CALIFORNIA'S PACIFIC BONITO RESOURCE, ITS STATUS AND MANAGEMENT

Robson A. Collins

and

Alec D. MacCall

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by

ROBSON A. COLLINS AND ALEC MacCALL
Operations Research Branch

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ABSTRACT

Pacific bonito, *Sarda chiliensis*, have become increasingly important to California's sport and commercial fishermen since the early 1960's, but are now showing signs of decline. Recent investigations have revealed much about the bonito's life history and population dynamics.

These recent discoveries have been brought together into a document which will serve as a guide to future management actions.

TABLE OF CONTENTS

ACKNOWLEDGMENT

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INTRODUCTION

The Pacific bonito of California, *Sarda chiliensis lineolata,* is a member of the mackerel-tuna family, Scombridae, and the tribe Sardini, whose taxonomic position is midway between the mackerels and the tunas (Collette and Chao, 1975). It is a pelagic schooling fish found in temperate waters over the Continental Shelf, and has been recorded in the North Pacific Ocean as far north as southern Alaska and as far south as Banderas Bay, Mexico. They are abundant however, only from Point Conception California, to Magdalena Bay in Baja California. The population is centered near Sebastian Vizcaino Bay in Baja California. Here they are their most abundant and are found throughout the year. The population appears to shift seasonally north and south in response to environmental conditions.

Several attempts have been made to separate at the specific level the bonito found off California from the one found off Chile and Peru *(Sarda chiliensis chiliensis)* but so far these studies have failed to demonstrate differences above the subspecific level. There is no doubt however, that the fish found in these two widely separated locations comprise two non-interbreeding populations, since they are separated by almost 5,000 km (3,100 miles) and another bonito species, *Sarda orientalis velox*[1/] occupies the tropical coastal waters in between.

At present, bonito are the subject of both sport and commercial fisheries off California and Baja California. The commercial take has increased rapidly during the last 10 years, while the sport catch has

1/ Synonymised with *S. velox* by Collett and Chao, 1975.

declined. Until recently the bonito resource was considered lightly exploited, and a considerable increase in catch was thought possible (Thayer 1973, Frey 1971, California Fish and Wildlife Plan 1965).

No regulations apply specifically to the commercial take of this species, and only general limits apply to sportfishermen.

FISHERIES

U. S. Commercial Fishery

Pacific bonito have been fished commercially in California waters since at least the beginning of this century. Commercial landings between 1916 and 1975 have varied widely, with a low of 57 Mg (64 tons) in 1956 and a high of 14,500 Mg (15,900 tons) in 1975 (Table 1, Figure 1). 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.

Except for 1975, the bulk of the commercial bonito catch has most recently been taken in California waters within 19 km (12 miles) of shore. However, during a few years (principally between 1943 and 1957) over 50% of the total catch has been taken off Baja California (Table 1). The Baja California catch is generally made between January and August each year between Cabo San Quintin and Cabo San Lazaro. California catches are concentrated in August and September in the Santa Barbara Channel, although some are made earlier in the season between the U.S.-Mexican border and San Onofre. We do not know yet what effect the establishment of exclusive fishery zones (370 km, 200 miles) by the U.S. and Mexico will have on the fisheries.

TABLE 1. Commercial Catch of Pacific Bonito Landed in California by Catch Area, 1916 - 1975.

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 1. Cont.

Year	Total landings *pounds* kilograms	Caught off California *pounds* kilograms	Percent	Caught south of state *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 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

* Preliminary

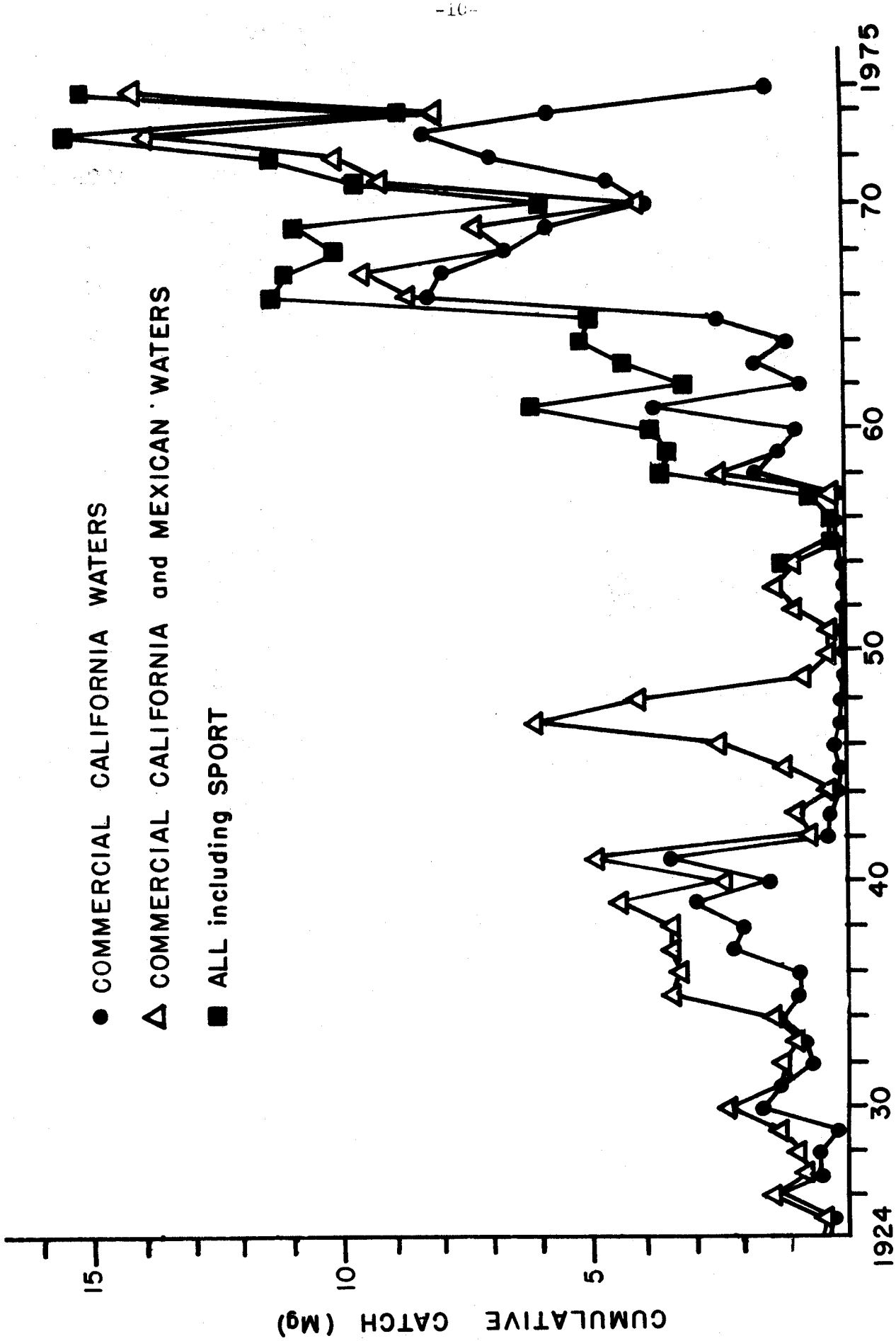

FIGURE 1. Cumulative catch of Pacific bonito by fishery segments, 1924-1975.

