GROWTH OF JACK MACKEREL, *TRACHURUS SYMMETRICUS*, IN CAPTIVITY

RODERICK LEONG
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Center
La Jolla, California 92038

ABSTRACT

Fishery data indicate that jack mackerel captured from inshore waters are seldom more than 380 mm in fork length (FL). This laboratory study shows that the inshore fish have the potential to grow as large as 425-450 mm FL. During a 2-year period laboratory-held mackerel grew more than three times faster in length and more than five times faster in weight than fish in the wild. Most of the surplus weight (65%) was fat, but a significant portion (26%) was fat-free dry weight, indicating that protein as well as fat was stored. The high levels of fat and protein accumulated by the laboratory fish indicate that the growth in length (skeletal growth) may have been near the maximum rate. The excess fat was deposited in the red and white muscles and viscera in different proportions.

RESUMEN

Los datos de pesca indican que los *Trachurus symmetricus* capturados en aguas costeras raramente alcanzan más de 380 mm de longitud a la horquilla. Los estudios en el laboratorio señalan que los peces costeros tienen un potencial de crecimiento que llega a los 425-450 mm de longitud de horquilla. Los charritos mantenidos en el laboratorio durante dos años, incrementaron su longitud y peso con una rapidez tres y cinco veces mayor respectivamente, que los peces que habitan su medio natural. La mayor parte del exceso en peso estaba constituido por grasas (65%) pero una porción significativa (26%) corresponde a peso seco sin grasas, lo cual indica que almacenan tanto proteínas como grasas. Los altos niveles de grasa y proteínas acumulados por los peces mantenidos en el laboratorio indican que el crecimiento en longitud (crecimiento del esqueleto) debió alcanzar un valor cercano a la tasa máxima de crecimiento. El exceso de grasa se depositó en diferentes proporciones en los musculos blancos y rojos, y en las vísceras.

INTRODUCTION

Reports by MacCall et al. (1980) and MacCall and Stauffer (1983) on the biology of the jack mackerel, *Trachurus symmetricus*, indicate that little is known about the structure of the jack mackerel population. The reports state that the catch consists of two size groups; the inshore purse seine fishery off southern California takes fish ranging from 100 to 300 mm FL, whereas the offshore fishery, largely foreign trawlers, takes fish from 500 to 600 mm FL. Intermediate-sized fish are conspicuously absent in both fisheries. Mid-sized fish are sporadically caught (Blunt 1969) but have never been observed in numbers to support the hypothesis that the small inshore fish grow and eventually join larger fish offshore. The difference in length could be due to disparate fishing methods but may also indicate inshore-offshore populations with different growth patterns. To better understand the growth potential of the inshore mackerel, I held a school in captivity for two years to observe growth. Some adjunct observations on maturation and the accumulation of energy reserves during captivity were also made, since these aspects of mackerel biology are still inadequately known. This report presents the results of these observations and compares them with observations made on fish in the wild.

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METHODS

The observations on jack mackerel growth were made at the National Marine Fisheries Service, Southwest Fisheries Center in La Jolla, California. The fish were held in an outdoor circular swimming pool 7.3 m in diameter with 1 m of water (42 m^3 water volume). The pool had a fresh seawater inflow of 25 liters per minute and a recirculating pump with a capacity of 250 liters per minute. An overhead canopy shielded the pool from direct sunlight to reduce solar heating. The temperature ranged from 14.0° to 22.5°C and averaged 17.8° during the 2-year period. The fish were purchased from a bait dealer who caught them with a purse seine approximately 5 km southwest of La Jolla. The fish were fed daily until satiation with either chopped anchovy or squid and occasionally frozen euphausiids. The fish, about 200 in number, were feeding well and appeared adapted to captive conditions by the end of two weeks, when observations began.

