# SEASONAL GROWTH PATTERNS OF CALIFORNIA STOCKS OF NORTHERN ANCHOVY, *ENGRAULIS MORDAX*, PACIFIC MACKEREL, *SCOMBER JAPONICUS*, AND JACK MACKEREL, *TRACHURUS SYMMETRICUS*

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## ABSTRACT

Market sample data obtained from the California Department of Fish and Game were analyzed to show number, mean length, and mean weight of fish by age and month for northern anchovy, *Engraulis mordax*, Pacific mackerel, *Scomber japonicus*, and jack mackerel, *Trachurus symmetricus*. In addition, maximum and minimum lengths and weights and their standard deviations were calculated.

Graphs showing the relationship between age and length and between age and weight were produced for each of these three species. The graphs show that the age-length relationships of Pacific mackerel, jack mackerel, and northern anchovy landed in southern California and of northern anchovy landed in central California are adequately described by the von Bertalanffy growth curve. These graphs also show considerable seasonal variation in the age-weight relationships. These seasonal fluctuations may be related to the occurrence of spawning and feeding relationships. Analysis of the growth in weight suggests that a size limit would be expected to increase yields of Pacific mackerel, but not of jack mackerel or northern anchovy.

## RESUMEN

Datos de muestras de anchoveta del norte, *Engraulis mordax*, macarela, *Scomber japonicus*, y macarela caballa, *Trachurus symmetricus*, colectadas en el mercado por el California Department of Fish and Game, se analizaron para mostrar número, longitud media, y peso medio de los peces por edad y por mes. Adicionalmente, se calcularon las longitudes y los pesos máximos y mínimos y sus desviaciones estándard.

Se produjeron gráficas para cada una de estas tres especies, mostrando la relación entre edad y longitud y entre edad y peso. Las gráficas muestran que para la macarela, macarela caballa y anchoveta del norte desembarcadas en el sur de California, y para la anchoveta del norte desembarcada en California central, las relaciones entre edad y longitud están descritas adecuadamente por la curva de crecimiento de von Bertalanffy. Estas gráficas también muestran considerable variación estacional en las relaciones entre edad y peso. Estas variaciones estacionales pueden estar relacionadas con desove y alimentación. El análisis del crecimiento en peso sugiere que con un tamaño límite se puede esperar un aumento en los rendimientos de macarela, pero no así para macarela caballa ni anchoveta del norte.

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## INTRODUCTION

The purpose of this study is to describe the seasonal growth patterns of northern anchovy, *Engraulis mordax*, jack mackerel, *Trachurus symmetricus*, and Pacific mackerel, *Scomber japonicus* and to explore what these seasonal growth patterns suggest in terms of managing these fisheries.

Data for the study were provided by the California Department of Fish and Game (CDFG). Part of the data had been used previously to describe von Bertalanffy growth equations for northern anchovy (Spratt 1975), jack mackerel (Wine and Knaggs 1975), and Pacific mackerel (Knaggs and Parrish 1973). In our study, computer programs were developed to calculate and graph growth statistics for these three species.

At the time the market samples were taken, northern anchovy had a quota, a 5-inch size limit, and a closed season during summer. These regulations were established by the State of California. No such regulations existed for Pacific mackerel and jack mackerel. Currently, the Pacific Fisheries Management Council has established a quota, a 5-inch size limit, and a closed season for northern anchovy. The State of California has established a quota, a 10-inch size limit, and a closed season for Pacific mackerel. There are no such regulations for jack mackerel.

## METHODS

### *Description of Data Base*

Data for this study were obtained by the CDFG through their programs for sampling and aging commercial catches of northern anchovy, jack mackerel, and Pacific mackerel. Sampling procedures for northern anchovy have been described by Collins (1969). However, the sampling procedures for the jack mackerel and Pacific mackerel data have not been published.

Data for northern anchovy were taken from landings in San Pedro and Monterey. The samples from the San Pedro landings consist of 58,347 fish and include the 1966/67 season and the 1968/69 through 1978/79 seasons. The samples from the Monterey landings consist of 4,902 fish and include seasons 1966/67 through 1969/70 and seasons 1971/72 through 1977/78. In southern California, at the time these samples were taken, the anchovy season opened in September and closed during June, July, and August. However, during the 1978/79 season, the anchovy season closed during July and August. In central California, the anchovy season opened in August and closed during June and July.

The data for jack mackerel and Pacific mackerel were taken from landings in San Pedro. The jack mackerel samples include seasons 1966/67 through 1970/71, and consist of 20,109 fish. The Pacific mackerel samples include seasons 1962/63 through 1973/74 and consist of 7,005 fish. During this period of time there was a severe decline in the population of Pacific mackerel. Landings were extemely limited, and few fish were sampled. Finally, in 1970, the State of California put a moratorium on Pacific mackerel landings, which continued until 1977.

The individual fish data include date of capture, length, weight (g), sex, maturity, annuli (rings), and year class. Jack mackerel and Pacific mackerel lengths were recorded as fork length (FL), and northern anchovy lengths were recorded as standard length (SL).

For the purpose of portraying the data, it is assumed that all fish are born in the same month of the year. The spawning season for both jack mackerel and Pacific mackerel is March through October, with the majority of spawning taking place April through August (Knaggs and Parrish 1973; Wine and Knaggs 1975). For this study, May will be considered the birth month of both jack mackerel and Pacific mackerel. Northern anchovy has a year round spawning season, with the majority of spawning taking place in February and March (Ahlstrom 1966). For northern anchovy, February will be considered the birth month.

In Pacific mackerel (Fitch 1951) and jack mackerel, rings are laid down on the otoliths near the time of the birthday and, thus, can be used as a measure of age. In northern anchovy, however, rings are laid down during the spring, with the majority laid down by June 1st (Collins and Spratt 1969). Therefore, in our study ages of northern anchovy were calculated based on rings and date of capture.

### *Data Analysis*

A computer program was developed to calculate the number, the mean length, and the mean weight of fish by age and by month. The program also calculated maximum and minimum lengths, maximum and minimum weights, standard deviations of lengths, and standard deviation of weights by age and by month. Standard deviations were not calculated if there were less than ten observations. This program also produced graphs of age-length and age-weight relationships.

In order to more clearly describe the seasonal fluctuations in weight, the proportion of growth by month was calculated for each of the three species. The September mean weight was taken as a starting point because this is the month the fish are recruited to the fishery. The proportion was calculated by dividing each monthly mean weight of each age group by its corresponding September mean weight. This procedure resulted in an overlap of age groups. To avoid bias resulting from small numbers of fish at the older ages, the proportions were weighted by the number of fish. These calculations were made for younger fish (mostly immatures), for older fish (mostly adults), and for the total number of fish.

## RESULTS

The relationships between age and length and between age and weight for northern anchovy, jack mackerel, and Pacific mackerel are shown in the following tables and figures. When expressed graphically the seasonal fluctuations in growth in weight, and to a lesser degree growth in length, are evident. Growth in weight has different seasonal patterns in the three species, and it also differs between anchovy landed in Monterey and San Pedro.

### *Seasonal Distribution of Catch by Age*

The summaries of the number and mean length of fish by age and month for northern anchovy landed in San Pedro and Monterey show considerable differences in the age structure and the seasonality of the fisheries in the two regions. The data for northern anchovy sampled in San Pedro show that a very small percentage of the fish were less than one year old (3.2%); the bulk of the fish (83.8%) consisted of ages 1–3 (Table 1). One-year-old fish comprised 26% of the fish sampled; 33.8% of the fish were two years old, and 24% were three years old. The highest percentages of catch occurred in fall and early winter (October through January), with a small peak during the spring (April and May). Landings were low during the peak of the spawning season (February and March) and during the summer due to the closed season. A