Bonito are caught by several types of gear. Chief among these are purse seine vessels which have averaged 94% of the annual landings since 1970. Trollers land about 4% of the catch, while gill netters contribute less than 2% (Table 2).

Vessels from two different fleets participate in the purse seine fishery. These fleets are distinguished by the species towards which the majority of the fleet's effort is directed. The "local wet-fish" fleet is composed of about 35 small purse seine vessels which fish primarily for species such as anchovies and mackerel which are not cooked before canning, therefore being canned "wet". The primary targets of the local fleet are bluefin tuna in the summer (mid May-mid September), and anchovies during the remainder of the year. If the primary targets are scarce or if limits are placed on anchovy deliveries by the canneries, the fleet will turn to bonito as an alternate. This fleet is characterized by relatively small vessels of less than 350 net tons capacity and single day trips.

The "high-seas tuna" fleet fishes primarily for yellowfin and skipjack tuna throughout the eastern Pacific and eastern Atlantic oceans, taking Pacific bonito only to fill out incomplete loads or to make up the 85% of the load required to be other than yellowfin tuna during the period of the year when yellowfin tuna landings are restricted by a quota. About 35 to 40 of these vessels, some of which exceed 2000 net tons capacity, have landed bonito in California. Multi-week fishing trips are routine.

The "troll" fleet fishes primarily for albacore and salmon, taking bonito only incidentally. It is composed of vessels ranging in capacity from 2 to 150 net tons and averaging about 40-50 net tons. Since 1971

TABLE 2. Commercial Landings of Pacific Bonito by Gear Types and Nos. of Vessels Participating 1971-1974.

	Total landings		Roundhaul			Trolling			Entangling nets			Hook and line			Other		
Year	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
AVERAGE 1971-1974	412		71		94.2	167		3.5	57		1.5	58		0.7	59		0.1

between 50 and 300 boats per year from this fleet have landed bonito in California. Catches by other types of gear are incidental, comprising less than 3% of the total catch.

Commercial catches of bonito landed in California have been worth about $3 million per year over the last 6 years. About 54% of these landings have been taken in California waters, amounting to an income of $1.6 million per year. About 1200 commercial fishermen harvest Pacific bonito on more than an incidental basis.

U. S. Sport Fishery

At times bonito have been chief contributors to the southern California marine sport catch (Table 3). In a 1968 survey, southern California partyboat landing 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. In a later report on partyboat catches, he 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," weakening the hypothesis that the low reported catches of bonito were mainly due to angler preference, although a considerable bias against bonito appears to have been shared by many anglers of the time (Radovich CF&G, pers. commun.). Partyboat 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 2). 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

TABLE 3. California Partyboat Reported Catches of Pacific Bonito, 1947-1975.

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	-

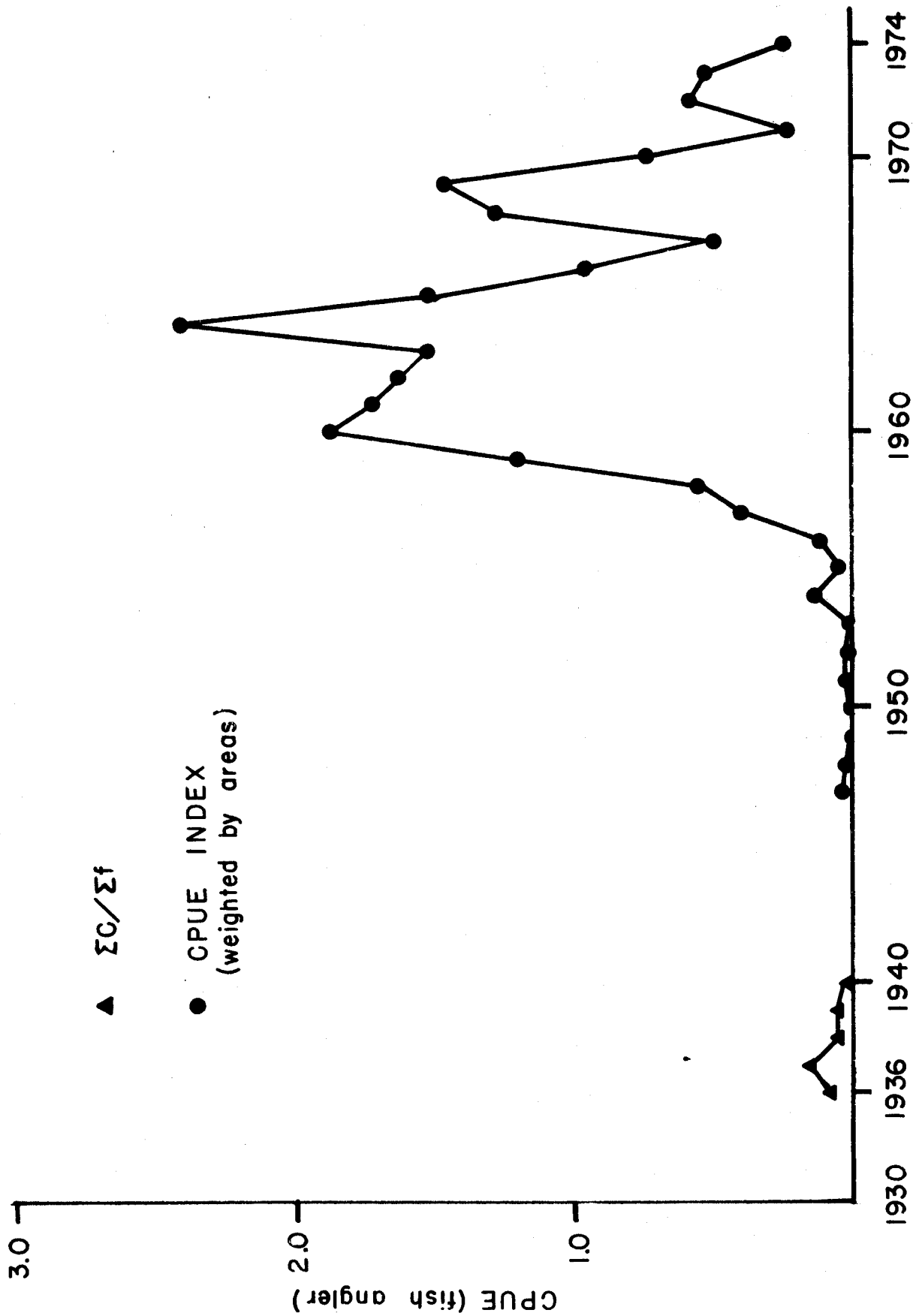

FIGURE 2. Southern California Partyboat CPUE for Pacific bonito, 1930-1974 (effort weighted by area fished)

organisms falling into 35 recorded species and species groups (Croker, 1941). In the early 1940's no sportfishing records were kept, however, Radovich (pers. commun.) recalls occasional good fishing for bonito in the Los Angeles area. When partyboat 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 partyboat 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 however, as water temperatures cooled in the years from 1961 to 1969 (Figures 1, 2). During the 1960's young bonito were abundant inshore and sportsmen landed record numbers. Since 1969 however, the sport catch has fallen drastically.

