for the two sexes. The ex-vessel value-per-recruit was also incorporated into the program by adding the function P(S) to equation (2), where P(S) is the price per kg, by size category. The average 1984 ex-vessel prices (all gears combined) received by Washington fishermen were applied: small, $0.34/kg; medium, $0.62/kg; and large, $0.86/kg.

An age of 30 years was used for the maximum exploited age (t_x). The length-weight and von Bertalanffy growth parameters derived in Chapters 3 and 4 were utilized in the model. Ages corresponding to the 50% recruitment length were used for the parameter t_r: 3.7 yrs for males and 3.2 yrs for females. An estimate of M was derived from the equation of Alverson and Carney (1975):

$$T_{mb} = (1/K) \ln[(M + 3K)/M)] \qquad (3)$$

where T_{mb} is the age that a cohort maximizes its biomass and can be first approximated as 0.25 times the maximum age in the unfished population. This maximum age is assumed to be 40 years.

An estimate of Z was calculated from the age sample presented in Fig. 9 by linear least-squares regression. Z was estimated by regressing the logarithm of the age-frequencies versus age. Assuming constant recruitment and mortalities, the slope of the regression line provides an estimate of Z (Ricker, 1975). Ages 4-19 were used in the regression.

Von Bertalanffy growth parameters (L_∞,K,t_0) are highly correlated with one another, and hence, so is the estimate of natural mortality since the Alverson-Carney procedure was used. To assess the bias that growth parameters have upon the optimal entry size, optimal size to maximize yield was plotted against F (i.e., eumetric fishing curves) for three von Bertalanffy growth curves published by Lai (1985) from the Gulf of Alaska. Lai's growth curves were substituted into my yield-per-recruit model and the optimal sizes were plotted against F for curves derived from the Southeastern, Yakutat and Shumagin-Chirikof INPFC areas. Similarly, eumetric fishing curves were plotted for M values of 0.1 and 0.2 to evaluate errors in estimating the instantaneous natural mortality rate.

Results

From the Alverson-Carney procedure, M was estimated as 0.12 for males and 0.13 for females. The average value of 0.13 was employed in the yield-per-recruit model. A value of $Z = 0.76$ was obtained from the age-frequency regression with ages 4-10 ($r^2 = 0.99$). When ages 4-19 were regressed, Z equalled 0.29 ($r^2 = 0.80$). This implies that F ranges from 0.16-0.63.

The optimal size at entry was 6-12 cm greater when maximizing value-per-recruit compared to yield-per-recruit (Fig. 13). For $F = 0.3$, yield was optimized at an entry length of 54 cm whereas the maximum value occurred at 60 cm. The greater entry sizes required to maximize value resulted from the higher prices received for larger fish.

Yield-per-recruit curves were relatively flat over a length range of 10 cm. For low fishing intensities ($F = 0.1$), yield was maximized

