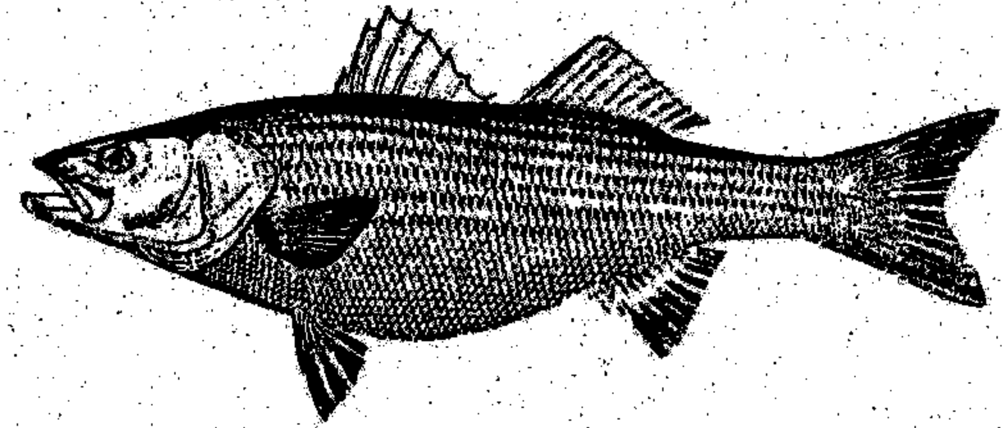
WRINT-DFG-Exhibit 3

A MODEL FOR EVALUATING THE IMPACTS OF FRESHWATER OUTFLOW AND EXPORT ON STRIPED BASS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY



David W. Kohlhorst
Donald E. Stevens
Lee W. Miller

Bay-Delta and Special Water Projects Division
California Department of Fish and Game
4001 North Wilson Way
Stockton, California 95205-2424

Entered by the California Department of Fish and Game
for the State Water Resources Control Board 1992
Water Rights Phase of the Bay-Delta Estuary Proceedings

ERRATA - Department of Fish and Game Exhibit 3

Page 4, line 3 - (DFG 1992) should be (CDFG 1992)

Page 25, line 23 - (Stevens 1977) should be (Stevens 1977b)

Page 44, REFERENCES - add the following two references:

Dixon, W. J. 1988. BMDP statistical software manual. University of California Press, Berkeley, California, 619 pages.

Johnson, R. A. and D. W. Wichern. 1988. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey, 607 pages.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

As part of The Department of Fish and Game's participation in the ongoing process by the State Water Resources Control Board which will revise water rights Decision 1485, we explored factors affecting adult striped bass abundance. This report presents evidence that freshwater outflow and water exports during the initial year of life are the primary factors controlling adult striped bass abundance in the Sacramento-San Joaquin Estuary. It also presents a quantitative approach for evaluating the impact on striped bass of alternative combinations of outflows and exports.

DECLINE IN STRIPED BASS ABUNDANCE

Adult striped bass abundance in the estuary, as estimated by the Petersen mark-recapture technique (Stevens 1977a), has declined substantially, from about 1.7 million in the early 1970s to less than 600,000 fish (exclusive of hatchery-produced fish) in 1990 (Figure 1). Young-of-the-year (yoy) abundance, indexed when their mean size is 38 mm in midsummer (Turner and Chadwick 1972; Stevens 1977a), has also declined precipitously, from a high index of almost 120 in 1965 to values less than six in the last 4 years (Figure 2). It is reasonable to expect that this decline in production of young fish has contributed significantly to the decreased adult numbers.

LOSSES OF ENTRAINED STRIPED BASS

Substantial mortality occurs between the time that the yoy index is set and recruitment of the year class to the fishery at about age 3. Much of this mortality results from losses in all

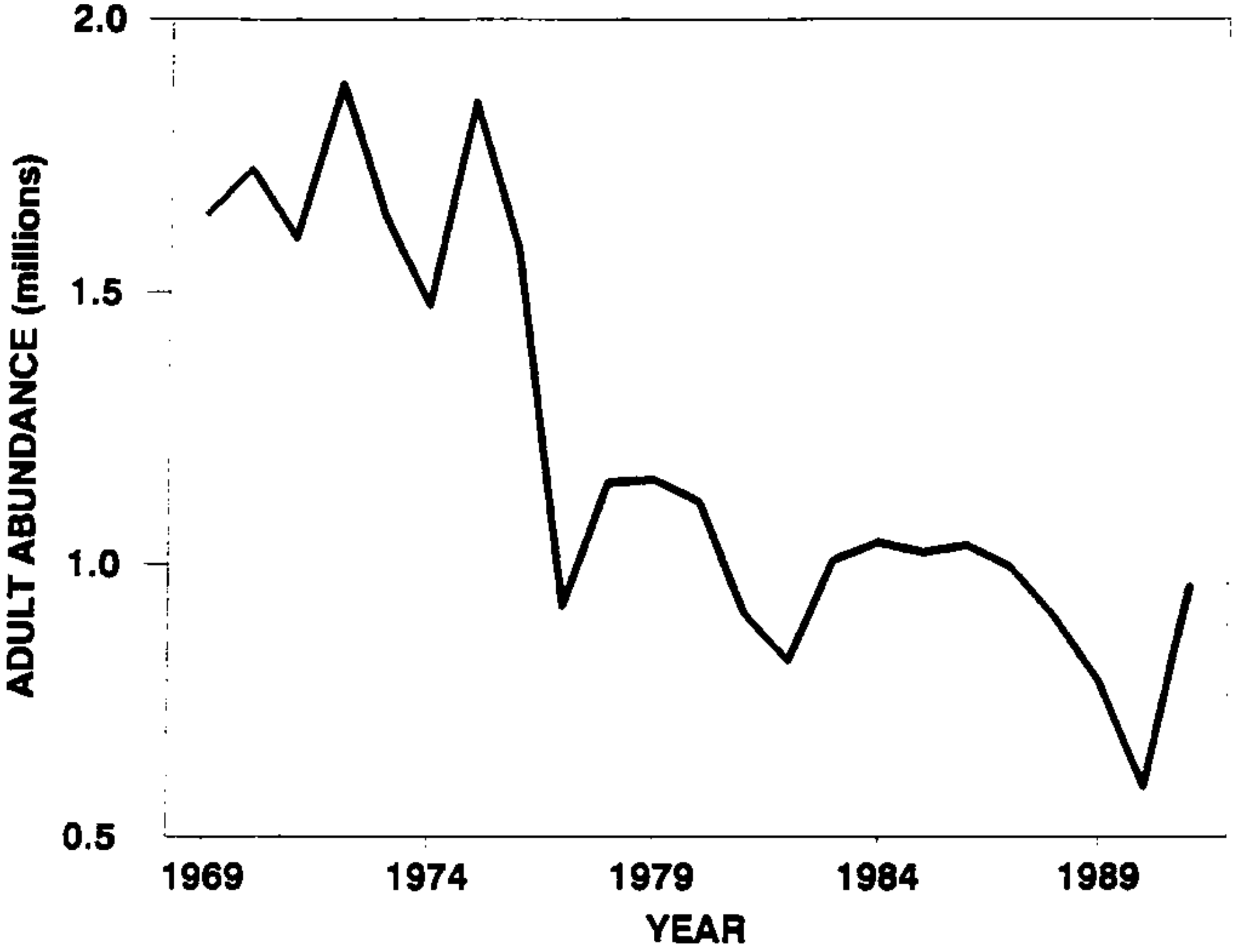


Figure 1. Trend in legal-sized striped bass abundance in the Sacramento-San Joaquin Estuary, 1969-1991.

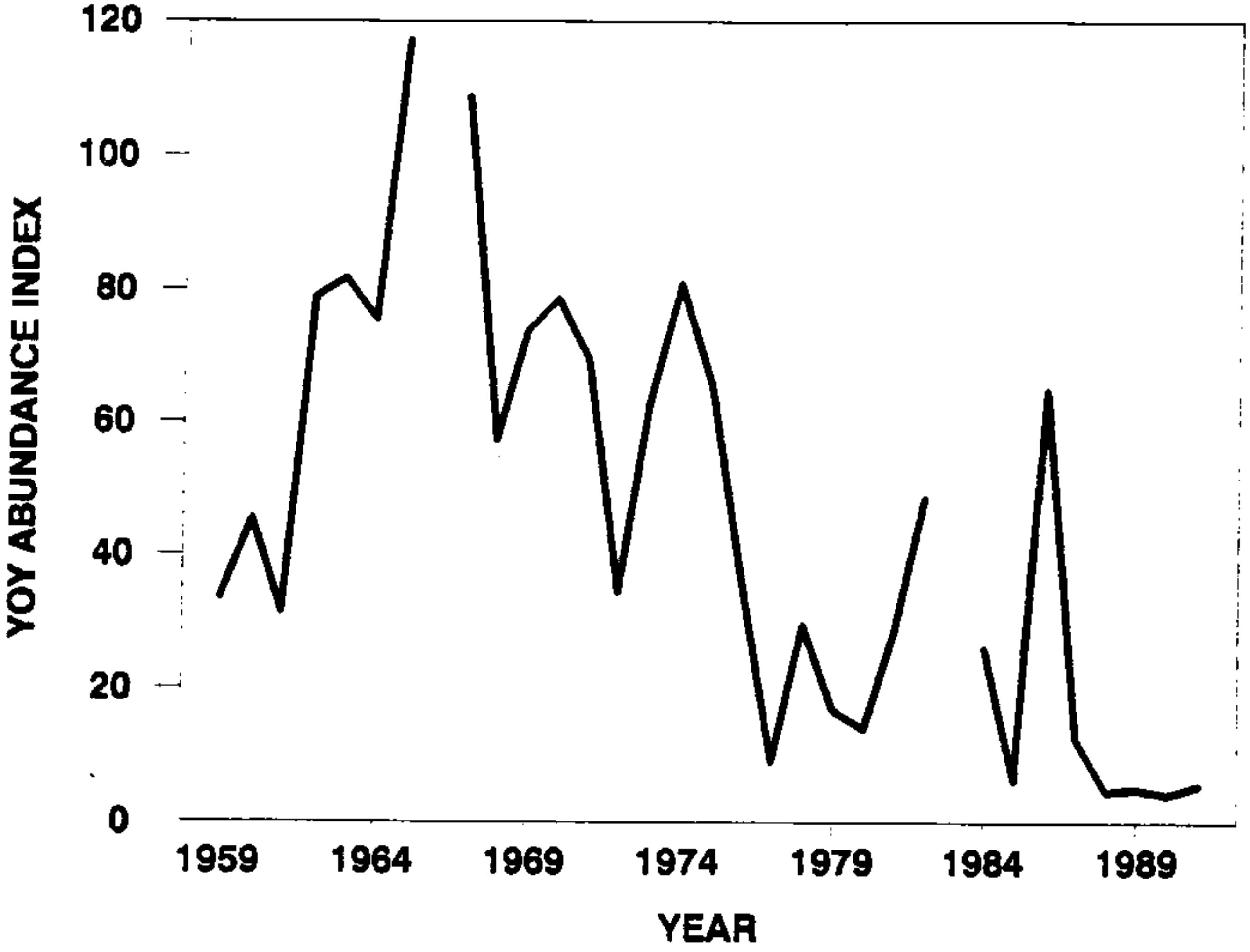


Figure 2. Trend in young-of-the-year striped bass abundance, as measured by the 38-mm index, in the Sacramento-San Joaquin Estuary, 1959-1991.

months from late summer through winter of 21-150 mm fish at the State Water Project (SWP) and Central Valley Project (CVP) export pumps in the south Delta (Table 1) (DFG 1992). These post-yoy losses have been estimated to range from less than 200,000 bass in 1983 to almost 22 million fish in 1974 (Figure 3). The loss estimates assume size-dependent predation losses in the SWP's Clifton Court Forebay beginning in 1971 which range from 93% for 21-25-mm bass to 3% for 141-150-mm fish (Table 2). Size-dependent predation losses at the Federal CVP fish screening facility where there is no forebay (and at the SWP facility before 1971 when a large predator population had developed) were scaled, for the same size range, from 17% to 1% (Table 2). For consistency, the Clifton Court Forebay predation curve is that used in the Four Pumps Mitigation Agreement. However, this curve appears to underestimate predation mortality when compared to results of experiments conducted with yoy striped bass (mean fork length from 47 to 56 mm) which found loss rates in the forebay of 94% in July, 1984 and 70% in August, 1986 (Kano 1985, 1986).

The magnitude of post-yoy index losses at the water export pumps is potentially affected by three readily identifiable factors: (1) the abundance of young bass; (2) the magnitude of water exports; and (3) Delta outflow, because it influences distribution of the young fish and their vulnerability to entrainment with exported water. For the purpose of evaluating the influence of water exports and outflow, the effect of young bass abundance can be removed by dividing post-yoy losses by the yoy index to produce a <u>loss rate</u> index which, conceptually, is similar to "fraction of the population removed" and is expressed as export loss per yoy index unit. This loss rate index has increased dramatically in recent years, from low values in the tens of thousands in the 1960s when only the CVP was exporting water from the Delta to over one million in 1987 and 1989 when both projects exported large amounts of water (Figure 4).

Table 1. Estimated monthly export losses of 21-150 mm striped bass after the time that the young-of-the-year index is set. Losses are calculated using size-specific mortality rates in Clifton Court Forebay and at the CVP fish screens. (Source: DFG 1992)

Year	Jun-Aug Loss	Sep Loss	Oct Loss	Nov Loss	Dec Loss	Jan Loss	Feb Loss	Mar Loss	Total Loss
1959	1.626.532	11,861	0	0	0	0	0	29.788	1,668.181
1960	2.386.894	15.967	0	0	0	0	0	11.187	2,414.048
1961	2.926,973	62.887	0	0	0	0	0	0	2.989.860
1962	2.661,480	32.829	0	0	0	0	0	0	2,694,309
1963	1.839.866	43.393	134	0	0	0	7.000	19,076	1,909,488
1964	783.167	46.263	0	0	0	0	0	4,707	834.137
1965	2.069.169	48,485	6.383	0	0	0	0	25.270	2.149,306
1966	4.770.193	22.668	9,235	0	0	0	0	9,010	4,811.106
1967	2,033,901	107.992	10.389	62	0	1.000	25.717	41.370	2,220.430
1968	4.287,280	78,458	30,784	25,511	11.671	30.435	7,456	2.332	4,473.927
1969	2,242,144	82,710	10,773	1,481	7,512	10,509	5.536	0	2,360.665
1970	9.448,287	301,313	125.281	62,687	37,959	12.234	18.672	47,294	10.053.728
1971	7,880.747	460,126	73,778	103.131	121,869	36.961	285,017	223.660	9.185,289
1972	2.750,649	458,776	67,452	25,731	147,205	65,451	46,128	6,666	3,568,058
1973	10.711,241	136,964	48,043	83,743	103,196	45,765	26,168	21,521	11,176,662
1974	21,010,359	179,413	33,791	14,912	192,003	213,451	113,155	50,113	21,807,197
1975	16,932,248	916.963	68,386	253.171	130,548	189,111	97.181	32,803	18,620,410
1976	3.287,871	74.682	36.146	52,297	41,158	72.419	31,959	18.515	3.615.048
1977	317,276	37,065	0	31,482	62,679	739.531	228.562	11,985	1,428,579
1978	2,053,451	51,367	195,614	237,158	192,891	48,928	13,193	5,460	2,798,063
1979	2,322,422	44,512	86,934	125,872	124,454	29,079	11,841	1,124	2.746,237
1980	2,170,581	286,882	50.453	108,343	135,890	64,180	28,959	8,263	2.853,551
1981	2,192,013	42.208	28.313	54,928	62,811	72,556	63 715	19.643	2,536,186
1982	2.296,121	200.544	43,759	58.609	171,333	33,438	14,227	2,940	2,820,971
1983	124.691	28.787	1.323	8,765	13.945	1,996	2.035	587	182.129
1984	5,894.345	30.476	188.231	160,425	159.665	28,401	18,363	6,300	6,486,207
1985	3,591,623	27.144	11,267	69,140	84,493	49,285	72,196	4,297	3,909,444
1986	18.727,707	205.013	82.520	83.011	60,302	27,512	29,013	6,529	19,221,607
1987	13.725.081	29.867	2,241	17,724	146.402	32,818	65.461	12,353	14.031.947
1988	1.683,936	12.366	7,592	99.770	78.538	29.360	23.621	13.955	1,949.138
1989	6.036,193	10,945	6.844	27,992	10.440	0	0	0	6.092,415

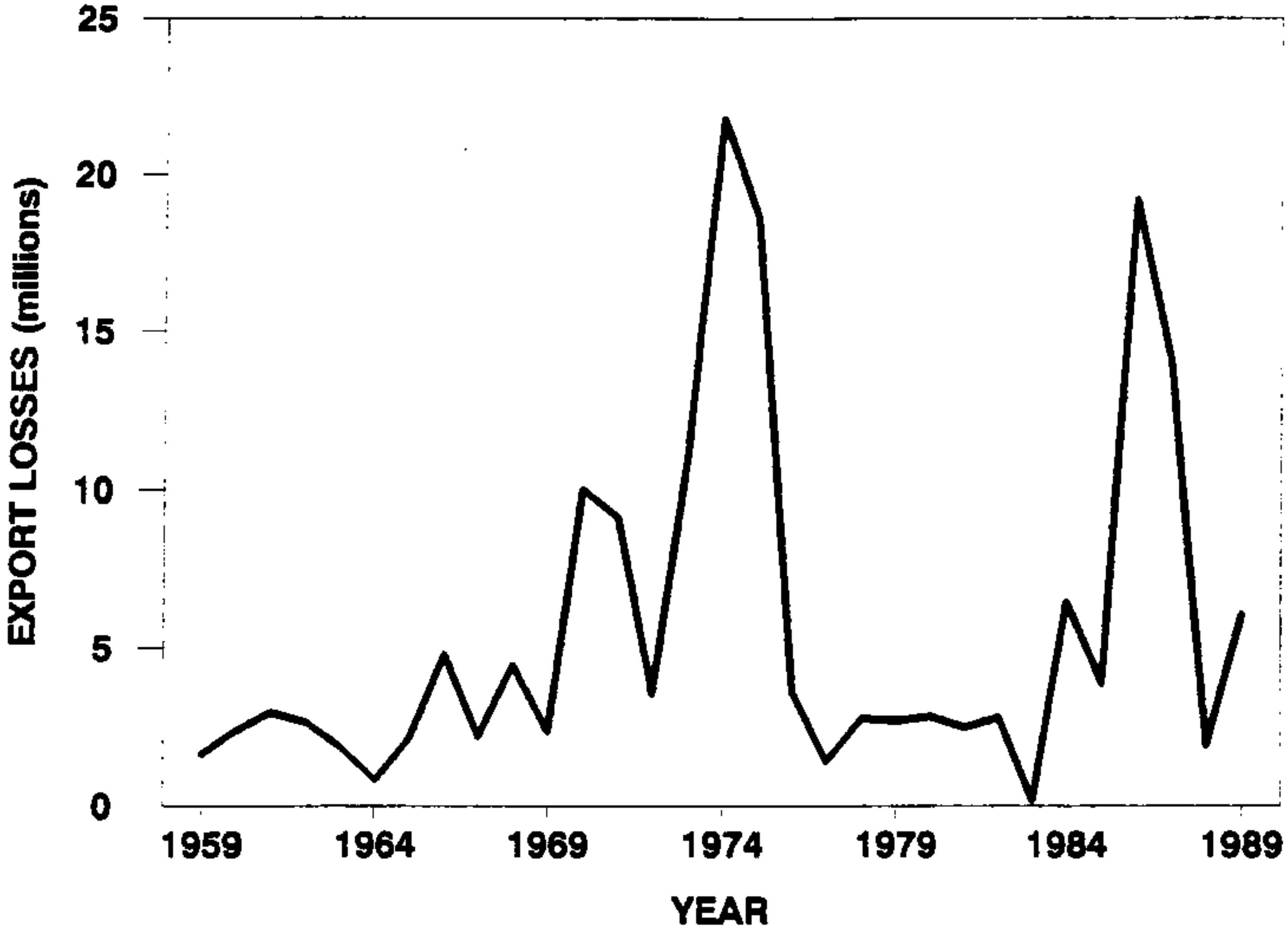


Figure 3. Trend in estimated losses to Central Valley Project and State Water Project export pumping of 21-150 mm striped bass after the time when the young-of-the-year index is set. Estimates assume size-dependent predation mortality in Clifton Court Forebay and at the CVP fish screens.