The sport catch of bonito is generally confined to southern California waters, although some are caught north of Point Conception. The heaviest partyboat catch is usually made during August and September from La Jolla to Redondo Beach. Sportfishermen 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 sports and commercial fishermen.

Bonito are occasionally caught in fair numbers by partyboat 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.

The average annual southern California (Pt. Conception to San Diego) partyboat 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 319,682 annually since. The average annual catch per angler for these three periods increased from 0.05 to 1.33 then dropped to 0.40 (Figure 2). 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 1964-1966 made estimates of the catch and effort of the sportfishermen from piers and jetties, private boats and shoreline, from Point Conception to the Mexican Border (Pinkas, Oliphant and Haugen 1968). The figures show that partyboat fishermen are, as a group, far more successful in capturing bonito than fishermen in other segments of the sportfishery (Table 4).

TABLE 4. Comparison of Sportfishing Catch and Effort.

Source	Year	Catch Nos.	Effort	Catch per hour
Pier & jetty	1963	283,068	5,100,100*	0.06
Partyboat	1963	773,036	2,480,054**	0.31
Private boat	1964	401,575	2,773,405*	0.14
Partyboat	1964	1,297,741	2,679,545**	0.48

* - Effort in man/hours

** - Effort in angler/hours

Partyboat figures are for southern California fleet only

The contribution of marine sportfishing barges to the total sport-catch was calculated as 21.2% of the reported partyboat catch, based on data collected in 1966 and 1970. All these are combined to give the total catch and effort for the southern California sportfishery (Table 5) developed by Thayer (1973).

Mexican Commercial Fishery

The take of Pacific bonito off Mexico by Mexican commercial fishermen has been relatively low (averaging less than 300,000 kg annually since 1965) compared to the take by U.S. fishermen there, but it appears there is considerable potential for harvest by Mexican fishermen.

Size and Age of Catch

Pacific bonito caught by sportsmen are generally 2 years or less old and often a single year-class supports the sportfishery for a period of 2 or 3 years, as was the case from 1972 through 1974 (Table 6, Figure 3). Commercial landings on the other hand, have until recently, consisted almost exclusively of fish 2 years and older (Figure 3).

TABLE 6. Year Class Composition of Pacific Bonito Partyboat Catches Made off Southern California.

Year class	1970	1971	1972	1973	1974	1975	TOTAL
Year							
1972	5,447	85,892	324,713	-	-	-	416,052
1973	0	4,724	466,701	472	-	-	471,897
1974	141	5,805	61,304	22,794	51,110	-	141,154
1975	-	-	74	167	78,622	1,575	80,438
TOTAL	5,588	96,421	852,792	23,433	129,732	1,575	1,109,541

TABLE 5. Fishing Mortality on Bonito in California Waters.

Year i	Aerial index I_i	Sport catch[1] 10^6 fish	Sport catch[2] 10^6 lb.	California commercial catch 10^6 lb.	Total catch C_i 10^6 lb.	Index of fishing intensity C_i/I_i	Annual fishing mortality rate if $F_{1969} = 1.5$ %
1963	1.71	1.53	4.59	4.01	8.60	5.0	10
1964	1.80	2.62	7.87	2.61	10.48	5.8	11
1965	1.48	1.63	4.89	5.63	10.52	7.1	14
1966	1.49	1.30	3.91	18.31	22.22	14.9	27
1967	1.03	0.71	2.13	17.84	19.97	19.4	33
1968	0.54	2.23	6.69	14.90	21.59	40.0	57
1969	0.28	2.29	6.87	13.18	20.05	71.6	78
1970	(0.1-0.2)[3]	1.32	3.96	8.79	12.75	(60-120)[3]	(72-92)[3]
1971	0.56	0.31	0.92	10.48	11.40	20.4	35
1972	1.11	0.85	2.55	15.60	18.15	16.7	30
1973	0.50	0.96	2.88	18.48	21.36	42.7	59
1974		0.29	0.86	13.78	14.64		
1975							

[1] Total sport catch is estimated as 1.9 partyboat catch (Thayer, 1973).

[2] A conversion of 3 lb/fish is used for the sport catch.

[3] Estimate, based on incomplete aerial survey data.

