PACIFIC BONITO MANAGEMENT INFORMATION DOCUMENT

R. COLLINS, D. HUPPERT,
A. MACCALL, J. RADOVICH
and G. STAUFFER

MARINE RESOURCES
TECHNICAL REPORT NO. 44 1980

CALIFORNIA DEPARTMENT OF FISH AND GAME
MARINE RESOURCES TECHNICAL REPORTS

****

Marine Resources Technical Reports are research documents by Department personnel that are of sufficient importance to be preserved, but which for some reason are not appropriate for primary scientific publication. No restriction is placed on subject matter.

These Reports may be cited in publication, but care should be taken to indicate their manuscript status. The material in these Reports may eventually appear in the primary scientific literature.

Inquiries concerning the Reports should be directed to The Editor, Marine Resources Region, 350 Golden Shore, Long Beach, California 90802.

PACIFIC BONITO
MANAGEMENT INFORMATION DOCUMENT

by

R. Collins, A. MacCall, J. Radovich
California Department of Fish and Game

and

D. Huppert, G. Stauffer
National Marine Fisheries Service

MARINE RESOURCES TECHNICAL REPORT NO. 44

CALIFORNIA DEPARTMENT OF FISH AND GAME

- 1980 -

- LDA -

ABSTRACT

Management of Pacific bonito in California is examined in this Management Information Document by a State-Federal team of scientists.

Abundance of Pacific bonito in southern California has fallen dramatically between the 1963-1969 period and the 1974-1977 period. Since 1976 the commercial fleet has found few large fish in southern California, and has caught fish in the size range of 15 to 57 cm (1.2 to 4.7 pounds). This fact, coupled with the low abundance indices, point out the need for a more active management regime.

To develop management measures for the California bonito fishery both a surplus yield analysis and a yield-per-recruit analysis were performed. A maximum sustained yield of 10,000 short tons was estimated for the fishery in southern California, while the whole fishery, including Baja California, has an estimated MSY of 13,000 tons. In order to achieve this level of catch, however, the stock abundance must be increased by a factor of five.

Yield-per-recruit considerations suggest that a minimum size limit in the commercial fishery has two important effects. A three-pound size limit could result in a slight increase in yield-per-recruit. If the size limit is increased to 5 or 7.5 lbs, the yield-per-recruit would fall significantly. Offsetting the effect on yield-per-recruit, however, would be a substantial

increase in average amount of spawning per recruit which should result in a proportional increase in recruitment. With the current depressed stock abundance both a reduced annual take and a minimum size limit on commercial catch would confer substantial benefits in the form of an increase in the future stock size.

After considering seven different types of management measures, the team finds that three types -- an annual commercial catch quota, a commercial size limit, and a recreational bag limit -- appear desirable.

Re-establishment of the stock in southern California was the major consideration in this evaluation because the stock is currently depressed. All segments of the fishery will benefit from a more abundant resource. The difficult issues for policy, however, concern the rate of rebuilding, the degree of risk that is acceptable, and the distribution of benefits among user groups. By judicious choice among the options discussed here, a variety of positions can be established with respect to these issues. The greater the size limit, for instance, the more benefit is provided the recreational sector while difficulties are imposed upon commercial fishermen. The higher the quotas adopted, the slower the stock rebuilding and the greater the risk of continued stock depletion. A final reconciliation of the management options involves social, political and legal considerations which must be thoroughly incorporated by decision-makers before adoption of a management plan.

TABLE OF CONTENTS

	Page
INTRODUCTION	7
1.0 MANAGEMENT OBJECTIVES	7
2.0 STOCKS	8
3.0 DESCRIPTION OF FISHERY	9
3.1 U. S. Commercial Fishery	9
3.1.1 Catches	9
3.1.2 The Fishing Fleet	14
3.1.3 Area and Season of Commercial Catch	19
3.1.4 Bonito Harvests by the Tropical Tuna Fleet	20
3.2 Mexican Commercial Fishery	28
3.3 U. S. Recreational Fishery	28
3.3.1 Catches	28
3.3.2 Number of Anglers	31
3.3.3 Area and Season of Catch	32
3.4 Mexican Sport Fishery	33
3.5 Recreational Commercial Conflicts	33
4.0 BIOLOGY	34
4.1 Reproduction	34
4.2 Food Habits	35
4.3 Size, Age, and Growth	35
4.4 Migration	37
4.5 Size and Age of Catch	42
4.6 Natural Mortality	42

Page

5.0 FISHERY ANALYSIS 43

5.1 Production Model. 43

5.1.1 Measurement of Abundance 43

5.1.2 Catch. 45

5.1.3 Fishing Intensity Index. 45

5.1.4 Fitting Procedure. 45

5.1.5 Discussion 54

5.2 Yield per Recruit Models. 55

5.3 Status of the Stock 59

6.0 ECONOMIC CHARACTERISTICS 60

6.1 Value of Landings 60

6.2 Processed Bonito Products 61

6.3 Economics of the Size Limit 65

7.0 MANAGEMENT OPTIONS 73

7.1 Alternatives Considered 73

7.1.1 Status Quo 74

7.1.2 Revise U.S. Yellowfin Tuna Regulations . . . 74

7.1.3 Closed Seasons 75

7.1.4 Area Closures 75

7.1.5 Bag Limits 76

7.1.6 Size Limits. 76

7.1.7 Catch Quotas 77

7.2 Size Limits 77

7.3 Quotas and Bag Limits 81

7.4 Discussion of Management Options. 85

8.0 REFERENCES 91

INTRODUCTION

This document was developed by a joint National Marine Fisheries Service, California Department of Fish and Game team of fisheries scientists. Their assignment was to examine the available data from the Pacific bonito fishery and evaluate alternative management actions in respect to their impact on the stocks, the fishery and the industry.

The first task of the team was to establish acceptable objectives for management as a basis for evaluating possible alternatives.

1.0 MANAGEMENT OBJECTIVES

The overall goal of bonito management is to achieve an optimal long-term balance among the following specific objectives:

(1) Ensure the reestablishment and maintenance of bonito in southern California,

(2) Enhance the recreational catch of bonito in southern California,

(3) Enhance the long-term yield from the U.S. commercial fishery, and

(4) Reduce conflicts between recreational and commercial fishermen.

Clearly the accomplishment of objective (1) will contribute directly to objectives (2) and (3). The emphasis upon stock enhancement is motivated by the depressed status of the stock found in recent years. The benefits derived from both the commercial and recreational fisheries should improve with improvement in the stock condition. The other major concern, reflected in objective (4) is that conflicts between fishery sectors arise due to competition for

fish or fishing areas.

2.0 STOCKS

Pacific bonito (*Sarda chiliensis lineolata*) is a schooling fish found off the west coast of North America. This fish occurs substantially between Cape San Lucas, Baja California and Point Conception, California. Young fish are found nearshore in close association with giant kelp (*Macrocystis* sp.) beds, and the older fish found in open waters and over nearshore banks.

Two segments of the bonito stock occur which are important to California fisheries. The southern segment, residing principally off southern and central Baja California, appears to be the larger and more permanent segment. The northern segment resides off northern Baja and southern California, and is of unknown stability, although it appears to have been present for most of this century with the notable exception of the period 1949-1955.

Both segments can contribute to fisheries in southern California waters. A portion of the older fish from the southern segment make an annual migration (of variable strength) into southern California waters. This migration occurs in the late summer and fall, and extends into the Santa Barbara Channel where it contributes to a commercial purse seine fishery, and to a lesser extent both recreational and commercial troll fisheries.

The northern segment is produced by local spawning and the largest of the young of the year appear inshore, moving northward along the coast, in late July or early August at about 35 to 40 cm total length and 4-6 months of age. Bonito are vulnerable to the inshore recreational fleet from this size until the fish have

completed their second summer at about 58 cm in length and 18 months of age. Very few fish over 60 cm occur in the sportfishery, as these fish tend to move offshore into deeper water, where they become available to the purse seine and troll fisheries. These fish become more likely to migrate as they become older, tending to overwinter in more southerly waters, although they may still contribute their progeny to the northern segment of the stock.

Young fish tagged off southern California have exhibited a tendency to remain in local waters over the winter and through the spawning period while larger fish tagged in the Santa Barbara channel have moved to the south to be recovered at the end of the spawning season south of Cedros Island, Baja California. Therefore, locally spawned fish seem to spawn locally for at least their first spawning and may remain in the area for a longer period of time than those fish from the southern segment.

Variability in the strength of the northward migration of the southern segment appears to be related to the ocean temperatures off southern California. Spawning success of the northern segment may be influenced by ocean temperatures, upwelling and other environmental factors.

3.0 DESCRIPTION OF FISHERY

3.1 U. S. Commercial Fishery

3.1.1 Catches

Pacific bonito have been fished commercially in California waters since at least the beginning of this century. Commercial landings between 1916 and 1977 have varied widely, with a low of 57 metric tons in 1956 and a high of 14,468 metric tons in 1975 (Figure 3.1, Table 3.1).

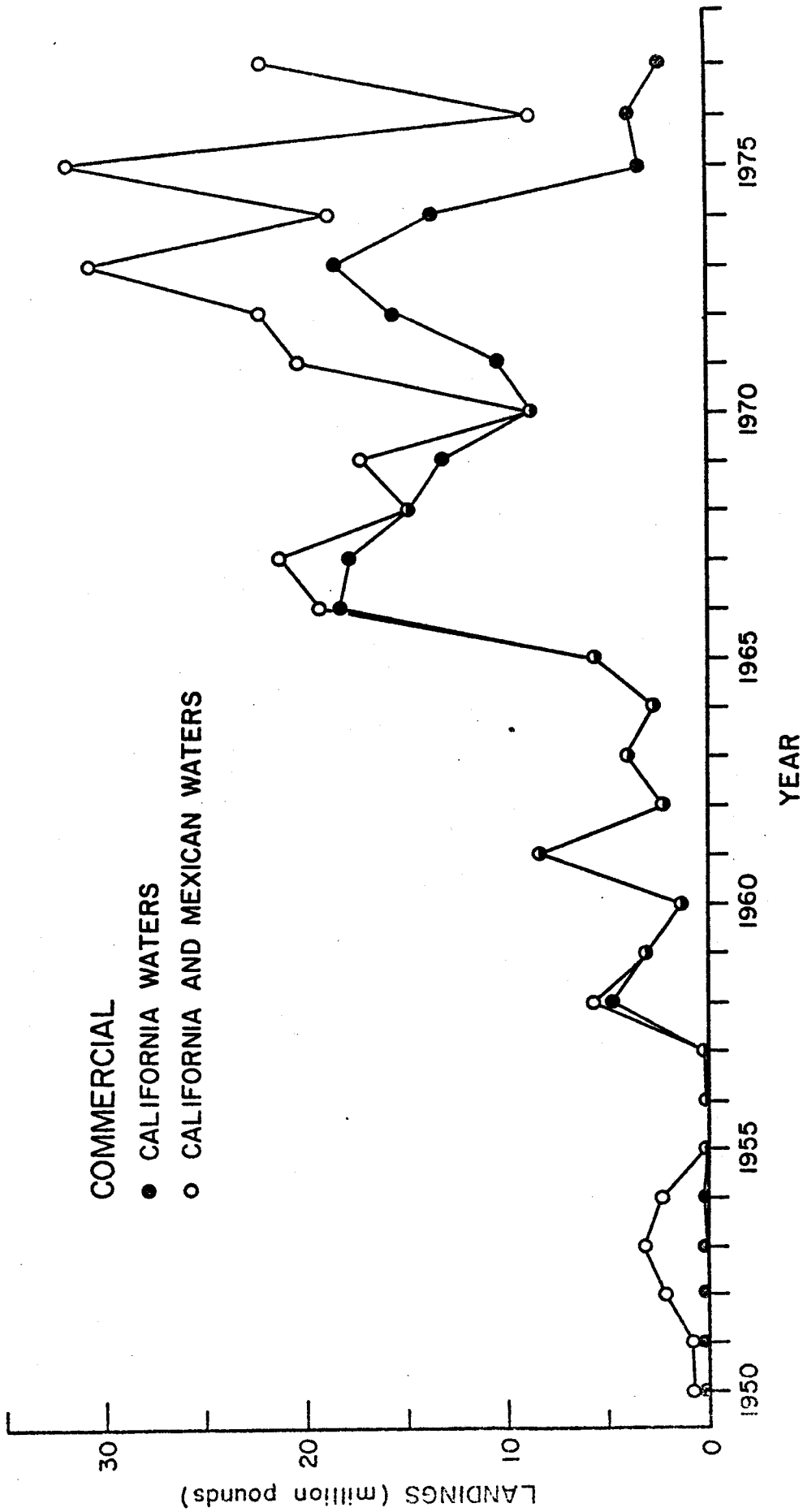

FIGURE 3.1. Cumulative catch of Pacific bonito by fishery segments, 1924-1977.

TABLE 3.1. Commercial Catch of Pacific Bonito Landed in California by Catch Area, 1916 - 1977.

Year	Total landings pounds / kilograms	Caught off California pounds / kilograms	Percent	Caught south of state pounds / kilograms	Percent
1916	*480,406*	*465,691*		*14,715*	
	217,912	211,337	97	6,675	3
1917	*889,376*	*889,376*		-	
	403,421	403,421	100	-	0
1918	*2,441,714*	*2,265,047*		*176,667*	
	1,107,561	1,027,425	93	80,136	7
1919	*3,509,098*	*2,908,745*		*600,353*	
	1,591,727	1,319,407	83	272,320	17
1920	*873,648*	*672,393*		*201,255*	
	396,287	304,997	77	91,289	23
1921	*324,737*	*241,859*		*82,878*	
	147,301	109,707	74	37,593	26
1922	*957,942*	*894,292*		*63,650*	
	434,522	405,651	93	28,872	7
1923	*1,115,247*	*478,771*		*636,476*	
	505,876	217,170	43	288,706	57
1924	*1,045,282*	*843,095*		*202,187*	
	474,140	382,428	81	91,712	19
1925	*879,166*	*782,868*		*96,298*	
	398,790	355,109	89	43,681	11
1926	*3,121,604*	*2,942,906*		*178,698*	
	1,415,960	1,334,902	94	81,057	6
1927	*1,718,008*	*1,121,476*		*596,532*	
	779,288	508,702	65	270,587	35
1928	*2,107,089*	*1,336,719*		*770,370*	
	955,756	606,336	63	349,440	37
1929	*2,918,544*	*593,886*		*2,324,658*	
	1,323,852	269,387	20	1,054,465	80
1930	*5,164,260*	*3,866,496*		*1,297,764*	
	2,342,508	1,753,843	75	588,666	25
1931	*3,079,673*	*3,014,135*		*65,538*	
	1,396,940	1,367,212	98	29,728	2
1932	*2,862,286*	*1,676,487*		*1,185,799*	
	1,298,333	760,455	59	537,878	41
1933	*2,252,199*	*1,967,244*		*284,955*	
	1,021,597	892,342	87	129,256	13
1934	*3,202,694*	*3,003,048*		*199,646*	
	1,452,742	1,362,183	94	90,559	6
1935	*7,896,484*	*2,263,740*		*5,632,744*	
	3,581,845	1,026,832	29	2,555,013	71
1936	*7,215,916*	*2,216,679*		*4,999,237*	
	3,273,139	1,005,486	31	2,267,654	69
1937	*7,808,070*	*5,707,212*		*2,100,858*	
	3,541,741	2,588,791	73	952,949	27

TABLE 3.1. Cont.

Year	Total landings	Caught off California		Caught south of state	
	pounds kilograms	*pounds* kilograms	Percent	*pounds* kilograms	Percent
1938	*7,839,993*	*4,684,570*		*3,155,423*	
	3,556,221	2,124,921	60	1,431,300	40
1939	*9,918,875*	*6,697,249*		*3,221,626*	
	4,499,202	3,037,872	68	1,461,330	32
1940	*5,291,140*	*3,553,121*		*1,738,019*	
	2,400,061	1,611,696	67	788,365	33
1941	*10,907,602*	*7,850,496*		*3,057,106*	
	4,947,688	3,560,985	72	1,386,703	28
1942	*1,650,689*	*860,833*		*789,856*	
	748,753	390,474	52	358,279	48
1943	*2,282,299*	*801,535*		*1,480,764*	
	1,035,251	363,576	35	671,675	65
1944	*818,871*	*326,175*		*492,696*	
	371,440	147,953	40	223,487	60
1945	*2,714,181*	*339,664*		*2,374,517*	
	1,231,153	154,072	13	1,077,081	87
1946	*5,625,648*	*582,948*		*5,042,700*	
	2,551,794	264,425	10	2,287,369	90
1947	*13,697,183*	*384,327*		*13,312,856*	
	6,213,042	174,331	3	6,038,711	97
1948	*9,135,126*	*214,992*		*8,920,134*	
	4,143,693	97,520	2	4,046,173	98
1949	*1,829,541*	*99,244*		*1,730,297*	
	829,880	45,017	5	784,863	95
1950	*695,614*	*33,456*		*662,158*	
	315,531	15,176	5	300,355	95
1951	*776,803*	*54,047*		*722,756*	
	352,358	24,516	7	327,842	93
1952	*2,142,517*	*7,504*		*2,135,013*	
	971,846	3,404	<1	968,442	>99
1953	*3,102,647*	*19,069*		*3,083,578*	
	1,407,361	8,650	1	1,398,711	99
1954	*2,319,060*	*218,701*		*2,100,359*	
	1,051,926	99,203	9	952,723	91
1955	*136,990*	*40,354*		*96,636*	
	62,139	18,305	29	43,834	71
1956	*127,614*	*22,491*		*105,123*	
	57,886	10,202	18	47,684	82
1957	*219,149*	*110,174*		*108,975*	
	99,406	49,975	50	49,431	50
1958	*5,546,806*	*4,804,784*		*742,022*	
	2,516,031	2,179,450	87	336,581	13
1959	*3,011,616*	*3,003,058*		*8,558*	
	1,366,069	1,362,187	99.7	3,882	0.3
1960	*1,250,544*	*1,219,682*		*30,862*	
	567,247	553,248	98	13,999	2
1961	*8,512,972*	*8,439,400*		*73,572*	
	3,861,484	3,828,112	99	33,372	1

TABLE 3.1. Cont.

Year	Total landings *pounds* kilograms	Caught off California *Pounds* kilograms	Percent	Caught south of state *Pounds* kilograms	Percent
1962	*2,134,902*	*2,071,998*		*62,904*	
	968,392	939,858	97	28,533	3
1963	*4,022,522*	*4,013,505*		*9,017*	
	1,824,616	1,820,526	>99	4,090	<1
1964	*2,612,269*	*2,606,411*		*5,858*	
	1,184,925	1,182,268	>99	2,657	<1
1965	*5,638,340*	*5,632,399*		*5,941*	
	2,557,551	2,554,856	>99	2,695	<1
1966	*19,148,494*	*18,308,175*		*840,319*	
	8,685,757	8,304,588	96	381,169	4
1967	*21,219,431*	*17,841,537*		*3,377,894*	
	9,625,134	8,092,921	84	1,532,213	16
1968	*14,921,929*	*14,903,357*		*18,572*	
	6,768,587	6,760,163	>99	8,424	<1
1969	*17,201,847*	*13,174,505*		*4,027,342*	
	7,802,758	5,975,956	77	1,826,802	23
1970	*9,191,304*	*8,793,788*		*398,516*	
	4,169,629	3,988,862	96	180,767	04
1971	*20,268,984*	*10,476,268*		*9,792,716*	
	9,194,011	4,752,035	52	4,441,976	48
1972	*22,312,627*	*15,600,361*		*6,712,266*	
	10,121,008	7,076,324	70	3,044,684	30
1973	*30,787,731*	*18,525,253*		*12,262,478*	
	13,965,315	8,403,055	60	5,562,260	40
1974	*18,817,766*	*13,776,716*		*5,040,380*	
	8,535,435	6,249,118	73	2,286,317	27
1975	*31,873,688*	*3,384,089*		*28,489,599*	
	14,457,905	1,535,023	11	12,922,882	89
1976	*8,896,859**	*3,882,312*		*5,014,547*	
	4,035,615	1,761,017	44	2,274,599	56
1977	*22,093,312**	*2,320,069*		*19,773,243*	
	10,044,414	1,054,577	11	8,987,838	89
1978	8,000,000*	2,000,000	25	6,000,000	75

*Preliminary

Landings have been relatively high since 1965 and have been dependent upon availability, but market demand limited landings for many of the years prior to 1965. Small quantities are now delivered to the fresh fish market while most of the catch goes to canneries, eventually reaching market shelves as a lower cost substitute for tuna.

