INVESTIGATION OF THE ABUNDANCE AND RECRUITMENT OF BOTTOMFISH OFF OREGON

SUBTITLE: ESTIMATED YIELDS OF DOVER SOLE (*MICROSTOMUS PACIFICUS*) IN WATERS OFF NORTHERN OREGON-SOUTHERN WASHINGTON

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INTRODUCTION

Dover sole (*Microstomus pacificus*) has been subject to intensive fishing in waters off northern Oregon-southern Washington (specifically PMFC Area 2D[1/]) since 1941 (Harry, 1956). This species has always been an important contributor to the trawl fishery and has been the most valuable species of groundfish landed in Oregon since 1966. Because of its importance in the fishery the Dover sole was chosen as the first species to be considered in a major program designed to investigate the population dynamics of Oregon groundfish. The most important segment of the study on sole was the calculation of potential levels of productivity or yield. This paper deals with the methods and results of those calculations.

CALCULATION OF PARAMETERS

In analyzing the potential productivity of the fishery reasonable estimates of fishing rate (F), recruitment (N), the proportion of each age class landed (U), and the age-specific weight (W) were determined for the present fishery. Next, it was postulated how changes in either age of entry or fishing intensity would affect these four parameters of the yield equation. As the last step, predicted yields were computed for several alternatives to present fishing practices. Specifically, yield was estimated at fishing rates of 0.5, 1.0, and 2.0 times present rates, for ages at entry varied simultaneously of 4, 5, 6, and 7 years. Because growth and mortality rates differ by sex the yield equation was evaluated by sex.

1/ *In 1968 Area 2D was incorporated into Area 3A. For purposes of this report, however, the 2D designation is retained.*

Age Composition of the Catch

Samples of the catch consist of about equal numbers of males and females. Relatively scarce age classes may not be represented in all annual samples, therefore sampling results were averaged for years 1966 through 1970 (Table 1).

Table 1. Average Age Composition by Sex and Average Weight Per Fish by Age and Sex in the Dover Sole Catch in PMFC Area 2D, 1966 through 1970.

Age Class	Proportion of Numerical Catch		Average Weight (Kg)	
	Male	Female	Male	Female
4	0.0004	0.0002	0.17	0.18
5	0.0108	0.0082	0.22	0.25
6	0.0849	0.0721	0.28	0.32
7	0.1640	0.1598	0.34	0.39
8	0.1986	0.2050	0.41	0.47
9	0.1740	0.1620	0.47	0.56
10	0.1375	0.1271	0.54	0.64
11	0.0931	0.0837	0.62	0.73
12	0.0689	0.0646	0.69	0.83
13	0.0366	0.0433	0.76	0.92
14	0.0170	0.0311	0.84	1.04
15	0.0088	0.0153	0.92	1.14
16	0.0030	0.0126	1.00	1.24
17	0.0014	0.0072	1.08	1.34
18	0.0002	0.0040	1.16	1.45
19	0.0002	0.0016	1.25	1.57
20	0.0006	0.0020	1.33	1.68

Weight by Sex

The following identity relates total numerical catch by sex to total catch in weight:

$$\overline{W}(\text{male}) \times C(\text{male}) + \overline{W}(\text{female}) \times C(\text{female}) = \text{Total Weight} \quad (1)$$

where $\overline{W}$ = average weight of an individual fish

C = total commercial catch in numbers

Total weight = average annual catch in kilograms (kg) (years 1965 through 1970 = 685,000 kg).

Average weight of an individual fish is obtained by combining the age composition and average weight data in Table 1 by:

$$\overline{W} = A' W \quad (2)$$

where $\overline{W}$ = average weight of a fish in the commercial catch,

$A' = (a_4, a_5, \ldots a_{20})$, the row vector in which an element is the proportion of the total catch made up of a given age class.

$W = (w_4, w_5, \ldots w_{20})$, the column vector in which an element is the average weight of a fish in a given age class.

The above computation was performed for each sex. For the commercial catch, the estimate of $\overline{W}$(male) is 0.48 kg and $\overline{W}$(female) 0.60 kg.

Numbers Caught by Age Class

Given the estimates of average weight the catch equation (1) was solved by a graphical procedure after introducing the condition that catches of males and females aged 4-10 were equivalent. This condition was based on the observation that in landed catches the numerical frequencies of age classes 4-10 are approximately the same. The estimate of the average annual catch is 616,000 males and 649,000 females. These values multiplied by the relative frequency of each age class gives the numerical age composition of the annual catch (Table 2).

