THE MORTALITY RATE OF *ENGRAULIS MORDAX* IN SOUTHERN CALIFORNIA[1]

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ABSTRACT

The annual mortality rate for the northern anchovy, *Engraulis mordax*, is estimated to be 66.5% in southern California waters, although the mortality rate increases sharply for older fish. A method for evaluating recruitment regularity and age constancy of mortality is presented.

INTRODUCTION

With the rise of a commercial reduction fishery exploiting the northern anchovy, *Engraulis mordax,* in California waters, questions have arisen concerning the proper management of this fishery. Many of these questions remain without concrete answers due to lack of basic knowledge regarding population parameters. In an effort to fill an important gap, I have developed an estimate for instantaneous and annual natural mortality rates of the adult northern anchovy population in southern California waters.

Three previous estimates of the mortality rate for the northern anchovy have been made by various workers, but there was little agreement among them. Beverton (1963) gave 0.9 as an estimate of the apparent instantaneous total mortality rate (Z). He states in the same paper that there is a strong tendency for Z to increase with age in the case of short-lived engraulid fishes. Beverton used the method of calculating mortality rates proposed by Heincke (1913), which was demonstrated by Robson and Chapman (1961) to underestimate the mortality rate when there is higher apparent survival in the younger age groups used in the calculation. Thus Beverton's estimate is probably low.

Bayliff (1967) arrived at a well documented estimate of $Z = 1.7$, using the catch curve analysis proposed by Chapman and Robson (1960); however, his choice of data led to erratic results. He used catch data from the live bait fishery, which was fraught with sampling errors (Crooke, 1969). The live bait catch is also subject to a strong bias: live bait fishermen consciously avoid taking large anchovies, since they are less desirable for bait than smaller anchovies. Bayliff also erred in lumping data from both central and southern California in arriving at his estimate. Firstly, there is good evidence that catch data from north of Point Conception are not fit for catch curve analysis due to extreme fluctuations in year class strength (Ahlstrom, 1956; Baxter, 1967), partially accounting for the lack of consistency in Bayliff's choice for age at full recruitment. Secondly, anchovies north of Point Conception probably are not characterized by the same population parameters as anchovies in southern California. In Bayliff's tabulation of individual mortality estimates from his various sources of data, he lists the reciprocal of the maximum age (T_{max}) of the fish in each source. The fish from north of Point Conception appear to be more long-lived than their southern counterparts which strongly suggests a lower mortality rate according to the relation between Z and T_{max} discussed in the same paper, as well as by Beverton (1963). Some other parameters, such as length-at-age appear to differ considerably between central and southern California anchovies (Collins, 1969).

Schaefer (1967) published a third estimate of $Z = 1.1$, however, he failed to document his work so little can be said concerning the assumptions he made.

All three estimates were based on the same group of data: Miller, et al. (1955), and Miller and Wolf (1958). Bayliff used one additional catch curve, obtained from Clark and Phillips (1952). All three papers considered the estimated total mortality rate (Z) to be a reasonably close approximation to the natural mortality rate (a) due to the low fishing pressure on the stock.

MATERIALS

Catch data for this study were gathered by the California Department of Fish and Game Pelagic Fish Investigations Sea Survey Project between October 1966 and April 1971 (Mais, 1969a, b, 1971a, b, c, 1972). Standard sampling gear was a 50 foot midwater trawl (occasionally replaced by a smaller 30 foot version when the larger net was damaged) towed for 20 minutes between 5 and 20 fathoms depending on sea conditions and depth of fish schools. Tows were generally made during hours of darkness, and were geographically distributed in an attempt to fully represent both inshore and offshore waters. When anchovies were taken, a random sample of ten fish was aged using otoliths (Collins and Spratt, 1969), and age frequency of combined samples for a single cruise was called the catch curve for that cruise. Catch curves were obtained from 16 cruises in southern California waters.