I observed growth by sampling the school at various elapsed times and noting the change in fork length. The number of fish sacrificed and the elapsed times from the beginning were:

Elapsed time in days	0	62	121	180	240	322	411	505	600	733
Number of fish sacrificed	24	22	20	10	10	10	11	10	11	23

No fish were added or replaced after removal of samples. Routine data on individual fish included fork length (FL) to the nearest 1 mm, body weight to the nearest g, sex, and gonad weight to the nearest g. I calculated the gonosomatic index—gonad weight/body weight x 100—for all fish. Observations were terminated after two years because some of the fish appeared to be in declining health and were not feeding well, possibly because of long-term stress.

The von Bertalanffy growth equation,

$$l_t = L_\infty [1 - e^{-k(t - t_0)}]$$

where

l_t = fork length at time t in mm,
L_∞ = maximum expected fork length,
t_0 = hypothetical time of zero length,
t = elapsed time in years after start of experiment,
k = a constant pertaining to metabolism

was applied to the length-time data to describe the growth and estimate L_∞, the length the fish would have reached had they remained indefinitely under laboratory conditions. I used a computer program (Abramson 1971) utilizing the least squares procedure of Tomlinson and Abramson (1961) to estimate the parameters.

The weight-length relation was determined by fitting the weight-length data to the equation $W = aL^b$

where

W = weight in g,
L = fork length in mm,
a = a constant,
b = slope of line after log transformation.

After growth observations, I measured the fat and water content in the red muscle, white muscle, viscera, and body as a whole of some of the laboratory fish and also of some sea-caught fish. The sea-caught fish were captured by a Russian trawler about 250 km from the California coast and were frozen. I used five fish from each group for whole-fish fat analysis. Each fish was passed through a meat grinder several times for homogenization and dried to constant weight at 55°C in a vacuum oven. Fat extraction was accomplished with a Soxhlet apparatus using chloroform and methanol as suggested by Kvaric and Muzinic (1950). Prior to homogenization, I measured the cross-sectional areas of the fishes' red and white muscle bundles. The measurements were made from a transverse steak taken one-third of the fish length anterior to the tail, as suggested by Greer-Walker and Pull (1975). I traced the outlines of the muscle areas onto a sheet of clear plastic and measured them with a planimeter.

Seven laboratory and seven wild fish were used for red muscle, white muscle, and visceral fat analysis. I dissected the red and white muscle tissues from the musculature at mid-fork length near and above the lateral line. The viscera included all the organs in the body cavity except the kidneys, which were inadvertently excluded. The procedure for fat analysis was the same as for whole fish.

RESULTS

The distribution of fish lengths at the various elapsed times and the von Bertalanffy growth curves for the captive and wild fish are given in Figure 1. The parameters describing the growth of the captive and wild fish are presented in Table 1. Figure 1 shows the two curves beginning at a time when the captive and wild fish were 243 mm FL, (t = 0; equivalent age is 2.26 years for wild fish). The curves show that an average fish in the laboratory grew to 408 mm FL for an increase of 165 mm during the 2-year period, while a typical wild fish would have grown to 304 mm FL for an increase of only 61 mm. Calculations with the Wine-Knaggs equation indicate that the time required to grow from 243 to 408 mm FL is 6.55 years. Hence the captive fish put on more than 6 years of growth in 2 years.

The estimate of L_∞ (Table 1) for captive fish suggests that they could have grown to an average fork length of 463.9 mm had they remained indefinitely under laboratory conditions. The L_∞ value for captive fish is much lower than that for wild fish (602.9 mm FL), although the captive fish had a higher growth rate during the 2 years under observation. Mackerel in the sea attain lengths slightly over 600 mm FL (MacCall and Stauffer 1983) and live over 30 years (Fitch 1956). The relatively high K value for captive fish indicates that their growth rate was declining rapidly. The t_0 values are not directly comparable because of differences in computation.

