1. Introduction
   1. Duration of larval stage is in synchrony with needs of species
2. Brief Background on planktotrohpic and lecithotrophic life history
   1. Species with feeding larvae/planktotrophic have smaller eggs = greater fecundity. They also have a longer time between fertilization and metamorphosis (1-3 weeks greater in lab experiments), which could signify a fecundity-mortality trade-off (Strathmann 1985)
   2. Larger eggs of lecitroph not only more organic and nutritive material, but proportionally more as well (Strathmann 1985)
   3. Bivalve larvae: can transport aa through velum soon after fertilization (gastropods absorb DOM as well); *C. gigas* larvae (and others) can de novo synthesize essential amino acids from glucose, evidence of biochemical plasticity in growth requirements (Manahan 1990)
   4. Lecithotrophic larvae have capacity to transport aa from trocophore through veliger, *Haliotis rufescens* (Manahan 1989)
   5. Feeding larvae can be advected great distances by currents. Sites tend to be good or bad for a finite periods, dispersal is more highly favored when there is greater habitat variability (Strathmann 1985)
   6. The clam *Gemma gemma* is lecithotrophic and has an estimated larval mortality of 0.052/day. *C. gigas* has planktotrophic larvae with mortality estimated at 0.13-0.22 per day. (Strathmann 1985)
   7. If increased fecundity is paired with increased mortality, then all may be equal between plankto and lecitho by adult life stages (Strathmann 1985)
3. Brief Background on Ocean Acidification
   1. Present-day decrease in PS from OA is 0.05-0.15 units (Feely et al. 2010)
   2. Highest [CO2] in near-surface waters (Sabine et al. 2004)
   3. Significant upper ocean OA in N pacific proportional to anthropogenic increase in atm CO2 (Byrne et al. 2010)
   4. Multiple stressors – acidified upwellings usually associated with water of different T, salinity, nutrient
      1. pH minimum zone (<7.3) between 29-56 degrees N in N Pacific generally coincident with O2 minimum zone, both due to decomposition of organic matter (Byrne et al. 2010)
4. Biology
   1. If not enough parental investment (yolk) for either, may not survive – adult stress can cause catabolism of carbohydrates and protein (Thompson et al. in TEO)
   2. CO2 can easily enter gametes and lower pHi, preventing fertilization and development (Kurihara 2008)
   3. Decreased fertilization success in *Heliocidaris erythrogramma* (lecitho)*, Acropora digitifera* (plankto)*, Holothuria* spp. (plankt) (Havenhand et al. 2008, Morita et al. 2009), but maybe not in *C. gigas* (Havendand & Schlegel 2009)
      1. In review of urchins, only significant effect was Havenhand, in general urchin fertilization is robust to OA (Dupont et al. 2010)
   4. In 2 species of planktotrophic urchin, *Hemicentrotus pelcherrimus* and *Echinometra mathaei*, fertilization was less at pH 7.77through 7.03, less early cleavage, and deformed pluteus – decrease in overall length, post-oral arm length, body length (Kurihara & Shirayama 2004)
   5. Planktotrophic brittlestar *Ophiothrix fragilis*: lowered pH to 7.7 and 7.9 (Dupont et al. 2008)
      1. 7.9: sig. mortality increase at 7d
      2. 7.7: sig mortality increase at 5d
      3. low pH; none reached 8-arm pluteus stage, high proportion abnormal or asymmetric, took longer to reach developmental stages
   6. Planktotrophic barnacles *Elminius modestus* and *Semibalanus balanoides*: 14 and 18C and 1000 ppm (7.7); impacted growth, Ca content; mortality highest at high T; CO2 is sublethal (Findlay et al. 2009)
   7. *Crassostrea gigas*: lag in development at pH 7.4 by 24 hpf, abnormal shape, smaller, lack of calcification, implications for feeding (Kurihara et al. 2007)
   8. Delay in development seen in many spp – lecithotrophic could run out of food
   9. Lecithotrophic *Haliotis rufescens*: effects of 990 ppm (~7.9 pH) on survivorship in temperature stress, pretorsion larvae were influenced by low pH (Zippay and Hofmann 2010)
   10. Timing: if larvae are in water column for less time then there is less of a chance they will encounter adverse conditions of upwelling
       1. *C. gigas* larvae fasted at different points pf: day 6 deprivation had worst survival (Kheder et al. 2010)
   11. Space: planktotrophic travel farther (Strathmann 1985), could be good or bad
       1. Could be advected by currents to more suitable habitat
       2. If sites are consistently good or bad, many larvae are still exported from good sites than are returned (Strathmann 1985)
   12. Broadcast spawners in both strategies
5. Behavior
   1. Salinity – importance of detecting halocline (Kennedy in TEO)
      1. As evidenced by PDO, climate change can trigger changes in ocean surface currents (Francis et al. 2003)
   2. Swimming
   3. Settlement if can’t detect cues/correct environmental cues not there
      1. After initial mortality, increased T may have beneficial effect of inducing faster settlement in lecithotroph *H. erythrogramma* (Byrne et al. 2011)
   4. Dispersal
6. Physiological Ecology
   1. Calcification and connections with carbonate chemistry and total alkalinity
   2. Sydney rock oyster (planktonic): with decreased pH (7.8 and 7.6) shell size decreased and abnormal shell growth (Watson et al. 2009)
   3. Planktotrophic *Strongylocentrotus franciscanus*: high CO2 (540 and 970 ppm, 7.98 and 7.87 pH) decreased larval ability to upregulate hsp70 under thermal stress (O’Donnell et al. 2009)
   4. Abalone larvae are sensitive to temperatures outside natal range during development (Leighton 1974)
   5. *H. erythrogramma*: fewer normal embryos at elevated T (26 C compared to 18 & 20C), but all larvae that survived T mortality settled successfully and more quickly than larvae at lower T (Byrne et al. 2011)
   6. Sea star *Crossaster papposus* (lecithotrophic): at pH of 7.7 larvae in acidic conditions grew faster, no negative effects on survival or skeletogenesis in 28 days, positive direct effect on metabolism. Maybe negative consequences later including problems with synchrony with food and temperature (DuPont et al. 2010)
   7. *H. erythrogramma* lecithotrophy evolved to minimize time in plankton in harsh native environment (T and pH fluctuations; Dupont et al. 2010)
   8. Abalone *Haliotis coccoradiata* more sensitive than urchin *H. erythrogramma* to changes in pH and T. The abalone has a limited thermal tolerance and calcification is more sensitive than in bivalves at pH 7.6 and 7.8. Urchin less affected overall although predicted warming of +4C breaks thermal tolerance of both. The abbreviated lecithotrophic larval stage may make them more robust to climate change (Byrne et al. 2010)
   9. Planktotrophic spider crabs *Hyas araneus*: population/latitude-specific responses to changes in T and CO2 (Walther et al. 2010)
      1. T-dependent development has led to shift in phenology in wild southern population
      2. South larvae have higher C:N = higher protein:lipid and increased fitness
      3. Narrowing of thermal tolerance at increased CO2
7. Conclusion
   1. Inter-population differences in echinoderm response to OA (Dupont et al. 2010)
   2. Broadcast spawning may provide key for long-term adaptation