Table 2. Size dependent predation rates in Clifton Court Forebay and at the CVP fish screen used to estimate export losses.

	Predation Rates	
Length Group (mm)	Clifton Court	CVP
21-25	0.93	0.17
26-30	0.83	0.15
31-35	0.75	0.14
36-40	0.68	0.12
41-50	0.60	0.11
51-60	0.50	0.09
61-70	0.42	0.08
71-80	0.35	0.06
81-90	0.29	0.05
91-100	0.23	0.04
101-110	0.18	0.03
111-120	0.14	0.03
121-130	0.10	0.02
131-140	0.06	0.01
141-150	0.03	0.01

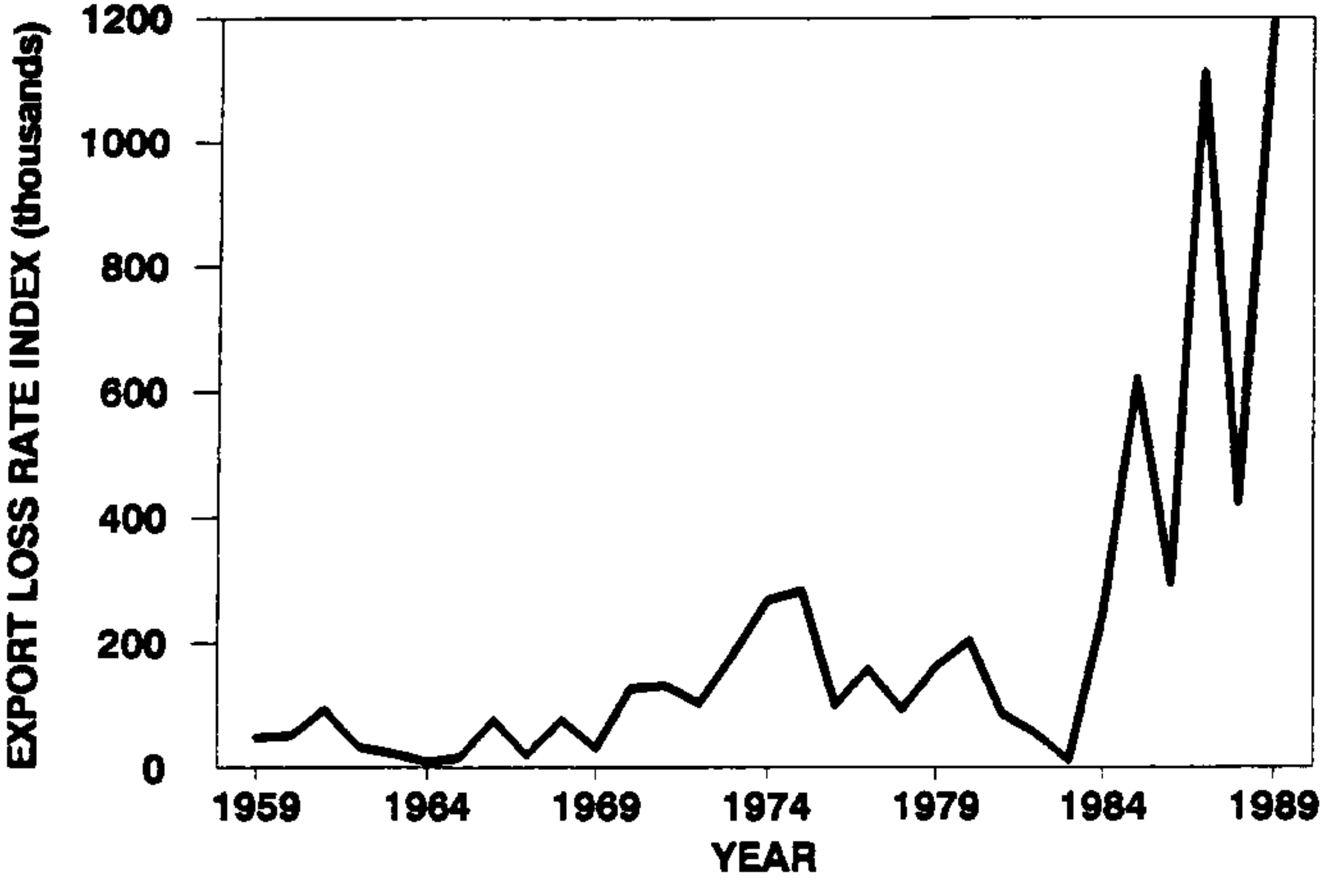
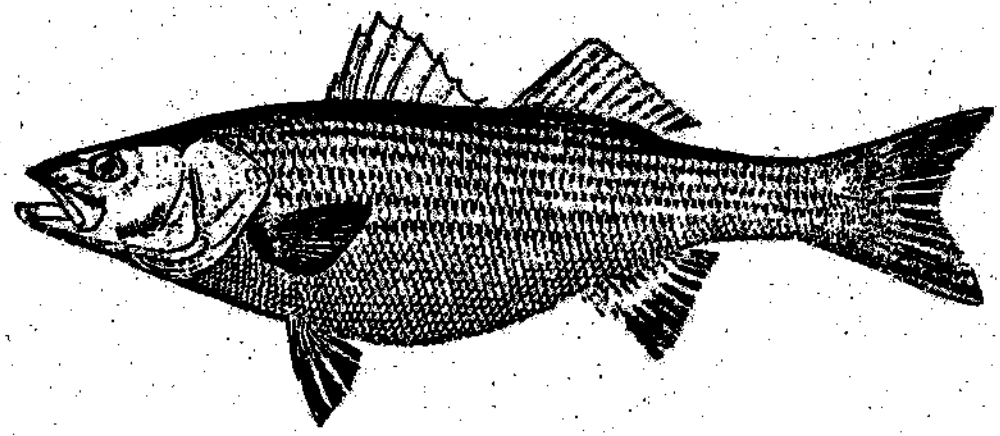


Figure 4. Trend in estimated loss rate of 21-150 mm striped bass to Central Valley Project and State Water Project export pumping after the time when the young-of-the-year index is set. Loss rate is the estimated export loss divided by the young-of-the-year index and represents the number of young bass lost per index unit.

WRINT-DFG-Exhibit 3

A MODEL FOR EVALUATING THE IMPACTS OF FRESHWATER OUTFLOW AND EXPORT ON STRIPED BASS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY



David W. Kohlhorst
Donald E. Stevens
Lee W. Miller

Bay-Delta and Special Water Projects Division
California Department of Fish and Game
4001 North Wilson Way
Stockton, California 95205-2424

Entered by the California Department of Fish and Game
for the State Water Resources Control Board 1992
Water Rights Phase of the Bay-Delta Estuary Proceedings

ERRATA - Department of Fish and Game Exhibit 3

Page 4, line 3 - (DFG 1992) should be (CDFG 1992)

Page 25, line 23 - (Stevens 1977) should be (Stevens 1977b)

Page 44, REFERENCES - add the following two references:

Dixon, W. J. 1988. BMDP statistical software manual. University of California Press, Berkeley, California, 619 pages.

Johnson, R. A. and D. W. Wichern. 1988. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey, 607 pages.

TABLE OF CONTENTS

Appendices - Statistical Comments on the Model

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

As part of The Department of Fish and Game's participation in the ongoing process by the State Water Resources Control Board which will revise water rights Decision 1485, we explored factors affecting adult striped bass abundance. This report presents evidence that freshwater outflow and water exports during the initial year of life are the primary factors controlling adult striped bass abundance in the Sacramento-San Joaquin Estuary. It also presents a quantitative approach for evaluating the impact on striped bass of alternative combinations of outflows and exports.

DECLINE IN STRIPED BASS ABUNDANCE

Adult striped bass abundance in the estuary, as estimated by the Petersen mark-recapture technique (Stevens 1977a), has declined substantially, from about 1.7 million in the early 1970s to less than 600,000 fish (exclusive of hatchery-produced fish) in 1990 (Figure 1). Young-of-the-year (yoy) abundance, indexed when their mean size is 38 mm in midsummer (Turner and Chadwick 1972; Stevens 1977a), has also declined precipitously, from a high index of almost 120 in 1965 to values less than six in the last 4 years (Figure 2). It is reasonable to expect that this decline in production of young fish has contributed significantly to the decreased adult numbers.

LOSSES OF ENTRAINED STRIPED BASS

Substantial mortality occurs between the time that the yoy index is set and recruitment of the year class to the fishery at about age 3. Much of this mortality results from losses in all

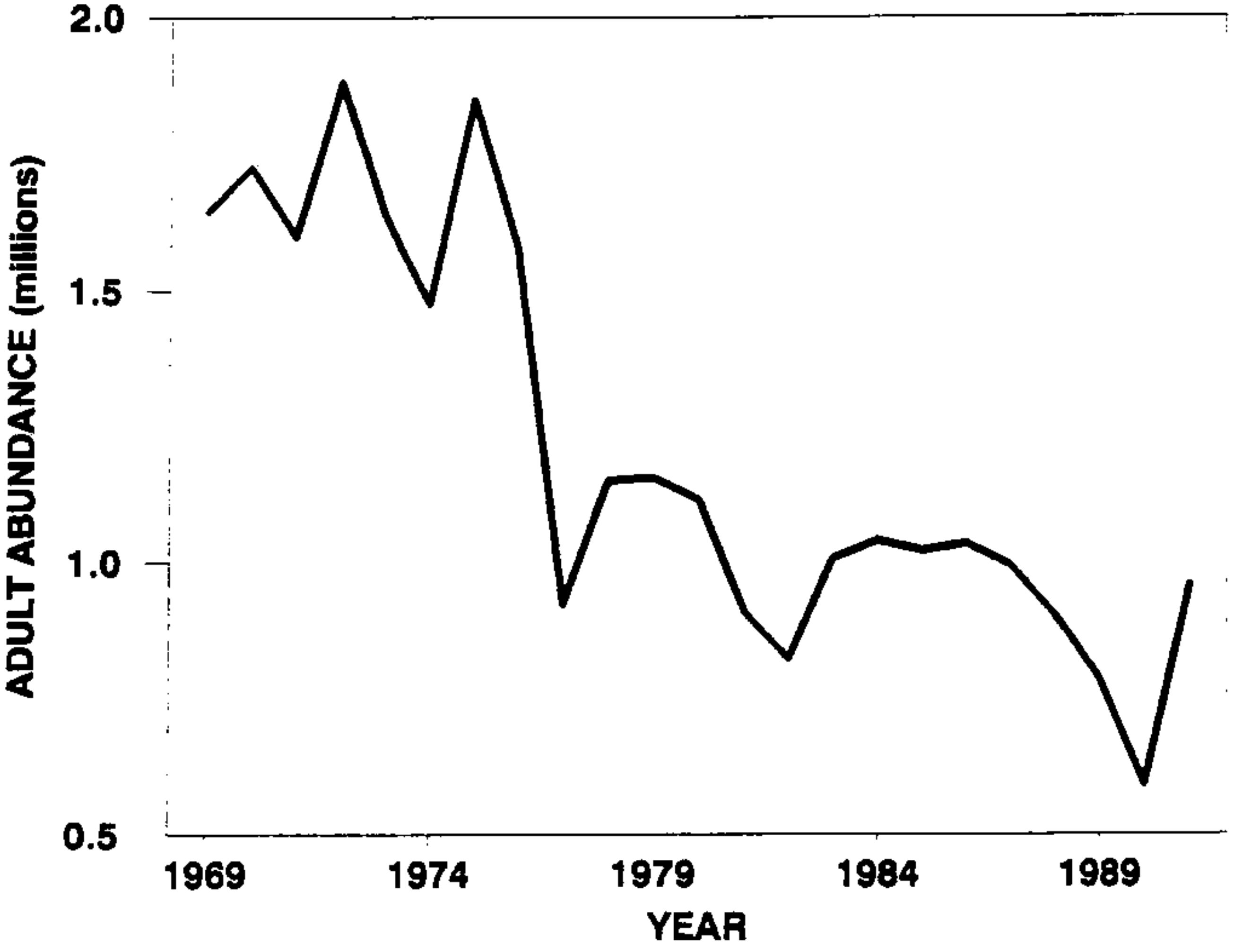


Figure 1. Trend in legal-sized striped bass abundance in the Sacramento-San Joaquin Estuary, 1969-1991.

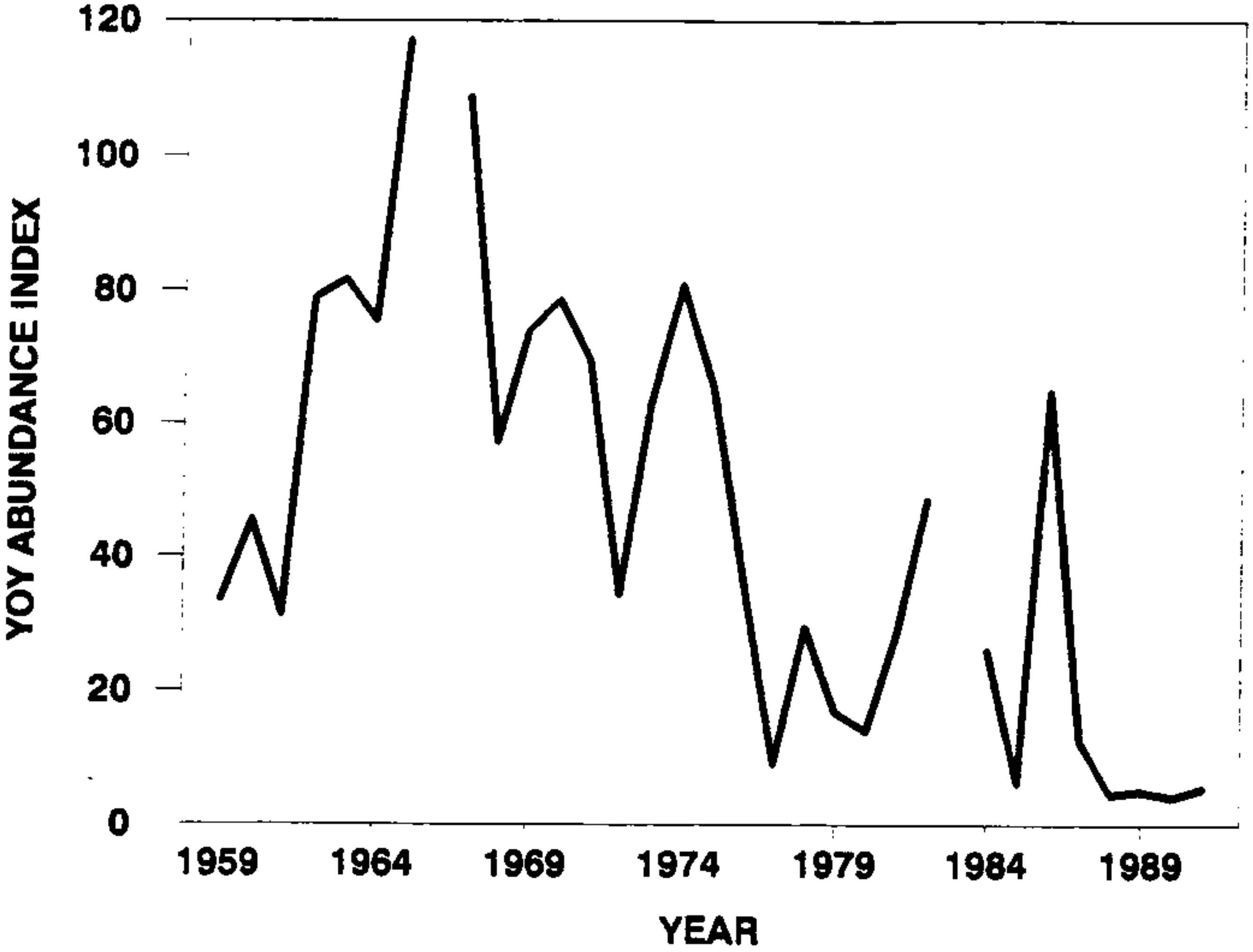


Figure 2. Trend in young-of-the-year striped bass abundance, as measured by the 38-mm index, in the Sacramento-San Joaquin Estuary, 1959-1991.

months from late summer through winter of 21-150 mm fish at the State Water Project (SWP) and Central Valley Project (CVP) export pumps in the south Delta (Table 1) (DFG 1992). These post-yoy losses have been estimated to range from less than 200,000 bass in 1983 to almost 22 million fish in 1974 (Figure 3). The loss estimates assume size-dependent predation losses in the SWP's Clifton Court Forebay beginning in 1971 which range from 93% for 21-25-mm bass to 3% for 141-150-mm fish (Table 2). Size-dependent predation losses at the Federal CVP fish screening facility where there is no forebay (and at the SWP facility before 1971 when a large predator population had developed) were scaled, for the same size range, from 17% to 1% (Table 2). For consistency, the Clifton Court Forebay predation curve is that used in the Four Pumps Mitigation Agreement. However, this curve appears to underestimate predation mortality when compared to results of experiments conducted with yoy striped bass (mean fork length from 47 to 56 mm) which found loss rates in the forebay of 94% in July, 1984 and 70% in August, 1986 (Kano 1985, 1986).