3.1.2 The Fishing Fleet

The Pacific bonito fishery includes a variety of gear types and vessel sizes. As indicated in Table 3.2 most of the landings are made by vessels with roundhaul nets. Bonito taken by troll gear, gill nets or hook and line gear are generally incidental to the primary target species. The roundhaul fleet consists of two general groups: the local "wetfish" vessels, and the larger tropical tuna seiners. "Wetfish" vessels target primarily upon anchovy and jack mackerel, but focus seasonally upon bonito, squid and bluefin tuna. Nearly all "wetfish" vessels fish out of San Pedro and they range from 30 to 100 net registered tons, and from 30 feet to 80 feet in length. The high seas tuna seiners fishing out of San Diego and San Pedro harvest bonito off Baja California. Tuna seiners which land bonito range in carrying capacity from 150 to 1100 short tons, but most of the bonito landings comes from vessels that are 500 tons or less in capacity.

The "wetfish" fleet consists of about 35 vessels.

TABLE 3.2. Commercial Landings of Pacific bonito by gear type and Nos. of Vessels Participating 1971-1976.

Year	Total Landings		Roundhaul			Trolling			Entangling Nets			Hook and Line			Other		
	No. boats	kg	No. boats	kg	%	No. boats	kg	%	No. boats	kg	%	No. boats	kg	%	No. boats	kg	%
1971	360	9,194,011	71	8,766,402	95.4	141	219,275	2.4	57	157,664	1.7	40	35,078	0.4	51	15,592	0.2
1972	596	10,121,008	73	9,168,573	90.6	297	747,055	7.4	41	113,400	1.1	75	64,955	0.6	110	27,024	0.2
1973	424	13,965,315	82	3,250,320	94.9	167	427,158	3.1	53	110,924	0.8	63	171,337	1.2	59	5,575	0.1
1974	268	8,535,435	59	8,179,205	95.8	63	95,238	1.1	76	199,732	2.3	53	60,370	0.7	17	886	0.01
1975	174	14,457,663	66	14,402,915	99.6	12	12,544	0.1	46	28,292	0.2	32	12,946	0.1	18	966	0.05
1976	226	4,035,548	67	3,931,446	97.4	12	18,881	0.5	64	59,695	1.5	57	21,858	0.5	26	3,668	0.1
AVERAGE 1971-1976	341		70		95.7	115		2.8	56		1.0	53		0.5	47		0.1

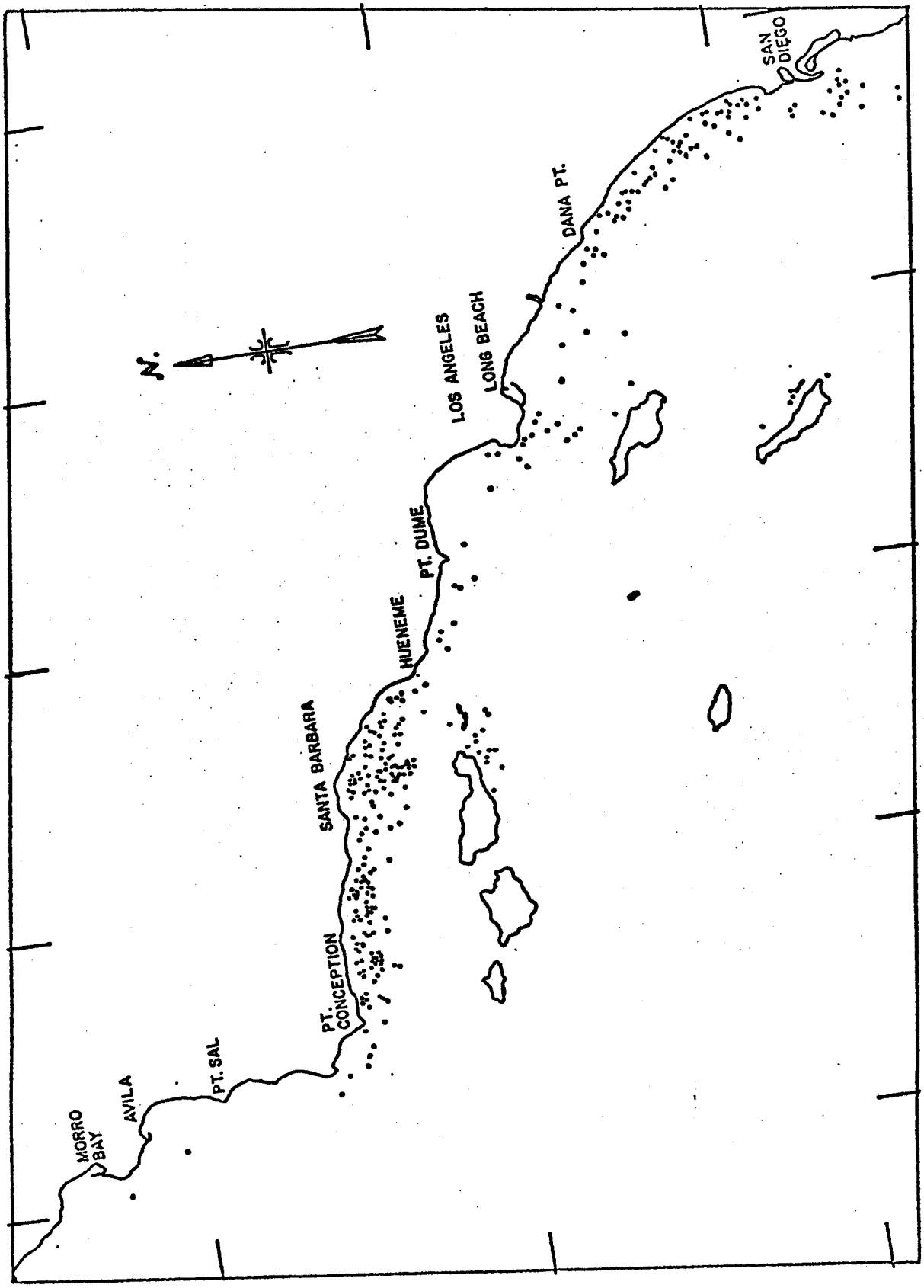

FIGURE 3.2. Pacific bonito schools sighted by aerial fish spotters, 1974-1977.

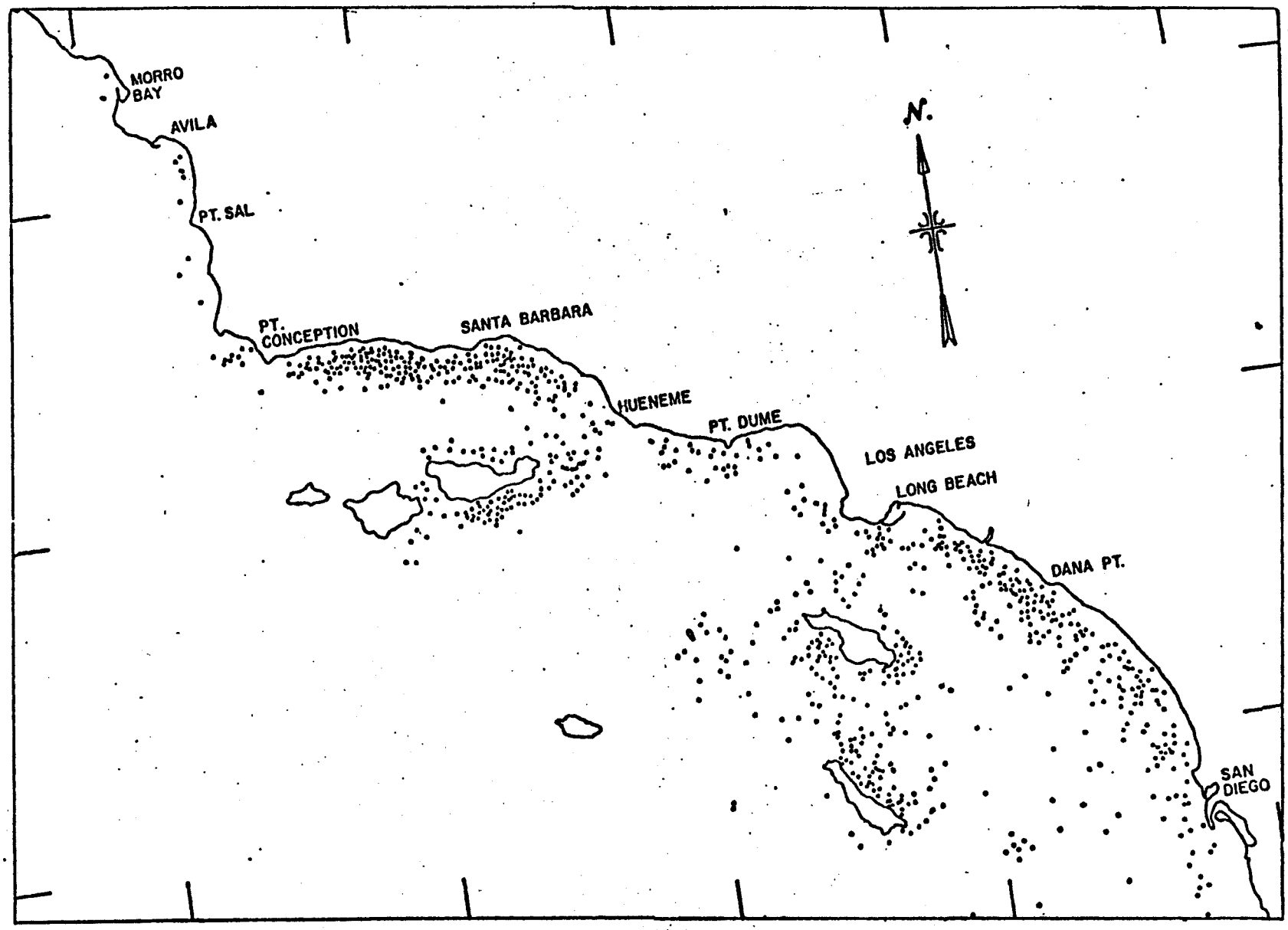

FIGURE 3.3. Pacific bonito schools sighted by aerial fish spotters, 1962-1965.

TABLE 3.3. Pacific Bonito Landings (Pounds & Percent) by Month and Area 1972 through 1976.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL
1972													
TOTAL LANDINGS	552,087	252,518	121,721	351,343	775,904	1,530,984	342,145	2,252,809	7,118,096	5,500,760	2,062,290	1,451,970	22,312,627
% of Total	2%	1%	1%	2%	3%	7%	2%	10%	32%	25%	9%	7%	>
S. of State	284,788	212,639	121,459	347,440	775,696	1,530,592	246,877	2,203,248	127,898	701,605	134,168	24,856	6,711,266
% S. of State	4%	3%	2%	5%	12%	23%	4%	33%	2%	10%	2%	<0.5%	30%
California	267,299	39,879	262	3,903	208	392	95,268	49,561	6,990,198	4,799,155	1,928,122	1,427,114	15,601,361
% California	2%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	1%	<0.5%	45%	31%	12%	9%	70%
1973													
TOTAL LANDINGS	3,757,172	688,071	1,036,320	558,569	332,951	3,292,052	3,860,955	4,543,269	4,012,992	4,450,646	1,934,751	2,319,993	30,787,741
% of Total	12%	2%	3%	2%	1%	11%	13%	15%	13%	14%	6%	8%	
S. of State	104,009	117,622	1,602	57,196	288,760	3,075,187	2,285,910	2,831,349	1,088,715	1,254,823	930,830	226,425	12,262,428
% S. of State	1%	1%	<0.5%	<0.5%	2%	25%	19%	23%	9%	10%	8%	2%	40%
California	3,653,163	570,449	1,034,718	501,373	44,191	216,865	1,575,045	1,711,920	2,924,277	3,195,823	1,003,921	2,093,568	18,525,313
% California	20%	3%	6%	3%	<0.5%	1%	9%	9%	16%	17%	5%	11%	60%
1974													
TOTAL LANDINGS	236,359	101,060	104,698	116,395	47,559	1,232,548	2,119,217	3,511,921	4,060,378	3,022,479	2,337,304	1,927,848	18,817,766
% of Total	1%	1%	1%	1%	<0.5%	7%	11%	19%	22%	16%	12%	10%	
S. of State	64,033	19,958	0	15,539	35,330	1,219,045	1,188,216	962,492	1,282,529	36,591	115,231	101,416	5,040,380
% S. of State	1%	<0.5%	0%	<0.5%	1%	24%	24%	19%	25%	1%	2%	2%	27%
California	172,326	81,102	104,698	100,856	12,229	13,503	931,001	2,549,429	2,777,849	2,985,888	2,222,073	1,826,432	13,777,386
% California	1%	1%	1%	1%	<0.5%	<0.5%	7%	19%	20%	22%	16%	13%	73%
1975													
TOTAL LANDINGS	1,172,865	70,295	4,107	2,399	70,807	218,960	8,436,057	10,986,337	8,553,507	1,470,822	800,900	86,632	31,873,688
% of Total	4%	<0.5%	<0.5%	<0.5%	<0.5%	1%	26%	34%	27%	5%	3%	<0.5%	
S. of State	19,392	9,322	995	1,126	67,680	217,303	8,250,109	10,595,062	8,448,830	847,792	25,720	6,268	28,489,599
% S. of State	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	1%	29%	37%	30%	3%	<0.5%	<0.5%	89%
California	1,153,473	60,973	3,112	1,273	3,127	1,657	185,948	391,275	104,677	623,030	775,180	80,364	3,384,089
% California	34%	2%	<0.5%	< .05%	< .05%	< .05%	5%	12%	3%	18%	23%	2%	11%
1976													
TOTAL LANDINGS	2,850	14,762	13,004	33,500	81,363	221,365	2,162,513	3,910,464	1,860,921	326,316	188,902	80,899	8,896,859
% of Total	<0.5%	<0.5%	<0.5%	<0.5%	1%	2%	24%	44%	21%	4%	2%	1%	
S. of State	250	14,629	12,669	32,965	81,269	3,361	774,011	2,656,155	1,461,775	9,900	30,567	18,171	5,095,722
% S. of State	<0.5%	<0.5%	<0.5%	1%	2%	<0.5%	15%	53%	29%	<0.5%	1%	<0.5%	56%
California	2,600	133	335	535	94	218,004	1,388,502	1,254,309	399,146	316,416	158,335	62,728	3,801,137
% California	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	6%	36%	32%	10%	8%	4%	2%	44%
1972-1976													
AVERAGE LANDING	1,144,267	225,341	255,970	212,441	261,717	1,299,182	3,384,177	5,040,960	5,121,179	2,954,205	1,464,829	1,173,468	22,537,536
% of Average	5.08%	1.00%	1.14%	0.94%	1.16%	5.76%	15.02%	22.37%	22.72%	13.11%	6.50%	5.21%	
S. of State	94,494	74,834	27,345	90,853	249,747	1,209,098	2,549,025	3,849,661	2,481,949	570,142	247,303	75,427	11,519,879
% S. of State Average	0.82%	0.65%	0.24%	0.79%	2.17%	10.50%	22.13%	33.42%	21.54%	4.95%	2.15%	0.65%	51.11%
California	1,049,772	150,507	228,625	121,588	11,970	90,084	835,153	1,191,299	2,639,229	2,384,062	1,217,526	1,098,041	11,017,857
% California Average	9.53%	1.37%	2.08%	1.10%	0.11%	0.82%	7.58%	10.81%	23.95%	21.64%	11.05%	9.97%	48.89%

Most fishing trips by the vessels are one- or two-day trips. Most of the bonito fishing by "wetfish" vessels occurs in the Santa Barbara channel or the Santa Catalina channel, whereas the tuna vessels generally find bonito off southern Baja California.

3.1.3 Area and Season of Commercial Catch

Historically, Pacific bonito commercial catches have come from two areas; off California between the Mexican border and Point Conception, and off the west coast of Baja California between Cedros Island and Magdalena Bay.

In U.S. waters, logs kept by commercial fish spotters show concentration of bonito schools in a relatively narrow coastal strip 12 miles or less wide (Figure 3.2). The distribution was apparently more widespread in the period immediately before the beginning of large scale commercial harvest (Figure 3.3)[1/]. Catches from U.S. waters occur primarily between July and January, peaking in September through November, but quite variable in the months of July, August, December and January (Table 3.3).

Catches off Mexico are also concentrated inshore, primarily on banks between Cedros Island and Cape San Lazaro, from June through to September (Table 3.3), with both June and September being months of variable catch.

Between 1966 and 1974, the bulk of the commercial bonito catch was taken in California waters within 19 km (12 miles) of shore. However, during a few years

1/ Data provided by J. Squire, National Marine Fisheries Service, La Jolla, CA

principally between 1943 and 1965 and from 1975 through 1977) over 50% of the total catch has been taken off Baja California (Table 3.1). The Baja California catch is generally made between Cape San Quintin and Cape San Lazaro. California catches are concentrated in the Santa Barbara Channel, although some are made earlier in the season between the U.S.-Mexican border and San Onofre.

3.1.4 Bonito Harvests by the Tropical Tuna Fleet

Since 1966 the international catch of yellowfin tuna in the eastern tropical Pacific has been restricted by a catch quota imposed by the Inter-American Tropical Tuna Commission (IATTC). During the first few years of the yellowfin tuna conservation program most of the harvest was taken by U.S. vessels and the unrestricted yellowfin tuna fishing season lasted most of the year. In recent years the tropical tuna fleets have expanded dramatically causing a reduction in both the length of the open fishing season and the dominance of the U.S. fleet. Since the beginning of the quota system, it has been recognized that some incidental catch of yellowfin would be unavoidable during the closed yellowfin season when fishing for skipjack, bigeye, and bluefin tuna continued. To avoid forcing the fishermen to discard the incidental catch of yellowfin, a 15% incidental catch allowance was instituted. Also, IATTC began allocating a portion of the yellowfin tuna quota to small vessels (i.e., those with under 400 tons of carrying capacity).

This "small boat allocation" amounts to 6,000 tons annually for the United States' fleet and can be taken before or after the unregulated yellowfin fishing season closes. The National Marine Fisheries Service divides the small boat allocation among the qualifying domestic vessels by allowing higher incidental catch allowances during the closed season. These range from 40 to 50% depending on vessel size and year considered. As a result of this yellowfin tuna regulation, therefore, many U.S. tuna purse seiners have been fishing during much of the year under an incidental catch allowance.

