MFR PAPER 1173

Southern California Recreational and Commercial Marine Fisheries

ALEC D. MacCALL, GARY D. STAUFFER, and JEAN-PAUL TROADEC

OVERVIEW

Southern California marine recreational and commercial fisheries exploit a large number of coastal fish species. An initial analysis of the current status of the more important stocks was undertaken in 1974. The results for northern anchovy, *Engraulis mordax*, California barracuda, *Sphyraena argentea*, Pacific bonito, *Sarda chiliensis*, jack mackerel, *Trachurus symmetricus*, white seabass, *Cynoscion nobilis*, and yellowtail, *Seriola dorsalis*, are documented in this report. Brief status reports for Pacific mackerel, *Scomber japonicus*, and Pacific sardine, *Sardinops caeruleus*, are included. These stocks are shared by various fleets fishing along the coast of southern California and the Pacific coast of Baja California. The U.S. partyboat fishery, in which fishermen rent space aboard a boat for a day or half day, has been popular in southern California since the 1920's (Young, 1969). In the last decade this fishery has caught about 4 million fish annually there. Fishing from private boats, shorelines, piers, and jetties is also very popular but statistics have not been routinely collected (Pinkas, Thomas, and Hanson, 1967 and Pinkas, Oliphant, and Haugen, 1968). A small round haul fleet supplies bait dealers with live anchovies for fishermen on partyboats and private boats to use as bait and chum.

The U.S. commercial fishery has two major components: a small purse seine fleet, which was once active in the sardine fishery and now harvests anchovies, jack mackerel, bonito, and tuna (Perrin and Noetzel, 1970) and market boats which use such gear as longlines and gill nets and supply the fresh and frozen fish market. Included in this report are discussions on the flexibility and trends in target species of the partyboat and purse seine fisheries, and analyses of anchovy fishery interactions and trophic relationships.

The tone of this investigation has been that of expedient fishery analysis, in which detail is sacrificed for speed, achieving maximum cost-effectiveness, and identifying areas where further investigation is needed and is likely to be fruitful. Originally this work was recommended at the State-Federal Marine Fisheries Research Program Planning Workshop held 12-15 March 1973 in San Clemente, Calif. (proceedings compiled by Squire, 1973).

This work should provide significant information for the formulation of positions and plans for regulatory agencies managing these resources. We have attempted to avoid making recommendations regarding the course of future exploitation of southern California fish resources except for the determination of approximate limits of sustainable yields and lower limits on age at first capture (Table 1). However, where resources are or appear to be exploited beyond maximum sustainable yield, reduction of catch and/or effort is strongly recommended.

The two California pelagic wetfish stocks showing very large standing biomasses, **northern anchovy** and **jack mackerel**, presently appear to be lightly exploited. Maximum sustainable yields of anchovy appear to be 10-20 times the present annual catch level of 130,000 tons, and jack mackerel should be able to sustain catches 4-8 times larger than the recent annual catch level of 55,000 tons. The "older" wetfish stocks—**Pacific sardine** and **Pacific mackerel**—are extremely depleted and show little likelihood of recovering to previous levels of abundance in the near future, even under the present fishing moratoria. Mexico is making large catches of these species; however, it is difficult to determine the proportion of catches coming from northern stocks relative to those coming from the southern stocks, or the Gulf of California.

The larger sport fish stocks are in various states of exploitation. The **yellowtail** resource appears to be lightly exploited, and has shown an apparent increase in availability to sport fishermen since the cessation of large-scale commercial fishing in 1954. The increase in availability may be due, in part, to more favorable ocean temperatures. Maximum sustainable yield (MSY) appears to be 3-6 thousand tons annually, with recent sport catches ranging from 0.5 to 2.0 thousand tons. As the sport catch appears to take a large fraction of the northward summer migration, it is unlikely that catches from California waters can be significantly increased.

White seabass appear to be somewhat depleted. Data from the commercial fleet operating in both Californian and Mexican waters indicate the species may be harvested at near maximum substainable levels. Catch per unit effort of white seabass from partyboats has declined over the last 2 decades, creating some uncertainty as to the true status of the stock. The white seabass

Alec D. MacCall is a member of the staff of the California Department of Fish and Game; Gary D. Stauffer, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038; Jean-Paul Troadec, United Nations Food and Agriculture Organization. This study was conducted in cooperation between the California Department of Fish and Game and the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, under contract 03-4-208-160. The authorship is arranged alphabetically.

Table 1.—Present state of exploitation and estimated potential of major recreational/commercial stocks.

Stock	Geographical range	Estimated mean annual catch 10³ short tons 1940-1949	1950-1959	1960-1969	1970-1973	Present major fishery segments (% 1970/72 total catch) U.S.-based sport	U.S. Comm.	Mexican Sport/Comm.	Potential yield 10³ short tons	State of exploitation	Remarks
Northern anchovy	Southern California, northern Baja California	3	18	30	129	5 (bait)	55	40	[1]1,500-2,000	Very lightly exploited	Allocation requirements may reduce rates of exploitation.
Pacific sardine	California, N. Baja California	428	91	10	3	some (bait)	0	large	[2]300-500	Depleted	Rehabilitation unlikely in near future.
Pacific mackerel	Central California to central Baja California	30	20	16	1	33	33	34	[3]30-50	Depleted	Rehabilitation unlikely in near future.
Jack mackerel	West coast of North America	34	38	39	24	0.1	89	11	210-450	Probably lightly exploited	Size of local stock is indeterminate, but large.
California barracuda	Southern California to central Baja California	2.1	1.9	1.2	0.5	48	2	48	[4]1-2	Depleted	Rehabilitation possible in near future.
Yellowtail	Southern California and Baja California	3.1	3.2	1.2	1.5	67	13	20	[4]3-6	Lightly exploited	Migration into Calif. is heavily exploited.
Pacific bonito	California and Baja California	2.7	1.4	7.6	11.8	11	87	2	10-20	Probably moderately to highly exploited	Biomass and potential highly fluctuating with recruitment. California residency may be a temporary event.
White sea bass	California and Baja California	0.5	1.0	0.6	0.5	8	76	17	0.8	Moderately/highly exploited	Indices of abundance conflict.

[1]At the 1970-1973 population level.
[2]If rehabilitated to the pre-1944 population level.
[3]If rehabilitated to the pre-1950 population level.
[4]The California yield is influenced by ocean temperature.

population may be overestimated by commercial fishery data and underestimated by partyboat data—a phenomenon that currently is being examined. We have investigated some of the potential results of various future developments in the sport and commercial fisheries which may be of use in management decision-making.

The status of the **California barracuda** stock is difficult to assess with respect to a definite level of MSY, but appears to be at a low level. Length frequency indicates a preponderance of very young fish in recent partyboat catches and it is possible that the previous allowance of fish shorter than 28 inches in bag limits has contributed to depleted spawning stock and consequently reduced recruitment. Maintenance of the present strict observance of 28-inch minimum length is a rational course of action. There appears to be sufficient stock remaining to engender optimism regarding rehabilitation of the resource in the next decade, given favorable environmental conditions. Abundance of barracuda off California is strongly influenced by ocean temperatures.

Pacific bonito appears to be a relative newcomer to the sport catch, having been absent for a number of years prior to 1956, and large-scale commercial fishing has increased to unprecedented levels in the past few years. Sport availability is an indicator of recruitment and is highly correlated with abundance of commercially exploitable fish 3 years hence. A crude production model indicates that bonito are presently being harvested at or above MSY (although the assessment is confounded by the possibility of a density-independent decline in recruitment). The 1973 catch appears to be considerably in excess of equilibrium yield. However, since Pacific bonito fishing success is influenced by ocean temperatures, conclusions drawn from the crude production model must be accepted with caution.

While it would be desirable to assess the stocks of other species, such as Pacific hake, saury, squid, and the rockfish group, the limited amount of data available for the southern California Bight prevents such undertakings. **Rockfish** appear to be abundant in southern California waters and are becoming progressively more important as a sport fishing resource. Separation of rockfish partyboat effort should lead to feasibility of southern California stock assessment for that species complex. **Squid** is receiving increased attention from commercial fishermen and marketers and is an important candidate for stock assessment. If a series of annual squid abundance estimates becomes available (such as by aerial survey), assessment by methods similar to those used for bonito should be possible.

Studies of interactions were brief, due to the extreme complexity of the subject. The northern anchovy fishery has a large number of interacting elements, and regulation is poorly coordinated. The southern California live bait fishery is a very important user of anchovies, and has occasionally reported poor bait availability, allegedly due to commercial fishing. Our results indicate that the availability of anchovies to the live bait fleet has increased considerably over the long term, and that while there may be a slight reduction in relative availability in the winter reduction season, the difference is very small and even of questionable existence. The Santa Barbara bait fleet appears to be anomalous in many respects, and may be in real difficulty, although it is difficult to attribute its problems to the anchovy reduction fishery.

Multiple species aspects of fisheries received brief attention. Quality of sport fishing seems to have been very good during the late 1950's and most of the 1960's. Sport fish now appear to be returning to levels typical of the early

1950's with respect to abundance of large and medium sport fish, although species composition is now different. This seems to be associated with the warm water period beginning in late 1956 and continuing into 1960. The commercial wetfish fleet appears to be flexible in its choice of target species and has gained independence of the availability of sardines.

An analysis of trophic interaction indicates that while both forage (anchovies and sardines) and game fish (yellowtail, bonito, albacore, barracuda, and white seabass) increased in abundance between the 1950's and 1960's, there seems to be little evidence that either prey or predator biomass shows strong dependence on the abundance of the other. It appears more likely that the abundance of both is determined largely by external conditions. If any interdependence is in effect, it should have been much weaker in the 1960's than in the late 1950's.

DATA AND METHODS

The following report briefly documents the analytical methods and data used for the "quick" stock assessment of some of the more important recreational and commercial fisheries of southern California. The analyses of the various stocks utilized similar methods and types of data, making a general discussion of procedures appropriate.

Stock assessment methods

Stock assessment methods were applied in a manner to give the most rapid assessment of fisheries stocks. Sophistication and accuracy are desirable, but suffer low priority in the face of an urgent need for information on critical fishery problems. Often the quick solution will serve as a guide in long-term investigation of problems, and can be considered as a "first cut."

Stock assessment procedures have three time-consuming operations: 1) collection of data, 2) development and refinement of models, and 3) justification and elimination of assumptions. Expedient methods minimize these steps. Only available data are used; where data are missing, reasonable estimates are made in order to fill the gaps. Methods tend to be restricted to application of very simple models. These are further simplified by relaxation of statistical procedures and tests of validity in favor of approximate solutions. Whereas in the more detailed investigations, considerable work is devoted to attempts at eliminating or justifying assumptions, "quick and dirty" methods rely on assumptions as a modus operandi. Within the constraints of generating a useful and meaningful report and of conforming to knowledge and information regarding the subject, all reasonable assumptions necessary to pursuance of the investigation are justified. The extent to which fundamental assumptions, which significantly influence conclusions, are not met in the real world, will affect the accuracy of the conclusions.

This investigation attempts to determine the status of fish stocks and their level of exploitation. Status, however, is a vague term, and may have different criteria for different users, particularly in the case of sport fishermen and commercial fishermen. We have used MSY as a standard criterion in these assessments for several reasons: MSY is a measurable quantity, and is the standard parameter determined from application of simple fisheries yield models; moreover, MSY is a likely upper bound for optimum sustainable yield whether the optimizing criterion be economic value, stability of yield, or recreational value. Optimum sustainable yield criteria are the subject of further investigation. Thus, we do not wish to imply, in assessing status relative to MSY, that catches should necessarily be brought to such levels. However, if MSY is exceeded, a reduction in fishing effort is to be strongly recommended.

Data

The most important information to fisheries assessment and management is total catch. The first step (besides familiarization with the species and fisheries) in these investigations was to compile a complete table of catches since about 1950. This required collation of data furnished by many sources (Table 2), both published and otherwise. Where data were unavailable, estimates were based on available information, suspected trends, and educated opinions. In many cases, the time series of catches for a particular fishery segment were estimated by the ratio of catch available for years indicated in Table 2 to known catch of a similar fishery.

In order to make all catches comparable, and for use in surplus production models, catches were converted to estimates of weight. This task presented no obstacle in the case of the commercial fisheries, where landings are already recorded in weight, and in the bait fishery, where the weight to volume ratio is approximately constant (15 pounds/scoop). In the sport fisheries, however, the problem is not as simple. Average weights per fish were calculated from length frequencies via weight-length formulae. For most sport species, length frequencies were available only for a few years in the 1950's from special studies of the California Department of Fish and Game (CDFG). Fortunately length-frequency

Table 2.—Catch data sources.

Catch	Source	Years	Availability	Units
Commercial				
California				
California waters	CDFG	1916-present	Published (CDFG Fish Bulletins)	Weight
Mexican waters	CDFG	1916-present	Published (CDFG Fish Bulletins)	Weight
Bait	Voluntary (CDFG)	1951-present		Volume
Mexico	INP	1962-present	Published (FAO Yearbook of	Weight
	FAO	1961-present	Fishery Statistics)[3]	Weight
Sport				
California				
Local partyboat	CDFG	1936-40	Published (CDFG Fish Bull. 86)	Number
		1947-present	Published (Young, 1969)	Number
Long range partyboat	CDFG	1960-present		Number
Barge	CDFG	1947-present		Number
Private boat[1]	CDFG	1964	Published (Pinkas et al, 1968)	Number
Pier and jetty[1]	CDFG	1963	Published (Pinkas et al, 1967)	Number
Shoreline	CDFG	1965-66	Published (Pinkas et al, 1968)	Number
Mexico				
Partyboat	Voluntary (ESFA)[2]	1961, 1971		Number

[1]Program in progress 1973, 1974.
[2]ESFA-Ensenada Sport Fishing Association, supplied through Instituto National de Pesca (INP).
[3]Tend to lack sufficient specificity for stock assessment.

sampling of sport catches has been recently instituted by CDFG. The 1972 and 1973 length frequencies made available by it were a great benefit to the stock assessments. Where length frequency was lacking, reasonable estimates were again employed.

The second important parameter necessary for stock assessment is an index of stock abundance. Traditionally this is obtained by measuring effort and calculating catch-per-unit-effort (CPUE) which is presumably proportional to stock abundance[1]. Effort was available for commercial white seabass and for the southern California partyboat sport fishery in general, wherein no distinction was made between species sought.

Partyboat effort and CPUE were adjusted to account for the change in the unit of effort from "angler-days" to "anglers" (angler-trips) and for regional differences between sizes of fishing area (Table 3). Conversion ratios for adjusting effort for the period 1947 to 1960 were estimated from 1960 and 1961 data in which both units were recorded. The variation of conversion ratios within regions was much smaller than between regions. The ratios were significantly different between regions based on an analysis of variance with years as replicates ($F = 56.7, d.f. = 5, 6; P\ (F>4.39) = 0.05$). As a result effort was adjusted for each region separately.

Abundance indices were calculated from partyboat catch-effort data in three ways. First, annual catch divided by annual effort for all areas combined was called CPUE. This was used when comparisons with early years were desired, as only total California catch was available for 1936-40. Second, annual catch per annual effort for the San Diego region alone was used as a possible index of abundance, San Diego being presumably closest to the population centers of our migratory southern species. Third, a "CPUE index" was calculated as the weighted average of annual CPUE's of the six regions. Weights were determined by estimating the area of water less than 20 fathoms deep in the geographical area in which each region's effort was presumably exerted (Table 3). In view of lack of statistical information on geographical distribution of effort, arbitrary nonoverlapping areas were used. Effort according to CDFG block origins was consistent with effort reported from each landings region. The "CPUE index" was felt to be the best partyboat CPUE-based index of abundance in most cases, but no other comparable abundance indices were available to verify this.

[1]Recent studies suggest that CPUE may not be linearly proportional to population size.

Table 3.—Effort unit conversion and area weighting factor.

Region	Conversion[1]	Area weighting factor[2]
San Diego, Mission Bay	1.201	0.19
Dana Harbor, Oceanside	1.318	0.10
Huntington Beach, Balboa	1.121	0.05
San Pedro, Long Beach	1.271	0.12
Malibu, Redondo Beach, Santa Monica	1.591	0.11
Santa Barbara, Port Hueneme	1.010	0.43
Total, Southern California	1.215	1.00

[1]Anglers/angler day.
[2]Depth ≤ 20 fathoms.

Other abundance indices used in these investigations included aerial, acoustic, and egg-and-larva surveys, which are best for pelagic schooling fish. Squire's (1972) day and night aerial indices of abundance were recalculated to include only the southern California area (regions A and B were excluded). Acoustic surveys carried out by CDFG were useful in measuring anchovy abundance, but due to lack of sufficient overlap with egg-and-larva abundance surveys verification of acoustic estimates by correlation methods is unfeasible. Egg-and-larva surveys were also useful for jack mackerel and sardines. Recent CDFG tagging of jack and Pacific mackerel provided useful biomass estimates for those species.

Separation of stocks was given little emphasis as such problems could not be resolved with available data. Where geographical limits for stocks were lacking, all catches were assumed to have come from a single panmictic stock.

Population parameters such as those for growth, length-weight, and mortality were generally available from published sources or were in press. Where values were lacking, reasonable estimates were used, or, in the case of white seabass natural mortality, a new estimate (described in more detail later) was made from more recent data. Individual estimates and assumptions are generally noted in the sections in which they occur, but many escape discussion.

Methods

Wherever possible, stock status was determined by a surplus production or "Schaefer" model, which in practice consists of plotting abundance as catch per effort against a mean effort averaged over half the fishable lifetime of the fish (Gulland, 1970). Usually effort (fishing mortality) is assumed to be related to the amount of fishing done by the exploiting fleets. A total effort index may be derived from catches and abundance indices that are somewhat independent of the fishing fleets, such as the aerial index, as was done for Pacific bonito. The presumably steady-state relationship between effort and abundance will generally show as decreasing CPUE with increased effort. A line describing this relationship is sketched in, or a straight line (sometimes not best approximation) can be statistically fitted to the observations. An approximation of an equilibrium yield curve can then be calculated by multiplying together the coordinates of the equilibrium abundance line (catch per effort × g effort = catch), and plotting against the same effort axis as in the previous plot. This will usually give a concave downward paraboloid curve (a true parabola results from the straight-line fit mentioned previously), and estimated MSY corresponds to the peak of the yield curve. Extrapolation of the equilibrium yield curve beyond points of observation (particularly toward greater effort) should be interpreted with caution, as MSY's and corresponding effort levels obtained in this manner are very imprecise. For most of the stocks investigated in this study, MSY fell within the observed spread of values.

This approach assumes that CPUE, particularly sport CPUE, is proportional to stock biomass. Changes in gear efficiency (e.g., introduction of monofilament line in the mid 1950's) may increase catchability, and artificially increase CPUE. More important, CPUE is influenced by the availability of fish. The northern migration of game fish such as yellowtail and barracuda from their population centers off Baja California into southern California waters is greatly influenced by oceanographic conditions. The apparent abundance, measured by sport CPUE, depends in part on the extent of this northern migration. The large catches during the warm water years of the late 1950's are examples. For the purpose of this report, the data points for these years are treated as outliers in the surplus production models.

For relatively unfished stocks, where biomass is many times larger than catch, as in the case of jack mackerel and northern anchovy, the surplus production model cannot be applied. In this case, we have used Gulland's (1970) approximation of MSY based on unfished biomass and natural mortality, which is itself postulated on surplus production concepts.

The Gulland formula is $Y_{pot} = XMB_0$ where Y_{pot} is potential yield, M is instantaneous natural mortality rate, and B_0 is mean virgin biomass of fish above length at first capture. X is a coefficient which is determined by M, K (von Bertalanffy growth rate)[2], and length at first capture relative to maximum length. Values for X tend to fall around 0.5, which is a reasonable value if other parameters are unknown. Yield values obtained by this method are recognized as first approximations, to be revised by more precise methods as a time series of catch and effort (or abundance) is acquired.

In fisheries where spawner-recruit relationships are obscure and surplus production models give inconclusive results, we have attempted to investigate yield per recruit (Y/R) as a basis for evaluating minimum length restrictions. We found the short-cut yield tables in Beverton and Holt (1966) very useful for this purpose. Where multiple fisheries interaction raised a particular problem, as in the white seabass, a complex Y/R analysis (Lenarz, Fox, Sakagawa, and Rothschild, 1974) was employed.

NORTHERN ANCHOVY

This report of northern anchovy, *Engraulis mordax*, is an overview of the relationship between present harvest levels and potential yields of the stock. Further investigations of the complex interactions between resource uses, live bait, reduction, and sport fish forage are not considered for best allocation of resource. These are briefly discussed elsewhere in this document.

[2]The von Bertalanffy growth curve is $l_t = L_\infty (1-e^{-k(t-t_0)})$ where l_t is length at time t, L_∞ is asymptotic maximum length, k is a growth rate constant, and t_0 is hypothetical age at zero length.

Table 4.—Northern anchovy, biomass estimates and indices of abundance.

Year	Overall population: Egg and larval surveys: Ratio anchovy spawning biomass[1] (10^3t) (1)	Regression anchovy spawning biomass[1] (10^3t) (2)	Central stock (Southern California and northern Baja California): Spawning biomass[1] (10^3t) (3)	Acoustic survey: Annual mean of surveys[2] (10^3 schools) (4)	Aerial surveys: Night index[3] (5)	Aerial surveys: Day index[3] (6)	Spawning biomass extrapolated from regression between (3) and (5) (10^3t) (7)
1940	2,359						
1950	279						
1951	690	637	294				
1952	856	797	410				
1953	(1,404)	1,335	807				
1954	1,937	1,816	855				
1955	1,855	1,676	1,386				
1956	1,307	1,491	919				
1957	1,869	1,964	1,576				
1958	2,875	2,771	1,832				
1959	(2,418)	2,299	1,686				
1960		3,079	1,918				
1961		3,189	1,264				
1962		6,248	4,362		1.57	0.045	
1963		6,030	4,861		2.24	0.50	
1964		5,121	3,866		3.86	0.57	
1965		7,771	6,211		4,08	0.71	
1966		5,116	4,154	107	3.05	0.86	
1967				174	5.14	2.02	4,784
1968		(2,167)	(2,048)	195	1.35	0.30	
1969		3,378	2,993	103	4.39	1.34	
1970				56	[4](7.46)	[4](6.65)	
1971				101	3.23	1.26	4,166
1972				194	1.41	1.33	3,577
1973				275			
1974				(362)			

[1]After P. Smith, 1972, tables 9 and 12 and figure 13, and A. Vrooman and P. Smith, 1971, table 2. Column (1) is derived from a ratio of anchovy larvae to sardine larvae relative to estimated sardine spawning biomass; column (2) is derived from the regression of this estimated anchovy spawning biomass on anchovy larvae.
[2]Information provided by K. F. Mais, CDFG.
[3]After J. Squire, 1972, table 7, completed with recent yet unpublished data.
[4]Six months only.

Biomass

Estimates or indices of abundance for the northern anchovy have been obtained through various independent methods, i.e., egg-and-larva, acoustic, and aerial surveys (Table 4). Separate data are available by geographical areas, months, or quarters. According to estimates from eggs and larvae collected during 16 years, the subpopulation centered off southern California and northern Baja California (the central stock) makes up 66 percent of the overall total spawning biomass (range of annual values: 40-83 percent) but in years since 1963 the ratio has been about 80 percent. Acoustic surveys from 4 years confirm the above estimate (range 65-86 percent). Increase in the central stock accounts for the increase in total biomass of the northern anchovy since 1950 (Fig. 1). Because of this and its proximity to the California fishing fleet, only the central stock is considered here.