The magnitude of post-yoy index losses at the water export pumps is potentially affected by three readily identifiable factors: (1) the abundance of young bass; (2) the magnitude of water exports; and (3) Delta outflow, because it influences distribution of the young fish and their vulnerability to entrainment with exported water. For the purpose of evaluating the influence of water exports and outflow, the effect of young bass abundance can be removed by dividing post-yoy losses by the yoy index to produce a loss rate index which, conceptually, is similar to "fraction of the population removed" and is expressed as export loss per yoy index unit. This loss rate index has increased dramatically in recent years, from low values in the tens of thousands in the 1960s when only the CVP was exporting water from the Delta to over one million in 1987 and 1989 when both projects exported large amounts of water (Figure 4).

Table 1. Estimated monthly export losses of 21-150 mm striped bass after the time that the young-of-the-year index is set. Losses are calculated using size-specific mortality rates in Clifton Court Forebay and at the CVP fish screens. (Source: DFG 1992)

Year	Jun–Aug Loss	Sep Loss	Oct Loss	Nov Loss	Dec Loss	Jan Loss	Feb Loss	Mar Loss	Total Loss
1959	1,626,532	11,861	0	0	0	0	0	29,788	1,668,181
1960	2,386,894	15,967	0	0	0	0	0	11,187	2,414,048
1961	2,926,973	62,887	0	0	0	0	0	0	2,989,860
1962	2,661,480	32,829	0	0	0	0	0	0	2,694,309
1963	1,839,886	43,393	134	0	0	0	7,000	19,076	1,909,488
1964	783,167	46,263	0	0	0	0	0	4,707	834,137
1965	2,069,169	48,485	6,383	0	0	0	0	25,270	2,149,306
1966	4,770,193	22,668	9,235	0	0	0	0	9,010	4,811,106
1967	2,033,901	107,992	10,389	62	0	1,000	25,717	41,370	2,220,430
1968	4,287,280	78,458	30,784	25,511	11,671	30,435	7,456	2,332	4,473,927
1969	2,242,144	82,710	10,773	1,481	7,512	10,509	5,536	0	2,360,665
1970	9,448,287	301,313	125,281	62,687	37,959	12,234	18,672	47,294	10,053,728
1971	7,880,747	460,126	73,778	103,131	121,869	36,961	285,017	223,660	9,185,289
1972	2,750,649	458,776	67,452	25,731	147,205	65,451	46,128	6,666	3,568,058
1973	10,711,241	136,964	48,043	83,743	103,196	45,765	26,168	21,521	11,176,662
1974	21,010,359	179,413	33,791	14,912	192,003	213,451	113,155	50,113	21,807,197
1975	16,932,248	916,963	68,386	253,171	130,548	189,111	97,181	32,803	18,620,410
1976	3,287,871	74,682	36,146	52,297	41,158	72,419	31,959	18,515	3,615,048
1977	317,276	37,065	0	31,482	62,679	739,531	228,562	11,985	1,428,579
1978	2,053,451	51,367	195,614	237,158	192,891	48,928	13,193	5,460	2,798,063
1979	2,322,422	44,512	86,934	125,872	124,454	29,079	11,841	1,124	2,746,237
1980	2,170,581	286,882	50,453	108,343	135,890	64,180	28,959	8,263	2,853,551
1981	2,192,013	42,208	28,313	54,928	62,811	72,556	63,715	19,643	2,536,186
1982	2,296,121	200,544	43,759	58,609	171,333	33,438	14,227	2,940	2,820,971
1983	124,691	28,787	1,323	8,765	13,945	1,996	2,035	587	182,129
1984	5,894,345	30,476	188,231	160,425	159,665	28,401	18,363	6,300	6,486,207
1985	3,591,623	27,144	11,267	69,140	84,493	49,285	72,196	4,297	3,909,444
1986	18,727,707	205,013	82,520	83,011	60,302	27,512	29,013	6,529	19,221,607
1987	13,725,081	29,867	2,241	17,724	146,402	32,818	65,461	12,353	14,031,947
1988	1,683,936	12,366	7,592	99,770	78,538	29,360	23,621	13,955	1,949,138
1989	6,036,193	10,945	6,844	27,992	10,440	0	0	0	6,092,415

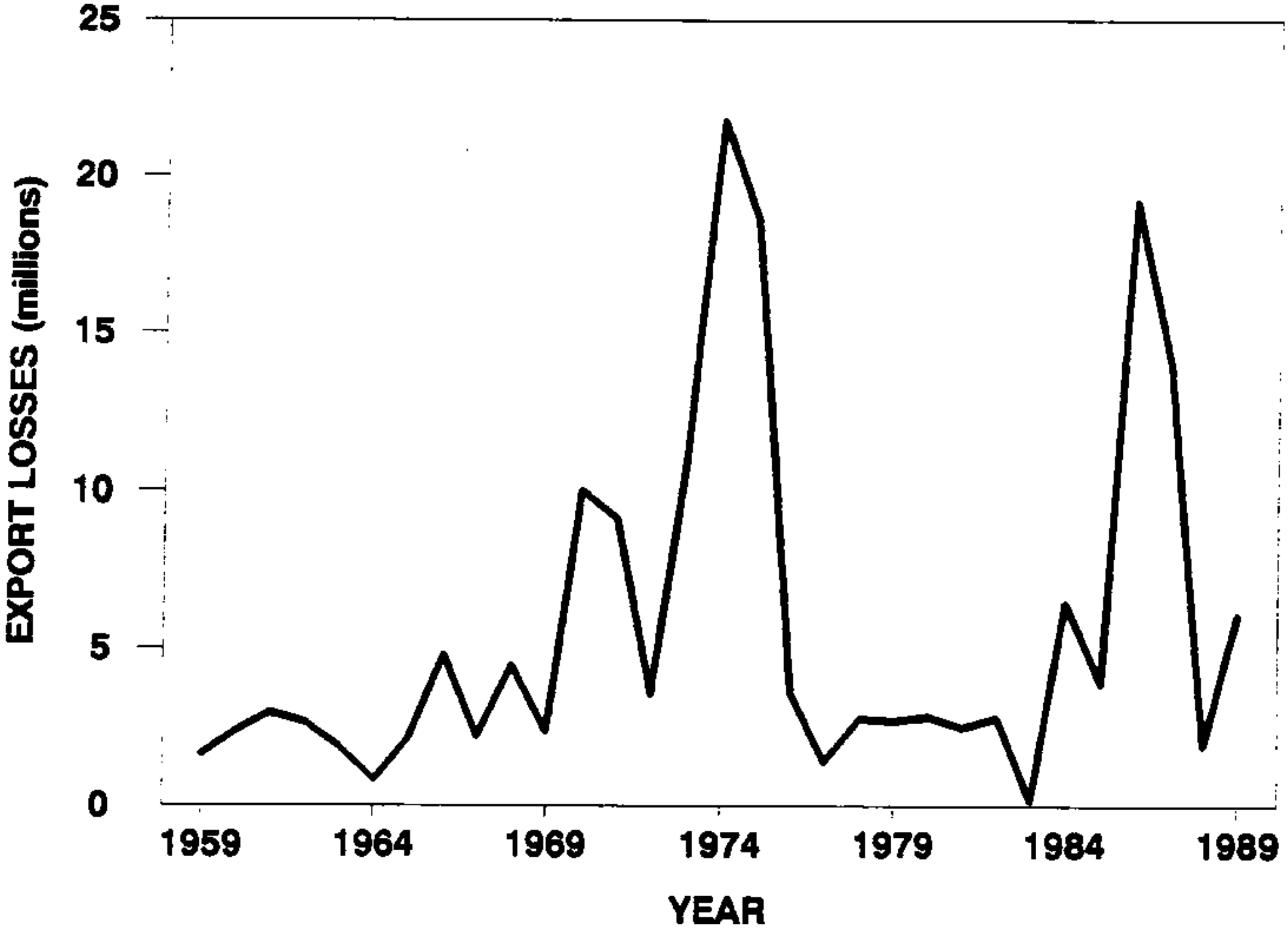


Figure 3. Trend in estimated losses to Central Valley Project and State Water Project export pumping of 21-150 mm striped bass after the time when the young-of-the-year index is set. Estimates assume size-dependent predation mortality in Clifton Court Forebay and at the CVP fish screens.

Table 2. Size dependent predation rates in Clifton Court Forebay and at the CVP fish screen used to estimate export losses.

Length Group (mm)	Predation Rates	
	Clifton Court	CVP
21-25	0.93	0.17
26-30	0.83	0.15
31-35	0.75	0.14
36-40	0.68	0.12
41-50	0.60	0.11
51-60	0.50	0.09
61-70	0.42	0.08
71-80	0.35	0.06
81-90	0.29	0.05
91-100	0.23	0.04
101-110	0.18	0.03
111-120	0.14	0.03
121-130	0.10	0.02
131-140	0.06	0.01
141-150	0.03	0.01

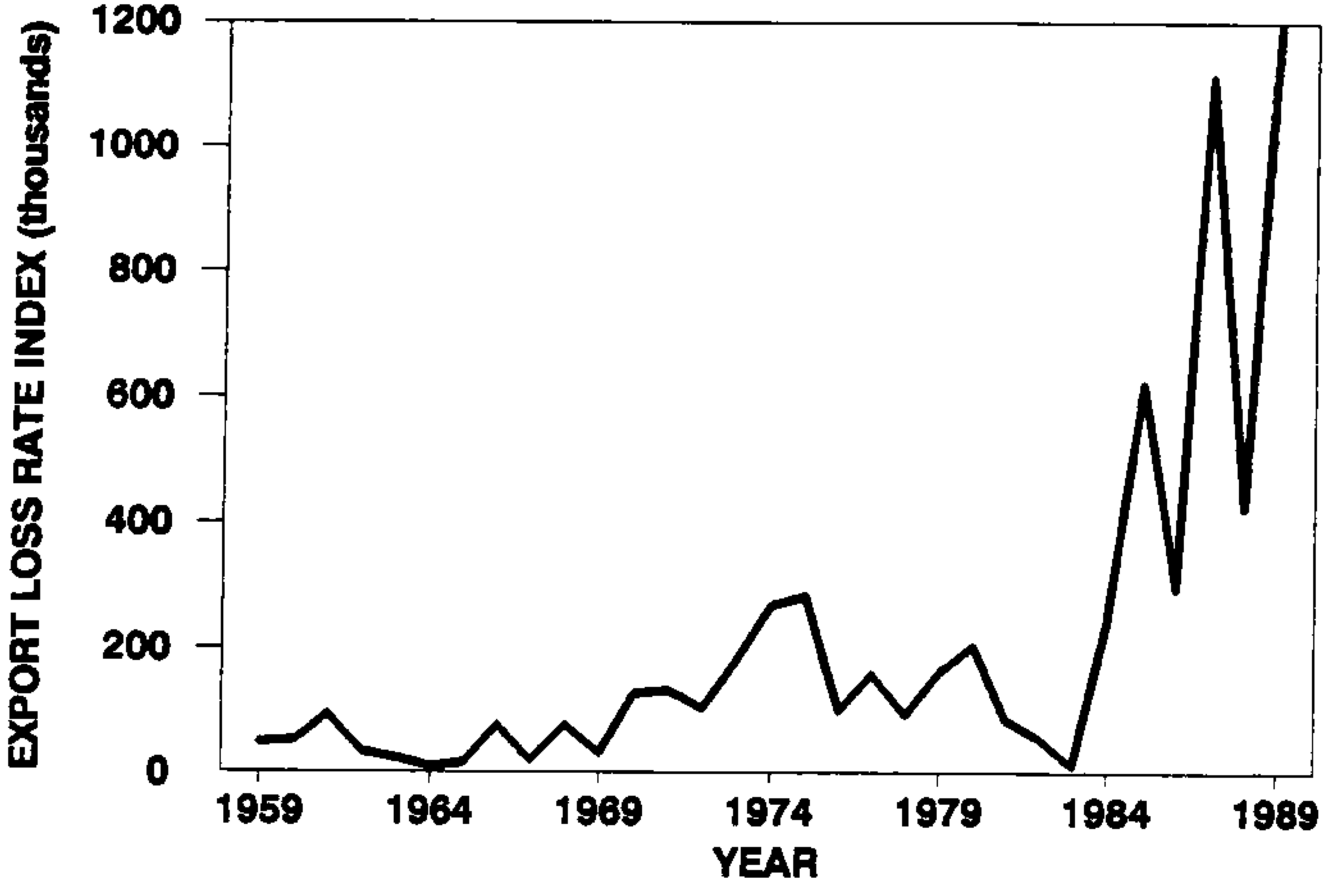


Figure 4. Trend in estimated loss rate of 21-150 mm striped bass to Central Valley Project and State Water Project export pumping after the time when the young-of-the-year index is set. Loss rate is the estimated export loss divided by the young-of-the-year index and represents the number of young bass lost per index unit.

IMPACT OF YOUNG STRIPED BASS ABUNDANCE AND SUBSEQUENT ENTRAINMENT LOSSES ON ABUNDANCE OF ADULTS

Our first step in determining the influence of freshwater outflow and water export on the bass population was to explore how well changes in adult striped bass abundance were explained by, individually, the yoy index, export losses, and the loss rate index. Since age 3-7 fish comprise a large proportion of the adult population (Figure 5), we looked at associations between adult abundance and the *weighted mean* yoy index 3-7 years earlier, *weighted mean* losses 3-7 years earlier, and *weighted mean* loss rate 3-7 years earlier. Weighting factors used were the average estimated abundance from 1969 to 1991 of each age class of adults relative to age 3 abundance (Table 3). Thus, the weighting factors reflect the relative contribution of each year class to the adult population and were used to calculate means as in the following example for yoy: weighted mean yoy index in year i = (yoy index in year i-3 + 0.5987(yoy_{i-4}) + 0.3083(yoy_{i-5}) + 0.1380(yoy_{i-6}) + 0.0740(yoy_{i-7}))/5. Linear and log-transformed forms of the variables were used in a correlation analysis which indicated that adult abundance is most strongly associated with the weighted mean yoy index (r=0.775), log(weighted mean yoy index) (r=0.742) and log(weighted mean loss rate) (r=-0.727) and that log(adult abundance) has the best correlations with the weighted mean yoy index (r=0.756), log(weighted mean loss rate) (r=-0.747), and log(weighted mean yoy index) (r=0.723) (Table 4).

Although simple correlation analysis suggests only a weak association between adult striped bass abundance and weighted mean losses, removing variability associated with yoy abundance by stepwise regression reveals that these losses are important in determining adult bass abundance ($R^2 = 0.76$) (Table 5). The positive correlation with young-of-the-year abundance and negative correlation (or regression coefficient) with both losses and the loss rate index indicates that high adult abundance

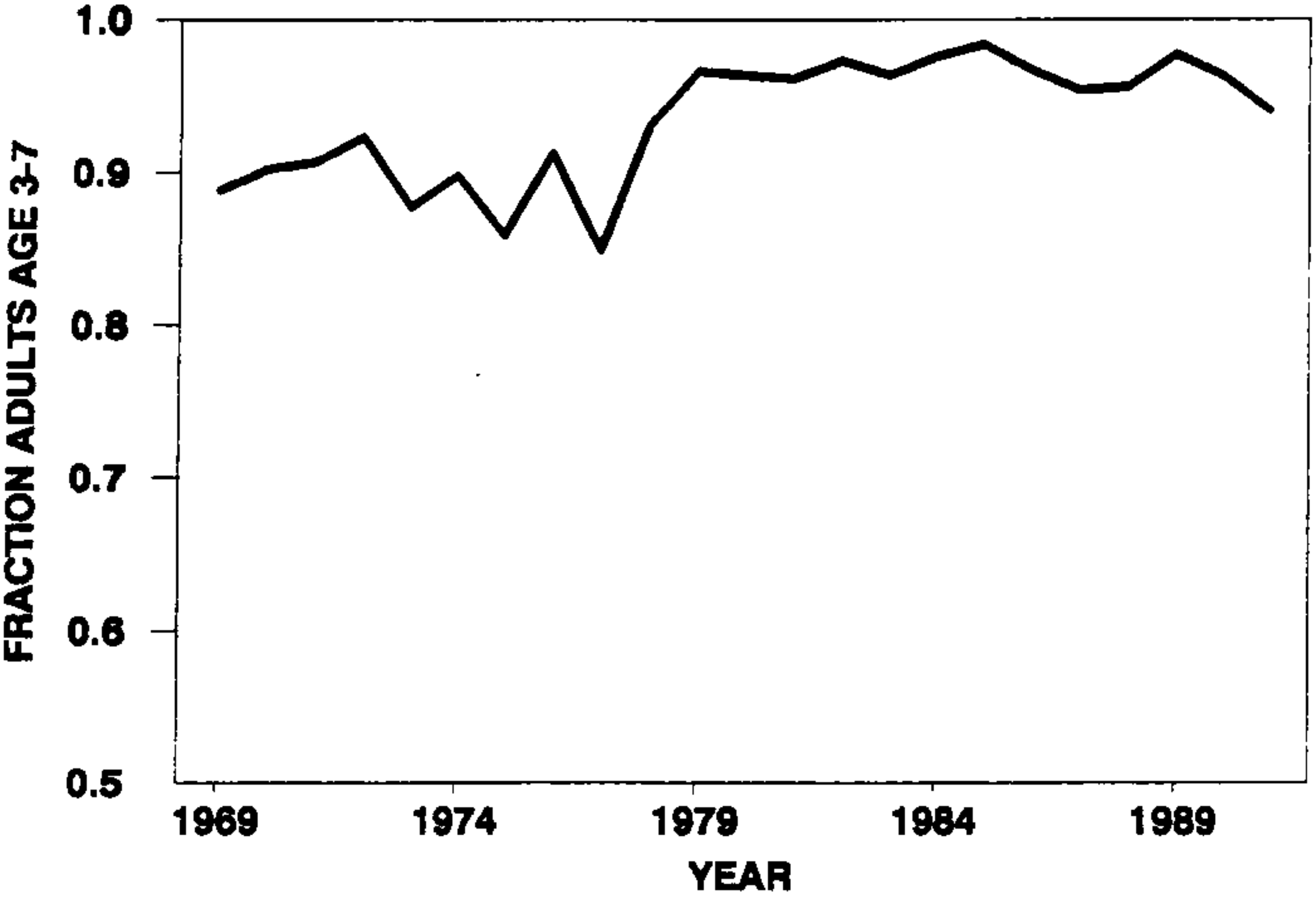


Figure 5. Proportion of the legal-sized striped bass abundance estimate that is age 3-7.