Many of the captive fish grew significantly larger than fish taken in the inshore southern California

TABLE 1
Estimated Growth Parameters in the von Bertalanffy Equation for Captive and Wild Jack Mackerel

	L_∞ (mm FL)	K	t_0 (years)
Captive fish	463.9	0.6836	−1.08
S.E.	16.1	0.0919	0.10
Wild fish (Wine and Knaggs 1975)	602.9	0.0935	−3.25
S.E.	5.9	0.0027	0.11

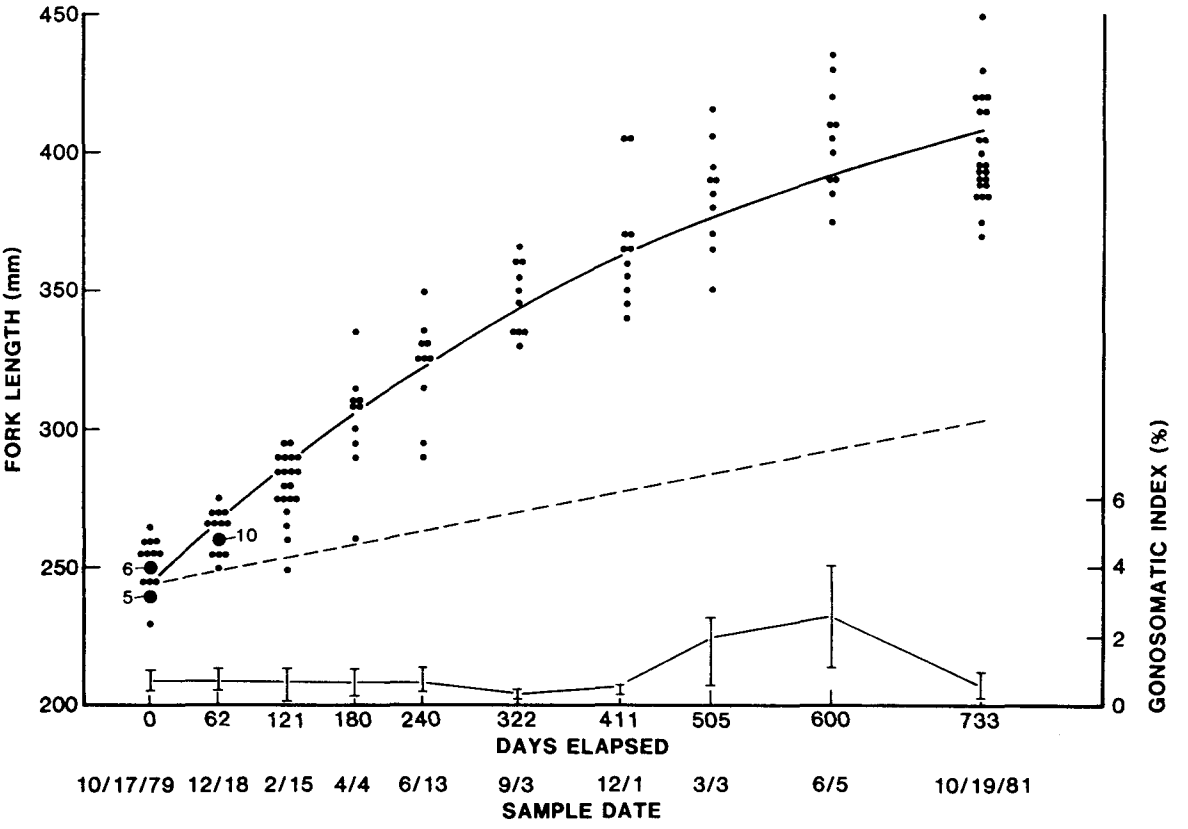

Figure 1. Growth of jack mackerel in the laboratory compared to growth of mackerel in the sea, and female ovarian development during captivity. Upper scale shows the distribution of fork lengths at elapsed times, the growth curve for fish in the laboratory (solid line), and the growth curve for fish in the sea (dashed line). Lower scale gives the ranges and means of female gonosomatic indices at sampling dates.

fishery. Data from Mallicoate and Parrish (1981) reveal that only a few mackerel of more than 20,000 sampled were over 350 mm FL, and none were over 380 mm FL during the years 1966-70. Most of the laboratory fish were larger than 350 mm FL in the 411-day sample (Figure 1), and none were less than 350 mm FL in the last three samples. The largest captive fish sampled was 450 mm FL. The sample of offshore fish in the present study contained 24 of 100 fish measuring less than 450 mm FL, with the two smallest between 300-350 mm FL. The remaining fish were larger, and two of the fish were over 600 mm FL.