The possible significance of this for the bonito fishery stems from two circumstances: (1) the geographical position of the Pacific bonito stock, and (2) the tuna-like characteristics of bonito. Because bonito can be caught off Baja California, it is convenient for tuna vessels returning to southern California to "top off" their fish wells with bonito. Also, these bonito are within the range of the smaller purse seiners from California that fish bluefin tuna and tropical tunas when available off Baja. Bonito is a particularly attractive fish to tuna vessels because it is physically similar to tunas, is bought by the canneries that buy tuna, and is moderately high-valued ($320 per ton, compared to $750 per ton for tunas but $100 per ton for mackerel in 1977). Once the yellowfin tuna season is closed, tuna vessels

have an additional incentive to harvest bonito. Because of the incidental allowance for yellowfin, any harvest of bonito represents not only a potential cash value in itself, but also an additional quantity of yellowfin that may be landed.

These circumstances have led some people to conclude that the tuna fleet harvests bonito largely to satisfy incidental yellowfin catch regulations. If this were true, a change in the yellowfin tuna regulations might be effective in protecting the bonito stock. Elimination of bonito from the catch utilized to cover the incidental catch of yellowfin for instance, would make it less attractive for tuna boats to "top off" with bonito. On the other hand, the sales value of bonito itself may provide sufficient incentive for fishing bonito that a change in yellowfin regulations would make little difference to the tuna fleet.

To evaluate these alternative positions, unloading data for tuna vessels has been reviewed for the period 1974 through October 1978. Trips involving bonito were sorted out and are summarized in Table 3.4. Two characteristics of the data not evident in Table 3.4 are (1) that only one trip during the 4-year period involved a "super seiner" of more than 600 tons carrying capacity and (2) that of the 139 unloadings with bonito, 93 had no yellowfin and 61 were from open season fishing for yellowfin. Because only smaller vessels were involved, essentially

TABLE 3.4. California Bonito Landings and Their Relationship to Yellowfin Tuna Fishery Landings in Thousands of Pounds.[1/]

		1975	1976	1977	1978
(1)	Total landings	31,874	8,897	23,246[2/]	n.a.
(2)	Caught from south of State	28,490	5,014	19,773	n.a.
(3)	Caught by tuna fleet	28,239	5,180	19,758	5,496
(4)	From CYRA in open yellowfin season	2,530	482	14,572	2,650[3/]
(5)	From CYRA in closed yellowfin season	25,709	4,698	5,182	2,846[3/]
(6)	Bonito landed with yellowfin in closed season	10,292	4,658	639	2,845
(7)	Yellowfin catch dependent on bonito	1,057	627	0	968[2/]
(8)	Quantity of bonito needed for yellowfin	2,305	814	0	591[2/]

n.a. = not available

1/ Source of data: Southwest Region, National Marine Fisheries Service, Terminal Island, California

2/ Preliminary

3/ As of October 23, 1978

all of the yellowfin tuna landed with bonito was caught inside of the Commission Yellowfin Regulatory Area (CYRA) and was therefore subject to an incidental catch allowance after the yellowfin season closed. The amounts of bonito caught in the open season, closed season, and in combination with yellowfin are listed in lines (4) through (6) of Table 3.4.

The degree to which tuna vessels use bonito as a "filler" is examined on a trip-by-trip basis. For each trip landing both bonito and yellowfin from the closed season, the total catch is divided into yellowfin tuna (YF), bonito (BO) and other (OT). Because the incidental catch allowance (I) varies among boats and years, a general relationship is developed as follows.

P_{YF} = YF/(YF + BO + OT) X 100 = % YF in catch.

If, P_{YF} is greater than I, then either the data are in error or the vessel was fishing illegally. (Only one such instance was found in the data examined, and that particular trip was ignored in further analysis). To determine whether the bonito landed was necessary in order to legitimize the yellowfin harvest, we calculate a modified P_{YF}

P_{YF*} = YF/(YF + OT) X 100 = % YF without bonito.

If P_{YF*} is greater than I, then the bonito catch was needed to justify the yellowfin. The quantity of yellowfin protected by the bonito (YF*) is calculated as

YF* = YF - [I/(1-I)] OT.

Finally, the amount of bonito which actually helped to "cover" the yellowfin catch (BO*) is calculated as

$$BO^* = [(1-I)/I] \cdot YF - OT.$$

The two computed quantities, YF* and BO*, were summed over all pertinent trips for each year and are listed in lines (7) and (8) of Table 3.4.

The foregoing computations show that only a small percentage of the bonito landings were actually necessary in order to meet the percentage requirements of the U.S. regulations. First, only 31% of the bonito landings by tuna vessels in the last 4 years were associated with yellowfin tuna landings in the closed season. Second, only 20% of the bonito that was associated with closed season yellowfin catch (i.e. only 5% of total bonito catch) was needed to satisfy the regulations.

This does not mean that much of the bonito harvested with yellowfin in the closed season is not caught as a safeguard to assure that the incidental catch allowance is met. Obviously, a fishing vessel skipper does not always know exactly how much yellowfin is in his vessel's hold. If bonito are available, it is prudent to err in having excess bonito rather than too little. Thus, more bonito may be landed due to the yellowfin regulations than is indicated in line (8) of Table 3.4. Because much of the bonito harvest occurs on unregulated trips and because it is not likely that all the bonito catch on regulated trips is motivated by the regulations, however,

TABLE 3.5. California Partyboat Reported Catches in Numbers of Fish of Pacific Bonito, 1947-1977.

Year	Total California	So. California	Central and No. California
1947	36,496	36,496	-
1948	14,519	14,519	-
1949	5,372	5,372	-
1950	2,359	2,352	7
1951	14,475	14,475	-
1952	7,649	7,646	3
1953	6,321	6,321	-
1954	70,078	70,078	-
1955	22,409	22,396	13
1956	61,404	61,404	-
1957	258,555	258,520	35
1958	422,568	422,565	3
1959	776,386	774,290	2,096
1960	1,199,919	1,199,846	73
1961	849,426	849,426	-
1962	798,725	798,723	2
1963	775,719	773,036	2,683
1964	1,298,804	1,297,741	1,163
1965	806,322	804,281	2,041
1966	644,415	642,283	2,132
1967	349,952	348,463	1,489
1968	1,102,936	1,101,690	1,246
1969	1,230,241	1,228,174	2,067
1970	651,898	650,241	1,657
1971	152,795	152,659	136
1972	416,429	416,052	377
1973	471,979	471,897	82
1974	141,193	141,154	39
1975	80,438	80,438	-
1976	197,382	197,379	3
1977	161,962*	161,945	17*
1978*	315,643*	315,632*	11*

*Preliminary

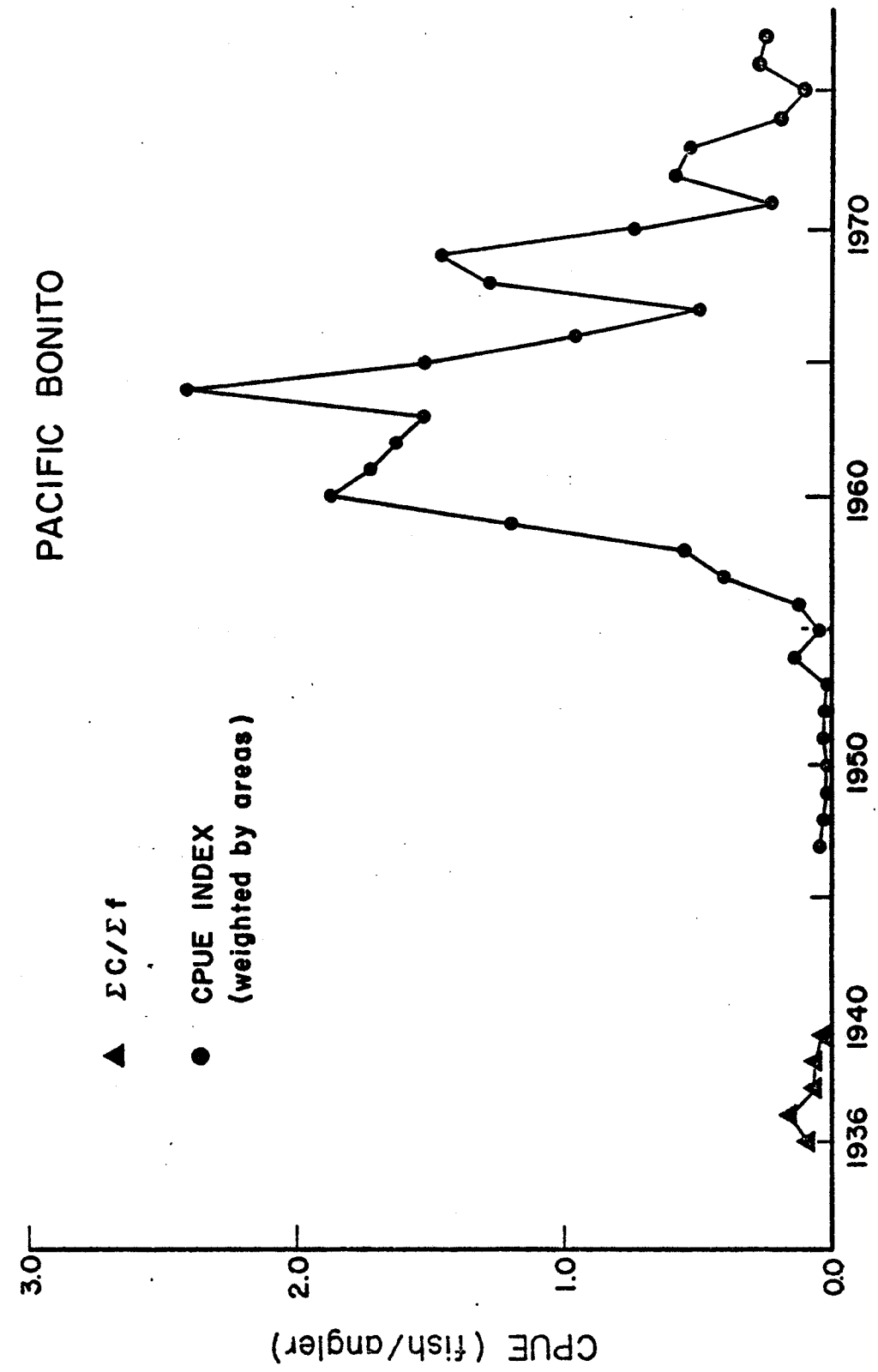

FIGURE 3.4. Southern California partyboat CPUE for Pacific bonito, 1930-1977 (effort weighed by area fished).

it must be concluded that the preponderance of the harvest by tuna vessels is motivated more by the sales value of the fish than by the need to meet yellowfin regulations.

3.2 Mexican Commercial Fishery

Recent annual catches by Mexico fisheries are not available but have been estimated for purposes of the fisheries analysis as 500 tons per year (see Table 5.2).

3.3 U. S. Recreational Fishery

3.3.1 Catches

At times, bonito have been chief contributors to the southern California marine recreational catch (Table 3.5). In the 1968 survey, southern California commercial passenger fishing vessel (partyboat) operators ranked bonito as the fourth most important species to their industry (Young 1969). Croker (1931) observed the catch of "a few" bonito from a barge anchored in Santa Monica Bay on March 22, 1931. However, fishing for bonito was good from piers during the summer in the early to mid-1930's. In a later report on commercial passenger fishing vessel catches, Croker indicates that during the period 1936-38, bonito were taken in small quantities (less than 6% of the total catch) (Croker 1939). He classifies bonito as "desirable game fish ". However it was less desirable than white seabass, yellowtail and relatively abundant barracuda and large kelp bass prevalent at that time. Commercial passenger fishing

vessel records for 1936-40 show bonito catch per unit of effort (CPUE) to have been relatively high in 1936 and 1937, declining to a very low value in 1940 (Figure 3.4). During the period 1937-40, an angler by the name of F.R. Hering compiled a list of all the species he caught during 492 days of fishing from a barge in Santa Monica Bay. While he attempted "to catch, by angling methods, as many fish of as many kinds as possible in one locality", not a single bonito occurs in a list of 30,487 organisms falling into 35 reported species and species groups (Croker 1941). In the early 1940's no recreational fishing records were kept; however, fishing was occasionally good for bonito in the Los Angeles area. When commercial passenger fishing vessel record keeping was resumed in 1946, the bonito had virtually disappeared, not to return in force until 1957.

For the 7 years following World War II, the commercial passenger fishing vessel catch of bonito was relatively low, only once exceeding 15,000 fish. During the next 3 years, catches improved considerably, averaging about 50,000 fish per year. With the advent of the warm water years (1957 to 1960), the catch began to climb, reaching almost 1.2 million fish in 1960. The catches did not decline as expected, when water temperatures cooled in the years from 1961 to 1969 (Table 3.5) although the catch per effort index did decline (Figure 3.4). During the 1960's young bonito were abundant inshore and recreational fishermen landed record numbers.

TABLE 3.6. Comparison of Southern California Recreational Fishing Catch and Effort for Pacific Bonito.

Source	Year	Catch Nos.	Effort	Catch Per Hour
Pier & jetty	1963	283,068	5,100,100[1/]	0.06
Partyboat	1963	773,036	2,480,054[2/]	0.31
Private Boat	1964	401,575	2,773,405[1/]	0.14
Partyboat	1964	1,297,741	2,679,545[2/]	0.48
Private Boat[3/]	1976	78,855	2,218,817[4/]	0.04
Partyboat	1976	197,379	2,462,371[2/]	0.08
Private Boat[3/]	1977	45,815	2,063,914[4/]	0.02
Partyboat	1977	161,945	2,452,236[2/]	0.07

1/ Effort in man/hours
2/ Effort in angler/hours
3/ Boats launched at launch ramps & hoists only
4/ Effort in angler-trip-hours. Data provided by the Southern California Independent Sport Fishing Survey, CDFG.

Partyboat figures are for southern California fleet only.

Since 1969, however, the recreational catch has fallen drastically.

The average annual southern California (Point Conception to San Diego) commercial passenger fishing vessel catch for the period from 1947 to 1956 was 24,107 fish, while the average catch from 1957 to 1969 was 801,075. The catch has averaged 301,730 annually since (through 1977). The average annual catch per angler for these three periods increased from 0.05 to 1.33, then dropped to 0.4 (Figure 3.4). The catch per angler curve indicates that the increased catch from 1957 on was not simply a function of increased effort, but reflected a change in the abundance or availability of bonito in California waters.

A survey conducted during the period of 1964-66 made estimates of the catch and effort of the recreational fishermen from piers and jetties, private boats, and shoreline from Point Conception to the Mexican border (Pinkas, Oliphant, and Haugen 1968). A later study estimated the catch of bonito and the effort expended by anglers fishing from boats launched at hoists or launch ramps in southern California during 1976 and 1977. The figures show that commercial passenger fishing vessel fishermen were, as a group, far more successful in capturing bonito than fishermen in other segments of the recreational fishery (Table 3.6).

3.3.2 Number of Anglers

The contribution of marine recreational fishing barges

to the total recreational catch was calculated as 21.2% of the reported commercial passenger fishing vessel catch, based on data collected in 1966 and 1970. All these are combined to give the total catch and effort for the southern California recreational fishery developed by Thayer (1973). We estimate, based on what data are available, that about 180,000 recreational fishermen annually fished for Pacific bonito in southern California waters in recent years.

3.3.3 Area and Season of Catch

The recreational catch of bonito is generally confined to southern California waters, although some are caught north of Point Conception. The heaviest commercial passenger fishing vessel catch is usually made during August and September from La Jolla to Redondo Beach. Recreational fishermen from Santa Monica Bay north make their best catches of large fish in October or November while to the south, the catch declines through October and November. The catch of fish in the open ocean is generally at a low level from the end of November until the following July. Occasionally however, fishing remains good until March for both recreational and commercial fishermen.

Bonito are occasionally caught in fair numbers by commercial passenger fishing vessel and pier and jetty fishermen during the winter months, especially around warm water outfalls along the coast. This provides considerable

recreation when most fishing is at a low ebb.

3.4 Mexican Sport Fishery

Commercial passenger fishing vessels operating out of Ensenada, Baja California, encounter Pacific bonito, but their main targets are more desirable species, and no figures are available to document their catch. An estimate of 0.12 times the U.S. partyboat catch was made for the fishery analysis, Section 5.

3.5 Recreational Commercial Conflicts

Between 1972 and 1975, less than a dozen letters were received by the Department of Fish and Game involving conflicts between recreational and commercial fishermen. However several of these letters were inquiries from legislators in response to numerous complaints from their constituents. All of the complaints involved commercial purse seine vessels operating in the Santa Barbara Channel, particularly during the late fall of 1972, 1974, and 1975.

Purse seine vessels often made catches of bonito in the Santa Barbara Channel near the coast and within sight of anglers aboard the recreational fishing vessels. Allegations were made of direct physical confrontation between recreational and commercial fishing vessels.

Subsequent to 1975 bonito landings declined sharply and the complaints from recreational fishermen subsided. Although less complaints have been lodged recently, the commercial fishery is now taking smaller fish of a size previously taken almost solely by the recreational fishery and may therefore be

competing more directly with them for the same resource than in the past.

4.0 BIOLOGY

4.1 Reproduction

Based on collections of eggs and larvae (Klawe 1961; Pinkas 1961; Sokolovskii 1971), bonito spawn off southern California and Baja California inside of the 200-m (656 feet) isobath and in waters ranging in temperature between 16°C and 20°C (61°F and 68°F).

A two-year study of bonito maturity and fecundity was initiated by the Department of Fish and Game (DFG) in September of 1974 and has shown, from external examinations of male gonads and from egg diameter measurements of female gonads, that bonito have a spawning season that lasts from March through July (Black 1970). Further analysis of the first year's samples appear to substantiate findings on the spawning behavior of the same species of bonito found off the coast of Peru (DeVildoso 1960): 1) bonito spawn between the beginning of spring and the end of summer, 2) the gonads are active for a longer period of time in males than in females, 3) older fish start to mature sooner in the season than do the younger ones, 4) females appear to spawn more than once each season, and 5) not all the eggs produced during a season are spawned, some remain in the ovary and are absorbed before the next spawning cycle.

The DFG study also revealed that females 3 years and older begin spawning in March and probably spawn more than once during the season, while younger females begin spawning activity in June

and may spawn only once. Reproduction takes place in 100% of the males and 97.5% of the females when 2 years of age, while all fish 3 years and older will reproduce. No estimates have been made of the number of eggs spawned by females of particular lengths and ages because of the difficulty of making such estimates for a multiple spawner which does not spawn all of its maturing eggs.

Evidence gathered in this study suggests that spawning by 1- and 2-year-old bonito takes place during cold water years in areas influenced by warm water discharges, even when bonito are absent from the rest of southern California water during the spawning season. Bonito tag returns indicate there may be small numbers of young resident fish that stay in these areas for as long as 2 years, providing some recruitment even in cold water years.

4.2 Food Habits

One study revealed that the northern anchovy, *Engraulis mordax*, is the major food item in the diet of Pacific bonito; that common squid, *Loligo opalescens*, forms an important part of the bonito diet from January through June; and that miscellaneous fish, such as sardines, and few crustaceans make up a small portion of the diet (Oliphant 1971).

4.3 Size, Age, and Growth

Campbell and Collins (1975) give the von Bertalanffy equation for length in cm

$L = 76.87\ [1-e^{-0.6215(t + 0.410)}]$, where L equals the fishes length at any given age t, and the length-weight relationship

$W(kg) = 7.62728 \times 10^{-6} L^{3.08962}$ (cm).

TABLE 4.1. Average Growth of Pacific Bonito in Length and Weight by Month*.