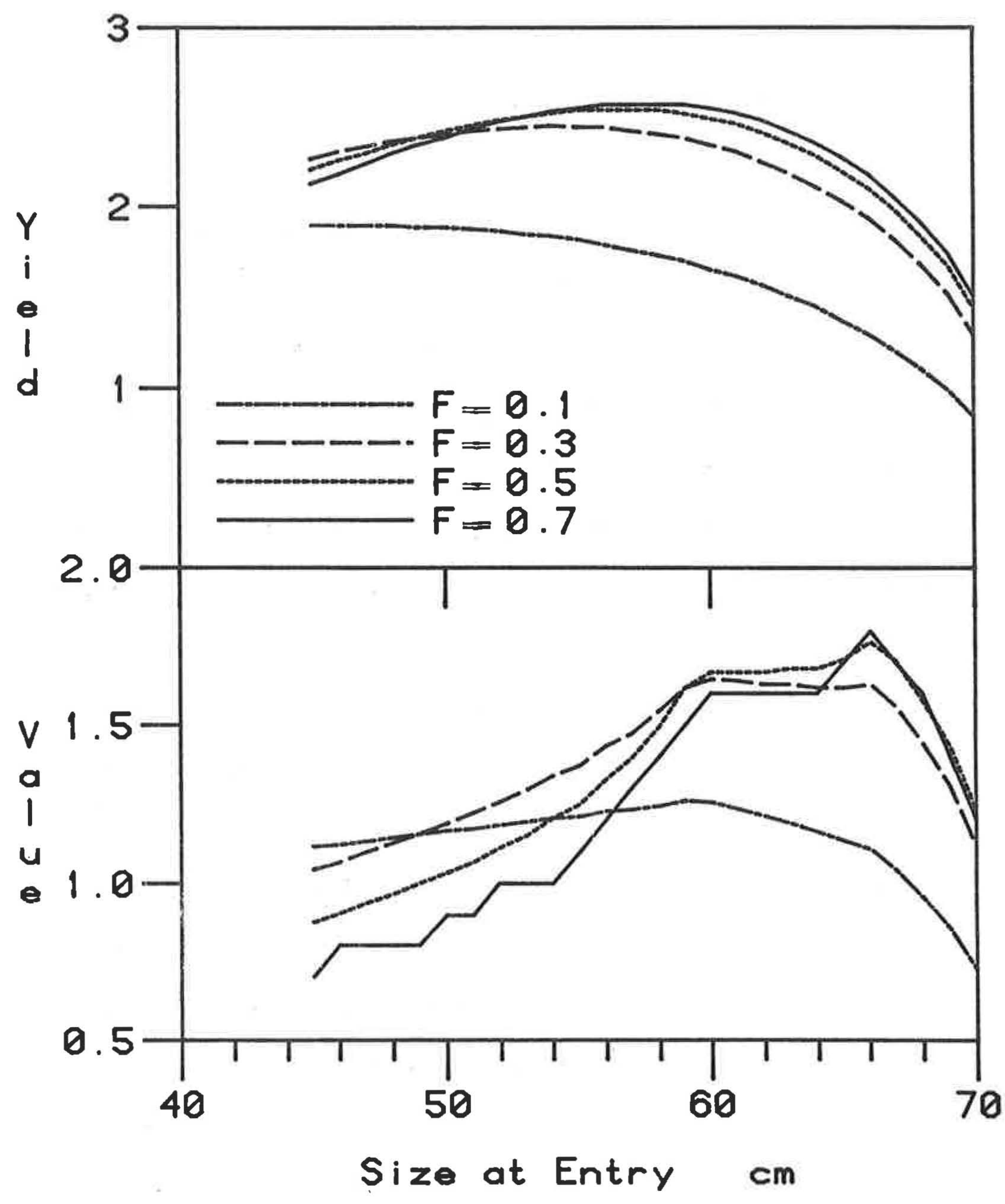

Fig. 13.--Yield-per-recruit (kg) and value-per-recruit ($) curves for fishing mortalities (F) of 0.1-0.7.

immediately after the fish recruit to the fishery (45-52 cm). For fishing mortalites exceeding 0.2, yield was maximized at entry lengths of 54-57 cm. The maximum yield increased from 1.9 to 2.5 kg/recruit as F increased from 0.1 to 0.3. At higher fishing mortalities, the marginal gain in yield-per-recruit was small.

For fishing mortalitites of 0.1-0.3, value was optimized at entry sizes of 59-60 cm (Fig. 13); therefore, sablefish would not be harvested until they grew into the medium size category (>2.3 kg). For fishing mortalitites greater than 0.3, only large sablefish (>66 cm) should be harvested in order to optimize the value-per-recruit.

The optimal value-per-recruit increased markedly from $1.26 to $1.65 for fishing mortalities of 0.1 and 0.3, respectively. For F = 0.5, the value-per-recruit was $1.67 for an entry length of 60 cm and $1.76 for the optimal length of 66 cm.

For the von Bertalanffy growth curves derived from the Gulf of Alaska, eumetric fishing curves for optimizing yield-per-recruit differed by less than 2 cm over a fishing mortality range of 0.1-0.7 (Fig. 14). In fact, the eumetric curves for the Southeastern and Shumagin-Chirikof areas were equivalent. When the Columbia area is included, optimal length differed by less than 4 cm among the four INPFC areas. Optimal yield values for F = 0.7 were 2.6, 2.7, 3.2 and 3.3 kg/recruit for the Columbia, Southeastern, Yakutat and Shumagin-Chirikof areas. For maximizing value-per-recruit, the optimal size was 66 cm for all INPFC areas when F exceeded 0.4. At F = 0.7, the optimal

