BIOLOGY AND FISHERY POTENTIAL OF JACK MACKEREL (*TRACHURUS SYMMETRICUS*)

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ABSTRACT

Young jack mackerel (age 0 to about 5 years) are most abundant in the Southern California Bight, where they school in open waters and near offshore banks. They progressively emigrate from these grounds, but the whereabouts of 6- to 15-year-old fish is not well known. The large fish, 15 to 30+ years old, school offshore in open ocean waters from Baja California to the Aleutian Islands. Ages 1 and older are capable of spawning, an exceptionally early age of maturity for a long-lived species. Spawning extends from central Baja California to British Columbia, with a tendency for larval abundance to progress northward from late winter to late summer. The Southern California Bight contains few jack mackerel larvae until late in the spawning season.

Year-class strengths are highly variable, with strong year classes typically separated by several relatively weak ones. On the basis of larvae collected on CalCOFI surveys, spawner abundance has been fairly constant since 1950. Spawning biomass is estimated to be 0.64 to 1.3 million metric tons (MT) in the CalCOFI region, with perhaps an equal biomass outside that region.

The estimated spawning biomass was allocated among age categories according to assumed mortality rate schedules. Because of age-specific mortality rates, potential yield was estimated by applying the Gulland approximation to each age category separately and summing the results. Overall potential yield estimates range from 130 to 260 thousand MT. The young inshore fish have a potential yield of 100 to 200 thousand MT, whereas the old offshore fish have a potential yield of 10 to 25 thousand MT. If a significant fishery were to develop on either segment, the other segment would probably be impacted indirectly.

RESUMEN

Jureles (*Trachurus symmetricus*) jóvenes, de hasta 5 años de edad son abundantes en el seno del sur de California, y sus cardúmenes se presentan en mar abierto y en las proximidades de los bancos costeros. Los jureles emigran progresivamente desde estas zonas, pero no se conoce con la debida precisión el paradero de las poblaciones con edades entre 6 y 15 años. Jureles grandes, de más de 30 años de edad integran los cardúmenes de mar abierto, desde Baja California hasta las Islas Aleutianas. Los jureles inician la reproducción al año de edad, madurez precoz y excepcional en peces que llegan a alcanzar una larga vida. La puesta se extiende desde Baja California hasta la Columbia Britanica, con una tendencia a que la abundancia de larvas progrese hacia el norte, desde finales del invierno hasta finales del verano. La zona del seno del sur de California contiene pocas larvas de jurel hasta el final de la época de puesta.

La dominancia de las generaciones es muy variable, observándose generaciones abundantes alternando con otras de escasez numérica. La abundancia de reproductores, tomando como base las larvas recolectadas durante las exploraciones del programa CalCOFI, resulta bastante constante desde 1950. La biomasa de reproductores en la región explorada por el programa CalCOFI se ha estimado entre 0.64 a 1.3 millones de Tm., y se considera que la cantidad será aproximadamente similar para las zonas adyacentes a esa región.

La biomasa estimada se distribuye entre categorías de edades de acuerdo con el valor asumido establecido para la mortalidad. Considerando los valores de mortalidad para las diversas edades se estimó el rendimiento potencial, aplicando la aproximación de Gulland separadamente para cada categoría de edad y sumando luego los resultados. Se estima que el total de rendimiento potencial oscila de 130 a 260 mil Toneladas. Los peces jóvenes costeros presentan un potencial de producción de 100 a 200 mil Toneladas, mientras que los oceánicos tendrían un potencial de rendimiento de 10 a 25 mil Toneladas. Si se desarrollase una pesquería importante en cualquiera de estos sectores, el otro sería afectado indirectamente por dicha pesca.

FISHERIES AND DISTRIBUTION

The jack mackerel, *Trachurus symmetricus*, was reported in the commercial landings of fish in California as early as 1888, but was of minor commercial importance before 1947. Of much greater commercial importance were the more profitable Pacific sardine,

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Sardinops sagax caerulea, and the more desirable Pacific mackerel, *Scomber japonicus*. Much of the jack mackerel catch between 1926 and 1946 was absorbed by fresh fish markets and consisted primarily of fish taken from mixed Pacific sardine and Pacific mackerel schools. Landings were low, varying between 180 and 14,000 MT. During these years, the fish were referred to as horse mackerel and had relatively little market appeal. In 1947 the fishing industry, after being hit hard by poor sardine landings, turned to jack mackerel and landed 58,535 MT. The following year, the U.S. Food and Drug Administration authorized the common name jack mackerel for use on labeling. This was expected to have greater consumer appeal than the original name horse mackerel. Jack mackerel have been a major contributor to California's commercial landings ever since (Figure 1).

There is presently only one fishery targeting on jack mackerel. This fishery uses purse seine gear, and operates out of southern California ports, harvesting small fish from local waters. Fisheries farther to the north take jack mackerel incidentally. The salmon troll fisheries operate in nearshore waters north of Point Conception, and take an unknown but probably large number of jack mackerel, which are discarded at sea. The foreign trawl fleets, which operate offshore north of Point Arena, take jack mackerel incidentally to fishing for Pacific whiting (*Merluccius productus*), but have actually avoided taking jack mackerel in recent years. If an expanded domestic offshore trawl fishery develops out of northern California and Oregon ports, large jack mackerel may become a target species, and will almost certainly be an incidental species of significant magnitude. Recreational fisheries all along the Pacific coast occasionally take jack mackerel but do not consistently target on the species. The various jack mackerel fisheries are described in detail by MacCall et al. (1980).

In the Vancouver Island area of Canada, large jack mackerel have been caught at the surface by purse seiners and are taken incidentally in the bottom trawl fisheries (Hart 1973). Although jack mackerel are quite abundant at times, there is no directed fishery for the species. Incidental catches are insignificant and are not included in catch records (S.J. Westrheim, Pacific Biological Station, Nanaimo, B.C., pers. comm.).

The distribution of jack mackerel extends northward into the Gulf of Alaska east of 160° W. A high-seas experimental salmon gill net survey found jack mackerel to be relatively abundant (Larkins 1964). Incidental catches along the coast of southeast Alaska occur infrequently and are not documented (D. Cantillon, Alaska Department of Fish and Game, Juneau, Alaska, pers. comm.). Jack mackerel have been found as far south as Cape San Lucas, Baja California. The offshore limit of the population is poorly defined, but various sources have been compiled by Blunt (1969) to produce a distributional map (Figure 2). The offshore limit is approximated by a line running from Cape San Lucas, Baja California, to the eastern Aleutian Islands, Alaska. A large portion of the range lies outside the 200-mile fishery jurisdiction zones of the U.S. and Mexico.

