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STATUS OF PACIFIC MACKEREL AND TRENDS IN ABUNDANCE DURING 1978-1993 (WITH DATA TABLES)

By

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ABSTRACT

Abundance data and virtual population analysis indicate that biomass of Pacific mackerel (Scomber japonicus) declined substantially after the early 1980's to less than 100,000 tons during 1993. Current conditions appear similar to those in the mid-1940's when Pacific mackerel declined after a period of high abundance. Recent catch levels (46,000 and 23,000 tons year^{-1} during 1992 and 1993) were large relative to biomass and may have exceeded the target 30% total exploitation rate policy that is the basis for management in California. The economic condition of the fishery is poor and resources available for management are at an all time low because of changing priorities and financial constraints. Landings of Pacific mackerel increased in Mexico during recent years while California landings remained relatively constant, and biomass declined. Thus, the future of the Pacific mackerel stock and fishery are uncertain.

INTRODUCTION

Pacific mackerel (Scomber japonicus, also known as chub mackerel), are a mainstay of the southern California purse seine fishery (Thomson 1993; Konno and Wolf 1992). Population dynamics during 1929-1984 are described in MacCall et al. (1985) and Prager and MacCall (1988). California Department of Fish and Game (1994) describes current conditions in the fishery. The purpose of this paper is to describe the current status of the stock, trends in abundance during 1978-1993, data, and models used for management purposes.

DATA

Landings data for the California commercial, California recreational, and Mexican commercial fisheries during 1978-1993 were used (Table 1 and Appendix 1). Landings data for the California commercial fishery are from fish ticket records maintained by the California Department of Fish and Game (CDFG). Insignificant amounts of Pacific mackerel taken off Oregon, Washington and British Columbia were not included.

For 1978-1989, recreational landings of Pacific mackerel were obtained from Marine Recreational Fishery Statistics Survey (MRFSS) estimates of mean weight and catch in numbers (Witzig et al. 1992). MRFSS data were not available for 1990-1993, so quarterly data for California commercial passenger fishing vessel (CPFV) catches, originally from vessel logbooks, were used instead. Data for the recreational fishery were imprecise and CPFV data underestimated total recreational landings of Pacific mackerel, but errors had little effect because recreational catch of Pacific mackerel was small.

Landings data for the Mexican fishery in Ensenada during July to December, 1993 were unavailable. To approximate the missing catch data, we multiplied California landings during July- September and October-December, 1993 by the ratio of Ensenada to California catches during the same periods in 1992.

Catch at age data from the California commercial fishery for

Pacific mackerel during 1979-1993 were obtained by multiplying California monthly landings by the proportional weight of each year class in samples from Terminal Island canneries and the San Pedro fresh fish markets. For each age class, tons landed were divided by the mean weight of fish in samples to estimate the total number of fish landed in each month. Monthly catch at age data for the California commercial fishery were then summed by calendar quarter for further analysis.

No age composition data were available for Pacific mackerel taken in the California recreational and Mexican commercial fisheries. To account for recreational and Mexican landings, we increased catch at age data for the California commercial fishery by an amount proportional to the sum of recreational and Mexican landings in each quarter. The absence of catch at age data for the Mexican fishery was a significant problem because landings in Mexico were relatively large in recent years (Table 1). Lack of age composition data for the small recreational fishery was not a serious problem. After correcting for recreational and Mexican landings, the catch at age data were further adjusted so that the sum of numbers landed in each age group times their mean weight was equal to total landings (Appendix 2).

Abundance Indices

The fish spotter index (SPOTTER) for Pacific mackerel (Table 2 and Figure 1) was calculated in the same way was as the index for northern anchovy (Engraulis mordax) developed by Lo et al. (1992) except that data were aggregated by April-March annual periods. Thus, data for April 1988-March 1989 were used as an index of relative abundance during the first quarter of 1989.

California Cooperative Oceanic Fisheries Investigations (CalCOFI) data for Pacific mackerel were used in two indices of relative abundance (Table 2 and Figure 1). The index DENSITY was the density of Pacific mackerel larvae per unit area calculated from catches in bongo nets. The index PROP+ was the proportion of bongo tows that were positive for Pacific mackerel larvae. We used both because PROP+ may work better than DENSITY when eggs are rare or patchy in distribution (Mangel and Smith 1990; Smith 1990). For purposes of standardization, CalCOFI indices were calculated using data from the current CalCOFI sampling grid (covering roughly the Southern California Bight, Hewitt 1988) that were collected during April-September of each year when spawning is most common (MacCall and Prager 1988). Both were assumed to measure egg production at midyear. CalCOFI data for 1993 were based on single cruise during the second calendar quarter; data for other years were from at least two cruises during the second and third calendar quarters.

Estimates of net fecundity at age for Pacific mackerel (fraction mature x spawning frequency x batch fecundity, Table 3) were used to interpret CalCOFI data (see below). Fraction mature was estimated by fitting a logistic regression model to age and fraction mature data in Dickerson et al. (1992). Spawning frequency was estimated by fitting a straight line to age and spawning frequency data from the same study. Following Dickerson et al. (1992), batch fecundity per gram was assumed constant.