Total Mortality

The catch curves for both sexes are convex and implies that mortality increases with age. The left limb of the catch curve is terminated at age 10 because, as explained later, age 10 is considered to be the first age fully exploited. Total mortality rates for ages <10 were assumed to be equal to age class 10 because mortality data for younger age classes are not available.

Total annual mortality rates, for age classes $\geq$10 was estimated by fitting short line segments by eye to the catch curve. The estimate of total mortality is the slope of the line segment coupling a particular age class to the next older age class (Table 3). Males appear to have a higher mortality rate than females.

Table 2. Estimated Average Annual Number of Dover Sole Caught in PMFC Area 2D, 1966-70.

Age Class	Catch, Thousands of Fish		
	Male	Female	Average
4	--	--	0.2
5	--	--	6.0
6	--	--	49.5
7	--	--	102.4
8	--	--	127.6
9	--	--	106.2
10	--	--	83.6
11	57.3	54.3	--
12	42.4	41.9	--
13	22.5	28.1	--
14	10.4	20.2	--
15	5.4	9.9	--
16	1.8	8.2	--
17	0.9	4.7	--
18	0.1	2.6	--
19	0.1	1.0	--
≥20	0.4	1.3	--

Table 3. Estimated Total Annual Mortality Rates for Dover Sole in PMFC Area 2D, 1966-70

Age Class	Annual Rate of Total Mortality	
	Male	Female
10	0.30	0.30
11	0.30	0.30
12	0.43	0.30
13	0.43	0.30
14	0.54	0.40
15	0.54	0.40
16	0.54	0.40
≥17	0.54	0.40

There is some evidence that older fish, particularly males, migrate to deep water and tend to remain there beyond the range of the commercial fishery (Westrheim and Morgan, 1963). Such behavior would remove fish from the fishing area and thus reduce yield. Quantitative evidence on the extent of this migrational habit is not available.

Rates of total mortality could increase with age because of systematic errors in aging. As Dover sole age, growth slows, and year marks on scales become closely spaced and difficult to distinguish. Older fish thus tend to be underaged and since adult males grow more slowly than females we would expect more frequent underaging for males. This would lead to the erroneous conclusion that males die off more rapidly than females. Underaging will affect yield analysis since erroneously high estimates of mortality rates for older age classes will justify premature exploitation of younger age classes.

Rate of Fishing

A tagging study conducted in 1964 provides a means of estimating the overall rate of fishing in Area 2D (Milburn, 1966). Lengths of tagged fish generally exceeded 30 cm and were therefore physically subject to capture with commercial gear. Fishing rate on tagged fish was assumed to be the same as that for the larger population of untagged fish.

The average annual fishing rate is estimated as follows:

$$\bar{F} = \Sigma R_i / \Sigma T_i \qquad (3)$$

where $\bar{F}$ = average annual fishing rate,

R_i = number of tag returns in year i (i = 1, 2, ...6), (ΣR_i = 630),

T_i = estimated number of tagged fish at large at beginning of year i.

We estimated the number of tagged fish in the population at the beginning of each year (T_i) during the recovery period:

$$T_i = 2{,}718 \exp -0.5570\ (i - 1). \qquad (4)$$

In which:

2,718 = number of tagged fish released at the beginning of the recovery period,

-0.5570 = instantaneous rate of total mortality of tagged fish as estimated from recovery data.

The instantaneous rate of total mortality was estimated by computing the slope of the weighted linear regression of ln R_i upon i. The values of ln R_i were weighted by the corresponding number of tag recaptures. This weighting increased the importance of data collected during early years of the recovery period when tagged fish were more abundant. The weighted regression analysis identified the source of approximately 97% of the observed variation in ln R_i.

Substituting in equation (3), $\overline{F}$ = 630/6,142 = 0.10, the estimated average fishing rate of ages 10 and greater. This applies only to the fully exploited age classes.

Fishing rate for partially recruited age classes was estimated as follows:

$$f_i = C_i / u_i N_i, \qquad (5)$$

where: i = subscript denoting a partially recruited (i = 4, 5, 6, 7, 8) age class

C = total catch of age class landed

u = proportion of actual catch landed

N = estimated numerical size of age class. Age specific fishing rates are shown in Table 4.