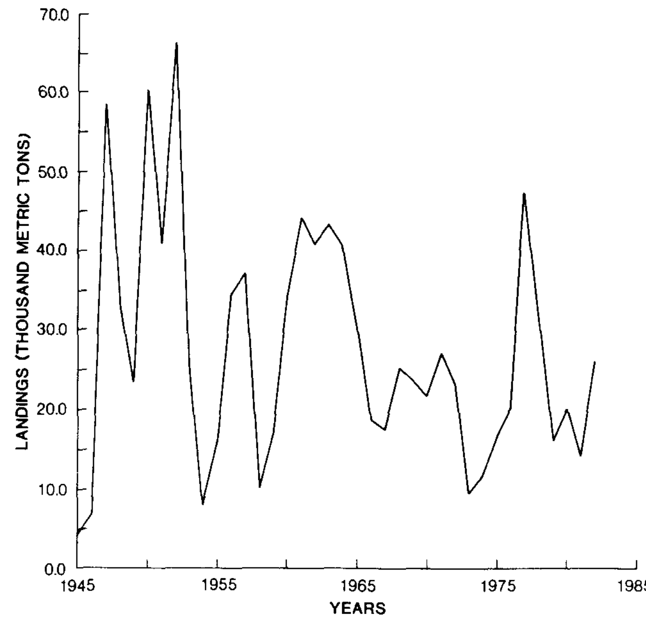

Figure 1. California jack mackerel landings (source: California Department of Fish and Game).

REPRODUCTION AND STOCK STRUCTURE

In their study of maturation of jack mackerel from the southern California fishery, Wine and Knaggs (1975) determined that most females become sexually mature at about their first birthday. Although immature fish were found at all times of the year, 50% or more of all females appear to be close to or in spawning condition from March through September. Very young spawners appear to reach a reproductive condition later in the season than do older spawners. Nothing is known of the maturity cycle of the large offshore fish.

MacGregor (1976) calculated the fecundity, in advanced eggs per gram of fish, of thirty jack mackerel. These fish could be divided conveniently into two distinct groups, representing small and large fish. The small fish (n = 15, $\bar{l}$ = 235 mm) had a mean fecundity of 68.5 advanced eggs per gram of fish. The large fish (n = 15, $\bar{l}$ = 519 mm) had a mean fecundity of

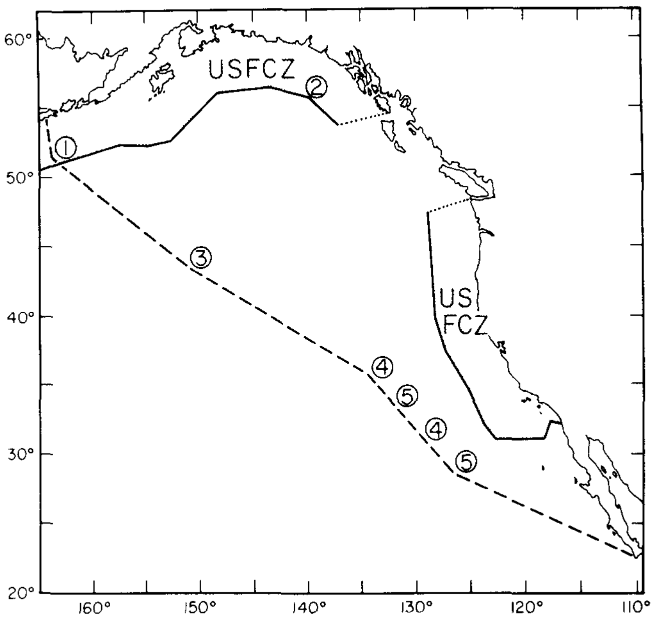

Figure 2. Distribution of the jack mackerel resource (modified from Blunt 1969). Circled numbers indicate the periphery as determined by various sampling methods: (1) gillnet catches, INPFC, 1963; (2) gillnet catches, INPFC, 1955; (3) eggs and larvae, NORPAC, 1955; (4) night-light stations, CDF&G, 1957-68; (5) eggs and larvae, CalCOFI, 1950-78.

152.3 advanced eggs per gram of fish. The small fish, which would correspond to age 2 years, had a fecundity of 65.8/152.3 = 0.43 relative to the large fish on a per unit body weight basis.

Jack mackerel eggs and larvae first become abundant in the waters far offshore of northern Baja California and southern California in March through June (Kramer and Smith 1970; Ahlstrom 1969). There is very little production of eggs and larvae in the Southern California Bight until July and August, presumably when the younger fish begin to spawn (see above). Also, the center of offshore spawning loosely moves north as the summer progresses. The northern and offshore areas of spawning have received very little sampling effort, so the seasonality and geographic limits to spawning by the offshore population are poorly known. A survey of the northeastern Pacific in August 1955 took jack mackerel eggs and larvae off Oregon and Washington from 100 to 1000 miles offshore (Ahlstrom 1956). CalCOFI cruise 7210 (October 1972) similarly found a large isolated area of spawning jack mackerel extending from 200 to 600 miles off the coast of Washington, verifying the existence of late northern offshore spawning. The northern limit of jack mackerel spawning was not determined.

There are two distinct and non-overlapping segments shown by available length frequencies (Figure 3). The southern California purse seine fishery presently catches fish ranging from 10 cm to 30 cm FL, whereas offshore and northern coastal captures tend to range from 50 cm to 60 cm FL. The intermediate lengths are distinctly lacking in either data set. The southern California fleet captured moderate quantities of fish ranging from 30 cm to 40 cm FL during the early years of the fishery (Figure 3), but whether this reflected biological availability, fishermen's tactics, or fishing pressure is not known. Length frequencies of jack mackerel taken off Monterey from 1958 to 1967 (not shown) resemble those of the early southern California fishery. The Monterey fish were slightly larger, with one-half of the catch ranging from 30 cm to 40 cm FL, but with few fish larger than 40 cm FL. Length frequency of jack mackerel captured by the California Department of Fish and Game's preseason offshore albacore cruises shows a few fish ranging from 40 cm to 50 cm FL, but no data show the 30-cm-to-50-cm fish in the abundance they must presumably have, assuming that the small fish eventually grow and join the large fish segment. Soviet research trawls taken from 1966 to 1977[1] show a clear geographic pattern of jack mackerel mean lengths, with small fish (20-30 cm FL) to the south and inshore, and large fish (ca. 53 cm FL) to the north and offshore.