METHODS

We used ADAPT to estimate biomass of Pacific mackerel. ADAPT is a virtual population analysis (VPA) approach with terminal fishing mortality rates and other parameters adjusted to match trends in abundance indices (Gavaris 1988). Catch at age data were stratified by year and quarter; ages 0 to 6+ were included (6+ includes fish six years of age and older). Pacific mackerel ages 5 and 6+ were assumed to experience the same fishing mortality rate during the last quarter of each year so that cohorts could be linked using Murphy's algorithm (Prager and MacCall 1988). Recruitment was assumed to occur on July 1 and natural mortality was assumed to be 0.5 yr^{-1}. Where necessary, a small value (1,000 fish) was substituted for zero catches and mean weights for 1978-1992 were substituted for missing weight at age data.

PROP+ data were modeled:

$$\hat{P}_y = \frac{e^{\eta_y}}{1+e^{\eta_y}} \qquad [1]$$

and

$$\eta_y = \alpha + \beta E_y \qquad [2]$$

where P_y is PROP+ for year y (constrained by eqn. [1] to lie between zero and one), hats (^) denote estimates, α and β are parameters, and E_y is egg production. Egg production was calculated:

$$E_y = \sum_{a=0}^{6} b_{a,y} n_a \qquad [3]$$

where $b_{y,a}$ is the biomass of Pacific mackerel age a at the time of the survey, and n_a is normalized net fecundity per gram at age a (Table 3). PROP+ data were assumed to include binomial measurement errors.

The relationship between Pacific mackerel biomass and SPOTTER data was modeled:

$$\hat{S}_y = qB_y^{\gamma} \qquad [4]$$

and

$$B_y = \sum_{a=0}^{6} b_{y,a} s_a. \qquad [5]$$

where S_y is the SPOTTER index for year y, q is a scaling parameter, and s_a is a selectivity parameter that measures the relative contribution of Pacific mackerel age a to the SPOTTER survey. The exponent γ accounts for nonlinearity in the relationship between Pacific mackerel biomass and the SPOTTER index (Bannerot and Austin 1983). DENSITY was modeled in a similar fashion except that egg production was substituted for B_y in eqn. [4]. Both SPOTTER and DENSITY were assumed to include lognormally distributed measurement errors.

Parameters in the ADAPT model were estimated by maximum likelihood as described in Jacobson (1993) except that log-likelihoods for PROP+ were calculated using the binomial distribution. Residuals were used to check goodness of fit. Variance estimates for parameters and biomass estimates were calculated by a parametric bootstrap procedure (50 iterations, Jacobson 1993).

RESULTS

Preliminary runs of the ADAPT model did not fit abundance data for early years so we excluded all abundance data for years prior to 1986. This problem may have been due to the absence of older age groups during 1978-1983, or temporal changes in age specific selectivity and scaling parameters.

Age specific selectivities for SPOTTER data could not be estimated directly using ADAPT. To estimate age specific selectivities, biomass estimates from a preliminary ADAPT run were compared to SPOTTER data. SPOTTER data were strongly correlated (ρ=.90) with the biomass of one year old Pacific mackerel during 1986 to 1993. Relationships were weaker for other age groups and when data for years prior to 1986 were included. SPOTTER data were, therefore, used in the model as a measure of the biomass of age one Pacific mackerel (i.e. s_1 set to one, selectivities for other ages set to zero).

We were not able to estimate terminal (last quarter in last year) fishery selectivities individually or as functions of age. In lieu of maximum likelihood estimates, we used average values calculated iteratively. To obtain estimates, we ran ADAPT and calculated average fourth quarter fishery selectivities during 1984-1993 which where then used to rerun ADAPT. The first year used in calculating averages was 1984 because there were few fish in the oldest age classes during 1978-1983. The process was repeated until average selectivities stopped changing. The assumption of average selectivities in the last quarter of the terminal year was not ideal because final results indicated a great deal of interannual variability in fishery selectivity patterns.

Final runs with SPOTTER and DENSITY data converged readily to a maximum in the log-likelihood surface. The log-likelihood surface for runs with SPOTTER and PROP+ was flat in the area of the maximum, however, and convergence was not complete. Terminal fishing mortality rates for ages 0 to 6+ were: 0.20, 0.36, 0.30, 0.17, 0.21, 0.29, 0.29 qtr^{-1} for SPOTTER and DENSITY data, and: 0.082, 0.16, 0.13, 0.075, 0.092, 0.13, 0.13 qtr^{-1} for SPOTTER and PROP+ data. Residual plots indicated that the exponent γ in eqn. [4] was necessary to fit SPOTTER and DENSITY data.

CONCLUSION

Final runs with average values for terminal fishery selectivities and abundance index data for 1986-1993 indicate that Pacific mackerel biomass increased dramatically during 1978-1982 and then declined to low levels by 1993 as recruitment declined (Table 4 and Figure 2). High Pacific mackerel biomass in early years was due to the strong 1978 and 1980-1982 year classes. Biomass estimates for Pacific mackerel age 1+ in July of 1993 were 35,000 tons from SPOTTER and DENSITY data, and 65,000 tons from SPOTTER and PROP+ data. It is likely that ADAPT underestimated Pacific mackerel biomass during 1992-1993 because El Niño conditions caused extensive movement of Pacific mackerel to the north and out of the area covered by CalCOFI and fish spotter surveys (California Department of Fish and Game 1994).

