# VARIATIONS IN THE CATCH OF JACK MACKEREL IN THE SOUTHERN CALIFORNIA PURSE SEINE FISHERY

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## ABSTRACT

Jack mackerel landings from southern California sampled by the California Department of Fish and Game show a high degree of variability in recruitment success. The period from 1947 to 1983 is examined for variations in landings due to changes in fishing effort of the multispecies purse seine fishery. Fishing effort for jack mackerel has been affected by the availability of alternative species such as Pacific sardine and Pacific mackerel, and by economic factors including cannery capacity and the price of imported mackerel. Significant variations in recruitment success are apparent. Above-average recruitment for jack mackerel and Pacific mackerel, both pelagic species in southern California waters, often occurs in the same years.

The age composition of jack mackerel landings has changed noticeably during this period. Before 1965, fish three years old or older contributed significantly to the fishery, but after 1965 the fishery was dominated by one- and two-year-old fish. The seasonal nature of the multispecies fishery and the decreased contribution of older fish from the fall fishery are reflected in this change in age composition. Other factors include economic effects, the frequency of relatively strong year classes, shifts in the areas fished, and possible changes in fish behavior.

## RESUMEN

Los desembarcos de la macarela (*Trachurus symmetricus*) del sur de California muestreada por el Departamento de Pesca y Caza de California muestra un alto grado de variabilidad en reclutamiento. Se examina el período de 1947 a 1983 con el fin de detectar variaciones en desembarco con respecto al esfuerzo de la pesquería de red de cerco multiespecífica. El esfuerzo de pesca de macarela ha sido afectado por la disponibilidad de especies alternativas como la sardina del Pacífico (*Sardinops sagax*) y la macarela del Pacífico (*Scomber japonicus*), y por factores económicos tales como la capacidad de las enlatadoras y el precio de la macarela importada. Se encontraron variaciones significativas en el éxito del reclutamiento. Reclutamiento por arriba del promedio de la macarela y la macarela del Pacífico, ambas especies pelágicas de las aguas del sur de California, ocurren a menudo en el mismo año.

La composición en edad de la macarela ha cambiado notablemente durante este período. Antes de 1965, peces de tres años de edad o mayores contribuían significativamente a la pesquería, pero después de 1965 la pesquería ha sido dominada por peces de uno y dos años. La estacionalidad de la pesquería multiespecífica y una menor contribución de los peces más viejos de la pesquería de otoño se reflejan en este cambio en composición de edad. Otros factores incluyen factores económicos, la frecuencia relativa de clases de edad fuertes, cambios en las áreas de pesca, y posibles cambios en el comportamiento de los peces.

## INTRODUCTION

Jack mackerel, *Trachurus symmetricus*, has been an economically important species for the southern California purse seine fleet since 1947, averaging nearly $2 million in landings per year since 1947 (values not adjusted for inflation; MacCall et al. 1980). The population ranges from Baja California to the Gulf of Alaska and far offshore. MacCall and Stauffer (1983) estimated the total biomass to be 1.48 to 1.81 million MT. Most of the jack mackerel landed (over 90%) are caught by purse seiners in southern California waters, with smaller sporadic landings to the north at Monterey, California, and to the south at Ensenada, Mexico (MacCall et al. 1980). The purse seine (wetfish) fleet harvests jack mackerel from only a small portion of its range and captures only young fish.

Canneries started packing jack mackerel as a substitute for Pacific mackerel, *Scomber japonicus*, and Pacific sardine, *Sardinops sagax*, during the collapse of the sardine population and the decline of the Pacific mackerel population in the late 1940s (Roedel 1953). Jack mackerel are taken by the fleet from nearshore waters along the coast between Point Conception and the Mexican border, around islands in the

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Southern California Bight, and offshore at Tanner and Cortez banks. Schools of mackerel are sometimes species specific, but often consist of a mixture of jack mackerel, Pacific mackerel, and Pacific sardine. The jack mackerel caught in the purse seine fishery are primarily small (about 100–350 mm fork length, FL) and young (0–5 years old). They are canned at Terminal Island and Port Hueneme for human consumption and pet food (MacCall et al. 1980).