As shown above, jack mackerel eggs and larvae are distributed widely in the northeastern Pacific. The quantity of spawning products released in the Southern California Bight is a small portion of the total. Nonetheless, the largest known concentrations of young-of-the-year jack mackerel are found in the Southern California Bight. Many of the southern California fish are undoubtedly spawned locally. However, it is likely that the extensive offshore spawning by large fish produces significant numbers of offspring and, judging from the scarcity of juvenile jack mackerel elsewhere, we believe these fish find their way to the Southern California Bight. Anecdotal evidence of this movement has been provided by the discovery of many young-of-the-year jack mackerel in albacore (*Thunnus alalunga*) stomachs taken off the coast of California in the summer of 1982 (M. Laurs, Southwest Fisheries Center, La Jolla, California, pers. comm.). Thus it is reasonable to assume that the southern California segment of the jack mackerel population is not self-sustaining, but depends to an unknown extent on spawning by the offshore large fish segment.

RECRUITMENT

Absolute magnitude of recruitment cannot presently be determined. However, examining the contributions

[1] Stepanenko, M.A. Some traits of biology and reproduction rate and conditions of California jack mackerel. Presented to the 1979 U.S.-U.S.S.R. Bilateral Meeting on Fisheries Assessment in the North Pacific, Seattle, June 5-8, 1979.

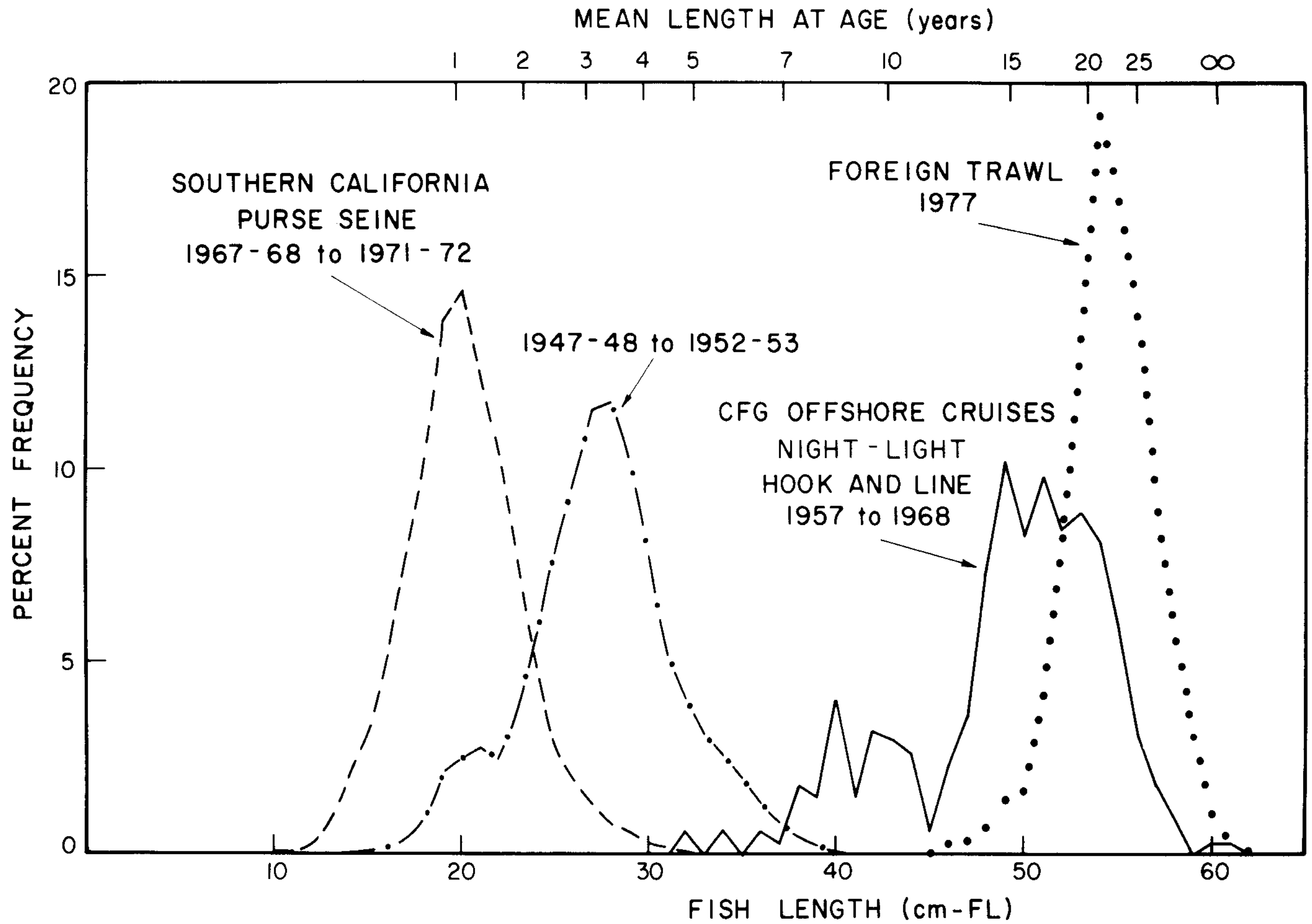

Figure 3. Length frequency of jack mackerel taken by various fishery segments and surveys. Age scale is not an accurate measure of age at length, and is provided only for comparison.

of various year classes to the southern California fishery provides a rough picture of recruitment variability. The fishery landings have been determined by processor orders rather than by availability, so actual volume of catch is not necessarily a good indicator of relative abundance. Virtual year-class strength, obtained by summing the percentage contributions of a year class to the various seasons in which it was fished, provides a rough indication of year-class variability. Age composition data were taken from Knaggs (1974a, b), Knaggs and Barnett (1975), Fleming and Knaggs (1977), and Fleming (California Dept. of Fish and Game, Sacramento, Calif., pers. comm.). Because we have used percentage contribution, an average year class will have a virtual strength of 100%. Long-term trends cannot be detected by this treatment, since year classes are effectively compared only with their near neighbors.

