

# A size-based egg-per-recruit model and parameter sensitivity analysis of red abalone, *Haliotis rufescens*, in northern California

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## Introduction

- Red abalone, *Haliotis rufescens*, is the largest marine gastropod in California and the target of its only recreational abalone fishery. The results of a previously published age-based egg-per-recruit (EPR) model support the current minimum legal size limit of 178 mm<sup>8</sup>.
- Recent description of regionally derived reproduction<sup>9</sup>, mortality<sup>6</sup>, and growth parameters necessitate a re-evaluation of the red abalone population in California and an analysis of the utility of EPR models for management.
- EPR models provide a framework to examine the effects of alternative management strategies on population egg production. The cumulative cohort egg production is estimated through simulation and can be compared over a range of fishing mortality rates and minimum size limits.
- The objectives of this study were to construct and analyze a size-based EPR model for red abalone based on regionally derived biological parameters (reproduction, growth, and mortality). This model was used to determine the mean number of eggs produced per recruit. Sensitivity of the EPR model to variations in model parameters (growth, fecundity, mortality) and model structure (size class width) was further analyzed to determine the effect of alternative parameters on model estimates.

### Biological Parameters

### EPR Model

### Growth

Incorporate mean biological parameter estimates (base model) to determine the number of eggs produced for each recruit in the population.

### Reproduction

### Mortality

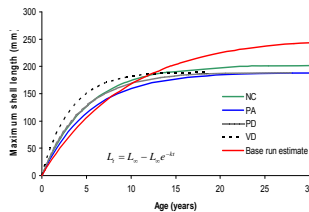
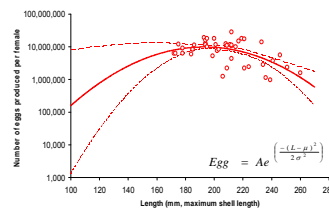
### Sensitivity Analysis

Determine the magnitude and direction of bias that results from altering mean biological parameters and 'base' model structure.



## Red abalone biological parameters

**Reproduction:** The mean number of eggs produced in each size class (solid line) was described using a three parameter Gaussian curve ( $n = 45$ ,  $A = 9.89 \times 10^6$ ,  $\mu = 193.02$ , and  $\sigma = 32.37$ ). Upper and lower 95% confidence intervals (dashed lines) were determined by Monte-Carlo re-sampling.



**Growth:** The age and growth relationship was described using the Von Bertalanffy growth function. Site-specific growth was determined at four locations in northern California: Cabrillo Cove North (NC,  $n = 351$ ), Point Arena (PA,  $n = 186$ ), Pedotti Ranch (PD,  $n = 208$ ), and Van Damme State Park (VD,  $n = 68$ ). Published von Bertalanffy growth parameters from a multi-site, multi-year study were used as the growth parameter estimates for the 'base run' simulation.

Instantaneous natural mortality ( $M$   $y^{-1}$ ) estimates were determined for three size classes using Cormack-Jolly-Seber mark-recapture analysis from areas that were closed to fishing or were lightly fished.  $M$  was  $0.05 y^{-1}$  (0.01 to 0.14, mean  $\pm$  s.d.,  $n = 24$ ) for individuals larger than 178 mm MSL at SC. Individuals 100 to 178 mm MSL had a mean  $M$  estimate of  $0.37 y^{-1}$  (0.30 to 0.46, mean  $\pm$  s.d.,  $n = 470$ ). The mean estimate of  $M$  for individuals smaller than 100 mm MSL was  $0.65 y^{-1}$  (0.56 to 0.75, mean  $\pm$  s.d.,  $n = 179$ ).<sup>6</sup>

## Size based model:

A size-based egg-per-recruit model was derived from the per-recruit model presented by Chen<sup>4</sup> and adapted for EPR analysis.  $F_g$  and  $M_g$  are the instantaneous fishing and natural mortality rates of size class  $g$ .

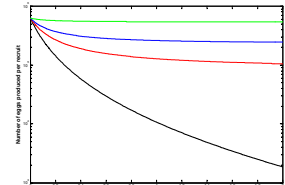
The time that an individual remains in size class  $g$ ,  $\Delta T_g$ , is based on VBGF parameters  $k$  and  $L_\infty$ .  $d_g$ , the width of the size class  $g$  and  $L_g$  is the minimum size of size class  $g$ .

The number of eggs-per-recruit is determined for a cohort at range of fishing mortalities ( $F$   $y^{-1}$ ) and minimum legal size limits.

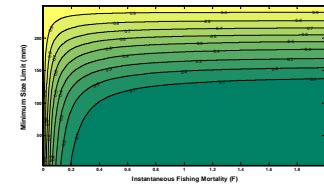
$$EPR = \sum_{g=1}^j \Delta T_g e^{-\sum_{s=1}^{g-1} (F_s + M_s) \Delta T_s} A e^{\frac{-((L_g - \frac{d_g}{2}) - \mu)^2}{2\sigma^2}}$$

## Results & Conclusions

Predicted egg-per-recruit values for a range of sizes of entry into the fishery. The predicted EPR is greatly reduced when the size limit is changed from the current value of 178 mm (blue) to 100 mm (black). A moderate decrease in EPR is observed when the size limit is reduced to 150 mm (red). An increase to near maximum production for all levels of fishing mortality is observed when the minimum size limit is increased to 230 mm (green).



Contour isopleth of the predicted fraction of the maximum EPR values for a range of sizes of entry into the fishery and fishing mortality rates.



Model sensitivity to alterations in biological parameters relative to the base run (mean biological parameter values) at four levels of fishing mortality.

Trial	Parameter change	Difference in EPR value relative to the base run estimates at F =			
		0	0.5	1.0	1.5
<b>Fecundity Regression Parameters</b>					
Lower 95% confidence interval		64%	51%	46%	44%
Upper 95% confidence interval		213%	146%	141%	140%
<b>Size specific mortality</b>					
	$M_{<100 \text{ mm}} (y^{-1})$	$M_{100-178 \text{ mm}} (y^{-1})$	$M_{>178 \text{ mm}} (y^{-1})$		
	0.56	0.30	0.01	229%	144%
	0.75	0.45	0.14	35%	29%
<b>Site-specific VBGF parameters</b>					
	Site	$k (y^{-1})$	$L_\infty (mm)$		
	NC	0.20	202.35	165%	198%
	PA	0.19	189.01	57%	77%
	PD	0.22	189.95	121%	160%
	VD	0.32	189.58	400%	512%

- Our findings suggest that the greatest change in EPR values using mean parameter values is observed at low fishing mortalities ( $F = 0$  to  $0.5 y^{-1}$ ).
- At the current minimum legal size limit (178 mm) the EPR at  $F = 0 y^{-1}$  is 627,764. Because much of the egg production of this species occurs at sizes smaller than 178 mm, EPR values at moderate to large fishing mortalities are predicted to be 40 to 50% of maximum.
- Model predictions were sensitive to alterations in size-specific mortality, growth, and reproduction, but were robust to small changes in the Von Bertalanffy growth parameter,  $L_\infty$  and changes in the size class width,  $d_g$ .
- Size-based models that incorporate regionally derived biological parameters provide managers with information about potential egg production for a range of management scenarios and serve as a valuable reference point for this fishery.