Jack mackerel have been sampled by the California Department of Fish and Game at the Terminal Island canneries since 1947 (Knaggs 1974a). Length is measured; sex is recorded; and otoliths are removed for age determination. The validity of otolith age determinations for this population was examined by Knaggs and Sunada (1974), and maturation and growth were documented by Wine and Knaggs (1975).

The purposes of this paper are to review the factors that have affected the jack mackerel landings, examine the age composition of the catch, and look at the pattern of recruitment.

## MULTISPECIES ASPECTS OF THE FISHERY

Large fluctuations in the volume of jack mackerel landings have resulted from a number of factors related to the variables present in a multispecies fishery. The southern California wetfish fleet developed in the 1930s to harvest Pacific sardine and Pacific mackerel, but took small amounts of jack mackerel (then called horse mackerel) incidentally to the target species. The history of the jack mackerel fishery up to 1951 was reviewed by Roedel (1953).

In the 1930s and 1940s Pacific sardine was by far the leading species landed by the fleet, with Pacific mackerel second (figure 1). Both Pacific mackerel and sardines were canned, but sardines commanded the highest price because they were also processed for fish oil and meal, and fish oil was in demand at that time. Canneries paid a much lower price for jack mackerel: in 1935 jack mackerel brought $6 per ton while Pacific mackerel brought $15 per ton. Northern California sardine landings declined in the mid-1940s, and many of the purse seiners went south, increasing the fishing pressure on Pacific mackerel and sardines in southern California waters (Fitch 1952). The sardine catch dropped in 1947 despite the increased effort, but revived briefly in southern California in 1949 and 1950 (figure 1).

In 1947, when Pacific mackerel and sardines became so scarce that fishermen could not fill the can-

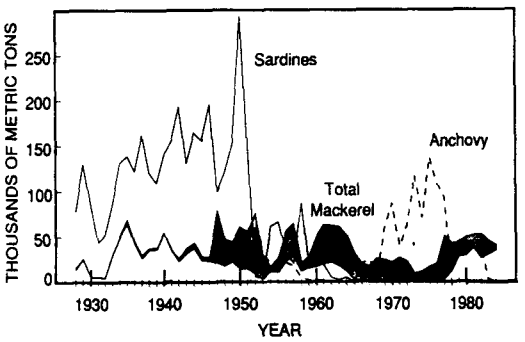


Figure 1. Annual landings of wetfish in southern California. Total mackerel comprises two species: Jack mackerel (*shaded area*) and Pacific mackerel (*area below shading*).

neries' demands, large quantities of jack mackerel were first accepted. The name was changed from horse mackerel to jack mackerel in 1948 to enhance consumer appeal, and canneries developed a marketable product. The jack mackerel catch, therefore, did not increase gradually as the fishery developed, but started with nearly the highest landings ever recorded for the species.

Northern anchovy, *Engraulis mordax*, has been an important species to the wetfish fleet since the beginning of the anchovy reduction fishery in late 1965. Within four years anchovy had topped jack mackerel landings and, except for 1978, continued to lead landings from 1969 to 1982 (Anon. 1984). Anchovy are fished by the same boats, but with nets with smaller mesh than the nets used for the other three species; so boats are not likely to fish for both anchovy and jack mackerel in the same trip. Anchovy are reduced to fish meal, but have a lower oil content than sardines. Anchovy do not command as high a price as jack mackerel, but fishing boats may shift between anchovy and jack mackerel when availability or marketability changes, or when the anchovy season opens or closes.

The fishing season for anchovy in southern California opens on September 15 and is limited to a quota on reduction landings. Fishing often starts a few weeks later, because the fishermen use the first few weeks of the season to negotiate prices with the canneries. Through 1978, the season closed on May 15 or as soon as the quota was filled. Since 1979, the closure date has been June 30, with an additional closed period on reduction landings in February and sometimes March. During the 1973 and 1974 seasons the increased cost of fuel kept boats nearer shore where jack mackerel could not be found, but an-

chovy were available. Anchovy fishing diverted effort away from jack mackerel fishing and contributed to reduced jack mackerel landings in 1973, 1974, 1977, and 1980 (Mason 1989).