The resulting series of virtual year-class strengths (Figure 4) shows a pattern of runs of weak year classes interrupted by occasional strong year classes. Until the 1966 year class, recruitment seems to have been either very good or very poor, with average recruitment a rarity. In more recent years, since 1966, year classes seem to have fluctuated less severely; however, the recent fishery, from which data are not yet fully available, suggests that the 1976 year class was very strong. The 1982 year class also appears to be extraordinarily abundant, based on high catch rates by a midwater trawl survey for young fish in the Southern California Bight (Mais 1982) and on the occurrence of young fish in albacore stomachs cited above.

ABUNDANCE

CalCOFI ichthyoplankton surveys are the principal source of information on jack mackerel spawner abundance. Because the CalCOFI region does not encompass the full range of the fish (see Figure 2), some assumptions are necessary. Principally, we assume that the density of fish in the CalCOFI region bears a reasonably constant relationship to the size of the total spawning population. CalCOFI surveys have shown

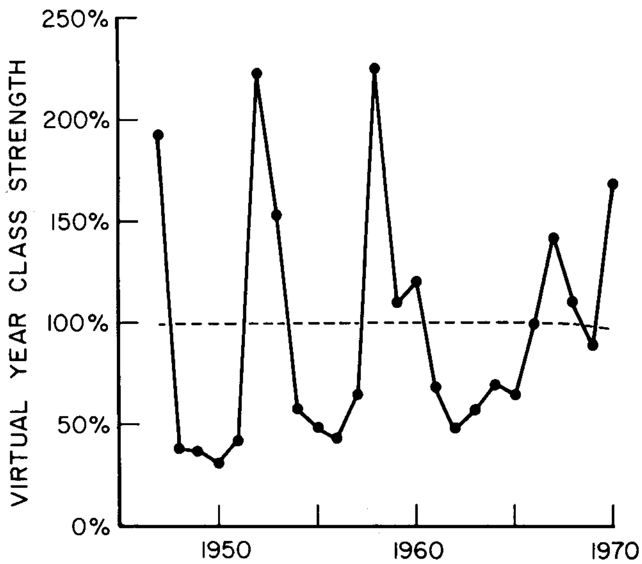

Figure 4. Relative recruitment strengths of jack mackerel year classes in southern California. Virtual year-class strength is measured by the sum of percentage contributions to seasonal landings over the lifetime of the year class. The dashed line indicates average strength.

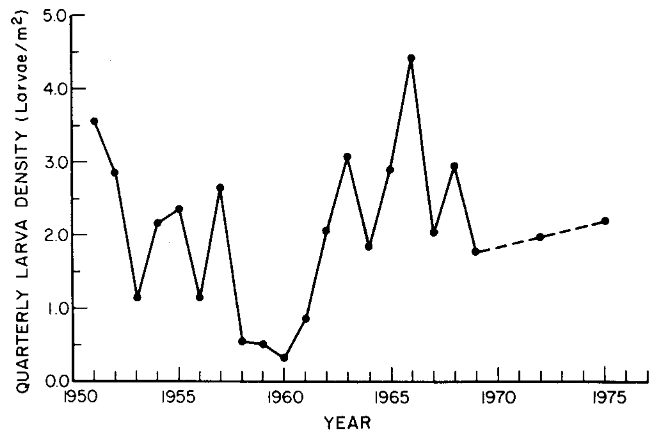

Figure 5. Density of jack mackerel larvae in selected areas of CalCOFI surveys.

that the center of spawning moves northward as the season progresses, from northern Baja California waters in March and April to as far north as Oregon in the fall (Ahlstrom 1956, 1969; Kramer and Smith 1970). Whether this shift is due to actual migration of spawners or to progressively later maturation of more northerly fish is not known.

Mean apparent density of jack mackerel larvae was calculated from CalCOFI samples in regions most consistently occupied by eggs and larvae. This density is the average quarterly density off northern Baja California in the first and second quarters of the year, and off southern California in the second and third quarters. The near inshore regions of Baja California and southern California were excluded. The densities are plotted in Figure 5. The unusually low densities from 1958 to 1961 may be due to the influence of abnormally warm oceanic temperatures from 1957 to 1960: the population may have shifted northward; gonadal maturation may have been affected; and abnormally rapid growth of larvae would decrease apparent abundance. Also, it is highly unlikely that abundance changes of the magnitude suggested by the larval density can actually occur, given the low rate of mortality exhibited by offshore jack mackerel. Data for 1958-61 will not be considered as representative of jack mackerel abundance during that period.

Larval densities show considerable year-to-year fluctuation (Figure 5), but there is no trend showing a long-term change. It would be difficult to show small changes in future jack mackerel abundance using the CalCOFI larval density because of natural variability and anomalies like those of 1958-61. Thus a minimum management response time to a decrease in abundance is probably greater than 6 years, given the present triennial schedule of CalCOFI surveys.

Ahlstrom (1968) estimated the jack mackerel resource to be 1.9 to 4.4 million MT of spawning biomass. Ahlstrom based his estimate on CalCOFI survey estimates of jack mackerel egg production (Farris 1961). He used two assumptions of fecundity: the low fecundity estimate was two spawning batches per year, based on the two modes of egg diameters observed in ovaries by MacGregor (1966); the high fecundity estimate was 3⅓ batches per year, based on a peak egg abundance (when all fish are assumed to spawn) to average egg abundance, and assuming that it takes at least 30 days to mature a batch of eggs. Ahlstrom also assumed that the total stock was 1½ to 2 times that measured in the CalCOFI area.

Knaggs (1973) used tag returns to estimate the total population available to the wetfish fleet off southern California. This estimate was 0.6 to 1.4 million MT, but must be considered tentative because sample size was very small, and many assumptions underlying tagging estimates could not be met.

Pashchenko[2] used an acoustic-trawl survey to estimate the jack mackerel biomass *outside* the CalCOFI area in the spring of 1978. Using the assumption that all fish in the path of the net were caught, he obtained a biomass of 308,000 ± 91,000 MT. If a portion of the fish in the trawl path were escaping capture, his estimate should be increased accordingly.

