Climate change causes molecular physiological change

* Temperature (+4°C) and OA (750 ppm) significantly affected larval metamorphosis, growth, and lipid synthesis in larval M. mercenaria and A. irradians (Talmage and Gobler 2011)

Climate change causes range shifts

CO2 can diffuse across tissues

CO2 causes acidosis

* Cuttlefish blood pCO2 increased with environmental CO2 in pH of 7.1 for 48 hours. Immediate drop in blood pH, but only 0.2 units compared to water’s decrease of 1 unit – increased [HCO3] and small but significant decrease in pHi (Gutowska et al. 2010)
* Sea urchin Psammechinus miliaris at decreased pH for 8 days – coelomic pH decreased, as did pCO2 (respiratory acidosis) (Miles et al. 2007)
* Short-term decrease in pH3 in M.edulis juveniles and adults at low pH of 7.3, but then compensated with increased HCO3; pHi also decreased within first day, but greater control (Michaelidis et al. 2005)

OA inhibits calcification

* Marine invertebrates may be more sensitive because have decreased ability to regulate pHe – no direct effect of omega since calcification occurs in internal compartments (Portner 2000)
* After 20 weeks at pCO2 of 3500 (pH 7.5 compared to 380 and 8.2) dry shell mass was decreased (and soft tissue mass) and shells had thicker calcitic laths, C. virginica (Beniash et al. 2010)
* Mussels at elevated CO2 for 8 weeks had decreased shell length and mass, but not decreased somatic growth , M. edulis (Thomsen & Melzner 2010)

OA causes shell dissolution

OA changes ion balances

Organisms dissolve CO3 structures under OA

* At pH of 7.68 compared to 8.07 after an extended period (26-55 days), adult C. gigas had decreased hemolyph pH and increased extracellular concentrations of HCO3 (Lannig et al. 2010)
* Limpet Patella vulgate at pH of 7.6 (control = 8.2) for 5 days had no change in hemolyph pH, but increased extracellular HCO3 and Ca (Marchant et al. 2010)
* Urchins P. miliaris dissolve tests as a last resort, but cannot completely buffer with HCO3 (Miles et al. 2007)
* HCO3 buffering is more efficient intracellularly than extracellularly (Portner et al. 2004)

Invertebrates have ion pumps

* Membrane carriers can transport H+ and/or HCO3 to accumulate HCO3 and compensate for pH drop; in general have ion pumps for H+ and HCO3 (Portner et al. 2004)

OA affects effectiveness of H+ ion pumps/H+ ion pumps are important

OA causes larvae to be smaller

* Sand dollars, *Dendraster excentricus*, had narrower bodies, smaller stomachs, and shorter arms at 1000 ppm (7.75) (Chan et al. 2011)

OA causes larvae to be abnormal

* At elevated pCO2 (600, 750, and 1000 compared to 375), C. gigas and S. glomerata larvae were more abnormal, had inhibited development, were smaller, and had less shell growth (Parker et al. 2010) – also temperature effect
* Delayed development and more abnormality in brittlestart Ophiothrix fragilis larvae at pH 7.9 and 7.7 compared to 8.1 over development (Dupont et al. 2008)

OA causes physiological changes

* *Hsp70* maximum expression in red urchin larvae occurred at higher temperatures but was induced to a lesser degree at 540 and 970 ppm compared to ambient/380 ppm (O’Donnell et al. 2009).
* Barnacle larvae up-regulated protein EF2, hemoglobin B-chains, acyl COA dehydrogenase; down-regulated regulator of endocytosis, cathepsin L-like, hsp83 (Wong et al. 2011)
* In C. virginica, up-regulatoin of proteins involved in oxidative stress (Tomanek et al. 2011)

Omega changes larval survival

* In Netarts Bay, upwelling and diurnal metabolic variability in bay cause omega to decrease. Exposure to low omega aragonite at spawning significantly affects larval production and mid-stage growth (Barton et al. in press)

Omega affects larval growth

* Decreased omega by decreasing TA with HCl, so pH was low (~7.65) and CO2 was ambient – decreased % viable Cg larvae, shell length and area, and amount of Ca incorporation (only OA did not). OA with same pH and OA with high TA did not have same effects and were in fact similar to controls (Gazeau et al. 2011)
* C.gigas grow much better at omega of aragonite >2 (Jesse Vance)
* Developmental delay under higher pCO2 caused by altered energy budgets (Stumpp et al. 2011)

Fish larvae don’t settle well, don’t recognize predators

* Dixson et al. 2010
* Munday et al. 2009

Oysters provide habitat for other animals

Oysters contribute to large industry

C.gigas larvae in the PNW are already affected by OA

* Dabob Bay, in fall/winter water intake into hatchery is at 700 µatm; shallow intake omega under 1 early in season and deep intake is always <1 (Benoit)
* Waters of Puget Sound can be corrosive – variable in both space and time. Surface waters have decreased omega aragonite 0.09-0.33 since pre-industrial (Feely et al. 2010)
* Low pH and undersaturation wrt aragonite in the CCS (Plattner et al. 2009)