The resurgence of Pacific mackerel in the 1970s, and regulations restricting its harvest have considerably affected jack mackerel landings. From the mid-1920s through the early 1960s, the Pacific mackerel fishery was unregulated and was one of the most important commercial fisheries in California (Klingbeil 1983), but by the mid-1960s the fishery had collapsed. Virtually no Pacific mackerel were caught for the next ten years. Because of the reduced biomass, a moratorium on Pacific mackerel took effect in August 1970 (Klingbeil 1983). Regulations allowed up to 18% Pacific mackerel in loads of jack mackerel to minimize the negative impact a recovering Pacific mackerel population might have on the jack mackerel fishery. As the population started to recover in 1977, mixed catches with Pacific mackerel in excess of this limit occurred, interfering with the landing of jack mackerel (Klingbeil 1983).

When the 1977 spawning biomass of Pacific mackerel was assessed at 30,000 tons, the moratorium was lifted, and a quota system was implemented. When a season's quota was filled, "interseason" regulations took effect. These restricted the percentage of Pacific mackerel that could be landed with jack mackerel until fishing on the next Pacific mackerel quota began. The allowable percentage of Pacific mackerel changed several times over the next few years, ranging from 18% to 50%. In the 1977–79 seasons, daily or weekly landing limits were imposed on mixed mackerel catches with high percentages of Pacific mackerel to delay reaching the quota. This shifted the effort of the larger vessels toward jack mackerel as long as they were available in relatively pure schools. Pacific mackerel landings increased to the point of dominating combined mackerel landings by the 1979 season and continued to dominate them for the next four seasons (figure 1).

Details on the remarkable recovery of the Pacific mackerel and the regulations governing it have been covered by Klingbeil (1983). The overall effect of these regulations on jack mackerel landings is hard to assess. Although tolerance levels were intended to keep pressure off the Pacific mackerel population, the restrictions may have also limited jack mackerel landings during periods when jack mackerel could not be found schooling as a single species. Overall, the regulations probably slowed the redirection of fishing effort from jack to Pacific mackerel.

## ECONOMIC CONSIDERATIONS

Jack mackerel are sold almost exclusively to canneries, and these canneries often limit the volume of landings they will accept (MacCall and Stauffer 1983). Canning capacities, stock on hand, and competition from other mackerel products, both foreign and domestic, have affected the volume of jack mackerel landed. Cannery orders limited landings in 1954, 1955 (Knaggs 1974a), 1959, 1960 (Knaggs 1974b), and 1977 (Mason 1989). Cannery capacity was reduced during the 1973–75 seasons after one cannery burned (Mason 1989). Cannery capacity in 1979 was estimated to be 80,000 MT (MacCall et al. 1980). Jack mackerel landings have not reached this level, partly because other species such as Pacific bonito (*Sarda chiliensis*) are also packed by these canneries, and partly because of the limited market for canned mackerel. Combined jack and Pacific mackerel landings since 1978 have only slightly exceeded the 45,000 MT of jack mackerel landed in 1977 (figure 1). Pacific mackerel are often found closer to shore than jack mackerel, decreasing fuel costs and making Pacific mackerel a more profitable target, as happened in the 1978 season (Mason 1989).

Purse seiners catch various species of pelagic fish. The selection of target species is one economic factor in which fishermen have some control. Profits are maximized by shifting effort among a variety of pelagic schooling fish as availability, marketability, and the opening and closing of fishing seasons and quotas allow. The fleet fished for sardines in the 1954 and 1955 seasons when availability increased and the price of jack mackerel was down, and in 1958 when sardines were again available and jack mackerel were unavailable. When other more profitable species such as Pacific bonito (in 1967, 1971) and both bonito and bluefin tuna, *Thunnus thynnus*, (in 1972, 1973, 1974, and 1980) became more available, fishermen shifted their effort for weeks or months to these species. In the fall of 1967, the fishing effort of the purse seine fleet was directed toward bonito, but price disputes over bonito and anchovy stopped all fishing by the fleet for three months (Fleming and Knaggs 1977). Thus the availability of different species to the purse seine fleet enhances fishermen's income, but confuses the interpretation of jack mackerel catch statistics as representative of availability.