[2] Pashchenko, V.M. Distribution, biology and biomass assessment of the jack mackerel. *Trachurus symmetricus* (Ayres). Presented to the 1979 U.S.-U.S.S.R. Bilateral Meeting on Fisheries Assessment in the North Pacific. Seattle. June 5-8, 1979.

We propose a new estimate of jack mackerel abundance. The approach is similar to Ahlstrom's, but assumptions regarding fecundity can be improved in light of recent work on other species (see below). Also, the methodology is changed slightly, and additional factors are considered in estimating egg production rates.

Egg production can be expressed by the following equation (Parker 1980):

$$E = Brfp \qquad (1)$$

where E is daily egg production, B is spawning biomass, r is fraction of the spawning population that is female, f is fecundity in eggs per body weight per spawning, and p is fraction of females spawning per day.

The equation can be rearranged to

$$B = E/rfp \qquad (2)$$

in order to estimate spawning biomass.

Egg production in the CalCOFI region for the years 1951-54 was estimated by Farris (1961). As was shown above, there is no visible trend in jack mackerel abundance since that time, so Farris' data are appropriate for estimating present biomass. Farris corrected his egg production estimates for a 3-day duration to hatching; however, he ignored the effects of natural mortality. Because of losses of eggs before hatching, the duration of an average egg would be somewhat less than 3 days. Paul Smith (Southwest Fisheries Center, La Jolla, Calif., unpublished data) has calculated approximate numbers of jack mackerel eggs surviving to each stage of development at 15°C. Time to hatching at 15°C is 86.4 hours, whereas mean duration of eggs is 53.2 hours, eggs being terminated either by mortality or by hatching. Thus the mean duration is 0.62 of the time to hatching. Farris' eggs were in an environment averaging 15.5°C, which is reasonably close to the above temperature. This change in assumed residence time requires that Farris's egg production estimate be multiplied by 1/0.62, or 1.62.

Peak egg production extends from March to June in the CalCOFI area, during which period 82.6% of the total year's eggs are released. Average egg production for March through June is 5.5×10^{14} eggs or 4.5×10^{12} eggs/day (Farris 1961). With the above mortality correction, the latter value is increased to 7.3×10^{12} eggs/day.

Ahlstom (1968) used a fecundity estimate of 306 eggs/gram/spawning, based on a single fish examined by MacGregor (1966). MacGregor (1976) gives fecundities of 30 fish, including 15 fish longer than 40 cm. The mean fecundity of these large fish was 153.2 advanced eggs/gram body weight, or about one-half the earlier estimate. Our biomass estimate will use MacGregor's fecundity estimates. However, it is likely that they are low. Pashchenko[3] examined 18 large female jack mackerel taken 390 miles west of San Diego in the spring of 1978. These fish were larger (mean 54.0 cm FL) than MacGregor's fish, and had a mean fecundity (362.6 eggs/gram) over twice that obtained by MacGregor. If Pashchenko's data are used, or are averaged with MacGregor's observations, resulting biomass estimates would be considerably lower.

Little is known of spawning rates of pelagic fish, and nothing is known for jack mackerel. Ahlstrom (1968) used a minimum estimate of two spawnings per year, because there were two modes of egg diameters in the single fish examined; and he used 3.3 spawnings per year as a high estimate, assuming 30 days is necessary to mature each batch of eggs. In comparison, similar spawning rates were suspected for the northern anchovy (*Engraulis mordax*), for essentially the same reason. However, recent work on anchovy gonad histology (Hunter and Goldberg 1980) has strongly indicated that about 15% of the mature female anchovy population is spawning each day during the peak spawning months. This spawning rate translates as approximately one spawning per week, and indicates that a batch of eggs may require fewer than 7 days to be produced. Because jack mackerel gonad morphology and the protracted spawning season are similar to those for anchovy, we assume that spawning rates are similar to those for anchovy. In our estimate of jack mackerel abundance we will use 15% spawning per day as an arbitrary upper limit, and 7.5% spawning per day as a lower limit. Lower percentages could be considered; the biomass estimate changes inversely with this percentage, which is a major source of imprecision. It is assumed that males exist in equal weight to females, so the proportion of females is 0.5.

Using the values in equation (2), $E = 7.3 \times 10^{12}$ eggs/day, $r = 0.5$, $f = 152.3$ eggs/gram of large female fish, $p1 = 15\%$ female fish spawning/day, $p2 = 7.5\%$ female fish spawning/day, we obtain spawning biomass estimates of 0.64 and 1.3 million MT in the CalCOFI region. If the fish migrate extensively, with virtually all fish spawning in the CalCOFI region and then dispersing, these may be direct abundance estimates. If the fish are less migratory, and only a fraction of the population spawns in the CalCOFI region, total abundance will be greater. Ahlstrom (1968) assumed that one-half of the total jack mackerel

[3] See footnote 2.

spawning biomass resides outside the CalCOFI area. Pashchenko[4] also feels that one-half of the resource may be spawning outside the CalCOFI area. Although the exact fraction of the resource outside the CalCOFI area cannot be quantified, we will assume the total spawning biomass to be 1.36 million MT (1.5 million short tons) as the working estimate.

This working estimate of 1.36 million MT of spawning biomass is considerably lower than Ahlstrom's (1968) range of 1.9 to 4.4 million MT. However, it is more consistent with current knowledge of the likely spawning frequency of pelagic fishes. This working estimate would suggest that available southern California biomasses are smaller than estimated by Knaggs (1973). However, Knaggs's estimate may be high because of emigration, and our estimate gives total biomasses approaching Knaggs's lower range of 0.6 million MT.

MORTALITY RATE

The natural mortality rate of jack mackerel has not been estimated previously. The necessary data for a direct estimate are very difficult to obtain, given the stock structure and poorly known migratory habits of the fish. Because of the size selectivity and geographic character of existing fisheries, age-frequency analysis is not feasible because mortality rates are confounded with rates of emigration. However, other information correlating with mortality rates is available, allowing reasonable values to be hypothesized. Pauly (1980) examined a large number of fish stocks, from which he derived an empirical natural mortality rate approximation based on von Bertalanffy growth parameters and water temperature. Wine and Knaggs (1975) obtained von Bertalanffy parameter estimates of the asymptotic length (L_∞ = 60.3 cm) and the growth rate coefficient (K = 0.0935/year). Using the 10-m annual mean water temperature off central California of about 14°C (Lynn 1967), Pauly's method gives a tentative natural mortality rate of M = 0.23. Fitch (1956) reports that some large jack mackerel are over 30 years of age, according to growth rings on their otoliths. The average mortality rate would have to be quite low to allow a significant number of fish to reach such an age, confirming the magnitude of the Pauly approximation.

