Multiple Stressors

Zippay & Hofmann 2010: high pCO2 affected survivorship of red abalone larvae at elevated T but did not affect expression of specific genes

Green & Barnes 2010: expression of 7 genes in S. glomerata had unique responses to 3 different stressors (Al, ASS, and salinity) as well as unique responses to interactive effects

Parker et al. 2010: pCO2 affected fertilization success, number of D-veliger larvae, abnormality and size of D-veligers in S. glomerata and C. gigas. Species responded differently and different temperatures affected response to pCO2.

Lopez et al 2010: lower pH increases metal bioavailability to juvenile clams

Molecular effects of OA

O’Donnell et al 2009: OA affects hsp70 expression in red urchin larvae

Zippay & Hofmann 2010: high pCO2 affected survivorship of red abalone larvae at elevated T but did not affect expression of specific genes

Green & Barnes 2010: expression of 7 genes in S. glomerata had unique responses to 3 different stressors (Al, ASS, and salinity) as well as unique responses to interactive effects

Wong et al. 2011: changes in larval barnacle proteome (and post-translationally) in response to OA

Tomanek et al. 2011: C. virginica mantle proteome response = cytoskeletal and oxidative stress

Dineshram et al. 2013: proteins differentially expressed in response to OA in larval C. hongkongensis and changes in phosphoproteome. Classes of DE proteins: structural and cytoskeletal, energy metabolism, calcification. Greatest changes were posttranslational (not expression).

Muralidharan et al. 2012: S. glomerata hemolymph proteome has unique and common responses to different metals

Liu & Wang 2012: proteome response to metal pollution in C. hongkongensis

Huan et al. 2012: identified developmental specific proteomes in C. gigas, qPCR for 6 proteins showed accordance in expression patterns of 5/6

Liu et al. 2012: cadmium exposure in scallop, clam, mussel, and S. glomerata showed species-specific responses in which proteins were differentially regulated and if responded to doses differently

Dickinson et al. 2012: low salinity and high pCO2 caused mortality (more than at high pCO2 only) and decreased somatic mass. Microhardness and fracture resistance affected by salinity x pCO2. Affected carbonic anhydrase activity and expression.

Wolschin & Amdam 2007: differential protein expression between bee nest workers & foragers

Papakostas et al. 2012: effects of salinity on proteomes of whitefish larvae from freshwater and brackish populations

Lackner et al. 2012: stress in fission yeast showed good correlation between mRNA and protein for up-regulated proteins, by poor regulation for down-regulated (either biology or failure of MS). Protein expression occurs a little later than mRNA. Some evidence of upregulated mRNA and no response at protein level – standing stock ready to produce protein when needed.

Hogstrand et al. 2002: proteomic response to zinc exposure in O. mykiss gills

Looso et al. 2013: used NGS and proteomics to discover proteins involved in limb regeneration in newts.

Viitamiemi & Leder 2011: sex-specific proteome profiles in livers of non-sexually active male and female sticklebacks

Parker et al. 2012: proteomics used to find correlations between protein expression and sanitary behaviors that decrease parasite infestation in honey bees

Environmental perspective on OA

Feely et al. 2010: estimated present-day decreases due to human-induced OA in PS is 0.05-0.15 pH units. Stratification and corrosiveness of different parts of PS change with season.

Feely et al. 2004: shoaling of aragonite undersaturation worldwide

Caldeira & Wickett 2003: ocean loses ability to buffer changes in pH if changes occur on scale less than 10^4 years

Zeebe et al. 2011: C produced by fossil fuels could overwhelm capacity of C reservoirs (biosphere, soils, surface ocean, atmosphere). Near complete removal of fossil fuel C from atmosphere would take 10,000-100,000s of years. Over several thousand years, CaCO3 saturation is controlled by weathering of continents (inputs) and burial in ocean sediment (output).

Physiological effects of OA

* Calcification: Lannig, Beniash, Thomsen, Marchant, Miles, Michaelidis, Talmage & Gobler, Dickinson, Melzner, Welladsen
* SMR: Lannig, Beniash, Thomsen
* Somatic growth: Beniash, Dickinson
* Developmental Delay: Kurihara et al. 2008
* Immune: Matozzo

Lannig et al. 2010: exposure to low pH for 55 days in adult C. gigas caused small decrease in body condition index, changes in hemolymph pH and [HCO3], and suppressed SMR when exposed to elevated temperature (no change in basal SMR).

Beniash et al. 2010: elevated pCO2 caused increased mortality in juvenile C. virginica, decreased shell and soft tissue mass, and decreased fracture toughness (also changes in shell microstructure). Greater effect on SMR in juveniles than adults. Changes in carbonic anhydrase expression in adult tissues.

Thomsen & Melzner 2010: shell growth and mass affected by pCO2 in M. edulis, decrease in SMR, evidence of protein degradation (as buffering mechanism?)

Marchant et al. 2010: limpet Patella vulgata can completely regulate pH probably by dissolving shell

Miles et al. 2007: urchins can dissolve tests to buffer moderate changes in pCO2, but not a long-term compensation and still see decreases in coloemic pH

Kurihara et al. 2007: developmental delay in C. gigas larvae

Beesley et al. 2008: OA exposed M. edulis for 60 days and main effect was leaky lysosomes, which could impact immune function (other tissues unaffected)

Portner et al. 2004: buffering by HCO3 is more efficient for intracellular than extracellular spaces. Membrane transporters move H+ and/or HCO3- to accomplish buffering (in inverts: v-type H+ ATPase, Na/H- and Na-dependent Cl/HCO3 exchange). CO2 tolerant species will drop metabolic rate (probably from decreased extracellular pH), which could change amino acid metabolism (produce more HCO3) and possibly decrease protein synthesis over time.

Michaelidis et al. 2005: OA (pH 7.3) for 3 months caused slower shell growth, rapid respiratory acidosis compensated by accumulation of HCO3, decreased O2 consumption in M. edulis

Talmage & Gobler 2011: juvenile M. mercenaria, C. virginica, and A. irradians exposed to OA for 45 days and different temperature. C. virginica shell growth lower, scallop high pCO2 x T decreased survival and T decreased shell growth, Mm not affected as much.

Dickinson et al. 2012: low salinity and high pCO2 caused mortality (more than at high pCO2 only) and decreased somatic mass. Microhardness and fracture resistance affected by salinity x pCO2. Affected carbonic anhydrase activity and expression.

Melzner et al. 2011: 7 weeks at high pCO2 and different food supply in M. edulis. Shell growth decreased by low food and high pCO2 (no interaction), shell length less at OA, shell corrosion over all pCO2 for low food but only at highest 2 for high food (energy budget reallocations)

Matozzo et al. 2012: hemocyte function affected in clams and mussels by decreased pH and increased temperature.

Welladsen et al. 2010: P. fucata shell strength decreased with pH (28 days), no difference in organic content, difference in nacre growth patterns

Adaptation

Parker et al. 2012 (?): S. glomerata adult exposure and bred vs. wild affects larval response to OA