Table 4. Estimated Annual Fishing Rate for Dover Sole in PMFC Area 2D, 1966-70

Age	Fishing Rate
4	0.0040
5	0.0376
6	0.0651
7	0.0664
8	0.0819
9	0.0902
≥10	0.1000

Natural Mortality

The annual rate of natural mortality was obtained for each age class and sex by subtracting the fishing rate 0.10 from annual rates of total mortality recorded in Table 3. The estimated annual rate of natural mortality for age 10 was applied to all younger fish of both sexes (Table 5).

Table 5. Estimated Annual Natural Mortality Rates for Dover Sole in PMFC Area 2D

Age Class	Annual Natural Mortality Rate Male	Female
≤10	0.20	0.20
11	0.20	0.20
12	0.33	0.20
13	0.33	0.20
14	0.44	0.30
15	0.44	0.30
16	0.44	0.30
≥17	0.44	0.30

Utilization of the Catch

The estimated commercial catch shown in Table 2 does not include small fish discarded at sea. An estimate of the discard was obtained from sampling-at-sea experiments between 1959 and 1961. Size composition was determined at sea before sorting and again at landing (Figure 1). Estimates of utilization or that part of the catch retained for market under present fishing practices is shown in Table 6. These values are based on mean length at age instead of the length range by age. Thus estimates of utilization levels are too high. This results in an underestimate of age at full utilization.

Table 6. Utilization Factors of the Catch of Dover Sole by Age in PMFC Area 2D, 1966-70