Biomass estimates for Pacific mackerel during 1986-1993 were imprecise (CV > 30%) and lack of precision was severe (CV > 50%) after 1989 (Table 4). Lack of precision was exacerbated by imprecise indices of abundance (Table 2), low levels of fishing mortality in some years (Pope 1972), and because abundance data for 1986-1993 were a "one way trip" (continuously decreasing, Hilborn and Walters 1992). It is likely, moreover, that we overestimated precision because errors in landings and catch at age data, uncertainty about index and fishery selectivities, and effects of El Niño were not considered in bootstrap calculations.

In view of the El Niño conditions, and considering all uncertainties, we estimate that Pacific mackerel biomass during

1993 was less than 100,000 tons. Thus, current conditions appear similar to those in the mid-1940's, when Pacific mackerel declined to biomass levels less than 100,000 tons after a period of high abundance (Prager and MacCall 1988). After 1945, the Pacific mackerel stock varied around an average biomass of about 70,000 tons until the fishery collapsed in 1965.

Recent catch levels (46,000 and 23,000 tons year^{-1} during 1992 and 1993, Table 1) were large relative to biomass estimates (< 100,000 tons) and may have exceeded the target 30% total exploitation rate policy that is the basis for California management (quotas are set at 30% of the Pacific mackerel biomass above 20,000 tons). The California fishery is managed using quotas that make no allowance for Mexican harvests while the Mexican fishery is not regulated by a quota. Thus, it seems likely that catches in the next few years will be large enough to deplete the stock, particularly if poor recruitment continues.

The Pacific mackerel fishery in California is at a crossroad and its future is uncertain. Economic conditions in the fishery are poor (Thomson et al. 1993; California Department of Fish and Game 1994). Resources available for management at state and federal levels are currently low because of changing priorities, low revenues from landings taxes, and other financial constraints. CDFG was not able to age Pacific mackerel collected in port samples collected during 1994, and a stock assessment may not be possible in 1995 due to lack of personnel and data. Landings of Pacific mackerel increased in Mexico during recent years while California landings remained relatively constant and biomass declined (Table 1). Thus, the Pacific mackerel fishery in California, already beset with economic problems, faces reduced management during a period of increased total landings and low biological productivity.

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LITERATURE CITED

Bannerot, S. P., and C. B. Austin. 1983. Using frequency distributions of catch per unit effort to measure stock abundance. Trans. Am. Fish. Soc. 112: 608-617.

California Department of Fish and Game. 1994. Review of some California fisheries for 1993. Calif. Coop. Oceanic Fish. Invest. Rep. 35: ??-??.

Dickerson, T. L., B. J. Macewicz, and J. R. Hunter. 1992. Spawning frequency and batch fecundity of chub mackerel, Scomber japonicus, during 1985. Calif. Coop. Oceanic Fish. Invest. Rep. 33: 130-140.

Gavaris, S. 1988. An adaptive framework for the estimation of population size. Can. Atl. Fish. Sci. Adv. Comm. (CAFSAC) Res. Doc. 88/29: 12 p.

Hewitt, R. P. 1988. Historical review of the oceanographic approach to fishery research. Calif. Coop. Oceanic Fish. Invest. Rep. 29: 27-41.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment. Choice, dynamics and uncertainty. Routledge, Chapman and Hall Inc., New York, NY. 570 p.

Jacobson, L. D. 1993. ADEPT: software for VPA analysis using Gavaris's procedure. National Marine Fisheries Service, Southwest Fisheries Science Center, Admin. Rep. LJ-93-02: 71 p.

Konno, E. S., and P. Wolf. 1992. Pacific mackerel, p. 91-93. In: W. S. Leet, C. M. Dewees, and C. W. Haugen (eds.). California's living marine resources and their utilization. Calif. Sea Grant Ext. Publ. UCSGEP-92-12. 257 p.

Lo, N. C. H., L. D. Jacobson, and J. L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526.

MacCall, A. D., R. A. Klingbeil, and R. D. Methot. 1985. Recent increased abundance and potential productivity of Pacific mackerel (Scomber japonicus). Calif. Coop. Oceanic Fish. Invest. Rep. 26: 119-129.

MacCall, A. D., and M. H. Prager. 1988. Historical changes in abundance of six fish species off southern California, based on CalCOFI egg and larva samples. Calif. Coop. Oceanic Fish. Invest. Rep. 29: 81-101.

Mangel, M., and P. E. Smith. 1990. Presence-absence sampling for fisheries management. Can. J. Fish. Aquat. Sci. 47: 1875-1887.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analyses using cohort analysis. Int. Comm. Northwest Atl. Fish. Res. Bull. 9: 65-74.

Prager, M. H., and A. D. MacCall. 1988. Revised estimates of historical spawning biomass of the Pacific mackerel, Scomber japonicus. Calif. Coop. Oceanic Fish. Invest. Rep. 29: 91-101.

Smith, P. E. 1990. Monitoring interannual changes in spawning area of Pacific sardine (Sardinops sagax). Calif. Coop. Oceanic Fish. Invest. Rep. 31: 145-151.