The parameters describing the weight-length relationship for captive and wild fish are given in Table 2. The Wine and Knaggs equation is applicable to fish measuring 100-300 mm FL, according to MacCall et al. (1980), whereas their equation is more applicable to the entire range of lengths.

The weights (g) for some selected lengths calculated from these equations are:

Length (mm FL)	250	300	350	400	450
MacCall et al. (1980)	171	294	465	692	982
Wine and Knaggs (1975)	177	319	524	807	1179
Captive fish this study	179	356	635	1048	1632

The calculated weight, 179 g, for the captive fish at 250 mm FL is not very different from the values obtained with the other equations. This difference increases markedly with length, however, and captive fish of 450 mm FL would weigh nearly 1.4 times as much as wild fish of similar length from the Wine-Knaggs equation and over 1.6 times as much as fish from the other equation. Calculations with the weight-

TABLE 2
Estimated Parameters in the Weight-Length Equation, $W = aL^b$, for Captive and Wild Jack Mackerel

	a	b
Wild fish (Wine and Knaggs 1975)	0.0000033101	3.223229
Wild fish (MacCall et al. 1980)	0.000012338	2.97785
Captive fish this study	0.000000176	3.75670

length equation for captive fish indicate that the weight should have increased from 161 to 1130 g as the mean length increased from 243 to 408 mm FL during the 2-year holding period. Calculations with the Wine-Knaggs length-growth equation and the weight-length equation from MacCall et al. (1980) indicate that mackerel in the sea would require 10.8 years to grow from 161 g to 1130 g. It thus appears that the captive fish gained weight about five times faster than fish in the wild.

The average whole laboratory fish contained less water (50.2% vs 70.7%) but more fat per unit wet weight (25.7% vs 6.4%) than the average sea-caught fish (Table 3A). The values for the sea-caught fish were close to those found for *Trachurus trachurus*, which had an estimated moisture content of 76.7% and fat content of 6.8% (Sidwell et al. 1974). The average laboratory fish used in whole-fish fat analysis was slightly longer—433 vs 426 mm—but much heavier—1332 vs 850 g—than the average sea-caught fish. For a further comparison of the wet and component weights, I calculated the expected wet weight of a 430 mm FL fish from the weight-length relationship for both groups. I then estimated the water, fat, and fat-free dry weights with the percentages in Table 3A. The calculations (Table 3B) show that fat accounted for 65.2% of the difference in wet fish weight, water only 8.4%, and fat-free dry weight 26.4%. The large difference in fat-free dry weight is of particular interest because it implies that the laboratory fish stored a substantial amount of protein in addition to fat.

The red muscle, white muscle, and viscera of the laboratory fish all contained much more fat per unit wet weight than did the sea-caught fish (Table 4). The viscera and white muscle of the laboratory fish had about 7.1 and 8.6 times more fat per unit wet weight than those of sea-caught fish. The percentage of fat in the red muscle of the laboratory fish was only 4.5 times higher, suggesting that the increase in fat was not distributed proportionately to the three body areas. The viscera were highest in fat content, followed by red muscle and white muscle in captive as well as sea-caught fish. Although lower in relative fat content, the white muscle tissues probably contain more total fat because they occupy a much greater portion of the body volume. The water content was higher in sea-caught fish for the three types of tissues examined.

The red and white muscle bundles appeared to have enlarged proportionately with fish girth, because the percentage of red muscle to total muscle was nearly the same at 11.1% and 10.8% (Table 3). These percentages were much lower than the 18.3% recorded for *Trachurus trachurus* by Greer-Walker and Pull (1975). Much of the difference may be due to technique and the exact position of the transverse cut. The same technique was applied to both laboratory and sea-caught groups of jack mackerel.