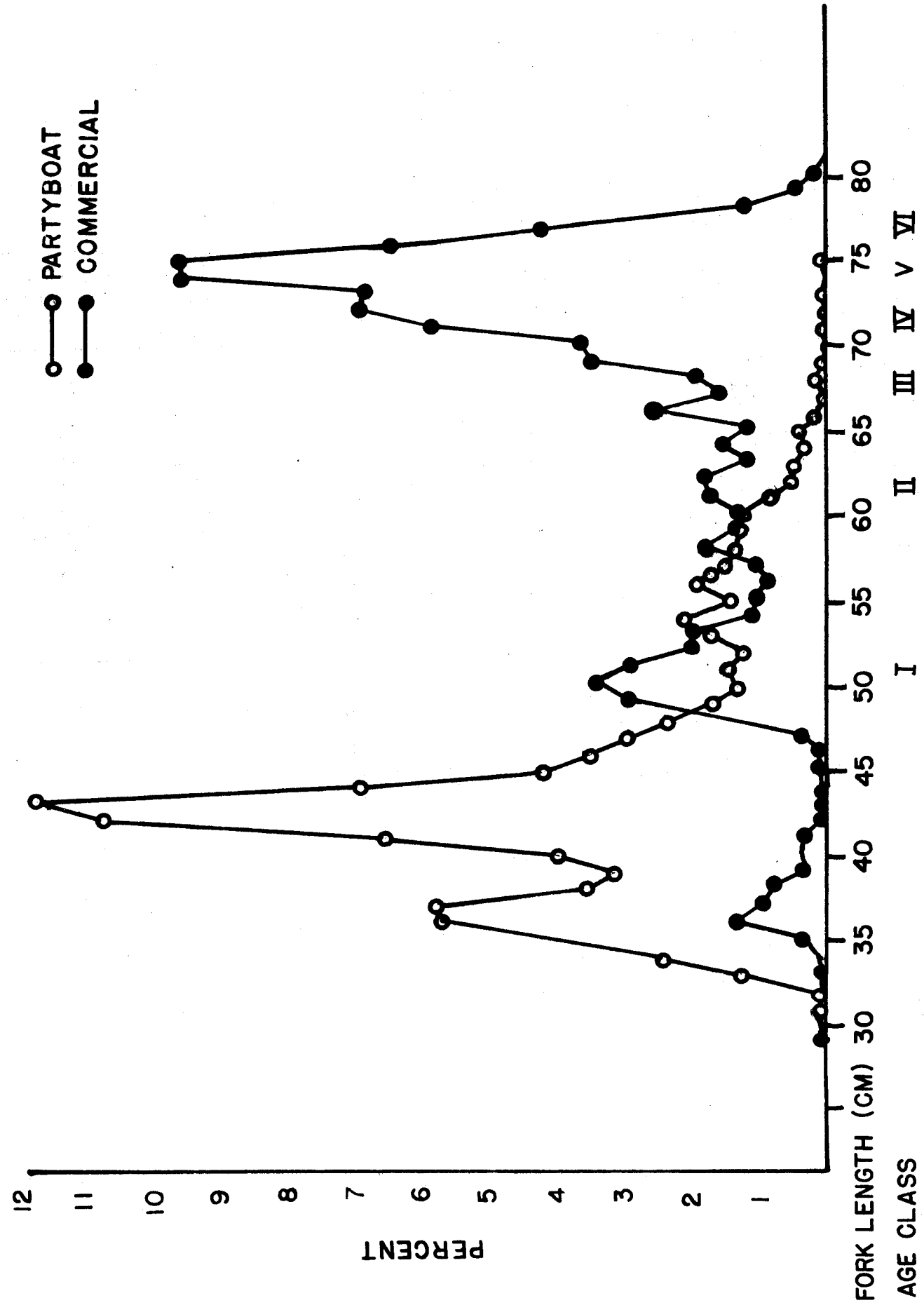

FIGURE 3. Average length composition of sport and commercial catches of Pacific bonito, 1972-1975.

These differences seem to be a function of both behavior and economics. Small bonito are very susceptible to sport capture methods, while the larger bonito are generally less susceptible. The price to commercial fishermen has usually been dependent on the size of the bonito landed and has caused purse seine fishermen to seek the larger bonito.

BIOLOGY

Reproduction

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

A 2-year study of bonito maturity and fecundity was initiated by the Department of Fish and Game 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 (Glenn F. Black CDF&G, pers. commun.). Further analysis of the first years' samples appear to substantiate findings on the spawning behavior of the same species of bonito found off the coast of Peru (Vildoso, 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.

Our 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 and only

spawn once. Reproduction takes place in 92% of the males and 78% of the females at 2 years of age, while all fish 3 years and older will reproduce. As of the present no estimates have been made of the number of eggs spawned by females of particular lengths and ages due to the problems presented by the bonito being a multiple spawner which does not spawn all mature 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 our local marine environment during the spawning season. Bonito tag returns indicate that there may be small numbers of young resident fish that stay in these areas for as long as 2 years, thus providing a small amount of recruitment even in cold water years.

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 a few crustaceans make up a small portion of the diet (Oliphant, 1971).

Size, Age and Growth

A study of bonito age and growth utilizing otoliths and vertebrae has recently been concluded. Fish 15 to 25 cm (6 to 10 inches) long are observed by fishermen in the early summer. By the following spring these fish, now 1 year old, are 40 cm (15 inches) in length and weight about 1 kg (2 lbs). These fish will weight 1.4 kg (3 lbs) or more by fall, and by the following May will weigh about 2.5 kg (5 to 6 lbs). The next year these 3 year olds will weigh 4.5 to 5.4 kg (10 to 12 lbs) and be

about 68 cm (27 inches) long (Campbell and Collins 1975). There is a verified report of bonito 100 cm (40 inches) in length weighing 11 kg (25 lbs), and an unverified report of a 17 kg (37 lb) fish (Bell, 1960).

Migration

In 1968 a tagging project was initiated to study the movements and growth rates of bonito and a manuscript is currently in preparation. 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 1100 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). A large proportion have been recovered by pier and jetty fishermen which indicates that these fishermen contribute a larger proportion of fish to the bonito sport catch now than when the last sportfishing survey was done, in 1963 (Pinkas, Oliphant and Haugen 1968).

Several bonito tagged off 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).

Two of the 22 bonito that have been recovered more than 2 years after

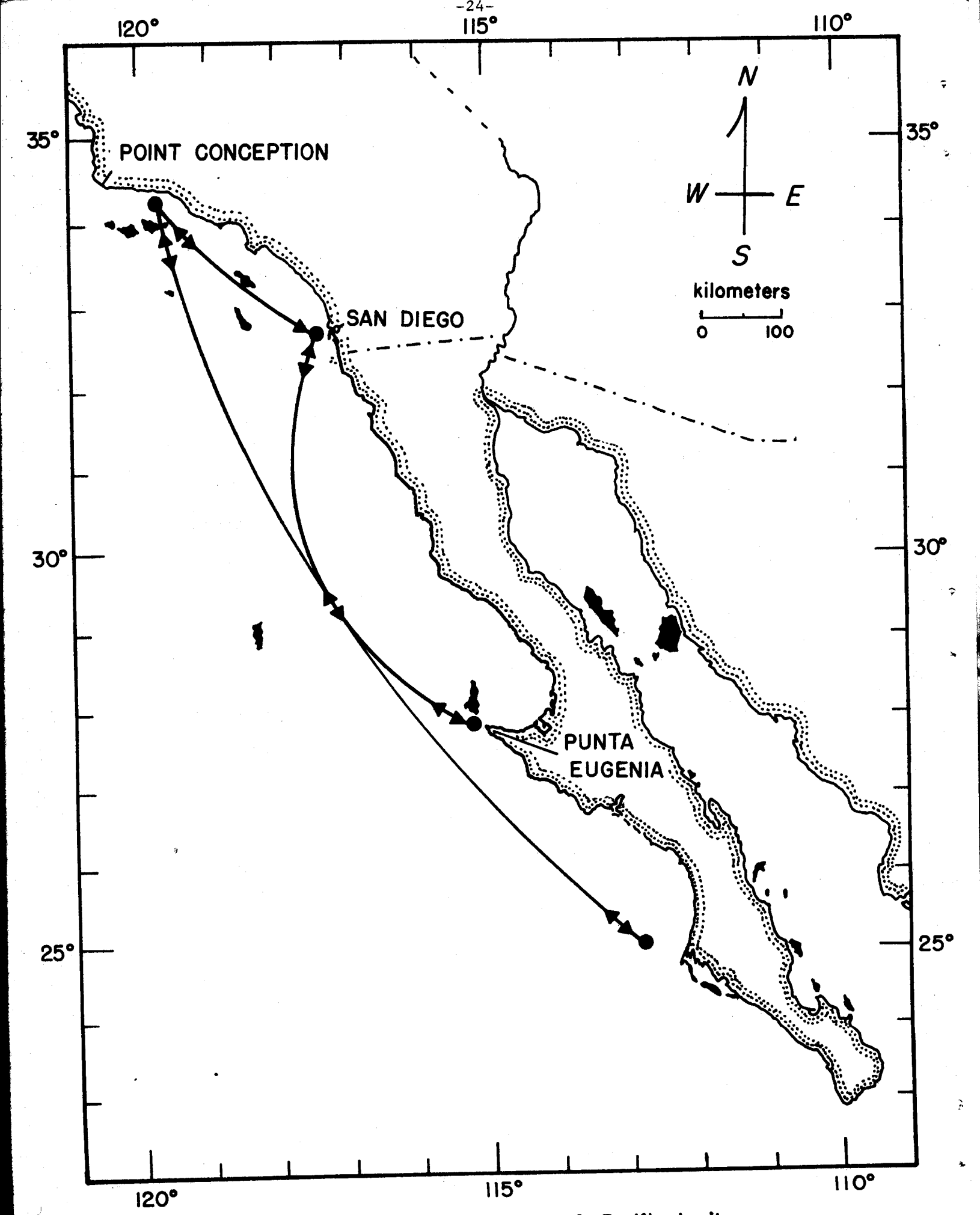

FIGURE 4. Gross migrations of Pacific bonito.

tagging were recovered within 2 km (1.6 mile) of the release point at King Harbor, Redondo Beach, a heated water discharge area.