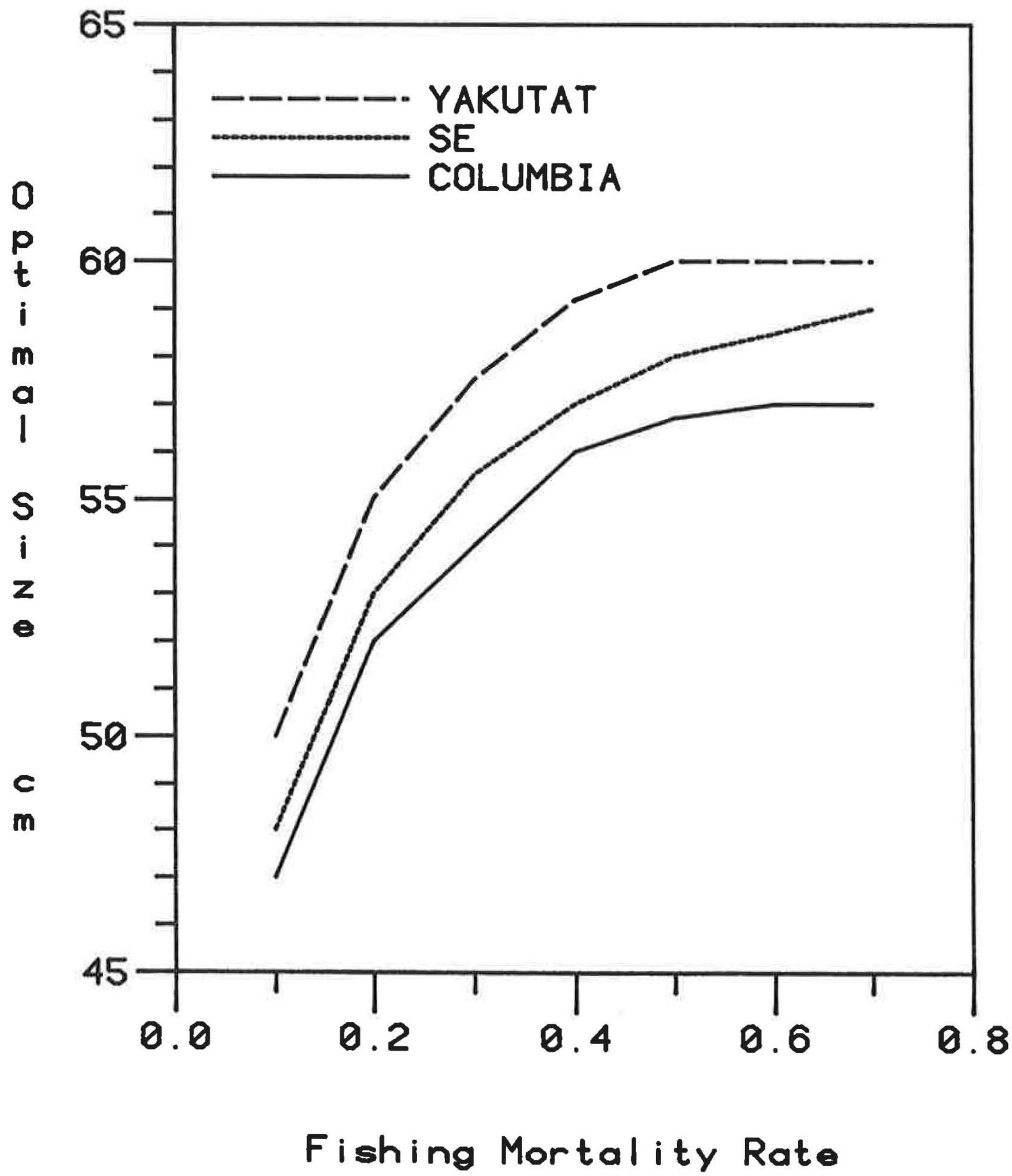

Fig. 14.--Eumetric fishing curves for the Columbia, Southeastern (SE), Yakutat and Shumagin-Chirikof INPFC areas; curves for SE and Shumagin-Chirikof areas are equivalent.

value-per-recruit ranged from \$1.96-\$2.46 in the Gulf of Alaska and was \$1.81/recruit in the Columbia area.

Unlike the growth curves, the natural mortality parameter strongly affected the optimal size at entry. For M = 0.1, the optimal yield-per-recruit occurred at 60 cm for F > 0.5, but for M = 0.2, optimum lengths were less than 51 cm even at high levels of fishing mortality (Fig. 15). When fishing mortality is greater than 0.3, optimal values-per-recruit were attained at 66 cm for M = 0.1 and 0.13 but 60 cm for M = 0.2. Thus, at the higher level of natural mortality, sablefish should be exploited at lengths 6-10 cm smaller than the optimal lengths corresponding to M = 0.1 and 0.13.