Thomson, C., G. Walls, and J. Morgan. 1993. Status of the California coastal pelagic fisheries in 1992. National Marine Fisheries Service, Southwest Fisheries Science Center, Admin. Rep. LJ-93-14: 59 p.

Witzig, J. F., M. C. Holliday, R. J. Essig, and D. L. Sutherland. 1992. Marine Recreational Fishery Statistics Survey, Pacific Coast, 1987-1989. Silver Spring, MD: U.S. Dept. Commerce, Nat. Oceanic and Atmospheric Admin., 367 p.

Appendix 1. Pacific mackerel landings by quarter during 1978-1993.

Year	Quarter	Calif. Commer. (tons)	Calif. Recr. (tons)	Mexican Commer. (tons)	Total (tons)
1978	1	4,800	132	931	5,863
	2	497	348	2,792	3,637
	3	4,481	861	4,655	9,998
	4	2,670	556	931	4,157
1979	1	5,341	144	635	6,120
	2	7,841	791	1,905	10,536
	3	5,346	1,364	3,175	9,884
	4	11,966	319	635	12,920
1980	1	8,508	228	467	9,204
	2	5,877	502	1,400	7,779
	3	15,823	1,577	2,334	19,735
	4	2,335	690	467	3,492
1981	1	8,875	150	227	9,252
	2	3,801	395	682	4,879
	3	18,428	894	1,137	20,459
	4	11,811	134	227	12,172
1982	1	10,154	181	498	10,833

	2	1,982	436	1,493	3,911
	3	7,918	905	2,488	11,312
	4	11,705	318	498	12,521
1983	1	2,223	147	0	2,369
	2	12,118	469	427	13,015
	3	12,626	727	776	14,129
	4	8,890	283	518	9,690
1984	1	6,998	237	730	7,965
	2	11,483	463	512	12,458
	3	15,021	606	596	16,223
	4	12,920	268	507	13,695
1985	1	7,356	144	2,309	9,809
	2	7,797	394	1,244	9,435
	3	11,629	503	1,906	14,038
	4	11,457	185	2,547	14,189
1986	1	8,499	128	1,690	10,316
	2	10,217	219	1,107	11,543
	3	13,280	536	2,052	15,869
	4	13,564	208	5,491	19,263
1987	1	12,332	98	82	12,512
	2	9,435	214	177	9,826
	3	16,376	482	445	17,303
	4	7,709	175	165	8,049

1988	1	9,134	99	44	9,277
	2	16,959	143	25	17,127
	3	12,199	444	3,863	16,506
	4	9,781	152	994	10,926
1989	1	14,654	17	944	15,615
	2	9,825	105	2,295	12,224
	3	12,813	451	12,423	25,687
	4	2,971	69	737	3,777
1990	1	8,425	68	0	8,493
	2	4,931	228	9,883	15,042
	3	21,259	532	26,291	48,082
	4	7,344	237	3,225	10,806
1991	1	7,015	69	3,045	10,129
	2	8,008	159	1,082	9,249
	3	9,801	432	10,996	21,228
	4	9,721	163	4,155	14,039
1992	1	6,614	104	7,618	14,336
	2	3,331	196	14,373	17,900
	3	9,712	224	1,843	11,779
	4	2,042	215	166	2,423
1993	1	6,392	83	0	6,475
	2	1,820	192	1,584	3,596
	3	2,647	495	4,100[a]	7,242[a]
	4	2,498	223	3,179[a]	5,900[a]

[a] Preliminary estimates.

Appendix 2. Catch and weight at age data for Pacific mackerel by year and quarter.[1,2]

		Catch at Age (millions)							Weight at Age (pounds)							
Year	Qtr	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	N Aged
1978	1	0.000	4.657	14.256	0.063	0.123	0.000	0.000	NA	0.280	0.710	1.370	1.790	NA	NA	NA
1978	2	0.000	2.064	8.078	0.000	0.000	0.000	0.000	NA	0.250	0.850	NA	NA	NA	NA	NA
1978	3	0.000	6.871	12.952	0.501	0.434	0.000	0.000	NA	0.690	1.050	1.680	1.910	NA	NA	NA
1978	4	0.023	3.652	5.696	0.117	0.000	0.000	0.000	0.290	0.720	0.970	1.330	NA	NA	NA	NA
1979	1	0.000	28.908	3.256	5.072	0.127	0.067	0.001	NA	0.140	0.740	1.080	1.410	1.980	NA	626
1979	2	0.000	27.760	5.820	6.802	0.090	0.129	0.001	NA	0.260	0.870	1.230	1.710	2.200	NA	903
1979	3	0.000	26.472	2.133	4.292	0.016	0.294	0.001	NA	0.410	1.100	1.380	1.660	2.140	NA	635
1979	4	0.000	27.724	4.892	5.696	0.243	0.373	0.001	NA	0.480	0.940	1.170	2.180	2.030	NA	1,189
1980	1	0.000	0.000	22.926	3.568	1.415	0.000	0.036	NA	NA	0.580	0.900	1.290	NA	2.400	1,087
1980	2	0.000	0.000	16.573	2.072	1.794	0.041	0.031	NA	NA	0.660	1.010	1.340	1.630	2.150	556
1980	3	0.000	0.180	34.357	4.088	4.672	0.028	0.082	NA	0.390	0.910	1.030	1.490	1.690	2.200	1,554