I obtained another independent set of catch curves from records of the anchovy reduction fishery catch at San Pedro (Hardwick, 1969; Collins, 1969, 1971; Spratt, 1972, 1973). The commercial fleet tends to operate near San Pedro, with most fishing effort expended in the San Pedro Channel. Most catches are made over deep water due to legal regulations prohibiting inshore fishing. Since the area sampled is very localized, catch curves are highly affected by migrations of fish. For the purpose of sampling the entire population, these samples depend on movement

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of fish into and out of the sampling area. Various subdivisions of seasonal catch were tried, but any division smaller than the entire seasonal catch resulted in a loss in consistency of age structure, so each season's catch was treated as a whole. Unfortunately there were almost no fish taken for reduction in southern California during the 1967–1968 fishing season due to low fish prices (Hardwick, 1969), creating a discontinuity in my data.

METHODS

The apparent instantaneous mortality rate (Z) was estimated by applying the catch curve analysis proposed by Chapman and Robson (Chapman and Robson, 1960; Robson and Chapman, 1961). This method was shown to yield an unbiased estimate of the annual survival rate and was proven to be subject to the smallest sampling error of the various methods that can be devised.

The annual survival rate(s) is estimated by:

$$s = \frac{T}{n + T - 1}$$

and the variance about s is estimated by

$$\sigma_s^2 = \frac{s(1-s)^2}{n}$$

with $n = N_0 + N_1 + N_2 + N_3 + \ldots + N_K + \ldots$

$T = N_1 + 2N_2 + 3N_3 + \ldots + KN_K + \ldots$

where:

K = coded age, where $K = 0$ for the youngest age group fully vulnerable to the sampling, assuming all older ages are completely vulnerable.

N_K = number of fish of age K present in the catch.

Validity of catch curve estimations of mortality rates by the method of Chapman and Robson (1960) depends on three conditions: (1) Year classes must not vary in strengtgh, (2) survival must be constant over all ages used in the analysis, and (3) survival must not vary on a seasonal or yearly basis. It is highly unlikely that all three provisions are met in a real situation. However, if violations are small, the mortality rate estimate can be shown to be a good approximation.

A convenient method for determining variability of recruitment as well as changes in mortality rate with age (i.e. assumptions 1 and 2) is analysis by logarithms of ratios of abundance of successive year classes. This method follows from a model based on the usual formula for number of fish surviving a source of mortality over a period of time:

$$N_t = N_o e^{-Z(t-t_o)} \tag{1}$$

where N_t = number of fish alive at time t.

N_o = number of fish alive at time t_o.

Z = instantaneous coefficient of mortality from all causes.

This equation can be rewritten as:

$$N_{i,t} = R_i e^{-ZT}$$

where the new symbols are:

$N_{i,t}$ = number of fish belonging to year class i which are alive at time t.

R_i = Recruitment: number of fish belonging to year class i which were alive at a standard age, at which the fish became subject to the mortality rate described by Z.

$T = t - t_o$, for simplicity, where t is the time of estimation of $N_{i,t}$, and t_o is the time at which $N_{i,t} = R_i$, a standard date in the lifetime of every year class.

Individual year classes will occur in a catch with frequencies proportional to their abundances once they become fully available to the sampling gear. Moreover, the ratio of frequencies of two year classes in a catch will approximate the ratio of numbers of fish in those groups residing in the sampling area. Thus the catch ratio, $C_{i,t}$ will be defined as:

$$C_{i,t} = \frac{n_{i+1,t}}{n_{i,t}} = \frac{N_{i+1,t}}{N_{i,t}} \tag{2}$$

with: $n_{i,t}$ = number of fish of year class i appearing in a catch at time t.

And, according to (2),

$$C_{i,t} = \frac{R_{i+1}e^{-Z(T-1)}}{R_i e^{-ZT}} \tag{3}$$

which assumes Z is constant.

However, if Z varies with age, the equation must assume a form requiring integration. The formulation can be simplified for practical purposes by letting Z vary as a step function of age. The mortality rate for each age interval K will be called Z_K. Now (3) can be revised as:

$$C_{i,t} = \frac{R_{i+1}e^{-(Z_1+Z_2+\ldots+Z_{K-1})}}{R_i e^{-(Z_1+Z_2+\ldots+Z_{K-1}+Z_K)}}$$

with $K = t - i$. Finally, taking logarithms of both sides, the duplicate Z_K values cancel leaving:

$$\ln C_{i,t} = \ln R_{i+1} - \ln R_i + Z_K$$

or:

$$\ln C_{i,t} = \ln \frac{R_{i+1}}{R_i} + Z_K \tag{4}$$

The logarithm of the catch ratio of two year classes will be equal to the mortality rate of the older year class during the previous year plus a constant which is the logarithm of the ratio of recruitment strengths for the two year classes under consideration. Since ln $C_{i,t}$ is undefined when either n_i or n_{i+1} is 0, catch ratios containing values of 0 are simply discarded.

