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### A NOTE ON SPAWNING OF THE PACIFIC MARKET SQUID, *LOLIGO OPALESCENS* (BERRY, 1911), IN THE BARKLEY SOUND REGION, VANCOUVER ISLAND, CANADA

In California, *Loligo opalescens* (Berry, 1911), has large spawning schools and spawn masses (McGowan 1954; Fields 1965; Hobson 1965; Cous-teau and Dirole 1973; Hochberg and Fields 1980). Spawns and spawning effort of this squid in the Pacific Northwest are poorly known and, to our knowledge, large spawns or spawning events have not been quantitatively described.

*Loligo opalescens* spawns regularly in Barkley Sound near Bamfield, British Columbia, (lat.

48°50.0'N, long. 125°07.5'W) in spring. We examined and measured portions of a spawn using scuba during early June 1982. The largest single capsule mass aggregation in our 200 × 50 m survey area was measured. Adjacent areas of smaller solitary egg capsule masses were surveyed using transects to determine overall spawn dimensions and percent cover of individual capsule masses. Dimensions of 23 typical masses were determined. Four representative masses were collected; the number of capsules in each was counted; and from each, 10 capsules were randomly selected and the number of eggs in each capsule was determined. These eggs were examined microscopically to determine the developmental stage, which was compared with the embryological stages illustrated in Fields (1965) to estimate the time of deposition.

The spawn, including areas of continuous and solitary egg capsule masses, was larger than the area surveyed, as the spawn extended below our deepest possible survey depth. Within our survey area, the largest capsule mass aggregation covered about 69.3 m<sup>2</sup> and averaged 0.28 ± 0.09 m ( $n = 4$ ) in thickness. The mean density of the individual masses was 1.3 ± 0.1/m<sup>2</sup>, and the mean area covered by 23 masses was 0.28 ± 0.14 m<sup>2</sup>/mass, with a range of 0.13-0.66 m<sup>2</sup>. The mean number of egg capsules per solitary mass was 1,937 ± 912 ( $n = 4$ ), with 149 ± 35 eggs/capsule ( $n = 40$ ). Thus, the total number of eggs per isolated mass was 288,000 ± 125,000. For the large areas of isolated masses, the potential number of larvae produced per 100 m<sup>2</sup> ranged from 19 to 58 × 10<sup>6</sup>, with a mean of 37 × 10<sup>6</sup>. The number of potential larvae from the single large aggregation of 69.3 m<sup>2</sup> ranged from 27 to 204 × 10<sup>6</sup>, with a mean of 72 × 10<sup>6</sup>.

Based on embryological stages observed, deposition probably occurred during the night of 31 May-1 June 1982. Small squid schools were observed spawning near the survey area on that date. None of the embryos were old enough to be deposited before 31 May, and all were of the same embryological stage.

Female squids from Californian populations deposited about 21 capsules, each containing about 200 eggs, in one night (Fields 1965); fecundity data from our region are not available. Hochberg and Fields (1980) stated that *L. opalescens* females produce 180-300 eggs/capsule. Our data indicate a lower mean value of about 150 eggs/capsule. If each female deposited 20 capsules, the large measured aggregation would be the result of about 24,000 females.

In conclusion, northern *Loligo opalescens* populations form large spawning schools and deposit massive egg capsule masses similar to those observed in the Californian populations.

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#### ARITHMETIC VERSUS EXPONENTIAL CALCULATION OF MEAN BIOMASS

Mean biomass ( $\bar{B}$ ) within a time interval ( $t$ ) is used in the Ricker method of estimating yield per recruit and can be calculated either arithmetically as

$$(i) \quad B_t = \frac{B_t + B_{t+1}}{2}$$

or exponentially as

$$(ii) \quad B_t = \frac{B_t (e^{G_t - Z_t} - 1)}{G_t - Z_t}$$

(Ricker 1975). The choice of calculation method may influence the yield estimates and consequently the determination of optimal levels of exploitation.

Ricker (1975) and Paulik and Bayliff (1967) alluded to the importance of the difference in magnitude between instantaneous growth and total mortality rates ( $G_t - Z_t$ ). They indicated that if the difference was small, arithmetic and exponential calculations approached one another. Ricker suggested using small intervals if the rates are rapidly changing. In this paper we 1) examine the difference in the two estimates of mean biomass as a function of the instantaneous rates of growth and mortality, and 2) reexamine the consequences of the choice of mean biomass estimates on estimates of equilibrium yield per recruit using data previously employed by Ricker (1975) and Paulik and Bayliff (1967), showing that under many conditions, exponential estimates of mean biomass are preferable.

The difference between arithmetic and exponential estimates of mean biomass increases rapidly as  $G_t - Z_t$  increases in a positive direction, but diverges less rapidly when  $G_t - Z_t$  increases in a negative direction. When  $B_t$  is arbitrarily taken in unity, the relationship is satisfactorily represented by a polynomial regression (Fig. 1).

With many fisheries it is only possible to estimate instantaneous fishing mortality ( $F_t$ ) on an annual basis. Thus, a large interval must be used. The larger the interval, the more likely it is that  $G_t - Z_t$  is of a magnitude that would cause significant differences in estimates of  $\bar{B}_t$  calculated arithmetically and exponentially. Also, in heavily exploited fisheries there may be a large difference between growth and mortality rates within an interval especially at older ages.