Data from our tagging study indicates 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 are older.

STOCK ASSESSMENT

Catch-per-unit of effort (CPUE) data for the Pacific bonito commercial fishery are not available, restricting one of the classic approaches to stock assessment. However, there are several other sources of data which can give us an insight into the dynamics of the population. Among these is the aerial scouting index of Squire (1972), derived from flight logs kept by commercial fish spotters. Partyboat logs also provide useful information, especially concerning the abundance of young fish.

Spawner-Recruit Relationship

Squire's (1972) day aerial index of abundance is a potential index

of spawning biomass, and partyboat CPUE is a potential index of recruitment strength. The two may be combined to give a tentative description of the relative annual reproductive success of Pacific bonito in southern California waters.

Spawning takes place during the spring and summer, involving 78% of age II and all older bonito. The aerial index is primarily based on observations made during the fall commercial fishing season, on fish being sought by the fleet. The length frequency of fish caught by the fleet will therefore tend to reflect the length distribution of fish included in the aerial index, with some bias toward under-representing the smaller fish due to cannery preference for large fish. Age I fish are well represented, particularly in 1973 (Figure 3), however, no age 0 fish occur in the length frequencies. The age I fish will be age II fish by the following spawning season (March to July) and will therefore be mostly spawners.

On the other hand, the commercial catch removes fish from the pool measured by the aerial index, so a correction for the commercial catch should be applied. For purposes of this tentative model, the correction factor was estimated by the following method: a multiple regression relating abundance and catch (recruitment was also included, but gave no significant results) gave the following equation of best fit:

$$I_{i+1} = 0.97\ I_i - 0.017\ C_i \quad (r^2 = 0.92;\ F = 36.2;\ P < 0.01)$$

where I is day aerial abundance index, C is commercial catch from California waters, in millions of pounds and i denotes the year of observation. While the regression is of little use for prediction, the coefficient of C_i can be taken as a first approximation of the correction factor sought above. Use of the above coefficient as the correction factor was found to give very small estimated spawning biomass indices

in some years, so its value was arbitrarily reduced to 0.010 as an intermediate value. Thus two indices of estimated spawning biomass (S) were obtained: an upper value (Su) of

$$Su_i = I_{i-1}$$

and a catch-corrected value (Sc) of

$$Sc_i = I_{i-1} - 0.010\ C_{i-1}$$

The recruitment index (R) is the CPUE index of MacCall, Stauffer and Troadec (1976), being the average catch per angler for six southern California subareas, weighted by the approximate geographic size of the area fished in each subarea. Length frequency indicates that the party-boat catch consists of age I fish on the average (Figure 3). We will assume these fish were spawned in the previous year, and R_{i+1} corresponds to the recruitment resulting from spawning in year i.

The spawner-recruit relationship (Figure 5) is shown, with labelled years indicating the year of spawning. The right end of each solid horizontal bar represents the Su value and the left end is the Sc value. If the correction coefficient were increased to the regression value, the left end of the dashed line indicates the approximate position of the spawning point. A 1963 estimated point is included, based on a hypothetical value of 1.56 to 2.0 for the aerial index for 1962. There is no simple functional curve describing the spawner-recruit relationship. Spawning points fall in a broad diagonal band, with large spawning biomasses tending to yield larger recruitments than do small spawning biomass, however poor recruitments may result from high spawning biomasses (1966) as well as low (1970, 1971). Good recruitments ($R > 1.0$ fish/angler day) are only apparent for years of high spawning biomass.

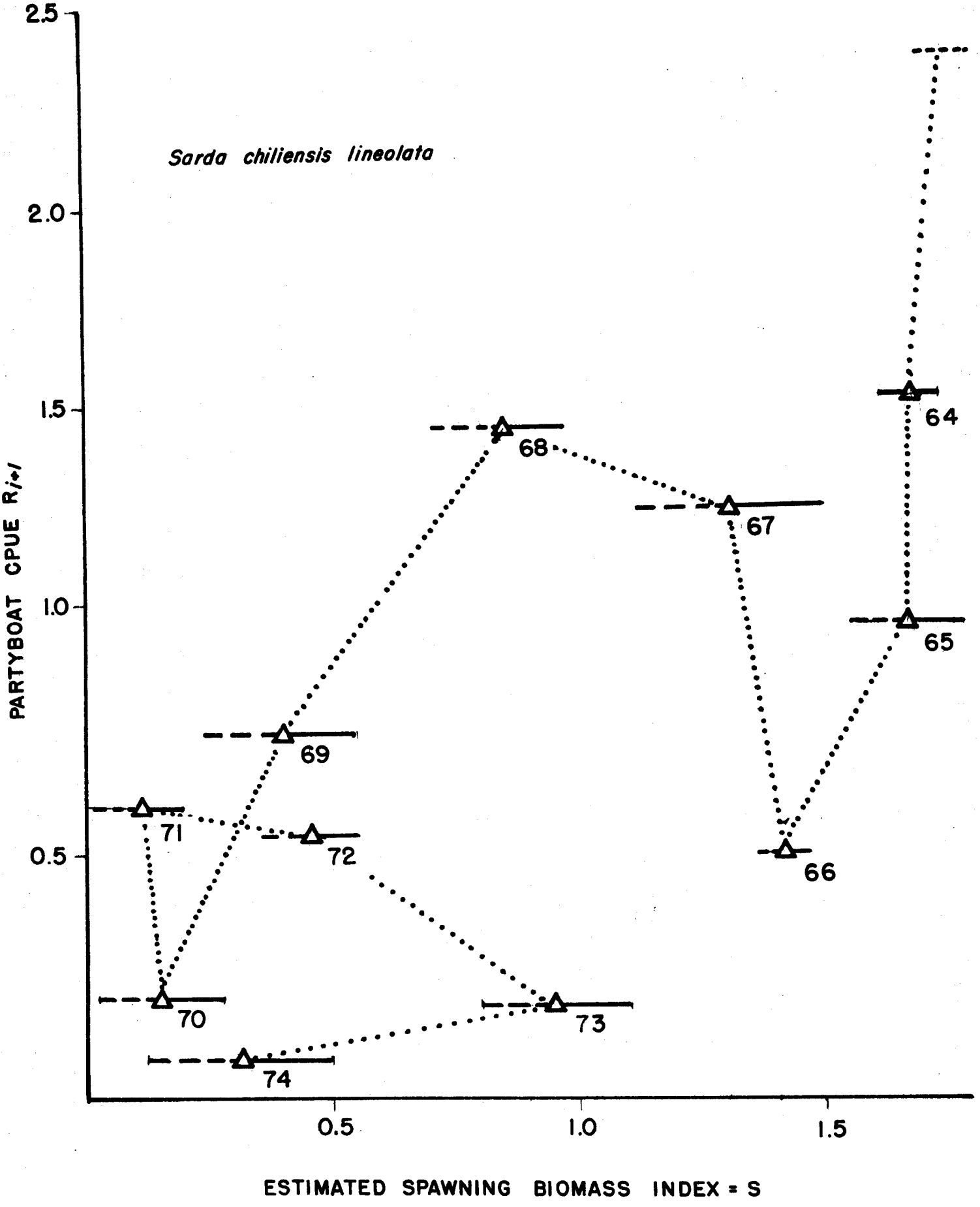

FIGURE 5. Spawner-recruit relationship.