If ln $C_{i,t}$ is plotted with respect to age K and the points for each year class i are joined, the behavior of Z_K and R_{i+1}/R_i can be observed. The slope of the line will indicate the rate of increase or decrease in Z_K. Thus a horizontal line would indicate no change Z or a constant mortality rate over all ages. Similarly, the constant factor ln (R_{i+1}/R_i) will displace the line upwards or downwards depending on whether the younger year class was recruited in greater or smaller numbers than the older year class. Constant recruitment strength would give little variation in vertical displacement so plots of various year classes would tend to coincide. In short, assumption 1 (constant year class strengths) will be tested by observing the degree to which the lines are coincidental, and assumption 2 (constant mortality rates for all ages) will be tested by observing the degree to which the lines depart from the horizontal. Violations of assumption 3 (constant mortality from season to season) cannot be tested by this model except to the extent to which variable mortality, along with other factors, will affect the degree to which plots resemble each other in shape.

A single value for Z, ignoring age differences, was obtained from the annual survival by:

$$Z = -\ln s - \frac{(n-1)\ (n-2)}{n(T+1)\ (n+T-1)}$$

which is no longer an unbiased estimate (Chapman and Robson, 1960), but the extent of bias is very small.

Instantaneous fishing mortality (F) was calculated using the catch equation:

$$C = P\frac{F}{Z}(1-s)$$

or solving for F:

$$F = \frac{CZ}{P(1-s)} \qquad (5)$$

where: C = annual harvest

P = recruited population

with the simplifying assumption that C and P have the same age distribution. Instantaneous natural mortality (M) is then the remaining portion of Z:

$$M = Z - F$$

In terms of annual fishing mortality m and annual natural mortality n, F and M are substituted respectively for Z in (1) and the time interval is set at one year. Annual mortality is then the ratio of N_t to N_o. Finally it should be noted that annual mortality rates m and n will not superficially add up to the total mortality rate a, due to interactions between m and n. Letting a equal the total annual mortality rate $(1 - s)$:

$$a = m + n - mn$$

RESULTS

The best estimate of Z is 1.09 (Table 1) based on combined results from sixteen Sea Survey cruises. The estimated annual mortality rate a of anchovies in southern California waters is 66.5%, with a pooled standard error of 7%. For comparison, mortality estimates based on commercial landing data (Table 2) indicate Z is 1.16 and a is 68% with a pooled standard error of 19%, based on between-sample variance alone. The within-sample variance estimator used in the Chapman and Robson (Robson and Chapman, 1961) method gives unrealistically small estimated standard errors due to large sample sizes in commercial landing data.

TABLE 1

Mortality Rate Estimates Based on Sea Survey Data

Cruise	Date	Number sampled*	Annual mortality rate (a)	Standard error of a	Instantaneous mortality rate (Z)
71A7	9-13-71 to 9-28-71	162	.66	.030	1.06
71A3	4- 7-71 to 4-30-71	92	.61	.040	.94
71A1	2- 1-71 to 2-19-71	85	.71	.042	1.20
70A7	9-28-70 to 10-22-70	111	.67	.037	1.11
70A4	5-22-70 to 6-14-70	145	.73	.032	1.30
70A1	1-22-70 to 2-18-70	92	.75	.040	1.35
69A11	11-10-69 to 12- 8-69	127	.72	.034	1.26
69A8	8- 5-69 to 9- 1-69	146	.68	.032	1.13
69A6	5-12-69 to 6-10-69	105	.66	.038	1.07
68A9	11- 1-68 to 11-25-68	55	.62	.052	.95
68A8	9-12-68 to 10-11-68	128	.69	.034	1.17
68A4	4-18-68 to 5- 7-68	145	.53	.030	.75
68A1	1-18-68 to 2- 6-68	34	.72	.067	1.22
67A8	10-24-67 to 11-12-67	40	.63	.062	.97
67A2	4- 1-67 to 4-20-67	60	.66	.050	1.07
66A8	10- 3-66 to 10-22-66	106	.60	.037	.90
Mean			.665	.068†	1.09

* Number of fish 2 years old or older.
† Standard error from pooled variances.

