Appendix 6
English Sole

PROGRESS REPORT ON THE STATUS OF ENGLISH SOLE (*Parophrys vetulus*) IN THE INPFC VANCOUVER AND COLUMBIA AREAS AND RECOMMENDED ABC FOR 1987

by
Jim Golden

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OREGON DEPARTMENT OF FISH AND WILDLIFE
MARINE REGION
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STATUS OF ENGLISH SOLE (*Parophrys vetulus*) IN THE INPFC COLUMBIA AND VANCOUVER AREAS AND RECOMMENDED ABC FOR 1987

SUMMARY

English sole catch-at-age data spanning 1966-1983 from the INPFC Columbia area and PMFC area 3B were used to conduct virtual population analysis (VPA) (Golden, et al., 1986). Estimated recruitment of three-year-old females was used in a dynamic pool model to estimate maximum sustainable yields (MSY) and equilibrium biomass for a range of fishing mortality rates, recruitments, and assumed stock recruitment parameters using a Beverton and Holt recruitment model (program POPSICLE).

Recruitment estimated by VPA has been lower than average and has had a declining trend since 1979. Using the low recruitment scenario, acceptable biological catch (ABC) for 1987 ranged from 551 to 1,088 mt in the INPFC Vancouver and Columbia areas. Recent catches have fallen within this range and there appears to be no point of concern at this time. Recent biomass levels appear to be capable of producing recruitment near the low recruitment scenario level of 4.5 million fish with the assumed stock recruitment relationship. The effects of the El Nino need to be monitored in the future to determine if recuitment of three-year-old fish falls below the low recruitment scenario levels.

METHODS

Three different estimates of recruitment of three-year-old English sole were obtained from VPA to initiate dynamic pool modeling after Pitcher and Hart (1982). Population numbers at age estimates were from mid-range starting F VPA described by Golden, et al. (1986). The low estimate of recruitment

(Table 1) was obtained by back calculating from the lowest VPA estimated numbers of five-year-old female English sole (1978 year-class) using F averaged over 1966-1983 and age specific catchabilities. Estimated numbers of age 3 fish in 1983 were the lowest observed in VPA, and were not used for two reasons. First, 1983 was the first year used to initiate VPA, and fishing mortality rate supplied at age 3 was conditioned to reflect incomplete vulnerability of fish. Second, recent recruitment may be much lower than average due to environmental conditions. The highest recruitment at age 3 was estimated by back calculating using the population numbers of the 1961 year-class from age 5. In addition to the previous low and high recruitment scenarios, VPA average population numbers at age 3 from 1966-1983 were used to drive the model.

In the first phase of simulation modeling, each level of recruitment in numbers at age 3 was used to set up a population in numbers of female English sole from ages 3 to 13. The population was then advanced forward in time using fishing mortality rates from F = .05 to F = 1.00. Each fishing mortality rate was applied for 100 years to bring the population into equilibrium with the stock recruit function (Lenarz and Hightower, 1985).

$$R_i = C \times B_s / (1 - A \times (1 - B_s/B_1))$$

where: R_i = recruits in numbers in year i

C = a constant relating weight in kg to numbers

K = age of recruitment

B_{i-k} = spawning biomass in kg of mature female English sole in year i-k

A = a constant describing shape of stock and recruitment curve

B_1 = spawning biomass in kg of mature female English sole, in absence of fishing mortality

Estimates of exploitable biomass and yield in metric tons were obtained and plotted. Fishing mortality at 10% of maximum slope of yield versus F was approximated by:

$$F_{0.1} = \frac{(Y_{n+1} - Y_n)/(F_{n+1} - F_n)}{(Y_2 - Y_1)/(F_2 - F_1)} = 0.1$$

Where: Y_n = Yield at a fishing mortality

Y_{n+1} = Yield at an adjacent fishing mortality rate to Y_n

F_1 = 0.025

F_2 = 0.050

A fixed F policy was selected to generate acceptable biological catches (ABCs) with F set at M, $F_{0.1}$ and F_{max}. This second phase of modeling included forecasting catches beyond 1986 using F = M, $F_{0.1}$ and F_{max} for low and average recruitment scenarios and a stock recruitment function which produces 95% of the recruits when spawning biomass under no fishing mortality ($^{r}(0.5)/r(1.0)$. F_{max} was the fishing mortality rate producing maximum sustainable yield. Fishing mortality rates were adjusted to produce yields observed or predicted for 1984-1986. VPA derived estimates of population numbers at age in fishing years 1981-1983 were used to generate estimated numbers of age 3 recruits in years 1984-1986. Short-term yields through the year 2000 were generated as well as 100 year yields (sustainable or equilibrium yields).