Discussion

The natural mortality estimate of 0.13 derived in this study is similar to the value of 0.11 obtained by Funk and Bracken (1984), but significantly lower than the values of 0.19-0.25 published by Low et al. (1976) and Maeda and Hankin (1983). Since optimum sizes at entry are very sensitive to the value of M (Fig. 15), precise estimates of M are required. Ageing validation studies by Beamish and Chilton (1982) suggest that sablefish are much older than previously thought and that the lower mortality rates are applicable.

Estimates of fishing mortality ranged from 0.16-0.63 under the assumptions of constant recruitment and mortality for ages 4+ in the sample. The high correlations found in the regressions of ln-frequency versus age indicate that these assumptions were not violated. The

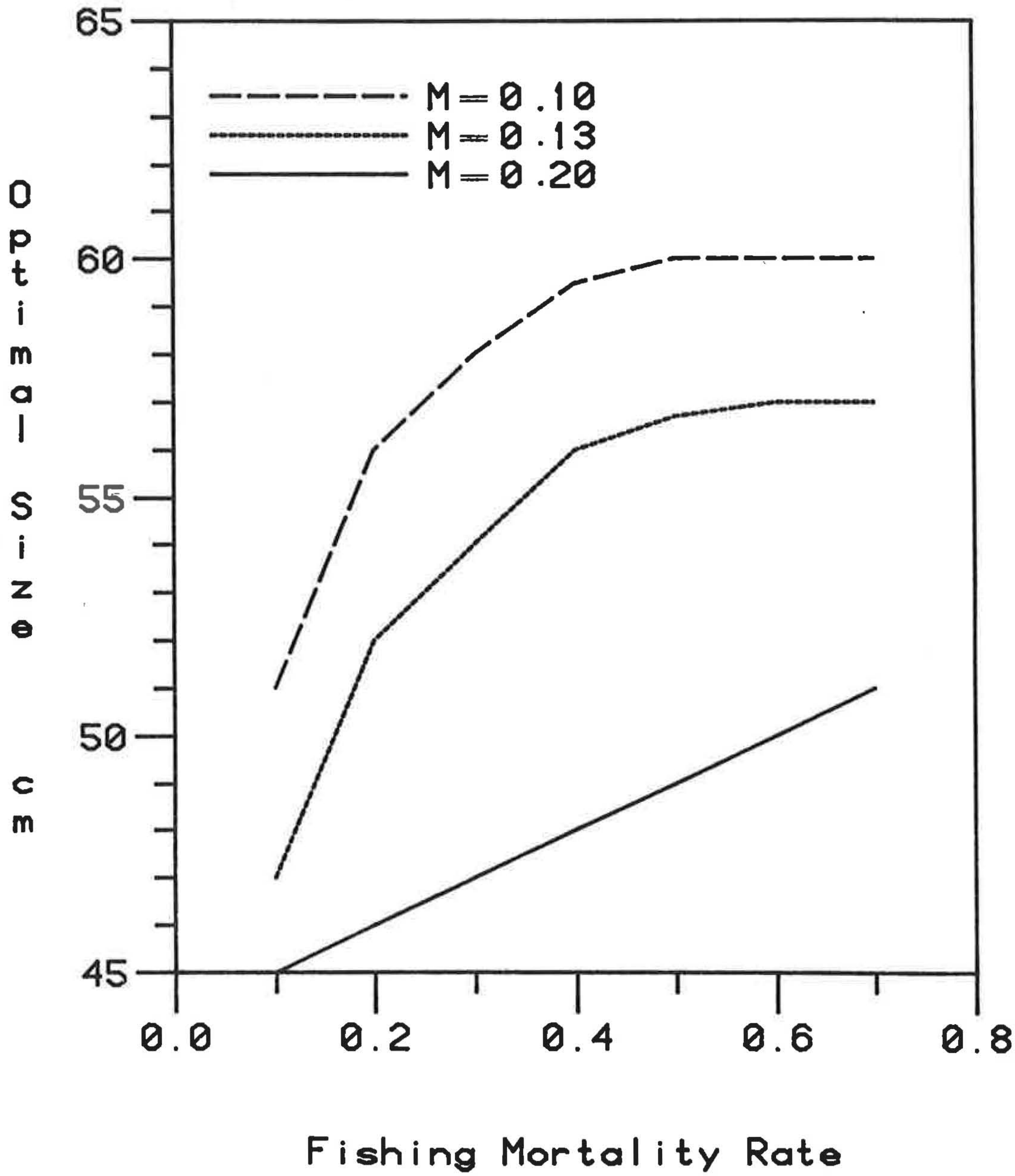

Fig. 15.--Columbia area eumetric fishing curves for natural mortality rates (M) of 0.10, 0.13 and 0.20.

estimate of F = 0.63 seems excessively high, implying a very intensive fishery. I suspect F is more likely equal to 0.3, which still suggests an intensive fishery since F is over two times the natural mortality rate.