Estimates derived from egg-and-larva surveys, which may be our most reliable source, correspond only to the spawning biomass while data from other sources may include biomass of immature fish. Therefore, the estimates are not directly comparable. Insufficient information regarding age at first maturity does not permit precise assessment of the ratio of total biomass to spawning biomass. However, as the majority of fish appear to be mature at 1 year (Knaggs, CDFG[3]), which also corresponds to approximate age of recruitment to the fishery, exploited biomass should not be substantially higher than spawning biomass. As a first approximation, spawning biomass is used here as exploitable biomass. If it would be possible to expand exploitation upon juvenile stages, the exploitable biomass would exceed spawning biomass.

Various estimates and indices have been compared. Correlation coefficients

[3]E. Knaggs, CDFG, 350 Golden Shores, Long Beach, CA 90802. Pers. commun.

between the independent methods for years in which the surveys have coincided are given in Table 5. Correlations are in general not high and positive only in the case between estimates derived from egg-and-larva surveys and night aerial surveys. The apparent contradiction between acoustic surveys and night aerial surveys may result from the fact that these two methods do not actually sample the same portion of the overall biomass. Acoustic surveys may not suitably detect fish occurring close to the surface, while aerial surveys record only fish concentrations visible in the upper layer of the sea. An important source of error is the fact that sonar-based acoustic surveys have been employed only since 1969. Data for 1966 and 1967 have been inferred from echo-sounding surveys. The biomass estimates from the egg-and-larva surveys and indices from the aerial surveys are in more agreement particularly when night sightings are considered. As observed by Squire (1972), this may be due in part to higher efficiency of aerial surveys conducted at night as compared with daytime observations. A correlation coefficient cannot be calculated for egg-and-larva survey estimates and acoustic data because the time series do not overlap enough. On the other hand, acoustic estimates of biomass tend to agree with egg-and-larva estimates when schools are assigned an arbitrary—but likely—average value of 17 tons (Smith, 1970), or when expanded to volume and assigned a packing density of 50 fish/m^3 (Mais, pers. commun.). Considering general knowledge on reliability of egg-and-larva survey methodology, together with the extent of sampling done both in time and space, it is assumed that biomass estimates used here provide a picture of the stock sufficiently accurate for present assessment problems.

Table 5.—Comparison of biomass estimates and indices of availability obtained through various methods.

Source	Correlation coefficient	Years of observation
Acoustic surveys/ aerial surveys (night)	−0.47	1966, 67, 68, 69, 71, and 72
Acoustic surveys/ aerial surveys (day)	−0.08	1966, 67, 68, 69, 71, and 72
Egg-and-larva surveys/ aerial surveys (night)	+0.30	1962, 63, 64, 65, 66, 68, and 69
Egg-and-larva surveys/ aerial surveys (day)	−0.05	1962, 63, 64, 65, 66, 68, and 69

Table 6.—Northern anchovy catches in short tons.

Year	U.S. commercial	U.S. bait	Mexico commercial	Total
1973	110,885	(6,000)	10,613	(127,498)
1972	69,101	(6,000)	[1](60,000)	(135,101)
1971	44,853	6,387	(40,000)	(91,240)
1970	96,243	6,105	(55,000)	(157,348)
1969	67,639	5,314	4,258	77,211
1968	15,538	7,177	15,694	38,409
1967	34,805	5,387	22,115	62,307
1966	31,140	6,691	14,567	52,398
1965	2,867	6,148	10,088	19,103
1964	2,488	5,191	5,059	12,738
1963	2,285	4,442	1,039	7,766
1962	1,382	6,167	736	8,285
1961	3,856	5,913	(500)	(10,269)
1960	2,529	4,658	(500)	(7,687)

[1]Estimated from informal sources.

Table 7.—Central stock: biomass (*B*), annual catch (*C*), and fishing mortality (*F*) during the 1968-73 period.

Year	Central stock spawning biomass (10^3 tons)	Estimated annual catches (10^3 tons)	$F = \frac{C}{B}$
1968	2,048	59	0.03
1969	2,993	114	0.04
1970	—	157	—
1971	(4,166)	91	0.02
1972	(3,577)	135	0.04
1973	—	132	—

Indices derived from nighttime aerial surveys were regressed on concurrent estimates of the spawning biomass of the central stock to estimate the biomass in 1967, 1971, and 1972 (column 7, Table 4) for which no egg-and-larva surveys are available.

Catches

Catch statistics for the 1960-73 period are given in Table 6. These data refer to the central stock which is essentially the only one exploited. The mean lengths of the catches for successive years have decreased. The trend and year-to-year fluctuations can be caused by changes in recruitment and natural mortality rates, exploitation, and/or size selection of the fishery. (Average lengths of fish in catch[4]: 123.0 mm in 1965-66; 123.1 mm, 1966-67; 120.5 mm, 1968-69; 120.9 mm, 1969-70; 127.5 mm, 1970-71; 116.1 mm, 1971-72; and 116.0 mm, 1972-73.)

Maximum potential yield

Fishing mortality (F) can be derived from catch data and biomass estimates (Table 7). The F values confirm that the rate of exploitation has been very low. Considering that, as mentioned above, biomass estimates do not include the juvenile stages, fishing mortality may be lower than the average value of 0.03 observed from 1968 to 1972.

Total mortality has been calculated by MacCall (1973) from catch curves for 5 different years. The value of $Z = 1.1$ thus obtained indicates that natural mortality M cannot be smaller than 1.00-1.05. Spratt (1975) gives values of 0.3 and 165.5 mm (standard length) for von Bertalanffy growth curve parameters K and L_∞, respectively. The average size at first capture, l_c, is not exactly known, since recruitment occurs during a rather long period (affecting individuals from about 85 mm to 115

[4]From Messersmith (1969), Collins (1971), Spratt (1972, 1973a, b), and Sunada (1975).

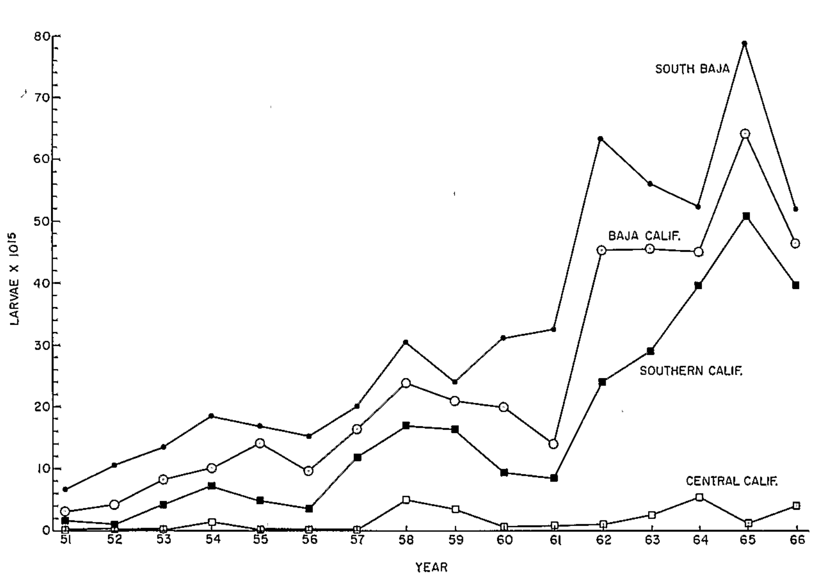

Figure 1.—Time series comparison of the annual total census estimates of anchovy larvae as grouped by coastal section (from Smith, 1972).

mm). In the following calculations, the value of 105 mm has been used.

Considering that the stock is very near to virgin state, Gulland's equation $Y_{pot} = XMB_0$ can be used for assessing the maximum potential yield. With $M/K = \frac{1.05}{0.3} = 3.5$ and $c = \frac{l_c}{L_\infty} = \frac{105.0}{165.5} = 0.63$, the coefficient X would be about 0.6 (Gulland, 1970, p. 3). The maximum potential yield should therefore be about 60 percent of the fishable biomass. As the latter has shown considerable fluctuations during the years under observation, several values of potential harvest can be derived (Table 8).

From the analysis of available data, it can be concluded that the central stock of northern anchovy can produce a yield from 10 to 20 times higher than present catches. There is some information that Mexico is considering development of its present production to about 500,000 tons, of which 200,000 tons would be caught by vessels operating from Ensenada. If this occurs, such vessels will most likely exploit the central stock. This target catch represents about one-eighth of the potential of the central stock as derived from biomass estimates for the period 1951-72 and about one-thirteenth of its potential when calculated for years following the collapse of the Pacific sardine stock. The USSR has also shown interest in offshore trawling for anchovies, with possible catch rates as high as 25,000 tons per ship-year. Their ultimate catches are likely to depend on success of the venture and the course of international law.

Size of first capture

On the basis of available values of M, K, l_c, and L_∞, yield per recruit tables indicate that a reduction of size at first capture would lead to considerable gain, if the fishery were unrestricted and if juveniles were fully vulnerable to fishing gear. For example, with the present rate of exploitation ($E = 0.05$), if the size at first capture were at 90 mm instead of the present assumed value of 105 mm, both annual yield and catch rates would, in theory at least, double. Because of the high rate of natural mortality of anchovy, even for high rates of exploitation (e.g., $F/Z \simeq 0.8$) maximum yields and catch rates would be achieved with sizes at first capture below 80 mm. Therefore at the present

level of exploitation, it does not seem reasonable from Y/R to implement in California regulatory measures aimed at limiting the size at first capture or the allowed landing sizes.

Conclusions

At present the potential yield of northern anchovy can be estimated at above 2 million tons. Remembering that biomass estimates used in this appraisal include only the spawning population, this resource may even be substantially larger than in the figures given in Table 8. Because of high natural mortality of anchovy, there is no need to limit the size at first capture in California at the present level of harvest. In this context, it should be stressed that the stock apparently shows very large year-to-year fluctuations. Therefore, in the event that substantially higher levels of exploitation are considered, careful monitoring of the stock abundance and size composition would be essential in order to prevent overexploitation during periods of successive low recruitment.

BARRACUDA

The California barracuda, *Sphyraena argentea*, fishery has undergone a long decline, beginning in the 1930's and ending with the present virtual extinction of a commercial fishery and the maintenance of a stable but unacceptable sport fishery in which only small fish are available. Here we attempt to assess the present status of the stock.

Data

Catch records for barracuda are similar to those of other recreational species. Long time series of catch records in weight are available for U.S. commercial fisheries operating in California waters and off Mexico, and records in number for California partyboat catch and Mexican commercial catches are known since 1966. Catches for other fishery segments were estimated from data for specific years as footnoted in Table 9. Sport fish catches were converted to weights by using available length frequency data and the length-weight curve given by Walford (1932), and from weight given by Baxter and Young (1953). Length frequency data for the California partyboat fishery are available for the years 1958, 1959, 1960, and 1961 (Pinkas, 1966) and 1972 and 1973 (D. L. Schultze, CDFG pers. commun.). The 1972 and 1973 samples are not representative of the landings because undersized fish that were released after capture were included. A constant 4.9 pounds/fish was assumed for the 1936-51 period (Baxter and Young, 1953). No weight samples are available for the period from 1952 to 1957. Mean weight values for the sport-caught fish were not assumed for this period because the fishery declined during these years but immediately increased with the start of the warm water years. Mean weights of 4.16, 3.87, 2.64, and 2.59 pounds/fish for 1958, 1959, 1960, and 1961 respectively were estimated from mean lengths given in Pinkas (1966). An estimate of 2.6 pounds/fish based on the 1961 samples was applied to all following years through 1970. Because the two undersize fish (less than 28 inches) allowance in the bag limit was eliminated, a value

Table 8.—Biomass and corresponding potential yields for the total population and the central stock for 1) the 20-year period of observation and 2) after the depletion of Pacific sardine stock.

Time period	Population	Biomass mean and range (10^3 tons)	Corresponding potential yields (10^3 tons)
1951-69	Total	3,200 (640-7,800)	1,900 (400-4,700)
1951-72 after sardine collapse	Central stock	2,600 (290-6,200)	1,500 (200-3,700)
1965-69	Total	4,600 (2,200-7,800)	2,800 (1,300-4,700)
1965-72	Central stock	4,000 (2,050-6,200)	2,400 (1,200-3,700)

Table 9.—Catches of California barracuda for various fisheries.

Years	U.S. commercial California (lb)	U.S. commercial Mexico (lb)	Mexico commercial (lb)	Sport Partyboat California (fish)	Sport Other California (fish)[1]	Sport Mexican waters (fish)[2]	Sport Total (fish)	Sport Total est. weight (lb)	Total commercial and sport (lb)	Fraction sport
					× 1,000					
1928	4385.2	2067.2								
1929	3925.9	1302.7								
1930	3513.6	1250.2								
1931	3336.1	841.5								
1932	2505.1	421.7								
1933	2912.2	160.8								
1934	1801.3	381.6								
1935	2003.9	613.9								
1936	2247.9	730.0		492.5			(500)	(2450)	(5428)	0.45
1937	1799.0	1139.4		598.5			(600)	(2940)	(5878)	0.50
1938	1260.8	1269.0		314.2			(320)	(1568)	(4098)	0.38
1939	2969.2	1122.8		663.5			(670)	(3283)	(7375)	0.44
1940	2545.4	1151.9		704.5			(710)	(3479)	(7176)	0.48
1941	2971.3	1230.6							(4202)	
1942	2243.2	1211.4							(3455)	
1943	2382.8	1392.5							(3775)	
1944	2317.3	1330.9							(3648)	
1945	1744.6	2110.7							(3855)	
1946	1636.1	1470.4							(3107)	
1947	1695.9	969.9		677.4	(10)	(10)	(697)	(3415)	(6081)	0.56
1948	1100.1	1025.7		384.1	(20)	(20)	(424)	(2078)	(4204)	0.49
1949	903.6	1570.3		366.4	(30)	(30)	(426)	(2087)	(4561)	0.46
1950	890.4	1368.0	(0)	256.4	(33.7)	(41.0)	(331.1)	(1622.4)	(3880.8)	0.42
1951	670.0	1436.9	(10)	269.5	(35.4)	(51.2)	(356.1)	(1744.9)	(3851.8)	0.45
1952	747.7	1346.5	(20)	336.9	(44.3)	(74.1)	(455.3)	(1365.9)		
1953	565.9	872.9	(30)	170.6	(22.4)	(37.5)	(230.5)	(691.5)		
1954	485.9	1076.8	(40)	282.6	(37.1)	(79.1)	(398.8)	(1196.4)		
1955	322.8	818.1	(50)	155.0	(20.4)	(48.0)	(223.4)	(670.2)		
1956	50.2	702.4	(60)	87.6	(11.5)	(29.8)	(128.9)	(386.7)		
1957	387.1	295.5	(60)	577.2	(75.9)	(213.6)	(866.7)	(2600.1)		
1958	753.3	162.0	(60)	782.8	(102.9)	(313.1)	(1198.8)	(4987.0)	(5962.3)	0.84
1959	1110.4	42.2	(60)	1195.6	(157.2)	(478.2)	(1831.0)	(7086.0)	(8298.6)	0.85
1960	1147.8	81.8	(60)	755.4	(99.3)	(302.2)	(1156.9)	(3064.2)	(4353.8)	0.70
1961	478.4	231.0	(60)	391.9	(51.5)	111.4	(554.8)	(1446.3)	(2215.7)	0.65
1962	521.8	224.7	79.5	335.5	(44.1)	(134.7)	(514.3)	(1337.2)	(2163.2)	0.62
1963	347.4	31.4	41.4	483.7	(63.6)	(193.8)	(741.1)	(1926.9)	(2347.1)	0.81
1964	251.0	83.1	99.8	303.1	(39.8)	(122.8)	(465.7)	(1210.8)	(1644.7)	0.75
1965	273.0	89.1	60.3	443.3	(58.3)	(178.3)	(679.9)	(1767.7)	(2190.1)	0.81
1966	233.3	85.8	61.9	892.7	(117.3)	(358.4)	(1368.4)	(3557.8)	(3938.8)	0.90
1967	281.2	32.0	32.8	470.5	(61.8)	(190.4)	(722.7)	(1879.0)	(2225.0)	0.84
1968	114.5	26.0	14.4	372.2	(48.9)	(150.4)	(571.5)	(1485.9)	(1640.8)	0.91
1969	70.8	3.8	9.2	358.5	(47.1)	(149.3)	(554.9)	(1442.7)	(1526.5)	0.95
1970	22.5	2.1	3.3	373.8	(49.1)	(154.2)	(577.1)	(1500.5)	(1528.4)	0.98
1971	17.3	0.0	6.6	50.5	(6.6)	194.7	(251.8)	(638.6)	(662.5)	0.96
1972	13.9	0.0	(5)	38.2	(5.0)	(154.0)	(197.2)	(591.6)	(610.5)	0.97
1973	37.6	0.0	(15)	92.5	(12.2)	(370.9)	(475.6)	(1426.8)	(1479.4)	0.96

[1]Other California sport landings estimated as 0.1315 California partyboat landings.
[2]Mexican sport landings estimated as long-range partyboat catch plus 0.4 (declining to 0.16 from 1958 to 1950) of California partyboat landings.

of 3.0 pounds/fish was used for 1971, 1972, and 1973. Length frequency data are also available for the California commercial fisheries for the years 1928 (Walford, 1932), 1958, 1959, 1960 (Pinkas, 1966), and 1973 (D. L. Schultze, CDFG, pers. commun.)

California partyboat records on catch and angler effort provide the only index of abundance. The aerial survey (Squire, 1972) recorded too few sightings of barracuda to be useful. Egg-and-larva surveys gather barracuda larvae but the data as of yet have not been processed. It is not known if the observations are sufficient to provide an index of abundance.

Historical trends

Total landings of barracuda have generally declined since the mid-1930's except for short term peaks in 1966 and in the warm water years of 1957-60 (Figure 2). The U.S. commercial fishery landed an annual average of 3,800 short tons of barracuda during 1920-25. These decreased to 1,400 tons annually for the years 1932 through 1938, and then increased to 1,900 tons for 1939-45. After 1945 the commercial catches steadily declined to the present level of 5-20 tons. However, from the beginning of sport fishing records in 1936, sportsmen consistently landed approximately 1,200 tons annually prior to 1952. During the warm water years, when barracuda were considerably more available, annual sport catches ranged from 1,300 to 3,500 tons. Prior to 1951 the sport catch amounted to 46 percent of the total landings but since 1968 it has made up more than 90 percent of the total.

Examination of the length frequency samples from U.S. commercial and from partyboat fisheries suggests that the barracuda stock presently lacks the larger size groups (Figs. 3, 4). The length frequencies for the commercial fishery may differ somewhat due to changes in fishing gear. The method of capture was predominantly purse seines in 1928, gill nets and jigs from 1958 to 1960, and gill nets in 1973. Since samples for years 1952 to 1957 do not exist, it is not known if the above trend started in the early 1950's or early 1960's. The warm water years are associated with an extensive northward migration of the barracuda population. Occurrence of large fish in these samples may be a result of this migration. The decline in frequency of larger fish may have paralleled the decline in catch rather than the abrupt change suggested by the length frequencies available. In any event, the

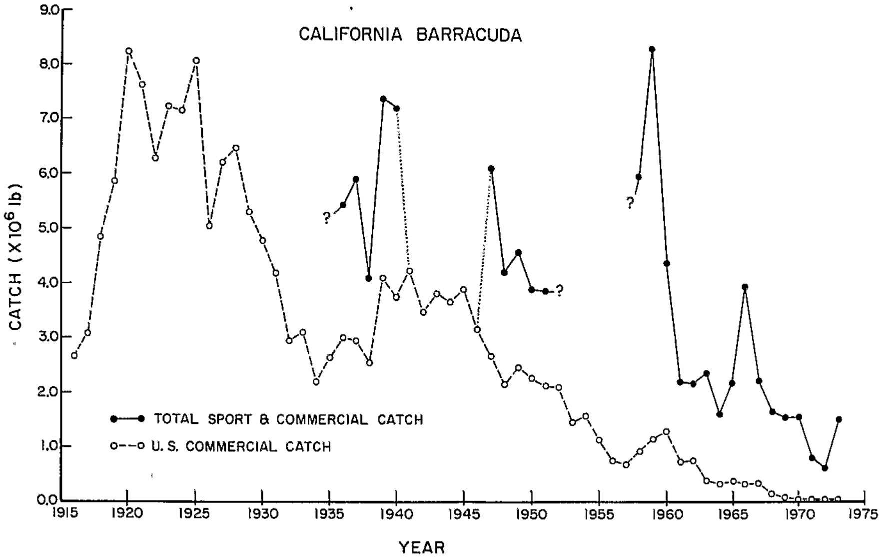

Figure 2.—California barracuda U.S. commercial landings (1916-1973) and estimated total landings (1936-1973).

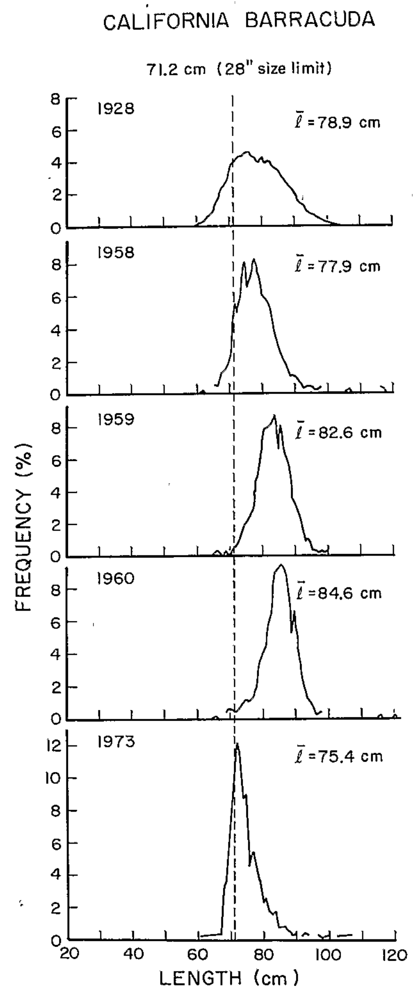

Figure 3.—Length frequencies for California barracuda from U.S. commercial fishery for 1928 (Walford, 1932), 1958, 1959, and 1960 (Pinkas, 1966) and 1973 (D. L. Schultze, CDFG, pers. commun.)

fishery has harvested the younger age groups, particularly 2-, 3-, and 4-year old fish in recent years.

The number of sport-caught undersize barracuda permitted per bag has been altered a number of times. Between 1933 and 1949 sport fishermen were allowed not more than five fish weighing less than 3 pounds each. Between 1949 and 1957 the undersize allowance was five fish less than 28 inches. These size limits were effectively identical since a 28-inch barracuda weighs approximately 3 pounds (age 5 years). The allowance was reduced to two undersized fish per bag in 1957. In March 1971 the possession of barracuda under 28 inches was prohibited altogether. As it is illegal to possess undersize barracuda, sport fishermen release a large number of undersize fish as indicated in length frequency samples for 1972 and 1973 (Fig. 4). If the released fish have poor survival, the beneficial effect on the stock may be reduced and/or retarded.

The CPUE (Σ catch in weight/ Σ anglers) for the U.S. partyboats has two periods of extreme highs, the years prior to 1948 and the warm water years (Fig. 5). If these extremes are eliminated, the two remaining sequences are somewhat level. On the other hand each segment shows a decline in itself.