Age Class	Proportion Retained
4	0.01
5	0.04
6	0.25
7	0.69
8	0.95
≥9	1.00

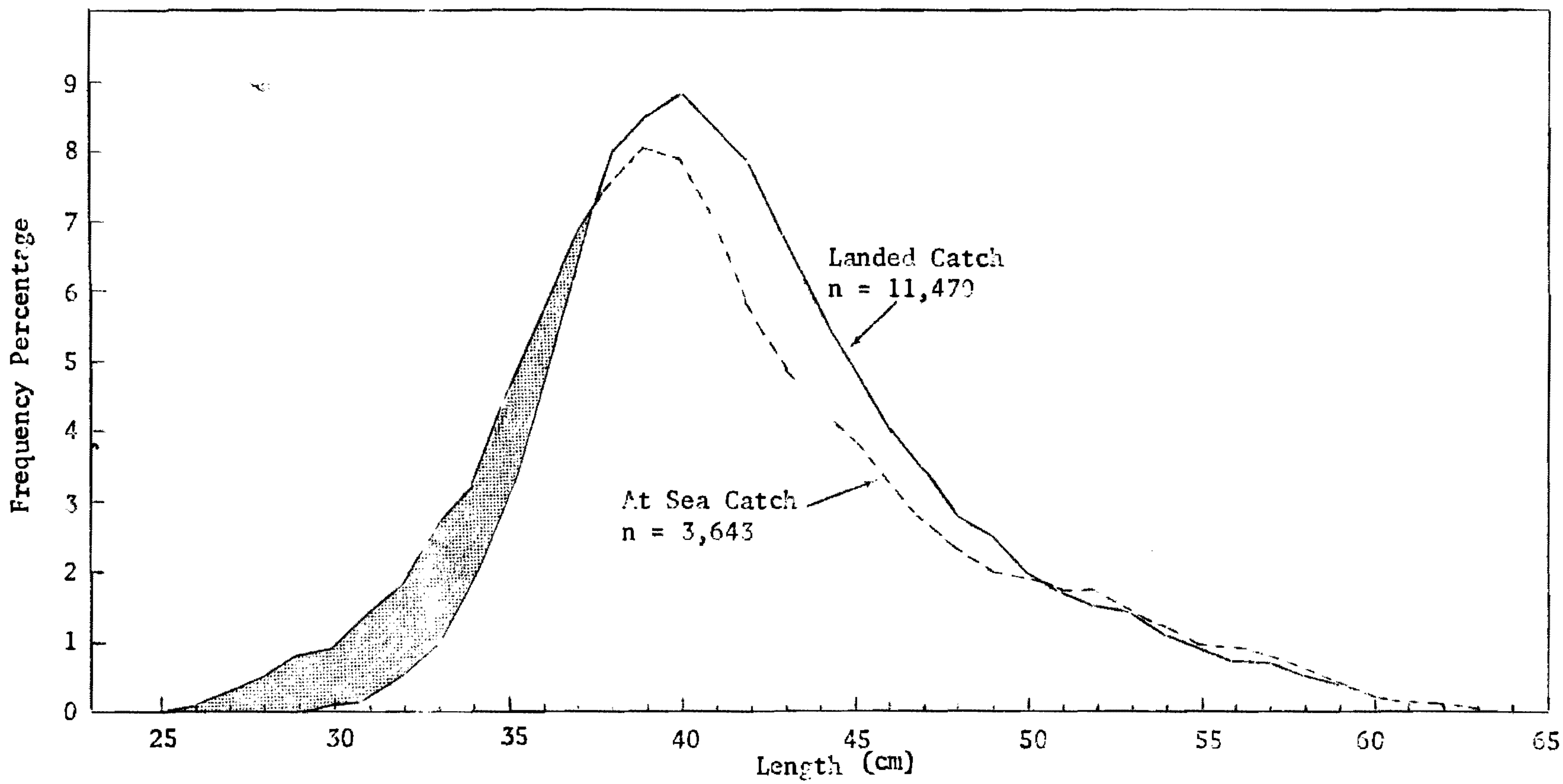

Figure 1. Length Frequency of Dover Sole Illustrating the Difference between What is Caught and What is Landed. The Shaded Area is the Discard.

Catch utilization factors were not estimated by sex because such data are not available. The graphical procedure used is too insensitive to discriminate differences between sexes. Fortunately, size differences between sexes are not pronounced except for fully utilized age classes.

Figure 2 shows how age and size of fish relate to their physical vulnerability to fishing gear and their utilization in the catch. These relations would have an important bearing on sustained yield if minimum mesh size of trawls were increased to reduce wastage.

The heavy line shows the curve of average length by age of fish landed. The thin line merging from below is the curve of average length by age for the population on the fishing grounds. The population growth curve is based on an FCO survey conducted in 1966 with a small-meshed trawl. Differences in the curves between fish plant and population samples vanish for fully exploited and utilized age classes. The point of tangency occurs at about age 10. Both curves were drawn by eye.

The two lines parallel to the population growth curve show the approximate 2σ bounds on variation of length of individual fish within age classes. Comparison of sizes of fish sampled at fillet plants with those caught demonstrates that fishermen keep virtually all fish greater than 37 cm, but discard almost all fish less than 29 cm. Horizontal lines in Figure 2 show the significance of culling. The line of 100% commercial retention length intersects the lower 2σ bound on the population growth curve between age classes 10 and 11, illustrating that all fish within a year class do not reach commercially acceptable size until age 10 or so. The line of 0% commercial retention length intersects the upper 2σ bound on the population growth curve at about age 4. This is expected since commercial landings include few 4-year-old fish. Graphical contrast between fishing gear

