# The Impacts of Ocean Acidification on the Development and Survivorship of Juvenile Red Abalone (*Haliotis rufescens*)

**Daryll Carlson**
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**Abstract**

pH and temperature are significant drivers of change in marine ecosystems, and likely have synergistic effects in addition to their individual impacts. Anthropogenically driven ocean acidification (OA) and ocean warming (OW) are drastically altering these conditions in marine ecosystems around the world. Calcifying organisms in shallow, nearshore ecosystems are particularly vulnerable to these drastic changes. One such calcifying species that may be vulnerable to OW and OA is the red abalone (*Haliotis rufescens*). Juveniles have thinner shells and are in a critical period of growth, making them especially vulnerable. This study seeks to quantify the individual and synergistic impacts of future OA and OW conditions on the development and survivorship of juvenile red abalone in order to inform conservation policy and use abalone as a model for other marine calcifiers. A gas-controlled aquarium (GCA) system housed at Monterey Bay Aquarium Research Institute was utilized, 64 tanks that are individually and randomly delivered water from each of 4 predefined treatments: (1) ambient pH with ambient temperature (control); (2) reduced pH with ambient temperature (OA individually); (3) ambient pH with heated temperature (OW individually); and (4) low pH with heated temperature (OA and OW). Ambient seawater was collected from an intake in Monterey Bay. Offset values from ambient were used as opposed to constant treatments to achieve fluctuation that matched the degree of natural daily/seasonal fluctuations in Monterey. Low pH was defined as a -0.5 pH unit offset from ambient to represent potential OA conditions projected for the year 2100, exacerbated by upwelling. Erroneous system functioning caused unexpected spiking of temperature within temperature treated tanks, thus these treatments were not utilized in analysis. 256 juvenile *H. rufescens* (post-settlement, <1 yr) of 2 size classes were weighed and photographed for later measurement of initial shell length and surface area using ImageJ. Individuals were randomly distributed into GCA system tanks in groups of 4, 2 of each size class. After 28 days, abalone were once again photographed and weighed. Shells and tissue were separated, and shells were dried and measured for final dry shell weight. There was a significant interaction between pH and size class, $F(1,124) = 4.31$, $p = 0.04$. The small size class in low pH was significantly different in change in surface area from the other group means, with a mean change of -0.006 ± 0.039 cm2 (mean ± SD) while all others had positive average changes. Final dry shell weight varied with size class and pH, $F(1,124) = 422.9$, $p < 0.001$, and $F(1,124) = 6.61$, $p = 0.01$, respectively. The small size class in high pH had a significantly higher average final dry shell weight, 0.138 ± 0.052 g (mean ± SD), than that of the small size class in low pH, 0.104 ± 0.034 g (mean ± SD), $p = 0.027$. Size class significantly predicted mortality, $z = 2.515$, $p = 0.012$. The small size class had higher mortalities than the larger size class in both pH treatments. The small size class was most noticeably impacted by low pH conditions, with a significantly lower mean change in surface area than that of other groups, a negative mean change in surface area suggesting dissolution, and the lowest mean final dry shell weight. This is strong evidence that younger/smaller juveniles are highly susceptible to growth delays as a result of OA. Delays in growth in these smaller size classes would have a major effect on red abalone population sizes and demographics as smaller-than-average individuals have lower fecundity, reduced likelihood of reaching sexual maturity, and higher natural mortality. Red abalone populations could quite possibly experience further decline in future projections of oceanic conditions in this region, and this also suggests a high vulnerability for other calcifying species that will be undergoing similar environmental changes. This makes the development of better management and conservation strategies and further study for this species, as well as other mollusc, even more important as anthropogenic activity continues to alter the marine environment.