The CPUE index in numbers of fish for all regions combined was compared to the CPUE for the San Diego region

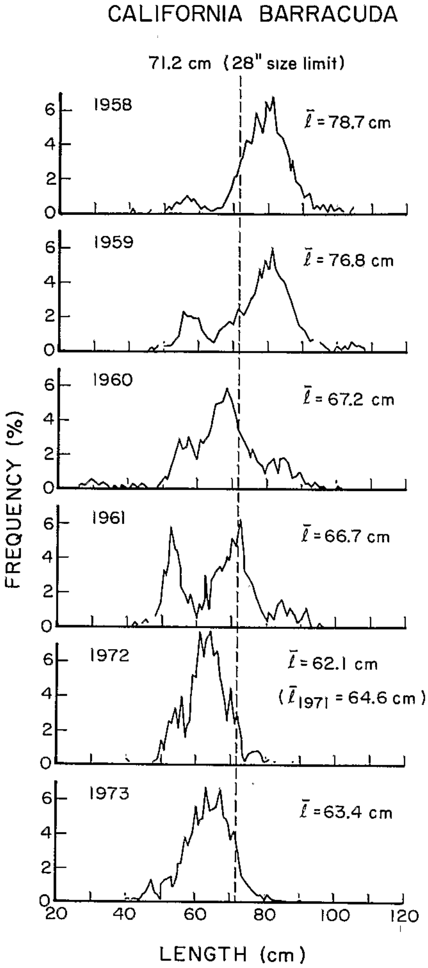

Figure 4.—Length frequencies for California barracuda from U.S. commercial partyboats for 1958, 1959, 1960, 1961 (from Pinkas, 1966) and 1972 and 1973 (D. L. Schultze, CDFG, pers. commun.)

only (Fig. 6). For many of the years, the points lie well above the 1:1 line, which means that the sport catch rate was high in the San Diego region, yet relatively low overall. This suggests that the barracuda migrations in the early 1950's

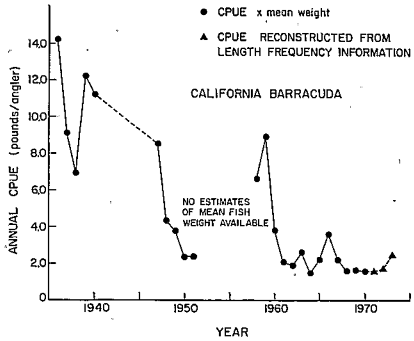

Figure 5.—California barracuda partyboat CPUE for years 1936-1970.

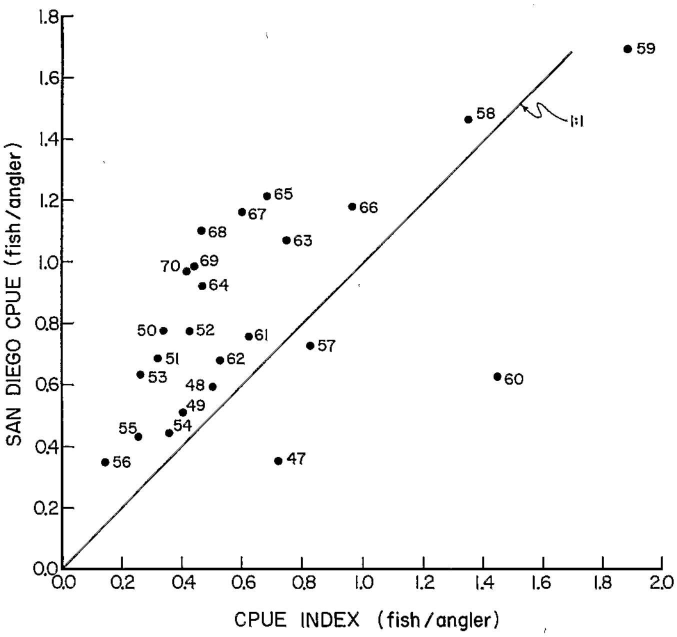

Figure 6.—Comparison of partyboat CPUE for San Diego region with CPUE index for all regions combined for California barracuda, 1947-70.

and late 1960's may not have extended fully into the southern California fishing grounds.

Since World War II the price of barracuda per pound (adjusted by the wholesale price index) paid to fishermen, has remained relatively constant (Fig. 7). The price did drop during warm water years when the supply was high. In recent years of very low supply the price has increased. As market price did not increase during the long-term decrease in landings, there was little economic incentive to maintain a fishery at the level of the early 1950's.

Stock assessment

Pinkas' (1966) study on the California barracuda utilized a Beverton and Holt dynamic pool model to investigate optimum minimum size in relation to yield per recruit. Maximum yield per recruit was estimated to occur at an age at first capture of 5 years, or approximately 28 inches minimum length. This length restriction also should have helped insure the reproductive capacity of the stock as the onset of sexual maturity occurs at age 2 for most individuals (Walford, 1932).

Commercial fishing has observed a 28-inch minimum size since the 1930's. Sport fishing has also had a 28-inch size limit but with the provision that a certain number of undersized fish could be kept (five under-sized fish from 1933 to 1957, and two under-sized fish to 1970).

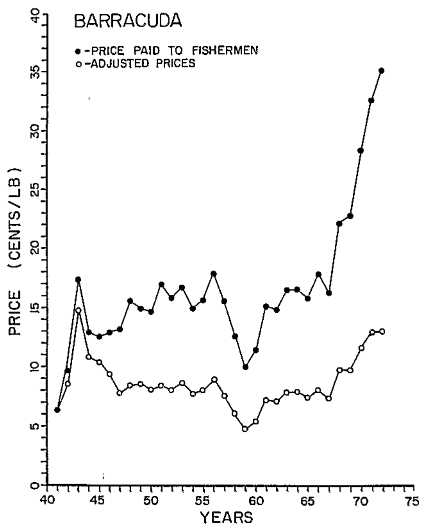

Figure 7.—Commercial ex-vessel prices for barracuda adjusted by wholesale price index, 1941-71.

Before the mid-1950's the undersize fish allowance should have had relatively little effect on yield, since the sport fishery accounted for only 30-40 percent of the total catch and large fish were presumably in abundance. By the late 1960's however, the sport fishery accounted for more than 90 percent of the landings, and fish larger than 28 inches had become relatively scarce, so that the bulk of the landings was composed of fish under 28 inches in length. In March 1971 the undersized fish allowance was abolished, making the theoretically optimum size limit effective once again.

Yield per recruit considerations, however, do not explain the observed trends in the catches, nor do they indicate the present status of the stock. In order to ascertain recent levels of exploitation with regard to catch and effort, Schaefer model analysis was attempted.

Various indices of CPUE were examined for application to the model. As previously discussed, distribution patterns have varied, with the migration not extending much north of San Diego in some years. Thus we have calculated CPUE as total annual partyboat catch of barracuda divided by total annual partyboat effort for southern California, multiplied by estimating average weight per fish to get CPUE in weight. This procedure allowed inclusion of 1936-40 partyboat catch information, which, while of relatively poor quality, provides the only "fix" on earlier levels of exploitation. Total effort is then estimated as total landings divided by CPUE. Using Gulland's approach, effort is averaged over half the fishable lifespan, hence we used 3-year averages.

As each minimum size (or characteristic length frequency) results in a different equilibrium line in the Schaefer model, the observed data points are difficult to interpret (Fig. 8). The southern California sport fishery exploits a fringe of the stock, with oceanic temperature strongly influencing availability (Radovich, 1962, 1975). Such changes in availability result in a variable relationship between nominal sport fishing effort and actual fishing mortality rate. Four groups are apparent, corresponding to different, presumably homoge-

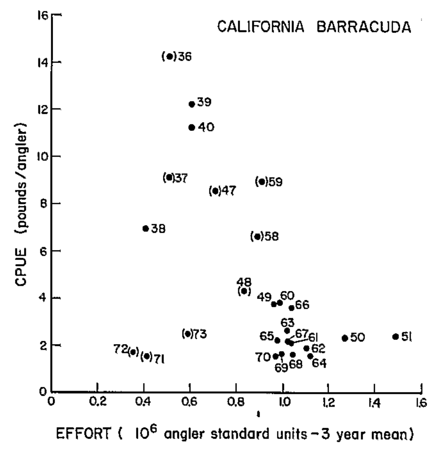

Figure 8.—California barracuda partyboat CPUE (pounds/angler) versus nominal effort (standard angler units) for 1936-73 (see text for calculation of effort for 1971-73).

neous, periods in the fishery. Data points for the late 1930's comprise a loose group included primarily for the purposes of establishing a basic relationship between catch and effort for the earlier years of the fishery. Tentative values for 1936 and 1937 are shown. Presumably an effective minimum length of 28 inches was in effect during the late 1930's (mean annual catch = 3,000 short tons). A second group, comprised of years 1947 to 1951, is characterized by declining catches (mean annual catch = 2,300 tons) and probably a minimum effective size limit of about 28 inches. The third group is composed of observations from the 1960's, a fairly stable period in effort and landings (mean annual catch = 1,200 tons), however, with an effective minimum length considerably shorter than 28 inches. The higher CPUE for 1960 may be the result of successful local spawning in previous years as suggested by the large numbers of small barracuda in the 1960 length frequency (Fig. 4).

Imposition of a strict 28-inch minimum size limit in March 1971 resulted in a sharp drop in reported partyboat catch, although the number of anglers fishing was unchanged. To adjust CPUE to pre-1971 conditions, partyboat CPUE values were increased by the ratio of total fish caught to fish of legal size (Fig. 4). This ratio was estimated from length frequency sampling done aboard partyboats. For purposes of this analysis, the length restriction resulted in decreased fishing mortality of younger fish, which takes the form of reduced "effort" in Figure 8, according to the formula: $f' = C / CPUE_{est}$, where f' is a derived measure of effort, presumably proportional to fishing mortality, C is total landings of all fisheries segments, and $CPUE_{est}$ is as described above. In this case, C is smaller than the catch used to calculate CPUE, and f' is smaller than actual number of anglers fishing. In Figure 8, the years 1971, 1972, and 1973 were thus moved to the left of the earlier group. With time, we expect to see the points progress toward the upper right, as fish landed show increasing mean weight. This should increase CPUE, and simultaneously increase the proportion of legal fish to fish caught, which will increase "effort" as it has been defined here.

Table 10.—Annual catches of Pacific bonito by main fishery segments.

Year	U.S. commercial: Calif. (10³ lb)	U.S. commercial: Mexico (10³ lb)	Mexico[1] commercial (10³ lb)	Sport: Partyboats Calif. (10³ fish)	Sport: Other Calif.[2] (10³ fish)	Sport: Mexican waters[3] (10³ fish)	Sport: Total (10³ fish)	Sport: Total (10³ lb)	Total Comm. and sport (10³ lb)
1950	33	662	(0)	2.4	(2.1)	(0.1)	(4.6)	(14)	(709)
1951	54	723	(0)	14.5	(13.1)	(0.8)	(28.4)	(85)	(862)
1952	8	2,135	(0)	7.6	(6.9)	(0.5)	(15.0)	(45)	(2,188)
1953	19	3,084	(0)	6.3	(5.7)	(0.5)	(12.5)	(38)	(3,141)
1954	219	2,100	(0)	70.1	(63.4)	(6.1)	(139.6)	(419)	(2,738)
1955	40	100	(0)	22.4	(20.3)	(2.2)	(44.9)	(135)	(275)
1956	22	105	(0)	61.4	(55.5)	(6.0)	(122.9)	(369)	(496)
1957	110	109	(25)	258.6	(233.7)	(30.3)	(522.6)	(1,568)	(1,812)
1958	4,805	742	(50)	422.6	(382.0)	(49.4)	(854.0)	(2,562)	(8,159)
1959	3,003	9	(75)	776.4	(701.1)	(90.8)	(1,568.3)	(4,705)	(7,792)
1960	1,220	31	(100)	1,199.9	(1,083.5)	(140.4)	(2,423.0)	(7,270)	(8,621)
1961	8,439	74	(163)	849.4	(767.0)	(119.7)	(1,736.1)	(5,208)	(13,884)
1962	2,072	63	67	798.7	(730.2)	(94.3)	(1,623.2)	(4,870)	(7,072)
1963	4,014	9	1,118	775.7	(662.4)	(91.7)	(1,529,8)	(4,589)	(9,730)
1964	2,606	6	1,125	1,298.8	(1,172.8)	(152.7)	(2,624.3)	(7,873)	(11,610)
1965	5,633	6	735	806.3	(728.1)	(96.0)	(1,630.4)	(4,891)	(11,265)
1966	18,308	840	2,044	644.4	(581.9)	(76.2)	(1,302.5)	(3,908)	(25,100)
1967	17,842	3,378	1,343	350.0	(316.0)	(42.3)	(708.3)	(2,125)	(24,688)
1968	14,903	19	779	1,102.9	(996.0)	(131.6)	(2,230.5)	(6,692)	(22,393)
1969	13,175	4,027	147	1,130.2	(1,020.6)	(139.9)	(2,290.7)	(6,872)	(24,221)
1970	8,794	399	(163)	651.9	(588.7)	(78.3)	(1,318.9)	(3,957)	(13,313)
1971	10,476	9,793	(325)	152.8	(137.8)	(16.7)	(307.3)	(922)	(21,516)
1972	15,600	6,712	(325)	419.0	(377.8)	(53.6)	(850.4)	(2,551)	(25,188)
1973	18,477	12,263	710	472.5	(426.1)	(60.5)	(959.1)	(2,877)	(34,327)

[1]Source: FAO Yearbook of Fishery Statistics, and catch data furnished by Instituto Nacional de Pesca.
[2]Estimated by Thayer (1973, table 3) less reported partyboat catch.
[3]Sum of estimated Ensenada partyboat catch (est. catch = 0.117 California partyboat catch, based on mean of 1961 and 1971 reported catches, with smaller ratio for earlier years: linearly decreasing from 1958 to 2/5 of ratio in 1950) and California long range partyboat catch.

Although it is possible to draw a curve through the six points from year groups one and two, such a line would probably not be a valid equilibrium curve because of the changing nature of the fishery. From the examination of the time series of catches and length frequencies, it appears that the barracuda resource was fully exploited in the late 1930's and quite heavily overexploited by the 1960's. The decline of the stock may have partly resulted from recruitment failures. The large catches during the warm water years, which were facilitated by an influx of fish into California waters, almost certainly accelerated the decline in the 1960's. It may take several years for the stock to regenerate its number from the increased spawning potential afforded by strict maintenance of a 28-inch minimum length. The unrestricted Mexican fishery and lowered survival of returned undersized fish must be expected to have dampening effects on rehabilitation of the fishery, but the end result should be an improved angler CPUE and overall yield of combined fisheries over what would be expected without the size limit.

PACIFIC BONITO

After an absence of several years, the Pacific bonito, *Sarda chiliensis*, returned in numbers in southern California waters in the latter half of 1956. Both sport and commercial fisheries presently exploit this resource virtually unchecked. Knowledge of potential sustainable yields and fisheries interactions is lacking, making an attempt at stock assessment vital.

Data

Long time series of catch statistics are available for the U.S. commerical fleet (in weight) and for the U.S. partyboats (in numbers of fish caught). Since 1961 Mexican commercial catches are regularly reported in the FAO *Yearbook of Fishery Statistics* and catches for 1962-69 and 1973 were furnished by the Instituto Nacional de Pesca (INP). For the other segments of the fishery, information is much more scanty. However, total annual catches (Table 10) were reconstructed for the period 1950-73 on the basis of specific annual catches occasionally reported for some particular segments of the fishery, general knowledge on the relative importance of respective fishery sections, and known or assumed trends in their historical development. In 1973 U.S. commercial and sport catches—with distinction made between catches taken off California and off Baja California—were regularly sampled for length frequency (Fig. 9). Length distributions for U.S. sport fishery and available weight/length relationships (Campbell, in press) were used for converting catch in numbers to weight. The conversion was done using an average weight of 3 pounds/fish (1973 partyboat average weight was 2.87 pounds), which has been the usual conversion used by CDFG. Also, the long-range partyboat catch, while taking considerably larger fish, accounts for less than 1 percent of the total catch, and does not need to be included in the calculation. Lack of length frequency information for earlier years necessitates the use of a constant mean weight estimate.

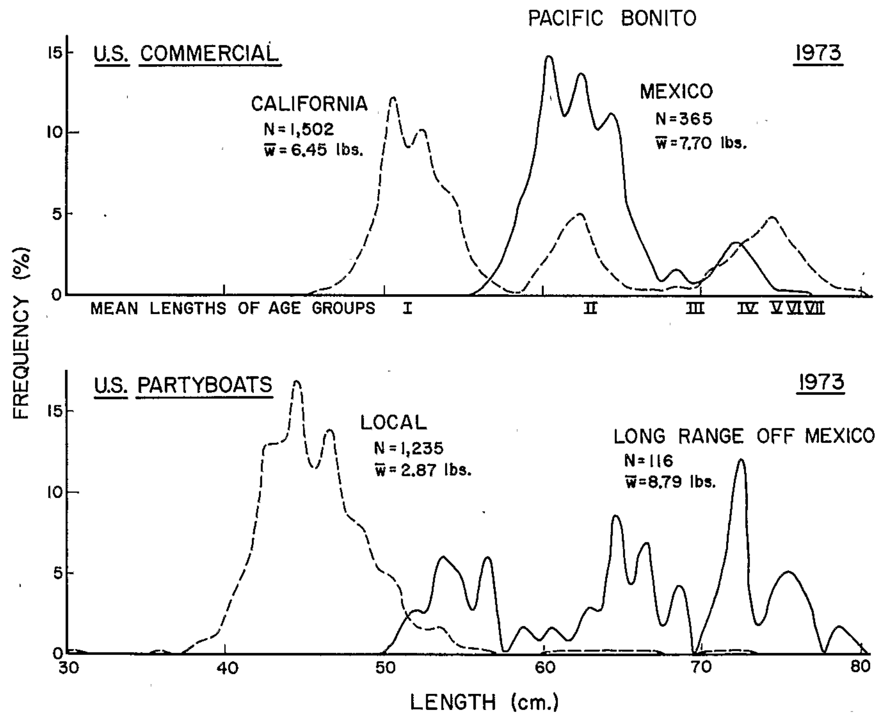

Figure 9.—Pacific bonito length frequency distributions for U.S. catches by fleet and location for 1973.

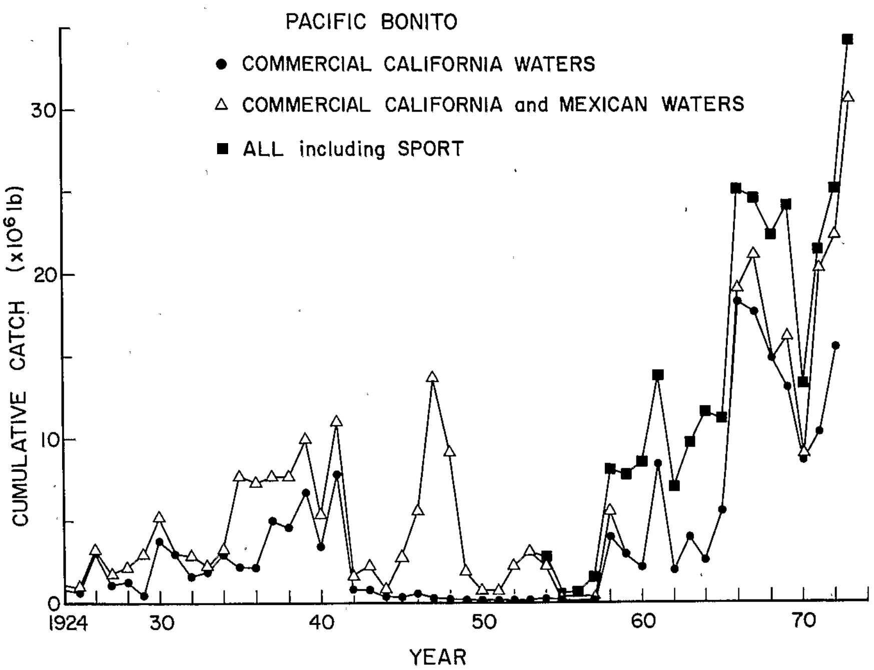

Figure 10.—Historical development of the Pacific bonito fishery: total catches of major fishery segments.

The CPUE (in numbers of fish caught per angler) data are also available for the partyboats. Source data were processed as follows:

1) Annual $\left(\frac{\Sigma C}{\Sigma f}\right)$ for all southern California areas combined.

2) Weighted mean, (or CPUE index)

$$\frac{\sum\left[a_i\left(\frac{\Sigma C}{\Sigma f}\right)_i\right]}{\Sigma a_i}$$, with weighting factor proportional to the area (0-20 fathoms), a_i, of six respective statistical divisions (described in Table 3).

Indices of apparent abundance, derived from aerial surveys, are available for the period 1962-72 (Squire, 1972).

Trends of fishery segments

As illustrated in Figure 10, until about 1957-58, catches as a whole were at a rather low level—although showing marked oscillations. They subsequently increased in two steps. The first, from late 1950's to mid-1960's, corresponded to the development, both in Mexico and California, of sport catches. The second, beginning in the mid-1960's, corresponded to an expansion of U.S. commercial landings (Table 10).

From length frequency distributions of U.S. catches sampled in 1973 (Fig. 9), it is clear that the various fishery sections exploit different parts of the population. Such segregation in sizes caught reflects an uneven geographical distribution of various age groups. Roughly, older fish are more available offshore and in Mexico, although large fish are taken in the Santa Barbara area in the fall. The local U.S. sport fishery essentially takes individuals less than 60 cm (age 1). Long-range U.S. partyboats harvest older fish, but make a small contribution to the sport catch. Commercial vessels tend to take larger fish: 1 year old and above off California, 2 years old and above off Mexico.

Sport fishery and recruitment to commercial fishery

Indices of apparent abundance have been derived by Squire (1972) from tonnages of bonito estimated during aerial surveys (Table 11). Day and night indices have been calculated separately. Since the 1962 source data covered the last period of the year only, indices for that year were discarded in the following analyses. The aerial survey indices have been recalculated to exclude the area north of Pt. Conception in order to correspond with other biomass estimates, particularly southern California partyboat CPUE for bonito.

A number of correlations between aerial survey indices and partyboat CPUE—with various yearly lag times and combination—were calculated (Table 11). Highest values of the correlation coefficient (r) were found with indices derived from daytime observations. Squire (1972) felt that daytime aerial observations were more efficient than night observations for estimating bonito abundance. The highest correlation was observed between partyboat CPUE and daytime aerial index 3 years later (Fig. 11). Taking into account age composition of catches made by sport and commercial fisheries respectively (Fig. 9) and the fact that airplanes are mainly assisting the commercial fishery and therefore likely concentrate their surveys over commercial fishing grounds, it is reasonable to assume that aerial surveys mainly reflect changes occurring in that part of the bonito stock exploited by commercial vessels, while partyboat CPUE provides an index of prerecruit abundance before they start to be exploited by the commercial fleet. However, there is not an exact 3-year lag in age composition of partyboat and commercial catches. Moreover, while partyboats may essentially exploit a single age group, commercial vessels exploit several age groups. In order to account for mortality, plus selectivity by commercial fishing, various reasonable combinations of partyboat CPUE (in numbers) over years were tentatively correlated with daytime aerial survey indices. The highest correlation (r = 0.71) was found for the combination:

$$\text{Day } AI_i \propto \tfrac{1}{4}\, CPUE_{i-1} e^{-i} + \tfrac{1}{2}\, CPUE_{i-2}\, e^{-2} + \sum_{j=3}^{4} CPUE_{i-j} e^{-j}$$

(Fig. 12).

(A value of 1.0 was arbitrarily used for Z.) This formula attempts to relate abundance as measured by the daytime aerial index (day AI) to the history of recruitment as measured by partyboat CPUE index values. The CPUE's were multiplied by coefficients to account for mortality and recruitment (25 percent and 50 percent were used for the younger age groups).

Table 11.—Aerial survey indices, partyboat CPUE, and correlations between various combinations of CPUE and aerial indices.