For F = 0.3, yield-per-recruit and value-per-recruit are optimized at entry lengths of 54 and 60 cm, respectively. Higher fishing mortalities would require a disproportionate increase in fishing effort with only marginal increases in yield and value. A balance between maximizing yield and value at the suspected range of F (0.3-0.4) would be an entry length of 60 cm since the yield curve is flat over entry lengths of 54-60 cm, whereas the value curve increases sharply over this range.

At the suspected level of fishing intensity, the present minimum size limit of 52 cm is near the optimum for maximizing yield in weight. Increasing the size at entry to 60 cm would decrease the yield/recruit only 5% but would increase value/recruit 31%. Fishermen would receive $1.65/ recruit with a 60 cm size limit compared to $1.26/recruit with the present size limit. By delaying harvest until fish grow into the medium size category (>60 cm), fishermen would increase their gross revenues by about one-third.

Low et al. (1976) estimated M = 0.22 and found that yield-per-recruit was maximized with an entry level of 51 cm for F = 0.3; at M = 0.15, they found that an entry length of 55 cm maximizes yield, which is equivalent to the value reported here. Using M = 0.11, Funk and Bracken (1984) found that optimal entry size increased from 47-53 cm as

F increased from 0.1 to 0.5 -- slightly smaller sizes due to the lower estimate of natural mortality.

Brody growth coefficients (K) varied between 0.16-0.34 for males and 0.11-0.42 for females among the Gulf of Alaska (Lai, 1985) and Columbia INPFC areas. Yet the eumetric fishing curves were very similar over this range of growth coefficients. For F = 0.2, yield is maximized at entry lengths of 54-57 cm among the four INPFC regions. Therefore growth parameters are not as critical as M for determining optimal sizes at entry.

Faster growth rates occurred in the Gulf of Alaska than the Columbia INPFC area. Optimal yield and value were highest in the Shumagin-Chirikof and Yakutat areas and lowest in the Columbia area, which suggests greater productivity in the Gulf of Alaska than the Washington-Oregon-California coast. Stauffer and McDevitt (in prep.) surmised that the center of sablefish abundance is the Gulf of Alaska. They found that production rates (catch per unit area of habitat) were lower in the Bering Sea, Aleutian Islands and WOC coast when compared to the Gulf of Alaska.

Chapter 6

Management Implications for an Increased Size at Entry

In the last chapter, higher ex-vessel revenues were found to occur when the size at entry is increased above the present minimum size limit of 52 cm. Over the length range of 52-60 cm, increased revenues result because the growth in value of surviving sablefish exceeds the value lost due to natural deaths. A 60 cm size at entry would delay harvest until males attain an age of 9.2 years and females 6.8 years. Such a delay would increase ex-vessel revenues by one-third, assuming:

1) The natural mortality rate is less than 0.15; at higher rates of M, delayed harvest does not increase revenues.
2) Fishing mortality is at least 0.2. Gross revenues increase 19% and 46% for fishing mortalities of 0.2 and 0.4.
3) Ex-vessel prices for large, medium and small sablefish retain a ratio of 2.5:1.8:1. In particular, the prices of medium and large sablefish must be significantly higher than the price for smalls.

All of these assumptions appear to be valid, but the least certainty is associated with the assumption of $M < 0.15$.

Under the above assumptions, an increase in the length at entry from 52 to 60 cm would not alter yield but would increase the value. An increased size at entry would cause immediate but short-term decreases in yield and revenue. Although increased revenues would likely occur after two years, the full benefit of delayed harvest to 60 cm would not be realized until five years later because the age at entry is increased 5 years for males and 4 years for females.