Month	Age (months)	Fork length cm	Fork length inches	Total length cm	Total length inches	Weight kg	Weight lbs
October	5	30.9	12.2	35.5	14.0	0.31	0.67
November	6	33.2	13.1	37.9	14.9	0.38	0.84
December	7	35.4	13.9	40.2	15.8	0.47	1.03
January	8	37.5	14.8	42.3	16.7	0.56	1.23
February	9	39.5	15.6	44.3	17.5	0.65	1.44
March	10	41.4	16.3	46.3	18.2	0.75	1.67
April	11	43.2	17.0	48.1	18.9	0.86	1.90
May	12	44.9	17.7	49.8	19.6	0.97	2.14
June	13	46.5	18.3	51.5	20.3	1.08	2.39
July	14	48.0	18.9	53.0	20.9	1.19	2.63
August	15	49.5	19.5	54.5	21.5	1.31	2.89
September	16	50.9	20.0	55.9	22.0	1.42	3.13
October	17	52.2	20.6	57.3	22.6	1.54	3.41
November	18	53.4	21.0	58.5	23.0	1.66	3.66
December	19	54.6	21.5	59.7	23.5	1.78	3.92
January	20	55.7	21.9	60.9	24.0	1.89	4.17
February	21	56.8	22.4	62.0	24.4	2.01	4.43
March	22	57.8	22.8	63.0	24.8	2.12	4.67
April	23	58.8	23.2	64.0	25.2	2.23	4.92
May	24	59.7	23.5	64.9	25.6	2.34	5.16
June	25	60.5	23.8	65.8	25.9	2.45	5.38
July	26	61.4	24.2	66.7	26.3	2.55	5.63
August	27	62.2	24.5	67.5	26.6	2.65	5.86
September	28	62.9	24.8	68.2	26.9	2.75	6.07
October	29	63.6	25.0	68.9	27.1	2.85	6.28
November	30	64.3	25.3	69.6	27.4	2.94	6.48
December	31	64.9	25.6	70.2	27.7	3.03	6.68
January	32	65.5	25.8	70.4	27.7	3.12	6.87
February	33	66.1	26.0	71.5	28.1	3.20	7.07
March	34	66.6	26.2	72.0	28.3	3.29	7.24
April	35	67.1	26.4	72.5	28.5	3.37	7.41
May	36	67.6	26.6	73.0	28.7	3.44	7.58
June	37	68.1	26.8	73.5	28.9	3.52	7.75
July	38	68.5	27.0	73.9	29.1	3.59	7.89

* Reference, Campbell and Collins, 1975.

Fish 15 to 25 cm (6 to 10 in.) long are observed by fishermen in the early summer; by the following spring these fish, now 1-year-old, are 45 cm (15 in.) in length and weigh about 1 kg (2 lb.). These fish will weigh 1.4 kg (3 lb.) or more by September, 4 pounds in December and by the following May will weigh about 2.3 kg (5 lb.). The next year these 3-year-olds will weigh 3.2 to 3.5 kg (7 to 7.5 lb.) and be about 68 cm (27 in.) long (Table 4.1). There is a verified report of bonito 100 cm (40 in.) in length weighing 11 kg (25 lb.), and an unverified report of a 17 kg (37 lb.) fish (Campbell and Collins 1975).

4.4 Migration

In 1968, a tagging project was initiated to study the movements and growth rates of bonito.[2/] Since 1968, over 11,200 bonito have been tagged and released along the coast from Monterey Bay, California, to Cape San Lazaro, Baja California. Over 1,100 tags have been recovered by sport and commercial fishermen. These have provided information about bonito movements and have confirmed short-term growth rate estimates. These fish appear to move randomly in local waters, although there is a definite movement down the southern California coast during the winter months, and northward in the late summer and early fall, in an apparent response to changes in the temperature of the ocean water.

The majority of tag returns came from fish that had traveled less than 32 km (20 miles). Several bonito tagged off

---

2/ Collins, Robson A., and S. Gail Campbell, M.S. The migration of Pacific bonito in the eastern North Pacific. On file at California State Fisheries Laboratory, Long Beach.

Baja California in June were recaptured by purse seiners near Santa Barbara 4 to 6 months later. Bonito tagged near Santa Barbara have been recovered a year and a half later off Baja California. Bonito that traveled long distances moved from Mexico to local waters in the summer months and back again in the winter (Figure 4.1).

Two of the 22 bonito that have been recovered more than 2 years after tagging were recovered within 2 km (1.6 mi.) of the release point at King Harbor, Redondo Beach, a heated water discharge area.

Data from our tagging study indicate that heated water discharges from coastal electric generating stations strongly influence the migration of young bonito in southern California waters. Extensive tagging of fish found in heated water plumes has revealed that these fish either remain in the area of the discharge or tend to migrate to another heated discharge area. Most of these fish were at liberty less than 2 years. However, two fish at liberty for almost 3 years were recovered in the same heated water discharge where they were originally tagged.

We currently believe that the fish found in the heated water discharge areas are, for the most part, young of the year spawned in southern California waters, that have been intercepted on their way south during the early winter. These fish remain in southern California waters the year round and are less likely to migrate south into Baja California waters during the winter when they get older.

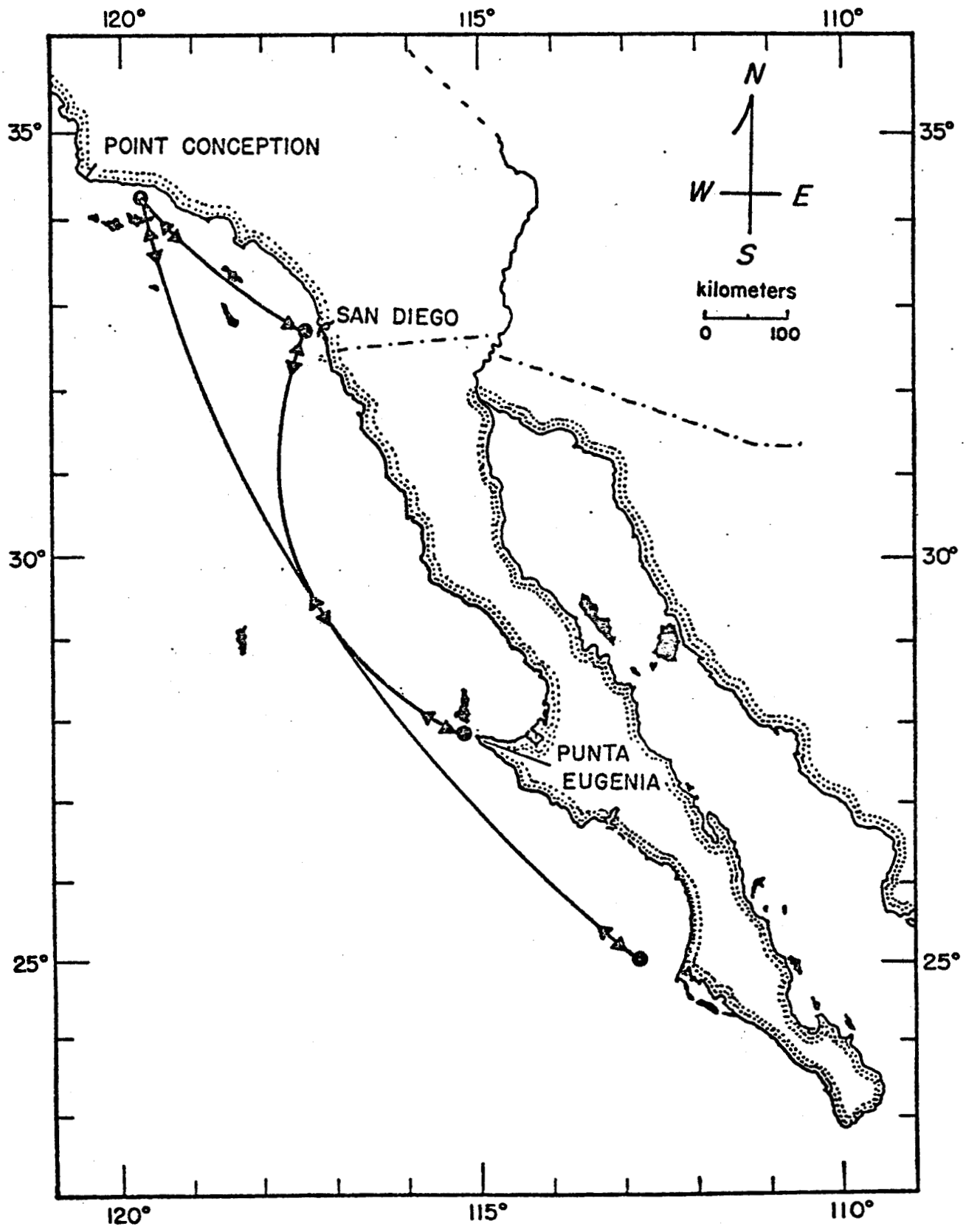

FIGURE 4.1. Gross migrations of Pacific bonito.

TABLE 4.2. Year-Class Composition of Pacific Bonito Commercial Passenger Fishing Vessel Catches Made Off Southern California.

Year class	1970	1971	1972	1973	1974	1975	1976	1977	1978	TOTAL
Year										
1972	5,447	85,892	324,713	0	0	0	0	0		416,052
1973	0	4,724	466,701	427	0	0	0	0		417,897
1974	141	5,805	5,805	22,794	51,110	0	0	0		141,154
1975	0	0	0	167	78,622	1,575	0	0		80,438
1976	0	0	0	0	0	0	197,382	0		197,382
1977	0	0	0	0	0	0	45,564	116,398		161,962
1978										
TOTAL	5,588	96,421	852,792	23,433	129,732	1,575	242,946	116,398		

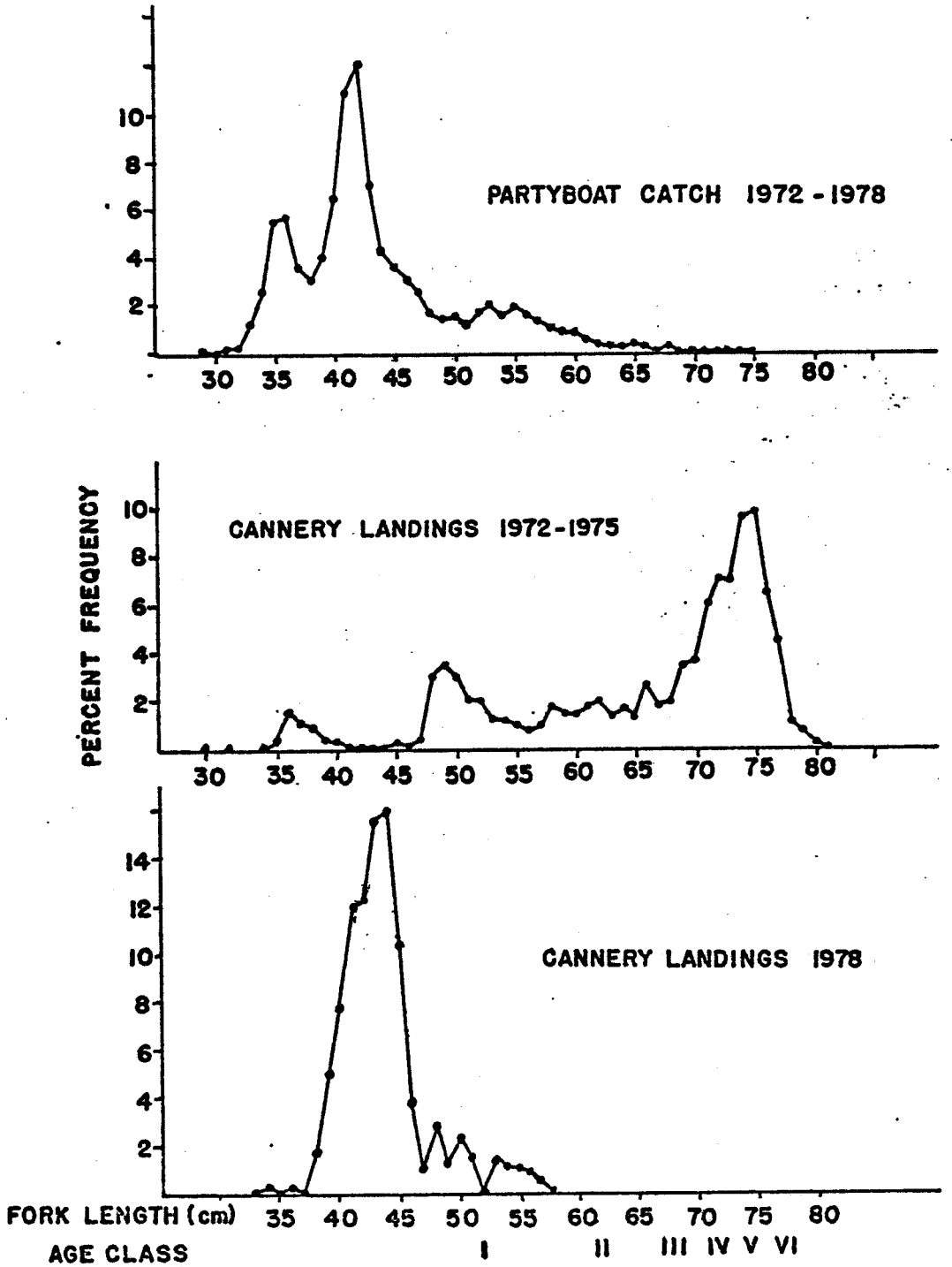

FIGURE 4.2. Average length composition of sport and commercial catches of Pacific bonito.

4.5 Size and Age of Catch

During the period 1969-1974 bonito caught by sportsmen were generally less than 2 years of age and often a single year-class supported the fishery through a period of 2 to 3 years, as was the case from 1972 through 1974 (Table 4.2). Commercial landings on the other hand consisted almost exclusively of fish 2 years and older. Recently however, both sport and commercial catches from California waters have been primarily composed of young of the year, with a few 1 year-old fish being taken in the early summer (Figure 4.2).

4.6 Natural Mortality

An estimate of instantaneous rate of natural mortality, M, for bonito is not available, but reasonable values can be derived based on the population biology of the stock. The maximum age, T_{max}, of bonito in age frequency studies is 6 years and K, the von Bertalanffy growth parameter, is 0.62 (Campbell and Collins 1975, see Sec. 4.3). Based on these values, M would be between 0.8 and 1.1 using relationships from Beverton and Holt's (1959) review. Using the method of Alverson and Carney (1975), M equals 0.60 for the above values of T_{max} and K. The Beverton and Holt relationship between K and M was based on temperate water species and may not apply to warmer water species such as bonito. Also the estimates of asympotic maximum length, L_∞, and T_{max} were most likely on the low side which would lower the estimates of K and M using both methods. A reasonable value of M for population models is likely between 0.6 and 0.8.

5.0 FISHERY ANALYSIS

5.1 Production Model

5.1.1 Measurement of Abundance

The recreational fishery usually catches bonito age 0 and 1, and the catch per angler reflects the abundance of these fish (MacCall, Stauffer and Troadec 1976). The commercial fishery usually caught bonito aged 2, 3 and 4, up until the 1975 season when the age composition began shifting toward younger fish. The commercial fishery itself uses aerial scouting to locate fish, and the log-books from these pilots provides a second index of abundance (Squire 1972). If these two indices of abundance pertain to the same stock of fish, the age composition of the catches by the two fishery segments suggests that a time lag is necessary to compare values. When the aerial index is compared with the mean angler CPUE index of two and three years earlier (Figure 5.1), a good relationship is evident ($r = 0.91$). This agreement supports the hypothesis that each index relates to the abundance of the same stock, and a combined index is the best available measure of relative abundance. In order to provide equal weighting of the two indices, the catch per angler index was multiplied by 0.674 to bring its average value to equivalence with the aerial log-book abundance index. The overall index of abundance is calculated by the following formula:

$$I_i = 0.5\ (A_i + 0.5 \times 0.674\ (P_{i-2} + P_{i-3}))$$

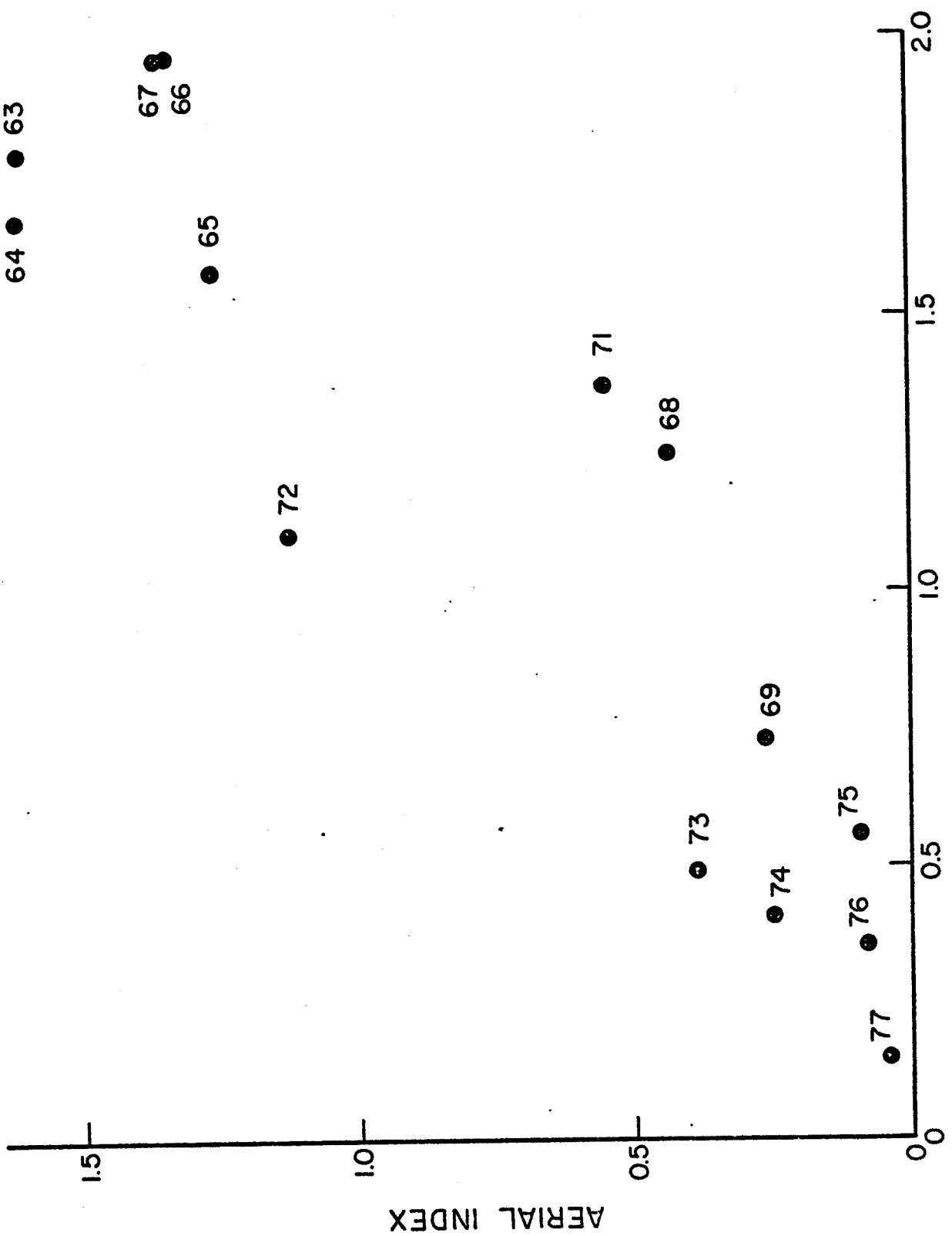

FIGURE 5.1. Comparison of aerial index of bonito abundance with mean angler CPUE index of 2 and 3 years earlier ($r = 0.91$). Years 1976 and 1977 may not be appropriately logged due to younger age composition of commercial catches.

where I_i is abundance index in year i,

A_i is day aerial spotter index for bonito, and

P_i is catch per angler index.