$Year_i$	Aerial survey: Day index	Aerial survey: Night index	Partyboat CPUE index: $CPUE_i$	$CPUE_{i-1}$	$CPUE_{i-2}$	[1]$CPUE_{i-3}$	$CPUE_{i-4}$	A	B	[2]C
1963	1.71	0.85	1.53	1.63	1.73	1.87	1.20	0.95	0.65	0.38
1964	1.80	0.31	2.41	1.53	1.63	1.73	1.87	0.90	0.62	0.37
1965	1.48	0.22	1.53	2.41	1.53	1.63	1.73	1.21	0.76	0.44
1966	1.49	0.37	0.96	1.53	2.41	1.53	1.63	1.00	0.71	0.41
1967	1.03	0.49	0.50	0.96	1.53	2.41	1.53	0.71	0.53	0.34
1968	0.54	0.31	1.28	0.50	0.96	1.53	2.41	0.43	0.34	0.23
1969	0.28	0.18	1.46	1.28	0.50	0.96	1.53	0.61	0.38	0.23
1970	0.01	0.10	0.74	1.46	1.28	0.50	0.96	0.75	0.48	0.26
1971	0.56	0.21	0.23	0.74	1.46	1.28	0.50	0.54	0.41	0.24
1972	1.11	0.20	0.59	0.23	0.74	1.46	1.28	0.28	0.24	0.17
r day	—	0.58	0.50	0.39	0.60	0.69	0.26	0.56	0.64	0.71
r night	0.58	—	0.20	0.15	0.44	0.66	0.07	0.30	0.40	0.46

A: $\sum_{j=1}^{4} CPUE_{i-j} e^{-j}$

B: $\tfrac{1}{2}\, CPUE_{i-1} e^{-1} + \sum_{j=2}^{4} CPUE_{i-j} e^{-j}$

C: $\tfrac{1}{4}\, CPUE_{i-1} e^{-1} + \tfrac{1}{2}\, CPUE_{i-2} e^{-2} + \sum_{j=3}^{4} CPUE_{i-j} e^{-j}$

[1]These are plotted in Figure 3.
[2]These are plotted in Figure 4.

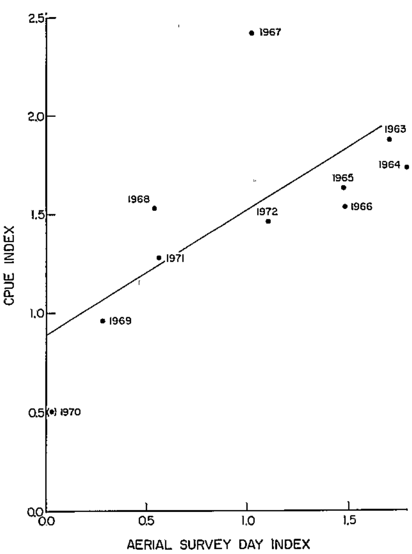

Figure 11.—Regression of aerial survey day index against partyboat CPUE index 3 years earlier.

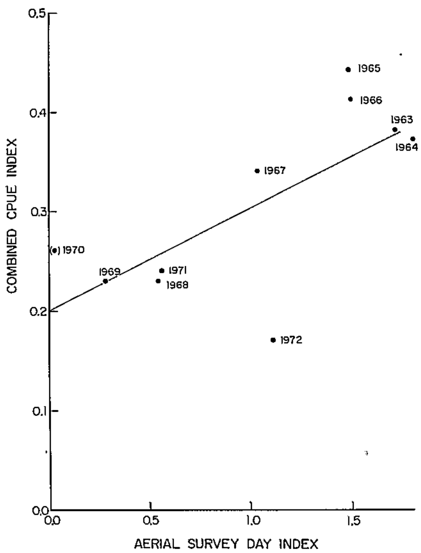

Figure 12.—Regression of aerial survey day index against CPUE adjusted for mortality and recruitment.

Although 1973 length frequency samples from the partyboat catch are dominated by a single age group, this may not have been the case in earlier years. Consequently, partyboat CPUE may reflect the spectrum of age groups available to the commercial fishery (or more precisely, the aerial index) 3 years later rather than reflect the recruitment strength of a single year class as suggested by the 1973 frequencies. In either case, partyboat CPUE appears to be a valid indicator of recruitment to the commercially exploitable phase for recent years. The history of CPUE values (Fig. 13) indicates recruitment, from presumably local spawning, was very low before 1957, after which it sharply increased.

Annual catches of 1,000-4,000 tons of bonito were taken commercially from California waters between 1926 and 1941, but information on the effort required to make those catches is lacking. Between 1942 and 1957 annual catches were very low, never exceeding 500 tons and often below 50 tons. Partyboat CPUE of bonito was low before 1956. Reporting of bonito-like species by partyboats was fairly good (Pacific mackerel, 90 percent; "other species," 68 percent) in the period 1947-51 (Baxter and Young, 1953). During the 1920's and 1930's, bonito were commonly caught from fishing piers along the coast and from fishing barges anchored offshore (J. Radovich, pers. commun.).

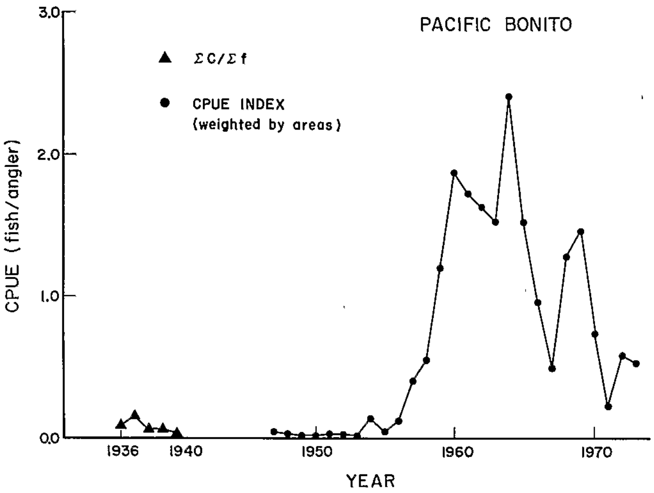

Figure 13.—Partyboat CPUE (in numbers) as an index of annual recruitment.

For unknown reasons, bonito became scarce sometime during the early 1940's. This disappearance of the resource was independent of fishing, which was curtailed during World War II. Subsequently, bonito catches on partyboats were dependent on migratory fish until 1956, when large quantities of bonito moved into California waters and became reestablished as a locally spawning population. Management of the resource will assume different forms according to whether the resource is migratory or permanent. It is here assumed that the resource is sufficiently permanent to attempt management on the basis of sustainable yield. Nonetheless, there is no evidence that residency is other than a temporary event.

Stock assessment

The present state of the bonito resource has been assessed using total catch and a combination of partyboat CPUE and aerial survey data index for the years 1963 through 1972. Previous discussions suggested that aerial survey data index has some validity as a measure of apparent abundance of the biomass exploited by commercial boats, and similarly partyboat CPUE index is probably proportional to biomass exploited by sportsmen. Since sport and commercial fisheries exploit different age groups and commercial effort data do not exist, a combination of the above two indices provides the only means for stock evaluation using a surplus production model.

The combined index for each year was an average of the two indices standardized by their respective means for the 10-year time series (excluding 1970) and weighted by their respective annual catches (Table 12). The ratio of total catch (C) to this mean index should vary in relation to fishing effort $\left(\frac{\text{Catch}}{\text{Index}} \propto \frac{C}{B} = K\right)$. The units of measurement for this ratio or f are abstract. The mean index for biomass (B) and total catch were plotted against the effort index (Fig. 14). In order to take into consideration the average duration of the exploited phase (slightly above 4 years), the effort index was averaged for 2 successive years. The biomass index decreases with increasing effort in a nearly linear fashion. The relationship does suggest a concave upward curve, but this has little effect on conclusions. The sudden increase in commercial catch in 1966 apparently was greater than equilibrium level as would be expected from large-scale fishing of a previously unexploited stock. However, for the level of recruitment since 1960, the stock appears to be intensively exploited. In fact, the 1973 catch of 34 million pounds apparently is substantially above the MSY suggested by the analysis. Given that recent partyboat CPUE values do not indicate any strong year classes in the present population, this high catch may prove to be disastrous to the bonito stock. Determination of equilibrium abundance and yields are confounded by a possibly density-independent decrease in recruitment, highly variable availability due to behavioral changes (Collins, CDFG[5]) and generally low precision and coverage of available data. Nonetheless it appears likely that fisheries take an appreciable share of each year class.

In the absence of information on mortality rates (or even comparative mortality rates for similar species) yield per recruit analysis was not attempted. Moreover, lack of mortality rate estimates preclude analysis of the interaction between sport catch and commercial yield or rates of exploitation. Comparison of numbers of fish caught by sport and commercial vessels respectively (Table 13), and observations made above suggest that the sport rate of exploitation is relatively low. However, expansion of the sport fishery will directly affect the recruitment to the phase exploited by commercial vessels and consequently affect their catches.

Expansion of commercial activities will not directly affect the sport fishery, which exploits younger fish. However, decrease in sport CPUE could result from a reduction of parental stock to a point where recruitment is significantly reduced. Up to now this has most likely not occurred; however, the 1973 fishing season appears to have been considerably in excess of equilibrium yield and may have severely affected the resource. Although such events cannot be neglected, their occurrence is very

Table 12.—Index of exploited biomass, total catch, and calculated effort for Pacific bonito, 1963 to 1972.

Year	Aerial survey day index	Comm. landings 10^3 lb	Partyboat CPUE index	Sport catch 10^3 lb	Weighted mean index	Total catch 10^3 lb	Effort index (10^3)	Effort index 2-year mean (10^3)
1963	1.71	5,141	1.53	4,589	1.43	9,730	6,782	—
1964	1.80	3,737	2.41	7,873	1.93	11,610	6,031	6,406
1965	1.48	6,374	1.53	4,891	1.33	11,265	8,496	7,264
1966	1.49	21,192	0.96	3,908	1.26	25,100	19,860	14,178
1967	1.03	22,563	0.50	2,125	0.89	24,688	27,843	23,852
1968	0.54	15,701	1.28	6,692	0.67	22,393	33,424	30,634
1969	0.28	17,349	1.46	6,872	0.54	24,221	45,152	39,288
1970	0.01	9,356	0.74	3,957	—[1]	13,313	—	—
1971	0.56	20,594	0.23	982	0.49	21,576	43,900	—
1972	1.11	22,637	0.59	2,551	0.95	25,188	26,464	35,182

[1]Aerial survey data for 1970 incomplete.

[5]R. Collins, CDFG, 350 Golden Shores, Long Beach, CA 90802. Pers. commun.

difficult to determine for a stock subject to large natural fluctuations in recruitment, as is the Pacific bonito.

JACK MACKEREL

The jack mackerel, *Trachurus symmetricus* (Ayres), fishery has been one of the mainstays of the southern California wetfish fleet since the decline of the Pacific sardine. On rare occasions large sport catches are made but jack mackerel remains primarily of commercial interest.

Catches

Long time series of landings in weight are available for the main segments of the fishery: California cannery landings, Mexican cannery landings, and California live bait landings (Table 14). A similar time series in numbers of fish landed is available for the California partyboat fishery, and landings for other sport fisheries were estimated by means of a simple ratio to partyboat landings (3.0 fish/partyboat fish). Sport-caught fish were arbitrarily assigned a weight of 1 pound apiece in the calculation of total landings. In the year of largest sport landings, 1953, sport-caught fish comprised only 1.3 percent of total landings, and the percentage for most years falls far below this value.

Commercial landings have been strongly influenced by the availability of more lucrative species. Landings during the 1950's tend to be inversely related to sardine availability. The slight decline

Table 13.—Pacific bonito—number of fish caught (in thousands) by commercial fleets and sport fishery.

	Commercial				
	U.S.				
Year	Calif.	Mexico	Mexico	Total	Sport total
1950	5	86	0	91	5
1951	8	94	0	102	28
1952	1	277	0	278	15
1953	3	401	0	404	13
1954	34	273	0	307	140
1955	6	13	0	19	45
1956	3	14	0	17	123
1957	17	14	3	34	523
1958	745	96	6	847	854
1959	466	1	10	477	1,568
1960	189	4	13	206	2,423
1961	1,308	10	1	1,319	1,736
1962	321	8	9	338	1,623
1963	622	1	90	713	1,530
1964	404	1	146	551	2,624
1965	873	1	95	969	1,630
1966	2,838	109	266	3,213	1,303
1967	2,766	439	174	3,379	708
1968	2,311	2	101	2,414	2,231
1969	2,043	523	18	2,584	2,291
1970	1,363	52	21	1,436	1,319
1971	1,624	1,272	42	2,938	307
1972	2,419	872	42	3,333	850
1973	2,685	1,593	92	4,370	959

Table 14.—Catches of jack mackerel for various fisheries

	Commercial			Sport			
	United States						
Year	Cannery 10³ lb	Bait 10³ lb	Mexico cannery 10³ lb	Partyboat California 10³ fish	All other California plus Mexico[3] 10³ fish	Total sport 10³ lb[4]	Total commercial and sport 10³ lb
1950	133,255.8	0.4	[1](7,000)	0.6	(1.8)	(2.4)	(140,259)
1951	89,838.1	0.0	(4,000)	0.2	(0.6)	(0.8)	(93,839)
1952	146,521.7	33.1	(3,000)	4.4	(13.2)	(17.6)	(149,572)
1953	55,750.9	1.4	(3,000)	196.3	(588.9)	(785.2)	(59,538)
1954	17,333.6	0.4	440	19.4	(58.2)	(77.6)	(17,852)
1955	35,754.7	0.0	13,300	39.5	(118.5)	(158.0)	(49,213)
1956	75,762.1	0.0	14,200	23.5	(70.5)	(94.0)	(90,056)
1957	82,011.8	0.0	[1](8,000)	6.9	(20.7)	(27.6)	(90,039)
1958	22,065.8	6.2	(2,000)	27.9	(83.7)	(111.6)	(24,184)
1959	37,507.2	40.0	(500)	11.8	(35.4)	(47.2)	(38,094)
1960	74,945.5	4.0	(5,000)	8.5	(25.5)	(34.0)	(79,984)
1961	97,606.3	0.0	3,934	28.9	(86.7)	(115.6)	(101,656)
1962	89,978.9	0.0	6,978	9.0	(27.0)	(36.0)	(96,993)
1963	95,442.3	15.0	30,153	9.3	(27.9)	(37.2)	(125,648)
1964	89,692.9	0.0	6,871	6.6	(19.8)	(26.4)	(96,590)
1965	66,666.4	0.0	8,420	25.6	(76.8)	(102.4)	(75,189)
1966	40,862.4	25.0	12,919	19.0	(57.0)	(76.0)	(53,882)
1967	38,180.5	0.0	4,285	16.2	(48.6)	(64.8)	(42,530)
1968	55,667.7	158.0	3,549	13.6	(40.8)	(54.4)	(59,429)
1969	51,921.2	103.0	3,336	11.3	(33.9)	(45.2)	(55,405)
1970	47,746.5	0.0	[2](5,000)	15.7	(47.1)	(62.8)	(52,809)
1971	59,883.0	9.0	(5,000)	10.6	(31.8)	(42.4)	(64,934)
1972	51,117.6	5.0	(5,000)	5.9	(17.7)	(23.6)	(56,146)
1973	20,615.8		438	15.8	(47.4)	(63.2)	(21,117)

[1]Estimated from reported catch of Pacific and jack mackerel combined.
[2]Information not available—rough maximal estimate.
[3]Estimated as partyboat catch × 3.0.
[4]Estimated from assumed weight of 1 pound per fish.

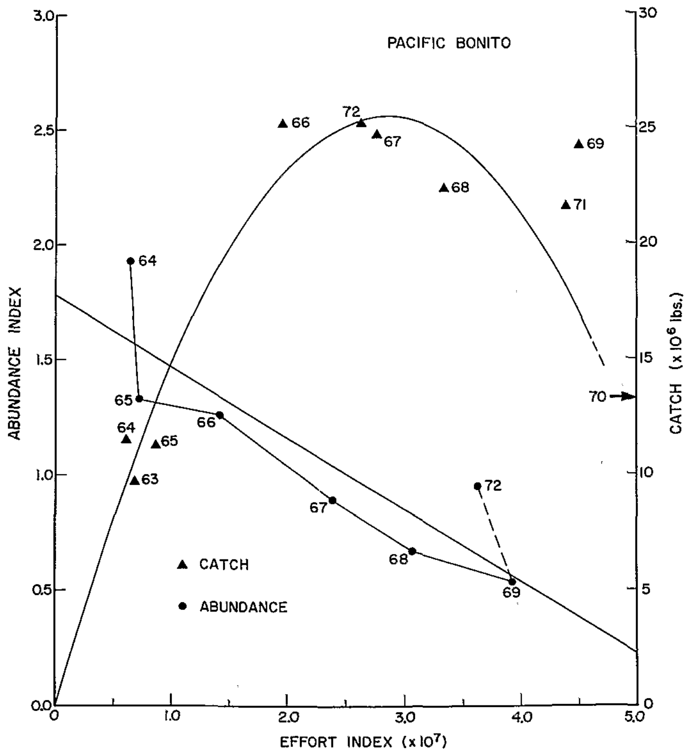

Figure 14.—Relationship between combined CPUE and effort and the corresponding estimates of surplus production for Pacific bonito.

Table 15.—Indices and estimates of biomass.

Year	Larvae CalCOFI area[1] (10^9)	Aerial survey index Night	Aerial survey index Day	Biomass estimate 10^6 tons	
1950	6,846				
1951	4,233				
1952	3,921				
1953	1,484				
1954	2,413				
1955	2,635				
1956	1,372			0.35	(Spawning biomass, local area based on eggs and larvae[2])
1957	2,876				
1958	830				
1959	545				
1960	655				
1961	981				
1962	2,516				
1963	3,122	2.98	1.41		
1964	3,045	2.18	1.62		
1965	2,681	1.36	0.71	1.4-2.2	(Spawning biomass, CalCOFI area based on eggs and larvae[3])
1966	6,288	1.94	0.28		
1967		1.41	0.20		
1968		2.25	0.30		
1969		0.65	0.11		
1970		0.58	0.16		
1971		0.92	0.04		
1972		0.74	0.13	0.7-1.5	(Exploited biomass, based on tagging[4])

[1]Uncorrected for temperature. 1957-59 are probably underestimated.
[2]MacGregor (1964).
[3]Ahlstrom (1968).
[4]Knaggs (1973).

in landings since 1965 has been primarily due to expansion of fisheries on the Pacific bonito and on the northern anchovy.

Status of the stock and its exploitation

Aged landings of jack mackerel were not completed in time to be included in this report; however, they are now available (Knaggs, 1974 and Knaggs and Barnett, 1975). This information will afford an opportunity for detailed analysis of the fishery by use of cohort analysis (Murphy method); the present discussion is restricted to very simple and general terms.

Various indices of abundance (Table 15) show that the resource tends to be highly variable in magnitude and egg-and-larva surveys show the stock to be extremely widespread. Ahlstrom (1968) estimated the spawning biomass in the CalCOFI region to have been between 1.4 and 2.4 × 10^6 tons, based on egg and larval occurrences in 1964-66. Knaggs (1973) estimated from tag returns that between 0.7 and 1.5 × 10^6 tons were available to the fishery in 1972. These estimates are in agreement with trends in the aerial survey index (Squire, 1972). This suggests that jack mackerel are now about half as abundant as they were in the mid-1960's. However, egg-and-larva estimates of spawning biomass do not necessarily correspond to exploitable biomass. Juveniles are exploited, while old fish emigrate from the fishing grounds.

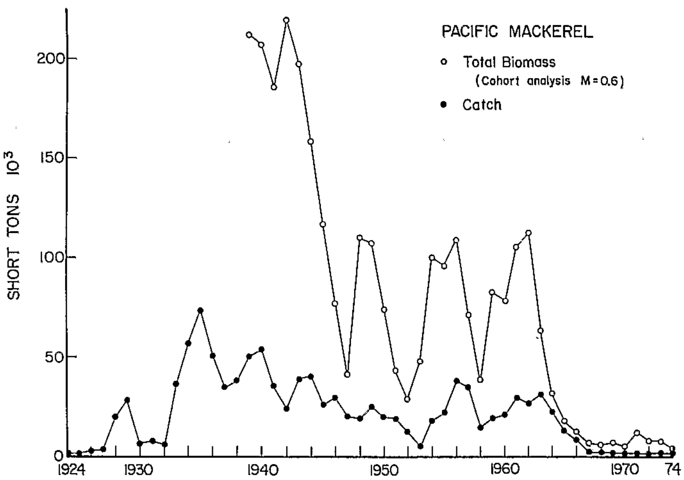

Figure 15.—Pacific mackerel annual catches and biomass estimates.

The present level of fishing is very low, with an F of 0.02-0.04 (Table 16), indicating that the yield could be increased manyfold. Application of Gulland's quick calculation of potential yield ($Y_{pot} = 0.5 \times M \times B_0$) gives 210,000 to 450,000 tons, assuming $M = 0.6$ and using the 1972 estimates of biomass, B_0. Yield values will vary according to the biomass, and would be proportionately larger if the stock were at the 1964-66 level of abundance.

There are indications that estimation of MSY may not be so simple. Knaggs and Barnett (1975) have noted a decrease in average age of the catch, which suggests the possibility of a much higher total mortality rate or smaller stock size than generally believed. Fishermen are of the opinion that jack mackerel abundance has decreased considerably (E. Knaggs, pers. commun.). Comparative biology and exploitation of similar *Trachurus* species and detailed analysis of aged landing data may resolve this dilemma of response of the California stock to apparently very low fishing mortality.

PACIFIC MACKEREL

Inception of Pacific mackerel, *Scomber japonicus*, canning in the late 1920's caused a sudden rise in landings, which, augmented by what was the strongest year class (1932) in the documented history of the fishery, peaked at a record 146 million pounds in the 1935-36 season. Subsequently, the catches went through a long, fluctuating decline, ending with a severely depleted stock in 1933 (Fig. 15). However the 1953 spawning was highly successful, leading to a resurgence of the stock and the fishery, which remained healthy throughout the decade. Beginning in 1963, a sequence of six exceptionally severe recruitment failures resulted in extinction of the commercial fishery.

The Pacific mackerel remains a rather popular and sufficiently abundant target of sport fishermen, although lacking the esteem given to the larger game fish.

Exploitation and dynamics

The Pacific mackerel has been subject to severe and rather unpredictable fluctuations in recruitment, although a 6-year cyclic pattern has been described. Parrish (1974) showed that the fishery has depended largely upon occa-

Table 16.—Biomass, catches, and fishing mortality of jack mackerel.

Years	Biomass (10^6 tons)	Catch (10^3 tons)[1]	$F = C/B$
1964-66	1.4-2.2	37.3	0.02-0.03
1972	0.7-1.5	28.1	0.02-0.04

[1]3-yr average.

sional strong year classes and has tended to overexploit successive weak year classes. As the spawning biomass was reduced, variance in spawning success increased, augmenting the dependency on strong year classes, while reducing the mean age and number of age classes in the population to a point where the stock could not withstand an extended period of recruitment failure. However, intensive fishing is probably not the only cause responsible for such collapse.

As for most stocks where similar events were experienced, the respective roles of natural causes and of those due to fishing have not been satisfactorily explained. Long-term fluctuations in the environment and the species composition of the southern California pelagic community have been observed since the late 1950's and early 1960's, e.g., waters generally warmer than during the previous decade, progressive predominance of anchovy over the sardine, and reestablishment of a local population of Pacific bonito, a likely competitor with the Pacific mackerel.