There have been other causes for the fluctuations in catch during the history of the jack mackerel fishery (figure 2). Scarcity of fish was blamed for the reduced catches in 1953 (Knaggs 1974a), 1957, 1958 (Knaggs 1974b), 1966 (Knaggs and Barnett 1975), 1972–74, 1979, and 1983 seasons (Mason 1989).

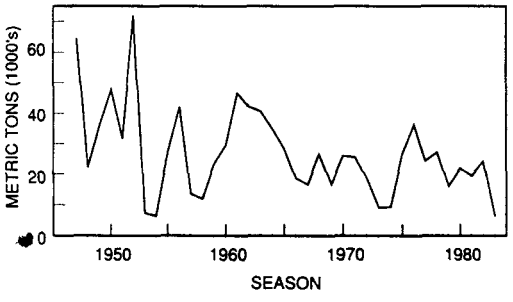


Figure 2. Landings of jack mackerel in southern California by season (1 August to 31 July).

These were many of the seasons with the lowest catches. Other factors had noticeable effects in certain seasons. In 1969, high levels of the pesticide DDT were found in jack mackerel, making it unfit for human consumption. Only pet food could be produced for six months until fish with lower DDT levels were caught (Fleming and Knaggs 1977). Several months of bad weather may have been one factor in reducing the jack mackerel catch in the 1972, 1973, and 1982 seasons (Mason 1989); however, weather conditions severe enough to prevent fishing lasted only a few months, so it was not rough weather alone that caused severe drops in seasonal landings. During the 1983 El Niño, however, jack mackerel were unavailable in southern California throughout the fall; the wetfish fleet moved north to Monterey, where most of the season's jack mackerel landings were made (Mason 1989).

In summary, the following factors have affected the jack mackerel landings by season:

- Landings of sardines: 1954, 1955, 1958
- Landings of anchovy: 1973, 1974, 1977, 1980
- Landings of Pacific mackerel: 1979–83
- Landings of bonito and/or bluefin tuna: 1967, 1971, 1973, 1974, 1977, 1980
- Market conditions: 1954, 1955, 1959, 1960, 1977
- Reduced cannery capacity: 1973–75
- Scarcity of schools of jack mackerel: 1953, 1957, 1958, 1966, 1972–74, 1979, 1983
- El Niño events: 1958, 1983
- DDT levels: 1969

## POPULATION ASSESSMENT

### *Sampling Methods*

The California Department of Fish and Game samples jack mackerel at the Terminal Island canneries. There is no closed season on jack mackerel fishing, so for reporting purposes, the season has been 1 August to 31 July of the following calendar year (Knaggs 1974a). The sampling plan has changed several times since 1947. Sampling methods for various periods are presented in a series of technical reports published by the California Department of Fish and Game (Knaggs 1974a,b; Knaggs and Barnett 1975; Fleming and Knaggs 1977; Mason 1989). The reports include estimates of numbers of fish landed for each month, and age composition.

### *Age Composition*

The fish caught by the southern California purse seine fleet are less than 400 mm FL and under 8 years old. Fish larger than 400 mm FL are rarely caught by the purse seine fleet, but are taken incidentally by the salmon and albacore troll fisheries off California and Oregon, and by the offshore whiting trawl fishery (MacCall et al. 1980). Some of these larger fish have been over 30 years old (Fitch 1956). Thus the purse seine fishery harvests jack mackerel from a limited segment of the total population.