TABLE 1
**Number ($N$), Mean Standard Length mm ($\bar{X}$), and Percentage of Fish by Age and Month for Northern Anchovy Sampled in San Pedro.**

| AGE | | FEB | MAR | APR | MAY | JUN* | JUL | AUG | SEP | OCT | NOV | DEC | JAN | SUBTOTAL | % BY AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | $N$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52 | 297 | 280 | 575 | 665 | 1869 | .032 |
| | $\bar{X}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 104 | 103 | 106 | 104 | 105 | | |
| 1 | $N$ | 684 | 1778 | 1842 | 1870 | 519 | 0 | 0 | 707 | 2059 | 1610 | 2016 | 2091 | 15176 | .260 |
| | $\bar{X}$ | 104 | 106 | 109 | 112 | 110 | 0 | 0 | 117 | 117 | 119 | 117 | 116 | | |
| 2 | $N$ | 1236 | 993 | 1526 | 1592 | 75 | 0 | 0 | 1585 | 3630 | 3514 | 3348 | 2234 | 19733 | .338 |
| | $\bar{X}$ | 113 | 116 | 117 | 118 | 119 | 0 | 0 | 121 | 123 | 124 | 124 | 122 | | |
| 3 | $N$ | 970 | 662 | 1700 | 1593 | 31 | 0 | 0 | 999 | 1743 | 2717 | 2187 | 1422 | 14024 | .240 |
| | $\bar{X}$ | 119 | 125 | 125 | 123 | 129 | 0 | 0 | 124 | 127 | 129 | 129 | 130 | | |
| 4 | $N$ | 409 | 554 | 1306 | 639 | 2 | 0 | 0 | 186 | 500 | 896 | 620 | 454 | 5566 | .095 |
| | $\bar{X}$ | 127 | 133 | 132 | 130 | 131 | 0 | 0 | 129 | 131 | 133 | 133 | 138 | | |
| 5 | $N$ | 110 | 348 | 591 | 180 | 0 | 0 | 0 | 25 | 63 | 125 | 88 | 95 | 1625 | .028 |
| | $\bar{X}$ | 136 | 139 | 138 | 138 | 0 | 0 | 0 | 133 | 136 | 136 | 138 | 144 | | |
| 6 | $N$ | 32 | 97 | 132 | 33 | 0 | 0 | 0 | 3 | 7 | 12 | 6 | 6 | 328 | .006 |
| | $\bar{X}$ | 141 | 146 | 144 | 145 | 0 | 0 | 0 | 144 | 136 | 142 | 142 | 156 | | |
| 7 | $N$ | 2 | 8 | 10 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 24 | .0004 |
| | $\bar{X}$ | 162 | 151 | 147 | 147 | 0 | 0 | 0 | 0 | 124 | 0 | 0 | 0 | | |
| 8 | $N$ | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | .00003 |
| | $\bar{X}$ | 0 | 147 | 172 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| SUBTOTAL | | 3443 | 4441 | 7108 | 5910 | 627 | 0 | 0 | 3557 | 8300 | 9154 | 8840 | 6967 | 58347 | |
| % BY MONTH | | .059 | .076 | .122 | .101 | .011 | 0 | 0 | .061 | .142 | .157 | .152 | .119 | | |

*Represents only one season of data (1978/79)

small percentage (7.4%) of the anchovies sampled in Monterey were age group 0; most (83.7%) were age groups 1–4 (Table 2). The 1- to 4-year-old fish comprised 17.4%, 22.2%, 27.4%, and 16.7%, respectively, of the sampled catch. Peak landings occurred in the late summer and fall (August through November).

A comparison of the anchovy landings in the two areas shows that the fish landed in Monterey tend to be older than those landed in San Pedro. The median age in the Monterey samples was three, and the median age in the San Pedro samples was two. Peak landings in Monterey occurred earlier in the season and were more seasonally concentrated than those in San Pedro. In Monterey, 66% of the sampled catch was landed during the September-November period, whereas in San Pedro, 45.1% was landed during October-December.

The San Pedro landings of jack mackerel consisted primarily of young fish; 27.3% of the fish sampled were less than one year old, 49.5% were one-year-old fish, and 16.5% were two-year-old fish (Table 3). Only 6.6% of the fish were age three and older. The dominance of young fish in the catch is influenced by the fact that the bulk of the adult stock is not available

TABLE 2
**Number ($N$), Mean Standard Length mm ($\bar{X}$), and Percentage of Fish by Age and Month for Northern Anchovy Sampled in Monterey.**

| AGE | | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | SUBTOTAL | % BY AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | $N$ | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 45 | 46 | 252 | 11 | 4 | 364 | .074 |
| | $\bar{X}$ | 0 | 0 | 0 | 0 | 0 | 0 | 110 | 110 | 109 | 112 | 109 | 122 | | |
| 1 | $N$ | 1 | 28 | 19 | 11 | 0 | 0 | 175 | 228 | 242 | 112 | 15 | 21 | 852 | .174 |
| | $\bar{X}$ | 124 | 108 | 114 | 110 | 0 | 0 | 121 | 123 | 123 | 122 | 127 | 124 | | |
| 2 | $N$ | 7 | 46 | 52 | 14 | 0 | 0 | 122 | 275 | 295 | 152 | 65 | 60 | 1088 | .222 |
| | $\bar{X}$ | 126 | 120 | 125 | 126 | 0 | 0 | 131 | 133 | 131 | 133 | 132 | 132 | | |
| 3 | $N$ | 18 | 54 | 61 | 17 | 0 | 0 | 135 | 246 | 381 | 234 | 98 | 100 | 1344 | .274 |
| | $\bar{X}$ | 136 | 124 | 135 | 133 | 0 | 0 | 139 | 141 | 139 | 138 | 137 | 138 | | |
| 4 | $N$ | 22 | 55 | 47 | 1 | 0 | 0 | 71 | 141 | 188 | 153 | 72 | 67 | 817 | .167 |
| | $\bar{X}$ | 144 | 146 | 147 | 134 | 0 | 0 | 146 | 147 | 146 | 143 | 141 | 145 | | |
| 5 | $N$ | 23 | 14 | 29 | 2 | 0 | 0 | 28 | 78 | 62 | 63 | 24 | 22 | 345 | .070 |
| | $\bar{X}$ | 149 | 146 | 151 | 135 | 0 | 0 | 153 | 152 | 151 | 149 | 145 | 151 | | |
| 6 | $N$ | 7 | 9 | 20 | 0 | 0 | 0 | 4 | 24 | 6 | 6 | 5 | 1 | 82 | .017 |
| | $\bar{X}$ | 155 | 152 | 155 | 0 | 0 | 0 | 155 | 161 | 153 | 153 | 152 | 154 | | |
| 7 | $N$ | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 10 | .002 |
| | $\bar{X}$ | 0 | 0 | 155 | 0 | 0 | 0 | 0 | 158 | 0 | 165 | 0 | 0 | | |
| SUBTOTAL | | 78 | 206 | 233 | 45 | 0 | 0 | 541 | 1040 | 1220 | 974 | 290 | 275 | 4902 | |
| % BY MONTH | | .016 | .042 | .048 | .009 | 0 | 0 | .110 | .212 | .249 | .199 | .059 | .056 | | |

TABLE 3
**Number *(N)*, Mean Fork Length mm $(\bar{X})$, and Percentage of Fish by Age and Month for Jack Mackerel Sampled in San Pedro.**

| AGE | | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | SUBTOTAL | % BY AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | $N$ | 0 | 0 | 0 | 1 | 16 | 265 | 274 | 629 | 770 | 809 | 1507 | 1219 | 5490 | .273 |
| | $\bar{X}$ | 0 | 0 | 0 | 187 | 156 | 160 | 166 | 171 | 172 | 172 | 180 | 180 | | |
| 1 | $N$ | 1560 | 1868 | 904 | 1091 | 1175 | 1144 | 687 | 742 | 171 | 253 | 227 | 135 | 9957 | .495 |
| | $\bar{X}$ | 183 | 186 | 186 | 198 | 201 | 210 | 213 | 214 | 215 | 219 | 218 | 225 | | |
| 2 | $N$ | 589 | 506 | 351 | 200 | 168 | 427 | 264 | 243 | 100 | 134 | 199 | 144 | 3325 | .165 |
| | $\bar{X}$ | 227 | 230 | 228 | 233 | 237 | 238 | 235 | 235 | 241 | 242 | 243 | 249 | | |
| 3 | $N$ | 218 | 205 | 123 | 29 | 57 | 184 | 29 | 8 | 26 | 60 | 41 | 22 | 1002 | .050 |
| | $\bar{X}$ | 249 | 259 | 249 | 275 | 278 | 274 | 282 | 297 | 279 | 265 | 263 | 278 | | |
| 4 | $N$ | 43 | 61 | 28 | 3 | 33 | 48 | 10 | 5 | 18 | 17 | 14 | 7 | 287 | .014 |
| | $\bar{X}$ | 271 | 273 | 270 | 282 | 298 | 302 | 308 | 311 | 301 | 292 | 297 | 335 | | |
| 5 | $N$ | 3 | 4 | 5 | 1 | 1 | 8 | 4 | 2 | 2 | 12 | 1 | 0 | 43 | .002 |
| | $\bar{X}$ | 324 | 304 | 289 | 327 | 302 | 342 | 357 | 330 | 325 | 320 | 330 | 0 | | |
| 6 | $N$ | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 4 | .0002 |
| | $\bar{X}$ | 345 | 0 | 0 | 0 | 0 | 0 | 362 | 0 | 0 | 317 | 325 | 0 | | |
| 7 | $N$ | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | .00005 |
| | $\bar{X}$ | 0 | 0 | 335 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| SUBTOTAL | | 2414 | 2644 | 1412 | 1325 | 1450 | 2076 | 1269 | 1629 | 1087 | 1286 | 1990 | 1527 | 20109 | |
| % BY MONTH | | .120 | .131 | .070 | .066 | .072 | .103 | .063 | .081 | .054 | .064 | .099 | .076 | | |

to the San Pedro purse seine fleet. Adult fish occur farther offshore and to the north of the fleet's fishing grounds (Blunt 1969). In addition, the absence of a size limit allows the take of small jack mackerel, which were apparently available to the fishery year round, since the data show no sharp peaks in monthly landings.