1980	4	0.805	0.079	6.474	0.472	0.392	0.001	0.007	0.300	0.680	0.930	1.180	1.480	NA	1.810	322
1981	1	0.000	8.038	0.547	16.936	1.458	0.765	0.041	NA	0.260	0.490	0.800	0.900	1.560	2.540	1,186
1981	2	0.000	3.084	0.358	8.803	0.490	0.441	0.000	NA	0.270	0.610	0.860	1.010	1.470	NA	823
1981	3	0.000	3.635	1.412	29.337	2.563	1.543	0.194	NA	0.490	0.790	1.110	1.030	1.580	2.100	809
1981	4	0.751	7.891	1.214	14.597	0.859	0.867	0.001	0.330	0.500	0.840	1.150	1.180	1.550	NA	739
1982	1	0.000	0.000	8.571	1.309	8.515	0.380	0.239	NA	NA	0.490	0.680	1.850	1.190	1.610	1,464
1982	2	0.000	2.904	4.640	0.457	2.388	0.180	0.019	NA	0.210	0.500	0.640	1.820	1.260	1.590	388
1982	3	0.000	1.072	6.850	1.799	9.301	0.312	0.206	NA	0.410	0.730	1.090	1.550	1.310	2.000	304
1982	4	0.228	1.017	3.613	2.066	13.499	1.460	0.216	0.230	0.470	0.720	1.040	1.300	1.260	1.810	597
1983	1	0.000	0.121	4.932	2.122	0.368	1.049	0.063	NA	0.240	0.430	0.610	0.700	0.900	1.526	244
1983	2	0.000	0.620	9.893	8.802	2.469	8.180	1.126	NA	0.320	0.550	0.770	1.020	1.140	1.587	1,311
1983	3	0.000	0.704	9.630	14.796	1.737	6.774	0.090	NA	0.370	0.690	0.810	0.990	1.110	1.630	804
1983	4	0.280	0.388	6.023	8.247	1.409	5.301	0.095	0.170	0.430	0.680	0.910	1.060	1.120	1.550	480
1984	1	0.000	0.000	0.484	8.980	6.115	1.556	3.189	NA	NA	0.430	0.630	0.830	0.980	1.090	565
1984	2	0.000	0.000	0.809	16.755	9.508	1.310	1.936	NA	NA	0.520	0.730	0.900	1.000	1.246	747
1984	3	0.000	0.000	1.399	10.856	9.604	2.975	4.587	NA	NA	0.730	0.920	1.140	1.390	1.390	695
1984	4	0.492	0.172	2.016	11.149	7.723	2.235	2.767	0.210	0.690	0.810	0.880	1.150	1.380	1.365	515
1985	1	0.000	0.000	0.000	2.545	11.651	4.625	1.555	NA	NA	NA	0.790	0.880	1.150	1.318	356
1985	2	0.000	1.061	0.265	2.927	12.639	2.356	0.246	NA	0.340	0.510	0.830	0.950	1.550	1.216	691

1985	3	0.000	7.555	1.003	3.671	14.503	2.982	0.720	NA	0.560	0.790	0.960	1.020	1.230	1.513	693
1985	4	0.000	5.275	1.421	4.125	12.354	3.691	0.816	NA	0.650	0.900	1.020	1.080	1.360	1.373	511
1986	1	0.000	0.000	1.139	1.195	4.915	10.579	2.294	NA	NA	0.620	0.940	1.010	1.040	1.242	576
1986	2	0.000	1.527	3.231	1.456	3.132	10.910	2.490	NA	0.430	0.720	0.950	1.060	1.130	1.240	768
1986	3	0.000	5.471	7.279	1.375	2.927	9.637	2.812	NA	0.550	0.900	1.090	1.220	1.290	1.437	453
1986	4	3.731	20.550	8.007	1.240	2.543	7.112	2.982	0.370	0.620	0.900	1.080	1.160	1.260	1.333	905
1987	1	0.000	14.212	11.662	3.596	0.885	1.436	5.470	NA	0.300	0.640	0.840	1.100	1.270	1.370	1,195
1987	2	0.000	0.626	4.725	2.770	1.488	1.899	5.896	NA	0.580	0.770	0.950	1.180	1.250	1.510	447
1987	3	0.000	30.383	11.024	1.295	0.875	0.899	3.012	NA	0.550	0.830	1.080	1.300	1.530	1.613	1,021
1987	4	3.025	11.048	5.768	0.968	0.358	0.758	1.037	0.310	0.550	0.850	1.120	1.310	1.390	1.529	875
1988	1	0.000	11.647	16.050	4.810	0.692	0.575	0.492	NA	0.260	0.580	0.840	1.140	1.220	1.425	1,285
1988	2	0.000	3.105	12.515	10.583	2.170	1.057	4.555	NA	0.380	0.790	1.060	1.290	1.440	1.684	1,019
1988	3	0.000	3.634	17.584	5.738	1.005	0.508	2.607	NA	0.730	0.940	1.210	1.500	1.390	1.801	516
1988	4	29.221	4.608	6.281	2.359	0.174	0.247	1.921	0.220	0.590	0.890	1.290	1.400	1.540	1.803	787
1989	1	0.000	54.816	4.945	7.652	3.032	1.057	1.736	NA	0.220	0.670	0.870	1.410	1.680	1.826	2,160
1989	2	0.000	23.966	1.644	3.342	2.149	0.713	5.074	NA	0.260	0.730	0.990	1.570	1.650	1.808	1,016
1989	3	0.000	105.86	1.859	1.947	1.439	1.122	2.295	NA	0.380	0.660	1.120	1.480	1.570	1.692	1,745
1989	4	5.113	12.878	1.133	0.078	0.001	0.001	0.018	0.240	0.430	0.600	NA	NA	1.530	1.570	659
1990	1	0.000	20.160	25.053	1.359	0.620	0.080	0.229	NA	0.230	0.470	0.780	1.200	1.360	1.735	998