Minimum retention lengths of 52 and 60 cm correspond to mesh sizes of 113 mm (4.5 in.) and 133 mm (5.25 in.), respectively (Table 9). Assuming the growth and mortality parameters found in this study are representative, higher ex-vessel revenues would result from establishing a minimum size limit of 60 cm and/or a mesh size limitation of 133 mm. The advantage of a mesh size limitation is that incidental captures and discards of small sablefish would be reduced, at least for trap and set-net gear. A 60 cm minimum size limit, on the other hand, would be easier to enforce since the amount of undersized sablefish would be recorded as smalls (< 2.3 kg or 5 lbs) on fish tickets.

With any change in the length at entry, the resulting sex ratio must be considered. Sex ratios for set-net mesh sizes of 133-140 mm were 56% female, so an increase in the entry length to 60 cm would not significantly alter the sex ratio. Mesh sizes greater than 148 mm harvest a high proportion of females (Table 14), so mesh sizes should be decreased in the commercial set-net fishery. For trawl and trap gear, mesh sizes should be increased.

Trawl, trap, longline and set-net fishermen would all be differentially affected by minimum size/mesh size regulations. Klein (1984) found that sablefish catch rates (catch per 100 fathoms of net) from 133 and 152 mm mesh set-nets were equivalent. Therefore, set-net fishermen would not suffer a loss in yield by using smaller mesh sizes, but revenues would decrease since smaller fish are captured.

Trap fishermen commonly use a 102 mm mesh size, so a 30 mm increase in mesh size is necessary to avoid captures of small sablefish. Thus trap fishermen would experience decreases in yield and revenue until the benefits of delayed harvest occurred 2-5 years later. Mesh size regulations could be phased in gradually to minimize these immediate losses.

Incidental catch allowances of undersized sablefish, coupled with a 60 cm size limit, would have to be implemented to equitably allocate resources, particularly for the longline and trawl fisheries. Longline selection, of course, cannot be controlled by mesh size limitations. Since hook selection is much broader than mesh size selection, it is doubtful whether a regulation on hook size could reduce captures of small sablefish. Although the selection range of longline gear is 45-90 cm, landings average 67% large sablefish. With an incidental allowance for small sablefish, longline fishermen would only benefit from size limit/mesh size regulation.

Trawl fishermen would probably not benefit from an increase in the size at entry. Coastwide, sablefish comprise less than 10% of the trawl groundfish landings. Also, large sablefish are able to avoid trawls. For trawl gear then, the issue is how to control captures of small sablefish, particularly since mesh size does not necessarily control the size at entry (Chapter 4). Assuming 40% of the trawl catch is graded small (Table 11), 3,000 mt of small sablefish was landed off the WOC coast in 1984. This tonnage represents 25% of the 1984 sablefish landings (all gears combined) but only 4% of the 1984 groundfish landings.

Gaining the full benefit of increased revenues from a 60 cm length at entry requires little or no fishing mortality upon small sablefish, including discards. Trawl gear is selective for small sablefish, and one way to reduce captures of small sablefish is to prohibit trawlers from retaining this species. However, even if trawlers are prohibited from landing sablefish, mortality upon discarded fish will occur.

In the case of trawls, the harvest of small sablefish could be controlled in two ways: (1) a minimum size limit with an incidental catch allowance for undersized sablefish, or (2) the prohibition of trawl landings of sablefish. To equitably allocate sablefish resources, the first method is preferred. The degree to which trawlers can reduce captures of small sablefish with a minimum size limit/incidental catch allowance must be addressed for both roller and bottom trawl gears. Survival rates of discarded sablefish must also be quantified.

An increase in the size at entry also has important implications for future recruitment, most notably due to an increase in the percentage of mature fish, and secondly, because of the increase in the average age of the population. Length at 50% maturity is 52 cm for males and 58 cm for females (Mason et al., 1983) so by increasing the size at entry to 60 cm, captures of immature sablefish would be reduced and equilibrium spawning biomass would be increased. A maximum mesh size regulation insures a male:female ratio of unity and probably increases the number of age groups in the population.

Leaman and Beamish (1984) assert that the longevity in many species, including sablefish, is an adaptive mechanism for ensuring evolutionary persistence under reproductive uncertainty. Year class strength is highly variable in sablefish and the strong 1977 year class has sustained sablefish fisheries from Canada to the Bering Sea from 1981 to the present. In order for the species to produce strong year classes, an abundance of older, sexually mature fish may be necessary to take advantage of conditions which promote them (McFarlane and Beamish, 1983b). Accordingly, it appears that mesh sizes of 125-145 mm are appropriate not only for maximizing yield and value, but also for maintaining the stock composition, sex ratio and longevity at levels that maximize recruitment.