Pacific mackerel landings in San Pedro were dominated by age groups zero and one, 38.6% and 28.2% respectively (Table 4). The remaining percentage, 33.2%, was widely distributed among the other ages. In contrast to jack mackerel, older Pacific mackerel are available to the purse seine fishery as evidenced by the higher percentages of two- to six-year olds in the data. In addition, Fitch (1951) reported that the early fishery was dominated by two- to six-year olds. Catches of Pacific mackerel show strong seasonality, with a sharp peak in October/November. A second, minor peak, composed primarily of juveniles, occurred in May.

### *Growth in Length*

The monthly distribution of lengths of northern anchovy in samples taken from the San Pedro and Mon-

TABLE 4
**Number *(N)*, Mean Fork Length mm $(\bar{X})$, and Percentage of Fish by Age and Month for Pacific Mackerel Sampled in San Pedro.**

| AGE | | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | SUBTOTAL | % BY AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | $N$ | 0 | 0 | 0 | 0 | 150 | 720 | 579 | 369 | 329 | 268 | 139 | 152 | 2706 | .386 |
| | $\bar{X}$ | 0 | 0 | 0 | 0 | 201 | 211 | 226 | 231 | 245 | 237 | 230 | 237 | | |
| 1 | $N$ | 697 | 326 | 273 | 220 | 173 | 167 | 72 | 12 | 5 | 15 | 4 | 12 | 1976 | .282 |
| | $\bar{X}$ | 266 | 272 | 280 | 282 | 278 | 298 | 301 | 301 | 292 | 308 | 291 | 305 | | |
| 2 | $N$ | 64 | 35 | 107 | 55 | 45 | 138 | 57 | 16 | 1 | 10 | 8 | 42 | 578 | .083 |
| | $\bar{X}$ | 301 | 309 | 310 | 314 | 313 | 320 | 323 | 321 | 305 | 324 | 323 | 328 | | |
| 3 | $N$ | 33 | 41 | 62 | 29 | 62 | 148 | 84 | 45 | 4 | 19 | 12 | 5 | 544 | .078 |
| | $\bar{X}$ | 331 | 333 | 334 | 331 | 332 | 336 | 339 | 339 | 341 | 337 | 340 | 353 | | |
| 4 | $N$ | 60 | 27 | 51 | 36 | 23 | 105 | 39 | 27 | 0 | 6 | 7 | 3 | 384 | .055 |
| | $\bar{X}$ | 348 | 351 | 356 | 358 | 358 | 359 | 363 | 354 | 0 | 357 | 356 | 363 | | |
| 5 | $N$ | 68 | 13 | 23 | 29 | 11 | 182 | 61 | 66 | 4 | 8 | 8 | 2 | 475 | .068 |
| | $\bar{X}$ | 369 | 373 | 375 | 375 | 372 | 377 | 381 | 378 | 391 | 383 | 380 | 379 | | |
| 6 | $N$ | 24 | 2 | 14 | 5 | 8 | 115 | 32 | 52 | 18 | 9 | 0 | 0 | 279 | .040 |
| | $\bar{X}$ | 384 | 381 | 397 | 383 | 389 | 385 | 388 | 387 | 408 | 394 | 0 | 0 | | |
| 7 | $N$ | 1 | 0 | 7 | 2 | 1 | 17 | 1 | 9 | 5 | 2 | 0 | 0 | 45 | .006 |
| | $\bar{X}$ | 398 | 0 | 400 | 394 | 393 | 400 | 410 | 385 | 408 | 413 | 0 | 0 | | |
| 8 | $N$ | 1 | 0 | 3 | 0 | 1 | 9 | 0 | 0 | 0 | 1 | 0 | 0 | 15 | .002 |
| | $\bar{X}$ | 408 | 0 | 419 | 0 | 428 | 411 | 0 | 0 | 0 | 385 | 0 | 0 | | |
| 9 | $N$ | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | .0004 |
| | $\bar{X}$ | 0 | 0 | 408 | 0 | 0 | 416 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| SUBTOTAL | | 948 | 444 | 541 | 376 | 474 | 1603 | 925 | 596 | 366 | 338 | 178 | 216 | 7005 | |
| % BY MONTH | | .135 | .063 | .077 | .054 | .068 | .229 | .132 | .085 | .052 | .048 | .025 | .031 | | |

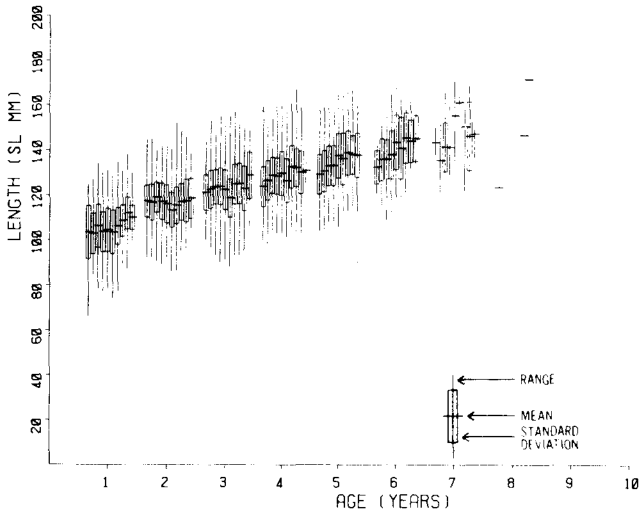


Figure 1. Monthly distribution (February-January) of the length of northern anchovy in samples taken from San Pedro (58,347 fish, 1966-78).

terey fisheries shows these fish have a slow growth rate, little seasonal fluctuations in mean standard length, and that anchovies landed in Monterey were larger than those landed in San Pedro. Young-of-the-year anchovies were recruited to the fishery in the fall (September-October). In San Pedro this occurred at a mean standard length of 103 mm (Figure 1, Table 1). By age four these fish had grown to a mean standard length of 130 mm. In Monterey, young-of-the-year anchovies were recruited to the fishery at a mean standard length of 109 mm and by age four had grown to a mean standard length of 146 mm (Figure 2, Table 2). At the time they entered the fishery, the anchovies landed in Monterey were 6 mm longer than the anchovies landed in San Pedro. This difference in standard length had increased to 16 mm by age four. The growth curves of anchovies in the two regions are almost linear and free of fluctuations.

The growth of anchovy described in this study differs from other published studies in that growth to age one is more rapid and growth after this age is slower. Clark and Phillips (1952) found one-year-old anchovies in central California to be 92 mm in standard length, and Spratt (1975) found one-year-old anchovies in southern California to be 92 mm in standard length. Using February as the birth month, we found one-year-old anchovies to be about 110 mm in central California and 104 mm in southern California. We also found that at age four anchovies in central California were 144 mm and anchovies in southern California were 127 mm. Clark and Phillips, however, found that anchovies in central California were 152 mm at age four, and Spratt found that anchovies in southern California were 135 mm at age four. The most likely explanation for the differences in growth rates among these studies is that anchovies have different growth rates in different years. Spratt's data cover the years 1966–72 and consist of 677 aged fish. Clark and Phillips' data cover the years 1946–51 and consist of 211 aged fish. Our study covers the years 1966–78 and consists of 58,347 aged fish for southern California and 4,902 aged fish for central California.

Young-of-the-year jack mackerel first entered the fishery during September-October at a mean fork length of 158 mm and reached 300 mm by the time they were four years old (Figure 3, Table 3). Fish that were three years and older tended to exhibit seasonal fluctuations in mean fork length; growth was more rapid in the spring and summer than in the winter. Growth in length of jack mackerel is well described by

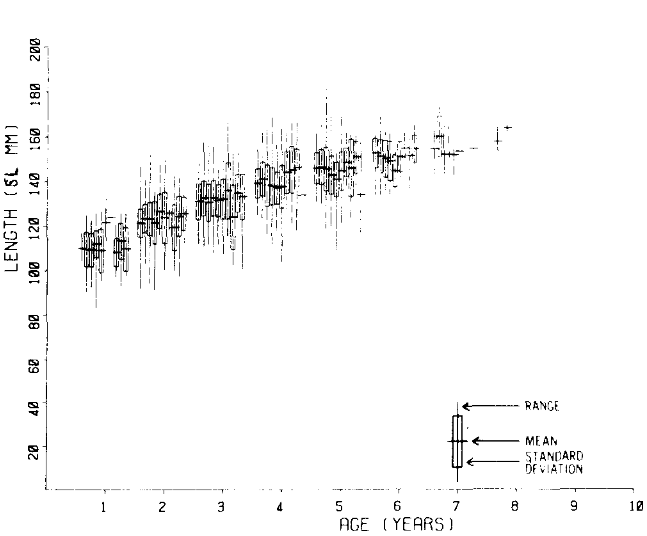


Figure 2. Monthly distribution (February-January) of the length of northern anchovy in samples taken from Monterey (4,902 fish, 1966-77).