It is highly unlikely that jack mackerel exhibit a constant natural mortality rate throughout their life. Small young fish living in the predator-rich nearshore area are likely to have much higher mortality rates than the large offshore fish. Based on this speculation, the following age-specific natural mortality rate schedule is postulated for jack mackerel: M_0 = 0.5, M_1 = 0.5, M_2 = 0.45, M_3 = 0.4, M_4 = 0.35, M_5 = 0.3, M_6 = 0.25, M_{7+} = 0.2. Other tentative mortality rate schedules could be proposed (see MacCall et al. 1980).

[4] See footnote 2.

FISHERY ANALYSIS AND POTENTIAL YIELD

A simple "piece-wise" dynamic pool model can be used to represent the long-term average or steady-state population structure. Natural and fishing mortality rates and weights at age are used to estimate relative biomass at age from the working estimate of 1.36 × 10^6 MT (1.5 × 10^6 short tons) spawning biomass. The total spawning biomass is allocated among the ages according to these relative contributions. The biomass of young of the year (age 0.5) was calculated by the ratio of cohort weights at age 0.5 and age 1.

As discussed previously, it is likely that young jack mackerel have a lower batch fecundity and may spawn fewer times than do older mature fish. Spawning biomass, being based on egg censuses, is expressed in terms of body weight equivalents of fully mature spawning females. Total fishable biomass is therefore likely to be greater than spawning biomass. Two alternative fecundity models are used here. The first model simply assumes that all fish are equally fecund on a unit body weight basis (Table 1). The second model assigns partial fecundities to young fish. If mature fecundity is given a relative value of 1.0, ages 1 through 4 are assigned relative fecundities of 0.2, 0.4, 0.6, and 0.8, respectively (Table 2).

The above method of allocating biomass among age categories is subject to considerable imprecision. Both assumed rates of natural mortality and relative fecundity of young fish have strong influences on the age structure and total biomass of the model population. Since the spawning biomass is fixed, different mortality rate schedules will result in inverse changes in allocation of biomass to small fish (ages 0-8) and large fish (ages 15-30). As can be seen in Table 2, assumption of reduced fecundity of young fish results in an increase in estimated total biomass.

The dynamic pool model was used to estimate fishing mortality rates by an iterative process. Fishing mortality rates at age (F_j) are given by

$$F_j = C_j / \bar{B}_j \tag{3}$$

where C_j is catch of age j fish, and $\bar{B}_j$ is mean biomass. Mean biomass was approximated by

$$\bar{B}_j = (B_j + B_j + 1) / 2 \tag{4}$$

The iterative process is as follows: initially, fishing mortality rates of 0 are input to the dynamic pool model, and biomasses are estimated (allocated). Esti-

TABLE 1
Dynamic Pool Model of Jack Mackerel Population and Estimates of Potential Yield, Using Assumed Schedule of Natural Mortality Rates

Age	Assumed natural mortality rate	Fishing mortality rate	Relative number	Length (mm-FL)	Mean weight[1] (g)	Initial biomass (10^3 MT)	Mean catch[2] (10^3 MT)	Potential yield (10^3 MT) Low X=0.3	High X=0.5
0	(0.5)	—	1,000	—	—	—	—	—	—
0.5[3]	(0.5)	0.018	779	—	60	(123.3)	2.360	9.3[4]	15.4[4]
1	0.5	0.043	602	198	85	135.0	5.728	20.2	33.7
2	0.45	0.046	350	234	140	129.3	5.664	17.4	29.1
3	0.4	0.058	213	267	207	116.5	6.340	14.0	23.3
4	0.35	0.032	135	297	285	101.2	3.024	10.6	17.7
5	0.3	0.012	92	324	370	89.7	1.048	8.1	13.4
6	0.25	0.004	67	349	461	81.8	0.337	6.2	10.3
7	0.2	0.002	52	372	556	76.6	0.124	4.6	7.6
8	0.2	0.001	43	392	653	73.5	0.025	4.4	7.3
0-8	—	—	—	—	—	926.8	24.649	94.8	157.9
9-15	0.2	—	145	411-493	959	367.0	—	22.0	36.7
16-30	0.2	—	45	503-576	1598	190.3	—	11.4	19.1
0-30						1360.8 (spawning) 1484.1 (total)		128.3	213.7

[1]Weight is based on length-weight relationship with correction for σ_L = 21.5 mm (Pienaar and Ricker 1968)
[2]Catch includes only San Pedro landings.
[3]Age O fish are assumed to be unavailable for the first half year; mean weight is approximate; and biomass does not spawn.
[4]Potential yield reduced by ½ because fish are only available for ½ year.

mates of F_j are then made by equations (3) and (4), given the mean catch of fish at age for the 1952-53 through 1971-72 fishing seasons (Fleming and Knaggs 1977). These fishing mortality rates are then used in the dynamic pool model to produce new biomass estimates for the second iteration. The estimates of F converge to two significant digits with three iterations.

Estimates of F are given in Tables 1 and 2 and reflect a southern California fishery of approximately 24,649 MT per year, which is the average San Pedro catch for the 1952-71 period. Fishing mortality on older fish caused by incidental catches and the foreign trawl fishery has been ignored, because of lack of information on magnitude and age composition. Recent foreign trawl catches are up to 2,000 tons per year, but the 1952-71 average is much smaller—not large enough to significantly affect the model.