Table 3. Petersen population estimates for age 3–7 wild striped bass (excluding hatchery–produced fish) and the proportion of each age relative to age 3 used to calculate weighting factors for mean yoy, losses, and loss rates.

	Abundance Estimates					Proportion Relative to Age 3					
Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 3	Age 4	Age 5	Age 6	Age 7	
1969	1,083,448	412,448	269,245	170,505	69,147	1.0000	0.3807	0.2485	0.1574	0.0638	
1970	1,309,098	484,360	201,040	128,928	69,809	1.0000	0.3700	0.1536	0.0985	0.0686	
1971	858,574	602,350	224,357	118,366	77,139	1.0000	0.7016	0.2613	0.1379	0.0898	
1972	1,249,964	521,549	407,093	124,223	61,635	1.0000	0.4173	0.3257	0.0994	0.0493	
1973	742,520	480,825	234,728	176,698	173,945	1.0000	0.6476	0.3161	0.2380	0.2343	
1974	941,360	338,683	272,919	136,202	108,783	1.0000	0.3598	0.2899	0.1447	0.1156	
1975	933,690	619,066	265,656	160,725	76,422	1.0000	0.6630	0.2845	0.1721	0.0818	
1976	1,037,674	480,548	190,596	130,718	123,493	1.0000	0.4631	0.1837	0.1260	0.1190	
1977	534,040	176,888	223,172	92,257	25,101	1.0000	0.3312	0.4179	0.1728	0.0470	
1978	1,213,574	254,939	136,032	33,091	42,797	1.0000	0.2101	0.1121	0.0273	0.0353	
1979	929,368	398,345	179,211	48,490	26,797	1.0000	0.4286	0.1928	0.0522	0.0288	
1980	379,696	560,208	211,661	85,511	29,323	1.0000	1.4754	0.5574	0.2252	0.0772	
1981	531,916	342,590	186,680	54,036	27,787	1.0000	0.6441	0.3510	0.1016	0.0522	
1982	821,584	217,768	97,861	41,291	35,796	1.0000	0.2651	0.1191	0.0503	0.0436	
1983	564,464	394,577	232,066	39,333	25,684	1.0000	0.6990	0.4111	0.0697	0.0455	
1984	667,977	359,026	187,021	27,919	10,341	1.0000	0.4136	0.2155	0.0322	0.0119	
1985	418,749	538,559	190,319	64,699	5,267	1.0000	1.2861	0.4545	0.1545	0.0126	
1986	526,171	328,553	282,682	105,575	22,710	1.0000	0.6244	0.5372	0.2006	0.0432	
1987	629,384	274,892	172,848	132,469	56,632	1.0000	0.4368	0.2746	0.2105	0.0900	
1988	373,668	386,400	133,161	112,265	43,050	1.0000	1.0341	0.3564	0.3004	0.1152	
1989	292,166	384,082	145,643	43,819	46,890	1.0000	1.3146	0.4985	0.1500	0.1605	
1990	373,078	149,257	144,696	59,245	27,361	1.0000	0.4001	0.3884	0.1588	0.0733	
1991	910,111	185,598	128,858	86,513	39,158	1.0000	0.2039	0.1416	0.0951	0.0430	Overall Mean
					Mean	1.0000	0.5987	0.3083	0.1380	0.0740	0.4238

Table 4. Results of correlation analysis between wild adult striped bass abundance (without hatchery-produced fish) and weighted mean yoy abundance index, weighted mean post-yoy losses, and weighted mean post-yoy loss rate 3-7 years earlier.

	ADULTS	LOG_{10}(ADULTS)
MEAN YOY	0.775	0.756
LOG_{10}(MEAN YOY)	0.742	0.723
MEAN LOSSES	-0.263	-0.282
LOG_{10}(MEAN LOSSES)	-0.186	-0.210
MEAN LOSS RATE	-0.619	-0.679
LOG_{10}(MEAN LOSS RATE)	-0.727	-0.747

Table 5. Results of stepwise regression of wild adult striped bass abundance (without hatchery-produced fish) on weighted mean young-of-the-year index (WTMNYOY), weighted mean post-yoy losses (WTMNLOSS), and weighted mean post-yoy loss rate (WTMNLOSSRATE) 3-7 years earlier. Values in the table are coefficients of determination (R^2) expressed as percentages. The R^2 value for the final model selected by stepwise regression is underlined.

Independent Variables	ADULTS
WTMNYOY	60
WTMNLOSS	7
WTMNLOSSRATE	53
WTMNYOY & WTMNLOSS	76
WTMNYOY & WTMNLOSSRATE	71

results from initially strong year classes that experience only small late summer through winter losses to export pumping. We decided to use the yoy abundance index in combination with loss rate rather than losses in the final equation to describe the effects of these variables on adult striped bass abundance. The model with loss rate is more straightforward because it allows evaluation of post-yoy index water management scenarios that are not dependent on the yoy index. The equation

LEGAL-SIZED ADULTS = 18940 WEIGHTED MEAN YOY INDEX - 446608 LOG(WEIGHTED MEAN LOSS RATE) + 2960840

explains 71% of the variability in adult striped bass abundance (Figure 6).

VERIFICATION OF THE PREDICTABILITY OF ADULT STRIPED BASS ABUNDANCE FROM YOUNG STRIPED BASS ABUNDANCE AND SUBSEQUENT ENTRAINMENT LOSSES

Other data and methods were explored for the purpose of evaluating the reasonableness of the results relating adult striped bass abundance to young bass abundance and entrainment losses.

Discriminant Analysis

Stepwise discriminant analysis with the same linear and log-transformed variables employed in the above regression analysis was used to assign the annual adult population estimate to one of two groups, high abundance (>1.4 million) or low abundance (<1.2 million). A jackknife validation procedure (Dixon 1988, p 337; Johnson and Wichern 1988, p 498) classified each year into a group based on classification functions computed from all years except the year being classified. Jackknife discriminant analysis was 100% successful at assigning each year's adult

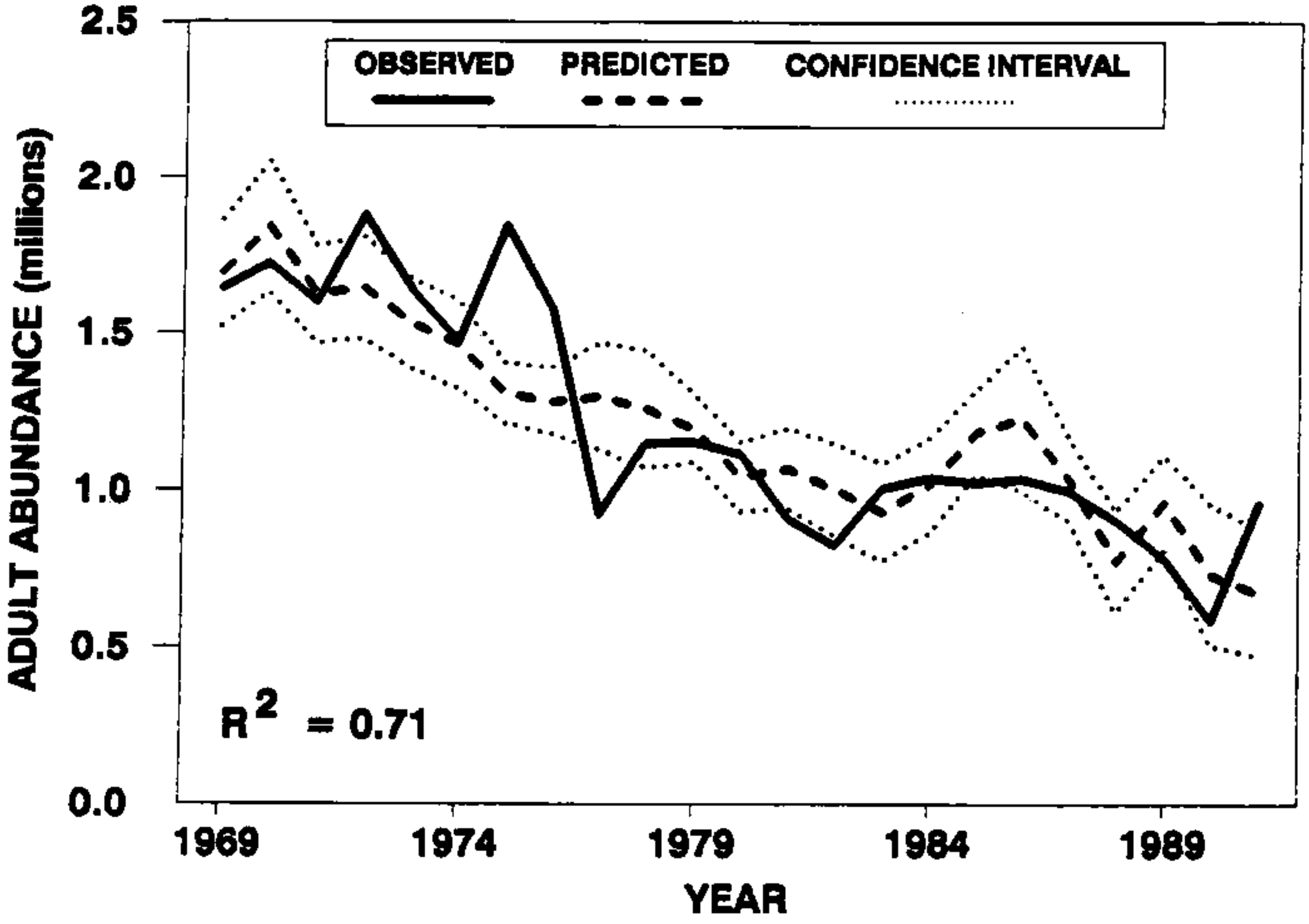


Figure 6. Observed and predicted adult striped bass abundance in the Sacramento-San Joaquin Estuary from 1969-1991. Predicted values are from the relationship between adult abundance and weighted mean young-of-the-year index and export loss rate 3-7 years earlier. The 95% confidence limits for the predicted values are shown.

population estimate to the proper group with classification functions which selected weighted mean yoy, weighted mean export loss, and log(weighted mean export loss) as significant variables (Table 6). Five replications of an analysis which randomly split the data set and used the classification functions developed from one subset to classify the years in the other subset resulted in a high proportion of correct classifications in the test subsets (Table 6).

Thus, this approach provides strong support for our model.

Analysis with Ages 3, 4, and 5

Petersen population estimates are available for individual age groups up to age 7 (Table 3) so that the relationship of each age group to its abundance in the first summer of life and subsequent first-year entrainment losses can be explored. We chose to examine this relationship for recruits (ages 3 and 4) and age 5, which is the age at which most females become sexually mature and, thus, fully vulnerable to capture by our tagging program during the spring spawning migration.

Stepwise regression of estimated abundance at each age and consecutive combinations of ages on yoy index, export losses, and loss rate with appropriate lags (weighted means over the appropriate years for combinations of ages) yielded results that were generally consistent with the analysis using total adult abundance (Table 7). In all cases (except for age 4), yoy index and export losses produced the "best" model (highest R^2 and including all independent variables allowed to enter by the stepwise process), explaining from 42% to 65% of the variance in abundance of individual or combinations of ages. Loss rate was also related to abundance, but explained much of the same variance as the yoy index and was removed from the model when yoy entered.

The results with the individual ages generally support our model.

Table 6. Results of discriminant analyses to distinguish between two levels of wild adult striped bass abundance: >1.4 million and <1.2 million. Potential classification variables were linear and log-transformed weighted mean yoy abundance index (WTMNYOY), weighted mean post-yoy losses (WTMNLOSS), and weighted mean post-yoy loss rate (WTMNLOSSRATE) 3-7 years earlier. Jackknifed classification was used in all analyses. Analyses 2-6 randomly split the data set and used classification functions calculated with the first subset to classify the second subset.

	Variables in		Classification Subset			Test Subset	
Analysis Number Total	Classification Function		Correctly Classified >1.4 mil.	Correctly Classified <1.2 mil.	Total	Correctly Classified >1.4 mil.	Correctly Classified <1.2 mil.
1	WTMNYOY WTMNLOSS LOG(WTMNLOSS)	# %	8 100	15 100	23 100		
2	WTMNYOY	# %	2 100	6 100	8 100	6 67	615 10080
3	WTMNYOY WTMNLOSS WTMNLOSSRATE	# %	2 100	9 100	11 100	4 67	612 10083
4	WTMNYOY WTMNLOSS WTMNLOSSRATE	# %	2 100	8 100	10 100	4 67	713 10085
5	WTMNYOY	# %	5 100	5 83	11 91	3 100	812 8992
6	WTMNYOY WTMNLOSS LOG(WTMNLOSS)	# %	4 100	9 100	13 100	4 100	610 100100

Table 7. Results of stepwise regression of wild age 3-5 striped bass abundance (without hatchery-produced fish) on the yoy abundance index (YOY), post-yoy losses (LOSSES), and post-yoy loss rate (LOSS RATE). Combinations of ages are regressed on weighted means of the independent variables with appropriate time lags. Weighting factors are age-class abundance relative to age 3 (Table 3). Values are coefficients of determination (R^2) expressed as percentages. The R^2 value for the final model selected by stepwise regression is underlined.

Independent Variables	Age 3	Age 4	Age 5	Age 3 & 4	Age 4 & 5	Age 3-5
YOY	27	6	27	38	21	52
LOSSES	2	20	5	4	12	4
LOSS RATE	17	18	21	28	28	34
YOY & LOSSES	42	33	44	54	42	65
YOY & LOSS RATE	33	19	36	47	37	61

Analysis with Yearling Equivalent Losses and Loss Rate

Impacts of losses vary, depending on when they occur and the size of entrained fish because survival increases with age and size. Thus, losses of large yoy fish late in their natal year are potentially more damaging than losses of smaller fish in their first summer of life. To account for these differences in survival to age 1, estimated survivals (L. W. Miller, DFG, file report) were applied to adjust all losses to yearling equivalents. Then we reexamined the relationship between adult striped bass abundance and the yoy index, entrainment losses, and loss rate by using yearling equivalents rather than actual estimated losses. The yoy index and yearling equivalent losses were treated as in the original analysis, where weighted means 3-7 years earlier were used as independent variables in stepwise regression with estimated adult abundance and its logarithm as dependent variables.

In the final stepwise regression models (those with highest R^2 and including all independent variables allowed to enter by the stepwise process), weighted mean yoy index and yearling equivalent losses accounted for 67% of the variability in adult abundance and weighted mean yoy index alone explained 57% of the variability in log (adult abundance) (Table 8). Weighted mean yearling equivalent loss rate explained 43% and 42% of the variability in adults and log (adults), respectively, but was removed from the regression equation when weighted mean yoy index entered.

This yearling equivalent approach provides results that are generally consistent with our model, although one would expect the relationships to be stronger with yearling equivalents than with actual losses since yearlings are more proximal to adults. The somewhat poorer results with yearling equivalents suggest that survival rates used to estimate the yearling equivalent value of different sizes of yoy may be inaccurate.

Table 8. Results of stepwise regression of wild adult striped bass abundance (without hatchery-produced fish) on the weighted mean yoy abundance index (WTMNYOY), weighted mean post-yoy yearling equivalent losses (WTMNYELOSS), and mean weighted post-yoy yearling equivalent loss rate (WTMNYELOSSRATE) 3-7 years earlier. Weighting factors are age-class abundance relative to age 3 (Table 3). Results with linear and log-transformed values of adult abundance are presented. Values in the table are coefficients of determination (R^2) expressed as percentages. The R^2 value for the final model selected by stepwise regression is underlined.

Independent Variables	ADULTS	LOG_{10}(ADULTS)
WTMNYOY	60	57
WTMNYELOSS	18	15
WTMNYELOSSRATE	43	42
WTMNYOY & WTMNYELOSS	67	63
WTMNYOY & WTMNYELOSSRATE	61	58

Analysis with Tagging Catch per Effort Index of Adult Abundance

Besides the Petersen estimate of adult striped bass abundance, another measure of bass abundance is available based on catch per effort (cpe) during tagging (Stevens et al. 1985). The standard unit of effort used to calculate this cpe index is 36 trap months at Clarksburg on the Sacramento River and 4 boat-months of gill netting in the Delta. Tagging cpe indices are available for most of the same years as the population estimates (1969-1991) except for years when the traps were not fished (1977 and 1978) or when they were fished at locations other than Clarksburg (1981, 1990, and 1991) (Table 9). The traps are now fished exclusively at Knights Landing where the river is narrower and shallower than at Clarksburg, thus, cpe is not comparable at the two sites and no tagging cpe index is available after 1989.

Stepwise regression of the tagging cpe index on weighted mean yoy, losses, and loss rate resulted in only yoy entering the regression equation and explaining 83% of the variance in the index (Table 10). Weighted mean losses and loss rate explained only 0.1% and 21%, respectively, of the variance in the tagging cpe index.

These cpe results markedly contrast with our model based on Petersen population estimates. This difference may be due to bias resulting from more efficient use of the fishing gear in recent years as abundance declined and bass became more difficult to catch. This explanation is consistent with the manner in which the gear is fished. The gill net crews actively seek fish in alternative areas when unsuccessful in the usual fishing area (San Joaquin River at Sherman Island).

Analysis with Detrended Data

All data sets used in the analysis up to this time have a distinct time trend (Table 11). To determine the impact of coincident time trends on the observed relationships between adult abundance and mean weighted yoy index, losses, and loss rate, all four variables were detrended by differencing, ie.

Table 9. Catch-per-effort index of striped bass abundance developed from catches of legal-sized fish during annual spring tagging in the western Delta and in the Sacramento River near Clarksburg. Annual effort is four boat-months of gill netting and 36 trap-months of trapping. Traps were not fished in 1977 and 1978 and were fished at other locations in 1981 and after 1989.

Year	Catch-per-Effort Index
1969	25447
1970	19623
1971	23207
1972	19812
1973	19898
1974	15075
1975	10691
1976	11930
1977	Missing
1978	Missing
1979	13249
1980	7394
1981	Missing
1982	6077
1983	6532
1984	5919
1985	8805
1986	9257
1987	9436
1988	9107
1989	11906

Table 10. Results of stepwise regression of striped bass tagging catch-per effort index on weighted mean young-of-the-year index (WTMNYOY), weighted mean post-yoy losses (WTMNLOSS), and weighted mean post-yoy loss rate (WTMNLOSSRATE) 3-7 years earlier. Weighting factors are age-class abundance relative to age 3 (Table 3). Values in the table are coefficients of determination (R^2) expressed as percentages. The R^2 value for the final model selected by stepwise regression is underlined.