Values are given in Table 5.1.

5.1.2 Catch

Two sets of catches were examined. The catch from California waters was estimated by combining the commercial landings from California waters with the estimated recreational catch from California waters. Recreational catch was estimated to be 2.02 times the reported partyboat catch in number, at an average weight of 3.56 lb/fish. Total landings from all waters included the above, plus commercial landings from south of the border, long range partyboat catches, estimated Mexican recreational catches (12% of California catch), and reported or estimated Mexican commercial catch. Values are given in Table 5.2.

5.1.3 Fishing Intensity Index

An index of fishing intensity was obtained by dividing catch by the index of abundance.

$$f_{i*} = C_i / I_i$$

where f_i is fishing intensity index in year i, and

C_i is catch (either California or total).

Values are given in Table 5.3.

5.1.4 Fitting Procedure

Catches and fishing intensity index values were used as input to the program PRODFIT (Fox 1974). Because two

TABLE 5.1. Abundance Indices Used in Production Model.

Year	Aerial Day Index	Angler CPUE Index	2 Year Mean CPUE, Lagged 2 Years	Combined Abundance Index (Aerial Basis)	Scaled Abundance Index (Percent, 2.0 = 100%)
1960		1.87			
1961		1.73			
1962		1.62			
1963	1.62	1.53	1.80	1.42	71
1964	1.62	2.41	1.68	1.38	69
1965	1.26	1.53	1.58	1.16	58
1966	1.34	0.96	1.97	1.33	67
1967	1.35	0.50	1.97	1.34	67
1968	0.43	1.28	1.25	0.64	32
1969	0.26	1.46	0.73	0.38	19
1970	-	0.74	0.89	(0.60)[1/]	(30)[1/]
1971	0.55	0.23	1.37	0.74	37
1972	1.12	0.59	1.10	0.93	47
1973	0.39	0.53	0.49	0.36	18
1974	0.25	0.19	0.41	0.26	13
1975	0.086	0.11	0.56	0.23	12
1976	0.075	0.28	0.36	0.16	8
1977	0.039	0.25	0.15	0.07	4

1/ Aerial Index Data Lacking. Abundance based on angler CPUE alone.

TABLE 5.2. Catches in Thousands of Pounds Used in Production Model.

	California			South of State			
Year	Sport[1]	Commercial	Total	Sport[2] and Mexico Commercial	U. S. Commercial	Total	Total Fishery
1963	5,119	4,014	9,133	1,445	9	1,454	10,587
1964	8,799	2,606	11,405	1,668	6	1,674	13,079
1965	5,462	5,632	11,094	1,077	6	1,083	12,177
1966	4,366	18,308	22,674	2,315	840	3,155	25,829
1967	2,371	17,842	20,213	1,492	3,378	4,870	25,083
1968	7,472	14,903	22,375	1,249	18	1,267	23,642
1969	7,657	13,174	20,831	646	4,027	4,673	25,504
1970	4,417	8,794	13,211	440	398	838	14,049
1971	1,035	10,476	11,511	384	9,793	10,177	21,688
1972	2,837	15,600	18,437	516	6,712	7,228	25,665
1973	3,199	18,525	21,724	925[3]	12,262	13,187	34,911
1974	894	13,777	14,671	1,127[3]	5,040	6,167	20,838
1975	509	3,384	3,893	1,071[3]	28,490	29,561	33,454
1976	1,248	3,882[4]	5,130	1,176[3]	5,014[4]	6,190	11,320
1977	1,023	2,320[4]	3,343	1,144[3]	19,773[4]	20,917	24,260

1/ California sport catch is 2.02 x partyboat catch, at 3.56 lb/fish.
2/ Mexican sport catch is 0.12 x U.S. partyboat catch, at 3.56 lb/fish.
3/ Mexico commercial catch assumed to be 1000.
4/ Preliminary

TABLE 5.3. Fishing Intensity Indices Used in Production Model.

		CALIFORNIA FISHERY			TOTAL FISHERY		
Year	Abundance Index (Aerial Basis)	Catch (Thousands of pounds)	Fishing intensity index	2 year weighted average fishing intensity	Catch (Thousands of pounds)	Fishing intensity index	2 year weighted average fishing intensity
1963	1.42	9,133	6,430	(6,430)[2/]	10,587	7,460	(7,460)[2/]
1964	1.38	11,405	8,260	7,650	13,079	9,480	8,807
1965	1.16	11,094	9,560	9,127	12,177	10,500	10,160
1966	1.33	22,674	17,050	14,553	25,829	19,420	16,447
1967	1.34	20,213	15,080	15,737	25,083	18,720	18,953
1968	0.64	22,375	34,960	28,333	23,642	36,940	30,867
1969	0.38	20,831	54,820	48,200	25,504	67,120	57,060
1970	(0.60)[1/]	13,211	22,020	32,953	14,049	23,420	37,987
1971	0.74	11,511	15,560	17,713	21,688	29,310	27,347
1972	0.93	18,437	19,820	18,400	25,665	27,600	28,170
1973	0.36	21,724	60,340	46,833	34,911	96,980	73,853
1974	0.26	14,671	56,430	57,733-	20,838	80,150	85,760
1975	0.23	3,893	16,930		33,454	145,450	123,683
1976	0.16	5,130	32,060		11,320	70,750	95,650
1977	0.07	3,343	47,760		24,260	346,570	

1/ Aerial index data lacking. Abundance based on partyboat CPUE alone.
2/ Not averaged due to lack of previous data point.

year classes (ages 2 and 3) contribute most of the commercial catch, a two-year weighted average of fishing intensity (f_{i*}) was used as an equilibrium approximation:

$$f_{i*} = 2/3\ f_i + 1/3\ f_{i-1}$$

When no restrictions were put on the fitting procedure, the California fishery data gave a virgin abundance index of about 1.8, while the total fishery data gave a virgin abundance index of about 2.2. The true virgin abundance index must be the same for both the California and the total fisheries, and the above two values represent the statistical variability in its estimation. An intermediate value of 2.0 for the virgin level of abundance appears reasonable, and the two sets of data were forced to conform to this intercept. Catches for 1963 to 1974 were used for the California fishery, where more recent years have shown a shift in age composition and are not comparable. The data series for the total fishery was extended to 1976.

The resulting production curves (Figures 5.2 through 5.5) are now consistent with each other as well as with the observed data. The abundance index has also been scaled such that 100% is equal to a value of 2.0, allowing a generalization of the production curve. Abundance, expressed as percent of maximum, may be interpreted independently of the method of measurement, and will be used in the management section of this document.

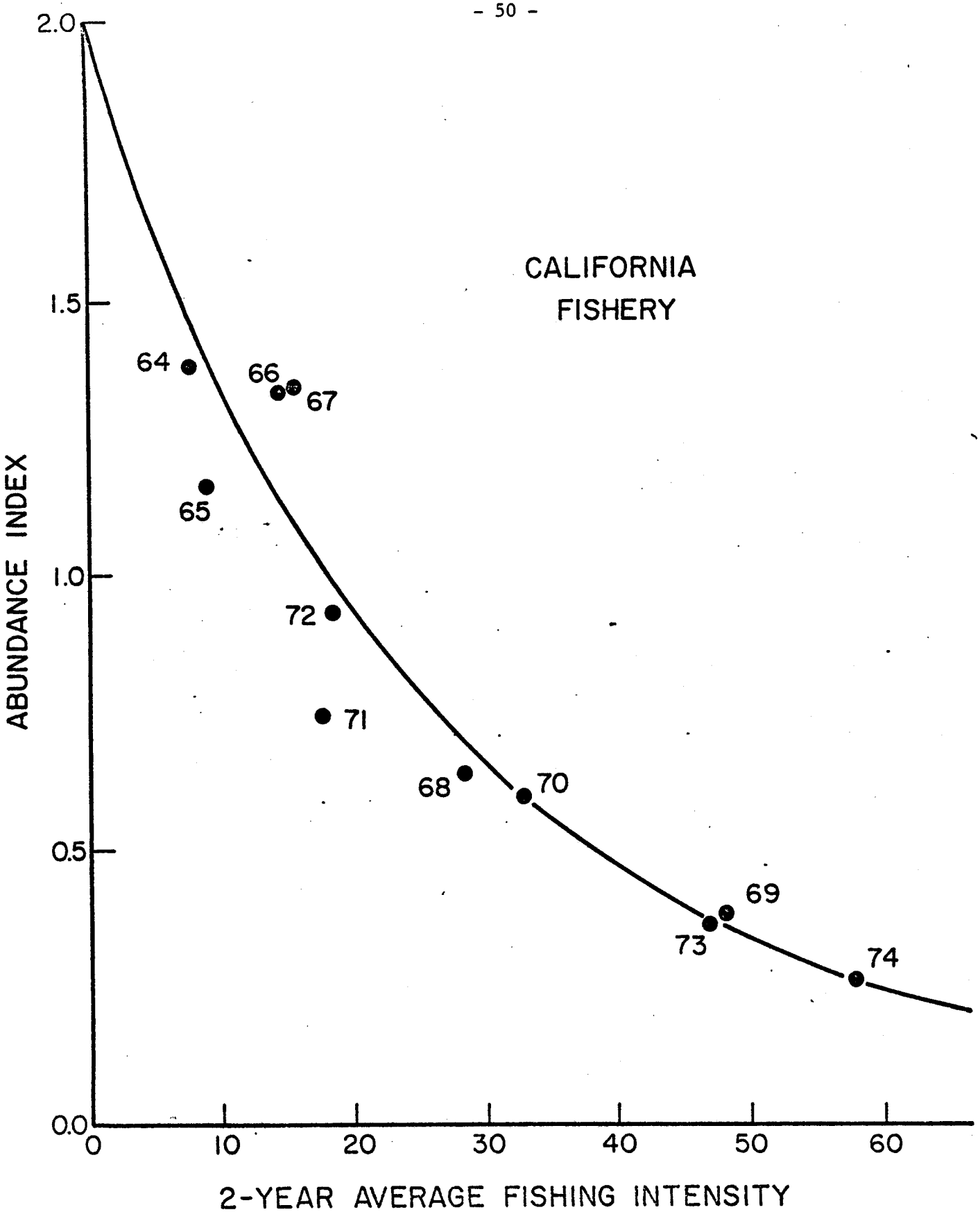

FIGURE 5.2. Production model fit to the California segment of the bonito fishery.

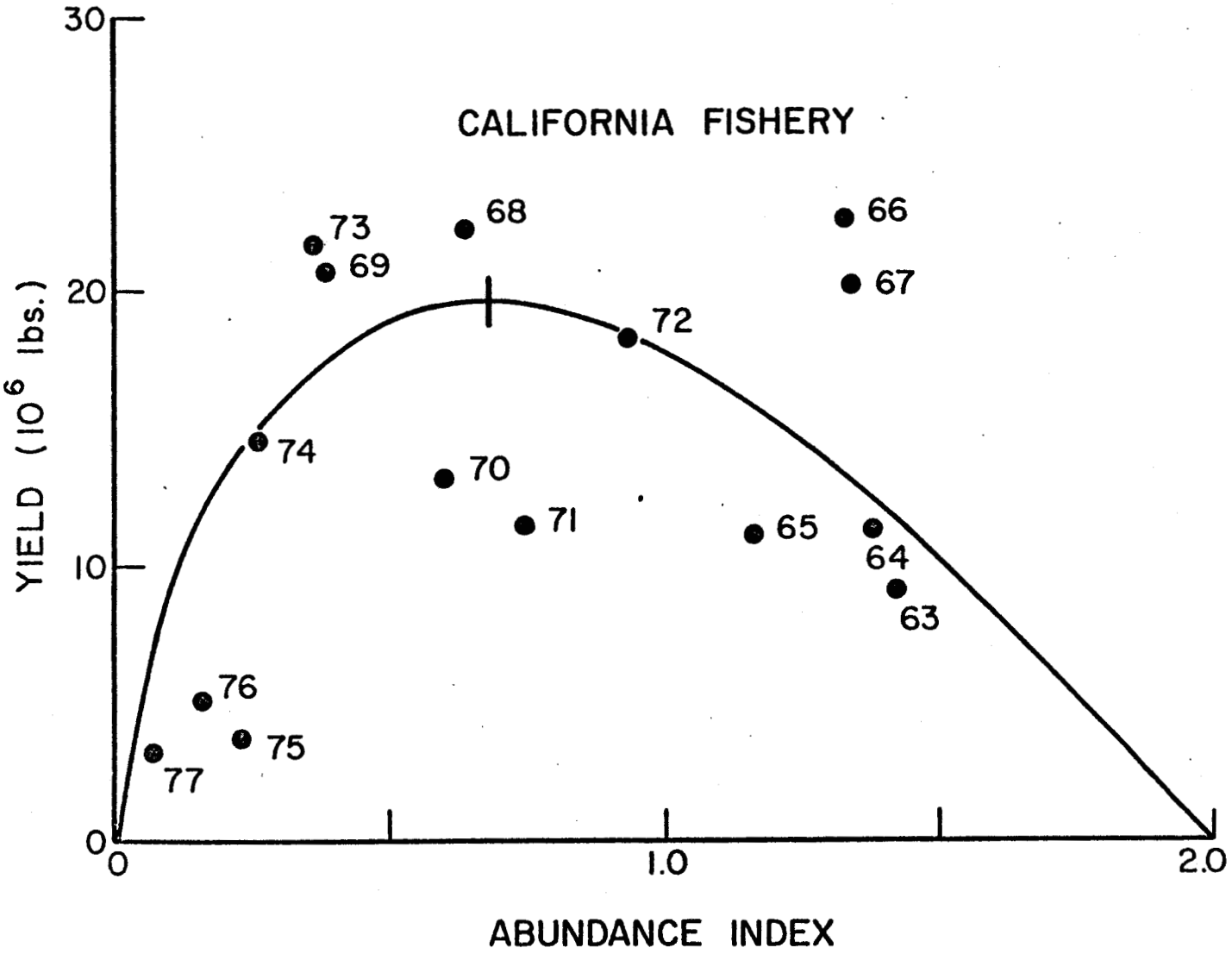

FIGURE 5.3. Equilibrium yield curve for the California segment of the bonito fishery.

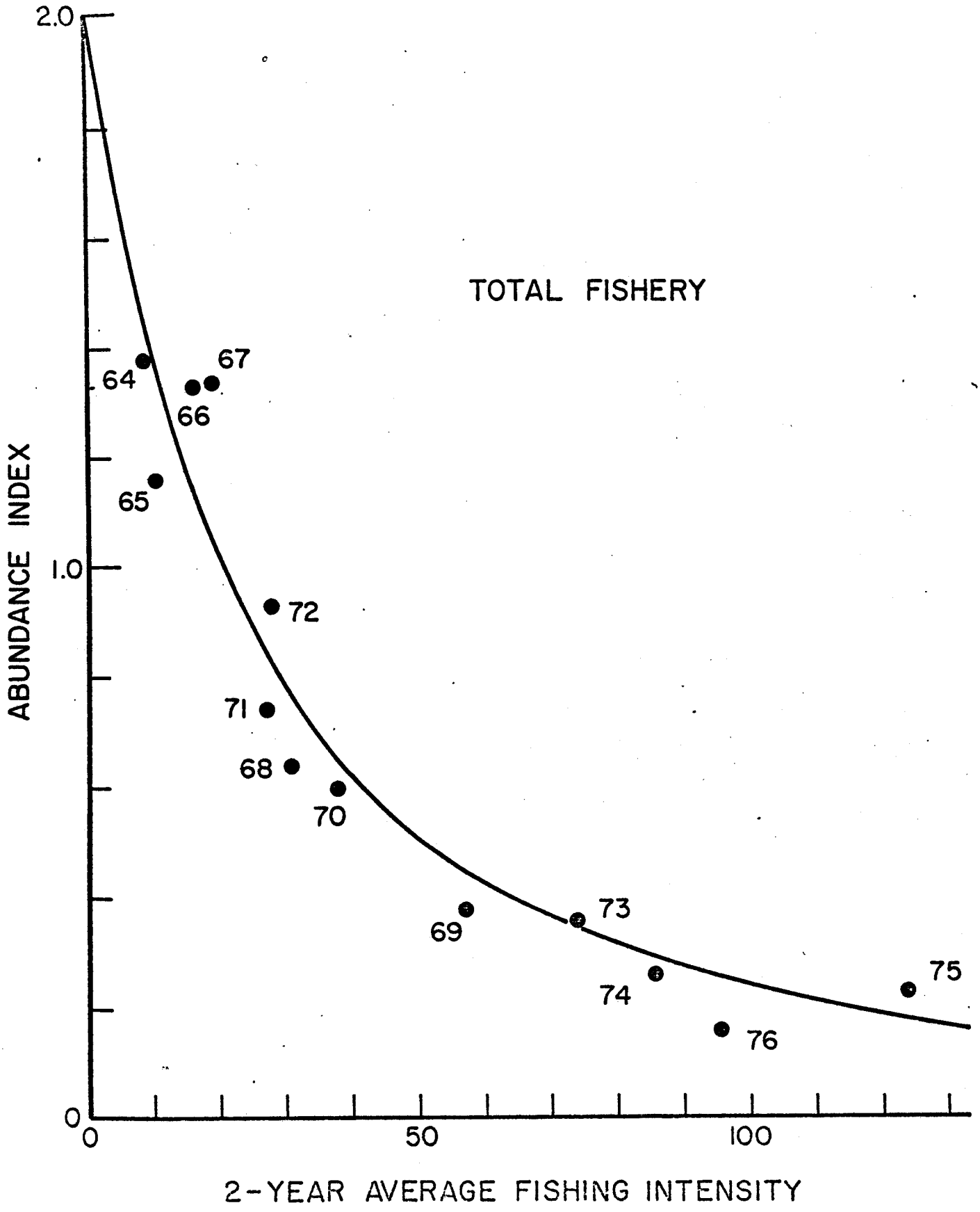

FIGURE 5.4. Production model fit to the total bonito fishery.