The age composition of the jack mackerel landings has not been consistent throughout the history of the fishery. The average age of the fish caught by the wetfish fleet has decreased markedly. In the first decade of the jack mackerel fishery (1947–56) the catch was dominated by fish age 3 or older (figure 3). Younger fish contributed no more than 16,000 MT (35 million pounds) to the fishery per season. The next eight seasons (1957–64) appear to be a transition period when the weight of younger fish reached a level of about 18,000 MT (40 million pounds) per season, but older fish still contributed significantly to the catch in some years. In the final period (1965–83) fish younger than age 3 continued

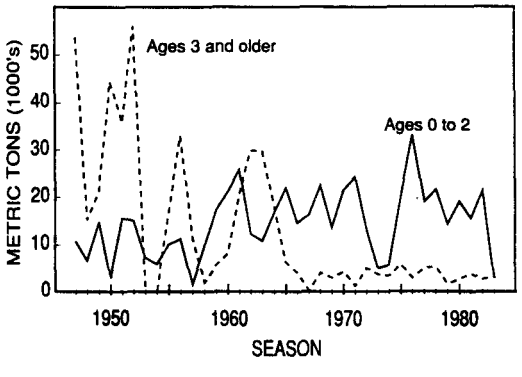


Figure 3. Jack mackerel landings divided into two age groupings: 0–2 (*solid line*) and 3 and older (*dashed line*).

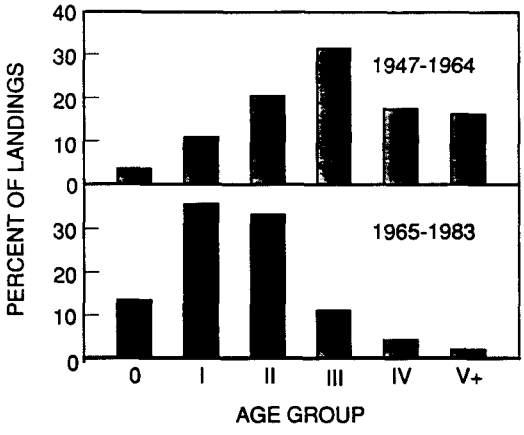


Figure 4. Age composition of jack mackerel landings from two time periods.

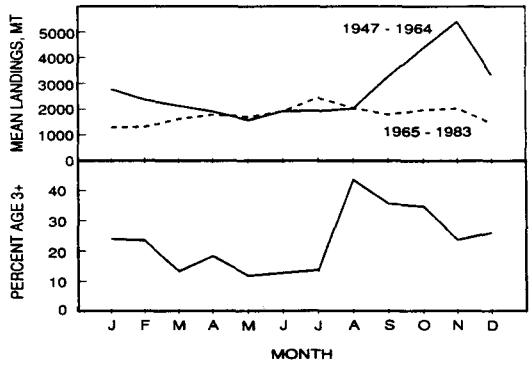


Figure 5. Seasonality of jack mackerel in southern California. *Upper panel*, mean seasonal landings from 1947 to 1964 (*solid line*) and 1965 to 1983 (*dashed line*). *Lower panel*, landings of fish age 3 and older from 1972 to 1983 as a percentage of each month's landings.

to be caught at about the 18,000-MT (40-million-pound) level, consistently dominating the catch, while older fish dropped out of the fishery, contributing less than 7,000 MT (15 million pounds) per season. Thus the catch shifted from older to younger fish during the middle 1960s.

A comparison of the age composition of the 1947–64 period with the 1965–83 period (figure 4) reveals that the earlier period was dominated by age-3 fish, whereas the later period was dominated primarily by age-1 fish and secondarily by age-2 fish. During the earlier period, fish of age 3 or older composed 65% of the catch; in later years those age groups contributed only 18%.

### *Seasonality in Age Composition*

During the early period (1947–64), when older fish appeared in the fishery, the highest landings were made during the late fall, and the lowest landings during spring and summer (figure 5). This pattern reflected increased fishing effort at the opening of the sardine season (October 1) from boats looking primarily for sardines, but prepared to catch Pacific mackerel or jack mackerel if they could not find sardines (Roedel 1952). The lower catches of jack mackerel in the spring of these earliest years were associated with decreased fishing effort in the late spring when the sardine season was closed and Pacific mackerel was seasonally unavailable (Roedel 1953). However, by 1950 the fleet discovered that jack mackerel did not always disappear in the spring, and fishing continued year-round. More recently, from 1965 to 1983, seasonality was reduced, with only a slight peak in July. During this period, anchovy was the alternate fishery available to the purse seine fleet, and the closure of the anchovy reduction season, in May or June, increased fishing pressure on jack mackerel during the summer.