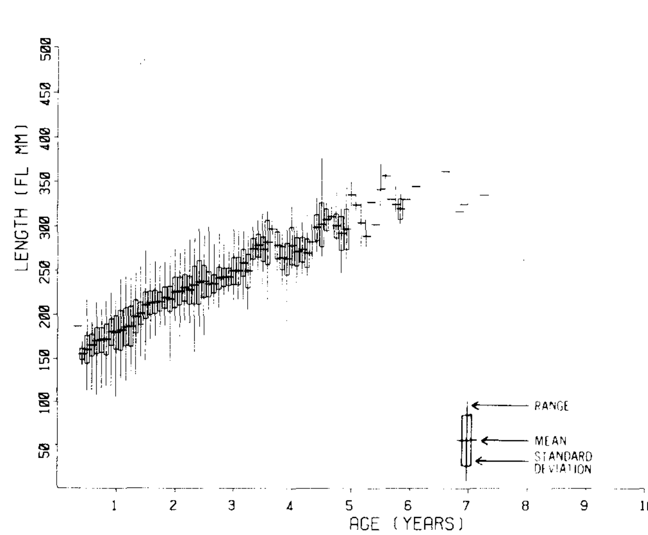


Figure 3. Monthly distribution (May-April) of the length of jack mackerel in samples taken from San Pedro (20,109 fish, 1966-70).

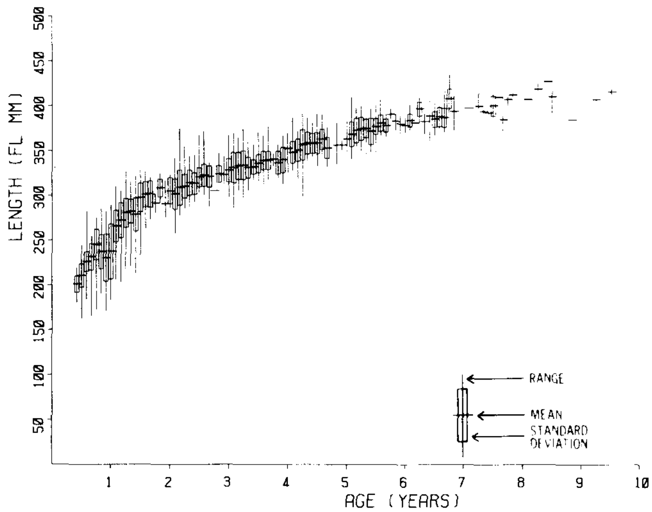


Figure 4. Monthly distribution (May-April) of the length of Pacific mackerel in samples taken from San Pedro (7,005 fish, 1962-73).

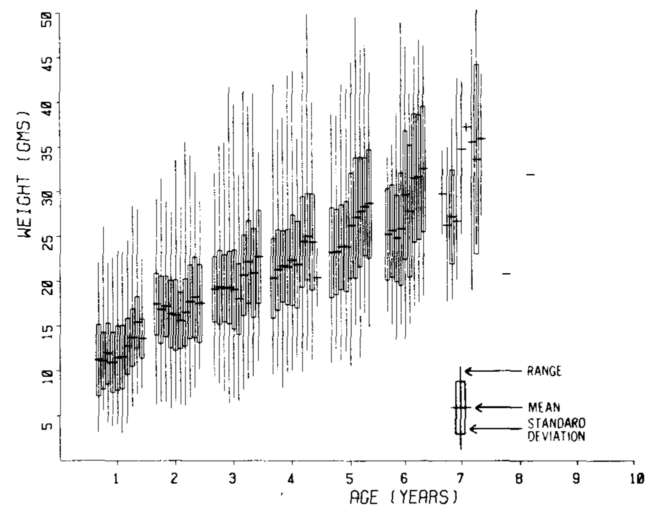


Figure 5. Monthly distribution (February-January) of the weight of northern anchovy in samples taken from San Pedro (58,296 fish, 1966-78).

a von Bertalanffy growth equation (Wine and Knaggs 1975).

Young-of-the-year Pacific mackerel are recruited to the fishery in September-October at a mean fork length of 206 mm (Figure 4, Table 4). These fish attained a length of 359 mm by the time they were four years old. Growth was particularly rapid during the spring and summer for one-year-old fish. Growth in length of Pacific mackerel appears to exhibit a close fit to a typical von Bertalanffy growth equation (Knaggs and Parrish, 1973).

Growth in length of jack mackerel and Pacific mackerel have several differences. Pacific mackerel initially have a faster rate of growth than jack mackerel. Although both enter the fishery in September (at about six months of age), Pacific mackerel have a mean fork length of 206 mm, whereas jack mackerel have a mean fork length of only 158 mm. Growth in Pacific mackerel is very rapid to about two years of age, then decreases somewhat in older fish. Jack mackerel, however, maintain a moderate, almost linear, growth rate. In addition, Pacific mackerel growth in length displays seasonality in one-year-old fish, whereas jack mackerel growth displays seasonality in fish three years and older.

### *Growth in Weight*

The monthly distribution of northern anchovy weights in samples taken from the San Pedro fishery indicates that anchovies first entered the fishery at a mean weight of 11.1 g and by age four had increased to a mean weight of 23.2 g (Figure 5, Table 5).[1] In a period of four years, these fish had increased their weight by a factor of 2.1. Growth in weight shows a step-like fluctuation with no growth during the fall and winter months, followed by a spurt of growth beginning in late winter or early spring, which continues through early summer. Although there are no data over the summer months, it appears that younger fish (ages 1 and 2) increased in weight over these months, whereas older fish (ages 3+) lost weight over this period.

Northern anchovies were recruited to the Monterey fishery at a mean weight of 15.5 g (Figure 6, Table 6). By age four, they had increased to a mean weight of

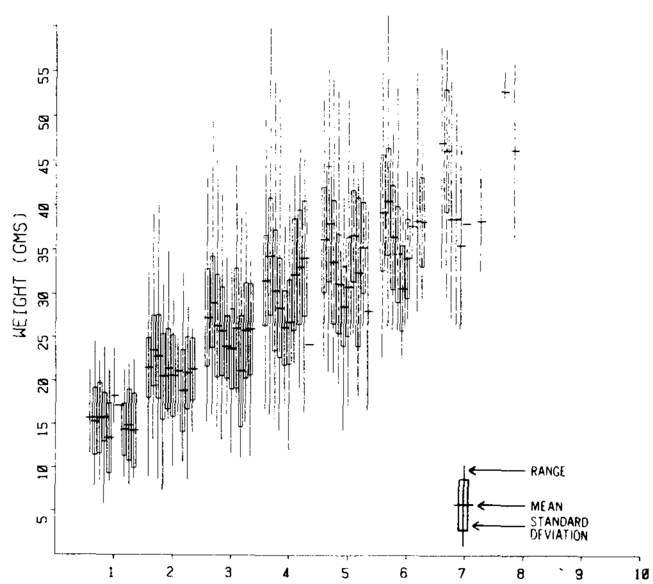


Figure 6. Monthly distribution (February-January) of the weight of northern anchovy in samples taken from Monterey (4,807 fish, 1966-77).

[1]The total numbers of fish in Tables 1-4 are different from those in Tables 5-8 because some fish were not weighed.