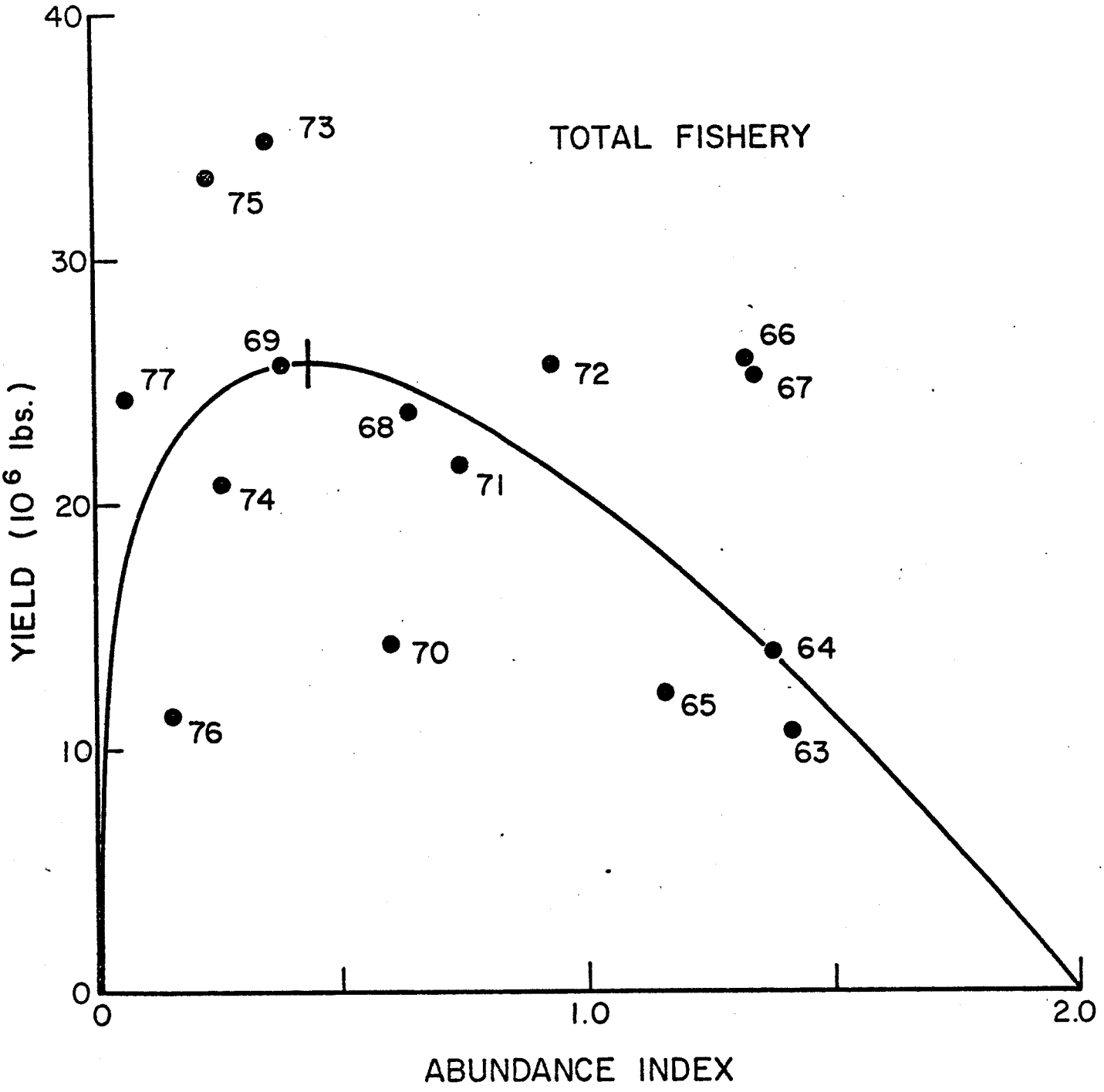

FIGURE 5.5. Equilibrium yield curve for total bonito fishery.

5.1.5 Discussion

The production curves indicate MSY from California waters to be about 10,000 short tons, occurring at a scaled abundance index of 33%. MSY for the total fishery is about 13,000 tons, occurring at an abundance index of 22%. The production curves are skewed, with peak production occurring at less than one half maximum abundance.

As is appropriate, the production curve for California waters, representing a fraction of the stock, lies within the production curve for the total stock. The difference between the curves is not as great as should be expected if the southern segment is large compared to the northern segment. A reason for this inconsistency is the fact that the fishery did not exploit the southern stock heavily until recently (see Table 3.1, Figure 3.1). Thus, the production model tends to reflect the extent of actual fishing which occurred rather than the potential yield which could occur. As a result, this production model may overestimate the southern California equilibrium yield as a proportion of the total equilibrium yield. However, if the fishery in California waters effectively exploits the entire resource, the southern California equilibrium yield would be identical to the total equilibrium yield. This latter case does not seem reasonable based on recent catch history. In addition, violations of the equilibrium assumption may lead to over-estimates of productivity. The model assumes that the abundances

observed are near the true equilibrium abundance for the level of average fishing intensity indicated. The 2-year averaging of fishing intensity is intended to approximate equilibrium conditions. In actuality, the fishery developed so rapidly that the observed abundance probably was higher than the true equilibrium abundance. This bias causes MSY to be over-estimated, and also causes the peak of the apparent equilibrium yield-curve to be shifted toward low abundance. Thus, we strongly suspect that the true equilibrium yield is lower than shown for California waters, and possibly for total catch, and the level of abundance corresponding to any particular equilibrium yield is higher than given by the model. For this reason, yield recommendations arising from literal interpretation of these production curves probably err on the side of over-exploitation. Accordingly, optimum yield is likely to occur at lower catch levels and higher abundances than given by these production models.

Finally, these production models are based on an age structure of commercial catch corresponding to fish age 2 years and older. If the future fishery departs from this average age composition, the predictions of the model will not be accurate, and actual equilibrium yields are likely to be lower than given here. This is an important factor in considering minimum size restrictions to be placed on the fishery.

5.2 Yield per Recruit Models

A yield per recruit model was developed for the bonito

fishery treating the recreational and commercial fisheries as separate competing harvestors. Yield per recruit analyses provide criteria for setting minimum size limits and suggesting levels of exploitation, but ignore the impact of exploitation on the reproductive potential of the stock. Examination of the spawning biomass per recruit provides a means of evaluating the impact of alternative size limits on the relative magnitude of the spawning biomass.

The yield per recruit analysis was done using the computer program MGEAR modified to include spawning biomass per recruit. This program allows for age specific growth rates and fishing and natural mortality rates for multiple gear fisheries. Growth data were taken from Campbell and Collins, 1975 (see section 4.3). Two alternative values for instantaneous rate of natural mortality were assumed, 0.6 and 0.8 (section 4.6). The birth-date of bonito was assumed to be May 1 and age 0 fish were assumed to enter the fisheries in October at 0.42 years of age. The relative magnitude of age specific fishing mortality rates (F vector) were based on the age composition for recreational and commercial fisheries (section 4.5) and in general on a level of F for the recreational fishery equal to 0.1 of the F for the commercial fishery for age 0 and 1. This latter relationship is based on the ratio of recreational catch to commercial catch for the years 1971-1974 (Table 5.2).

Results of the yield per recruit analysis including percent of maximum spawning biomass per recruit are presented in Table 5.4 and 5.5 for size limits of 3 lb, 5 lb, and

TABLE 5.4. Pacific Bonito Yield per Recruit and Spawning Biomass per Recruit for Minimum Size Evaluation.

1) Yield per recruit for commercial fishery in pounds

a) M = 0.8

	F	0.4	0.6	0.8	1.0
Size limit lbs.	7.5	.25	.34	.40	.46
	5.0	.46	.60	.71	.80
	3.0	.61	.79	.92	1.02
	0	.67	.84	.96	1.03

b) M = 0.6

	F	0.4	0.6	0.8	1.0
Size limit lbs.	7.5	.52	.68	.81	.91
	5.0	.80	1.03	1.20	1.32
	3.0	.96	1.20	1.36	1.48
	0	.99	1.20	1.32	1.39

2) Percent of maximum spawning biomass per recruit

a) M = 0.8

F	0.4	0.6	0.8	1.0
7.5	92	90	87	85
5.0	82	76	71	67
3.0	68	58	49	42
0	59	47	37	30

b) M = 0.6

F	0.4	0.6	0.8	1.0
7.5	89	85	82	79
5.0	78	70	65	60
3.0	65	53	45	38
0	56	43	34	26

TABLE 5.5. Percentage Change in Yield per Recruit and Spawning Biomass per Recruit for Minimum Size Evaluations.

1) Percentage change in yield per recruit

a) M = 0.8

	F	0.4	0.6	0.8	1.0
Size limit	0→7.5	-62.8	-60.2	-57.7	-55.4
	0→5.0	-32.5	-28.9	-25.4	-22.2
	0→3.0	- 9.1	- 6.2	- 3.6	- 1.0

b) M = 0.6

	F	0.4	0.6	0.8	1.0
Size limit	0→7.5	-47.4	-42.8	-38.5	-34.0
	0→5.0	-19.5	-14.3	- 9.4	- 4.2
	0→3.0	- 3.3	0	+ 3.3	+ 6.4

2) Percentage increase in spawning biomass per recruit

a) M = 0.8

	F	0.4	0.6	0.8	1.0
Size limit	0→7.5	35.6	92.0	135.6	187.5
	0→5.0	38.8	63.5	92.6	126.9
	0→3.0	15.4	29.9	33.1	43.0

b) M = 0.6

	F	0.4	0.6	0.8	1.0
Size limit	0→7.5	58.6	97.4	143.9	199.6
	0→5.0	38.8	63.5	92.6	126.9
	0→3.0	15.4	29.9	33.1	43.0

7.5 lb[3/]. Generally yield per recruit will decrease by an amount less than 10% for a 3 lb minimum size limit, and spawning biomass per recruit will increase by 15 to 43%. For a 5 lb size limit yield per recruit could decrease by as much as 33% depending on values of F and M but spawning biomass per recruit could increase by 39 to 127%. The increase in spawning biomass per recruit for a 7.5 lb minimum size limit could range from 56 to 200% for a 7.5 lb size limit while yield-per-recruit could decrease by as much as 63%.

Although the stock/recruitment relationship is not known for bonito, the increase of spawning biomass per recruit caused by a minimum commercial size limit should result in greater recruitment, at least with the currently depressed stock size. Thus the reduced yield-per-recruit resulting from a 5 or 7.5 lb size limit will probably be more than compensated for by the concomitant increase in recruitment.

5.3 Status of the Stock

The bonito resource appears to have been overfished beginning with 1973 when the index of abundance first dropped and remained below 25% (Table 5.1). Commercial landings taken in California waters have declined from the maximum of 9,300 tons in 1973 to a little over 1,000 tons in 1977 (Table 3.1). During this period U.S. commercial catches off Mexico increased to a peak of 14,200 tons in 1975 (Table 3.1) and then declined

---

3/ These size limits in pounds are equivalent to the following lengths and ages

1. 3.0 lb, 20 inches FL, 16 months
2. 5.0 lb, 24 inches FL, 2 years
3. 7.5 lb, 27 inches FL, 3 years

to about 3,000 tons in 1978. In 1973 both the aerial day index and the catch per angler index dropped to below one-half of their value observed in the early 1960's and have continued to decline. Commercial landings of bonito caught in southern California in 1977 and 1978 are of fish of the 0 age group. Also the analysis of the production model (section 5.1) confirms the stock has been overfished since 1973. The stock in 1978 continues to be depressed and there are no significant signs of improvement.

6.0 ECONOMIC CHARACTERISTICS

6.1 Value of Landings

In amount and value of landings, bonito are one of the top ten fish landed commercially in California. Bonito have ranked approximately seventh in landings and seventh and eighth in value over the past few years. Bonito have ranked behind the four tuna species (yellowfin, skipjack, albacore and bluefin), and anchovy, jack mackerel and squid in landings and have ranked behind these as well as salmon and rockfish in value. The value of landings increased markedly after 1970, jumping from a previous high value of 0.9 million dollars in 1967 to over 3.9 million dollars in 1975 (Table 6.1). The average value of landings for the period 1971-1977 is 2.6 million dollars. The exvessel price has also been rising in the 1970's. The average exvessel price for the period 1960-1969 ranged from $50-94/ton. The price jumped to $142/ton in 1970 and was approximately $322/ton in 1977[4/].

4/ In 1979, cannery fish brought $580/ton for fish over 4 pounds, and $550/ton for fish less than 4 pounds. Some fish are at canneries and at the San Pedro market for $315/ton. These lower-valued fish weigh less than 3 pounds.

6.2 Processed Bonito Products

Pacific bonito are primarily utilized for canning. An average of six plants canned bonito in the period 1970-1976, when the number of plants fluctuated between 4 and 7 plants. The majority of bonito is canned by the major tuna canneries operating in Terminal Island. One cannery in San Diego also regularly cans bonito. A processor in Port Hueneme canned bonito in 1972 and 1973, but no longer handles this product. Bonito are canned in several different packs (Table 6.2). The greatest quantities are canned solid or chunk in oil, with some canned as flakes in oil. Small amounts of bonito are cured and smoked. There have been from 3 to 11 plants processing smoked bonito during the period 1970 to 1976. These plants have been located in such places as San Diego, Santa Barbara, and Los Angeles. The total amount of bonito processed through canning or smoking has ranged during the period 1970-1976 from 2.814 million lbs in 1970 to a high of 13.088 million lbs in 1973, with the value of processed bonito ranging from 1.5 to 10.0 million dollars for these years (Table 6.2, Table 6.3).

The wholesale price of canned bonito, deflated by the wholesale price index, has fluctuated during the period 1960-1977 (Figure 6.1). The price fluctuations have closely followed those for canned tuna in the past few years. The price spread between tuna and bonito has been fairly consistent over the years, with bonito remaining a lower-priced product.

Small quantities of bonito may be sold fresh or frozen, but there are no recorded figures on this. The offal from the

TABLE 6.1. California Bonito Exvessel Price and Values of Landings.

Year	Landed value	Exvessel price
	($1000)	($/ton)
1960	37	59
1961	218	51
1962	63	59
1963	113	56
1964	66	50
1965	149	53
1966	761	80
1967	891	84
1968	620	83
1969	805	94
1970	651	142
1971	1,841	182
1972	2,056	184
1973	3,202	208
1974	2,512	267
1975	3,895	244
1976	1,253	283
1977	3,759	322

TABLE 6.2. Processed Bonito Products - Quantities in Thousands of Pounds.

Year	Canned, solid in oil	Canned, chunk in oil	Canned, flakes in oil	Cured, smoked fish	Total processed bonito
1970	1,497	1,160	157	41	2,814
1971	92	5,323	138	16	5,553
1972	1,456	4,710	466	12	6,633
1973	2,157	8,396	18	9	10,572
1974	1,664	6,087	38	14	7,789
1975	3,165	9,704	219	13	13,088
1976	1,834	1,449	31	3	3,314
1977[1]	n.a.	n.a.	n.a.	n.a.	7,116

[1] data not available

Source: NMFS, Processed Fishery Products, various annual reports.

TABLE 6.3. Processed Bonito Products - Wholesale Values in Thousands of Dollars.

Year	Canned, solid in oil	Canned, chunk in oil	Canned, flakes in oil	Cured, smoked fish	Total processed bonito
1970	782	567	102	27	1,485
1971	59	3,168	89	9	3,326
1972	1,034	2,778	338	10	4,160
1973	2,016	4,978	9	8	7,011
1974	1,404	4,296	26	20	5,746
1975	2,753	7,159	155	20	10,086
1976	1,663	1,253	25	3	2,944
1977[1]	n.a.	n.a.	n.a.	n.a.	7,733

[1] data not available.

Source: NMFS, Processed Fishery Products, various annual reports.

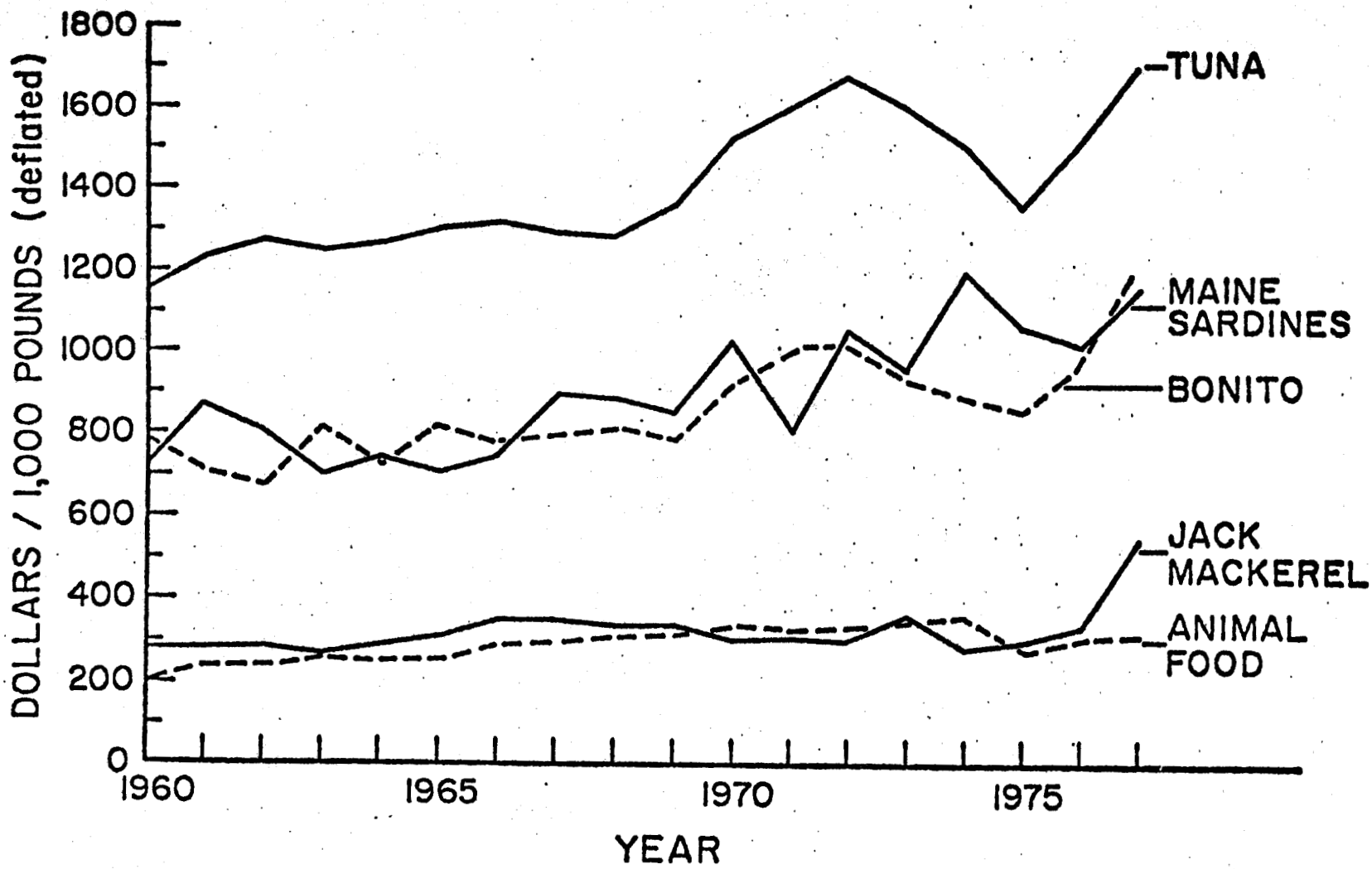

Figure 6.1. Wholesale value (deflated)[1] per 1,000 lbs. of canned fish product.

[1] deflated by Wholesale Price Index, 1977=100.

Source: National Marine Fisheries Service, Current Fisheries Statistics, Canned Fishery Products, Annual Summaries.

canning operations is mostly utilized for pet food and reduction, as is the offal from tuna canning.

6.3 Economics of the Size Limit

Imposition of a size limit for commercial landings has three important effects: (1) it alters the physical and economic yield per recruit, (2) it alters the spawning biomass per recruit, and (3) it may reduce the direct competition for fish by recreational and commercial fishermen. The first of these effects is discussed in detail below, but the latter two also deserve some serious consideration. Because a yield-per-recruit analysis essentially ignores any stock-recruitment relationship, the size limit and fishing intensity chosen on the basis of yield-per-recruit may lead to "recruitment overfishing" (see Cushing, 1973, p. 114). If the level of recruitment is depressed due to fishing, then the economic value is reduced along with the total catch. An explicit incorporation of effects on recruitment in the analysis is not possible, unfortunately, because the relationship of recruitment to spawning stock size is unknown. Nevertheless, it is likely that maintenance of a larger spawning stock will result in a larger average annual recruitment. Since the yield-per-recruit analysis ignores any marginal effect of fishing on recruitment, and because an increase in size limit results in a larger spawning stock per recruit, it is also likely that the economically optimal size limit is somewhat greater than is determined solely through a yield-per-recruit analysis. Thus the size limit for the commercial fishery derived below is a <u>lower limit to the range</u> of size

limits to be considered.