A seasonal pattern also appears in the age composition of the catch. Landings from 1972 to 1983 were examined on a monthly basis for age composition (data for earlier years were unavailable). Even during this period, when older fish were less commonly caught, fish age 3 and older composed more than one-third of the catch from August through October (figure 5). They contributed less than 25% of the catch during the rest of the season, and less than 15% during May, June, and July.

The age composition of the catch was undoubtedly influenced by the interaction of two seasonal factors: (1) larger fish were most often caught in the fall, and (2) the fall fishery contributed less after 1964. Using the monthly age composition data from the later period (1972–83) on mean monthly landings from the earlier period (1947–64) to estimate the contribution of fish of age 3 and older in the earlier period gives an expected 25% of the season's catch as age 3 or older. However, age 3 and older fish actually composed 65%, not 25%, of the catch in the earlier period. Therefore changes in the seasonality of fishing effort explain only a small proportion of the change in age composition.

### *Recruitment*

The relative strength of different year classes has varied widely throughout the history of the jack mackerel fishery. To minimize confusion with variations in seasonal cannery production, comparisons of different year classes are based on the relative

virtual year-class strength as described by MacCall and Stauffer (1983). These strengths are produced by summing the percentage contribution of a year class (from numbers of fish) to each season it appeared in the fishery. For example, the 1970 year class contributed 30% of the season's catch as young-of-the-year in 1970, 65% of the 1971 catch as 1-year-olds, 37% as 2-year-olds, 17% as 3-year-olds, 14% as 4-year-olds, and 3% as 5-year-olds, for a total index of 165. An average year class would contribute about 100%, and an above average class would contribute more by providing a higher percentage of the catch than surrounding year classes. Year classes are effectively compared only with other year classes occurring simultaneously in the fishery.

The series of year classes can broken into three periods with different patterns of strength. During the first period, from the first fully represented year class in 1947 until 1958, strongly represented jack mackerel year classes in 1947, 1952, 1953, and 1958 (figure 6) were separated by strings of weakly represented year classes. The second period (1959–73) had clusters of strongly and weakly represented year classes, with the dominant 1958 year class being followed by two strong ones in 1959 and 1960. The next four year classes (1961–65) contributed much less to the catch, and stronger classes followed from 1966 to 1970 (especially 1967 and 1970), with less-dominant year classes in 1971–73 (figure 6). The third period (1974–80) features a remarkable series of alternating strong and weak year classes. The 1974, 1976, 1978, and 1980 classes were all relatively strong, whereas those of 1973, 1975, 1977, and 1979 were relatively weak. A scarcity of young fish in southern California during the 1982–83 El Niño enhanced the relatively high year-class strength of 1980.

Variability in year-class strength is an important factor in the age composition of the catch. In the early period of the fishery (1947–58) relatively strong year classes were separated by strings of four much weaker classes. Fish from the more prominent year classes dominated the catch until another strong class appeared five years later. Only a strong year class could contribute large numbers of fish for several seasons. As the relatively strong 1958, 1959, and 1960 year classes disappeared from the fishery (in 1964), and there were not any strong year classes to provide large numbers of older fish, the catch became limited to ages 0 to 3. After the 1966 season, relatively strong year classes appeared frequently, usually every two to three years, so younger fish were readily available. If younger fish were easier to catch, they might have been expected to dominate the catch as long as there was a ready supply of them.