Independent Variables	Catch-per-Effort Index
WTMNYOY	$\underline{83}$
WTMNLOSS	<1
WTMNLOSSRATE	22
WTMNYOY & WTMNLOSS	
WTMNYOY & WTMNLOSSRATE	83

Table 11. Results of detrending adult abundance, weighted mean yoy index, weighted mean export losses, and weighted mean loss rate by differencing so that $x_i = x_i - x_{i-1}$, where i = year.

Time trend: variable regressed on year

	Original Data		Detrended Data	
Variable	Slope	r^2	Slope	r^2
ADULTS	-47513	0.74	7335	0.02
WTMNYOY	-1.383	0.80	0.018	0.00
WTMNLOSS	27357	0.01	-8175	0.00
WTMNLOSSRATE	7471	0.48	1513	0.05
Relationship with Adults				
WTMNYOY	27684	0.61	-18145	0.05
WTMNLOSS	-0.0533	0.07	-0.0710	0.08
WTMNLOSSRATE	-3.157	0.38	-1.283	0.02

replacing the value in year i by the difference between the value in year i and the value in year i-1. If the difference is positive, it means the variable increased between year i-1 and year i; if negative, it decreased. Differencing removed the time trend and also eliminated the strong relationships of adults with the mean weighted yoy index and mean weighted loss rate (Table 11) (Recall that there was never a strong relationship between adult abundance and mean weighted export losses without yoy in the equation).

Elimination of the strong relationships when the time trends are removed does not mean that the relationships are spurious, only that they are mostly due to simultaneous major changes in yoy striped bass abundance, entrainment losses, and loss rate that have occurred over time.

EFFECT OF HYDROLOGY ON STRIPED BASS ABUNDANCE AND LOSSES

Young Bass Abundance

The next step in the process was to determine how well hydrologic variables account for the decline in adult bass abundance through their effect on the yoy index and loss rate. Dealing first with the yoy index, past studies have shown that it is strongly related to spring and early summer outflow and diversions (exports + channel depletion in the Delta) (Turner and Chadwick 1972; Stevens 1977) , but that this relationship over-predicts the yoy index after 1976 (Figure 7) (Stevens et al. 1985; IESP 1987). Note in Figure 7 that the regression equations (based on 1959-1976 data) in the caption predict the Delta portion of the yoy index from log(April-July outflow), (log(April-July outflow))^2 and April-July diversions and they predict the Suisun Bay portion of the index from log(April-July outflow) only. These equations incorporate two changes from past regression relationships:

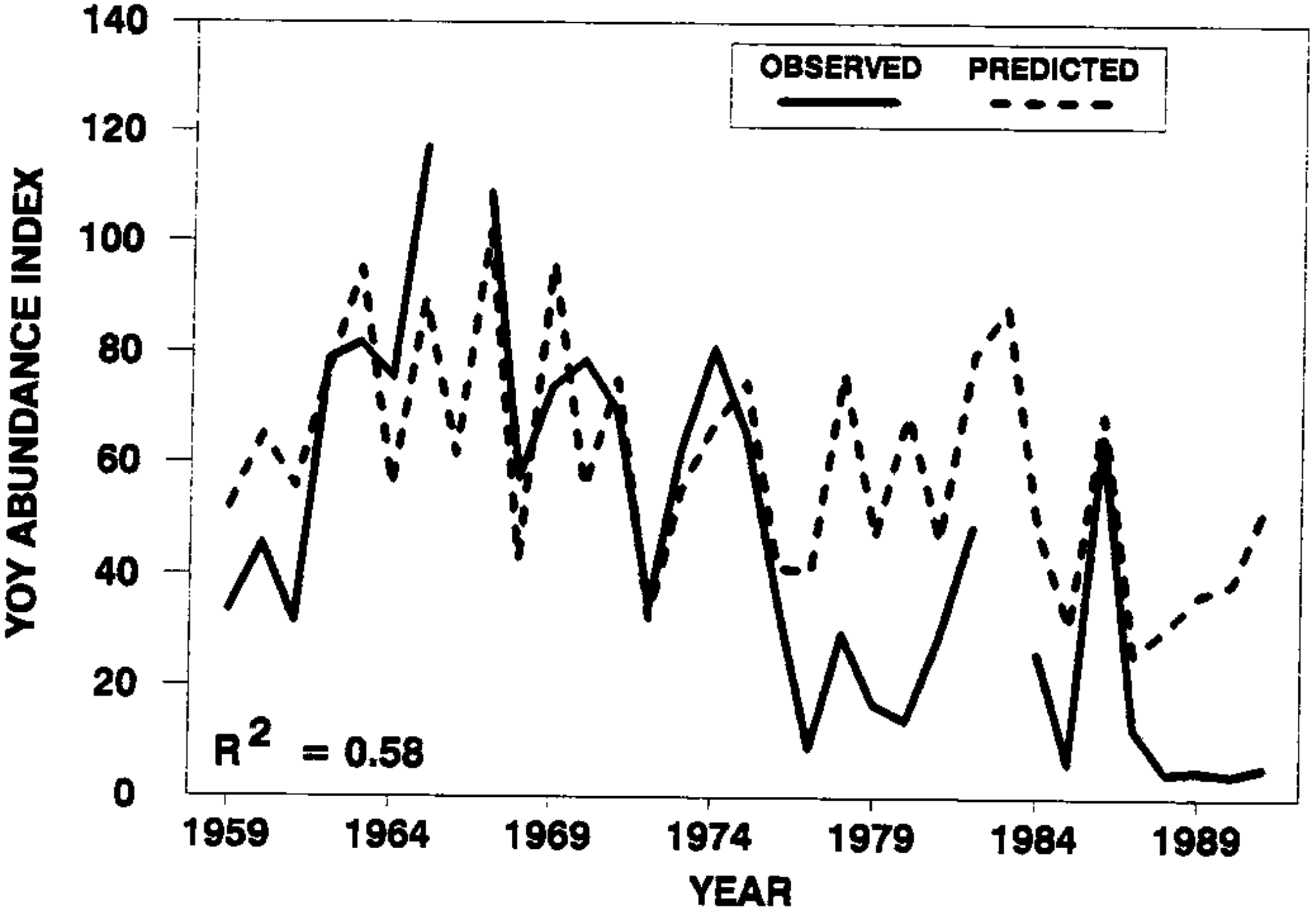


Figure 7. Observed and predicted striped bass young-of-the-year indices from 1959 to 1991. The following prediction equations are based on 1959-1976 data only:
DELTA INDEX = 292.332 LOG(APRIL-JULY OUTFLOW) - 34.866 (LOG(APRIL-JULY OUTFLOW))^2 - 0.00561 APRIL-JULY DIVERSIONS - 534.5475
SUISUN INDEX = 46.680 LOG(APRIL-JULY OUTFLOW) - 159.077.
For the April-July period, diversions = exports + 3108.

1) April is now included because increased April water exports in recent years have made this month more important in determining yoy abundance and

2) the relationship for the Suisun Bay index no longer contains a "squared" outflow term, so it is now linear rather than curvilinear.

The latter change reflects our conclusion that yoy striped bass abundance west of the Delta continues to increase with increasing outflow and the decrease in the index at the highest flows is simply the result of incomplete sampling in the farthest downstream areas (Stevens 1977a, 1977b; Stevens et al. 1985; IESP 1987).

Correction for Variations in Egg Production

To determine whether the over-prediction of the yoy index after 1976 is the result of reduced spawning stock and egg production, we examined the relationship between the residuals (observed - predicted) from Figure 7 and estimated egg production. Egg production was estimated from the age-stratified Petersen population estimates for females and age-specific fecundity data. (Using these egg production and adult abundance data, we derived the equation EGG PRODUCTION (billions) = 92.25 (PETERSEN POPULATION ESTIMATE (millions))^2 + 38.58, with r^2 = 0.734, which can be used to estimate egg production in the absence of age composition data.) After coding the residuals by adding 60 to each one (to eliminate negative numbers), we fit a Beverton-Holt stock-recruit curve to these data (Figure 8). The stock-recruit equation is

$$\text{RESIDUAL YOY} = (1/(0.0095 + (2.59/\text{EGGS}))) - 60,$$

with $r^2 = 0.379$. The linear relationship between residual yoy and egg production provides essentially identical results (r^2 = 0.379), but we used the curvilinear Beverton-Holt relationship

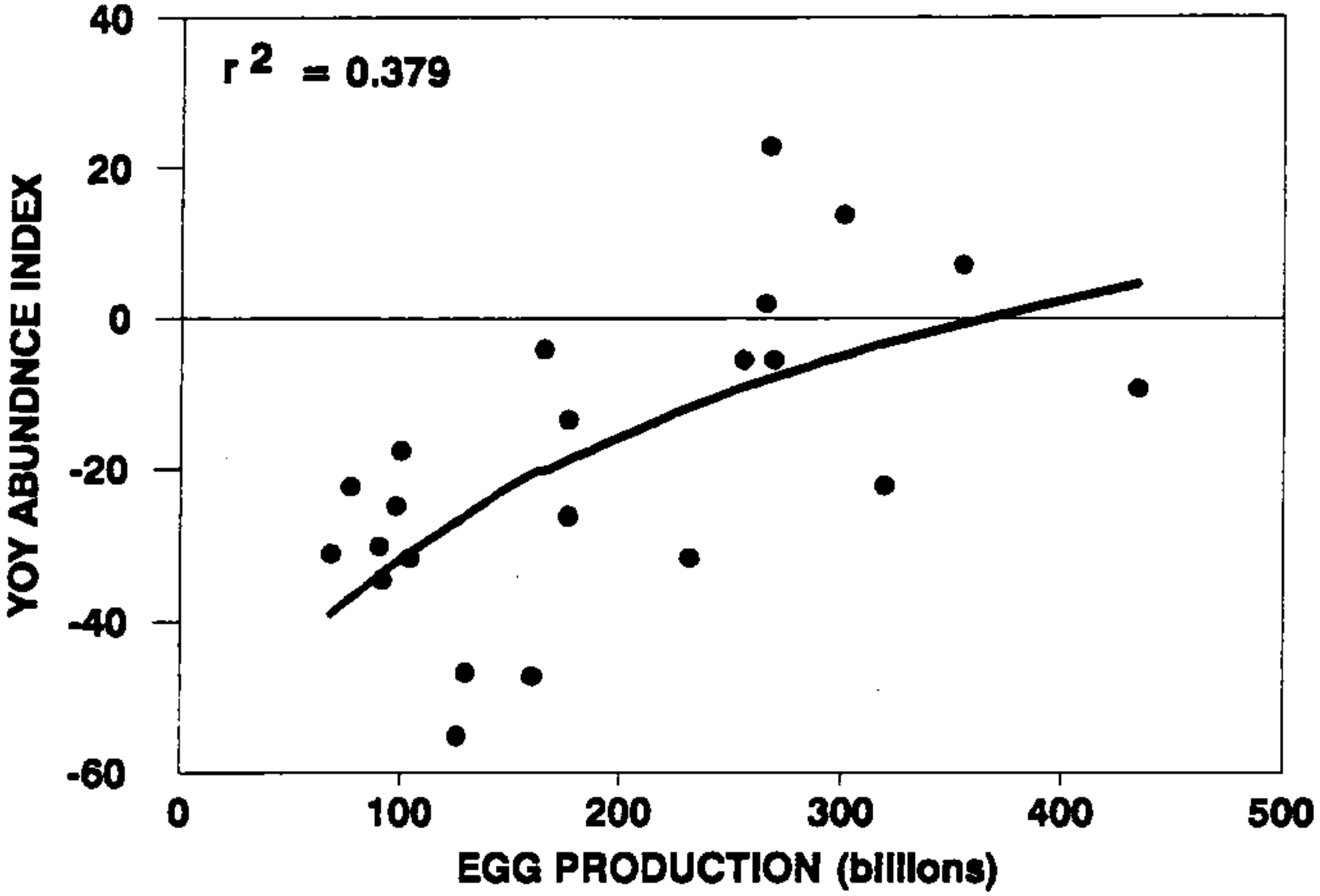


Figure 8. Stock-recruit relationship for striped bass in the Sacramento-San Joaquin Estuary based on the residual young-of-the-year index (after removing the effect of flows and diversions) and estimated egg production (<u>in billions</u>) from the Petersen population estimate and age-specific fecundity estimates. The predictive equation is:

RESIDUAL YOUNG-OF-THE-YEAR = 1/(0.0095 + (2.59/EGGS)) - 60.

because of its accepted place in fish population dynamics theory and the logic that young bass production would not increase indefinitely as stock size increases. Revising the predicted yoy indices from the flow and diversion relationships by adding the predicted residuals from the stock-recruit curve yields much better predictions of observed abundance (Figure 9).

Thus, we can estimate the yoy index component of the adult abundance prediction equation from April-July outflow and diversions and egg production.

Loss Rate

The next step was to express the loss rate component of the adult abundance prediction equation in terms of hydrologic variables. As losses occurred in all months (through March) after the yoy index is set (Table 1), the logical variables to examine were outflows and exports from August to March. Correlations between loss rate and mean daily exports for individual months and combinations of months (Table 12) generally suggest a strong positive association. As exports in all months are well-correlated with loss rate, we continued the analysis with August-March exports.

The post-yoy index loss rate showed a distinctly curvilinear association with mean August-March exports (Figure 10, $r = 0.704$) which was made linear by logarithmically transforming loss rate (Figure 11, $r= 0.796$). The regression equation

$$\text{LOG(LOSS RATE)} = 0.00015208\ \text{MEAN AUGUST-MARCH EXPORT} + 4.2828$$

explains 63% of the variability in loss rate.

The importance of outflow in determining loss rate after accounting for the effect of exports was evaluated by examining the association between the residual log(loss rate) from the above relationship with exports and mean daily outflow in all combinations of months from August to March (Table 13). The

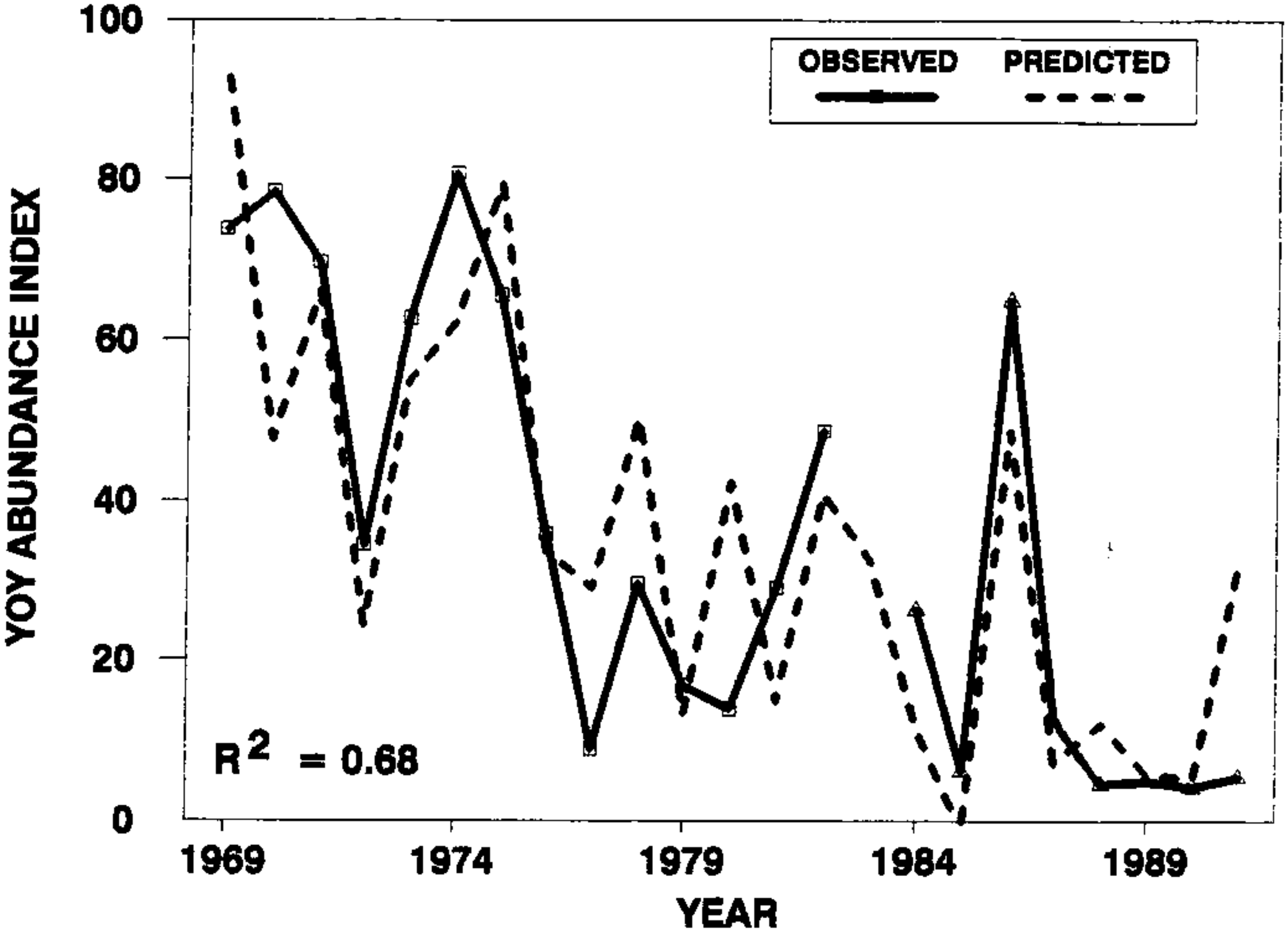


Figure 9. Observed and predicted young-of-the-year indices where predicted values are based on April-July outflow and diversions (Figure 7) and the stock-recruit relationship (Figure 8).

Table 12. Correlation coefficients of loss rate with all monthly combinations of August to March exports.