When commercial fishermen take the small fish (less than about 60 cm) that are prevalent in the recreational catch, the total mortality of small fish is increased and, therefore, the abundance of small bonito is reduced. A reduced angler catch rate may result and the reduced catch rate could result in less satisfactory experiences in marine angling. The economic value of recreational fishing and the amount of income generated by the marine recreational fishery in California might, therefore, be improved with a larger size limit on commercially taken bonito. The analysis of this phenomenon has not been carried out due to the paucity of pertinent data. Despite the lack of quantitative results, however, this consideration, like that of recruitment effects, suggests that a size larger than that determined by a strict yield-per-recruit analysis would be beneficial. These comments serve to place the following analysis in proper perspective.

An economics approach to the selection of a size limit for bonito parallels that of the yield-per-recruit analysis in section 5.2 above. The economic value per fish increases with age and size, and the mortality occurring within an age year-class reduces the number of animals in the year-class as the year-class ages. Thus the increasing value per recruit must be balanced against the mortality rate in selecting an optimum size limit. If economic value is given by simply multiplying a constant price times the yield-per-recruit, then the economic size limit would be identical to the yield-per-recruit size limit.

However, two other factors must be considered in the economic approach. First, the percentage yield of fishery product increases with the size of bonito, at least for fish in the range of 1-1/2 to 4 pounds. Also, the amount of labor involved in cleaning and preparing a given quantity of canned bonito is greater when small fish are processed than when large fish are processed. For these reasons, the canners value larger fish more highly and offer a higher price for large fish. In 1979 the canners were paying $580/ton for fish greater than 4 pounds and $550/ton for smaller fish. Also, some bonito less than 3 pounds are sold to non-cannery buyers for $315/ton. If we take into consideration these landed values, rather than the weight per fish, then an economic yield-per-recruit analysis differs from the biological yield-per-recruit.

The second economic concept is that of investment and discounting. In any given year the commercial fishery could take an increased catch and generate an increased economic value if it took smaller fish. In the long run the increased catch of small fish might cause a reduction in annual value of the fishery. Thus the foregoing of the small fish catch involves a trade-off through time. Current value is sacrificed in order to achieve a future value. The economic theory of optimum investment (or capital budgeting) can be used in determining the point at which additional investment no longer is economically useful. In the case of size limits for commercial fish, the analysis of this investment problem has been considered in some detail by Clark (1976, pp. 269-292). The optimum economic

decision is determined by maximizing the present value (PV) of the harvest rather than maximizing the average annual value. Present value is defined as:

$$PV = \sum_{t=1}^{\infty} V_t \, e^{-rt}$$

where V_t is the value of landings in period t, and r is a discount rate. The two keys to understanding this formula are the interpretation of the discount rate and the dependence of annual landings value, V_t, upon the size limit.

The discount rate, r, is seen to be a reflection of the rate of return that the investor could earn by placing the money in a regular investment instrument. If the future payments are risky (that is, may not be paid) then the discount rate used in the calculation of present value should be higher than the rate of return on risk-free investments (see Baumol, 1965, p. 454). A discount rate of $r = 0.1$ is used in the size limit analysis. In applying this discounting feature to the size limit analysis, the value of fish harvested at each age is discounted back to the value at the age of 5 months. This assumes that the fish could be caught at 5 months, but are normally allowed to grow older.

The annual value from the fishery, V_t, depends upon the age at first capture and upon the fishing intensity, just as in the yield-per-recruit analysis. As noted above, the size-varying price comes into play also, because the economic value per pound of bonito varies with the size of the fish. Finally, the discounting procedure requires that the catch from each age cohort

be discounted to reflect the present value at age 5 months. Tables 6.4 and 6.5 summarize the results for the economic yield-per-recruit analysis.

Since the yield varies with the rate of fishing mortality, F, the analysis was performed for a reasonable range of fishing mortality rates. With lower rates of fishing, the ideal size limit is lower than with higher rates of fishing. The discount rate used throughout was 10 percent. In view of the uncertainty regarding the true natural mortality rate, two different rates were used -- .8 in Table 6.4 and .6 in Table 6.5. With the higher mortality rate, the optimum size limit is, naturally, lower than with the higher rate. A final source of uncertainty arises from the market pricing arrangements. The canneries offer only two prices, $375/ton for fish less than 4 pounds and $405/ton for fish greater than 4 pounds. In 1978 some vessels were delivering smaller fish (less than 3 pounds) to the San Pedro "market" for $200/ton. These fish were reportedly bought by pet food manufacturers. The fishermen's union, however, has sought to eliminate the sale of the smaller fish for $200/ton. Thus it is not clear whether a 2-part pricing arrangement or a 3-part pricing arrangement will prevail in the future. The analysis was carried out for both of the possible price structures.

The size limits considered in the work were discontinuous, with dicrete jumps from 1.44 to 2.63 pounds and from 4.17 to 4.43 pounds, because the fish are generally not available in the purse seine fishery during the time (February through June) when the fish pass through these intermediate sizes. A summary of the

Table 6.4. Economic Yield-per-Recruit for Two Different Price Structures and Three Fishing Mortality Rates. Natural Mortality (M) = .6.

Size Limit[1]			3-Part Pricing[2] Fishing Mortality Rate:			2-Part Pricing[3] Fishing Mortality Rate:		
Weight (lbs.)	Length (inches)	Age (months)	.6	.8	1.0	.6	.8	1.0
			dollars per recruit					
.67	14.0	5	.176	.195	.207	.192	.216	.232
.84	14.9	6	.178	.199	.212	.193	.219	.236
1.03	15.8	7	.180	.203	.217	.194	.221	.239
1.23	16.7	8	.183	.207	.223	.194*	.222	.241
2.63	20.9	14	.184	.210	.228	.194	.223*	.243*
2.89	21.5	15	.186*	.214*	.233	.189	.218	.239
3.13	22.0	16	.184	.213	.234*	[For remaining sizes,		
3.41	22.6	17	.177	.206	.228	the economic yield		
3.66	23.0	18	.171	.199	.221	per recruit is the		
3.92	23.5	19	.164	.192	.213	same as for 3-part		
4.17	24.0	20	.155	.183	.204	pricing at left.]		
5.63	26.3	26	.147	.173	.194			
5.86	26.6	27	.139	.164	.184			
6.07	26.9	28	.131	.155	.174			
6.28	27.1	29	.122	.145	.163			
6.47	27.4	30	.114	.135	.153			
6.68	27.7	31	.106	.126	.142			
6.87	28.0	32	.097	.115	.130			
7.9	29.1	38	.089	.106	.120			

1/ Based on same information as used in earlier yield-per-recruit analysis (Sec. 4.7).

2/ Prices are $200/ton, $375/ton and $405/ton for bonito less than 3 lbs., 3 to 4 lbs., and over 4 lbs.

3/ Prices are $375/ton for bonito of less than 4 lbs. and $405/ton for bonito which are greater than 4 lbs.

* Denotes optimum economic size for given natural and fishing mortality rates and for given price structure.

Table 6.5. Economic Yield-per-Recruit for Two Different Price Structures and Three Fishing Mortality Rates. Natural Mortality (M) = .8.

Size Limit[1]			3-Part Pricing[2] Fishing Mortality Rate:			2-Part Pricing[3] Fishing Mortality Rate:		
Weight (lbs.)	Length (inches)	Age (months)	.6	.8	1.0	.6	.8	1.0
			dollar per recruit					
.67	14.0	5	.123	.141	.152	.138	.159	.175
.84	14.9	6	.125	.143	.155	.138*	.160	.176
1.03	15.8	7	.126	.145	.158	.138	.160*	.177
1.23	16.7	8	.127	.147	.161	.134	.160	.177*
2.63	20.9	14	.127*	.148	.164	.135	.159	.177
2.89	21.5	15	.127	.149*	.166*	.130	.153	.171
3.13	22.0	16	.124	.146	.164	[For remaining fish sizes the values are the same as those at left.]		
3.41	22.6	17	.117	.139	.156			
3.66	23.0	18	.110	.131	.148			
3.92	23.5	19	.104	.124	.140			
4.17	24.0	20	.095	.114	.129			
5.63	26.3	26	.088	.105	.119			
5.86	26.6	27	.081	.098	.111			
6.07	26.9	28	.075	.090	.103			
6.28	27.1	29	.068	.082	.094			
6.47	27.4	30	.062	.075	.086			
6.68	27.7	31	.056	.068	.078			
6.87	28.0	32	.050	.060	.069			
7.9	29.1	38	.044	.053	.061			

1/ Based on same information as used in earlier yield-per-recruit analysis (Sec. 4.7).

2/ Prices are $200/ton, $375/ton and $405/ton for bonito less than 3 lbs., 3 to 4 lbs., and over 4 lbs.

3/ Prices are $375/ton for bonito of less than 4 lbs. and $405/ton for bonito which are greater than 4 lbs.

* Denotes optimum economic size for given natural and fishing mortality rates and for given price structure.

conclusions for economically optimal size limits on commercial catch appears in Table 6.6. In using these results it should be remembered that the derivation of these values took no account of the possible benefits to recruitment or recreation of a larger size limit. Also, Tables 6.4 and 6.5 allow a computation of the percentage gain or loss caused by a size limit other than the nominal optimum. With M = .8 and F = .6 and 3-part pricing, for instance, an increase in size limit from 2.89 to 4.17 (i.e. approximately 3- to 4 lbs), results in a 16 percent reduction in economic yield-per-recruit. It is not known to what extent such a reduction in value per recruit would be compensated by the increased spawning biomass and the increased availability of small fish to the recreational fishery.

TABLE 6.6. Size Limits to Maximize Economic Yield-per-Recruit for Various Values of Fishing Mortality (F), Natural Mortality (M) and Prices.

	Natural Mortality = .8		Natural Mortality = .6	
	3-part pricing	2-part pricing	3-part pricing	2-Part pricing
	-------pounds---------		-------pounds---------	
F = .6	2.6	.8	2.9	1.2
F = .8	2.9	1.0	2.9	2.6
F = 1.0	2.9	1.2	3.1	2.6

7.0 MANAGEMENT OPTIONS

7.1 Alternatives Considered

In developing the detailed management options presented below in sections 7.2 and 7.3, a wide range of alternative measures was considered. These measures were:

1. Maintain the status quo
2. Revise U.S. yellowfin tuna regulations
3. Closed seasons for commercial fishing
4. Closed areas for commercial fishing
5. Bag limits for recreational fishing
6. Size limits for commercial harvest
7. Annual commercial catch quotas

Rationales for either discarding or further pursuing each of these alternatives are summarized in this section.

The consideration of possible management measures was undertaken with the premise that restrictions placed on each fishery segment ought to be proportional to the impact of that segment on the stock. Severe restriction of the take of a minor fishery segment will produce only a minor impact on the stock, while moderate restriction of a major fishery segment could produce a major effect.

Currently, roundhaul nets, chiefly purse seines, are responsible for 95% of the impact on the bonito resource. Other commercial fishery segments; gill nets, trollers and hook and line fishermen account for about 3%, and recreational fishermen about 2% of the total impact.

7.1.1 Status Quo

Present lack of management regulations has resulted in a depressed level of bonito abundance in the southern California area. Yet the bonito stock is important to the recreational fisheries (sec. 3.3) and is commercially valuable (sec. 6.1). If any effective management measures can be instituted to encourage the re-building of this stock of fish, then the status quo is not an acceptable alternative.

7.1.2 Revise U.S. Yellowfin Tuna Regulations

Section 3.1.4 discusses the linkage between the tropical tuna fleet and the bonito fishery. It is shown that a significant portion of the bonito taken from southern Baja California waters is caught by tropical tuna purse seiners from San Pedro and San Diego. Some of the bonito is taken by tuna vessels fishing under a yellowfin tuna incidental catch regulation. The elimination of bonito from the species which are included in the total catch for purposes of calculating the percent of yellowfin in catch would presumably reduce the incentive for catching bonito during tuna fishing trips. The analysis of bonito and yellowfin catches summarized in Table 3.3, however, indicates that bonito are fished largely for their market value and not because of the yellowfin regulations. Thus we have concluded that revisions to yellowfin regulations would not effectively control bonito fishing by tuna vessels.

7.1.3 Closed Seasons

Commercial fishing for bonito occurs primarily in the months of July through January. The fish are rarely available to the fleet during the remaining 5 months of the year. Any season closure to control annual harvest must close some of the months in which fish are readily available to the fleet. Examination of the monthly catches in Table 3.2, however, reveals that there is no stable pattern of the fishery during the 7-month season. Monthly catch for July, for instance, varied from 1% to 36% of the annual total during the period of 1972 through 1976. Thus the effect of a time closure on the annual catch would be highly unpredictable. This unpredictability renders a seasonal closure an unreliable management measure.

7.1.4 Area Closures

Area closures might be used to either reduce total catch or to prevent the capture of smaller fish in nearshore areas. The distribution of schools sighted by aerial spotters (sec. 3.1.3) indicates that the bonito schools sought by commercial vessels in southern California are widely dispersed along the coast from Point Conception to San Diego. Also, many of the schools exploited by the U.S. fleet are in southern Baja California waters. No specific areas appear to be sufficiently important to the fleet that a closure would effectively limit the annual catch. Confrontations between recreational and commercial fishermen indicated by complaints

to the Department do not appear to be widespread or consistent enough to warrant closures for the purpose of reducing conflict.

7.1.5 Bag Limits

Because the recreational catch is occasionally large enough to be a significant source of mortality, a limit to catch by anglers may be an important management measure when bonito stocks are depressed. In most years the recreational catch is so much smaller than commercial catch that control over total mortality can only be exercised through commercial catch regulation. Also, recreational fishermen catch smaller fish which are more abundant than the larger, spawning fish. Nevertheless, during years of exceptionally low bonito abundance, a reduced bag limit for recreational fishermen can be an important management measure. An option for reducing the bag limit is discussed below in Section 7.3.

7.1.6 Size Limits

As noted in both Sections 5.3 and 6.3 a size limit on commercially landed fish can have an effect on the yield-per-recruit in both physical and economic terms. Reproductive potential of the stock is enhanced if the young adults are allowed to spawn at least once. Further, if the size limit is above the size at which recreational fishermen take bonito, this option can be used to reduce direct competition for fish between recreational and commercial fishermen. A size limit on the recreational

fishery though, would essentially eliminate any sport catch since fish over 60 cm (24 inches) are seldom caught. Such a severe restriction on the recreational take seems unwarranted in view of the impact of this fishery segment on the resource, and we have evaluated the effect of a 50% reduction in the allowable individual take when the stock is at a low level in its stead. The analysis of various size limits suggests that the degree of potential impact is great enough to make this useful for managing the stock. Also, the enforceability and acceptability of size limit regulations makes this a promising management tool. Suggested alternatives are discussed below in Section 7.2.

7.1.7 Catch Quotas

Catch quotas represent the most direct and effective control over total mortality in the bonito stock. Any serious attempt to improve the abundance of bonito in southern California must seek to reduce fishing mortality. There are various ways to formulate and alter catch quotas for commercial fishing. Some alternatives are discussed in Section 7.3.

7.2 Size Limits

Four alternative minimum size limits are evaluated for the commercial fishery. A minimum size limit for the recreational fishery is not considered because this would eliminate any sport catch since fish age 2 or older are seldom caught. The four limits for the commercial fishery are: 1) no limit (status quo),

2) 3.0 lb minimum size, 3) 5.0 lb minimum size, and 4) 7.5 lb minimum size.

Size Limit Option 1. No minimum size limit (present conditions).

Discussion: This option allows the commercial fishery to exploit bonito of all sizes. Historically the commercial fishery has taken fish predominantly 5 lbs and larger, but in recent years, as the abundance has declined, the size of the fish taken has shifted towards smaller fish.

This option results in the largest yield-per-recruit of the four options considered (0.84 to 1.32 lbs per recruit). The commercial value-per-recruit is $0.12 to 0.22 per recruit and the spawning biomass-per-recruit is relatively low at 34 to 47% of potential maximum. Although the yield-per-recruit value declines when a minimum size limit is imposed, increases in spawning biomass per recruit and economic value per recruit suggest that the commercial yield would be enhanced if the average size of landed fish could be shifted towards larger fish (Table 7.1).

Size Limit Option 2. No fish under 3 lbs (50 cm or 20 inches FL).

Discussion: A 3 lb limit would delay commercial exploitation until 16 months of age. The yield-per-recruit though, could be as much as 6% lower than the no limit option. Spawning biomass would increase to 45 to 58% of maximum, a 30 to 33% gain over Option 1 even though bonito do not spawn until 24 months of age. Incidental catch of bonito less than 3 lbs would likely be a problem because bonito attain 3 lbs in the midst of a fishing season so that some seine hauls may have high percentage of bonito just under 3 lbs.

TABLE 7.1. Summary of the Effect of Size Limit Options

	Option	1	2	3	4
	Minimum size	None (present condition)	3 POUNDS (50 cm or 20 inches)	5 POUNDS (60 cm or 24 inches)	7½ POUNDS (68 cm or 27 inches)
	INCIDENTAL OCCURRENCE OF SUBLEGAL FISH IN CATCH		POTENTIALLY LARGE NUMBERS OF SUBLEGAL FISH	SMALL NUMBERS OF SUBLEGAL FISH	LARGE NUMBERS OF SUBLEGAL FISH
(2)	YIELD PER RECRUIT[1/]	0.84-1.32	0.79-1.36	0.60-1.20	0.34-0.81
	(Change from option 1)	(0)	(-6 to +3%)	(-29 to -9%)	(-60 to -38%)
(3)	NUMBER OF SPAWNING SEASONS BEFORE CAPTURE	0	0	1 (Partial)	2
(4)	SPAWNING BIOMASS PER RECRUIT[1/]	34 to 47	45-58	65-76	82-90
	(Percent of maximum)	(0)	(30-33%)	(64-93%)	(92-144%)
(5)	COMMERCIAL VALUE ($) PER RECRUIT[1/]	0.12-0.22	0.12-0.21	0.09-0.15	0.04-0.09
(6)	RELATIVE POTENTIAL VALUE OF COMMERCIAL CATCH[2/]	1.0	1.30-1.33	1.23-1.32	0.64-1.0

[1/] Range of values for M = 0.8, F = 0.6; M = 0.6, F = 0.8 from Tables 5.3 and 5.4.

[2/] Value per recruit times estimated increase in spawning biomass from row 4 above, divided by value for no size limit, value per recruit is from Table 5.5 for F = 0.8 and a 3-part price structure.

The commercial value per recruit would be about the same as the previous option. The potential value of the catch, taking into account increased spawning biomass per recruit, would be 30 to 33% greater than under the no minimum size limit option.

Size Limit Option 3. No fish under 5 lbs (24 inches or 60 cm TL).