We employed Ricker's (1975:242-243, table 10.3) example of bluegills from Muskellunge Lake to illustrate the difference between the two methods of computing mean biomass. This set was chosen because Ricker's data have been used previously as a historical data set and are readily available through his text. Mean biomass was computed arithmetically in the text example and also by Paulik and Bayliff (1967), who used the same data to introduce their computer program. We used the data in two separate runs to compute yield per

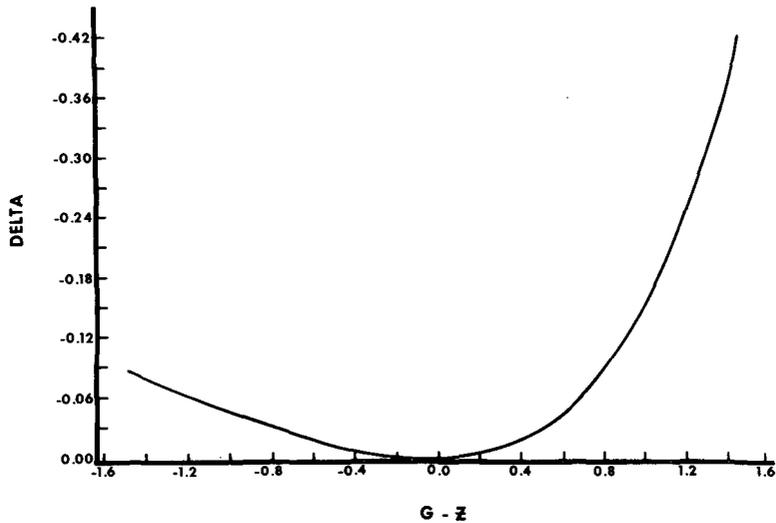


FIGURE 1.—Difference between arithmetic and exponential calculations of mean biomass when  $dt = 1.0$  and  $B_t = 1.0$ ,  $DELTA = B_t(B_t, \exp - B_t, \text{arith}) = B_t \{0.0061 + 0.0037(G_t - Z_t) - 0.1095((G_t - Z_t)^2) - 0.0491((G_t - Z_t)^3)\}$ ,  $r = 0.998$ .

recruit. In one,  $B_t$  was computed arithmetically, and in the other it was computed exponentially (Fig. 2). In both runs, the number of survivors was followed across the intervals and biomass was

tracked within each interval. There were obvious significant differences. Evaluating various  $F$ -multiples and ages of entry, when  $B_t$  was calculated arithmetically, the maximum yield exceeded the maximum biomass of the stock (5,522.6

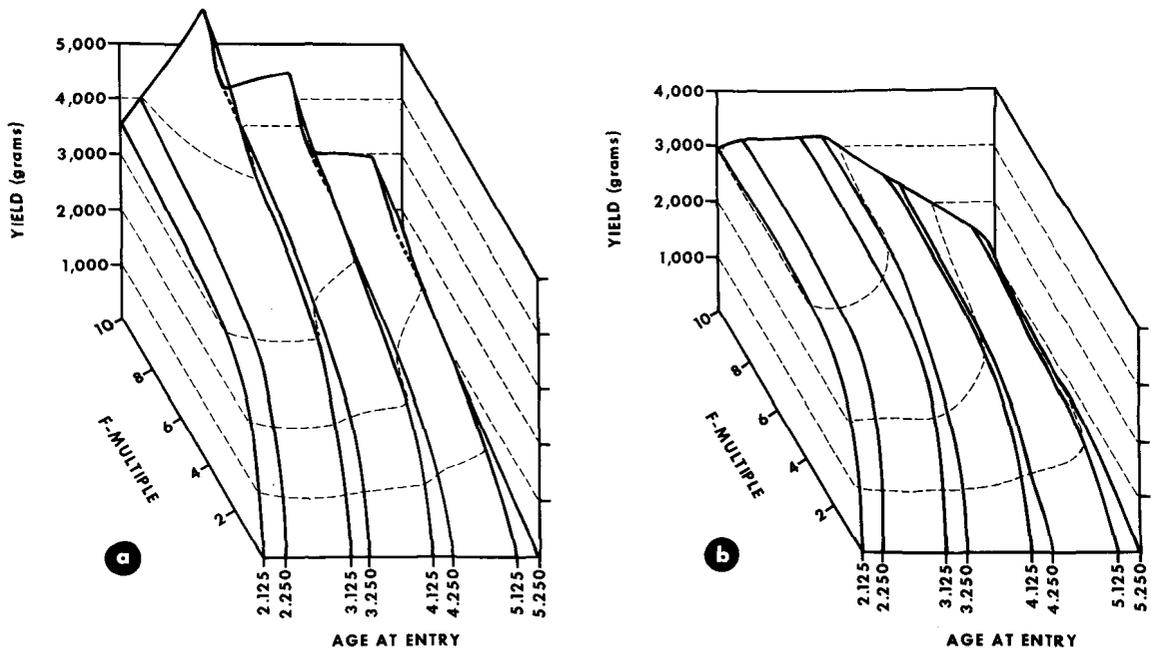


FIGURE 2.—Yield per recruit estimates for bluegills of Muskellunge Lake calculating mean biomass a) arithmetically and b) exponentially (data from Ricker 1975: table 10.3).

g vs. 3,439.2 g) when  $F$ -multipliers were large, which is impossible. Maximum biomass of the stock was estimated at  $F$  equals zero; the time intervals used were four one-eighth of a year intervals followed by one-half year intervals. Despite the small intervals, the difference between the yield per recruit estimates was large, indicating a need to minimize the  $G_t - Z_t$  difference if  $B_t$  is calculated arithmetically, regardless of the size of the time intervals. Therefore, in similar circumstances and for the example data set, we recommend that  $B_t$  be calculated exponentially.

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