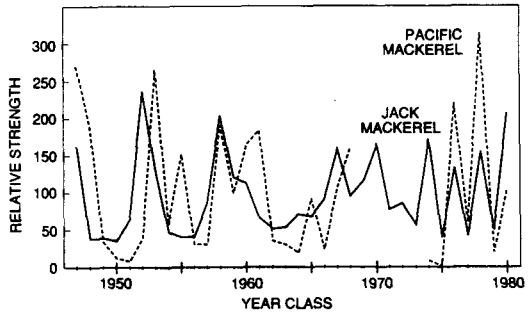


Figure 6. Recruitment strength of year classes of jack mackerel (*solid line*), and Pacific mackerel (*dashed line*), as measured by the sum of the percentage contribution of each year class to seasonal landings in southern California.

However, if older fish were still present, one would expect to have seen older fish during the 1973 and 1974 seasons, when young jack mackerel were hard to find. The catch during this period, although reduced, remained ages 0 to 2. The relatively strong 1970 year class did not appear strongly in the catch after age 2 (Mason 1989, table 18). To some extent, the frequency of relatively strong year classes may have contributed to the shift toward younger fish in the fishery.

## DISCUSSION

### *Decline in Age Composition*

The decline in the abundance of older fish in the catch stands out as an important change in the fishery. What has produced this change? Two factors presented above have contributed to this decline. First, the distribution of fishing effort during the season combined with the pattern of large fish being available in the fall accounts for part of the change in age composition. Second, the higher frequency of relatively strong year classes since 1965 may explain some of the decline in abundance of older fish.

But these factors don't appear to account for all of the change observed. Overfishing should be examined to see if it contributed to the change. Economic factors have both enhanced and reduced fishing pressure at different times, affecting the ages at which particular year classes were caught. Shifts in effort from one species to another may have added complications in fishing techniques and spatial distribution. Environmental factors may have affected different ages in different ways. By examining these factors we may be able to tell which ones have con-

tributed to the change in the age composition of the catch.

The decreased abundance of older fish in the catch between the early years of the fishery and the post-1965 period could reflect a true reduction of older fish in the population, or only a decline in their contribution to the southern California fishery. It is not possible to assess changes in the age composition of the whole population, since only young jack mackerel are harvested, and the fishery operates over a small portion of the total range. Although it is likely that some of the change in the age composition in the very earliest years (1947–51) is attributable to the presence of older fish from year classes unexploited before the fishery began, these fish disappeared from the landings by 1953 (Knaggs 1974a, table 17). They do not account for older fish present from 1954 to 1964. MacCall and Stauffer (1983) estimated that fish age 8 or younger compose less than two-thirds of the population, and that the purse seine fleet harvests only a small percentage (13%–20%) of the potential yield of this age group. If this is true, then the decline in older fish in the catch reflects a change in what is caught by the fishery, not a decline in the population due to overfishing.

Depressed market conditions were an economic factor that affected the age at which jack mackerel were caught in some seasons. During the 1953 and 1954 seasons the low price of imported mackerel protected the 1952 year class from exploitation as 1- and 2-year-olds (Knaggs 1974a), so more fish from this year class were caught at older ages in 1955–57. However, the 1958–60 year classes did not have this protection as young fish (except in the 1958 season, when sardines were being caught) but still contributed large amounts to the catch as 3- and 4-year-olds. Thus depressed market conditions had a limited effect on age composition.

Although it is possible that some undocumented changes in fishing tactics caused by the shift in fishing effort from sardines to anchovy may have contributed to the decline in age composition, I could find no evidence to support this theory. It appears that the change in age composition truly reflects the age of fish available to the purse seine fleet.

Another factor that may have contributed to the change in apparent age composition is related to the areas fished. Before 1965, sardines were the most desirable species to the purse seine fleet, followed by Pacific mackerel; therefore, boats fished where they expected to find sardines or Pacific mackerel. Most of the jack mackerel landed before 1965 came from the Channel Islands area off Santa Barbara or the area near San Pedro harbor (Clothier and Greenwood 1956; Duffy 1968). Boats rarely fished the more southern areas around San Clemente Island and Tanner and Cortez banks. However, from 1964 to 1971, when sardines and Pacific mackerel were absent, most of the catches were from these offshore southern areas (MacCall et al. 1980). This leads to the assumption that more fish from older age groups are caught in the Channel Islands area or the area near San Pedro harbor than on Tanner and Cortez banks. This assumption cannot be rigorously examined because information about catch locations is inadequate. The assumption does not hold true for the 1952 season, when older fish composed 79% of the catch, and 78% of the catch came from San Clemente Island and Tanner and Cortez banks (Knaggs 1974a, tables 2 and 15). In addition, since the return of Pacific mackerel in 1977, the fleet has spent more of its effort inshore, in search of Pacific mackerel (Anon. 1980), but the large jack mackerel once caught inshore have not reappeared in the catch.