TABLE 2

Mortality Rate Estimates Based on Commercial Catch Data

Season*	Number sampled†	Annual mortality rate (a)	Instantaneous mortality rate (Z)
1965–1966	533	.65	1.01
1966–1967	1,882	.62	.95
1968–1969	648	.65	1.06
1969–1970	2,688	.79	1.56
1970–1971	3,209	.70	1.20
Mean	--	.68‡	1.16

* Insufficient samples were taken during the 1967–1968 season.
† Number of fish 2 years old or older.
‡ Standard error is .19 based on between-sample variance only.

The logarithmic analysis described in the previous section was applied to data from the two sources. A graph of the commercial catch data (Figure 1) according to equation (4) presents a clear picture because of the periodicity of fishing seasons. Sea Survey data graphed in the same manner (Figure 2) yield a more confusing picture because of irregular spacing of cruises and much smaller size of samples taken. Nevertheless there are many features common to the two independent sets of data. In particular, the 63–64 plot shows a peculiar peak between the third and fifth year in both figures, and the 64–65 plot indicates a sudden rise from a low catch ratio at age 3 to a high catch ratio around ages 4 and 5. These events appear independently in both sampling programs, and strongly indicate a biological cause. Another event of importance is the exceptionally large catch ratio values in 66–67. Collins (1969) indicated the 1967 year class seemed to be exceptionally strong and these data support his observation. The mortality rate estimates obtained using the Chapman and Robson catch curve analysis reach a peak with the influx of the 1967 year class which became 2 years old in the summer of 1969 (Table 1). This is to be expected when a strong year class becomes the youngest age group used in the calculations.

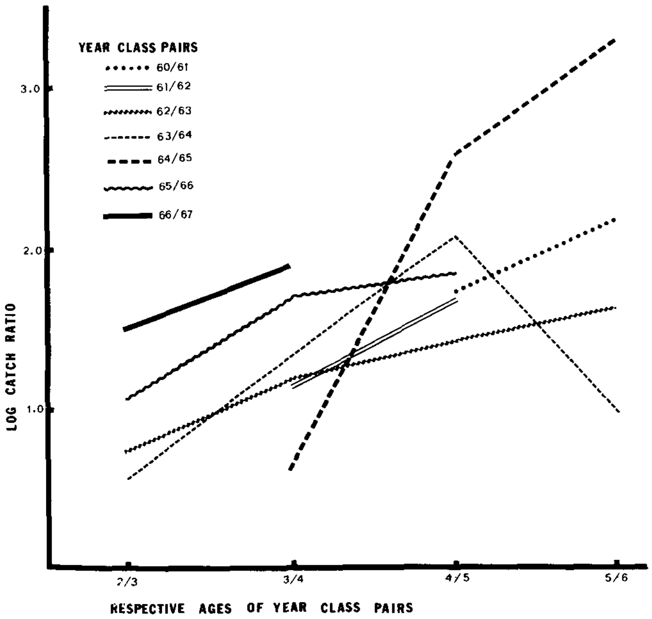

FIGURE 1. Commercial landings data: mortality rates and recruitment strengths of *Engraulis mordax* as determined by logarithms of catch ratios of year class pairs at successive ages.