MONTH	CORRELATION COEFFICIENT
Aug	0.606
Sep	0.652
Oct	0.630
Nov	0.636
Dec	0.700
Jan	0.648
Feb	0.623
Mar	0.536
Aug-Sep	0.647
Sep-Oct	0.653
Oct-Nov	0.645
Nov-Dec	0.681
Dec-Jan	0.689
Jan-Feb	0.653
Feb-Mar	0.622
Aug-Oct	0.651
Sep-Nov	0.659
Oct-Dec	0.683
Nov-Jan	0.688
Dec-Feb	0.680
Jan-Mar	0.661
Aug-Nov	0.658
Sep-Dec	0.687
Oct-Jan	0.694
Nov-Feb	0.685
Dec-Mar	0.685
Aug-Dec	0.683
Sep-Jan	0.698
Oct-Feb	0.693
Nov-Mar	0.689
Aug-Jan	0.698
Sep-Feb	0.700
Oct-Mar	0.698
Aug-Feb	0.701
Sep-Mar	0.705
Aug-Mar	0.704

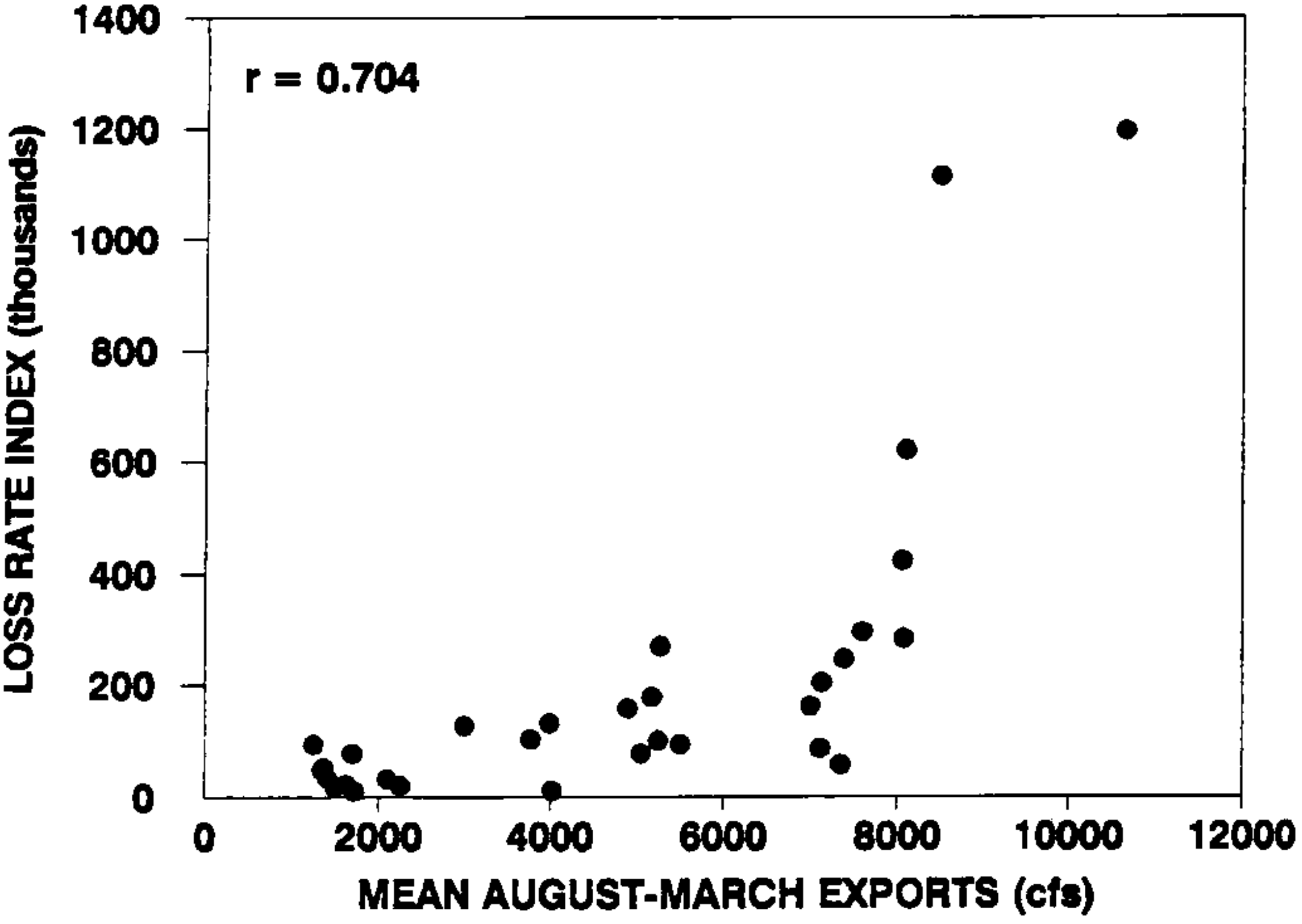


Figure 10. Scatterplot of export loss rate and mean August-March exports from 1959-1989.

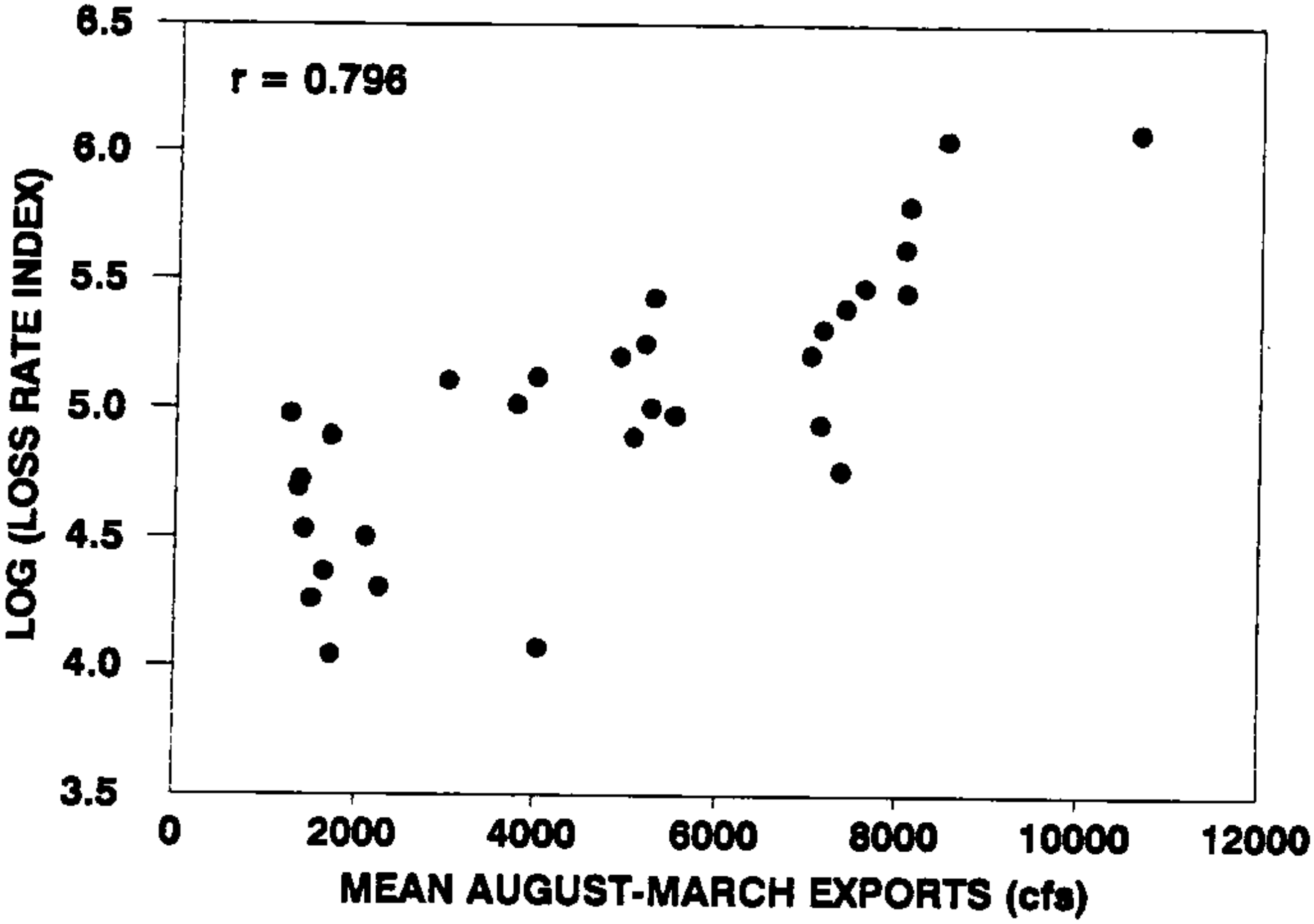


Figure 11. Scatterplot of $\log_{10}$(export loss rate) and mean August-March exports from 1959-1989.

Table 13. Correlation coefficients of the residuals from the regression of log(loss rate) on August-March exports with all monthly combinations of August to March outflows.

MONTH	CORRELATION COEFFICIENT
Aug	-0.484
Sep	-0.491
Oct	-0.399
Nov	-0.499
Dec	-0.570
Jan	-0.408
Feb	-0.275
Mar	-0.228
Aug-Sep	-0.495
Sep-Oct	-0.478
Oct-Nov	-0.520
Nov-Dec	-0.571
Dec-Jan	-0.532
Jan-Feb	-0.383
Feb-Mar	-0.283
Aug-Oct	-0.492
Sep-Nov	-0.539
Oct-Dec	-0.583
Nov-Jan	-0.550
Dec-Feb	-0.478
Jan-Mar	-0.366
Aug-Nov	-0.542
Sep-Dec	-0.593
Oct-Jan	-0.567
Nov-Feb	-0.504
Dec-Mar	-0.447
Aug-Dec	-0.596
Sep-Jan	-0.580
Oct-Feb	-0.520
Nov-Mar	-0.471
Aug-Jan	-0.586
Sep-Feb	-0.536
Oct-Mar	-0.486
Aug-Feb	-0.546
Sep-Mar	-0.500
Aug-Mar	-0.508

correlation was highest for August-December outflow ($r = -0.596$). The correlations are negative, as would be expected if losses decline in response to increased flows, and are similar for all combinations of months from August to December. January through March alone, or in combination with other months, generally exhibited lower correlations with residual log(loss rate). Stepwise regression revealed that August-December outflow explained 29% of the variability in log(loss rate) compared to the 63% explained by August-March exports (Table 14). Together, these two variables explained 77% of the variability in log(loss rate) using the regression equation

LOG(LOSS RATE) = 0.00013593 MEAN AUGUST-MARCH EXPORTS -
0.00001553 MEAN AUGUST-DECEMBER OUTFLOW + 4.6226.

Some might question the biological importance (absent the statistical results from the foregoing analysis) of controlling export losses in all months after the yoy index is set. However, data are available to show the effect of monthly variation in export rate on cumulative annual losses (Figure 12). In the 1960s, when there was minimal fall pumping by the CVP and before the SWP began water exports, essentially 100% of the losses occurred by the end of October. With operation of the SWP and the availability of San Luis and other reservoirs leading to increases in fall and winter exports in the 1970s and 1980s, losses through October averaged 90% of total post-yoy losses. Most recently, in 1988, 87% of losses had taken place by October. Hence, losses are being spread over a longer and longer time period.

The year 1977 is a very important anomaly (Figure 12). Due to low fall export rates associated with drought-caused water quality problems, only 25% of annual post-yoy losses had occurred by the end of October. However, substantial losses began shortly after water export increased dramatically when winter rains began (Figure 13). The loss estimate for January exceeded 700,000 and

Table 14. Results of stepwise regression of log(loss rate) on mean August-December outflow (A-D OUT)and mean August-March exports (A-M EXP). Values are coefficients of determination (R^2) expressed as percentages. The R^2 value for the final model selected by stepwise regression is underlined.

Independent Variables	Log(Loss Rate)
A-D OUT	29
A-M EXP	63
A-D OUT & A-M EXP	<u>77</u>

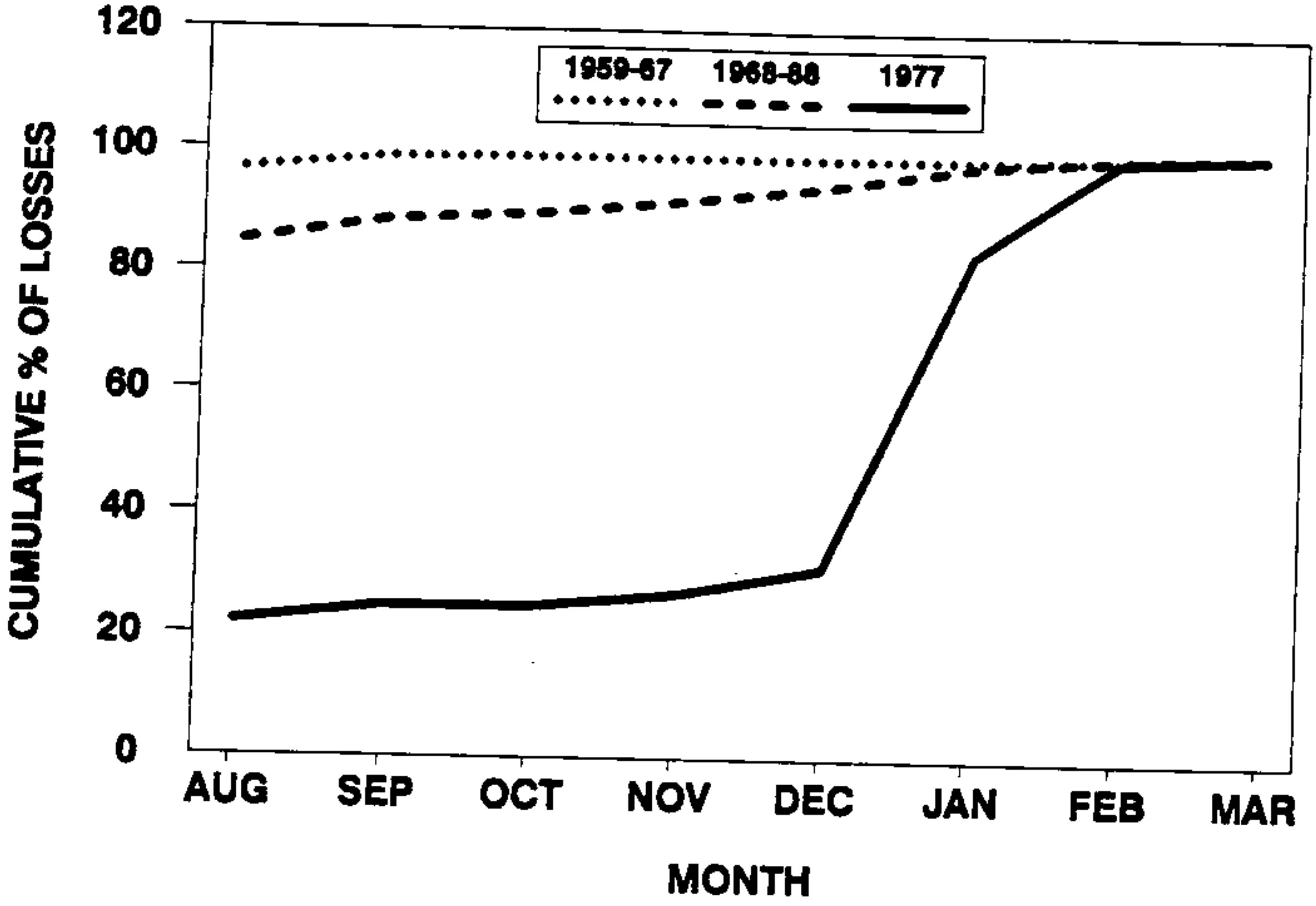


Figure 12. Comparison of cumulative monthly percent of annual post-yoy export losses for three time periods.

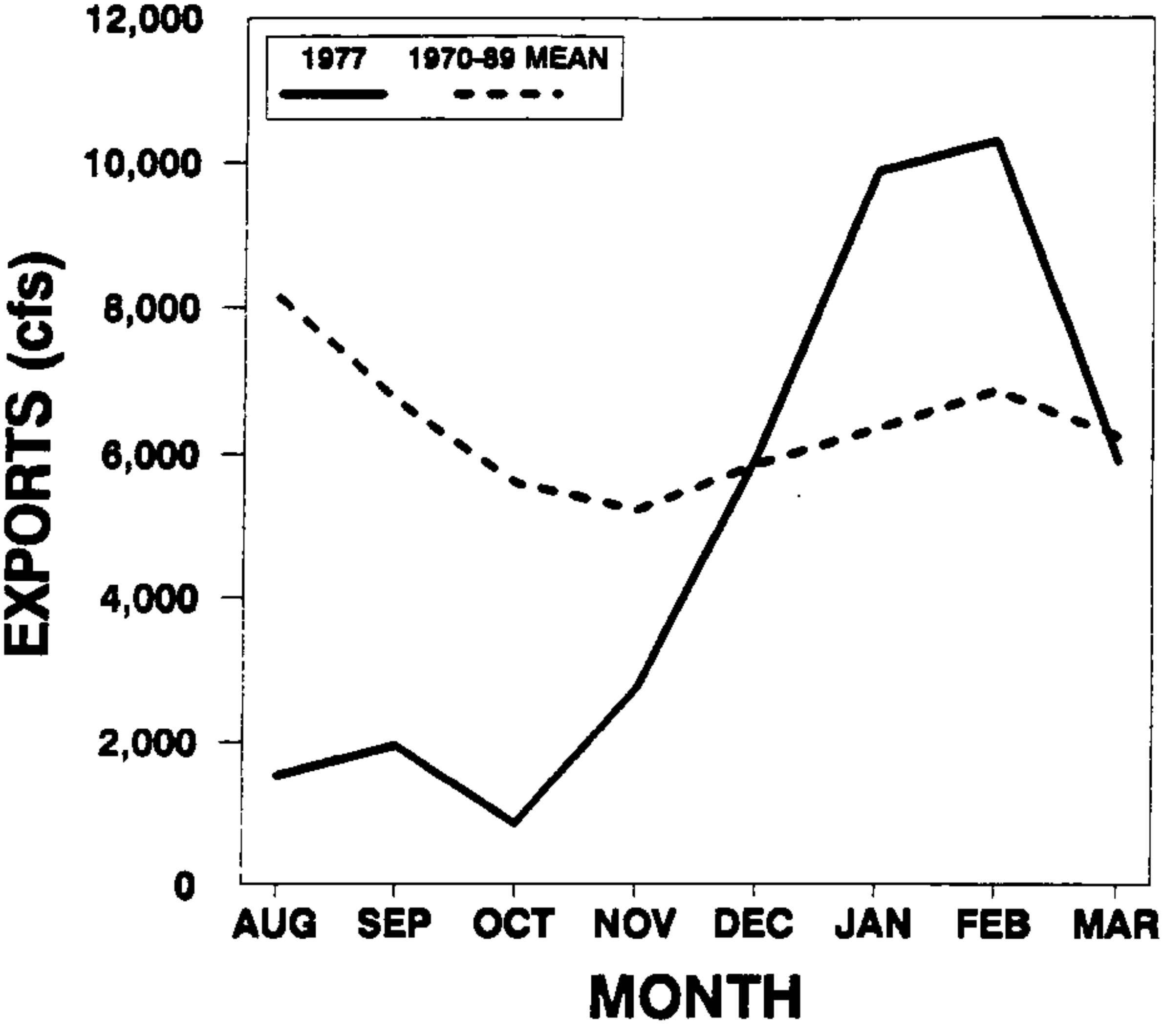


Figure 13. Comparison of mean monthly water exports by the CVP and SWP in 1977 with mean monthly exports in 1970-1989.

it was over 200,000 in February (Table 1). These losses likely removed a major portion of the relatively weak 1977 year class. This indicates that high exports at any time in the 8 months after the yoy index is set can lead to high losses of young bass and have a deleterious effect on the striped bass population.