1990	2	0.000	0.543	13.849	3.944	3.846	2.824	4.109	NA	0.490	0.640	1.120	1.320	1.500	1.763	181
1990	3	9.958	16.272	26.763	7.560	9.378	13.119	14.736	0.160	0.560	0.780	1.140	1.360	1.460	1.637	675
1990	4	2.842	1.853	4.552	1.123	3.351	3.795	2.676	0.180	0.660	0.870	1.150	1.320	1.520	1.663	481
1991	1	0.000	12.754	5.507	6.866	0.900	0.875	3.925	NA	0.210	0.590	0.790	1.200	1.370	1.692	585
1991	2	0.000	3.086	0.424	2.744	2.359	3.053	3.678	NA	0.300	0.800	0.990	1.300	1.550	1.830	360
1991	3	0.000	0.350	0.746	6.310	5.475	7.615	10.241	NA	0.660	0.880	1.080	1.260	1.440	1.652	317
1991	4	15.099	27.704	1.509	2.898	2.183	1.582	1.711	0.140	0.500	0.870	1.020	1.180	1.480	1.722	766
1992	1	0.000	11.504	28.560	7.140	4.663	1.368	0.399	NA	0.190	0.460	0.840	1.100	1.180	1.565	543
1992	2	0.000	0.629	25.673	11.407	6.570	1.115	2.281	NA	0.680	0.470	0.930	1.160	1.540	1.483	49
1992	3	0.000	0.212	2.112	3.315	4.800	4.083	4.790	NA	0.400	0.600	0.970	1.210	1.440	1.528	423
1992	4	2.233	5.927	2.152	0.223	0.254	0.254	0.294	0.210	0.360	0.490	0.930	0.860	1.190	1.581	209

1993	1	0.000	4.828	12.282	3.407	2.307	0.919	0.566	NA	0.192	0.382	0.819	1.096	1.197	1.627	1,216
1993	2	0.000	2.434	2.063	1.101	1.657	1.680	0.510	NA	0.193	0.476	0.910	1.167	1.194	1.574	157
1993	3	0.000	0.533	2.324	1.259	1.428	3.050	3.619	NA	0.505	0.640	0.778	1.173	1.320	1.673	162
1993	4	2.405	2.510	3.871	0.305	0.974	1.830	2.158	0.190	0.463	0.661	0.932	1.343	1.409	1.603	312

[1] "N Aged" is the number of fish aged.

[2] "NA" means data not available.

Table 1. Pacific mackerel landings during 1978-1993.

Year	Calif. Commer. (tons)	Calif. Recr. (tons)	Mexican Commer. (tons)	Total (tons)
1978	12,448	1,898	9,309	23,655
1979	30,495	2,618	6,348	39,461
1980	32,544	2,997	4,668	40,209
1981	42,916	1,574	2,273	46,763
1982	31,759	1,841	4,977	38,577
1983	35,857	1,626	1,721	39,204
1984	46,422	1,573	2,345	50,340
1985	38,240	1,227	8,005	47,472
1986	45,560	1,092	10,340	56,992
1987	45,852	969	869	47,690
1988	48,072	838	4,926	53,837
1989	40,263	641	16,399	57,303
1990	41,959	1,065	39,400	82,423
1991	34,545	823	19,277	54,645
1992	21,700	738	24,001	46,439
1993	13,358	991	8,863[a]	23,212[a]

[a] Preliminary estimates.

Table 2. Indices of relative abundance for Pacific mackerel.

Year	SPOTTER (tons $block^{-1}$)	CV	DENSITY (larvae $10\ m^{-2}$)	CV	PROP+	N (tows)
1978	21.93	0.44	9.9054	0.32	0.1377	247
1979	40.46	0.42				
1980	31.44	0.42				
1981	31.20	0.44	45.5338	0.36	0.3333	105
1982	32.42	0.42				
1983	38.56	0.43				
1984	32.25	0.47	2.1382	0.60	0.0536	112
1985	40.39	0.47	3.5956	0.46	0.1642	67
1986	21.21	0.48	2.8246	0.44	0.1000	70
1987	15.50	0.46	18.7083	0.66	0.0941	85
1988	6.50	0.51	4.5224	0.45	0.1282	78
1989	11.23	0.53	2.4788	0.45	0.0843	83
1990	3.04	0.60	0.3052	1.00	0.0130	77
1991	3.14	0.55	0.5695	0.59	0.0698	43
1992	4.40	0.52	0.2694	0.53	0.0430	93
1993	2.48	0.68	0.0603	1.00	0.0116	86