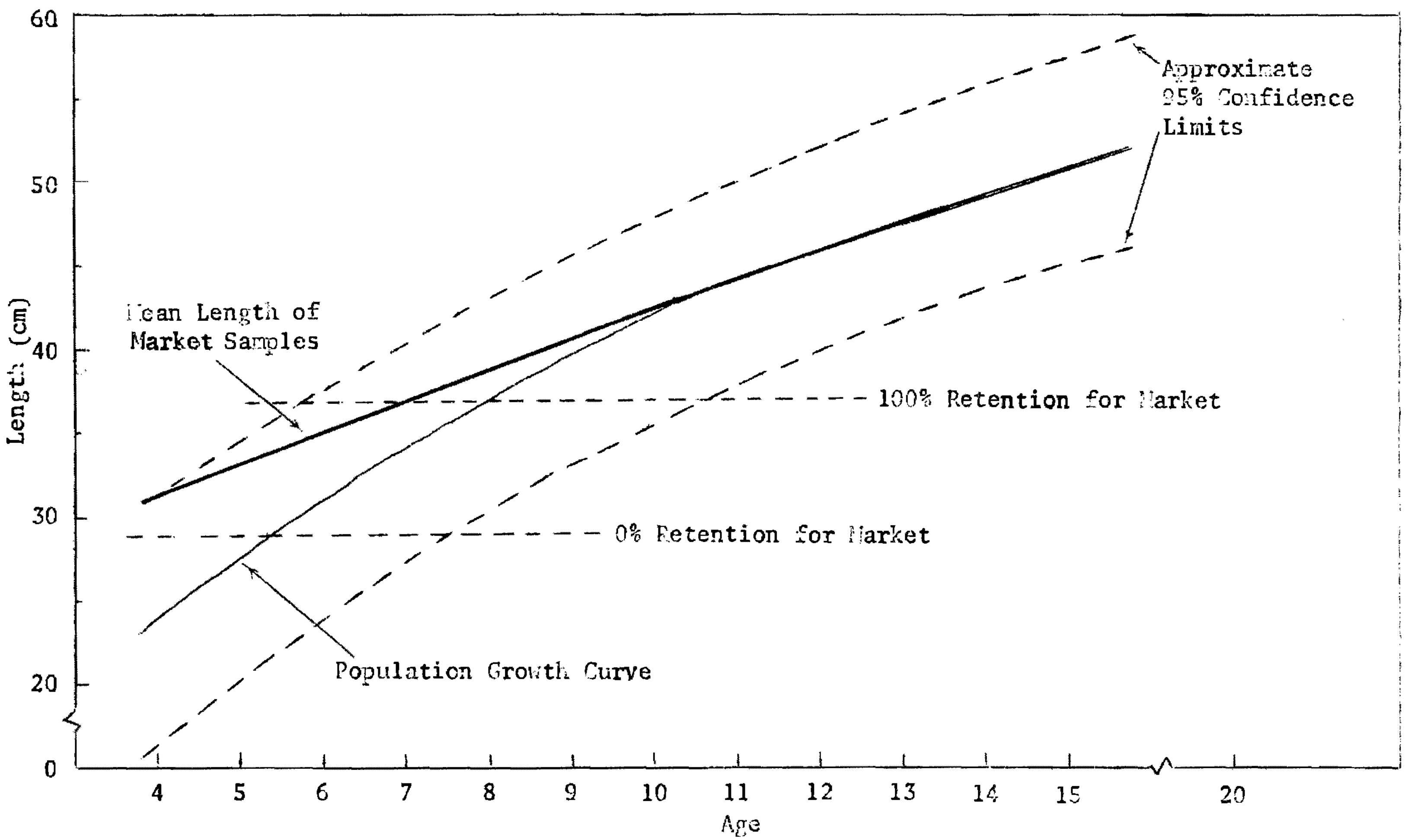

Figure 2. Growth Curves of Dover Sole As Indicated By Population Surveys and Market Samples. The 95% Confidence Limits Apply Only to the Population Curve.

effectiveness and market requirements shows that gear used in the present fishery is capable of catching all commercial size fish within the population. A decrease in present mesh size would result in an appreciable increase in the catch of unmarketable fish with little or no improvement in the commercial catch.

Marketing requirements determine present fishing practices. Fishing gear in common use maximizes the catch of available, commercially usable fish at the risk of reducing future productivity of the fishery through wastage of small fish. Analysis of potential fishery productivity should consider the probable result of increasing mesh size to conserve small unmarketable fish. For example suppose mesh size was regulated to prevent capture of unmarketable fish <37 cm. To accomplish this, the 0% retention length would have to be increased to 37 cm and would intersect the upper 2σ bound on the population growth curve at age 6. This means that any mesh regulation guarantying protection of all undersized Dover sole would force age at entry to age 6. With no capture of unmarketable fish, all age specific catch utilization factors would become 1.0.

If 0% retention length of the fishing gear is set to equal the upper 2σ bound of the population growth curve at age 4, minimum age at entry becomes 5 years. If minimum age at entry were increased to 5 years, then all fish caught would exceed the 0% retention length for market use, and all fish caught would have some probability of being included in the marketed catch. Catch utilization factors for ages 5 through 8 would obviously be greater than at present. To estimate them a hypothetical utilizalton curve was constructed assuming 50% utilization of 5-year-old fish and 100% utilization at age 9. From this curve the following set of catch utilization factors were obtained:

Age	Utilization Factor
5	0.50
6	0.60
7	0.80
8	0.95
≥ 9	1.00

Recruitment

A yield equation requires an estimate of the number of fish recruited to each age class. Procedures used to estimate this ties together information developed in earlier sections on average fishing rate, age composition of the catch, natural mortality rates, and utilization of the catch. As the first step, the average catch of age class 10 was divided by the estimated average fishing rate to estimate recruitment to age class 10.

$$N_9 = N_{10} + (C_9) + 0.20\ N_9$$

$$0.80\ N_9 = (836.0 \times 10^3) + (106.2 \times 10^3)$$

$$N_9 = 1.178 \times 10^6$$

In general, for any age class i ($4 \leq i \leq 9$),

$$N_i = N_{i+1} + (C_i/u_i) + 0.20\ N_i \qquad (6)$$

where: i = age class

N = estimated recruitment,

C = commercial catch (Table 2)

u = catch utilization factor (Table 6)

0.20 = an assumed constant, the annual rate of natural mortality for all fish less than 10 years old.