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APPENDIX

FORTRAN Program for Yield-per-Recruit Analysis

```
$RESET FREE
FILE  1(TITLE="YIELD/PER/RECRUIT/VB/INPUT3",FILETYPE=7,KIND=DISK)
FILE  2(TITLE="YIELD/PER/RECRUIT/VB/OUTPUT",KIND=PRINTER,MAXRECSIZE=21)
FILE  3(TITLE="YIELD/PER/RECRUIT/VB/PLOT4",KIND=DISK,MAXRECSIZE=14)

CCC --- PURPOSE -----------------------------------------------------------
C
C   For fixed fishing mortalities and varying sizes at entry (45-70 cm),
C     (1) yield in kg per recruit and (2) economic yield in dollars
C     per recruit is calculated by a modified Beverton-Holt yield-per-
C     recruit model.

CCC --- VARIABLES ---------------------------------------------------------

      INTEGER  I, J, L, N

      REAL     TO(2), K(2), LMAX(2), A, B, T, LR, TL, TC(2), M, F, X,
     .         PRICE(5), Y(2), PYIELD(2), EY(2), YIELD(100),EYIELD(100),
     .         WT(100), AGE, TR(2)

C     DEFINITIONS
C
C       I = LOOP INDEX
C       J = SEX (1=MALE, 2=FEMALE)
C       L = LENGTH (CM)
C       F = INSTANTANEOUS FISHING MORTALITY COEFFICIENT
C       M = INSTANTANEOUS NATURAL MORTALITY COEFFICIENT
C       N = NUMBER OF GROWTH CURVES USED IN RUN
C       T = TIME STEP (0.1 YRS)
C       X = AGE (YEARS) AT MIDPOINT OF TIME INTERVAL
C       AGE = AGE IN YEARS
C       LR = LENGTH AT RECRUITMENT ONTO FISHING GROUNDS (CM)
C       TR(J) = AGE AT RECRUITMENT ONTO FISHING GROUNDS (YEARS), BY SEX
C       TC(J) = AGE AT RECRUITMENT INTO FISHERY (YEARS), BY SEX
C       TL = MAXIMUM AGE
C       WT(L) = WEIGHT (KG) CORRESPONDING TO LENGTH L
C       A,B = LENGTH-WEIGHT PARAMETERS:  WT(L) = A*(LENGTH)**B
C       TO(J),K(J),LMAX(J) = VON VERTALANFFY GROWTH PARAMETERS, BY SEX:
C         TO = THEORETICAL AGE CORRESPONDING TO ZERO LENGTH
C         K  = BRODY GROWTH COEFFICIENT
C         LMAX = ASYMPTOTIC LENGTH
C       PRICE(I) = EX-VESSEL PRICE, BY SIZE CATEGORY:
C         (1 = SMALL, 2 = MEDIUM, 3 = LARGE)
C       PYIELD(J) = PARTIAL YIELD (KG/REC), BY SEX, CORR. TO A SINGLE
C                   AGE AND SEX; SUMMATION OVER AGE = Y(J)
C       Y(J) = YIELD PER RECRUIT (KG/REC), BY SEX, SUMMED OVER LIFESPAN
C       YIELD(L) = YIELD PER RECRUIT (KG/REC), BOTH SEXES COMBINED,
C                  SUMMED OVER LIFESPAN FOR TC=L
C       EY(J) = ECONOMIC YIELD PER RECRUIT (DOLLARS/REC), BY SEX, CORR.
C               TO A SINGLE AGE AND SEX
C       EYIELD(L) = ECONOMIC YIELD PER RECRUIT (DOLLARS/REC), BOTH SEXES
C                   COMBINED, SUMMED OVER LIFESPAN FOR TC=L
```

```
C --- INPUT KNOWN AND SIMULATED PARAMETERS -----------------------------

      READ (1,1) T, TL, A, B, (PRICE(J), J=1,3)
      DO 100  I=1,1
       READ (1,2) (TO(J), K(J), LMAX(J), J=1,2)
        DO 110  M=.1,.21,.1
          DO 120  F=.1,.71,.1
            DO 130  LR=45,46,5