Management

In response to the collapse of the stock a moratorium on commercial fishing was adopted in 1970. Later, a more comprehensive management bill was passed by the California legislature which provides for the rehabilitation and subsequent regulation of a sustained and controlled commercial fishery should the stock recover and increase over a minimum biomass. In essence, the law provides for a harvest equivalent to 20 percent of the spawning biomass in excess of 10,000 tons and to 30 percent of the spawning biomass above 20,000 tons. The closure of the commercial fishery for spawning biomass below 10,000 tons—the present situation—aims at ensuring that a minimum parental stock is maintained and a minimum sport fishing stock is provided.

Above the 10,000-ton and 20,000-ton thresholds, the adopted regulation ensures that the maximum amount of fishing is controlled and that it will gradually increase, tending towards an asymptote of $F = 0.3$ as the stock gains in size.

Direct limitation of effort would achieve the same effect of limiting F, without the difficulties and costs inherent in forecasting recruitment and subsequent fishable biomass. This aspect is particularly relevant to the Pacific mackerel stock, which has shown fluctuations of large amplitude. However the practical difficulties involved in implementing management based on effort limitation may well counterbalance its previously mentioned advantages. In that respect it should also be noted that while quota limitation alone is insufficient to prevent economic overfishing, enforcement of quotas adjusted on early estimates of the recruits should dampen year-to-year oscillations in the fishable biomass and thus provide the fishery with greater stability than was had previously.

Present state of exploitation and perspectives

As a result of the above restrictions on commercial fishing, sport fishing is presently the largest user of Pacific mackerel in California (Table 17). Fishing mortality is at present low ($F = 0.06$), indicating that it is not necessary to implement further restrictions on the sport fishery.

Recovery of the stock to commercial viability is now largely a matter of fortune, as the spawning biomass is so small that local environmental fluctuations may have a large influence on spawning success. Moreover, potential response of the stock in the present environmental regime is unknown. Based on knowledge of present biomass and recent recruitment, it is unlikely that a fishery will develop in the next 5 years.

PACIFIC SARDINE

The purpose of this report on Pacific sardine, *Sardinops caeruleus*, is not to discuss the population dynamics of the stock but only to document the total biomass time series. The southern California spawning biomass of Pacific sardine may presently be less than 5,000 tons (P. Smith, National Marine Fisheries Service, (NMFS), pers. commun.), and a moratorium on fishing is in effect. Accordingly, no further attempt is made to determine the status of the stock.

We are interested though in the sardine stocks because, along with anchovies, they make up a major portion of the forage for many of the southern California sport fishes. Also, the present wetfish fleet is the remnant of the sardine purse seine fleet. During the collapse of the sardine fishery the fishermen began redirecting their effort towards other pelagic species, including Pacific mackerel, jack mackerel, and later, anchovy and bonito. The response of the sardine resource to fishing pressure is now mainly of academic interest and is discussed by Clark and Marr (1955) and Murphy (1966).

Various indices of biomass reflect the tremendous decline in the stock from 1.3 million tons in 1940 to the 2,000-5,000 tons at present (Table 18, Fig. 16). Sardine biomass combined with anchovy biomass estimates show an interesting cycle with the lowest amount at 1 million tons in 1950 increasing to over 6 million tons by 1961 (Fig. 16). Combined forage fish biomass has increased 6-7 fold since its low in 1950.

Such cycles in biomass are apparently common events in history as demonstrated by occurrence of fish scales in ocean bottom sediments examined by Soutar and Isaacs (1974). Their work suggests that for the Santa Barbara Basin the level of anchovy stock over the past 150 years has been relatively constant. The level since about 1920, though, appears to be below average

Table 17.—Recent biomass, catches, and fishing mortality rates of Pacific mackerel.

Year	Biomass[1] Spawning 10^3 lb	Biomass[1] Total 10^3 lb	Sport catch[2] Number 10^3	Sport catch[2] Weight[3] 10^3 lb	Commercial catch Calif. 10^3 lb	Commercial catch Mexico 10^3 lb	Total catch 10^3 lb	$F = C/B$
1972	10,000	15,772	495.1	415.9	108.0	(400)	924	0.06
1973	11,000	15,224	376.5	425.4	56.7	438	920	0.06

[1]Knaggs, CDFG, pers. commun.
[2]Estimated from known partyboat and barge catches, all other sport estimated as 0.826 partyboat catch.
[3]Weight conversions: 1972—0.84 pounds/fish, 1973—1.13 pounds/fish, based on 1970 year class.

Table 18.—Biomass estimates: anchovy and sardine (After P. Smith, 1972, Table 12 and Figure 13).

Year	Ratio anchovy spawner biomass (10^3t)	Regression anchovy spawner biomass (10^3t)	Mean (1,2)	Murphy sardine spawner biomass (10^3t)	Regression sardine spawner biomass (10^3t)	Mean (4,5)	Anchovy and sardine spawner biomass (3+6)
	(1)	(2)	(3)	(4)	(5)	(6)	
1940	2,359		2,359	1,296		1,296	3,655
1941	2,871		2,871	2,001		2,001	4,872
1942				1,913		1,913	
1943				1,647		1,647	
1944				1,142		1,142	
1945				691		691	
1946				412		412	
1947				387		387	
1948				524		524	
1949				682		682	
1950	279		279	716		716	995
1951	690	637	664	570	553	562	1,226
1952	856	797	827	554	542	548	1,375
1953	(1,404)	1,335	1,370	709	450	1,159	2,529
1954	1,937	1,816	1,877	668	658	1,326	3,203
1955	1,855	1,676	1,766	425	404	829	2,595
1956	1,307	1,491	1,399	293	351	322	1,721
1957	1,869	1,964	1,917	212	234	223	2,140
1958	2,875	2,771	2,823	281	299	290	3,113
1959	(2,418)	2,299	2,359	190	117	154	2,513
1960		3,079	3,079		201	201	3,280
1961		3,189	3,189		132	132	3,321
1962		6,248	6,248		151	151	6,399
1963		6,030	6,030		78	78	6,108
1964		5,121	5,121		104	104	5,225
1965		7,771	7,771		226	226	7,997
1966		5,116	5,116		151	151	5,267
1967		—	—		—	—	—
1968		(2,167)	(2,167)		—	—	—
1969		(3,378)	(3,378)		27	27	3,405
1970					—	—	
1971					2-5	2-5	

Table 19.—White seabass—catches by year and by main fishery segments.

Year	Commercial (10^3 lb) U.S. Calif.	Commercial U.S. Mexico	Commercial Mexico	Sport (10^3 Fish) Party-boats Calif. waters	Other open water (U.S., Mex.) est.[3]	Shore-line, pier, jetty, bay est.[4]	Total sport catch	Total sport catch (10^3 lb)	Est. total catch (10^3 lb)
1950	1,123	408	[1](74)	54.7	4.7	(9.0)	(68.4)	(532)	(2,137)
1951	955	578	(74)	44.4	5.2	(9.0)	(58.6)	(445)	(2,052)
1952	692	455	(74)	41.0	6.0	(9.0)	(56.0)	(423)	(1,644)
1953	471	402	(74)	28.2	5.8	(9.0)	(43.0)	(288)	(1,235)
1954	434	772	(74)	41.6	7.9	(9.0)	(58.5)	(445)	(1,725)
1955	545	370	(74)	30.1	7.6	(9.0)	(46.6)	(341)	(1,330)
1956	414	667	(74)	19.8	7.1	(9.0)	(35.9)	(246)	(1,401)
1957	1,262	245	(74)	19.0	7.5	(9.0)	(35.5)	(243)	(1,824)
1958	2,751	99	(74)	34.0	10.2	(9.0)	(53.2)	(398)	(3,322)
1959	3,386	38	(74)	10.6	6.7	(9.0)	(26.3)	(161)	(3,659)
1960	1,087	149	(74)	15.7	7.7	(9.0)	(32.4)	(215)	(1,525)
1961	458	236	(74)	14.1	7.5	(9.0)	(30.6)	(199)	(967)
1962	209	366	158	14.6	7.8	(9.0)	(31.4)	(125)	(858)
1963	372	519	47	19.8	9.0	(9.0)	(37.8)	(262)	(1,200)
1964	551	840	82	14.9	8.1	(9.0)	(32.0)	(211)	(1,684)
1965	578	851	87	9.8	7.1	(9.0)	(25.9)	(157)	(1,673)
1966	675	663	69	4.0	5.6	(9.0)	(18.6)	(93)	(1,500)
1967	508	715	36	3.4	5.5	(9.0)	(17.9)	(87)	(1,346)
1968	210	652	18	4.1	5.7	(9.0)	(18.8)	(95)	(975)
1969	251	848	93	4.1	5.8	(9.0)	(18.9)	(94)	(1,286)
1970	426	675	(92)	4.4	6.5	(9.0)	(19.9)	(98)	(1,291)
1971	552	272	(62)	5.3	6.5	(9.0)	(20.8)	(164)	(1,050)
1972	548	227	[2](157)	3.9	5.7	(9.0)	(18.6)	(133)	(1,065)
1973	581	228	(100)	7.1	7.0	(9.0)	(23.1)	(130)	(1,039)

[1]1950-1961 catches estimated as 1962-1969 mean, other Mexican data courtesy of Instituto Nacional de Pesca.
[2]Preliminary estimate based on information through September and mean catches for October, November, and December.
[3]Includes long-range partyboats, private boats (linear interpolation: 1964—0.225 partyboat catch, 1950—0.05 partyboat catch) and Mexican partyboats (linear interpolation: 1971 catch = 4,338, 1961 catch = 4,901, 1950-1956 increasing from 2,000).
[4]1963 pier and jetty catch = 8,551 (Pinkas et al., 1967), 1965-66 shoreline catch = 699 (Pinkas et al., 1968).

(Fig. 17). During the same period the sediments reveal cyclic occurrences of sardines. Sardines probably peaked during 1854 to 1864, 1889 to 1899, and 1914 to 1924 (Fig. 17). Just prior to the decade of 1870, sardines apparently declined to a very low level but the stock had rebounded by 1890. During the last 150 years sardine scale deposits only exceeded those of the anchovies in four 5-year periods. Scale deposition rate for anchovies, however, seems to be higher per unit of biomass than for sardines. Despite this, it seems that, on the average, the anchovy biomass has exceeded that of the sardine. Therefore, since anchovies may usually be the dominant species, if the sardine stock does rebuild, it should not be expected to overweigh, on the average, that of the anchovy.

WHITE SEABASS

The white seabass, *Cynoscion nobilis*, is one of the most highly esteemed game fishes found in southern California waters, both in the catching and in the eating. Accordingly, it commands a high market price. Recent conflicting trends in indices of apparent abundance or availability have given rise to concern over the status of the stock. This study attempts, with the limited information available, to assess the present condition of the stock, interactions between the fisheries seg-

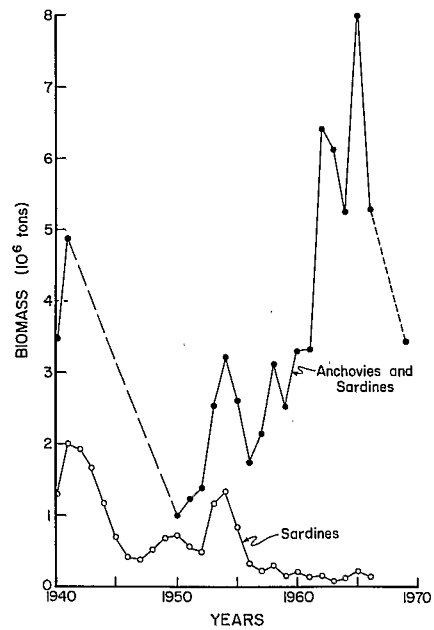

Figure 16.—Combined spawning biomass of anchovies and sardines for years 1940-69.

ments, and the possible effects of various management alternatives.

Data available

Catch and CPUE data available for the various fishery segments suffer from similar limitations as described for other sport species. Long time series of catch statistics are available for fleets responsible for the bulk of total catches, i.e., the U.S. and Mexican commercial fisheries (only since 1966 for the latter). Annual numbers of fish caught by partyboats have also been regularly reported for the whole period under review. For the other sectors, quantitative information is only available for a few occasional years. On the basis of such information and on known or assumed trends in the history of their respective developments, annual catches have been reconstructed for insufficiently documented fishery sections. Assumptions made are given in footnotes on Table 19. Catches in numbers of fish have been converted to catches in weight using the following mean weights of fish caught by fishery sectors: 8.8 pounds when one or two undersized fish can be kept and 16.9 pounds when no fish under 28 inches can be kept. Since unreported catches represent only a small percentage of total catches in weight (e.g., 5, 5, 6, and 11 percent in 1968, 1969, 1970, and 1971, respectively) estimated total catches should not depart significantly from actual figures.

The CPUE data for white seabass are available for the period considered for U.S. commercial fishery in units of:

1) Pounds of fish/boat; 2) pounds of fish/boat landing more than 1 ton during the year; 3) pounds landed/boat landing.

The CPUE for the U.S. partyboat fishery is calculated in units of numbers of fish/angler weighted by the surface area of six geographical subareas, i.e., CPUE index.

These data are summarized in Table 20 and in Figure 18.

Historical trends in annual catches and CPUE

Information presented in Figure 18 shows that total white seabass catches have decreased during the period under review, i.e., from 1950 to 1972. If year-to-year fluctuations in fishing activity,

Table 20.—White seabass—CPUE available for the commercial fishery[1] and for the partyboats and estimated total effort derived from estimated total catch (Table 19) and commercial CPUE (pounds/boat with catches > 1 ton).

Year	Commercial lb/boat	Commercial lb/boat ($C > 1$ ton)	Pounds landing	Partyboats fish/angler day[2]	Estimated Total effort standard unit[3]
1947	—	—	—	0.0428	—
1948	—	—	—	0.0451	—
1949	—	—	—	0.0654	—
1950	—	—	—	0.0603	—
1951	5,476	16,973	435	0.0486	123.2
1952	4,498	9,369	380	0.0585	179.6
1953	4,456	6,417	501	0.0360	201.7
1954	6,348	16,243	751	0.0533	108.6
1955	4,597	8,081	484	0.0516	169.4
1956	7,508	16,689	772	0.0314	86.3
1957	5,057	11,491	417	0.0243	162.1
1958	6,521	23,712	572	0.0547	141.7
1959	13,916	29,918	552	0.0170	123.6
1960	7,631	12,136	293	0.0340	128.9
1961	4,157	7,074	278	0.0264	142.2
1962	3,779	7,102	340	0.0388	125.7
1963	6,232	11,033	377	0.0493	114.7
1964	8,917	19,405	633	0.0340	88.4
1965	10,274	18,199	567	0.0196	93.4
1966	10,213	16,738	473	0.0089	92.6
1967	8,734	16,284	556	0.0066	87.0
1968	6,113	14,606	578	0.0060	69.3
1969	9,391	19,294	844	0.0068	69.9
1970	8,408	17,839	794	0.0049	75.2
1971	6,242	13,426	409	0.0109	80.1
1972	5,015	10,818	394	0.0065	106.5
1973	—	—	—	0.0087	—

[1]Commercial effort information courtesy of R. Collins and C. Hooker, CDFG.
[2]Based on angler CPUE index as described in text.
[3]Standard unit is boat ($C > 1$ ton).

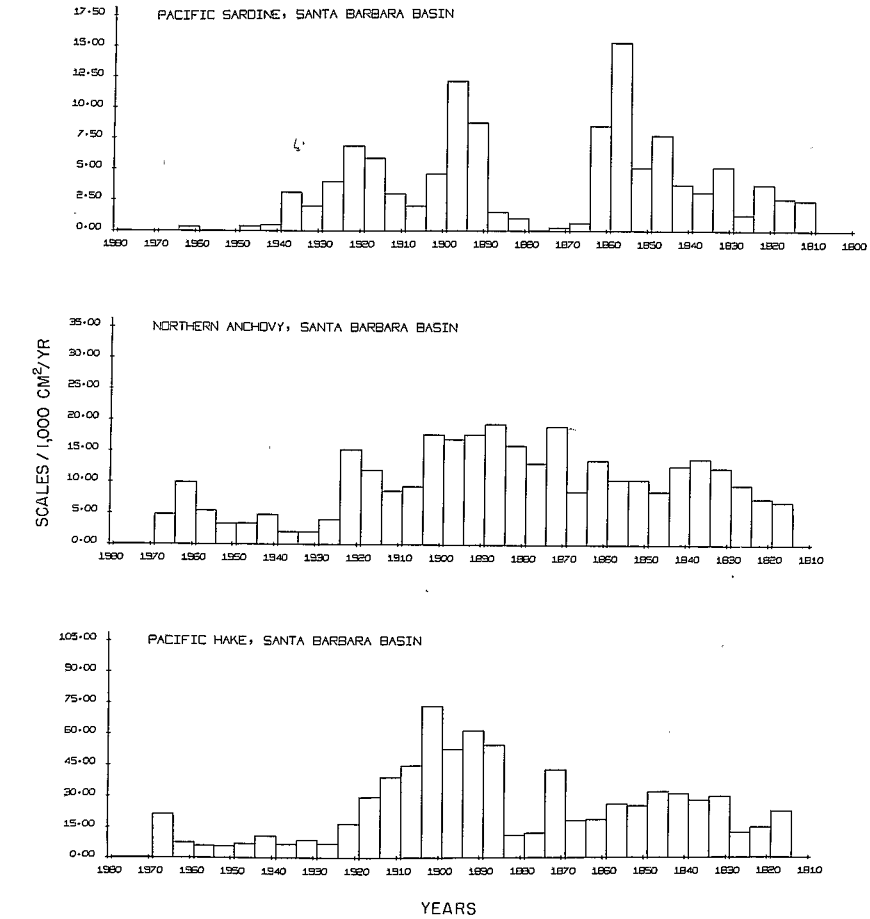

Figure 17.—Histogram plot of the scale-deposition rate of the Pacific sardine, the northern anchovy, and the Pacific hake in sediment of Santa Barbara Basin, 1810-1969 (from Soutar and Isaacs, 1974).

recruitment, and availability (in particular the sudden increase observed in 1958-59 and said to be associated with exceptionally warm waters) are neglected, total catches regularly decreased by 42.5 percent from 1950 to 1972. This drop is essentially due to the reduction in activity of the U.S. commercial fishery, the landings of which have dropped by some 50 percent during the same period. The Mexican commercial fishery is believed to have remained fairly stable during the whole period. Catches of the U.S. sport fishery and particulary of partyboats have also regularly decreased during the whole period. Although smaller in absolute terms than the decline experienced in the commercial fishery, catches of partyboats have shown a drop of almost 90 percent during the last two decades.

Although the overall partyboat CPUE of white seabass has also decreased by approximately the same amount as the catch during this period, the drop in annual catch and CPUE for partyboats cannot be explained by a general reduction in stock abundance related to fishing activity of the various fishery sections unless the catchability coefficient, q, is positively correlated with population size. The positive trend in U.S. commercial fishery CPUE, which has seen an average increase of 27 percent between 1951 and 1972, suggests q for the commercial fishery may be negatively correlated with population size. The most likely explanation for the opposite trends in CPUE of partyboats and commercial vessels is that the q's for the two fisheries are nonlinear and oppositely (or at least differently) related to population size.

Total stock appraisal

A preliminary assessment of white seabass was made from overall annual catches (Table 20) and commercial fishery CPUE (pounds/boat with annual landings > 1 ton). For that purpose, Gulland's (1969) approximation method has been used. The CPUE figures were plotted against average effort during the 5 previous years (average duration of exploited phase = 9-10 years). Fishing power has probably not increased substantially since the early 1950's as boats have remained fishing about the same amount of gear. Introduction of nylon net material may have had some effect on fishing power (R. Collins and C. Hooker, CDFG, pers. commun.). The 1958 and 1959 values have been deleted in the fitting because of abnormally high catches. Subsequent CPUE observed during these years were most likely due to above-average availability of the stock in relation with exceptionally warm waters. The equilibrium yield curve derived from the CPUE line against effort suggests that the stock is at present moderately exploited, the present catches being some 20 percent below the maximum potential estimated by pooling together the various fishery sections (Fig. 19). On the other hand, if the catchability coefficient is strongly negatively related to population size, the maximum potential yield may have been exceeded, and the population may be overfished.

Interaction between fishery segments

Processing catch and CPUE data by combining the various segments of the white seabass fishery may lead to at least partly erroneous conclusions since the segments exploit various age groups of the stock in different proportions, and since catchability coefficients of the various segments may vary differently. The pier and jetty fishery takes juvenile "sea trout" nearshore and in estuaries. The U.S. partyboats take large numbers of juveniles but adults are also caught. The U.S. private boat catch is probably similar to a mixture of the pier and jetty and partyboat fisheries. The U.S. commercial fishery operating in both California and Mexican waters fishes with large mesh gill nets (6-inch mesh or larger). Although age 4 white

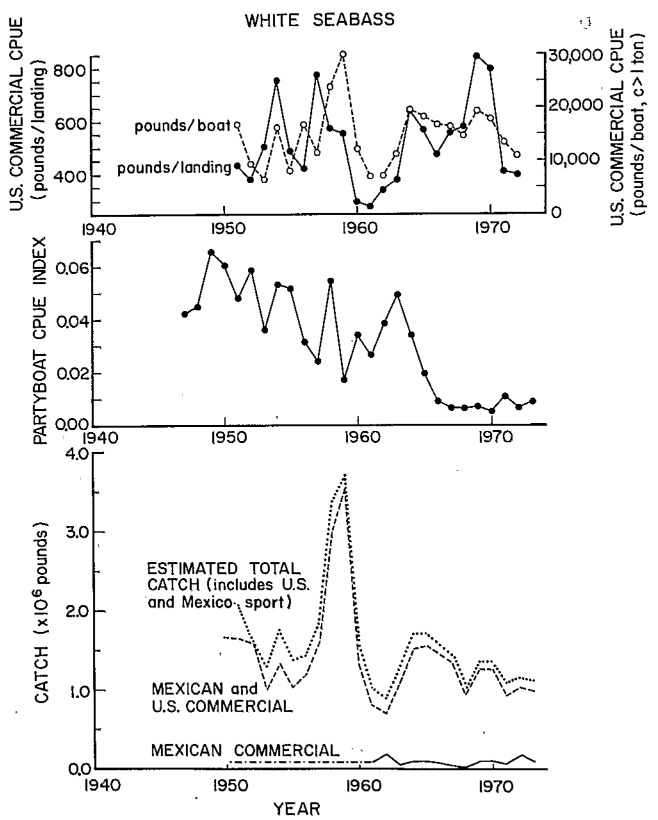

Figure 18.—Catches and CPUE for the various segments of the white seabass fishery.

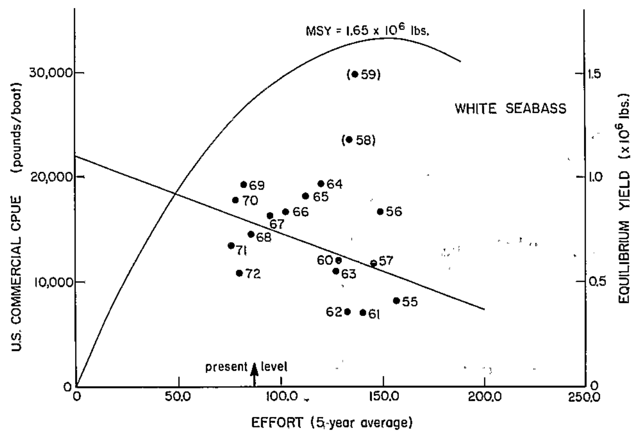

Figure 19.—Relationship between commercial CPUE and effort and the corresponding estimates of surplus production for white seabass.