Acceptable biological catch (ABC) was corrected for discard, ages not included in the analysis, males, and catch from the U.S. portion of PMFC Area 3C using 1981-1985 catch data. ABCs were expressed as metric tons of potential landed catch of English sole from the INPFC Columbia and Vancouver areas, and were equal to 1.2306 X yields from dynamic pool modeling.

RESULTS AND RECOMMENDATIONS

Sustainable yields of female English sole from the INPFC Columbia Area and PMFC Area 3B ranged from 482 to 3,360 mt (Table 2). Maximum sustainable yields ranged from 524 to 3,360 mt and exploitable biomass at MSY ranged from 1,709 to 7,274 mt.

Acceptable biological catches (ABCs) in the INPFC Vancouver and Columbia areas ranged from 551 mt to 1,896 mt in 1987 with R(0.5)/R(1.0) = 0.95 under the low and average recruitment scenarios (Table 3). ABCs include catch of all age groups, males, and English sole in the U.S. Section of Area 3C, but exclude discarded fish. In the low recruitment scenario, $F_{0.1}$ = 0.40 came closest to maintaining the population at equilibrium in the short term. $F_{0.1}$ = 0.43 came closest to producing short-term equilibrium biomass with the average recruitment scenario. F_{max} = 0.80 produced the highest short- and long-term yields.

Since recruitment has been lower than average, the range of ABCs recommended were limited to those from the model assuming a low recruitment scenario. In 1987 the recommended ABCs for English sole in the INPFC Columbia and Vancouver areas range from 551 mt to 1,088 mt, while long-term equilibrium yields ranged from 636 to 773 mt. Projected catch in 1986 is estimated to be 754 mt.

Less risk is associated with the $F_{0.1}$ policy than with setting fishing rates at F_{max} since there is a 49% loss in spawning biomass for only a 6% gain in yield. Short-term penalties are high for adopting $F_{0.1}$, since a 31% loss in yield would occur in 1987 for a potential 23% gain in spawning biomass. ABC at $F_{0.1}$ is 751 mt in 1987. There is a sizeable penalty for choosing F=M. Long-term yields would be reduced 12% for a 36% gain in spawning biomass. Short-term penalties are even more severe. A 27% loss in yield would occur to achieve a 10% increase in spawning biomass. Spawning biomass in 1987 appears to be above equilibrium biomass with $F_{0.1} = 0.4$. The $F_{0.1}$ policy and corresponding yield of 751 mt seems to be in balance with the risks, benefits, and current catch levels.

Recent warm water conditions and poor upwelling (1982-83 El Nino event) may adversely impact short-term recruitment patterns. Recruitment should continue to be monitored and catch-at-age data incorporated into VPA analysis and dynamic pool modeling.

LITERATURE CITED

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Table 1. Parameters used in dynamic pool modeling of female English sole (*Parophrys vetulus*) from INPFC Columbia Area and PMFC Area 3B. Natural mortality rate M = 0.26.

Age Yrs	Ave. Wt. (kg)	Percent Maturity	Vulnerability	Population size in 1983
3	0.265	0.00	0.1245	1,406,742
4	0.305	0.30	0.4663	1,569,791
5	0.334	0.42	0.7625	2,309,291
6	0.369	0.95	0.9163	1,869,018
7	0.408	1.00	1.0000	1,511,911
8	0.455	1.00	1.0000	818,865
9	0.516	1.00	1.0000	783,041
10	0.552	1.00	1.0000	412,111
11	0.593	1.00	1.0000	85,123
12	0.636	1.00	1.0000	81,919
13	0.650	1.00	1.0000	87,800

Recruits at Age 3

Low	R (1.0)	= 4,471,127
Average	R (1.0)	= 8,445,730
High	R (1.0)	= 19,032,003

Stock/Recruit Parameters

R(0.5)/R(1.0)	C	A
0.90	1.04	0.89
0.95	1.04	0.95
0.99	1.04	0.99

Table 2. Equilibrium (EY) or maximum sustainable yields (MSY) and biomass (B_{ey} or B_{msy}) sustainable yield in metric tons for female English sole (*Parophrys vetulus*) in the INPFC Columbia area and PMFC Area 3B.