The potential yield estimator of Gulland (1970) is intended to provide a reasonable limit to exploratory expansion of a fishery. It is not meant to be an esti-

TABLE 2
Dynamic Pool Model of Jack Mackerel Population and Estimates of Potential Yield, Using Assumed Natural Mortality Rates and Partial Fecundity of Young Fish

Age	Assumed fecundity	Assumed natural mortality rate	Fishing mortality rate	Initial biomass (10^3 MT)	Potential yield (10^3 MT) X=0.3	X=0.5
0.5[1]	0	(0.5)	0.032	(148.2)	11.2[2]	18.5[2]
1	0.2	0.5	0.036	161.0	24.1	40.3
2	0.4	0.45	0.038	155.1	21.0	34.9
3	0.6	0.4	0.048	140.9	16.9	28.2
4	0.8	0.35	0.026	123.6	13.0	21.6
5	1.0	0.3	0.010	110.3	9.9	16.5
6	1.0	0.25	0.003	100.8	7.5	12.6
7	1.0	0.2	0.001	94.3	5.6	9.4
8	1.0	0.2	0.001	90.6	5.4	9.1
0-8	—	—	—	1124.9	114.6	191.1
9-15	1.0	0.2	—	452.5	27.1	45.3
16-30	1.0	0.2	—	234.6	14.1	23.5
0-30				1360.8 (spawning) 1812.0 (total)	155.8	259.9

[1]Age 0 fish are assumed to be unavailable for the first half year; mean weight is approximate; and biomass does not spawn.
[2]Potential yield reduced by ½ because fish are only available for ½ year.

mate of maximum sustainable yield (MSY), but is an interim limit to catches while data sufficient to estimate MSY are being accumulated. Thus Gulland's estimator should not be treated as a goal for fishery development. In some cases it may be considerably in excess of true MSY, but we cannot know for the case of the jack mackerel fishery until more information is gained.

The potential yield estimator is given by

$$Y_{\mathrm{pot}} = X\,M\,\bar{B}_0 \qquad (5)$$

where Y_{pot} is potential yield; M is natural mortality rate; $\bar{B}_0$ is mean virgin biomass; and X is a coefficient based on M, on Von Bertalanffy growth parameter K, and on c, the ratio of length at first capture to asymptotic length. The present biomass is only very lightly fished, and can be used for $\bar{B}_0$. A value of $X = 0.5$ is commonly used and will be used here for a "high" estimate. The value obtained from Gulland (1970) for $M/K = 2.5$ to 5.0, and relative length at first capture $c = 0.3$, is $X = 0.3$, providing a "low" estimate of potential yield. Gulland's estimator assumes a constant mortality rate, but M varies with age in the dynamic pool model. Therefore, the Gulland estimator is applied to each age separately, and potential yields are summed afterward (Tables 1 and 2).

The sensitivity of potential yield estimates to different assumed rates of natural mortality is somewhat different than sensitivity of biomass estimates. For the large-fish segment, decreases in natural mortality rate (M) result in offsetting increases in estimated biomass ($\bar{B}_0$), making potential yield estimates relatively constant (cf. equation 5). However, the sensitivity is compounded for the small-fish segment, where decreased overall rates of mortality result in a decreased portion of the total biomass being allocated to the small-fish segment, and potential yield drops considerably. Without good estimates of biomass and mortality rates, these estimates of potential yield must remain only tentative. Other estimates of potential yield, based on alternative mortality rate schedules and other assumptions, are given by MacCall et al. (1980).

Potential yield is estimated for three segments of the resource. Ages 0.5 through 8 represent the inshore small-fish fishery, and have a potential yield of about 100 to 200 thousand MT. The historical fishery has exploited fish aged 1 through 4 years more heavily than the other ages in the small-fish fishery. Based on yield-per-recruit considerations, there would be no detriment in obtaining an equivalent total yield from younger fish (e.g., ages 1-4) rather than in proportion to their biomasses over the entire range of ages. This argument does not extend to the large-fish segment, which is harvested independently. Potential yield of large fish ranges from 10 to 25 thousand MT. The intermediate group of ages 9 to 15 years has a potential yield of 20 to 50 thousand MT. The total stock has a potential yield of 130 to 260 thousand MT.

COMPARISON WITH OTHER *TRACHURUS* FISHERIES

The world catch of *Trachurus* is composed of about 13 species from the Atlantic, Pacific, and Indian oceans, and Mediterranean Sea (Berry and Cohen 1972). Two or more species often co-occur in the same region (e.g., Stephenson and Robertson 1977). In these cases one species typically attains a maximum size of 60-70 cm, and the other reaches a size of 40-45 cm. The smaller species is usually a coastal pelagic schooling fish vulnerable to purse seine fisheries. The larger species tends to be distributed widely offshore, forming semidemersal or pelagic schools, which are caught by bottom or midwater trawls. *Trachurus symmetricus* is the sole inhabitor of the northeast Pacific, and appears to fill both of these ecological niches.

Except for growth, population parameters are poorly known for most stocks of *Trachurus*. Rates of growth are relatively slow. Age at first maturity ranges from 1 to 4 years. Longevity varies from 6 years for *T. japonicus* to 35 years for *T. trachurus* (Macer 1977), the latter value being similar to that for *T. symmetricus*. Differences in longevity can be attributed to differences in age determination techniques and exploitation rates as well as inherent differences among species. Stock abundance, recruitment, and mortality rates have not been estimated for any of the *Trachurus* stocks, making *T. symmetricus* among the best-known cases. Fisheries on these stocks have developed with very little management information on their status or potential yield.

The total world landings of *Trachurus* have increased in the last 20 years from about 0.9 to 2.7 million MT in 1980 (Table 3). The major fisheries occur along the eastern Atlantic from the English Channel to South Africa; the total annual Atlantic harvest has exceeded 1 million MT since 1971, although some fisheries such as *T. trachurus capensis* off South Africa have declined severely. The large fishery off Japan has declined steadily from 0.6 million MT in 1965 to 0.06 million MT in 1980. This decline suggests that the stock was overfished, but has not collapsed catastrophically. The South American fishery off the coasts of Peru and Chile has increased rapidly since the collapse of the Peruvian anchoveta fishery in 1972, although the extent to which stock abundance or productivity has increased is unknown. The South American catch has exceeded 1 million MT since 1978, and accounts for all of the recent increase in

TABLE 3
World Catch of *Trachurus* spp by Oceanic Regions for 1965 to 1980 in 1,000 MT[1]