A catch-corrected index of relative recruitment success (r_c), is calculated by

$$r_{ci} = \ln (R_i + 1/Sc_i)$$

and is given in Figure 6. The poor recruitment successes of the 1973 and 1974 spawnings are evident, and can be seen to be relatively poorer than any of the previous seasons shown. On the other hand, in the early years, before 1966 when the commercial fishery became intense, the population was able to maintain its abundance despite a sequence of poor relative recruitment successes from 1964 to 1966. From 1968 to 1971 reproductive success was much higher but the population remained at a low level of abundance due to lowered spawning biomass. As the commercial fishery is a major cause of mortality, it is probably the principal cause of the low bonito abundance prior to 1974. This hypothesis is explored in the next section.

Fishing Mortality

The fishing mortality rate F is related to catch C and mean abundance N by the equation $F = C/N$. If we assume the aerial index of abundance is related to true abundance by a proportionality constant k, so that $N = kI$, then the instantaneous fishing mortality rate is estimated by $F = C/kI$, but since k is not known, an index of fishing intensity can be obtained by $kF = C/I$. Catches are those from California waters, and the partyboat fishery served as a basis for estimating the total sportcatch in pounds (Table 5).

The index of fishing mortality (Table 5) can be converted to a presumptive annual mortality rate if a value of k is given. Based on experience in other purse seine fisheries, intense fishing may generate

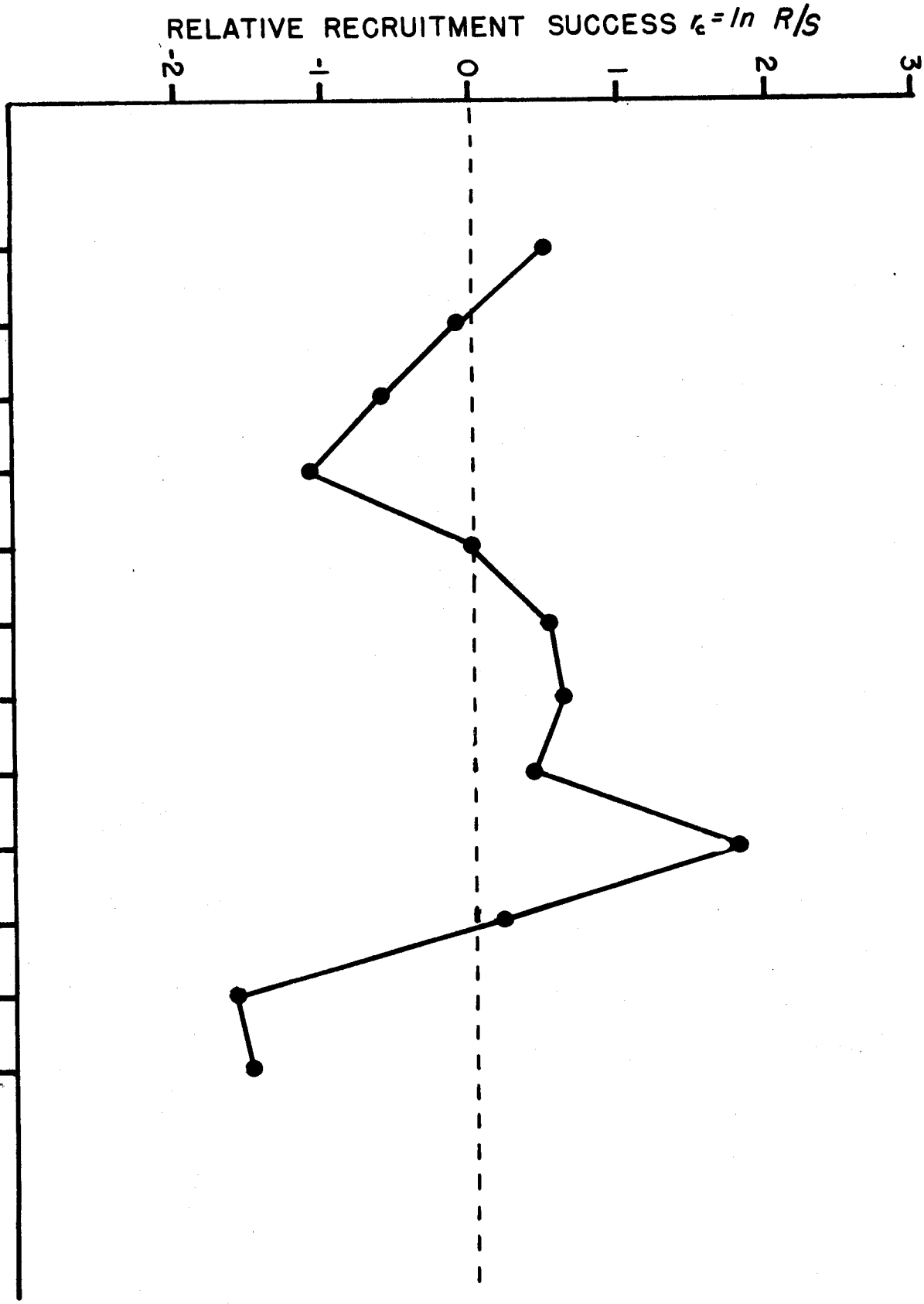

FIGURE 6. Relative recruitment success

a fishing mortality rate of F = 1.5, and assuming the 1969 fishery was of such intensity, a conversion factor of k = 47.73 is obtained. Annual fishing mortality rate estimates (a), expressed in percent (Table 6) are obtained by the equation: a = 100% (1-exp(-F)).

The first increase in fishing mortality occurred in 1966, and was partially the result of increased cannery demand, imports from Peru having declined considerably. Ex-vessel prices rose in the late 1960's and early 1970's (Stauffer, MacCall and Wahlen, 1975). The 1968 anchovy season found anchovies relatively unavailable and many vessels may have turned to bonito as an alternative species. Cooperative vessel groups have since come into existence, wherein one vessel may fish to fill the anchovy reduction orders for the group and the other vessels may seek alternative species such as jack mackerel and bonito. Thus various mechanisms have brought about an increase in fishing intensity on bonito. Mortality rates jumped in 1966 and again in 1968, peaking in 1969 and 1970 when fishing operations may have been catching over half the available population each year. Fishing intensity declined somewhat in 1971 and 1972, but increased to a high level in 1973. Fishing intensity appears to have been sufficient to explain the decreased spawner abundance in the late 1960's and early 1970's.