TABLE 5
**Number *(N)*, Mean Weight g *($\bar{X}$)*, and Percentage of Fish by Age and Month for Northern Anchovy Sampled in San Pedro.**

| AGE | | FEB | MAR | APR | MAY | JUN* | JUL | AUG | SEP | OCT | NOV | DEC | JAN | SUBTOTAL | % BY AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | $N$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52 | 297 | 280 | 575 | 665 | 1869 | .032 |
| | $\bar{X}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11.2 | 11.1 | 12.0 | 11.0 | 11.4 | | |
| 1 | $N$ | 684 | 1778 | 1842 | 1870 | 519 | 0 | 0 | 707 | 2059 | 1610 | 2016 | 2091 | 15176 | .260 |
| | $\bar{X}$ | 11.6 | 12.8 | 13.7 | 15.4 | 13.6 | 0 | 0 | 17.4 | 16.8 | 17.2 | 16.3 | 16.2 | | |
| 2 | $N$ | 1236 | 993 | 1517 | 1592 | 75 | 0 | 0 | 1585 | 3630 | 3514 | 3348 | 2234 | 19724 | .338 |
| | $\bar{X}$ | 15.6 | 16.5 | 17.7 | 18.3 | 17.5 | 0 | 0 | 19.1 | 19.3 | 19.2 | 19.3 | 19.1 | | |
| 3 | $N$ | 970 | 662 | 1683 | 1593 | 31 | 0 | 0 | 999 | 1743 | 2717 | 2187 | 1422 | 14007 | .240 |
| | $\bar{X}$ | 18.0 | 20.7 | 22.2 | 20.9 | 22.7 | 0 | 0 | 20.3 | 21.3 | 21.7 | 21.6 | 22.3 | | |
| 4 | $N$ | 409 | 554 | 1288 | 639 | 2 | 0 | 0 | 186 | 500 | 896 | 620 | 454 | 5548 | .095 |
| | $\bar{X}$ | 21.8 | 24.4 | 25.0 | 24.4 | 20.4 | 0 | 0 | 23.2 | 23.2 | 23.8 | 23.9 | 26.3 | | |
| 5 | $N$ | 110 | 348 | 586 | 180 | 0 | 0 | 0 | 25 | 63 | 125 | 88 | 95 | 1620 | .028 |
| | $\bar{X}$ | 27.1 | 27.8 | 28.4 | 28.7 | 0 | 0 | 0 | 25.2 | 25.7 | 24.8 | 25.8 | 29.6 | | |
| 6 | $N$ | 32 | 97 | 130 | 33 | 0 | 0 | 0 | 3 | 7 | 12 | 6 | 6 | 326 | .006 |
| | $\bar{X}$ | 27.8 | 31.5 | 31.6 | 32.5 | 0 | 0 | 0 | 29.7 | 26.3 | 27.2 | 26.7 | 34.7 | | |
| 7 | $N$ | 2 | 8 | 10 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 24 | .0004 |
| | $\bar{X}$ | 37.2 | 35.5 | 33.6 | 35.9 | 0 | 0 | 0 | 0 | 18.1 | 0 | 0 | 0 | | |
| 8 | $N$ | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | .00003 |
| | $\bar{X}$ | 0 | 31.9 | 58.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| SUBTOTAL | | 3443 | 4441 | 7057 | 5910 | 627 | 0 | 0 | 3557 | 8300 | 9154 | 8840 | 6967 | 58296 | |
| % BY MONTH | | .059 | .076 | .121 | .101 | .011 | 0 | 0 | .061 | .142 | .157 | .152 | .120 | | |

*Represents only one season of data (1978/79)

35.7 g. These fish had increased their weight by a factor of 2.3 in four years. The growth of Monterey anchovies shows significant seasonal fluctuations. During the fall to mid-winter months, prior to the peak spawning period, there is a loss in mean weight, which is more pronounced in fish three years and older. Growth appears to be erratic from mid-winter to spring, and finally, from spring to fall, there is a marked spurt in growth.

There are differences in the growth in weight of anchovies in the two areas. At the time they entered the fishery, the anchovies landed in Monterey were 4.4 g heavier than those landed in San Pedro. This difference in weight had increased to 12.5 g by age four. In addition, the anchovies landed in Monterey have different seasonal fluctuations from those landed in San Pedro.

Jack mackerel increased their weight by a factor of 7.6 over a period of four years. Young-of-the-year fish entered the fishery at a mean weight of 42 g and reached a mean weight of 319 g by the time they were four years old (Figure 7, Table 7). Jack mackerel have a moderate rate of growth with little seasonality until age three. For fish three years and older, there is an

TABLE 6
**Number *(N)*, Mean Weight g *($\bar{X}$)*, and Percentage of Fish by Age and Month for Northern Anchovy Sampled in Monterey.**

| AGE | | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | SUBTOTAL | % BY AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | $N$ | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 45 | 46 | 252 | 11 | 4 | 364 | .076 |
| | $\bar{X}$ | 0 | 0 | 0 | 0 | 0 | 0 | 15.7 | 15.3 | 15.7 | 15.8 | 13.4 | 18.2 | | |
| 1 | $N$ | 1 | 28 | 19 | 11 | 0 | 0 | 175 | 228 | 240 | 112 | 15 | 21 | 850 | .177 |
| | $\bar{X}$ | 17.1 | 14.3 | 14.9 | 14.2 | 0 | 0 | 21.4 | 23.4 | 22.8 | 20.4 | 21.3 | 20.5 | | |
| 2 | $N$ | 7 | 46 | 52 | 14 | 0 | 0 | 122 | 275 | 279 | 152 | 65 | 60 | 1072 | .223 |
| | $\bar{X}$ | 21.1 | 18.9 | 20.9 | 21.3 | 0 | 0 | 27.2 | 29.0 | 26.3 | 25.7 | 23.9 | 23.7 | | |
| 3 | $N$ | 18 | 54 | 61 | 17 | 0 | 0 | 135 | 246 | 339 | 234 | 98 | 100 | 1302 | .271 |
| | $\bar{X}$ | 26.0 | 21.1 | 25.7 | 25.9 | 0 | 0 | 31.5 | 34.3 | 30.3 | 28.4 | 26.1 | 26.8 | | |
| 4 | $N$ | 22 | 55 | 47 | 1 | 0 | 0 | 71 | 141 | 163 | 153 | 72 | 67 | 792 | .165 |
| | $\bar{X}$ | 32.1 | 33.0 | 34.0 | 24.1 | 0 | 0 | 36.1 | 37.9 | 33.6 | 31.1 | 28.6 | 30.8 | | |
| 5 | $N$ | 23 | 14 | 29 | 2 | 0 | 0 | 28 | 78 | 53 | 63 | 24 | 22 | 336 | .070 |
| | $\bar{X}$ | 36.6 | 32.4 | 35.3 | 28.1 | 0 | 0 | 39.2 | 40.4 | 36.4 | 34.5 | 30.6 | 34.0 | | |
| 6 | $N$ | 7 | 9 | 20 | 0 | 0 | 0 | 4 | 24 | 5 | 6 | 5 | 1 | 81 | .017 |
| | $\bar{X}$ | 37.6 | 38.2 | 38.1 | 0 | 0 | 0 | 47.0 | 46.2 | 38.4 | 38.5 | 35.5 | 37.9 | | |
| 7 | $N$ | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 10 | .002 |
| | $\bar{X}$ | 0 | 0 | 38.2 | 0 | 0 | 0 | 0 | 52.8 | 0 | 46.2 | 0 | 0 | | |
| SUBTOTAL | | 78 | 206 | 233 | 45 | 0 | 0 | 541 | 1040 | 1125 | 974 | 290 | 275 | 4807 | |
| % BY MONTH | | .016 | .043 | .048 | .009 | 0 | 0 | .113 | .216 | .234 | .203 | .060 | .057 | | |

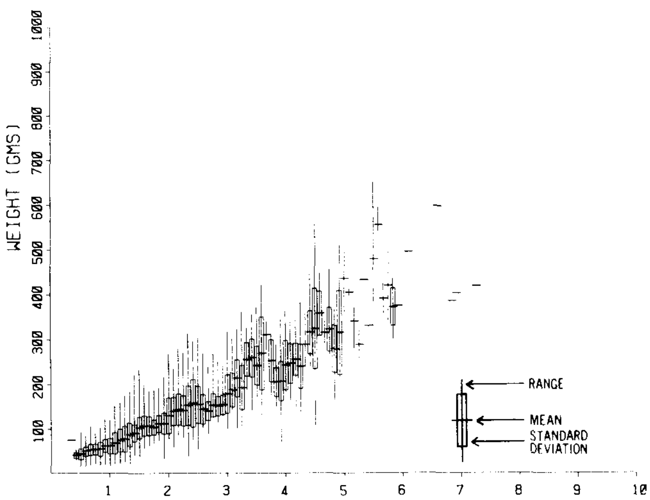


Figure 7. Monthly distribution (May-April) of the weight of jack mackerel in samples taken from San Pedro (20,068 fish, 1966-70).

increase in mean weight from late spring to late fall, followed by a loss in mean weight from winter to early spring.

Pacific mackerel entered the fishery at a mean weight of 102 g (Figure 8, Table 8). By age four, they had increased to a mean weight of 654 g, which represents an increase of 6.4 times the starting weight during this four-year period. Pacific mackerel, age groups 0-2, show a high growth rate and marked seasonal fluctuations. In these fish, a spurt of growth occurs from the spring to mid-winter months, followed by a small loss in weight during the mid-winter to spring months. For older fish (ages 3+), the number of fish per month was not sufficient to show a distinct seasonal pattern.