APPROACH TO EVALUATING OUTFLOW AND EXPORT NEEDS OF STRIPED BASS

Our analysis provides equations that allow estimation of adult striped bass population levels produced from outflows and exports 3-7 years earlier. Although adult bass abundance is well-predicted by these equations, there is a tendency to slightly under-predict at high population levels (1.7 million) and to over-predict at lower abundance (1 million). Comparison of observed and predicted values when observed abundance averages 1.7 million (1969-1976) indicates that predicted values better mimic observed values when multiplied by 1.08; at observed abundance of 1 million (1977-1989), predicted values need to be multiplied by 0.936. This is necessary even though residual analysis for each of the regression equations in the model indicates that they adequately describe the relationships between variables. With these adjustments, the set of equations developed here closely mimic the historical trend in striped bass abundance (Figure 14).

These same equations also estimate outflows and exports that will maintain any given initial adult striped bass population level. Table 15 presents several of the many combinations of outflows and water exports that would maintain populations of 600,000 (estimated abundance in 1990), 1 million (average estimated abundance from 1977 to 1989), and 1.7 million (average estimated abundance from 1969 to 1976) adult bass. These results show that, with average outflows for each year type, exports must be much more restricted to maintain an adult population of 1.7 million than for a population of 600,000. The approach shown in

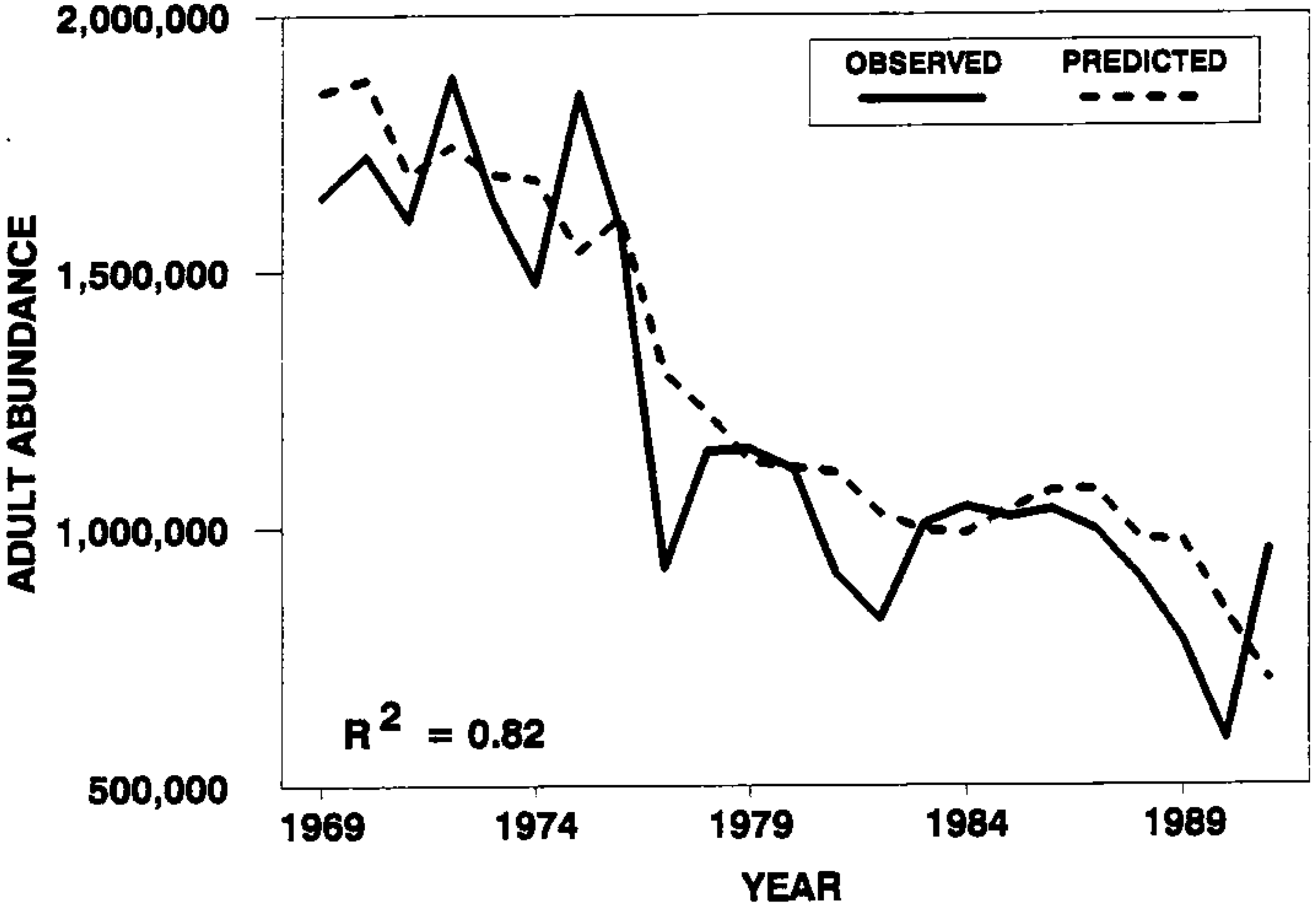


Figure 14. Observed and predicted adult striped bass abundance where predicted values are based on April-December outflow, April-March exports, and adult stock size.

Table 15. Some options for maintaining the adult striped bass population at 600,000, 1,000,000, and 1,700,000 fish.

INITIAL ADULTS	YEAR	APRIL-JULY		AUGUST-DECEMBER	AUGUST-MARCH	PREDICTED		PREDICTED
(millions)	TYPE	OUTFLOW	EXPORT	OUTFLOW	EXPORT	YOY	LOSS RATE	ADULTS
.6	Crit	4500	2600	3700	8600	10	542,200	601,200
		5600	3700	3600	8800	11	579,300	600,600
	Dry	7200	5100	7900	9300	11	580,800	601,700
		8600	6100	4500	8900	11	578,800	599,200
	B Norm	9600	6600	10200	9600	11	587,700	598,000
		9000	7300	4700	8200	5	461,600	599,200
	A Norm	15300	8100	11000	10000	14	647,200	599,700
		12600	8900	4800	8100	4	445,700	602,000
	Wet	29000	9700	14300	10600	16	694,000	597,900
		18000	10300	7000	8300	4	438,600	601,400
1.0	Crit	4500	2100	3700	3600	25	113,400	998,100
		5600	1700	3600	4900	34	170,900	998,200
	Dry	7200	4000	7900	4700	29	137,700	1,001,100
		8600	3500	4500	5400	38	193,500	999,400
	B Norm	9600	5000	10200	5300	32	153,000	1,001,400
		9000	4500	4700	4800	33	159,200	1,002,100
	A Norm	15300	6000	11000	6100	33	191,000	1,001,500
		12600	5500	4800	5200	36	179,800	1,001,700
	Wet	29000	7000	14300	7100	36	232,100	1,002,300
		18000	6500	7000	5700	38	194,400	1,000,900
1.7	Crit	4500	0	3700	0	57	36,700	1,676,100
		5600	0	3600	600	65	44,500	1,702,700
	Dry	7200	700	7900	1700	70	53,800	1,698,600
		8600	1600	4500	1300	69	53,600	1,700,600
	B Norm	9600	1800	10200	2200	71	58,000	1,700,700
		9000	2300	4700	1000	67	48,500	1,698,700
	A Norm	15300	3200	11000	2700	33	65,900	1,701,000
		12600	4100	4800	800	36	45,400	1,698,700
	Wet	29000	4500	14300	3500	77	75,200	1,700,400
		18000	5100	7000	1300	67	49,000	1,697,800

Table 15 produces the same number of fish each year by balancing initial populations (as measured by the yoy index) with export loss rates after the index is set. Thus, low initial abundance requires a reduction in loss rate to produce the same numbers of adults as high initial abundance produces with a high loss rate.

The sensitivity of the output variable in the model, sustained adults, to proportional changes in each of the input variables (initial adults, April-July outflow, August-December outflow, April-July exports, and August-December exports) was evaluated by increasing or decreasing each of the input variables by various percentages and determining the percentage change in sustained adults. Results of this sensitivity analysis suggest that changes in April-July outflow have substantially more effect in dry than in wet year types and that changes in fall and winter water export have greater impact on adult striped bass abundance in wet years (Table 16). Changes in fall-winter export have proportionally more impact than changes in spring and early summer export. This differential in effect between spring and fall-winter exports is greatest in dry years with lower initial adult abundance. The effect of changes in initial adult bass abundance is greater than any of the environmental variables when adult abundance is high.

It is important to recognize that the values in Table 16 underestimate the true impact of the proportional changes in flows and exports if they were sustained over enough years so that they continued to affect the population after it responded as shown in the table. The alterations in egg production associated with the population changes would result in continued population increases or decreases until new equilibriums were reached.

Table 16. Results of sensitivity of output variable (sustained adults) to proportional changes in values of each input variable while the other input variables are held constant. Values in the table are percentage change in sustained adults.

		Change in the Input Variable					
Condition	Input Variable	+10%	-10%	+20%	-20%	+50%	-50%
1 million adults Critical year	Initial Adults	2.4	-2.4	4.9	-4.8	11.9	-11.0
	Outflow:Apr-Jul	2.5	-2.9	4.8	-6.3	10.1	-21.1
	Aug-Dec	0.3	-0.3	0.5	-0.5	1.4	-1.4
	Export: Apr-Jul	-0.9	0.9	-1.8	1.8	-4.4	4.4
	Aug-Mar	-2.2	2.2	-4.3	4.3	-10.8	10.8
1 million adults Wet year	Initial Adults	2.5	-2.4	4.9	-4.8	11.9	-11.1
	Outflow:Apr-Jul	0.7	-0.8	1.2	-1.9	2.2	-7.5
	Aug-Dec	1.5	-1.5	3.0	-3.0	7.5	-7.5
	Export: Apr-Jul	-3.4	3.4	-6.8	6.8	-17.1	17.1
	Aug-Mar	-4.3	4.3	-8.6	8.6	-21.6	21.6
1.7 million adults Dry year	Initial Adults	2.2	-2.4	4.3	-5.1	9.3	-13.4
	Outflow:Apr-Jul	1.4	-1.7	2.7	-3.6	5.7	-12.4
	Aug-Dec	0.6	-0.6	1.1	-1.1	2.9	-2.9
	Export: Apr-Jul	-0.3	0.3	-0.7	0.7	-1.7	1.7
	Aug-Mar	-0.7	0.7	-1.5	1.5	-3.7	3.7
1.7 million adults Wet year	Initial Adults	2.2	-2.4	4.3	-5.1	9.3	-13.4
	Outflow:Apr-Jul	0.4	-0.6	0.8	-1.3	1.5	-5.1
	Aug-Dec	1.0	-1.0	2.0	-2.0	5.1	-5.1
	Export: Apr-Jul	-1.3	1.3	-2.6	2.6	-6.6	6.6
	Aug-Mar	-1.8	1.8	-3.6	3.6	-9.1	9.1

REFERENCES

California Department of Fish and Game (CDFG). 1992. Revised and updated estimates of fish entrainment losses associated with the State Water Project and Federal Central Valley Project facilities in the south Delta. WRINT-DFG-Exhibit 1 submitted to the State Water Resources Control Board, June, 1992.

Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary (IESP). 1987. Factors affecting striped bass abundance in the Sacramento-San Joaquin Estuary. IESP Technical Report 20:144p + Appendices.

Kano, R. M. 1985. 1984 Clifton Court Forebay evaluations of predation losses to juvenile chinook salmon and striped bass. Memorandum to Clifton Court Forebay Files dated 3/18/85. California Department of Fish and Game, 9p.

Kano, R. M. 1986. 1986 evaluations of predation losses to juvenile striped bass. Memorandum to Clifton Court Forebay Files dated 8/28/86. California Department of Fish and Game, 5p.

Stevens, D. E. 1977a. Striped bass (*Morone saxatilis*) monitoring techniques in the Sacramento-San Joaquin Estuary. In: W. VanWinkle, ed. Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations. Pergamon Press, New York, New York, p. 91-109.

Stevens, D. E. 1977b. Stripe bass (*Morone saxatilis*) year class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 106:34-42.

Stevens, D. E., D. W. Kohlhorst, L. W. Miller, and D. W. Kelley. 1985. The decline of striped bass in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 114:12-30.

Turner J. L. and H. K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 101:442-452.

APPENDIX A

JAN 0 9 1992

STRIPED BASS IMPACT MODEL - Preliminary Comments: D.G. Hankin

It is natural to review any impact model with regard to the underlying quality of the data that are subjected to statistical analyses, and to the merits of the statistical models used for analysis of these data. I have therefore separated my comments into those that involve quality of data and/or methods used to calculate estimates of particular quantities, and into those that involve construction and interpretation of statistical (regression) models.

Data

The 1986 summary document presents basic descriptions of methods used to calculate estimates of annual (1) adult striped bass abundance, (2) adult age composition, and (3) the YOY index. Generally, the YOY index seems based on an impressive level of field sampling, although details were not provided regarding how data collected at different locations were "averaged". Adult abundance based on Petersen mark-recapture estimates appears generally consistent with the YOY indices. Figures 1 and 2 from Kohlhorst et al. suggest that mark-recapture estimates of adult numbers and YOY indices both showed two "periods" of high and low, but moderately stable, levels: 1969-1976 (high), and 1977-1987 (low). Estimates for both adults and YOY appear to have plummeted since 1987. Catch per unit effort indices of adult abundance presented in the 1986 report, however, suggest a steady and continuing decline in adult bass numbers. This steady decline is inconsistent with the mark-recapture estimates and YOY indices and the discrepancy should certainly be followed up or addressed in any impact report. The 1986 report suggests that adult age composition estimates are poor, although estimates of age four abundance are not too bad. Although the 1986 report suggests that age 4 should be treated as the age of recruitment (fish are all legal size), the draft report appears to treat age 3 as the first recruited age. This issue needs to be further addressed as well. Estimates of total adult abundance and annual recruitment should be adequate for analysis purposes, however, and I am not concerned about age composition data for older ages (especially since almost all fish are less than age 8).

Although the 1986 report gives some estimated adult exploitation and natural mortality rates (p. 23, Table 8), there is no mention of methods used to derive these estimates. The accuracy of these estimates is important because the draft CFG report argues that most of the fluctuations in adult numbers arise due to variable mortality during the first year of life. This contention requires that adult mortality rates are relatively stable.

The most serious concern I have regarding data subjected to analysis involves calculations used to estimate export losses due to entrainment/predation. Kohlhorst et al. appear to assume that entrained YOY bass suffer a constant 82% predation loss in the SWP's Clifton Court Forebay. This assumption seems logically untenable and appears inconsistent with the 1986 Interagency Report. First, a constant predation loss would not be expected if (a) predator abundance varied, but prey abundance was fixed, or if (b) predator abundance was fixed but prey abundance varied. Only through smooth and implausible joint fluctuations in predator and prey abundance could a constant rate be achieved. Second, the 1986 report, at page 91, states that "predator losses are <u>inversely</u> related to [export] pumping rates". My interpretation of this language is that predation rates would be less under conditions of greater export flows, possibly because duration of YOY bass to predators (primarily adult bass ?) would be decreased. At any rate, I really have no idea how these export loss calculations were made and there are central to the draft CFG impact model. The 1986 document only presents summaries of results of some mark-recapture studies of experimental bass groups released at the "radial gate" and at the "trashboom" of the Clifton Court Forebay.

Statistical Models

As I read the draft report by Kohlhorst et al., they are using regression analyses for two general purposes: (1) to establish statistical relations among (a) adult bass abundance, YOY abundance Indexes, and export "loss rates"; and (2) to establish a connection between "loss rates" and Sacramento water management (export and Delta outflow). Based on these analyses, they then attempt to develop (3) a statistical "management model" whereby export and Delta outflow could be manipulated to produce certain levels of adult striped bass abundance. "Loss rate" is defined as the calculated export losses in year *t* divided by the YOY index in year *t*.

1. <u>Adult bass abundance vs mean YOY index (3-7 years earlier) and mean loss rate (3-7 years earlier)</u>. Although I am uncertain regarding the general effect of relating adult bass abundance in year *t* to arithmetic means of YOY indices and loss rates in the previous 3-7 years, I cannot agree that such "error-averaging" across years should generally produce "statistically better results than a relationship simply based on recruitment at age 3 and YOY and losses 3 years earlier" (quotes from p. 11 of Kohlhorst et al.). I also find that arithmetic means are inappropriate because each YOY index should be "discounted" by the survival from year *t* to year *t+i*, where *i* = 3,4,5,6,7. These survivals from YOY stage to age *i* would, of course, be progressively smaller, thus suggesting some weighting (as in their refinement 2) at p. 10).

Surely it would be far more natural to relate year-class strength at age 3 (or 4 - see Data, above) to YOY index and water management 3 (or 4) years earlier. The effects of "averaging" across years may possibly be assessed through simulation analyses, but this would be time-consuming. The authors intimate that the more natural and straightforward analysis did *not* produce "good results". I am concerned about this and would certainly like to see these results!

Also, it should be noted that, because the "loss rate" is calculated from the YOY index, the independent variables in the equation at the bottom of page 3 are not, in fact, independent. This may explain the failure of the YOY index to have statistical "significance" after the loss rate was accounted for.

2. YOY index vs water management. At page 4 of the draft report, and in Figure 9, the authors present results of regression analyses relating the YOY index to Delta outflow and diversions (export). I gather that these relations are only a minor revision of previous statistical models which have substantially overpredicted YOY index post-1976. It seems clear from inspection of their Figures 1 and 2, without any statistical analysis, that YOY index and adult abundance are positively correlated and that both have been much lower after 1976 than before. One can hardly expect a predictor based solely on water management to take account of this effect. It is therefore no surprise that a "residual analysis" identifies a significant "stock effect". However, I see no need for adoption of a Beverton-Holt stock-recruitment model in this context and, as the authors admit, a linear relation between adult abundance (egg production) and YOY index provides nearly as good a fit. Generally, it seems to me that the authors should explore a model of the form:

$$\text{YOY index} = \alpha \cdot \text{Egg Production} \cdot F(\text{Export Flows, Delta Outflow}).$$

I failed to understand the point of the equation used to predict egg production from Petersen estimates of adult abundance (unless this is to avoid use of age-specific fecundities and age-composition data?) at the bottom of page 6. In any event, I would like to see some more exploration of the database pertaining to fecundity of adult bass. The 1986 report, at page 26, suggests poor egg quality, incomplete gonad development, and egg resorption during 1984 (?). Is this true of more recent data as well? If so, it would seem of substantial biological importance.