This procedure determined recruitment to age class 4 to be approximately 5 million fish of each sex and was used in all yield calculations.

The following formula was used for estimating recruitment to successive age classes under present or hypothetical fishing conditions.

$$N_i = N_{(i-1)}\ s_{(i-1)} \qquad (7)$$

where, s is the annual rate of survival or the complement of the annual rate of total mortality.

As a check on the plausibility of these estimates the biomass of the population was estimated by summing the product of recruitment times average weight by age class and sex. The estimate of biomass was 12×10^6 kg (26×10^6 pounds). The point estimate from a population survey in 1971 was 4.7×10^6 kg (10×10^6 pounds) for the southern part of Area 2D. The fishing area in the southern part is 0.45 of Area 2D, thus the expanded point estimate of biomass is 10.4×10^6 kg (23×10^6 pounds). These results compare favorably.

Effect in Change of Fishing Intensity

Changes in yield were assessed by evaluating the yield equation with present fishing rate of F, 0.5 F, and 2F.

THE YIELD EQUATION

Quantitative relations of yield (catch) from a fishery may be expressed in matrix notation as follows: $Y = F' N U W$ (8)

The term Y is the equilibrium catch or sustained yield as defined by Ricker (1958): "The catch (by weight) taken from a fish stock when it is in equilibrium with fishing of a given intensity, and (apart from the effects of environmental variation) its density is not changing from 1 year to the next."

F is a vector of age-specific fishing rates. The age-specific fishing rate f_i is the fraction of fish initially present in an age class which is caught in the following fishing season, that is:

$$f_i = C_i / N_i \tag{9}$$

where C_i = catch of age class i and n_i = initial number (recruitment) of fish in age class i. For Dover sole in Area 2D, $F = (f_4, f_5, \ldots f_{20})$, since virtually all fish in the commercial catch fall within this age range.

This term N in the yield equation is a diagonal matrix, each element of which is the recruitment to a particular age class, that is:

$$N = \begin{bmatrix} n_4 & & 0 \\ & n_5 & \\ 0 & & \ddots n_{20} \end{bmatrix} \quad (10)$$

Recruitment to an age class is determined by recruitment to the leading age class (in this case n_4) and by mortality of n_4 and all intervening age classes.

The term U in equation (8) is a diagonal matrix. Elements of U specify the fraction of the catch of each age class actually landed, that is:

$$U = \begin{bmatrix} u_4 & & \\ & u_5 & \\ & & \ddots u_{20} \end{bmatrix} \quad (11)$$

Note: the matrix product $F' N U = C'$. $C' = (C_4, C_5 \ldots C_{20})$, the vector of commercial landings of Dover sole by age class.

Finally W in (8) is the vector of age-specific weights of commercially landed Dover sole. The vector product $(C'W = (C_5 W_5 + C_6 W_6 + \ldots C_{20}W_{20})$, is the catch produced by the fishery in a single year under prevailing equilibrium conditions of fishing intensity, population size, wastage, and average size of usable fish.

MAXIMUM EQUILIBRIUM YIELD

Under the imposed conditions of age at entry and fishing effort, maximum equilibrium catch occurs when age at entry is set at 6 years and fishing effort is doubled (Table 7). It is doubtful, however, if the economics of the fishery or the reproductive capacity of the species could

Table 7. Equilibrium Yield (Kg x 10^3) of Dover Sole in PMFC Area 2D.

Fishing Effort (1.0=present)	First Age of Capture 4	5	6	7
0.5				
Males	193	195	182	152
Females	247	251	238	205
Total	440	446	420	357
1.0				
Males	300	321	309	262
Females	376	403	394	345
Total	676	724	703	607
2.0				
Males	380	454	464	405
Females	459	550	570	513
Total	839	1,004	1,034	918

support a twofold increase in effort. However, yield from the fishery could increase in a modest manner if age at entry were increased to age 5 or 6 instead of the present age 4.

An increase in age at entry might have an additional beneficial result. The present fishery exerts a selective mortality upon the fastest growing fish, many of which are killed before they reproduce. This could cause genetic damage to the population. Genetic selection for slow growth traits would ultimately reduce fishery yield. An increase in age of entry to 5 or 6 years would moderate adverse genetic selection by allowing more fast growing fish to reproduce.

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