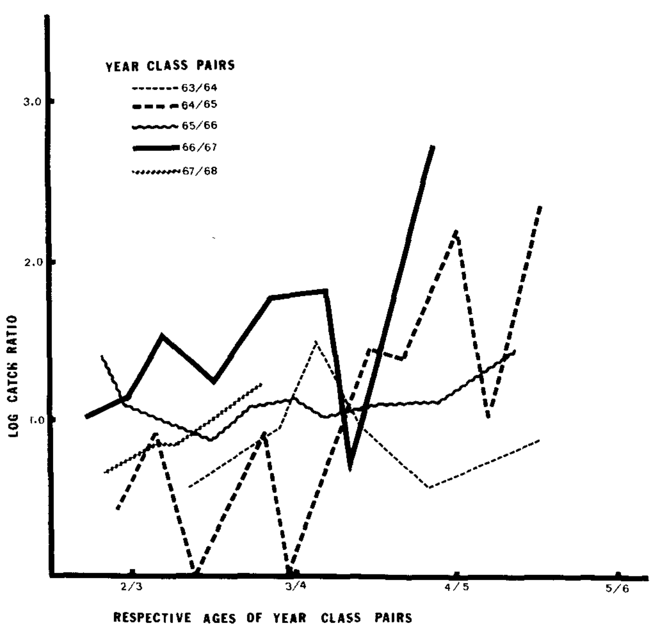

FIGURE 2. Sea survey data: mortality rates and recruitment strengths of *Engraulis mordax* as determined by logarithms of catch ratios of year class pairs at successive ages.

All in all, the assumptions on which the Chapman-Robson analysis is based are met very poorly by northern anchovies in southern California waters. Recruitment can vary by as much as 50% from year to year, which results in low confidence in the mortality rate estimated from any single catch curve. However, when a series of estimates based on data collected over several reproductive seasons are combined, the effect of irregular year class strengths is minimized. The high apparent mortality rate estimates resulting from entry of a large year class into the catch are balanced as that year class tends, in later years, to swell the ranks of the older fish and decrease the apparent mortality rate.

There is a strong tendency for the logarithms of the catch ratio to increase with age (Figures 1 and 2), substantiating Beverton's (1963) statements concerning the occurrence of increasing Z with age in engraulid fishes. In the commercial catch, the mean log catch ratios are 0.9 for ages 2/3, 1.3 for ages 3/4 and 1.9 for ages 4/5 and 5/6, which should provide rough estimates of the magnitude of the mortality rates at these ages. While the trend is apparent, the data at present are insufficient to support definitive estimates of mortality rates-at-age, and I present these values only as a crude starting point. For a good estimate by logarithmic analysis of catch curves, an independent set of estimates of year class strengths will reduce equation (4) to only one unknown. Moreover a longer uninterrupted series of catch curves will provide several sets of year class pairs which can be followed from recruitment to disappearance from the fishery.

Estimates of fishing mortality are difficult to make at the present low level of exploitation of the northern anchovy resource. Annual catches have ranged in magnitude from less than 10,000 tons in the mid sixties to 102,348 tons in 1970 (Crooke, 1972), with a 7 year mean of 41,836 tons. Since central California landings are included in the totals, but are relatively small, I have considered the mean annual catch in southern California to be 40,000 tons. The estimated standing biomass of anchovies in southern California is 2.5 million tons (Messersmith et al., 1969). Equation (5) estimates the instantaneous fishing mortality to be .026, which corresponds to an annual fishing mortality of 2.6%. Instantaneous natural mortality is then estimated to be 1.06, which corresponds to an annual natural mortality of 65%.

Increased fishing intensity in the most recent years yields higher estimates of fishing mortality, with $F = 0.066$ ($m = 6.4\%$) for the 1970 catch. This increase in fishing mortality may have also contributed somewhat to the slightly elevated total mortality rate estimates in late 1969 and 1970 (Tables 1 and 2).

CONCLUSIONS AND RECOMMENDATIONS

The northern anchovy in southern California has a mortality rate which increases with age. This makes a single valued mortality rate estimate somewhat inappropriate. However, since a more complete description is not presently feasible, I have presented an estimate for use in low level modeling and other general applications needed for management decisions.

The annual mortality rate is 66.5%, and can be separated into a natural component of 65%, and a fishing component of 2.6%. The instantaneous total mortality rate is 1.09 and the natural mortality rate is about 1.06.

Fisheries which exploit other species with similar mortality rates usually harvest a large portion of the standing biomass annually. Such is the case on the west coast of South America with the anchoveta, *Engraulis ringens*. There is little doubt that the northern anchovy, *Engraulis mordax*, in the waters off California could sustain a much greater harvest than is presently being attempted. However, due to the multiple uses of this fish, such as live bait, sportfish fodder, and commercial food production, the fishery should be expanded carefully.

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