Environmental Factors Influencing Recruitment Success

This section follows the work of Richard Parrish (PEG, NMFS, Monterey, Ca.), who has examined Pacific mackerel recruitment patterns in relation to environmental variables. Parrish has found that upwelling and related water movement patterns occurring midway down the Baja California coast, in the area of Punta Eugenia, may explain much of the variation in recruitment success of Pacific mackerel (a species sharing many similarities with the bonito). Due to the lack of refined data on the bonito, no sophisticated environmental models can be attempted.

Various environmental parameters were compared with the catch-corrected index of relative spawning success (r_c). Scripps pier temperatures showed no correlation with recruitment, although the possibility remains that water temperatures affect migration of older fish. The upwelling indices of Bakun (1973) for the regions 30°N and 33°N (March-July mean) showed a possible relationship to recruitment success with the more southerly region showing the stronger relationship (Figure 7). When Bakun's data series was updated to 1973 and 1974, both points are distinct outliers and reduce the strength of the apparent relationship, although a threshold effect may be possible, with good recruitment success more likely for periods of strong positive anomaly. Another upwelling related event, termed "wind stress curl" or "divergence", showed no apparent relationship to either recruitment success, or to the residuals from the upwelling relationships.

Since the upwelling-recruitment success relationship cannot be extended to years before the aerial abundance index was measured, the existence of a relationship between the two variables must be examined indirectly. Assuming that the partyboat catch per unit effort measures the strength of the recruitment which we are trying to measure, and in the absence of a large fishery, changes in spawning biomass from year to year would be minimal, a possible measure of relative changes in recruitment levels for spawning in year i is the quantity $\ln (CPUE_{i+1}/CPUE_i)$, which will be termed the relative recruitment ratio. A plot of this relative recruitment ratio against the March-July mean upwelling anomalies for years before 1964 (Figure 8) shows the same relationship suspected in the previous calculations explaining the sudden abundance of bonito in southern California waters. A supporting piece of evidence is the point for 1953, which may explain the small increase in CPUE for 1954 (Figure 3). Moreover, the success of the 1953 spawning may have added

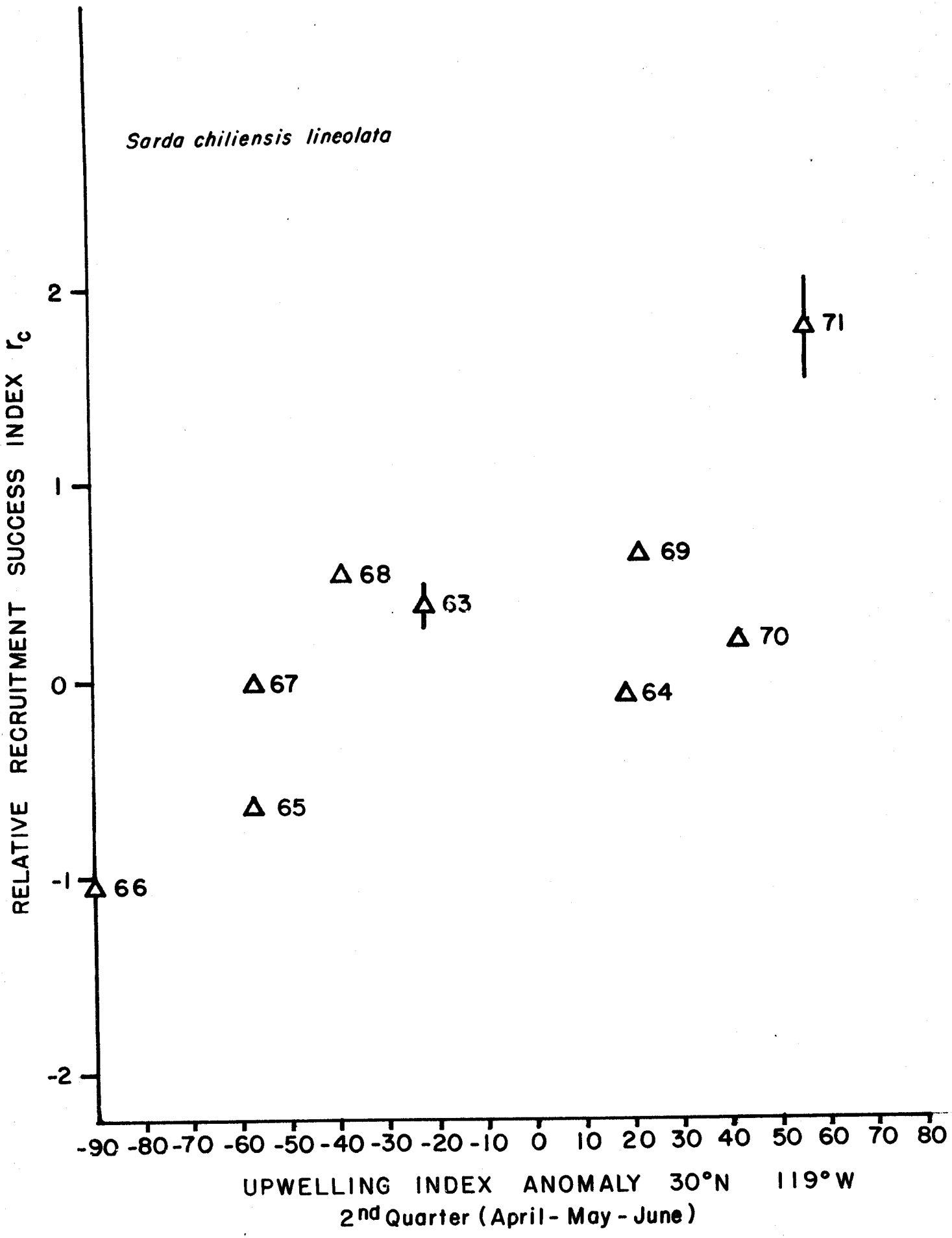

FIGURE 7. Relation between relative recruitment index and upwelling.