The fact that small jack mackerel are found in shallow schools fishable by southern California purse seiners, and that fish larger than 400 mm FL are found in other areas, either offshore or farther north (MacCall et al. 1980), suggests that the fish may have altered their behavior since 1965. Increases in sea-surface temperature or changes in ocean circulation patterns in southern California could have caused some jack mackerel to move to more northern, or deeper cool waters at an earlier age.

It seems that the change in the age composition of the jack mackerel landings between the 1947–64 period and the post-1964 period cannot be ascribed to just one cause, but is probably due to several factors: (1) changes in the seasonal pattern of the fishery, (2) the frequency of relatively strongly recruited year classes, (3) economic factors, (4) shifts in the areas fished, and (5) changes in fish behavior.

### *Recruitment Variability*

Both jack mackerel and Pacific mackerel have shown a high degree of recruitment variability from year to year. Because both species are taken by the same fleet and are of similar ecological type, it is very likely that environmental conditions might have correlated effects on recruitment. To compare the recruitment success of the two species, relative virtual population estimates were developed for Pacific mackerel. Catch by age and season, from table 6 of Parrish and MacCall (1978), was used to calculate relative year-class strengths in Pacific mackerel from 1947 to 1967. Similar data from table 3 of MacCall et al. (1985) were used to calculate relative year-class strength for 1974 to 1980. There is a gap in the time series from 1969 to 1973 because there

was no fishery for Pacific mackerel (and therefore no data) for the years when the fishery had collapsed. A correlation significant at the $p < 0.05$ level exists between the reproductively successful year classes for Pacific mackerel and successful year classes of jack mackerel ($r = .385$, df = 29). A comparison of jack and Pacific mackerel (figure 6) shows that both species had relatively successful year classes in 1947, 1953, 1958–60, 1967, 1976, 1978, and 1980. The 1974 year classes were also relatively successful for both species; however, the Pacific mackerel success is not apparent from figure 6, because it was this year class that started the recovery of the Pacific mackerel population (Anon. 1979), and its relative strength is underestimated because the moratorium was not lifted until 1977.

It is also interesting to note that these successfully recruited year classes for both Pacific and jack mackerel are opposite to (and alternating with) successfully recruited year classes for combined rockfish species (*Sebastes dalli* and *S. saxicola*) taken as juveniles in quarterly trawl surveys in southern California. Mearns et al. (1980) indicated that the peak catch years for juveniles of these species were 1971, 1973, 1975, and 1977—all very poor years for mackerel recruitment (figure 6). These years for the Santa Monica Bay and Orange County coastline had cool or cooling water with decreasing clarity. Thus conditions favorable for demersal rockfish recruitment may be very different from those supporting good pelagic mackerel recruitment.

## CONCLUSIONS

The high variability in landings seen in the southern California jack mackerel catch is due in some years to a lowered availability of jack mackerel and in other years to interspecific interactions within the wetfish fishery, as well as to economic factors. The decline in abundance of older fish in the catch after 1964 is partially caused by a decline in fall fishing effort. The increased frequency of relatively strong year classes after 1964 increased the availability of young fish. Changes in the areas fished by the wetfish fleet may have also contributed to catching younger fish. Nevertheless, the disappearance of older fish cannot be explained solely by fishery interactions, and may reflect a real change in the availability of these age groups to the purse seine fishermen. Pacific mackerel recruitment has also varied, and in most cases jack and Pacific mackerel have shown similar patterns in relative year-class strength.

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