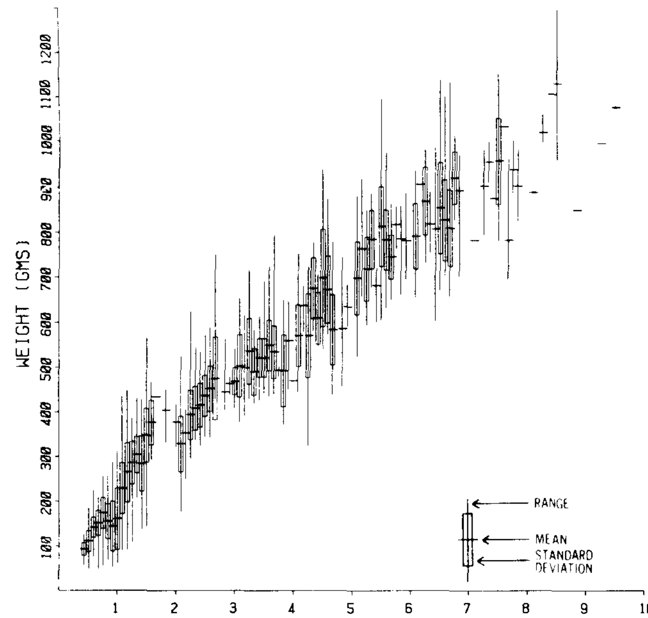


Figure 8. Monthly distribution (May-April) of the weight of Pacific mackerel in samples taken from San Pedro (6,054 fish, 1962-73).

There are several differences between the growth in weight of Pacific mackerel and jack mackerel. Pacific mackerel grow faster than jack mackerel, especially during their first few years. They enter into the fishery at a heavier weight (102 g) than jack mackerel (42 g) and seem to maintain this heavier weight overall. Pacific mackerel show seasonality in growth im-

TABLE 7

**Number *(N)*, Mean Weight g ($\bar{X}$), and Percentage of Fish by Age and Month for Jack Mackerel Sampled in San Pedro.**

| AGE | | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | SUBTOTAL | % BY AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | $N$ | 0 | 0 | 0 | 1 | 16 | 224 | 274 | 629 | 770 | 809 | 1507 | 1219 | 5449 | .272 |
| | $\bar{X}$ | 0 | 0 | 0 | 74 | 40 | 43 | 49 | 52 | 53 | 54 | 61 | 61 | | |
| 1 | $N$ | 1560 | 1868 | 904 | 1091 | 1175 | 1144 | 687 | 742 | 171 | 253 | 227 | 135 | 9957 | .496 |
| | $\bar{X}$ | 67 | 73 | 76 | 86 | 90 | 102 | 106 | 106 | 103 | 111 | 111 | 129 | | |
| 2 | $N$ | 589 | 506 | 351 | 200 | 168 | 427 | 264 | 243 | 100 | 134 | 199 | 144 | 3325 | .166 |
| | $\bar{X}$ | 139 | 143 | 140 | 152 | 157 | 154 | 143 | 139 | 152 | 150 | 153 | 177 | | |
| 3 | $N$ | 218 | 205 | 123 | 29 | 57 | 184 | 29 | 8 | 26 | 60 | 41 | 22 | 1002 | .050 |
| | $\bar{X}$ | 187 | 214 | 192 | 255 | 259 | 241 | 269 | 310 | 252 | 204 | 206 | 242 | | |
| 4 | $N$ | 43 | 61 | 28 | 3 | 33 | 48 | 10 | 5 | 18 | 17 | 14 | 7 | 287 | .014 |
| | $\bar{X}$ | 246 | 255 | 239 | 288 | 315 | 323 | 357 | 314 | 322 | 278 | 315 | 434 | | |
| 5 | $N$ | 3 | 4 | 5 | 1 | 1 | 8 | 4 | 2 | 2 | 12 | 1 | 0 | 43 | .002 |
| | $\bar{X}$ | 404 | 340 | 288 | 431 | 330 | 478 | 554 | 390 | 419 | 371 | 374 | 0 | | |
| 6 | $N$ | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 4 | .0002 |
| | $\bar{X}$ | 494 | 0 | 0 | 0 | 0 | 0 | 596 | 0 | 0 | 385 | 402 | 0 | | |
| 7 | $N$ | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | .00005 |
| | $\bar{X}$ | 0 | 0 | 418 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| SUBTOTAL | | 2414 | 2644 | 1412 | 1325 | 1450 | 2035 | 1269 | 1629 | 1087 | 1286 | 1990 | 1527 | 20068 | |
| % BY MONTH | | .120 | .132 | .070 | .066 | .072 | .101 | .063 | .081 | .054 | .064 | .099 | .076 | | |

TABLE 8
**Number *(N)*, Mean Weight g *($\bar{X}$)*, and Percentage of Fish by Age and Month for Pacific Mackerel Sampled in San Pedro.**

| AGE | | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | SUBTOTAL | % BY AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | $N$ | 0 | 0 | 0 | 0 | 150 | 720 | 576 | 369 | 329 | 260 | 138 | 150 | 2692 | .445 |
| | $\bar{X}$ | 0 | 0 | 0 | 0 | 93 | 111 | 141 | 151 | 174 | 155 | 144 | 161 | | |
| 1 | $N$ | 685 | 305 | 231 | 199 | 153 | 115 | 51 | 1 | 0 | 6 | 0 | 5 | 1751 | .289 |
| | $\bar{X}$ | 229 | 265 | 286 | 304 | 284 | 348 | 377 | 434 | 0 | 404 | 0 | 377 | | |
| 2 | $N$ | 41 | 9 | 78 | 32 | 32 | 110 | 41 | 11 | 0 | 6 | 6 | 24 | 390 | .064 |
| | $\bar{X}$ | 329 | 353 | 394 | 408 | 415 | 436 | 452 | 474 | 0 | 444 | 463 | 468 | | |
| 3 | $N$ | 17 | 8 | 20 | 13 | 50 | 114 | 63 | 39 | 4 | 15 | 9 | 1 | 353 | .058 |
| | $\bar{X}$ | 502 | 499 | 536 | 490 | 521 | 521 | 549 | 534 | 493 | 492 | 559 | 470 | | |
| 4 | $N$ | 47 | 6 | 12 | 13 | 11 | 38 | 22 | 23 | 0 | 4 | 7 | 0 | 183 | .030 |
| | $\bar{X}$ | 570 | 637 | 570 | 675 | 609 | 698 | 672 | 583 | 0 | 585 | 634 | 0 | | |
| 5 | $N$ | 64 | 6 | 13 | 21 | 8 | 131 | 52 | 66 | 4 | 4 | 8 | 0 | 377 | .062 |
| | $\bar{X}$ | 698 | 763 | 718 | 784 | 681 | 813 | 783 | 745 | 817 | 785 | 781 | 0 | | |
| 6 | $N$ | 23 | 1 | 13 | 5 | 7 | 87 | 32 | 52 | 18 | 9 | 0 | 0 | 247 | .041 |
| | $\bar{X}$ | 791 | 907 | 869 | 818 | 807 | 854 | 827 | 809 | 922 | 893 | 0 | 0 | | |
| 7 | $N$ | 1 | 0 | 7 | 2 | 1 | 16 | 1 | 9 | 5 | 2 | 0 | 0 | 44 | .007 |
| | $\bar{X}$ | 782 | 0 | 903 | 957 | 875 | 959 | 1036 | 782 | 939 | 904 | 0 | 0 | | |
| 8 | $N$ | 1 | 0 | 3 | 0 | 1 | 8 | 0 | 0 | 0 | 1 | 0 | 0 | 14 | .002 |
| | $\bar{X}$ | 889 | 0 | 1023 | 0 | 1109 | 1133 | 0 | 0 | 0 | 849 | 0 | 0 | | |
| 9 | $N$ | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | .0005 |
| | $\bar{X}$ | 0 | 0 | 998 | 0 | 0 | 1080 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| SUBTOTAL | | 879 | 335 | 378 | 285 | 413 | 1341 | 838 | 570 | 360 | 307 | 168 | 180 | 6054 | |
| % BY MONTH | | .145 | .055 | .062 | .047 | .068 | .222 | .138 | .094 | .059 | .051 | .028 | .030 | | |

mediately after entering the fishery, whereas jack mackerel show little seasonality until age three.