Discussion: A 5 lb size limit delays exploitation until bonito reach sexual maturity. The growth rate at this age is less than the mortality rate; consequently the yield-per-recruit could be 9 to 29% less than that for the no size limit alternative. On the other hand spawning biomass-per-recruit may be 65 to 76% of maximum, a 64 to 93% increase from the no limit alternative. The commercial value per recruit decreases to $0.09 to 0.15/lb per recruit. The potential value of the catch would be 23 to 32% greater than the no limit alternative and only slightly less than the 3 lb alternative. In addition, the recovery of the stock would be facilitated more than under Option 2.

Size Limit Option 4. No fish under 7.5 lbs (27 inches or 68 cm TL).

Discussion: This fourth alternative size limit allows bonito a second year to spawn before exploitation. The yield-per-recruit will fall to 0.34 to 0.81 lbs, a 38 to 60% decrease from no size limit. Spawning biomass will be as much as 82 to 90% of maximum, an increase of 92 to 144% over the no limit alternative. The commercial value per recruit would be as low as $0.04 to 0.09/ recruit. The potential value of the catch relative to no size limit would be 0.64 to 1.0, considerably less than alternative 2 and 3. We would expect that incidence of sublegal bonito to be higher for the 7.5 lb alternative limit than for the 5.0 lb

alternative. Size-age modes are not well defined above 5 to 6 lbs and therefore a minimum size limit of 7.5 lbs would probably result in a relatively high percentage of incidentally caught undersize fish in purse seine sets. However, this option would give the most rapid recovery of the stocks.

7.3 Quotas and Bag Limits

The recent history of the bonito fishery has demonstrated that some limitation on harvests is necessary to prevent severe over-exploitation of the resource. The 1977 level of scaled abundance (Table 5.1) was 4%, far below the level producing maximum equilibrium yield (Figure 7.1), and farther below optimum abundance with respect to benefits derived from the various fishery segments.

Maximum gross commercial revenue of bonito catches would be achieved by maintaining the stock at the level which produces the MSY. At greater stock levels, however, angler catch rates would be higher, cost per ton of making the commercial catch would probably be lower, and risk of resource depletion would be reduced. Thus combined benefit is obtained by maintaining abundance at a higher level than that producing MSY. To do this the annual quotas must average less than MSY.

Quota Option 1. No quota (present conditions).

Discussion: This has resulted, and will continue to result in low abundance, and low and unstable yields. This is a condition of severe overfishing and there is no prospect of recovery. Both commercial and recreational fisheries will continue to

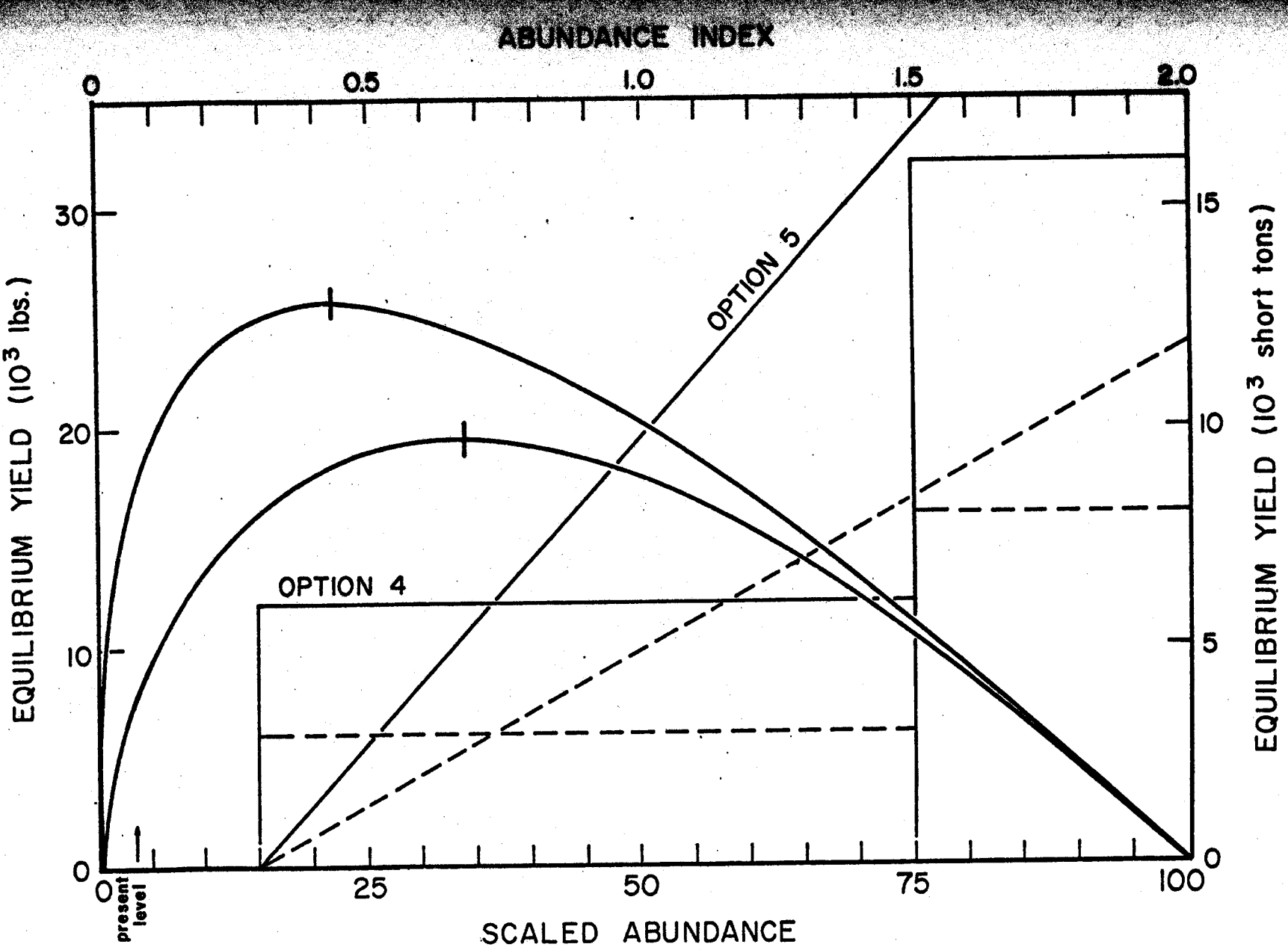

FIGURE 7.1. California (lower) and total fishery (upper) equilibrium yield curves, with comparison of variable quota options. Solid line is total area quota; dashed line is U. S. waters quota.

decline, making this option not a viable alternative (Table 7.2).

Quota Option 2. High level constant quota: Quota is 10,000 tons, not more than 6,000 tons to be taken from California waters.

Discussion: Due to large catches being allowed at very low levels of abundance, this option differs very little from the previous option in its benefits. Only if abundance were in the range of 50-100% would this be a viable option. Under present conditions of low abundance risk of overexploitation would remain high.

Quota Option 3. Low level constant quota: Quota is 6,000 tons, not more than 3,000 tons to be taken from U.S. waters.

Discussion: Recovery of the stock would be uncertain because of present low abundance. If the population were to increase due to favorable environmental factors, this option would allow a fishery to be maintained over long periods. Abundance would be highly variable with long periods of high abundance (ca. 75%) alternating with long periods of low abundance (less than 10%).

Quota Option 4. Step changes in quota: Quota is 0 if abundance is less than 15%. If abundance is between 15 and 75%, quota is 6,000 tons, not more than 3,000 tons to be taken from U.S. waters. If abundance is above 75%, quota is 16,000 tons, not more than 8,000 tons to be taken from U.S. waters.

Discussion: This option would result in rehabilitation of both fisheries segments due to the limitation on fishing at low levels of abundance. The stabilizing influence of high quotas at high abundance and low quotas at low abundance would result in decreased likelihood of extremely high or low abundances.

TABLE 7.2. Summary of the Effect of Quota Options.

OPTION NUMBER	1	2	3	4	5
TYPE OF QUOTA	NO QUOTA	HIGH LEVEL CONSTANT	LOW LEVEL CONSTANT	LEVEL OF QUOTA DEPENDENT ON STOCK SIZE[1/] STEP CHANGES	LEVEL OF QUOTA DEPENDENT ON STOCK SIZE[1/] CONTINUOUS CHANGE
Description	Present conditions	6,000 tons California 10,000 tons Total	3,000 tons California 6,000 tons Total	No fishing when stock size index less than 15% of maximum 3,000 tons California 6,000 tons Total when stock is between 15 and 75% of maximum 8,000 tons California 16,000 tons Total when stock is above 75% of maximum	Quota equals 28,000 tons multiplied by the stock size index minus 0.15[2/] of which not more than 60% can be taken from California.
Effect on Average Abundance of Stock	Low stock size and low average recruitment with large variability.	Low stock size and low average recruitment with large variability.	Slowly increasing stock size in Baja California waters, no increase in California waters and low recruitment.	Average abundance equal to 40 to 75% of maximum size, stock size relatively stable with high average recruitment.	Average abundance equal to 60% of maximum size, stable stock size with high average recruitment.
Future Average Yield	Low and very unstable	Low and unstable	Low but relatively stable ca 2,000 tons California 5,000 tons Total	ca 3,000 tons California 6,000 tons Total	ca 6,000 tons California 12,000 tons Total
Effect on the Rehabilitation of Stock	None	None	Uncertain	Both parts will recover	Both parts will recover
Effect on sportfishery	Continued decline	Continued decline	Relatively little effect	Slow recovery	Slow recovery

1/ If stock size index is less than 15 sport bag limit reduced to 5 fish.
2/ Stock size index is expressed as a fraction of the maximum.

Management can expect administrative difficulties when abundance is near transitional levels (Figure 7.1, Table 7.2).

Quota Option 5. Continuously variable quota: Quota is 0 if abundance is less than 15%. Quota is 28,000 tons times the scaled abundance in excess of 15%, not more than one half to be taken from U.S. waters.

$$\text{Quota} = 28{,}000 \text{ tons} \times \left(\frac{\text{abundance} - 15\%}{100\%} \right)$$

Discussion: Effects would be similar to the previous option; rehabilitation of both fisheries would result. Quotas would be smaller than option 4 in the range of 15 to 35%, but would exceed option 4 for abundances over 35%. The greatest stability of the stock would be expected from this option, and abundance is expected to average from 50 to 65% (Figure 7.1, Table 7.2).

Recreational Fishing Bag Limit: When abundance is less than 15%, the recreational bag limit is 5 fish per day. Above 15%, the bag limit is 10 fish per day.

Discussion: Although the recreational fishery is responsible for only a small portion of the total fishing mortality, recovery from low levels of abundance could be enhanced by reduced levels of recreational catch. A drawback of this option is that a reduced daily bag limit may result in lower abundance index values. This bias could be corrected by Fish and Game observers and by comparison with the aerial index of abundance.

7.4 Discussion of Management Options

The four objectives of this plan can be achieved in a balanced manner only by adopting a combination of size limit

and quota options. Combinations can be examined by means of a table, with quota options as rows and size limits as columns. For some pairs, the impact is insufficient to achieve the objectives, and others would result in unnecessary restrictions. For purposes of examining objectives, reestablishment of the southern California bonito stock and enhancement of southern California recreational catch can be considered in the same table (Table 7.3). Enhancement of long term commercial yield is considered separately in Table 7.4, although this objective is also partially dependent on reestablishment of the southern California bonito stock. The fourth objective, reduction of conflicts, will be addressed separately.

Each combination of the options is given a subjective score with respect to accomplishing the bonito management objectives adopted in this document. A "---" score represents no change from the present status. A "+" score suggests a positive step. A "0" score is an intermediate but ineffective step.

In general, with no quota, the recreational fishing success and the long term commercial yield is increasingly enhanced as the size limit increases. The same can be said for quota options going from option 1 (no quota) to option 5 under no minimum size limit. The combination of other size limit options with other quota options complement each other. With the 3 lb minimum size option, the scores for the quota options improve with a "+" score given only to option 5 for enhancing commercial yield and options 4 and 5 for enhancing recreational fishing success.

TABLE 7.3. Evaluation of Combinations of Size Limit and Quota Options[1/] for Enhancing Recreational Fishing Success[2/].

Quota options	Size Limit Options: No size limit	3 pound	5 pound	7.5 pound
None	---	--	-	+
High constant	--	-	0	+
Low constant	-	-	0	++
Step changes	0	+	++	+++
Proportional changes	0	+	++	+++

1/ Based on a 7 point scale from a low of "---" to a high of "+++". A value of "---" represents no change from the present condition.

2/ An evaluation of combinations of size limit and quota options for the objectives of rebuilding the stock is essentially the same as for enhancing recreational fishing success.

TABLE 7.4. Evaluation of Combinations of Size Limit and Quota Options for Enhancing Long Term Commercial Yield[1/].

Quota options	Size Limit Options: No size limit	3 pound	5 pound	7.5 pound
None	---	--	-	+
High constant	--	-	0	+
Low constant	-	0	0	0
Step change	0	0	+	-
Proportional change	+	+	++	-

1/ Based on a 7 point scale from a low of "---" to a high of "+++". A value of "---" represents no change from the present condition.

With the 5 lb minimum size option, a negative score remains only for the no quota option. With the 7.5 lb minimum size, all quota options have a positive score for enhancing recreational fishing success. For commercial yield options 4 and 5 were given "-" scores because implementation of both size limitations and quotas will reduce commercial catches.

Recreational and commercial fishermen compete for the same resource, making some conflict inevitable. Before 1975 actual conflict was slight because the commercial fishery took larger fish than those caught by most recreational fishermen. Since 1975 the commercial fishery was shifted to younger fish, competing directly with the recreational fishery (Figure 4.2). Enactment of a 5 lb minimum size would return the fishery to pre-1975 levels of conflict, while smaller minimum sizes would do little to reduce conflict. There has also been indirect conflict due to the influence of overfishing on the level of recruitment and hence on recreational catch rates. This conflict cannot be eliminated, but an optimum solution can be achieved by balancing the degree to which the commercial and recreational fisheries are enhanced.

The last option that needs to be considered is a bag limit on the recreational catch. For options 4 and 5 in years when the annual quota would be zero, the bag limit could be lowered to 5 fish. This would temporarily reduce recreational success but should enhance stock rebuilding.

Re-establishment of the stock in southern California has been the major consideration in this evaluation because the

stock is currently depressed. All segments of the fishery will benefit from a more abundant resource. The difficult issues for policy, however, concern the rate of rebuilding, the degree of risk that is acceptable, and the distribution of benefits among user groups. By judicious choice among the options discussed here, a variety of positions can be established with respect to these issues. The greater the size limit, for instance, the more benefit is provided the recreational sector while difficulties are imposed upon commercial fishermen. The higher the quotas adopted, the slower the stock rebuilding and the greater the risk of continued stock depletion. A final reconciliation of the management options involves social, political and legal considerations which must be thoroughly incorporated by decision-makers before adoption of a management plan.

Other issues not considered in this document should be addressed before management regulations are drafted for legislation. These are:

1) allowances for incidental catch by commercial fishing gear other than purse seiners. Bonito are frequently taken in small amounts by trollers and gill netters. The amount of bonito landed by these vessels should be specified, particularly in years with a zero quota or after a quota is filled. No allowance of incidental catch by purse seiners after quotas are filled for the year is necessary.
2) allowance for incidental catches of sublegal fish if a minimum size limit is implemented.

3) the accounting year for the quota has not been specified. The starting date should be consistent with start of the historical fishing season and compilation of data for measure of abundance and status of the resource.

8.0 REFERENCES

Alverson, D. L. and M. J. Carney. 1975. A graphic review of the growth decay of population cohorts. J. Cons. Int. Explor. Mer., 36(2):133-143.

Bakun, A. 1973. Coastal upwelling indices, west coast of North America, 1946-71. NOAA Tech. Rept., NMFS SSRF-671.

Baumol, William J. 1965. Economic theory and operations analysis, 2nd Ed. Prentice-Hall, Englewood Cliffs, New Jersey.

Beverton, R. J. H. and S. J. Holt. 1959. A review of the lifespan and mortality rate of fish in nature, and their relation to growth and other physiological characteristics. IN Ciba foundation Colloquia on Ageing, Vol. 5, The life span of animals. :142-177.

Black, Glenn. 1979. Maturity and spawning of the Pacific bonito, *Sarda chiliensis lineolata*, in the Eastern North Pacific. Calif. Dept. Fish and Game. Mar. Resour. Tech. Rpt. (41): 1:60.

Clark, Colin. 1976. Mathematical Bioeconomics. The optimal management of renewable resources. John Wiley and Sons, New York.

Campbell, Gail and Robson A. Collins. 1975. The age and growth of Pacific bonito, *Sarda chiliensis*, in the Eastern North Pacific. Calif. Fish Game, 61(4):181-200.

Collette, Bruce B., and Labbish N. Chao. 1975. Systematics and morphology of the bonitos (Sarda) and their relatives (Scombridae, Sardini). U. S. Fish. Bull., 73(3):516-625.

Croker, R. 1931. Sport fishing in southern California. Calif. Fish Game, 17(3):339-340.

_____. 1939. Three years of fisheries statistics on marine sport fishing in California. Amer. Fish. Soc., Trans., 69:111-118.

_____. 1941. A fishing record. Calif. Fish Game, 27(1):40-41.

DeVildoso, A. C. 1960. Estudios sobre la reproduccion del bonito *Sarda chiliensis* (C.y V.) en aguas adyacentes a la costa Peruana. Direccion de Pesqueria y Caza, Lima Serie de Divulgacion Cientifica 14.

Frey, Herbert W. (ed). 1971. California's living marine resources and their utilization. Calif. Dept. Fish and Game, Sacramento. 148.

Klawe, W. L. 1961. Notes on larvae, juveniles, and spawning of bonito (Sarda) from the Eastern Pacific Ocean. Pacific Science, XV (4):487-493.

Lenarz, W. H., W. W. Fox, Jr., G. T. Sakagawa and B. J. Rothschild. 1974. An examination of the yield per recruit basis for a minimum size regulation for Atlantic yellowfin tuna, *Thunnus albacares*. Fish. Bull. 72(1):37-63.

MacCall, A., G. Stauffer, and J. Troadec. 1976. Southern California recreational and commercial fisheries. Mar. Fish. Rev., 38(1):1-32.

Oliphant, Malcolm S. 1971. Pacific bonito food habits: 64-82 IN Food habits of albacore, bluefin tuna, and bonito in California waters. Calif. Dept. Fish and Game, Fish. Bull., (152):1-105.

Pinkas, Leo. 1961. Descriptions of postlarval and juvenile bonito from the Eastern Pacific Ocean. Calif. Fish Game, 47(2):175-188.

Pinkas, Leo, Malcolm S. Oliphant, and Charles W. Haugen. 1968. Southern California marine sportfishing survey: private boats 1964; shoreline 1965-66. Calif. Dept. Fish and Game, Fish Bull., (143):1-42.

Sokolovskii, A. S. 1971. Spawning of the bonito, *Sarda lineolata* Girard, in Californian waters. Izvestiia Tikhookeanskogo Nauchoissledovatel' skogo Instituta Rybnogo Khoziaistua i Okeanografii (Izv. Tinro), Vol. 79. 172-174.

Squire, J., Jr. 1972. Apparent abundance of some pelagic marine fishes off the southern and central California coast as surveyed by an airborne monitoring program. (U.S.) Fish. Bull., 70(3): 1005-1119.

Stauffer, G., A. MacCall, and B. Wahlen. 1975. Fish prices: Historical trends in southern California commercial fisheries. Mar. Fish. Rev., 37(11):22-30.

Thayer, Brian D. 1973. The status of the Pacific bonito resource and its utilization. Calif. Dept. Fish and Game Mar. Res. Tech. Rept., (7):1-13.