Table 21.—White seabass age composition of catches in 1973 for three fishing segments.

Age	U.S. commercial	U.S. partyboat	Pier & jetty	Total
		No. of Fish		
1	0	236	773	1,009
2	0	2,361	7,727	10,088
3	0	708		708
4	223	708		931
5	1,087	1,108		2,195
6	1,546	236		1,782
7	3,095	—		3,095
8	4,180	236		4,416
9	4,333	472		4,805
10	6,966	472		7,438
11	5,030	472		5,502
12	1,703			1,703

seabass are caught by gill netters, full recruitment appears not to occur until age 9 or 10 (Table 21). The age composition of the U.S. commercial fishery may be changing since the Mexican component is declining due to a reduction in permits issued by the Mexican Government.

There has been a minimum size of 28 inches for the sport fishery; however, the bag limit has included one undersized fish per person except from 1971 to mid-1973. Due to the low catch rate, this one undersized fish essentially eliminates the minimum size requirement. Also the "sea trout" fishermen often fail to recognize their catch as white seabass and consequently, frequently violate the minimum size regulation.

In order to take into account these differences and to detect the possible interactions between various fishery segments, a yield per recruit analysis was conducted using the computer program MGEAR (Lenarz et al., 1974). This program simultaneously calculates Y/R values for a multiple gear fishery as in the case of the white seabass. The following three fisheries were included: U.S. commercial gill nets, U.S. partyboats, and U.S. pier and jetty. The U.S. private boat and both Mexican fisheries were not included because of the unavailability of catch and age composition data. Therefore, it is implicit that they are a component of natural mortality. If they fluctuate they can affect the results of the analysis.

The necessary growth and mortality parameters were taken from Thomas (1968). His estimates for instantaneous mortality coefficients were reexamined and a new value of 0.13 was estimated for M, based on a regression of total mortality rates for 1958, 1959, and 1960 (obtained by cohort analysis) and for 1973 (obtained by catch curve analysis) upon effort measured in number of boats with an annual catch in excess of 1 ton. Thomas gave a value of $M = 0.303$. For 1973, Z was estimated to be 0.50 from age composition data for the U.S. gill net fishery provided by Rob Collins, CDFG. These data were also analyzed to generate values of fishing mortality for the various age groups and gear types (Table 22). This was done by dividing total F among the fisheries according to the proportion of total catch of each fishery.

Since the estimates of M are 0.13 and 0.30, the Y/R analysis was performed for $M = 0.13$, 0.20, and 0.30. It was also assumed that all undersized fish caught are released and do not subsequently die. Size limits or alternative fishing intensities may influence future recruitment; unfortunately the analysis could not take this into account.

Results of the analysis indicate that if a uniform minimum size limit was set such that Y/R for the entire fishery would be maximal, a 12 percent gain in Y/R would be realized ($M = 0.13$, minimum size = 96 cm). The expected increase would be only 4 percent if $M = 0.20$ (minimum size = 71 cm), and no gain would be expected if $M = 0.30$, whereupon no size limit should be imposed. These changes in yields are independent of the 20 percent gain in yield to be expected from increased effort described above.

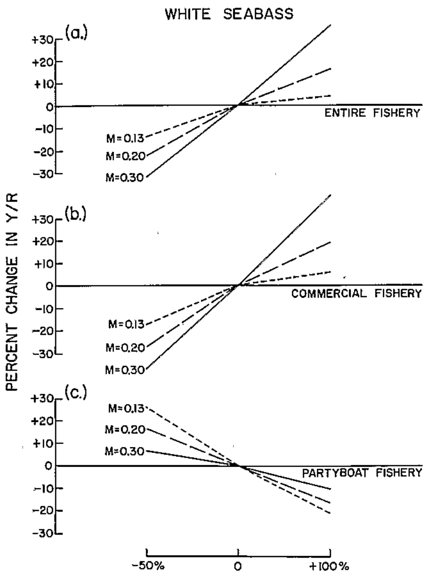

Figure 20.—Changes in Y/R for white seabass if only F for commercial fishery is changed.

Table 22.—Estimates of F for three segments of the white seabass fishery, for $M = 0.13$, 0.20, and 0.30.

Age	U.S. commercial	U.S. partyboat	Pier & jetty
$M = 0.13$			
1	0	0.0018	0.0061
2	0	0.0221	0.0724
3	0	0.0123	0
4	0.0029	0.0123	0
5	0.0164	0.0123	0
6	0.0274	0.0123	0
7	0.0656	0.0123	0
8	0.1105	0.0123	0
9	0.1501	0.0123	0
10	0.3591	0.0123	0
11	0.4566	0.0123	0
12	0.2600	0.0123	0
13-20	0.3577	0.0123	0
$M = 0.20$			
1	0	0.0009	0.0031
2	0	0.0121	0.0398
3	0	0.0090	0
4	0.0018	0.0090	0
5	0.0107	0.0090	0
6	0.0191	0.0090	0
7	0.0483	0.0090	0
8	0.0852	0.0090	0
9	0.1206	0.0090	0
10	0.2943	0.0090	0
11	0.3703	0.0090	0
12	0.2100	0.0090	0
13-20	0.2910	0.0090	0
$M = 0.30$			
1	0	0.0003	0.0041
2	0	0.0050	0.0149
3	0	0.0050	0
4	0.0008	0.0050	0
5	0.0052	0.0050	0
6	0.0152	0.0050	0
7	0.0281	0.0050	0
8	0.0534	0.0050	0
9	0.0803	0.0050	0
10	0.2020	0.0050	0
11	0.2294	0.0050	0
12	0.1420	0.0050	0
13-20	0.1950	0.0050	0

Next we examined what might happen to the Y/R for the various fisheries if the commercial fishery were to experience a 50 percent reduction in its fishing intensity or a 100 percent increase. The conclusions are:

1) A 50 percent reduction should benefit the partyboat fishery by increasing Y/R in numbers and weight. This increase is due to more large fish being available. The magnitude of the benefit decreases if the value of M is larger. The commercial fishery would obviously experience a decrease in Y/R. The opposite is true for each fishery for the 100 percent increase (Fig. 20a, b).

2) The trends for all three fisheries combined were similar to those of the commercial fisheries (Fig. 20a).

3) The curves in Figure 21 were essentially unaltered if the fishing intensity for the pier and jetty fishery were actually twice the original value.

4) Since the pier and jetty fishery was assumed to harvest only age 1 and 2 fish, its Y/R was unchanged by the variations in the commercial fishery.

Second, we examined what might happen if the commercial fisheries not only experienced a change in fishing intensity but also if a strict 28-inch minimum size were to be imposed on the three fisheries equally. The conclusions were:

1) A 50 percent reduction in commercial fishing plus a 28-inch size limit should benefit the sport fishery if natural mortality were less than 0.20. If, on the other hand, the commercial fishery remains unchanged or increases 100 percent, Y/R for the partyboats should be reduced because of the elimination of young age groups from the catch due to enforcement of the size limit. The larger M is, the greater this reduction in Y/R (Fig. 21c).

2) The size limit should improve commercial Y/R at all levels of fishing intensity except at the higher levels of M near 0.30. The improvement increases with lower M (Fig. 21b).

3) Trends in the fishery as a whole are similar to those for the commercial fishery.

4) The pier and jetty fishery would be eliminated if the size limit is enforced.

5) If the pier and jetty fishery were actually double the estimated size, a 28-inch size limit should cause the Y/R for all fisheries to increase by 5-10 percent if $M = 0.13$, by 2-5 percent if $M = 0.20$, and by 0-2 percent if $M = 0.30$ (Fig. 21).

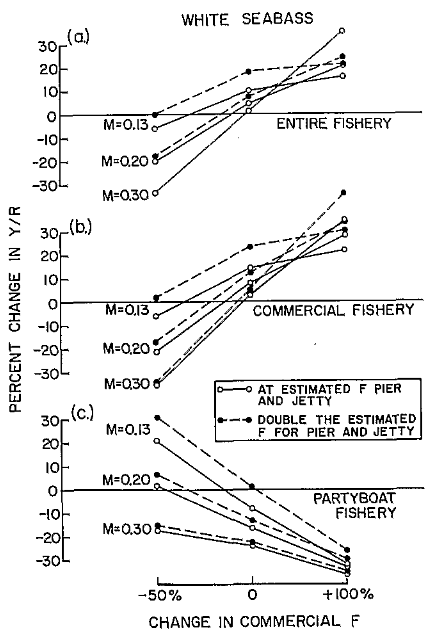

Figure 21.—Changes in Y/R for white seabass if F for commercial fishery is changed and at the same time a 28-inch size limit is enforced.

YELLOWTAIL

The yellowtail, *Seriola dorsalis*, is probably the most important single species to the southern California partyboat fishery, both in economics and angler preference. A large commercial fishery for yellowtail has existed in the past, and could be expanded at any time both off U.S. and Mexican shores. Therefore, it is essential to determine the present status of exploitation, maximum sustainable levels of yield, and probable interactions with the sport fishery.

Data

Data on yellowtail fisheries suffer the same shortcomings as do other primarily recreational species. Long time series catch records are available for California commercial landings in weight and for the California partyboat catch in numbers of fish. Mexican commercial landings in weight are known since 1966. The only length distributions available allowing transformation of catches in numbers to catches in weight refer to partyboat catches in 1973 and to individual samples occasionally taken from various U.S. catches (sport, commercial, and research) during the period 1952-54. Since size composition of catches is known to vary between fishery segments (see Fig. 22) and with time in relation to changes in the amount of fishing, these two sets of data are notably insufficient to build up the sport fishery catch (in weight) during the whole period considered.

Despite these limitations, annual catches by fleets have been tentatively reconstructed for two periods—1947-54 and 1966-72 respectively—selected for the following reasons: 1) Availability of length frequency distributions (and length/weight relationship); and 2) The relative stability of the amount of fishing taken as a whole during each of these two periods.

For such conditions of fishing stability, the sport fish catches were converted to weight by applying the corresponding average weight of fish in the size composition samples to all years within the respective time series.

For the various fishery segments for which no data are available—essentially U.S. sport fishery other than partyboats—estimates were made from information on their relative importance in certain years and from likely trends in their development. The importance of these estimated catches appears to be rather small compared to that of documented sections (about 1 percent of estimated total catches for the period 1948-53 and between 15 and 36 percent for the 1966-73 period). The assumptions made, though probably inaccurate in details, should provide a fair picture of actual trends (Table 23).

Annual catch per angler for the Coronado Islands (Mexico) area (CDFG statistical block 916) was chosen as the best available index of abundance. The Coronado Islands are the closest well-sampled area to the center of the yellowtail population and tend to be the mainstay of local yellowtail sportfishing in southern California, which exploits the fringe of a population which is centered off southern Baja California. Partyboat effort for pre-1960 years was calculated using the conversion 1.0073 angler/angler day based on the mean of 1960 and 1961 observations. Partyboat catch, in number of fish caught, was transformed to weight caught using the average weights of fish caught for the two periods (10.86 pounds for 1947-54 and 12.78 pounds for 1966-73). Overall standard effort was estimated by dividing total catch in weight for all fisheries by the Coronado Islands CPUE thus obtained.

Indices of apparent abundance derived from aerial surveys have also been published, but because yellowtail are seldom observed from planes, the method probably does not provide a reliable index of relative abundance for such species (Squire, 1972). Therefore, this source of data was not used in the present analysis.

Historical trends

During the warm water years of 1957 through 1959, yellowtail appeared in unusual abundance in southern California waters and angler success reached record levels. The warm water phenomena aroused interest in the effects of ocean temperature on fish distribution and availability, and Radovich (1963) presented a hypothesis that warm oceanic conditions may bring about a northward shift of the yellowtail population, and as southern California is normally at the extreme edge of the population, this movement considerably increases the local abundance. Examination of data from more recent years supports the hypothesis (Radovich, 1975) and a scatter diagram of CPUE in numbers per angler day at the Coronado Islands versus annual mean sea surface temperature at Scripps Pier in La Jolla shows a distinct relationship (Fig. 23). On the other hand, the temperature relationship is not as pronounced for the common range of water temperatures. It is still worthwhile to examine the effects of fishing in more "normal" years.

The period 1948-54 corresponds to the end of a stable era of high exploitation by U.S. commercial boats operating mainly near Magdalena Bay, Baja California. During this period, initiated in 1935, commercial landings fluctuated between 4 and 10 million pounds with an average of 6.3 million pounds. Between 1948 and 1954, U.S. commercial landings and sport catches amounted to about 92 percent and 8 percent of total catches respectively.

Cannery demand for yellowtail ceased after 1954, causing a considerable drop in U.S. commercial yellowtail fishing operations. As a consequence, their landings have fluctuated around 230,000 pounds since 1955. Since then a commercial fishery has developed in Mexico, and sport catches from California and Mexican boats have more than doubled. Yet these overall landings remain far below the previous level. During the 1966-72 period total catches have averaged 71 percent below the 1947-54 level. Simultaneously the catch per angler (partyboat) increased by about two-thirds above the 1948-54 level and the overall effort is now at 10 percent of its level at the end of the period of intensive fishery (1948-50) (Table 24). The result of such changes in participation in this fishery is well illustrated by the following percentages (of total catches):

Period	U.S. commercial	Mexico commercial	Sport fisheries
1948/54	95%	Negligible	5%
1966/72	11%	37%	52%

Reported mean weights of fish caught (about 10 pounds in 1935 according to Fry (1973), 10.86 pounds in 1952-54, and 12.78 pounds in 1973) are in agreement with the general reduction in the amount of fishing deduced from trends in total

Table 23.—Yellowtail: estimated annual catches.

Year	U.S. commercial California (10^3 lb)	U.S. commercial Mexico (10^3 lb)	Mexico commercial (10^3 lb)	U.S. partyboat (10^3 fish)	Other sport combined (U.S. + Mex.) estimate[1] (10^3 fish)	Total sport catch (10^3 fish)	Total[3] sport catch (10^3 lb)	Estimated total catch (10^3 lb)
1947	103.7	9,849.1		6.95	(1.6)	(8.6)	(93.4)	(10,046)
1948	246.6	10,138.1		13.03	(4.7)	(17.7)	(192.2)	(10,577)
1949	15.9	7,301.8		17.71	(3.7)	(21.4)	(232.4)	(7,550)
1950	5.7	3,524.2	assumed	6.97	(1.5)	(8.5)	(92.3)	(3,622)
1951	14.5	4,655.3	to be	23.72	(4.8)	(28.5)	(309.5)	(4,979)
1952	51.1	9,395.9	negligible	59.26	(12.2)	(71.5)	(776.5)	(10,224)
1953	14.4	5,198.0		27.70	(5.8)	(33.5)	(363.8)	(5,577)
1954	11.8	1,644.9		40.87	(9.1)	(50.0)	(543.0)	(2,200)
1955	5.6	158.8	—	36.47	(8.0)	(44.5)	—	—
1956	18.6	352.3	—	29.20	(6.8)	(36.0)	—	—
1957	150.9	358.1	—	242.69	(56.8)	(299.5)	—	—
1958	105.5	64.1	—	123.38	(29.6)	(153.0)	—	—
1959	207.2	24.1	—	457.35	(112.1)	(569.5)	—	—
1960	156.5	92.1	—	254.97	(63.5)	(318.5)	—	—
1961	80.7	300.1	—	42.12	(10.8)	(52.9)	—	—
1962	37.1	151.4	611.1	21.79	(5.7)	(27.5)	—	—
1963	25.4	44.3	261.3	41.68	(11.3)	(56.6)	—	—
1964	25.9	84.2	1,481.4	38.00	(11.5)	(49.5)	—	—
1965	12.5	115.3	938.3	11.68	(11.3)	(23.0)	—	—
1966	35.9	209.3	761.6	72.94	(29.0)	(102.0)	(1,303.6)	(2,310)
1967	13.2	137.5	642.7	16.00	(24.0)	(40.0)	(511.2)	(1,305)
1968	22.5	140.7	1,901.1	35.01	(39.4)	(74.5)	(952.1)	(3,016)
1969	11.7	222.4	671.2	44.70	(57.3)	102.0)	(1,303.6)	(2,209)
1970	56.3	127.9	528.0	72.55	(53.4)	126.0)	(1,610.3)	(2,323)
1971	31.0	359.5	30.8	17.30	(40.7)	(58.0)	(741.2)	(1,163)
1972	96.1	163.0	[2](740.0)	31.08	(46.0)	(77.0)	(984.1)	(1,983)
1973	82.5	152.8	1,869.2	189.89	(100.1)	(290.0)	(3,607.2)	(5,712)

[1]Mean between maximum and minimum guesses, calculated as following: (a) Ratio Mexican partyboat catch to U.S. partyboat catch: max = 0.23 (1961), min = 0.03 (1971); (b) Ratio U.S. private boat catch to U.S. partyboat catch: constant = 0.13 (1964), increasing = 0.01/(year-1950); (c) Long range partyboat catch as reported.
[2]Preliminary estimate based on 550,000 lb caught in 9 months and average catch/quarter from 1966 to 1971, other Mexican data courtesy of Instituto Nacional de Pesca.
[3]Based on mean weights of samples taken from partyboats ($\bar{w}$ = 12.78 lb) in 1973 and from sport, commercial, and research boats. ($\bar{w}$ = 10.86 lb) in 1952-54.

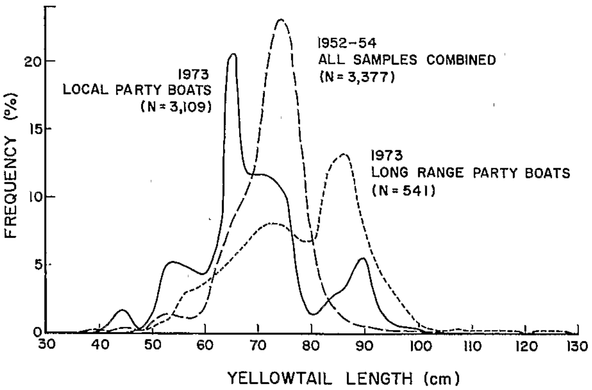

Figure 22.—Yellowtail length frequency distributions for 1952-54 and 1973.

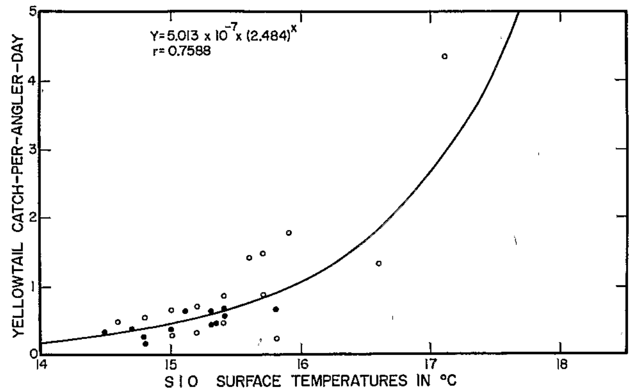

Figure 23.—Yellowtail CPUE in number per angler at the Coronado Islands plotted against annual mean sea surface temperature at Scripps pier (from Radovich, 1975); solid points are years used in production model.

catch. Length composition shows an increase in the proportion of older fish between 1952-54 and 1973.

Present state of exploitation

Using Gulland's (1969) approximation method for assessing equilibrium curve, yellowtail CPUE data (Table 24) for partyboat anglers were plotted against average total effort (average of past 3 years in order to take into account the approximately 6 years duration of exploited phase). Since data are only available for the periods of 1948-54 and 1966-72, respectively, the number of points is small; however, they appear to give a fair picture of the above trend in recent history of the fishery. A slightly curved line describes the relationship between CPUE and total effort (Fig. 24), and the derived equilibrium yield curve shows a maximum of about 8.5 million pounds for a corresponding total effort of 2.5 to 3 × 10^6 Coronado Islands partyboat angler standard units, i.e., roughly 8 to 10 times the 1966-72 level. Estimated MSY is slightly above the average catch for the 1935-54 period of high fishing.

Under the present conditions of exploitation, determination of the exact positions of the potential and of the corresponding effort is not essential. Although the data used suffer from various limitations, it seems reasonable to conclude that stock abundance increased following the reduction in the amount of fishing since 1955. The stock appears to be in very good health. Sport catches have improved under the present level since exploitation has been far from maximum sustainable levels. The stock is capable of producing much higher yields (3-4 times or more), however, at the cost of a corresponding decrease in sport CPUE (Fig. 24). It should also be noted that neither the southward extension of the stock nor its relationship with other stocks located in the Gulf of California and more southern waters, is very well known. It is, at present, assumed that such stocks do not contribute substantially to the California fisheries. If this assumption is not to be confirmed, expansion of fishing in more southern waters might provide higher yields.

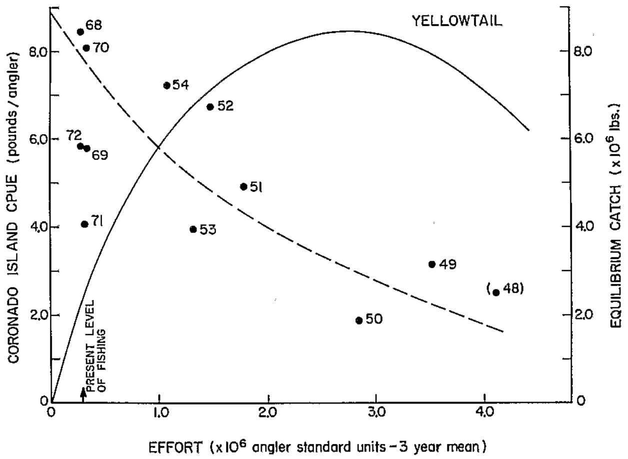

Figure 24.—Relationship between Coronado Islands CPUE and effort and the corresponding estimates of surplus production for yellowtail.

Table 24.—Yellowtail: CPUE and estimated total effort.

Year	Partyboat CPUE: Coronado Islands fish/angler	Partyboat CPUE: Estimated lb/angler	Estimated total effort 1,000 standard units[1]
1947	0.229	2.490	4035
1948	0.232	2.521	4197
1949	0.290	3.146	2400
1950	0.174	1,891	1914
1951	0.451	4.903	1016
1952	0.620	6.734	1518
1953	0.364	3.948	1413
1954	0.664	7.211	305
1955	0.644	—	—
1956	0.489	—	—
1957	1.913	—	—
1958	1.315	—	—
1959	4.312	—	—
1960	1.418	—	—
1961	0.559	—	—
1962	0.518	—	—
1963	0.869	—	—
1964	0.716	—	—
1965	0.304	—	—
1966	0.886	11.325	204
1967	0.380	4.860	268
1968	0.662	8.460	357
1969	0.452	5.779	382
1970	0.633	8.092	287
1971	0.319	4.082	285
1972	0.455	5.802	309
1973	1.441	18.414	315

[1]Standard effort unit is Coronado Island angler day. Total effort is the hypothetical amount of standard effort units necessary to take the entire catch.

Analysis, discussion of present management measures

Between May and August the U.S. commercial yellowtail fishery is now subject to several limitations: Catches per trip are limited to 500 pounds per fisherman and 2,500 pounds per boat; use of purse seine and round haul nets is prohibited, and gill nets must have a minimum mesh size of 3.5 inches. Similarly, a daily bag limit of 10 fish is applied to the sport fishery which uses only hook and line. Considering the present low level of exploitation of the stock and the fact that 50-60 percent of the total catches are taken in unregulated waters off Baja California, such regulations are not justified on biological grounds.