Table 3. Net fecundity calculations for Pacific mackerel.[a]

Age (yrs)	Observed Fraction Mature	Predicted Fraction Mature	Observed Spawning Frequency (% spawning day^{-1})	Predicted Spawning Frequency (% spawning day^{-1})	Net Fecundity (eggs g^{-1})	Normalized Net Fecundity (eggs g^{-1})
0	0.000	0.000	0.0	0.00	0.00	0.00
1	0.214	0.487	0.0	1.38	0.672	0.07
2	0.867	0.636	3.9	3.52	2.24	0.24
3	0.815	0.763	6.8	5.66	4.32	0.47
4	0.851	0.855	9.9	7.80	6.67	0.73
5+	0.882	0.916	7.7	9.94	9.11	1.00

[1] Observed fraction mature and observed spawning frequency from Dickerson et al. (1992). Predicted fraction mature from logistic regression. Predicted spawning frequency from linear regression. Normalized net fecundity is adjusted to a maximum value of 1.0. Batch fecundity assumed constant.

Table 4. Biomass and recruitment estimates (age zero fish on July 1) for Pacific mackerel during 1979-1993 from the ADAPT model using SPOTTER with DENSITY data, and SPOTTER with PROP+ data.

	SPOTTER and DENSITY			SPOTTER and PROP+	
Year	Biomass (1,000 tons)	CV[1]	Recruitment (million Fish)	Biomass (1,000 tons)	Recruitment (million fish)
1978	78	0.01	1,985	106	2,019
1979	303	0.06	428	307	445
1980	363	0.08	1,987	371	2,092
1981	550	0.15	3,154	572	3,341
1982	829	0.19	1,366	872	1,483
1983	781	0.22	280	830	302
1984	691	0.24	234	740	240
1985	498	0.25	992	534	1,096
1986	504	0.31	795	549	895
1987	480	0.37	434	533	543
1988	442	0.50	911	512	1,032
1989	340	0.54	260	399	314
1990	269	0.67	267	330	280
1991	185	0.75	135	233	190
1992	71	1.21	30	109	49

1993	35	1.58	16	65	37

[1] Calculated using a parametric bootstrap procedure with 50 iterations.

Figure 1. Indices of abundance for Pacific mackerel plotted in log scale for comparison.

Figure 2. Biomass and recruitment estimates (zero year old fish on July 1) for Pacific mackerel from ADAPT runs using SPOTTER and DENSITY data. Results using SPOTTER and PROP+ were similar.