The ovaries of the captive females were most highly developed during June 1981 (Figure 1). The eggs in the more mature ovaries were heavily yolked, and measured 0.5-0.7 mm in diameter, about the maximum size found by MacGregor (1966 and 1976) in his fecundity studies. Ichthyoplankton surveys indicate that June is one of the peak spawning months (Ahlstrom 1956; Farris 1961). The gonosomatic indices for the males were all under 1% except in June 1981 when two of the five males sampled had indices above 2%.

TABLE 3

A. Comparison of Water, Fat, Red Muscle, and Size of Five Laboratory and Five Sea-Caught Mackerel

	Laboratory		Sea-caught	
	Mean	S.E.	Mean	S.E.
Percent water[a]	50.2	1.4	70.7	1.4
Percent fat[a]	25.7	3.9	6.4	1.7
Percent red muscle to total muscle[b]	11.1	0.5	10.8	0.5
Fork length mm	443	4.8	426	4.5
Wet weight g	1332	49	850	46

B. Comparison of Wet and Component Weights (g) of Laboratory and Sea-Caught Fish[c], Applying above Data

	Laboratory	Sea-caught	Difference	Percent of 428-g wet weight difference
Weight of Water	655	619	36	8.4
Weight of fat	335	56	279	65.2
Fat-free dry weight	314	201	113	26.4
Wet weight of 430-mm mackerel[d]	1304	876	428	100.0

[a]Percent based on wet weight.
[b]Percent red muscle measured from transverse cut.
[c]Standardized to 430 mm.
[d]Wet weight obtained from weight-length relationship within each sample.

TABLE 4

Comparison of Seven Laboratory and Seven Sea-Caught Mackerel

	Laboratory		Sea-caught	
	Mean	S.E.	Mean	S.E.
Red muscle				
Percent water	48.4	1.7	71.2	0.8
Percent fat[a]	31.9	2.5	7.1	1.1
White muscle				
Percent water	63.5	1.9	75.0	0.8
Percent fat	12.7	1.9	1.5	0.3
Viscera				
Percent water	25.4	2.6	75.2	1.4
Percent fat	67.5	9.1	9.6	1.5
Length (mm)	394	3.0	395	16.2
Weight (g)	907	55	593	85

[a]Percent water based on wet weight.

These two males produced sperm upon stripping and appeared capable of spawning. The water in the tank was checked regularly for eggs but no sign of actual spawning was detected. The females did not show signs of advanced ovarian development during June of 1980, although they were large enough to be sexually mature (235 mm FL) according to Wine and Knaggs (1975).

DISCUSSION

The abundant food supply and lack of predators undoubtedly contributed much to the high growth rate observed in this study. The temperature and the absence of spawning may also have been important in increasing growth. The large increase in growth by fish in the laboratory over fish in the sea has been observed for other pelagic species including the Japanese jack mackerel, *Trachurus japonicus* (Ochiai et al. 1983) and northern anchovy, *Engraulis mordax* (Hunter and Leong 1981). In spite of the rapid growth rate observed, the ultimate length, L_∞, attainable by the captive fish appeared to be relatively small. The stress of confinement in a small volume of water and missing elements in the diet over an extended period are factors that can limit growth.

The captive fishes' growth in length exceeded that of the wild population by about three times. The captives' greater growth in body weight—about five times—suggests that the food ration exceeded that needed for skeletal growth and that growth in length may have been near the maximum for the given conditions. It is not surprising that a large food supply increased fat deposition, but the finding that it also resulted in a substantial increase in fat-free dry weight suggests that excess rations are stored not only as fat but also as protein.

That fact that some of the captive fish grew beyond 425 mm FL and one reached 450 mm FL indicates that the small jack mackerel in the inshore regions off southern California have the potential to reach those lengths. Observations in the present study do not exclude the possibility that these inshore fish have the potential to grow even larger.

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