### *Proportion of Growth in Weight by Month*

Growth in weight of northern anchovy is highly seasonal, and the pattern of growth differs between the fish landed at San Pedro and those landed at Monterey. The San Pedro anchovies achieved nearly all of their annual increase in weight during the period of February to May (Figure 9A, Table 9). However, the pattern of growth is somewhat different in young and old fish. Younger fish, age groups 0-1, showed a slight decrease in weight from September to February, while older fish, ages 2+, showed a small weight gain. The young fish grew rapidly from February to May and essentially maintained their weight until September, while older fish grew rapidly from February to April, but lost about half of this increase in weight by September. At the end of a year, the San Pedro anchovies had an 18% increase in weight. However, the younger fish exhibited much more growth than the older fish (24% versus 8%). In the Monterey fishery, anchovies lost weight from September to May, and gained weight May to September (Figure 9B, Table 9). The younger fish, age groups 0–1, showed a similar seasonal pattern, but they had a more rapid growth rate from May to September. (Notice that there were few young fish sampled from December to May.) The older fish, ages 2+, showed a marked weight loss (23%) from September to De-

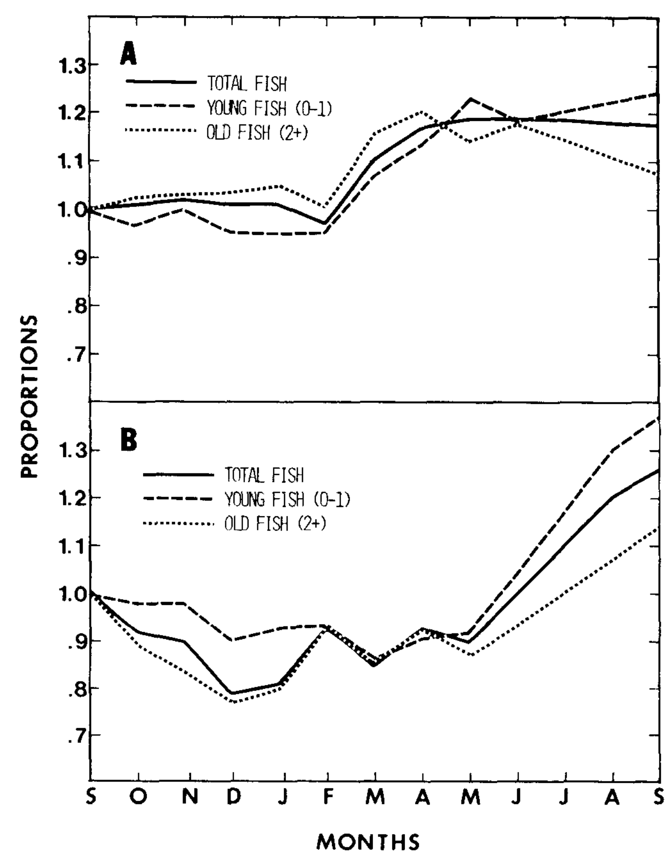


Figure 9. Proportion of growth in weight by month for (A) northern anchovy sampled in San Pedro (no data for July and August) and (B) northern anchovy sampled in Monterey (no data for June and July).

TABLE 9
**Seasonal Variation in the Weight* of Northern Anchovy, Jack Mackerel, and Pacific Mackerel.**

| | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| San Pedro anchovy | | | | | | | | | | | | | |
| Young (0-1) | 1.00 | .97 | 1.00 | .95 | .95 | .95 | 1.07 | 1.13 | 1.23 | 1.19 | | | 1.24 |
| Old (2+) | 1.00 | 1.02 | 1.03 | 1.03 | 1.05 | 1.00 | 1.16 | 1.20 | 1.14 | 1.18 | | | 1.08 |
| Total | 1.00 | 1.01 | 1.02 | 1.01 | 1.01 | .97 | 1.10 | 1.17 | 1.19 | 1.19 | | | 1.18 |
| Monterey anchovy | | | | | | | | | | | | | |
| Young (0-1) | 1.00 | .98 | .98 | .90 | .93 | .93 | .86 | .91 | .92 | | | 1.30 | 1.37 |
| Old (2+) | 1.00 | .89 | .84 | .77 | .80 | .94 | .85 | .93 | .87 | | | 1.07 | 1.14 |
| Total | 1.00 | .92 | .90 | .79 | .81 | .93 | .85 | .93 | .90 | | | 1.20 | 1.26 |
| Jack mackerel | | | | | | | | | | | | | |
| Young (0-2) | 1.00 | 1.09 | 1.13 | 1.18 | 1.26 | 1.28 | 1.43 | 1.48 | 1.60 | 1.74 | 1.75 | 2.07 | 2.16 |
| Old (3+) | 1.00 | .97 | 1.12 | 1.13 | 1.01 | .85 | .85 | 1.04 | .98 | .99 | .92 | 1.18 | 1.21 |
| Total | 1.00 | 1.08 | 1.13 | 1.18 | 1.25 | 1.25 | 1.42 | 1.47 | 1.59 | 1.72 | 1.73 | 2.07 | 2.14 |
| Pacific mackerel | | | | | | | | | | | | | |
| Young (0-1) | 1.00 | 1.20 | 1.50 | 1.62 | 1.86 | 1.66 | 1.53 | 1.72 | 2.39 | 2.80 | 2.65 | 3.02 | 2.78 |
| Old (2+) | 1.00 | 1.09 | 1.09 | 1.03 | 1.14 | 1.02 | 1.09 | 1.12 | 1.14 | 1.23 | 1.20 | 1.25 | 1.22 |
| Total | 1.00 | 1.16 | 1.40 | 1.42 | 1.81 | 1.58 | 1.47 | 1.63 | 2.17 | 2.70 | 2.39 | 2.68 | 2.32 |

*Expressed as a proportion of the September mean weight.

cember, much of which was regained between December and February; little change in weight occurred during the February to May period. All of their net annual increase in weight occurred from May to the following September. At the end of a year, the anchovies landed in Monterey showed a 26% increase in weight; young fish showed a 37% increase while the older fish showed a 14% increase. A comparison of the growth patterns of anchovies in the two regions shows that San Pedro anchovies increased in net weight from February to May and the Monterey anchovies increased in net weight from May to September. Other than the increase in weight that occurred from February to May, the anchovies in the San Pedro fishery showed little variation in weight. In the Monterey fishery, however, anchovies showed a loss in weight from September to May. At the end of a year, young anchovies at Monterey showed a 54% greater increase in weight than young anchovies at San Pedro; older anchovies at Monterey showed a 75% greater increase than those at San Pedro.

As previously mentioned, there are considerable differences in the growth patterns of jack and Pacific mackerel; growth is also different in the young and older individuals of both species. The data on these two species are heavily biased toward young fish, and therefore, the growth pattern of combined young and old fish is essentially the same as that for young fish. The ages chosen to represent young and old fish in jack mackerel differ from those chosen in the other two species. The natural break between the steady growth rate of young jack mackerel and the seasonal growth of older jack mackerel occurs between the ages of two and three (Figure 7).

The growth pattern for young jack mackerel, age groups 0–2, shows a steady increase in weight all year long (Figure 10A, Table 9). The older fish, ages 3+, showed an increase in weight from September to December, followed by a loss in weight from December

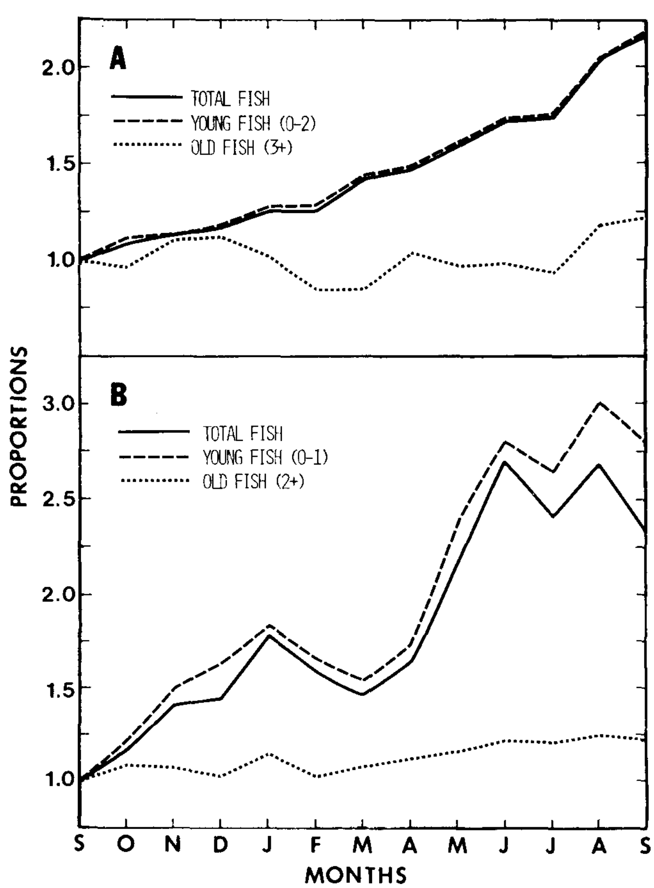


Figure 10. Proportion of growth in weight by month for (A) jack mackerel sampled in San Pedro and (B) Pacific mackerel sampled in San Pedro.

to February/March. There is little net growth from February to July. Essentially all of the net increase in weight occurs from July to September. At the end of a year, the older fish showed a 21% net increase in weight, while the younger fish showed a 116% net increase in weight.