3. Loss rate vs exports and Delta outflow. As the authors mention, they use the variable "loss rate" to try to remove the effect of YOY abundance from their analyses concerned with water management. Although this is a desirable objective, it does lead to difficulty in interpretation of their analyses. Again, it would seem most natural to assume that:

$$\text{Export loss} = \alpha \cdot \text{YOY index} \cdot F(\text{export flow, Delta outflow}),$$

where α is a scalar accounting for the unknown relation between true YOY abundance and the YOY Index, and $F(\cdot)$ is an unknown function. Dividing through by the YOY index and taking natural logs gives:

$$ln\ (\text{Export loss/YOY Index}) = ln\ \text{Loss Rate} = ln\alpha + lnF(\cdot)$$

For $F(\cdot) = e^{\beta \text{Export}}$, this would give:

(A) $ln\ \text{Loss Rate} = ln\alpha + \beta\text{Export}$

as at middle page 7. If instead $F(\cdot) = e^{\beta \text{Export} + \gamma \text{Delta Outflow}}$, one gets:

(B) $ln\ \text{Loss Rate} = ln\alpha + \beta\text{Export} + \gamma\text{Delta Outflow}$

as at top page 8. Although the authors suggest that forcing model (A) through the origin would prevent non-zero loss rate when Exports are zero (see refinement 1), it is not immediately clear to me that this would be an improvement and it would result in substantial ambiguity regarding interpretation of goodness of fit.

My more substantial concerns with these latter analyses concerns the contention that losses throughout the August-March period must be considered. Although this is probably true at a certain level, it also appears that losses during January-March have nearly always been small when compared to annual losses (with the exception of the 1977 drought year). The authors fail to give adequate details regarding how they selected the months for Export and Outflow that were used in the fitted regression model at the top of page 8. I doubt that a strong case for their choices could be made on the basis of regression R^2 or some other "objective" statistical criterion, but I believe that such an objective criterion would be desirable.

4. Use of Statistical Models for Evaluating Outflow and Export Standards. I suspect that the authors used the equation at the top of page 8 to predict loss rate from export and Delta outflow; a model incorporating export and Delta flows, revised to incorporate adult stock, to predict YOY index; and then the equation at the bottom of page 3 to predict resulting adult bass abundance from the predicted YOY index and predicted losses. If so, this procedure would require an initial adult abundance level, as suggested at Table 6. However, the authors do not explicitly state that this is what they did, and they should be forced to do so. If this is indeed what they have done, I am not certainly that it is correct in any event. "Predicted" values of YOY Index and Export Loss Rate are *not* the same as calculated values for a particular year that were used to construct the basic equation at

the bottom of page 3. I'd have to ponder this matter a bit more to determine what kinds of "errors of variables" problems this procedure creates, and I again suspect that simulation analyses might prove useful.

I suspect that there may be a more direct way to formulate such a prediction model, rather than trying to link several different models as appears in this draft report. I have not made any attempt to do that in this preliminary review.

Final Remarks

I'm no expert on life history of striped bass, but I am a bit concerned that there appears to be absolutely no consideration of possible effects of the marine environment on striped bass, especially because substantial declines have also been observed in striped bass in Coos Bay, Oregon. Where do young bass go from the end of the first year of their life until they are "recruited" to the fishery at age 3 or 4? Are adult bass present in the Bay/Delta throughout the year?

APPENDIX B

Review Scope of Proposed Work:

A MEANS OF EVALUATING IMPACTS OF ALTERNATIVE OUTFLOW AND EXPORT CRITERIA ON STRIPED BASS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

Report to California Department of Water Resources

Sacramento, CA

Prepared by

Joseph G. Loesch, Ph. D.
HC 1, Box 26
Gloucester Point, VA 23062

December 2, 1991

December 2, 1991

CRITIQUE by J. G. Loesch of:

A MEANS OF EVALUATING IMPACTS OF ALTERNATIVE OUTFLOW AND EXPORT CRITERIA ON STRIPED BASS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

by

D. W. Kohlhorst, D. E. Stevens, and L. W. Miller

General comments

This paper is difficult to objectively analyze inasmuch as it is largely based on data sets which are simply presented without reference as to source, collection methods or potential errors and biases. Even if these data sets can be assumed to be fundamentally accurate and possessing negligible estimation errors, the analyses presented here appear to have some serious flaws.

- Although the building of the final population prediction model is based almost entirely on equations built from probabilistic (stochastic) relationships, the final model appears to be completely deterministic. The degree of uncertainty associated with model estimates needs to be directly dealt with.

- The model appears to predict a complete stock collapse (i.e. negative adult abundance estimates) for 1991 and 1992. If this indeed occurs, the model becomes moot; if not, the assumptions of the model must be questioned.

- The young-of-the-year (YOY) component of the predictive equation is not, for all practical purposes, a germane parameter; there should be a re-examination of its relevance as an indicator of recruitment. I do not suggest that the determination of the annual YOY index be discontinued, but that the data set be assessed in some different manner. With alosids in Virginia, I found a relatively high correlation (r = 73%) between the YOY maximal CPUE and the mean CPUE of adults of the year class in later years. The maximal CPUE is the largest weekly CPUE in the annual YOY sampling program. The maximal CPUE occurs relatively early in the spring and, thereby, eliminates or minimizes some of the problems inherent in a protracted sampling season. With the index determined early, the problems of increasing gear avoidance with growth, and the emigration of precocious YOY from the sampling region are avoided. In Chesapeake Bay and its tributaries there is an encroachment of saline water on the lower portions of nursery ground; subsequently, the alosid YOY are "crowded" into a smaller tidal-freshwater area and, consequently, the index increases. The early occurrence of the maximal CPUE also makes it economically attractive. The problems of annual dissimilarities in the growth rate, gear avoidance, emigration, and saltwater encroachment can be very sizable. Use of a maximal CPUE may or may not be an applicable index for YOY striped bass abundance in the Sacramento-San Joaquin Estuary; regardless, the data set should be re-examined. There is no statistically valid reason for including the YOY index in the predictive equation simply because it makes "biological sense".

Specific comments

p. 1, par. 2 The largest declines in adult and juvenile abundance appear to occur almost simultaneously during the 1975-77 period, rather than after the lag that would be expected if the primary cause for the adult decline was decreased juvenile production.

p. 3, par. 1 To give equal weight to five year classes seems unrealistic, it implies that no adult mortality occurred during these ages. Were other combinations tried, and if so what were the results?

Statistical significance and acceptance levels need be presented in a forthright manner, both in Table 6 and for all subsequent statistical presentations. Including p values would be highly desirable.

Including the non-significant YOY component in the equation is a very questionable procedure, since at all previously observed levels of juvenile abundance the YOY term will make a relatively small contribution to the overall equation and large adult population estimates are possible even if the YOY term is zero. The equation essentially predicts a default population of 1.5 million individuals which can be augmented by up to a few hundred thousand at high levels of juvenile production and which will be linearly depleted by export loss rates, with population extinction inevitable if losses reach about the 1 million mark, which they have in recent years. There definitely seems to be a multi-colinearity problem with the two input variables which could be masking the true effect of juvenile production on ultimate population levels.

The poor fit at the upper end of Figure 8 may be the result of forcing a linear fit to what may be curvilinear relationships. Certainly the relationship in Figure 6 would be expected to pass through the origin and approach an ultimate asymptote, and Figure 7 also suggests a curvilinear relationship.

p. 4, par. 1 Why are there no observed values for 1966 and 1983 plotted in Figure 9, while they are given in Figure 2? The 1983 value seems to have been ignored, although not obviously omitted, in Figures 11 and 12 as well.

p. 5, par. 1	Were the age-specific data available for all years, or was an average age structure assumed across years.
	Was the relationship in the equation statistically significant?
p. 6, par. 2	The equation should be presented at the top of page 5 where the calculation of egg production is first discussed.
p. 7, par. 2	There is disagreement between the text and equation as to whether the export period is Aug - Mar or Aug - Oct, also in Figures 13 and 14 between captions and axis labels. The former appears to be correct.
p. 10, par 2 sec. 1	This is not the only equation that needs to be forced through the origin. Since the basic premise is that juvenile losses are determining adult stock size, a model which predicts zero abundance in the face of total loss of juvenile production seems obvious and necessary.
sec. 2	This effort should improve results.
sec. 3	Hatchery contributions will certainly become a major contribution to adult stock sizes if the natural stock continues to collapse. If it can be determined, the hatchery contribution to recent adult stock sizes should certainly be considered in these equations.

APPENDIX C

UNIVERSITY OF CALIFORNIA, DAVIS

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

DIVISION OF STATISTICS
STATISTICAL LABORATORY

DAVIS, CALIFORNIA 95616

March 29, 1992

Mr. Jim Sutton
State Water Resources Control Board
Division of Water Rights
P.O. Box 2000
Sacramento, CA 95812-2000

Jim,

I've looked over all of the criticisms that were leveled as the Striped Bass Model that was developed by the Department of Fish and Game. Rather than commenting on the criticisms individually, I found that they subdivide rather nicely into a number of categories, so I'll respond to them categorically instead.

I know that you were hoping to come up with a definitive answer as to whether the striped bass model was *right* or *wrong*. What I *can* say is that the model isn't inherently fallacious, but that there are limitations in the sorts of conclusions that can be drawn from it, some of which are common to all statistical models, and others of which apply particularly to this model. When I make a comment like this, you should bear in mind that I'm a statistician rather than an ecologist by training, and thus I have limited ability to assess how reasonable the assumptions may be on which this model is based.

Quite a few of the criticisms raised in the documents I was provided dealt with technical details of some of the inputs to the model. Since I'm no expert on fisheries or ecology, I can't respond to them. Of the *essentially statistical* comments, I've divided them into four general categories. I'm going to paraphrase each, give a few examples of the type of criticism, and then give my comments on those particular comments:

- *You need to assess the model's accuracy and/or sensitivity to certain inputs.* Chief among these criticisms is the question about the model's sensitivity to the estimated 82% mortality within the Clifton Court Forebay.

  It's certainly true that the value of a statistical model lies both in its ability to provide reasonably accurate predictions of future outcomes, as well as its identification of significant (i.e., influential) factors. Because of this, the statistical significance of a model is only part of the picture it portrays and both its quantitative and qualitative findings will be of interest. In this model, the main qualitative finding is the significance of export in forecasting the loss rate. The quantitative findings lie in the predicted response of the striped bass population to various types of rainfall years and water export strategies. The simplest of these questions to address is which of the factors are significant. Beyond that, the model could perform at any level of accuracy lying along a continuum. Given the limited amount of information in the model (the limited number of years of data) and in particular the limited number of *recent* years or *drought* years, it's asking a lot for the model to be especially precise in forecasting the future.

One possible limitation to their form of analysis is that in fitting a linear model with several predictors to a couple of dozen data points, they need to make the standard regression assumptions that the data are normally distributed with constant residual variance. In practice, when the sample size is this small, they have very little power for detecting violations of these assumptions (if in fact they checked). For this reason, it would be wise to do a more detailed analysis, either estimating the parameters and fit of the model through a bootstrapping technique, or else doing a sensitivity analysis to determine the changes that would occur in the model's predictions if the data are modified slightly. This sort of nonparametric assessment of the model would be reliant on the model's distributional assumptions to a relatively limited extent.

The question of the model's sensitivity to the estimate of the loss in the Clifton Court Forebay is a real concern. Fish and Game made a rather half-hearted effort to examine this when they compared the results using the 82% mortality figure to one that uses 15%. I would expect that the model's predictions would change mildly in the neighborhood of the true mortality figure, but as you got further and further from the true figure, the model would break down completely. Thus, in comparing 15% to 82%, they can make a case that the true figure is closer to 82% than 15%, but this doesn't imply that a different figure in the range of, say, 65% to 85% might yield similarly good fit and yet *quite* different predictions from a quantitative standpoint.

- *Some other predictor(s) should have been included in the model, or else the model should have been formulated differently.* I include under this general heading questions about the appropriate averaging of adult numbers for various ages, as well as a number of questions that raised new possible predictors.

The decision to use averaged adult numbers at lags of four to seven years as a predictor in the model seems a bit ad hoc, but in view of the limited number of years in the data, I can see that it was important to come up with a simple way of summarizing the data across age classes. An arithmetic average is probably *not* ideal, since younger fish presumably make a greater contribution to reproduction, but it's not reasonable to waste 3 or 4 degrees of freedom in estimating the differential contribution of the different age classes. If a simpler model existed that would put some of the age structure into the model, then this would be preferable to a flat average, but I for one don't know how to do this. Frankly, I doubt that this would change the conclusions appreciably, so if you pursue this, you should keep a careful eye on whether the additional parameters are necessary, in order to construct as simple a model as possible.

There are couple of aspects of this modelling and estimation problem that make it a difficult one. First, the predictors that are of central interest (water exports) are correlated with time (they increase over time) so this creates collinearity between exports and time. Moreover, most of the additional predictors that have been suggested also vary with time, and so it's rather difficult to separate between an effect due to water exports and due to other variables that vary similarly, such as the state's population, the number of registered cars, or the national debt, just to name a few that *haven't* been suggested for inclusion in this model. The significance of a given term in a regression model can be viewed only within the context of the other variables that are included in the model. Thus, you can't say definitively that a given variable or set of variables is important, regardless of what else might be put into the model, but rather just that a given variable is important in the context of the particular model in question.

Because there are countless variables that *might* be included in a model like this, I'm more than a little hesitant to play this type of game unless it's been demonstrated that a model including the new variables outperforms the old model, or unless there are biological reasons for choosing the new set of variables instead of the old set. Even if you change around the predictors that are included in the model, this won't necessarily alter the conclusions that come from the model. I'll have more to say about this later on when I discuss the problems associated with trying to impute a causal interpretation to this type of model.

The second aspect of this problem that makes prediction difficult is that the conditions in which we currently find ourselves are in no way similar to the bulk of the data based on which the model was fit. Thinking wishfully, we're coming out of an extended drought, and for whatever reason, the state's fish population has been depleted down to unprecedentedly low levels. It's well known that regression models perform best in the body rather than the extremes of the data, and yet we find ourselves having to make forecasts starting from those extreme conditions. From a statistical standpoint, there's limited (Fisher) information available on which to base those forecasts, and consequently you have to set your sights somewhat lower about this *or any* model's accuracy. Legitimate conclusions can be drawn from the model, such as that the fish population in the next few years will be extremely low, and that it will be lower still if water exports are maintained at elevated levels, but it's unrealistic to expect that you'll get accurate forecasts about just *how low* the population numbers will be. The information on which to base such forecasts simply doesn't exist.

- *The model gives silly (negative) predictions.*

Another manifestation of the problem of drawing inferences for extreme values of the predictor variables is that the slightest misspecification in the model can result in both inaccurate and biased forecasts. This can easily result in negative predictions, but rather than throwing away the entire model because it can predict a negative fish population, you should pay careful attention to the model because it's forecasting *really* low fish numbers. I have to admit that if I had been formulating this type of model, I probably would have chosen the logarithm of the fish index as a dependent variable because many ecological processes are well fitted by lognormal probability models, and because I view the thinning of the fish population as being basically a multiplicative process with random proportions of the population being eliminated at various stages along the way to adulthood. This would have eliminated the problem with negative population estimates, and I think it would also have been more in keeping with the observed variability in the data, which should increase as the population size increases. *However*, I doubt very much that this modification would have altered the qualitative conclusions of the model, which are the most important pieces of information that such a model has to offer us. As far as I'm concerned, criticizing the model because it predicts negative populations isn't constructive, and is equivalent to attacking a straw man. If the commentors have better models to propose (which in some cases they have), let them fit their models, and contrast the results against those from the Fish and Game model.

- *It's not a causal model.* Consequently you can't conclude that reducing water exports would improve the state of the striped bass population.

  I'm in basic agreement with this sentiment, but it's essential to recognize that this is a comment that could be aimed at *any* statistical model, and not just this one. There are some statistical theories that attempt to address questions of causality, but I've yet to see one that I found convincing. The strongest conclusion you can legitimately draw from a study like this is that increased water exports are *associated with* decreases in the striped bass population, and not that they necessarily *caused* the decreases. There are numerous examples of regression studies that found relationships between a supposed cause and an effect that turned out later to be spurious. A famous example of this is that when polio still presented a serious health problem, a large exploratory study was done to see what could possibly relate to polio. They found that polio outbreaks were strongly associated with sales of ice cream. Of course, there's no *causal* link between ice cream and polio; the reason for the correlation is that outbreaks of polio are associated with hot weather, as are ice cream sales. At the time, they didn't know what to make of this association, other than considering it as a topic for further study, but at the time there was no known biological link between ice cream and polio, so they didn't overreact to this result.

  By contrast, with the striped bass model, you *can* argue that there's a biological relationship between exports and fish losses, so this relationship must be taken more seriously. It's the biology, rather than the statistics that make this type of result noteworthy, however. This is another case in which if a critic claims that the model isn't causal, I think he or she should be encouraged to construct an alternative model that stands (presumably) on a firmer causal footing and shows water exports not to have an effect.

I recognize that these comments are rather general, but since I'm not an expert in fish biology or population dynamics, I thought it best to restrict my attention to the statistical issues and to present my thoughts in as broad a context as possible. My hope is that having done so, you can see how my comments may apply to objections that may not have been raised yet.

I wanted to raise one final point before I send this letter off. When we met around the first of the year, I mentioned that if water exports affect fish population in a predictable way, then you may want to consider strategies for managing the population that might seem somewhat counterintuitive. One of the difficulties in dealing with the current depressed condition of the striped bass population is that next year's fish production will be strongly dependent on this year's adult population. Thus, even if there's ample rain and runoff in the next year, the population will be able to gain only so much, since you started with such small numbers of fish. The idea I want to put forward is that in a wet year you can do more good for the population than you can *possibly* make up for in a dry year. Moreover, in a wet year, water conservation measures (limits on exports) will be less painful to carry out than in a dry year. That being the case, it makes sense to me to try to beef up the fish population during wet years by restricting the level of water exports, so that the population will be able to withstand the (hopefully only) occasional dry years. I should point out that this last comment is predicated on the fact that the fish population has been restored to reasonable levels. Obviously, the current fish numbers indicate that the population is seriously threatened and as things stand, we can't afford to wait for a wet year to restore the population numbers.

I hope that my comments are useful to you in interpreting the striped bass model. If my comments seem negative in tone, that wasn't my intention. However, I thought it was important to point out what a statistical model can reasonably be expected to accomplish and what it can't.

Sincerely,

Neil H Willits

Neil H. Willits
Senior Statistician,
Division of Statistics