	Atlantic Ocean				Pacific Ocean					
	North eastern	Central eastern	South eastern[2]	Medit. Sea	North western	South western	North eastern	South eastern	Indian Ocean	Total
1965	124	52	311	42	553	—	30	15	—	1,127
1966	109	37	300	41	487	<1	19	22	—	1,015
1967	119	102	245	62	334	<1	17	30	—	909
1968	143	166	206	43	315	<1	25	27	—	925
1969	152	258	148	42	286	<1	24	23	—	969
1970	249	297	232	37	222	<1	22	117	—	1,176
1971	241	480	384	42	283	14	27	168	<1	1,639
1972	260	456	363	56	156	19	24	180	<1	1,514
1973	356	486	482	65	131	16	9	164	3	1,712
1974	285	501	346	43	169	19	10	324	4	1,700
1975	277	444	444	45	193	14	17	299	5	1,738
1976	354	433	679	64	138	16	18	377	5	2,084
1977	224	492	753	64	95	18	50	848	35	2,579
1978	146	330	968	76	64	11	32	1,025	10	2,662
1979	143	250	768	118	93	8	17	1,287	8	2,692
1980	137	490	695	94	57	7	22	1,195	35	2,732

[1]Source is FAO catch statistics.
[2]Includes a few tons from southwestern Atlantic off South America.

world catch of *Trachurus*. *Trachurus symmetricus* off California, and the New Zealand and Indian Ocean species appear to be the only remaining lightly exploited *Trachurus* stocks.

LITERATURE CITED

Ahlstrom, E. 1956. Eggs and larvae of anchovy, jack mackerel, and Pacific mackerel. Calif. Coop. Oceanic Fish Invest. Rep., 1 April 1955-30 June 1956, p. 33-42.

———. 1968. An evaluation of the fishery resources available to California fishermen. *In* The future of the fishing industry of the United States. Univ. Wash., Pubs. in Fisheries - New series, 4:65-80.

———. 1969. Distributional atlas of fish larvae in the California Current region: jack mackerel, *Trachurus symmetricus*, and Pacific hake, *Merluccius productus*, 1951 through 1966. Calif. Coop. Oceanic Fish. Invest. Atlas 11:1-92.

Berry, F.H., and L. Cohen. 1972. Synopsis of the species of *Trachurus* (Pisces, Carangidae) Quart. Jour. Florida Acad. Sci. 34(4):177-211.

Blunt, C. 1969. The jack mackerel (*Trachurus symmetricus*) resource of the eastern North Pacific. Calif. Coop. Oceanic Fish. Invest. Rep. 13:45-52.

Farris, D. 1961. Abundance and distribution of eggs and larvae and survival of larvae of jack mackerel (*Trachurus symmetricus*). U.S. Fish Wildl. Serv., Fish. Bull. 61:247-279.

Fitch, J. 1956. Jack mackerel. Calif. Coop. Oceanic Fish. Invest. Progr. Rep., 1 April 1955-30 June 1956, p. 27-28.

Fleming, E., and E. Knaggs. 1977. The southern California jack mackerel fishery and age, length and sex composition of the catch for the 1967-68 through 1971-72 seasons. Calif. Dept. Fish Game, Mar. Res. Tech. Rep. 37:1-44.

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

Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Bd. Can., Bull. 180, 740 p.

Hunter, J., and S. Goldberg. 1980. Spawning incidence and batch fecundity in northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 77:641-652.

Knaggs, E.H. 1973. Status of the jack mackerel resource and its management. Calif. Dept. Fish Game, Mar. Res. Tech. Rep. 11:1-8.

———. 1974a. The southern California jack mackerel fishery and age composition of the catch for the 1947-48 through 1956-57 seasons. Calif. Dept. Fish Game, Mar. Res. Tech. Rep. 22:1-47.

———. 1974b. The southern California jack mackerel fishery and age composition of the catch for the 1957-58 through 1961-62 seasons. Calif. Dept. Fish Game, Mar. Res. Tech. Rep. 24:1-25.

Knaggs, E., and P. Barnett. 1975. The southern California jack mackerel fishery and age composition of the catch for the 1962-63 through 1966-67 seasons. Calif. Dept. Fish Game, Mar. Res. Tech. Rep. 28:1-28.

Kramer, D., and P. Smith. 1970. Seasonal and geographic characteristics of fishery resources. Calif. Current Region—I. Jack mackerel. Commer. Fish. Rev. 32(5):27-31.

Larkins, H.A. 1964. Some epipelagic fishes of the North Pacific Ocean, Bering Sea, and Gulf of Alaska. Trans. Amer. Fish. Soc. 93:286-290.

Lynn, R.J. 1967. Seasonal variation of temperature and salinity at 10 meters in the California Current. Calif. Coop. Oceanic Fish. Invest. Rep. 11:157-186.

MacCall, A.D., H.W. Frey, D.D. Huppert, E.H. Knaggs, J.A. McMillan, and G.D. Stauffer. 1980. Biology and economics of the fishery for jack mackerel in the northeastern Pacific. U.S. Dept. Commerce, NOAA, National Mar. Fish. Serv., Tech. Memo. 4, 79 p.

Macer, C.T. 1977. Some aspects of the biology of the horse mackerel (*Trachurus trachurus* (L.)) in waters around Britain. J. Fish. Biol. 10:51-62.

MacGregor, J. 1966. Synopsis on the biology of the jack mackerel (*Trachurus symmetricus*). U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 526, 16 p.

———. 1976. Ovarian development and fecundity of five species of California Current fishes. Calif. Coop. Oceanic Fish. Invest. Rep. 18:181-188.

Mais, K.F. 1982. Cruise Report 82-X-6, Assessment of commercial fisheries resources. California Department of Fish and Game, Marine Resources Region, 245 W. Broadway, Suite 350, Long Beach, CA 90802.

Parker, K. 1980. A direct method for estimating northern anchovy, *Engraulis mordax*, spawning biomass. Fish. Bull., U.S. 78:541-544.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer 39:175-192.

Pienaar, L.V., and W.E. Ricker. 1968. Estimating mean weight from length statistics. J. Fish. Res. Board Can. 25:2743-2747.

Stephenson, A.B., and D.A. Robertson. 1977. The New Zealand species of *Trachurus* (Pisces: Carangidae). J. Royal Soc. New Zealand 7:243-253.

Wine, V., and E. Knaggs. 1975. Maturation and growth of jack mackerel, *Trachurus symmetricus*. Calif. Dept. Fish Game, Mar. Res. Tech. Rep. 21:1-26.