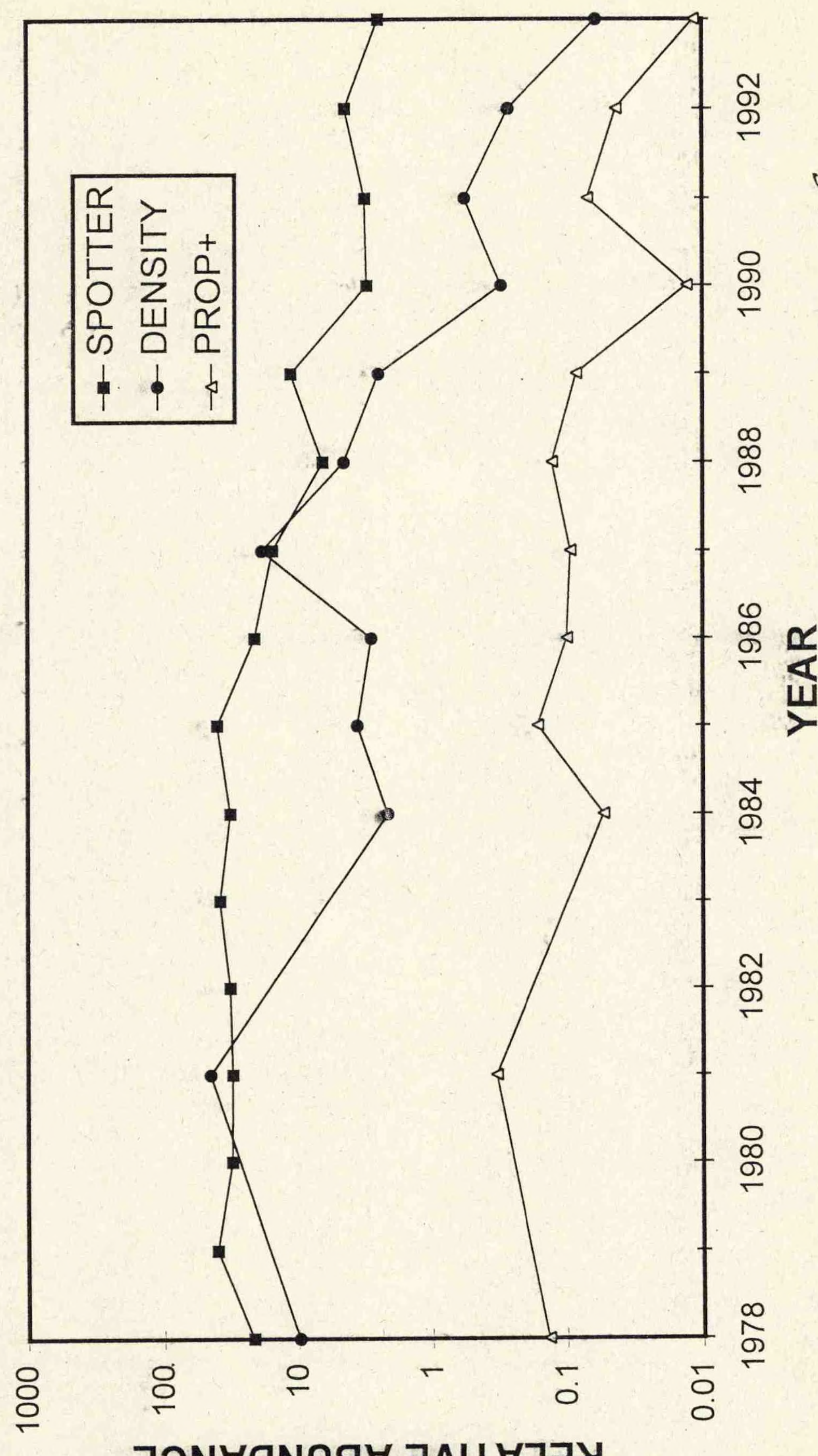

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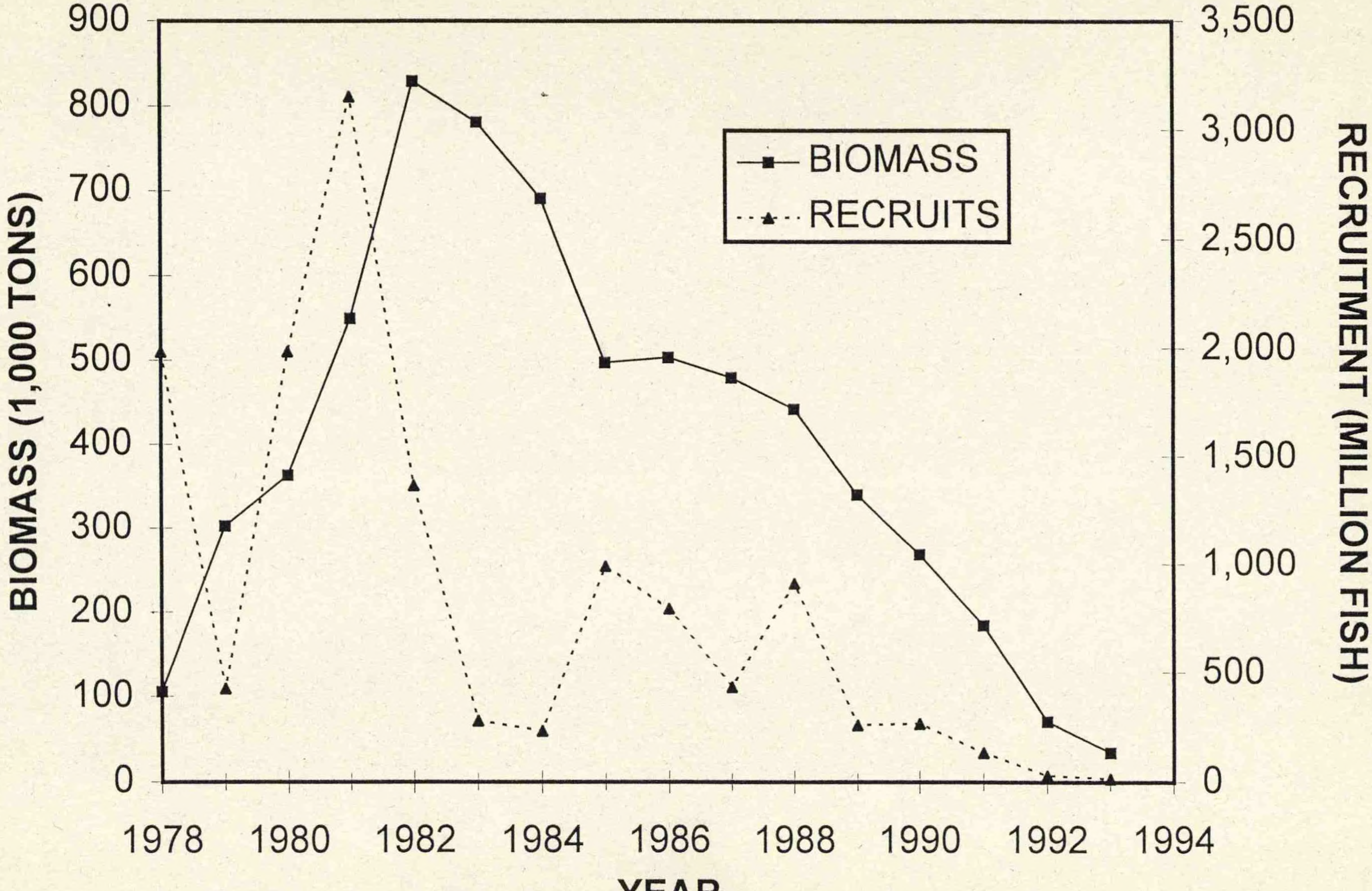
Fig. 1

Fig. 2



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