In addition, a 28-inch size limit has been introduced for the California commercial fishery. Apparently such a measure has been based on size of first maturity (all fish are said to be mature as 3 years old, or 27.8 inches). However, there is no scientific evidence, either in yield per recruit or in recruitment/parental stock to justify such regulation. Although M is not known, the present low level of exploitation strongly suggests that the maximum yield per recruit would be achieved for a smaller size at first capture than the legal one which represents about 0.55 the maximum sizes of fish caught. Examination of yield per recruit tables (Beverton and Holt, 1966) indicate that if $M/K = 1.50$ ($K = 0.136$), and fishing mortality is low (less than ⅓ M), yield per recruit could potentially be increased from 6 to 16 percent by lowering minimum size from 28 inches. If $M/K = 0.75$ only a 1-4 percent increase would be expected, as 28 inches is nearer proper minimum size for low mortality rates. Stock recruitment relationship should not raise particular problems at the present level of fishing, and even for substantially higher ones, since the long life span of yellowtail and the subsequent high number of year classes present in the population should make it less vulnerable to successive low recruitments. It should also be mentioned here that the minimum mesh size does not appear to correspond to the legal minimum size and sublegal size fish may be captured. Such a situation is inappropriate both on biological and economic grounds.

It can be concluded that at present no limitation appears to be necessary in the yellowtail fishery. However, the limited potential of the stock would require early formulation and implementation of proper management measures, should the fishery expand in the future.

INTERACTIONS

Fisheries seldom act in the absence of important interactions from other fisheries, species composition and trophic relationships, and exogenous environmental influences. These interactions are complex in southern California waters. Here we have selected some relevant aspects for quick investigation. Fisheries interactions are an important aspect of the northern anchovy exploitation controversy, and are briefly discussed, with emphasis on the live bait anchovy supply. Species composition of both commercial wetfish fleet and partyboat catches have undergone large changes in recent years. A strong argument against large-scale exploitation of the northern anchovy has been based on the necessity of this species as forage for game fish. Discussion of these topics may be of use in gaining perspective on the status of the individual stocks discussed in this report.

Northern anchovy fisheries interaction and allocation

Three separate fleets presently exploit the northern anchovy, *Engraulis mordax*: The southern California live bait fleet; the southern California wetfish fleet; and the Mexican wetfish fleet based in Ensenada (Table 25). To these may be added the possibility of the entry of Russian vessels as evidenced by recent experimental offshore trawling for northern anchovy. These fisheries must be expected to show both short- and long-term interactions, and the nature of these interactions should be a major input to plans for allocation of the anchovy resource to the various users.

The problem of allocation has generally been avoided since simple, conservative management has been acceptable to the interested parties. Future developments may alter present attitudes toward the fishery in California, and exploitation by foreign fleets will certainly undergo expansion in the near future.

Table 25.—Anchovy fisheries.

Exploiter	Geographic area of exploitation	Age of recruitment	Present catch (10^3 tons)	Present catch value ($$10^3$)	Ex-vessel price index $/ton	Probable catch in 5-10 yr (10^3 tons)	Regulating agency
Southern California wetfish fleet (reduction)	Inshore, near San Pedro and Port Hueneme facilities (San Diego in future)	2	100	[1]5,000	30-50	100-200	Calif. Fish, Game Comm.
Southern California live bait fleet	Shallow inshore near sportfishing ports in southern California	1	10	[2]direct 5,000 [3]indirect 5,000– Total 10,000–	[5]660+	10-15	Calif. legislature
Mexican wetfish fleet (reduction)	Inshore near Ensenada	1-2	30	[4]1,000+	[6]25-35+	50-200	Mexico (U.S. Gov't. has authority for negotiation)
USSR High seas trawler/ factory ships (canning)	Offshore	3	0	0	0	0-100	USSR (U.S. Gov't. may have strong control)

[1]100,000 tons @$50/ton (price generally lower).
[2]1,000,000 scoops @$5/scoop.
[3]600,000 partyboat angler-trips @$8/trip, assuming the partyboat industry is completely dependent on live bait. True indirect value will be less.
[4]30,000 tons @$33/ton. Economic value to Mexico not comparable with U.S. values.
[5]Based on $5/15 pound scoop. Inclusion of indirect value would increase index.
[6]Economic worth to Mexico may be greater than U.S. dollar value suggests.

Unfortunately, each fishery is presently regulated by a different agency and it will be impossible to manage the stock scientifically or efficiently unless the various agencies are able to establish a common basis for discussion and optimization of anchovy exploitation. Presently there is a healthy cooperation and communication at lower levels, as is necessary for formulation of management alternatives. Cooperation, however, must occur at the highest levels of State, Federal, and foreign governments so that coordinated and responsive management is implemented. Establishment of such a forum will be difficult.

An initial attempt at establishing suitable criteria for allocation might be based on price paid per ton of fish (Table 25), which tends to reflect the value consumers put on the fishery product. Such an index could be improved by including other factors such as yield relative to maximum (or optimum) sustainable yield and variations in price with supply, or these factors could be included as components in a general allocation model. By this simple price index, the live bait fishery far outweighs the reduction fishery in importance and should be given full consideration.

Live bait anchovy fishery

The southern California live bait fishery is the supplier of bait for sport fishermen. The bulk of the bait goes to partyboat utilization. Thus, the live bait fishery operates under two simultaneous sets of constraints. Supply is limited by availability (CPUE) of anchovies, while demand is determined by sport fishing activity. Fortunately, analysis of these relationships is possible due to the availability of voluntary live bait catch and effort logbook data and extensive partyboat effort data collected by CDFG.

Supply was approached as a problem in CPUE, with catch measured in scoops (about 15 pounds of fish) and effort in boat trips. The CDFG Statistical regions 6, 7, and 8, corresponding to Santa Barbara, Los Angeles, and San Diego areas respectively, were investigated separately.

Annual CPUE values were calculated as annual catch divided by annual trips. This glosses over seasonal variation, but gives a good view of the long-term trend (Fig. 25). Assuming fishing vessels have not changed in fishing power, and neglecting sardine catches, there has been a large increase in availability of anchovies in recent years.

Table 26.—Anchovy bait fishery—long and short term effects of reduction fishing.

Years	Region 6 (Santa Barbara)			Region 7 (Los Angeles)			Region 8 (San Diego)		
	Winter[1]	Summer[2]	ln (s/w)	Winter[1]	Summer[2]	ln (s/w)	Winter[1]	Summer[2]	ln (s/w)
Nonreduction									
60-61	—	157.6		186.4	462.1	0.908	319.5	791.6	0.907
61-62	151.0	265.8	0.565	286.9	407.7	0.351	708.3	518.7	−0.312
62-63	142.8	195.9	0.316	241.3	351.5	0.376	478.0	571.8	0.179
63-64	117.5	202.4	0.544	192.9	454.4	0.857	203.9	640.1	1.144
64-65	138.1	191.7	0.328	232.0	425.3	0.606	243.6	546.4	0.808
67-68	250.5	141.4	−0.572	940.8	574.8	−0.493	368.1	581.0	0.456
$\bar{x}$	160.0	192.5	0.236	346.7	446.0	0.434	386.9	608.3	0.531
σ	52.09	43.15	0.467	293.3	74.49	0.510	184.7	98.53	0.535
Reduction									
65-66	220.8	243.6	0.098	296.1	477.9	0.479	287.8	603.5	0.740
66-67	138.0	229.6	0.509	334.1	513.6	0.430	349.7	1,303.8	1.316
68-69	225.8	294.8	0.267	465.1	728.4	0.449	469.4	699.0	0.398
69-70	141.5	163.8	0.146	319.8	773.9	0.884	547.0	887.4	0.484
70-71	69.8	133.5	0.648	514.0	526.3	0.024	673.4	930.2	0.323
71-72	83.8	177.0	0.748	717.3	854.1	0.175	784.3	2,031.1	0.952
$\bar{x}$	146.6	207.1	0.403	441.1	647.7	0.407	518.6	1,075.8	0.702
σ	65.91	59.5	0.271	160.9	159.1	0.295	189.5	526.6	0.381

[1] $\Sigma c/\Sigma f$ for November, December, January, and March.
[2] $\Sigma c/\Sigma f$ for June, July, and August.

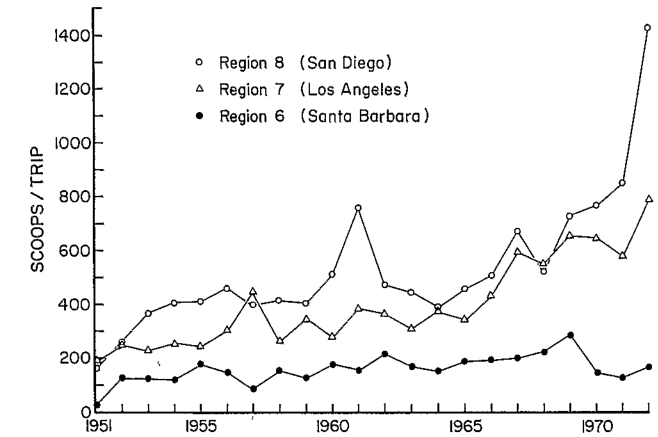

Figure 25.—Anchovy live bait CPUE (annual scoops/trip).

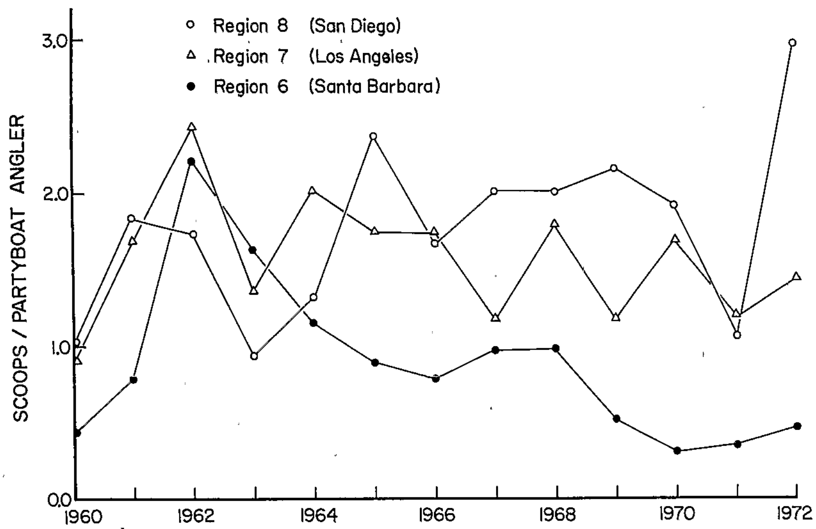

Figure 26.—Anchovy live bait catch per partyboat angler (scoops/angler).

Both the San Diego and Los Angeles regions show this trend. The Santa Barbara region appears to have experienced an increase in availability up to 1969, but it suffered a severe decline in CPUE in 1970, 1971, and 1972.

Separation of short-term (seasonal) and long-term trends in availability, vis-a-vis the reduction fishery, was accomplished by separating CPUE observations into long-term groups (reduction fishing seasons of 1965, 1966, 1968, 1969, 1970, and 1971, and nonreduction seasons of 1960, 1961, 1962, 1963, 1974, and 1967), and into short-term groups (reduction period, winter—November, December, January, and March; non-reduction period, summer—June, July, and August). The long-term availability has likely increased since the mean CPUE's for all three geographical regions for the summer period were higher for the reduction years than for the previous non-reduction years (Table 26). Winter availability shows a similar trend for Los Angeles and San Diego, but a slight decrease for Santa Barbara, particularly for the most recent years. The tendency for increased availability in recent years, despite the reduction fishery, presumably has been a result of an increase in anchovy abundance (we have assumed an increase in vulnerability or fishing power has not occured). Values of anchovy bait CPUE (Fig. 25) show a weak correlation with egg-and-larvae indices of abundance of the central stock of anchovies (r San Diego = 0.65, r Los Angeles = 0.51, r Santa Barbara = 0.45). Offsetting the years to account for the younger age of bait anchovies did not give significant increases in correlation coefficients.

Short-term changes in anchovy bait availability, presumably caused by decrease in winter availability due to reduction fishing, were examined by comparing summer/winter ratios (in natural logarithms) of CPUE during years of reduction fishing with ratios for years in which there was no reduction fishery (Table 26). Mean relative winter availability decreased 12 percent in the Santa Barbara region and 12 percent in the San Diego region during years of reduction fishing, but in the Los Angeles region, in which reduction fishing was presumably the heaviest, the mean of ratios showed an 8.6 percent increase in relative winter availability. The variance of the log ratios is large so no tests of significance were attempted.

It is concluded that bait anchovy availability has not shown either long- or short-term decreases connected with the anchovy reduction fishery up to the 1971-72 level of reduction catch. The San Diego and Los Angeles bait regions appear healthy, but the Santa Barbara region shows a large anomaly starting in 1970.

The live bait fishery is also highly influenced by bait demand, with commitments to bait users varying with amount of sport fishing effort. Letting the number of partyboat anglers be an index of demand (as we have no values for private boat utilization of bait) and letting the bait catch indicate the supply for that market, an index of bait supply to the sport fishermen can be calculated. The trend of live bait catch per partyboat angler shows a fluctuating, but fairly constant, supply to the angler for the San Diego and Los Angeles regions, but the Santa Barbara region shows a long downward trend since 1962 (Fig. 26). The years 1969 through 1972 show extremely poor bait supplies in Santa Barbara and the 1969 point is unusual in that CPUE was the highest on record for the Santa Barbara area (Fig. 25). Examination of trends in effort show the expected reduction in effort for San Diego and Los Angeles areas where CPUE increased, but shows a decrease in effort for Santa Barbara when CPUE also decreased (Fig. 27). This suggests that either commitments to the fishermen decreased, or it became economically unfeasible to fish at the low level of bait availability, which is unlikely as the price of bait can be adjusted accordingly. The anomalous behavior of the Santa Barbara fishery in 1969 supports the former hypothesis.

The ratio of bait catch to partyboat anglers was suggested as a measure of commitment above. Letting K be a constant value of commitment in scoops per partyboat angler, a linear relationship between the ratio of bait effort (f_b) to anglers (f_s) and the reciprocal of bait CPUE can be described.

Letting C_b be bait catch,

$$\frac{C_b}{f_s} = K,$$

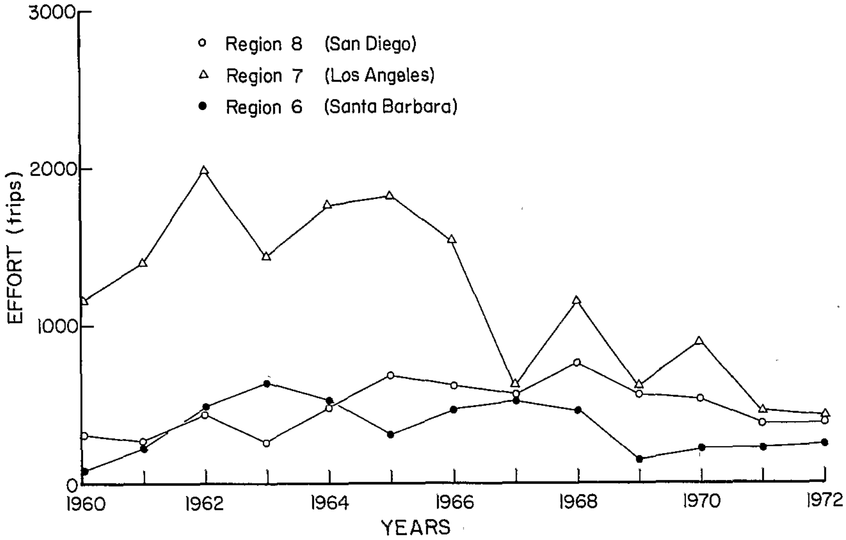

Figure 27.—Anchovy live bait effort (trips).

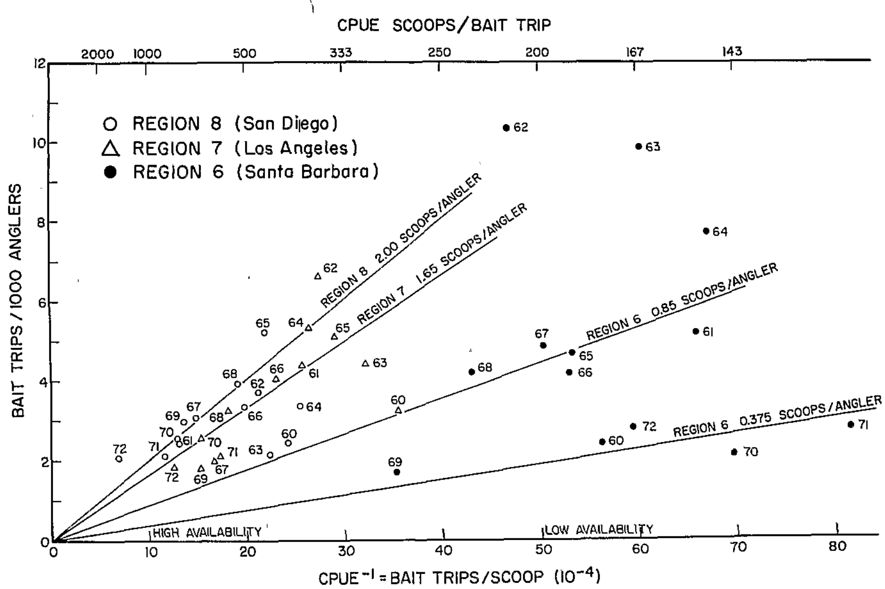

Figure 28.—Anchovy live bait demand commitment and supply.

$$\frac{C_b}{f_s}\times\frac{f_b}{f_b}=\frac{f_b}{f_s}\times\frac{C_b}{f_b}=\frac{f_b}{f_s}\times \text{CPUE} =K,$$

$$\text{or}\ \frac{f_b}{f_s} = K\ \text{CPUE}^{-1}.$$

A plot of f_b/f_s vs CPUE^{-1} (Fig. 28) shows a good linear relationship for Los Angeles and a fair one for San Diego. The early years 1960 and 1963 appear as outliers in both plots. San Diego (K = 2.0 scoops/angler) shows a somewhat higher commitment than does Los Angeles (K = 1.65 scoops/angler). Santa Barbara is again anomalous in not showing any well-defined relationship. Possible relationships are K = 0.85 scoops/angler for 1969-72, again suggesting a reduction in level of commitment for recent years.

Levels of commitment can presumably change due to changes in the relative number of nonpartyboat anglers buying live bait, or due to changes in sport fishing methods and target species. For example, fishing for rockfish requires less bait per angler than fishing for game fish where large amounts of chum are used. This partly explains the lower levels of commitment in the Santa Barbara area where bottom fishing predominates. It must be concluded that

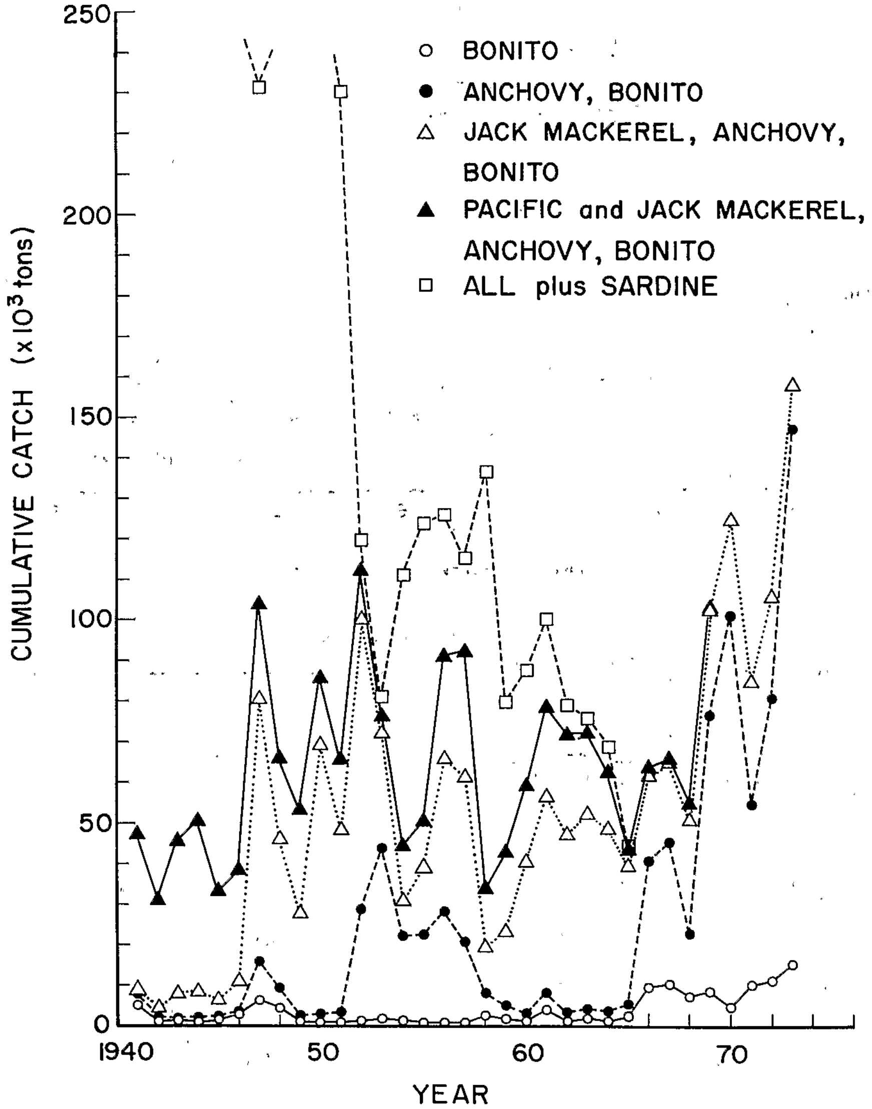

Figure 29.—Total commercial catch of fish species exploited by purse seine wetfish fleet, 1941-73.

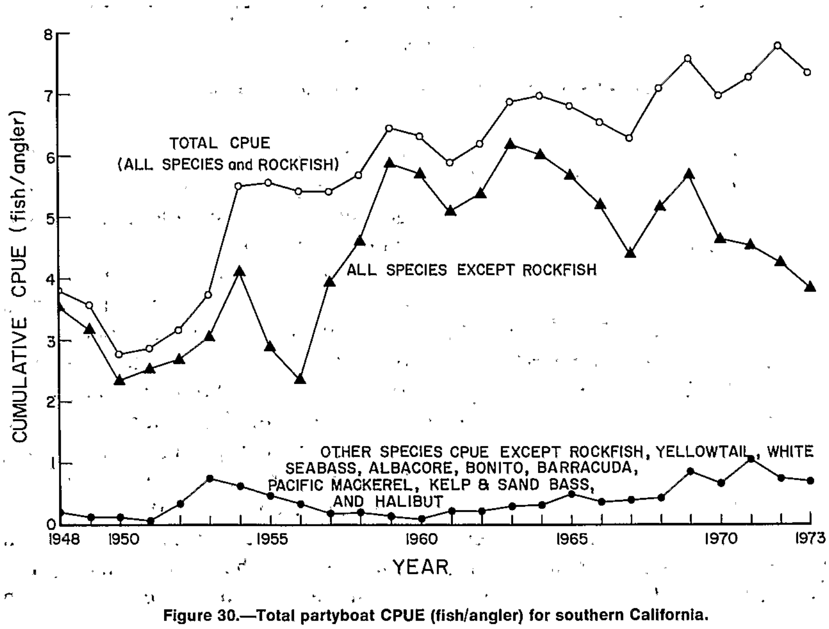

Figure 30.—Total partyboat CPUE (fish/angler) for southern California.

low availability in the Santa Barbara area is a condition which has existed at least since 1951, and is probably not the result of the anchovy reduction fishery. Moreover, there is some evidence that the Santa Barbara bait fishery has established lower commitments rather than increasing effort to maintain the supply to the sport fisheries. Lack of further information on the Santa Barbara bait fleet and fishery prevents a definite conclusion, and there may be other factors which explain this anomalous behavior.

