# APPENDIX A: METHODS FOR DENSITY CALCULATIONS AND AGING

## A1 EGG AND LARVAE DENSITY CORRECTIONS

Assignment into larval size classes was necessary prior to adjusting for extrusion and avoidance as the likelihood of extrusion decreases with length but avoidance increases with age (which is an increasing function of length). Sorting is based on preserved larval size which is recorded at the time of staging. Length thresholds for the larval size classes (Lo 1985a) are listed in table A1. Because of differences in mesh sizes of the nets, *CVT/PV* and *CB* nets differ in their sampling efficiency. Smaller larvae and eggs are more likely to extrude through the *CB* net, but are retained more efficiently in the finer mesh size of the *CVT/PV*. However, *CB* is more efficient at catching larger larvae. Extrusion factors (table A1), calculated by Lo (1983) to compensate for these differences, were applied to the size classes to obtain extrusion free counts (0.075 mm mesh was treated as extrusion free (Lo 1983)).

Avoidance corrections were made to *CB* samples to correct for the propensity for older developed larvae to avoid the net. No avoidance corrections are necessary for *CVT/PV* because the net is pulled vertically through the water column. The avoidance equation from Lo et al. (1989) was used for the correction:

$$avd_c = \frac{1 + DNl_c}{2} + \frac{1 - DNl_c}{2} * cos(2\pi * hr/24) \quad (1)$$

where $hr$ is the time of day on a 24 hour clock the tow was taken, and $DNl_c$ represents the day/night catch ratio for larval size class $c$. The $DNl_c$ used here differs from the one used in Lo et al. (1989). In contrast to Lo et al. (1989) we calclated $DNl_c$ as $DNl_c = e^{-0.229*c}$ because it is more up-to-date and logically consistent.

Raw egg and larval counts were standardized to an area-density using standard haul factors (*SHF*) (Kramer et al. 1972); where $SHF = 10*(\text{tow depth/volume of water filtered})$ which represents abundance beneath an area of 10 m$^2$ integrated over the depth of the tow. This 10 m$^2$ area-density will be refered to simply as a 10 m$^2$ density. A second adjustment was made for the percentage of total plankton volume sorted from the samples. The overall adjustment can be represented as $rct_k * shf_k / prst_k$ where $rct_k$ is the raw count (egg or larval), $prst_k$ is the percentage sorted and $shf_k$ is the *SHF* for sample $k$[1].

TABLE A1
**Larval size classes and length ranges, extrusion correction factors for bongo (CB), calvet and pairovet (CVT/PV) and growth curve coefficients.**

| Size Class | Range [a] | *CB*[b] | *CVT/PV*[c] | Month | $a^{mn}$ [d] |
|---|---|---|---|---|---|
| eggs | N/A | 12.76 | 1.10 | Jan. | 0.046 |
| 2.5 | [2,3.25] | 6.08 | 1.46 | Feb. | 0.048 |
| 3.75 | [3.25,4.25] | 2.58 | 1.37 | March | 0.05 |
| 4.75 | [4.25,5.25] | 1.62 | 1.30 | April | 0.052 |
| 5.75 | [5.25,6.25] | 1.24 | 1.25 | | |
| 6.75 | [6.25,7.25] | 1.10 | 1.21 | | |
| 7.75 | [7.25,8.25] | 1.00 | 1.00 | | |
| 8.75 | [8.25,9.25] | 1.00 | 1.00 | | |
| 9.75 | [9.25,10.25] | 1.00 | 1.00 | | |

[a]Assignment to classes is based on preserved larval lengths (section 2.2.2). All larval sizes are measured in mm.
[b]Extrusion factors for *CB* computed directly from the logistic model of Lo (1983) equation (6), table 4.
[c]Extrusion factors for *CVT* and *PV* are fitted values of a logistic regression on the raw estimates from Lo (1983).
[d]Gompertz growth second stage parameter (Methot and Hewitt 1980).

## A2 EGG INCUBATION TIME AND AGING OF LARVAE

Unstaged egg data precluded us from aging individual or even groups of eggs, however, the incubation time has a known temperature dependent functional from Lo (1983). Missing temperature data from the surveys were rare; occurances were interpolated using an inverse distance spatially weighted average of other observed temperatures during that cruise. Temperature measurements at each sample, $k$, were used in the relationship specified by Lo (1983) to calculate incubation times:

$$t_k^I = 18.726 * e^{-0.125 * tmp_k} \quad (2)$$

where $t_k^I$ is the incubation time and $tmp_k$ is the temperature measured in degrees Celsius.