		R(0.5)/(RC1.0)								
		0.90			0.95			0.99		
Recruitment		Low	Mid	High	Low	Mid	High	Low	Mid	High
F=M	E_y	482	910	2,050	520	982	2,214	543	1,026	2,312
	B_{ey}	2,400	4,534	10,218	2,592	4,896	11,032	2,706	5,112	11,520
	F	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
$F_{0.1}$	E_y	505	954	2,150	603	1,147	2,556	686	1,297	2,922
	B_{ey}	2,132	4,026	9,073	1,964	3,593	8,362	1,886	4,437	8,029
	F	0.30	0.30	0.30	0.40	0.43	0.40	0.50	0.50	0.50
F_{max}	MSY	524	990	2,232	642	1,213	2,733	789	1,491	3,360
	B_{msy}	1,709	3,228	7,274	1,152	2,176	4,904	1,178	2,225	5,014
	F	0.40	0.40	0.40	0.80	0.80	0.80	>1.0	>1.0	>1.0

Table 3. Estimated yield, spawning biomass and exploitable biomass in metric tons of female English sole (*Parophrys vetulus*) in the INPFC Columbia area and PMFC are 3B, 1987-2000. Acceptable biological catch (ABC) in the INPFC Columbia and Vancouver area estimated by multiplying yield of females in mt by 1.2036 to correct for discard, added male weight and the U.S. portion of PMFC Area 3c. R(0.5)/R(1.0) = 0.95 in all cases.

	Low Recruitment					Average Recruitment				
Year	F	Yield	B_s	B_e	ABC	F	Yield	B_s	Be	ABC
	F=0.26					F=0.26				
1987		458	1,645	2,191	551		787	2,781	3,760	947
1988		481	1,768	2,305	579		840	3,077	4,028	1,011
1989		495	1,853	2,378	596		875	3,261	4,198	1,053
1990		503	1,897	2,416	605		899	3,372	4,317	1,082
1991		508	1,924	2,441	611		920	3,459	4,419	1,107
1995		523	1,988	2,516	629		976	3,697	4,690	1,177
2000		527	2,003	2,533	634		993	3,772	4,77	1,195
MSY		528	2,008	2,539	636		998	3,793	4,796	1,201
	$F_{0.1}$=0.40					$F_{0.1}$=0.43				
1987		624	1,500	2,029	751		1,128	2,498	3,439	1,358
1988		622	1,509	2,026	749		1,132	2,552	3,460	1,362
1989		619	1,512	2,018	745		1,130	2,560	3,455	1,360
1990		614	1,503	2,001	739		1,131	2,558	3,457	1,361
1991		609	1,493	1,987	733		1,136	2,563	3,471	1,367
1995		605	1,479	1,973	728		1,151	2,606	3,519	1,385
2000		603	1,473	1,966	726		1,155	2,615	3,531	1,390
MSY		603	1,471	1,964	726		1,156	2,618	3,534	1,391
	F_{max}=0.80					F_{max}=0.80				
1987		904	1,165	1,649	1,088		1,575	1,997	2,863	1,896
1988		813	1,005	1,471	978		1,433	1,767	2,593	1,725
1989		768	928	1,385	924		1,366	1,645	2,460	1,644
1990		741	890	1,334	892		1,337	1,593	2,403	1,609
1991		718	860	1,293	864		1,315	1,562	2,363	1,583
1995		666	790	1,197	802		1,245	1,474	2,336	1,498
2000		649	766	1,164	781		1,222	1,442	2,193	1,471
MSY		642	756	1,152	773		1,213	1,429	2,176	1,460