Southern California wetfish fishery

Species caught by the wetfish fleet include Pacific sardines, Pacific mackerel, jack mackerel, Pacific bonito, and northern anchovy, and small amounts of a variety of other species. The majority of the commercial catch is landed in the Santa Barbara, Los Angeles, and San Diego regions with the San Pedro wetfish fleet accounting for most of the fishing effort. Prior to the collapse of the sardine stock, almost the entire effort was directed toward sardines. Since the 1951 collapse, the catches of the four other species have sustained the fishery but have fluctuated for various reasons (Fig. 29). Documentation of the fishery interactions between wetfish species is useful in the assessment of any one of the stocks.

After the virtual collapse of sardines in 1951 and until 1963, the total catch of the five species varied between 80,000 and 130,000 tons annually. When sardine catches temporarily improved, catches of the others usually dropped. The anchovy was canned for human consumption and made up from one-quarter to one-third of the fishery until 1958. Jack mackerel catches sustained the fishery when sardines were low and after the demand for canned anchovies declined. Pacific mackerel catches were consistent from 1954 until the collapse of the stock in the mid-1960's. Bonito catches were low because of low stock sizes in the early 1950's and lack of processors' demand. The combined catch of all five species reached a low of 43,000 tons in 1965.

Beginning in 1966 the composition of the wetfish catch changed. Sardine and Pacific mackerel catches failed to recover and fishing moritoria were imposed in 1967 and 1971 for the two stocks respectively. Bonito catches jumped in 1966 and have since fluctuated depending somewhat on processor demand (Perrin and Noetzel, 1970). The jack mackerel catch has dropped apparently as the result of effort being redirected toward anchovies. This new interest in anchovies is due to the California Fish and Game Commission allowing anchovy reduction for fish meal in the fall of 1965. Recent high catches are a result of high prices paid for fish meal brought on by the collapse of the Peruvian anchoveta fishery.

Southern California partyboat fishery

The status of the partyboat fishery is largely the result of the satisfaction obtained from the angling experience; however, angler satisfaction is a difficult concept with which to work. It is generally not quantifiable as is profit in the case of commercial fisheries. It varies widely between anglers, and generalizations are likely to result in overlooking the variety of individual experience. In view of these problems, the following discussion attempts to assess the status of the partyboat fishery in simple terms with enough quantifications to allow rough comparisons between years.

The partyboat catch is composed of a multitude of species of varying interest to the angler. Total CPUE regardless of species, in number of fish per angler-trip, shows an upward trend since 1950, having doubled the overall catch rate since that time (Fig. 30). Such a trend in CPUE of combined species has a limited meaning in assessing angler satisfaction, however, as species composition of the catch is of prime importance to the sport fisherman.

Nine species comprise the bulk of the landings (Fig. 30). These species were divided into three groups based on a subjective classification. The first group is composed of large sport fish: white seabass, yellowtail, and albacore (Fig. 31). The second group is composed of smaller sport fish: barracuda, bonito, and Pacific mackerel (Fig. 32). The third group is composed of "food" species: kelp and sandbass, rockfish and halibut (Fig. 33). The CPUE was calculated as total partyboat catch divided by total anglers, which in this case includes long-range partyboat data.

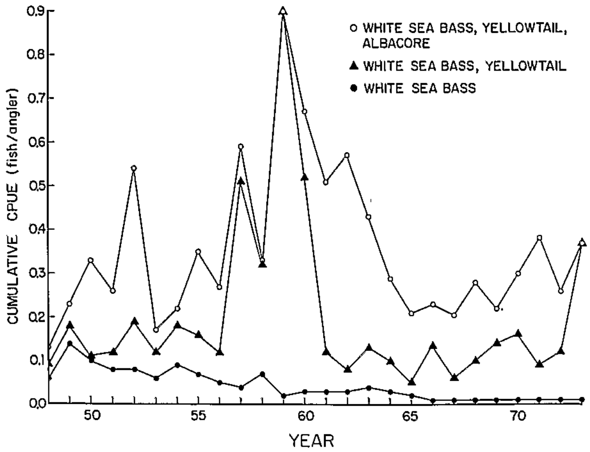

Figure 31.—Large sport fish partyboat CPUE.

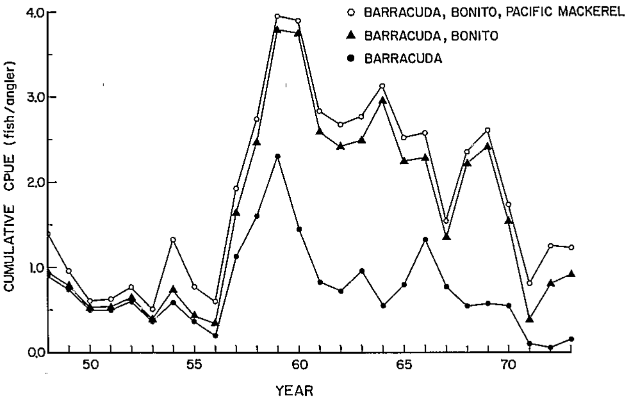

Figure 32.—Small and medium sport fish partyboat CPUE.

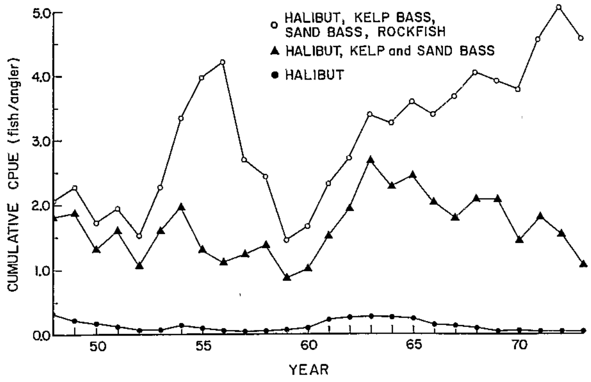

Figure 33.—"Food" fish partyboat CPUE.

Both the large and small sport fish groups show large increases in catch rate during and following the warm water years. Catch rates for these functional groups have tapered off more recently and appear to have returned to levels comparable to the early 1950's. The species composition within these groups has changed considerably since that time, however.

The biggest change that has occurred in the partyboat fishery is the increased effort directed toward the "food" group, particularly rockfish. The rockfish resource appears to have been "discovered" in the mid-1950's, but was later ignored in favor of the highly available sport fish species in the warm water years. With the slow decline of sport fish availability to previous levels, the "food" species were again sought. It appears likely that the period of high sport fish abundance caused an increase in the catch level necessary for angler satisfaction. This need for more fish has been filled mostly by rockfish, which furnishes the expected catch, but angler satisfaction falls short of that provided by the livelier sport fish. The ability of the rockfish resource to withstand increased harvesting is unknown and should be seriously investigated.

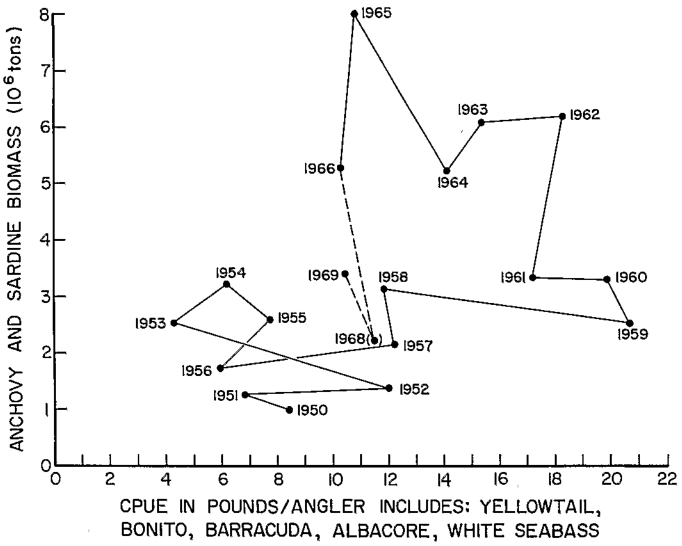

Figure 34.—Relationship between anchovy plus sardine biomass and game fish partyboat CPUE for 1950-69.

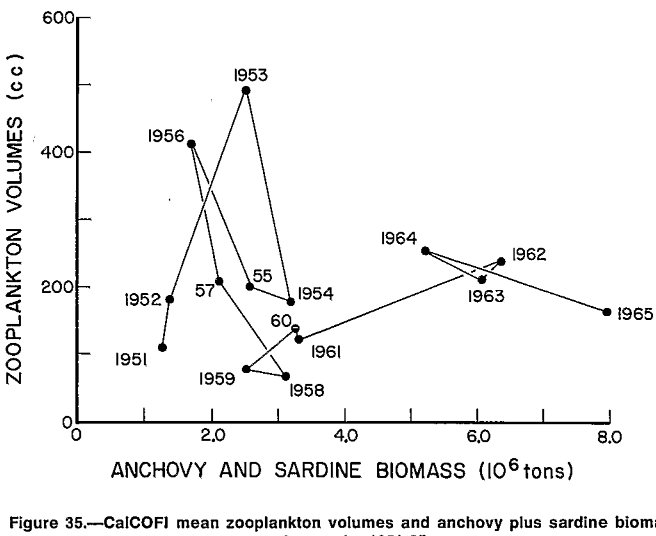

Figure 35.—CalCOFI mean zooplankton volumes and anchovy plus sardine biomass estimates for 1951-65.

In summation, the partyboat fishery experienced an increase in availability of medium and large sport fish during and following the warm water years. Catch rates for these groups of fish are now returning to levels similar to those of the early 1950's. The fishery appears to be producing an angler experience comparable to or better than that of the early 1950's and therefore must be considered to be fulfilling angler expectations no poorer than they did in the early 1950's.

Sport fish-anchovy relationships

The trophic relationships are complex between forage species such as anchovies and sardines and predatory game fish species such as yellowtail, barracuda, bonito, white seabass, and albacore. An attempt to describe the food webs and to quantify energy flows between trophic levels for the last 20 years is beyond the scope of this report. Furthermore, necessary estimates of growth rates, daily food rations, and predator biomass do not exist. On the other hand, biomass estimates for sardines and anchovies and partyboat CPUE provide enough information for a superficial examination of the relationship between biomass of these forage species and the availability of the major game fish.

A plot of anchovy and sardine biomass estimates for all stocks versus combined partyboat CPUE (pounds/angler) for yellowtail, barracuda, white seabass, bonito, and albacore for the years 1950-69 tend to support the general theory of Brocksen, Davis, and Warren (1970) (Fig. 34). They hypothesize that if forage is limiting, then a negative relationship would be expected between forage biomass and predator biomass such that high levels of predators should reduce forage to low levels, and at low levels of predators, forage would grow to high levels. If the system becomes more productive as a result of environmental events, the relationship still holds except at much higher levels of both prey and predator biomass.

The data for southern California suggest three time periods. The first is the years 1950-56 when forage biomass and game fish index were both relatively low. The second, 1957-60, appears to be a transitional period during which forage biomass remained low but the index of game fish increased greatly as a result of the warm water.

The third period, 1961-66, appears to be a regime of greater productivity in general. An examination of CalCOFI data from Thrailkill (1969) suggests a slight increase in plankton volumes for the 1960's over the 1950's if 1953 and 1956 are ignored (Fig. 35). This trend may be more significant if salps are eliminated from the volume means. If the first and third periods are treated separately, assuming levels of productivity are indeed different, it might be concluded for each that forage biomass is influenced by the abundance of these game fish.

Unfortunately this analysis is an oversimplification of the relationship and is not supported by a more detailed examination of the evidence. First of all the food web is much more complex than suggested by the analysis. The number of forage species is greater than two. Squid, for example, are also important but annual estimates of biomass are not available. The abundance of forage species in any one year may be more dependent on recruitment than on grazing by predators. Information from MacCall (1973) suggests that anchovy recruitment has been relatively constant for years 1960-65. The partyboat CPUE does not include all the major predators; birds and marine mammals must account for a large proportion of the annual mortality. Albacore has been included in the CPUE index for two reasons. First, the original CDFG partyboat statistics includes albacore trips and, second, stomach samples of albacore collected in southern California have contained 55 percent anchovies by volume (Pinkas, Oliphant, and Iverson, 1971). The species of game fish included in the CPUE index are highly migratory so that the quantity of game fish present in any one year is most likely due to contemporary conditions of the ecosystem rather than population dynamics of the game fishes. Furthermore, partyboat CPUE may not be proportional to biomass of game fish.

Additional evidence does not support the contention that increases in forage biomass will increase game fish availability in southern California nor does it support the contention that game fish influence anchovy stock as much as suggested in Figure 35. Examination of the time series in Figure 35 suggests that the increased availability of game fish during warm water years did not reduce anchovy-sardine biomass as theory would suggest. Either the productivity of forage increased simultaneously or the predator species being considered did not influence forage biomass significantly. The high CPUE values for the third period are not the result of a composite of similar increases for the five species but result mainly from increased catch of bonito which apparently established a larger population in the southern California bight during the warm water years. Whereas the CPUE declined during the mid-1960's while forage supplies increased, the abundance of game fish is not obviously dependent on forage supplies.

The biomass of anchovies and sardines lost to natural mortality each year can be estimated by $\Sigma M_i \bar{B}_i$ where instantaneous rate of natural mortality M_i is assumed to equal 1.0 and 0.8 for anchovies and sardines respectively, and where $\bar{B}_i$ is the annual average biomass of each species. The estimates average 1.0, 3.0, and 6.0 million tons from total stocks of anchovies and sardines for the years 1950-53, 1954-60, and 1961-65 respectively. The proportion of this natural loss due to predation by game fish can be estimated by making assumptions on feeding rates and game fish biomass. To find likely maximum values for these ratios, it was assumed that combined rates of exploitation on game fish for all fisheries were near 5 percent annually, that game fish consume 5 percent of their body weight per day in anchovies and sardines, and that game fish feed 200 days per year on the anchovies and sardines. The estimated proportions of mortality are 100 percent, 50 percent and 25 percent for the periods 1950-53, 1954-60, and 1961-65 respectively. For the earlier years, food supply may have indeed been a limiting factor. The assumptions and absolute values of the ratios are relatively unimportant, invariably leading to the conclusion that the influence of game fish on forage supply should have decreased rather significantly between the periods 1950-53 and 1961-65. This contradicts the suggestion that the forage supplies in 1950-53 were influenced by game fish to the same extent as those in 1961-65 as suggested by similar slopes and scatter of points in the anchovy-sardine biomass and game fish CPUE relationship (Fig. 35).

In summary, the trends in forage biomass and game fish availability are probably coincidental. The evidence is too incomplete at this time to demonstrate the degree of dependency of game fish on forage supplies.

ACKNOWLEDGMENTS

This study has been made possible by the cooperation of many people. Much of the data contained in this report were unpublished and were made available through Isadore Barrett, NMFS; Gail Campbell, CDFG; Harold Clemens, CDFG; Robson Collins, CDFG; Ignacio Felix Cota, the Instituto Nacional de Pesca (INP); Charles Hooker, CDFG; Eric Knaggs, CDFG; Kenneth Mais, CDFG; Leo Pinkas, CDFG; Patricia Powell, CDFG; Donald Schultz, CDFG; Paul Smith, NMFS; James Squire, Jr., NMFS; and James Thrailkill, NMFS. Bruce Wahlen and William Altland spent many weeks collating these source data. We wish to thank the INP for its contribution of vital Mexican catch data, and the southern California live bait fishermen and the Ensenada Sport Fishing Association for their voluntary submission of catch and effort information. We would like to thank Norman Abramson, NMFS; Clark Blunt, CDFG; William Fox, NMFS; David Kramer, NMFS; William Lenarz, NMFS; John Radovich, CDFG; and Brian Rothschild, NMFS for their review and criticism of the manuscript. We wish to extend our thanks to Roy Allen for preparing the illustrations and the SWFC typists for typing the manuscript.

This cooperative study was supported by the California Department of Fish and Game/National Marine Fisheries Service contract entitled Stock Assessment, Fishery Evaluation and Fishery Management of Southern California Recreational and Commercial Fisheries, No. 03-4-208-160 and 03-5-208-60.

LITERATURE CITED

Ahlstrom, E. H. 1968. An evaluation of the fishery resources available to California fishermen. Univ. Wash., Publ. Fish., New Ser. 4:65-80.

Baxter, J. L., and P. H. Young. 1953. An evaluation of the marine sportfishing record system in California. Calif. Fish Game 39:343-353.

Beverton, R. J. H., and S. J. Holt. 1966. Manual of methods for fish stock assessment. Part 2—Tables of yield functions. FAO (Food Agric. Organ. U.N.) Fish. Tech. Pap. 38, 77 p.

Brocksen, R. W., G. E. Davis, and C. E. Warren. 1970. Analysis of trophic processes on the basis of density-dependent functions. *In* J. H. Steele (editor), Marine food chains, p. 468-498. Univ. Calif. Press, Berkely and Los Ang., Calif.

Campbell, G. In press. The age and growth of the Pacific bonito, *Sarda chiliensis*. Calif. Dep. Fish Game, Fish Bull.

Clark, F. N., and J. C. Marr. 1955. Population dynamics of the Pacific sardine. Calif. Coop. Oceanic Fish. Invest. Rep. 1953-55:11-48.

Collins, R. A. 1971. Size and age composition of northern anchovies (*Engraulis mordax*) in the California reduction and canning fisheries, 1968-69 season. Calif. Fish Game 57:283-289.

Fry, H., Jr. 1937. Yellowtail. *In* Staff of Bureau of Commercial Fisheries, The commercial fish catch of California for the year 1935, p. 33-36. Calif. Dep. Fish Game, Fish Bull. 49.

Gulland, J. A. 1969. Manual of methods for fish stock assessment. Part 1. Fish population analysis. FAO (Food Agric. Organ. U.N.) Man. Fish. Sci. 4, 154 p.

_________. 1970. Preface. *In* J. Gulland (editor), The fish resources of the oceans, p. 1-4. FAO (Food Agric. Organ. U.N.) Fish. Tech. Pap. 97.

Knaggs, E. H. 1973. The status of the jack mackerel resource and its management. Calif. Dep. Fish Game, Mar. Res. Tech. Rep. 11, 12 p.

Knaggs, E. H., and P. A. Barnett. 1974. The southern California jack mackerel fishery and age composition of the catch for the 1947-48 through 1956-57 seasons. Calif. Dep. Fish Game, Mar. Res. Tech. Rep. 22, 47 p.

_________. 1975. The southern California jack mackerel fishery and age composition of the catch for the 1962-63 through 1966-67 seasons. Calif. Dep. Fish Game, Mar. Res. Tech. Rep. 28, 28 p.

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., U.S. 72:37-61.

MacCall, A. D. 1973. The mortality rate of *Engraulis mordax* in southern California. Calif. Dep. Fish Game, Mar. Res. Tech. Rep. 4, 23 p.

MacGregor, J. 1964. Average biomass estimates for the years 1955-57. *In* Calif. Mar. Res. Comm. Min., 6 Mar. 1964, Doc. 6.

Messersmith, J. D. 1969. The northern anchovy (*Engraulis mordax*) and its fishery 1965-1968. Calif. Dep. Fish Game, Fish Bull. 147, 102 p.

Murphy, G. I. 1966. Population biology of the Pacific sardine (*Sardinops caerulea*). Proc. Calif. Acad. Sci. Ser. 4 34:1-84.

Parrish, R. 1974. Exploitation and recruitment of Pacific mackerel, *Scomber japonicus*, in the northeast Pacific. Calif. Coop. Oceanic Fish. Invest. Rep. 17:136-140.

Perrin, W. F., and B. G. Noetzel. 1970. Economic study of the San Pedro wetfish boats. Fish. Ind. Res. 6:105-138.

Pinkas, L. 1966. A management study of the California barracuda *Sphyraena argentea* Girard. Calif. Dep. Fish Game, Fish Bull. 134, 58 p.

Pinkas, L., M. S. Oliphant, and C. W. Haugen. 1968. Southern California marine sportfishing survey: private boats, 1964; shoreline, 1965-66. Calif. Dep. Fish Game, Fish Bull. 143, 42 p.

Pinkas, L., M. S. Oliphant, and I. L. K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. Calif. Dep. Fish Game, Fish Bull. 152, 105 p.

Pinkas, L., J. C. Thomas, and J. A. Hanson. 1967. Marine sportfishing survey of southern California piers and jetties, 1963. Calif. Fish Game 53:88-104.

Radovich, J. 1963. Effects of water temperature on the distribution of some scombrid fishes along the Pacific Coast of North America. FAO (Food Agric. Organ. U.N.) Fish. Rep. 3(6):1459-1475.

_________. 1975. Ocean temperatures and southern California angling success. A paper presented at the Symp. on Fisheries Science held at the Higher School of Marine Sciences of the Autonomous Univ. of Baja California, Ensenada, Baja Calif., Mexico, February 16-22, 1975.

Smith, P. E. 1970. The horizontal dimensions and abundance of fish schools in the upper mixed layer as measured by sonar. *In* G. B. Farquhar (editor), Proc. Int. Symp. Biol. Sound Scattering in the Ocean, p. 563-591. Maury Center for Ocean Science, Dep. of Navy, Wash., D.C.

_________. 1972. The increase in spawning biomass of northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 70:849-874.

Soutar, A., and J. D. Isaacs. 1974. Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediment off the Californias. Fish. Bull., U.S. 72:257-274.

Spratt, J. D. 1972. Age and length composition of northern anchovies, *Engraulis mordax*, in the California anchovy reduction fishery for the 1969-70 season. Calif. Fish Game 58:121-126.

_________. 1973a. Age and length composition of northern anchovies (*Engraulis mordax*) landed in California for reduction during the 1970-71 season. Calif. Fish Game 59:121-125.

_________. 1973b. Age and length composition of northern anchovies, *Engraulis mordax*, in the California reduction fishery for the 1971-72 season. Calif. Fish Game 59:293-298.

_________. 1975. Growth rate of northern anchovy, *Engraulis mordax*, in southern California waters, calculated from otoliths. Calif. Fish Game 61:116-126.

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

_________. 1973. Proceedings of the State-Federal Marine Fisheries Research Program Planning Workshop, March 12-15, 1973, San Clemente, Calif. Calif. Dep. Fish Game and Natl. Mar. Fish. Serv., 327 p.

Sunada, J. 1975. Age and length composition of northern anchovies, *Engraulis mordax*, in the 1972-73 season, California anchovy reduction fishery. Calif. Fish Game 61:133-143.

Thayer, B. D. 1973. The status of the Pacific bonito resource and its utilization. Calif. Dep. Fish Game, Mar. Res. Tech. Rep. 7, 16 p.

Thomas, J. C. 1968. Management of the white seabass (*Cynoscion nobilis*) in California waters. Calif. Dep. Fish Game, Fish Bull. 142, 34 p.

Thrailkill, J. R. 1969. Zooplankton volumes off the Pacific coast, 1960. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish 518, 50 p.

Vrooman, A. M., and P. E. Smith. 1971. Biomass of the subpopulations of northern anchovy *Engraulis mordax* Girard. Calif. Coop. Oceanic Fish. Invest. Rep. 15:49-51.

Walford, L. A. 1932. The California barracuda (*Sphyraena argentea*). Calif. Dep. Fish Game, Fish Bull. 37, 122 p.

Young, P. H. 1969. The California partyboat fishery, 1947-1967. Calif. Dep. Fish Game, Fish Bull. 145, 91 p.

MFR Paper 1173. From Marine Fisheries Review, *Vol. 38, No. 1, January 1976. Copies of this paper, in limited numbers, are available from D825, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*