The growth pattern for young Pacific mackerel, age groups 0-1, shows tremendous growth all year long except for a small loss in weight from January to March (Figure 10B, Table 9). The older fish, ages 2+, showed a general increase in weight from September to January. Then there is a loss in weight during late winter followed by a period of steady growth from spring to the following September. Young Pacific mackerel showed an annual net increase in weight of 178%, while the older fish showed an annual net increase of 22%. The seasonal growth patterns of jack mackerel and Pacific mackerel show that both young and old Pacific mackerel and older jack mackerel have a loss in weight from approximately winter to spring. Both young jack mackerel and young Pacific mackerel grow very quickly, but the annual growth of young Pacific mackerel is 53% greater than young jack mackerel. Older Pacific mackerel showed a 5% greater annual increase in weight than older jack mackerel.

## DISCUSSION

The data presented for the seasonal distributions of lengths show that growth in length is relatively free of seasonal variation in the California stocks of northern anchovy, jack mackerel, and Pacific mackerel. The exceptions to this occur in jack mackerel older than three years, and in young-of-the-year and yearling Pacific mackerel, where growth in length is more rapid in the spring and summer than in the winter. Other than these minor exceptions, growth in length of these species is adequately described by von Bertalanffy growth equations. The situation for growth in weight is another matter; seasonal variation in growth is very large and can vary with age and geographical area.

Anchovies in California gain nearly all of their annual net increase in weight during a short period of the year. In southern California, growth begins in February and extends until April or May. Young fish essentially maintain this same weight until the next February, while older fish lose more than half of the weight gained by September. Anchovies in central California achieve their annual net increase in weight three to four months later than those in southern California. The net increase in weight starts in the period from May to July and extends to September. During the next winter, much or all of this increase will be lost, depending on the age of the fish. It should be noted that anchovies landed in San Pedro are from the central stock, whereas those landed in Monterey are probably from both the central and northern stocks (Vrooman et al. 1981).

Jack mackerel less than three years of age show little seasonality in growth in weight, whereas jack mackerel older than three years and post-recruit Pacific mackerel have weight losses during the late winter or early spring and weight gains during the rest of the year. The most rapid increase in weight in Pacific mackerel occurs when they are one year old, during the spring and summer. In jack mackerel the most rapid increase in weight occurs when they are three years old, also during the spring and summer. In jack mackerel this period marks the transition from a steady increase in weight to seasonal increases. In both Pacific and jack mackerel this rapid increase in weight occurs when the fish are about 250 mm in fork length. It appears that at this length there is a change in some life history feature, possibly in feeding habits, which results in a rapid increase in weight.

One of the major uses of data on the growth of commercially important fishes is the application of this information to fisheries management. The principal relationship of interest is that between the age and the total weight of an individual cohort. If fishing effort is large, it is theoretically possible to maximize yields by protecting the cohort from harvesting as long as the total weight of the cohort is increasing. The more quickly the cohort is gaining weight the more likely are there to be economic benefits from protection of younger fish. The relative advantage or disadvantage of a size limit can be readily observed by comparing the observed growth in weight with the growth that would be necessary to maintain a constant cohort weight.

The annual mortality rate for nothern anchovy is about 66% per year ($Z$ = 1.1, MacCall 1974). Without a fishery the number of fish in a cohort would be expected to decline annually by two-thirds. In order to maintain a constant cohort weight, anchovies would have to triple their weight each year; as shown earlier, anchovies do not triple their weight even in four years. The largest annual anchovy growth rate observed in our study was the 55% increase in weight achieved by age group zero fish at San Pedro. This indicates that the growth rate of post-recruit anchovies is not sufficient to maintain the cohort biomass. If younger fish were not protected by regulations, the age composition of the catch would be expected to approximate that of the population. That is, the numbers of fish in each succeeding age group would decline by two-thirds or more (depending on the size of the fishery). The age composition of northern anchovy in the San Pedro fishery does not approach this decay rate until the transition from age three to four. The observed proportions of age groups zero to four (0.03, 0.26, 0.33, 0.24, 0.09) indicate that the present regulations provide almost total protection for young-of-the-year fish, considerable protection for yearlings, and some protection for two-year-old-fish.

The data presented in this study suggest that, in anchovy, maximum cohort weight occurs before recruitment to the fishery. Therefore, the size limit provides protection to cohorts for at least two years beyond the time they achieve maximum biomass. Small pelagic fishes are subject to recruitment overfishing (Cushing 1975), and in the absence of any other controls a size limit could be a desirable regulation for preventing this. However, when protection against recruitment overfishing is provided by an annual quota based on the spawning stock size, as in the case with the California anchovy fishery, the principal effect of a size limit is to increase the total effort and costs necessary to harvest the quota.

The use of growth information as a tool for fisheries management of jack mackerel is affected by the lack of good estimates for their natural mortality rate. It is also influenced by the fact that jack mackerel are increasingly unavailable to the fishery after age two. If, for want of a better estimate, it is assumed that young jack mackerel (age 0-2) have a mortality rate equal to that of Pacific mackeral ($M = 0.5$, Parrish and MacCall 1978), in the absence of a fishery, about 40% of the fish will die each year. To maintain a constant cohort weight, young jack mackerel would have to gain about 67% of their weight each year. In their first year in the fishery, age group zero in September to age group one in September, jack mackerel increased in weight by about 125%. In their second and third years in the fishery the increase was about 74% and 64%. This growth rate implies that it might be possible to increase the yields of jack mackerel by protecting fish less than one year old. However, before it could be determined if a size limit would be economically beneficial, it would be necessary to have a good estimate of natural mortality. It would also be necessary to evaluate whether the probability of capturing jack mackerel, before they become unavailable to the purse-seine fishery, is high enough to warrant protection of young fish.

Pacific mackerel have the fastest growth of the three species discussed. They more than triple their weight during their first year in the fishery. In their second and third years in the fishery they increase their weight by 46% and 26%. The annual mortality rate of Pacific mackerel is about 40% per year ($M = 0.5$, Parrish and MacCall 1978). Maximum cohort weight occurs about two years after recruitment. However, after the fish have been in the fishery for one year, the cohort biomass does not increase greatly (i.e. growth at 46% and mortality at 40%). Growth is particularly quick during the yearling spring and summer. A size limit that would protect Pacific mackerel until they have completed this growth spurt would be expected to increase yields.

The growth patterns of northern anchovy, jack mackerel, and Pacific mackerel described in this study suggest different management strategies. Maximum cohort biomass occurs before the anchovy enter the purse-seine fishery. Therefore, growth overfishing is unlikely to occur in this species even without a size limit or mesh-size limitation. Pacific mackerel are subject to growth overfishing, and the question is as yet unresolved for jack mackerel.

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## LITERATURE CITED

Alhstrom, E.H. 1966. Distribution and abundance of sardine and anchovy larvae in the California Current Region off California. U.S. Fish Wild. Serv., Spec. Sci. Rept.-Fish. (534):1–71.

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

Clark, F.N., and J.B. Phillips. 1952. The northern anchovy *(Engraulis mordax mordax)* in the California fishery. Calif. Fish Game 38(2):189–207.

Collins, R.A. 1969. Size and age composition of northern anchovies *(Engraulis mordax)* in the California anchovy reduction fishery for the 1965–66, 1966–67 and 1967–68 seasons. Calif. Dep. Fish Game, Fish. Bull. (147):56–74.

Collins, R.A., and J.D. Spratt. 1969. Age determination of northern anchovies, *Engraulis mordax*, from otoliths. Calif. Dep. Fish Game, Fish. Bull. 147:39–55.

Cushing, D.H. 1975. Marine ecology and fisheries. Cambridge University Press, Cambridge, 278 p.

Fitch, J.E. 1951. Age composition of the southern California catch of Pacific mackerel 1939–40 through 1950–51. Calif. Dep. Fish Game, Fish Bull. 83:1–73.

Knaggs, E.H., and R.H. Parrish. 1973. Maturation and growth of Pacific mackerel, *Scomber japonicus* Houttuyn. Calif. Fish Game 59(2): 114–120.

MacCall, A.D. 1974. The mortality rate of *Engraulis mordax* in southern California. Calif. Coop. Oceanic Fish. Invest. Rep. 17:131–135.

Parrish, R.H., and A.D. MacCall. 1978. Climatic variation in the Pacific mackerel fishery. Calif. Dep. Fish Game, Fish. Bull. 167:1–110.

Spratt, J.D. 1975. Growth rate of the northern anchovy, *Engraulis mordax*, in southern California waters, calculated from otoliths. Calif. Fish Game 61(3):116–125.

Vrooman, A.M., P.A. Paloma, and J.R. Zweifel. 1981. Electrophoretic, morphometric, and meristic studies of subpopulations of northern anchovy, *Engraulis mordax*. Calif. Fish Game 67(1):39–51.

Wine, V.L., and E.H. Knaggs. 1975. Maturation and growth of jack mackerel, *Trachurus symmetricus*. Calif. Dep. Fish Game, Mar. Res. Tech. Rept. No. 32, 26 p.