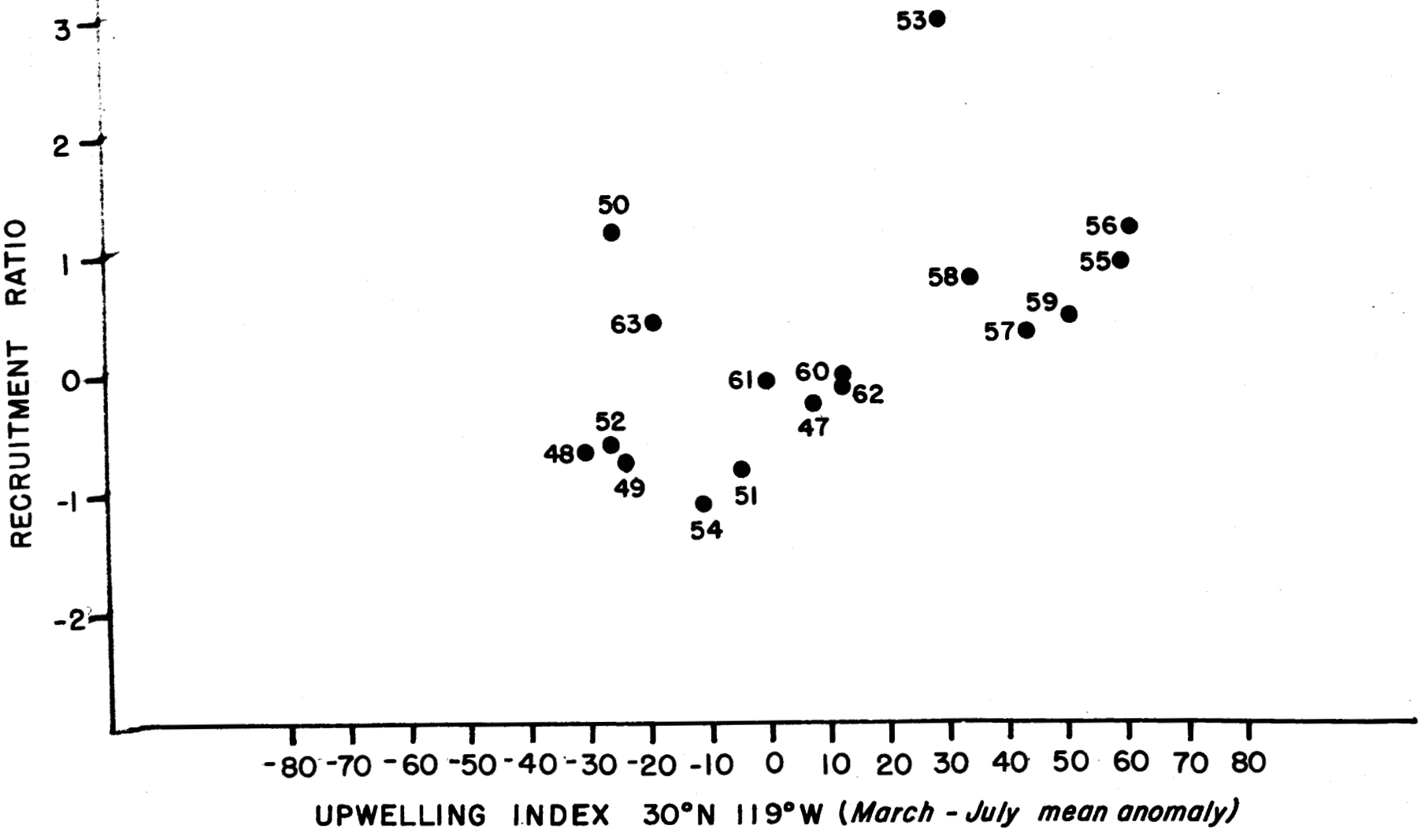

FIGURE 8. Upwelling recruitment success relationship.

considerable reproductive potential to the population 2 years later, which coincided with the series of excellent relative spawning successes beginning in 1955. Finally, the importance of the spawnings in 1953, 1955 and 1956 tend to argue against the hypothesis that the abundance of the bonito in southern California is simply the result of the warm water period in the late 1950's, although there remains a considerable likelihood that the warm ocean temperatures were a contributing factor.

MANAGEMENT IMPLICATIONS

The most important biological consideration for management is the seasonal and sporadic nature of the Pacific bonito's residence in California's waters. Since the bulk of the population is resident in Mexican waters, management will require close coordination and cooperation with the Mexican government.

Defining a "resident" stock as one which exhibits local recruitment, the Pacific bonito resource in California waters cannot be managed on a sustained yield basis, as it is not a permanent resident stock. Rather, the stock expands its range northward into southern California when a series of favorable (and presently unpredictable) oceanic events take place. Once established in California waters, an indeterminate period of residency may pass, with this northern segment of the stock falling somewhat short of being able to perpetuate itself, and, under normal oceanic conditions, undergoing a slow fluctuating decline in abundance. Following this, an indeterminate period may occur in which there is no appreciable local recruitment. Exploitation of the temporarily resident stock will shorten the term of residency. There is no harvestable surplus production in the usual sense, as there is annual net loss in abundance during average conditions. Yield must be considered on a non-

sustainable basis, being a balance between harvesting the stock while it is here and maintaining its presence as long as possible. Over-exploitation of an incipient resident stock may well abort its achieving that state, a condition which is likely if harvests remain uncontrolled.

A second group of bonito in southern California appears to be annual migrants from the more permanent southern segment of the stock, which tend to make annual fall northward migrations into California as large fish. It is likely that this group is the progenitors of our occasional resident stock, and moreover, is indistinguishable from the resident stock during those periods that the latter is here. Therefore, these annual northern migrants should also be given a degree of protection, while allowing some harvest.

The California partyboat fishery makes large catches of the recruits during periods of residency, furnishing one of the main attractions of marine sportfishing during these periods. The impact of exploitation of these younger age groups is minimal, as a great many would not reach maturity due to other sources of mortality. Historical evidence shows that a resident stock can become established despite normal sportfishing pressure. Considerable sportfishing also occurs on the older fish, particularly on the annual northward migrants, but the efficiency of sportfishing gear is low and the impact on the population is again slight. Commercial roundhaul fishing in California waters exploits both the annual northward migrants and the resident post-recruits quite heavily. This fishery is the major non-natural factor in determining local abundance.

There is evidence that the present decline of the population off southern California was precipitated by the increased commercial catches in the late 1960's and early 1970's and that the harvest of 1973 may have damaged the reproductive capacity of the southern California portion of the stock.

It is apparent that the population of Pacific bonito in southern California will not sustain a harvest at the level of the last 10 years under normal environmental conditions. The past history of bonito catches in southern California indicates that even under low harvest rates we cannot guarantee that bonito will remain abundant in our waters for a protracted length of time. Management action can prolong the length of time during which bonito are abundant here however, and maximize the recreational value to sportsmen, but only by restriction of the commercial catch. Short term losses to the commercial industry will be partially offset by long term gains arising from longer periods of residency.

If the management goal is to preserve sufficient bonito in southern California waters for sport use, then some restriction of the commercial catch is necessary.

REFERENCES

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

California, Dept. of Fish and Game. 1966. California Fish and Wildlife Plan. Vol. 2, Fish and Wildlife Plans. Sacramento. 215 p.

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.

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.

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

Oliphant, Malcom 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.

Vildoso, A. C. de. 1960. Studies of the reproduction of the bonito, *Sarda chiliensis* in water near the coast of Peru. Estudios Sobre La Reproduccion Del Bonito *Sarda chiliensis* En Aguas Abyacentes A La Costa Peruana. Biologo de la Direccion de Pesqueria y Caza. Pgs. 1-75.

MARINE RESOURCES TECHNICAL REPORTS

NO.

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