C --- CALCULATE AGE AT RECRUITMENT FROM LENGTH AND ECHO INPUT ----------

      DO 300  J=1,2
        TR(J) = TO(J) - (1.0/K(J)) * ALOG(1.0 - LR/LMAX(J))
300   CONTINUE

      WRITE(2,20) T,LR,(TR(J),J=1,2),TL,M,F,(LMAX(J),K(J),TO(J), J=1,2),
     .            A,B,(PRICE(J), J=1,3)

C --- CALCULATE YIELD AND ECONOMIC YIELD FOR EACH ENTRY SIZE -----------

      WRITE (2,50)
      WRITE (3,60)

      DO 500  L=45,70
        EYIELD(L) = 0.0
        Y(1) = 0.0
        Y(2) = 0.0
          DO 510  J=1,2
            TC(J) = TO(J) - (1.0/K(J)) * ALOG(1.0 - L/LMAX(J))

            DO 520  AGE=TC(J),TL,T
              X = AGE + T/2.0
              PYIELD(J) = F*EXP(-M*(TC(J)-TR(J)))*EXP(-(M+F)*(X-TC(J)))
     .          * (A*(LMAX(J)*(1.0 - EXP(-K(J)*(X-TO(J)))))**B) * T
              Y(J) = Y(J) + PYIELD(J)

              WT(L) = A*(LMAX(J) * (1.0 - EXP(-K(J)*(AGE - TO(J)))))**B
              IF (WT(L) .LT. 2.2)  EY(J) = PYIELD(J) * PRICE(1)
              IF ((WT(L) .GE. 2.2) .AND. (WT(L) .LE. 3.2))
     .          EY(J) = PYIELD(J) * PRICE(2)
              IF (WT(L) .GT. 3.2)   EY(J) = PYIELD(J) * PRICE(3)

              EYIELD(L) = EYIELD(L) + EY(J)

520         CONTINUE
510       CONTINUE
        YIELD(L) = Y(1) + Y(2)
        WRITE (2,51) L,TC(1),Y(1),TC(2),Y(2),YIELD(L),EYIELD(L)
        WRITE (3,61) L,YIELD(L),EYIELD(L)
500   CONTINUE
130         CONTINUE
120       CONTINUE
110     CONTINUE
100   CONTINUE
```

```
CCC --- FORMAT STATEMENTS ---------------------------------------------

1       FORMAT (F3.1,F4.0,F13.12,F7.5,3F4.2)
2       FORMAT (6F8.5)
20      FORMAT (//1H1,'YIELD PER RECRUIT (KG/RECR) AND ECONOMIC YIELD',
     .   ' (DOLLARS/RECR) WITH:'//8X,'TIME STEP = ',F3.1,' YEARS'/
     .  /8X,'LENGTH AT RECRUITMENT = ',F4.1,' CM',5X,'MALES = ',F3.1,
     .   ' YRS    FEMALES = ',F3.1,' YRS'//8X,'MAXIMUM AGE = ',F4.1//
     .  8X,'NATURAL MORTALITY = ',F3.2,'/YR',5X,'FISHING MORTALITY = ',
     .  F3.2,'/YR'//8X,
     .  'LENGTH AT AGE:  MALES',5X,'LENGTH(CM) = ',F7.4,' * (1 - EXP(-',
     .  F6.4,' * (AGE - (',F7.4,'))))'/
     .   24X,'FEMALES',3X,'LENGTH(CM) = ',F7.4,' * (1 - EXP(-',F6.4,
     .  ' * (AGE - (',F7.4,'))))'//8X,
     .  'WEIGHT AT LENGTH:  WEIGHT(KG) = ',E11.6,'*(LENGTH)**',F6.4//8X,
     .  'PRICE STRUCTURE:  SMALL  $',F3.2,'/KG'/8X,
     .  '                  MEDIUM $',F3.2,'/KG'/8X,
     .  '                  LARGE  $',F3.2,'/KG')
50      FORMAT (///,5X,' ENTRY ',5X,'AGE OF',4X,'YIELD/REC',5X,'AGE OF',
     .  5X,'YIELD/REC',5X,'TOTAL',5X,'ECONOMIC',/6X,'SIZE',7X,'MALES',
     .  7X,'MALES',7X,'FEMALES',5X,'FEMALES',4X,'YIELD/REC',3X,
     .  'YIELD/REC'//)
51      FORMAT (6X,F4.1,7X,F5.2,7X,F5.3,7X,F5.2,8X,F5.3,6X,F7.4,5X,F6.4)
60      FORMAT (/)
61      FORMAT (I5,2F8.4)

        LOCK 2
        LOCK 3
        STOP
        END
```