The calculation of larvae age requires the live larval length. Preserving agents used at the time of sampling and tow time can shrink larvae. Therefore adjustments for these factors were made before aging using the correction function specified in Theilaker (1980):

$$l_k = \log(ff * pls_k) + 0.289 * \exp(-0.434 * ff * pls_k * q^{-0.68}) \quad (3)$$

where $l_k$ is the estimated length of live larvae in millimeters (mm) from sample $k$ with a preserved larval length of $pls_k$ mm, a tow time of $q$ minutes, and $ff$ is a paramter base on the preserving agent. Formalin was the preserving agent so $ff = 1.03$ (Theilaker 1980). Tow time was not included in our data set and was assumed to be 15.5 minutes based on CalCOFI sampling guidelines (Cal-

[1]Sample indices $k$ are specific to a year, cruise, and station. Furthermore, occasionally multiple samples were observed at a station on a cruise, each would have its own index $k$. Without loss of generality, a single index is used here, and later, as explicitly specifying all dimensions of the indices would provide no further insight.

COFI 2010). The remaining numeric values were taken from Theilaker (1980). No rounding of *pls* by grouping into size classes was carried out prior to estimation of *l* and *pls* was recorded up to the precision of 0.1 mm in our data set.

Larvae were aged using a two-stage Gompertz growth curve (GGC). This approach was first proposed for the use on anchovy larvae by Methot and Hewitt (1980) and later with updated first-stage parameter estimates by Lo (1983). The first stage of the GGC accounts for growth through yolk-sac consumption, which is approximately the first two size classes 2.5 mm and 3.75 mm. Aging during the first stage of the GGC is temperature dependent while aging during the second stage is month-of-sampling dependent. Because of this, it is necessary to compute ages as sample specific. The first stage of the GGC is specified as:

$$T1(l_k) = \left( \frac{-1}{a_k^{tmp}} \right) * \log \left( \frac{\log(l_k/4.25)}{\log(0.32/4.25)} \right) \text{ for } l_k \leq 4.1 \text{ mm}$$

$$a_k^{temp} = 0.1108 * e^{0.1173 * tmp_k} \tag{4}$$

where $T1(l_k)$ is the estimated age of larvae with length $l_k$ (equation A3). The value 4.25 controls the upper bound of the growth curve (mm) during the first stage of growth while the value 0.32 is the hypothetical minimum larval size. The temperature dependent parameter $a_k^{tmp}$ was specified by Lo (1983). The second stage of the GGC is meant to capture the post yolk-sac consumption period of larval growth, and is specified as:

$$T2(l_k) = \left( \frac{-1}{a^{mn}} \right) * \log \left( \frac{\log(l_k/27)}{\log(4.1/27)} \right) \text{ for } 4.1 \text{ mm} < l_k < 27 \text{ mm} \tag{5}$$

where $T2(l_k)$ is the age of larvae length $l_k$ (from equation A3) since the first stage. The value 27 controls the upper bound of the second-stage GGC and 4.1 is the length at which larvae transition into the second stage of growth. The monthly parameter $\alpha^{mn}$ was estimated by Methot and Hewitt (1980) and its values are listed in table A1. The total age of the larvae is $t(l_k) = T1(l_k)$ for yolk-sac larvae which haven't entered the second stage of growth ($l_k \leq 4.1$ mm) and $t(l_k) = T1(4.1) + T2(l_k)$ for larvae beyond the yolk-sac stage ($l_k > 4.1$ mm)[2].

## A3 DAILY LARVAL PRODUCTION

Even with regularly scheduled ichtyoplankton surveys the number of eggs or larvae from a single sample on a given cruise at a station is too few to accurately characterize densities. To minimize small sample biases, aggregation over cruises was necessary prior to the calculation of production statistics and mortality estimation. Each sample tow was assigned to a CalCOFI station (Weber and McClatchie 2009; Eber and Hewitt 1979) and multiple samples observed at a station on a cruise were averaged. No weighting of cruises was used and all data were averaged across cruises occuring during January through April of a year to obtain annual station specific data. A final average over stations was needed to obtain accurate annual mortality curve estimates for the region as a whole.

The production of larvae in a size class per day per unit area, *DLP*, is estimated as standing stock of larvae in a size class over the days that larvae spend in that class, or duration. Duration is the difference between the ages (equations 4 and 5) at the size class break points (table A1). Let $n_{c,s}$ be the standing stock of larvae[3] and $d_{c,s}$ be the duration of size class $c$ in year $s$. *DLP* is then calculated as $dlp_{c,s} = n_{c,s} / d_{c,s}$. Avoidance by larvae older than twenty days (Lo 1985a) biases estimates of *DLP*. Larvae were found to have reached an age of twenty days towards the end or just after the 9.75 mm size class. To mitigate these biases we omitted class sizes larger than 9.75 mm from the analysis.

[2]Frequently, age will be referred to simply as $t$, and the functional dependence of age on length $t(l_k)$ being explicit only where needed.

[3]The standing stock of larvae is the total corrected count of all larvae in a size class and can be viewed as the integral over ages in that size class, e.g. $n_{c=3.75\text{ mm}} = P_h \int_{t(l=3.25\text{ mm})}^{t(l=4.25\text{ mm})} \left( x/t^t \right)^{-\beta} dx$.

## APPENDIX A LITERATURE CITED

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