1. Introduction
2. Background on Plasticity vs. Genetic Change
   1. Shifts in phenotype during adaptation can be caused by changes in genotype (microevolution) or phenotypic plasticity (Visser 2008)
   2. Plasticity is beneficial in a variable environment
   3. Plasticity is also a response to selection, but not an evolutionary one
   4. Plasticity occurs within a generation, microevolution occurs across generations
   5. Adaptation is beneficial when there is directed environmental change
   6. Two definitions of phenotypic plasticity: 1. Ecological important, a normal evolutionary trait that is subject to selection, and 2. A developmental process that facilitates evolution. (de Jong 2005)
      1. Plasticity can differ in the degree of environmental specialization: discrete or operates over a gradient
      2. A reaction norm can widen or shift
      3. Plasticity could delay evolution or adaptation to a large environmental change could be aided by plasticity
   7. Canalization is the opposite of plasticity. Canalization occurs when a trait is buffered against genetic variation and is revealed when a mutation creates major variance in a trait with respect to the wild type. Also can be revealed by changing environmental conditions. It is more likely to occur for traits that are important for fitness (Wagner et al. 1997).
3. Review of Examples of Genetic Basis to Phenotypic Change
   1. Guppies (*Poecilia reticulata*) transplanted from high to low predation site. Maturation occurred later and at larger size; fewer, larger offspring; fewer resources towards early life reproduction (over period of 11 years). But males changed faster than females for some traits. Differences in rates between sexes attributed to differences in heritabilities of traits since females had lower genetic variability for age and size at maturity. (Reznick et al. 1997)
   2. Pitcher plant mosquito *Wyeomiya smithii* collected from FL to Canada. Larval diapause is determined by photoperiod and critical photoperiod signaling onset and maintenance of diapause is a heritable trait. (Bradshaw & Holzapfel 2001)
      1. From 1972-1996 – shorter critical photoperiods, with shift more pronounced in the north than south
      2. Genetic variability of photoperiodic response is higher in the N; faster evolutionary response of northern populations due to stronger directional selection and greater capacity to evolve
   3. After 1977 drought on Daphne Major, *Geospiza fortis* had to switch to larger seeds and main beak size of population increased. In 1982, arrival of *G. magnirostris* and competitive exclusion of *fortis* from larger seeds. Exclusion and heavy rains (smaller seeds) led to decrease in mean beak size in 2004. There was extensive mortality pre-adaptation in both cases. (Grant & Grant 2006)
   4. Cod, *Gadus morhua*, response to fishing pressure – induced change or plasticity? Intense fishing prompted evolution of life history traits (earlier female maturation) and closure of the fishery halted the evolutionary trend (Olsen et al. 2004)
      1. Fishing selected for early- small-maturing genotypes; moratorium on fishing in 1993 seems to have reversed that selection pressure
      2. Evidence = decline in reaction norms
   5. *Tamiasciurus hudsonicus*: plasticity in response to food abundance to make breeding date earlier. Also genetic change to select for earlier breeders. Combined effects of within generation phenotypic change and between generation microevoultionary change resulted in large and rapid phenotypic response (Réale et al. 2003)
   6. Between 1973 and 1995 mean daily spring T increased along with advancement in caterpillar biomass, but great tit (*Parus major*) laying date did not increase. Climate change may not act uniformly on when the tit decides to lay and when resources are available for offspring, i.e. mean T did not increase for time period when decision to lay occurs (Visser et al. 1998)
   7. Observations of female great tits 1973-2004 that lay in more than one year. Average population phenotype: lay earlier after warm spring. There is significant inter-female difference in the estimated laying date at average spring temperature and in magnitude of response to temperature. Significant genetic variation and heritability for laying date plasticity and females with greater plasticity had greater fitness. Selection has increased over time period of caterpillar phenological shift and plastic females breed in closer synchrony with resources for offspring. (Nussey et al. 2005)
   8. Strong directional selection for earlier breeding phenotype in great tits, but change in egg laying date corresponds only to plasticity. Over 31 years, small evolutionary response of 1.5 days change in egg laying. Detection of microevolution near impossible because of breeding response to environmental variation. Strength of selection was reduced by: high adult survival, sex limitation (only females measured), low heritability. (Gienapp et al. 2006)
4. Interactions Between Genetic Adaptation and Phenotypic Flexibility Under Changing Environmental Conditions
   1. Two selection events on Darwin’s finches, *Geospiza* spp., 1976-66 and 1984-86. The first selected for larger size in 6 measurements. The second selected for smaller size but nutritional differences caused disjoint between observed and predicted outcomes for offspring in 1987 (plasticity and microevolution). Selection affected multiple correlated treats in both instances. (Grant & Grant 1995)
   2. In collared flycatcher relative body mass is an indication of fledgling survival. The trait is under significant positive directional selection and weaker, less consistent stabilizing selection and is heritable. Mean value has decreased from 1981-1999 due to countergradient variation – negative covariance between environmental and genetic influences across a gradient such that the environmental change masks the genotypic change. Microevolution is hidden by environmental influence on condition index, probably asynchrony with food. (Merilä et al. 2001)
   3. Collared flycatcher *Ficedula albicollis*: laying date changed significantly with North Atlantic Oscillation index, females bred earlier after warm, moist winters. In following individuals over multiple breeding seasons with different climates, discovered that laying response to NAO is purely plastic (Przybylo et al. 2000)
   4. Genetic adaptation can be slow. Two cases of phenotypic plasticity allow for adaptation to climate change quickly: learning and maternal effects (Visser 2008)
      1. These reactions will no longer be adaptive if there is uncoupling of environmental variables
5. Conclusions
   1. Need long term studies to determine effects of genetic change
   2. Traits are plastic if important for life history and need to be flexible
6. Rate of evolution
   1. Herbaceous species introduced to N America and Europe show genetic differentiation and clinal variation in response to climate change over decades-century. Climate change affects species differently through a range (mid vs edge) and dependent upon steepness of environmental gradient. If the gradient is steep, gene flow could inhibit adaptation in the periphery. (Davis et al. 2005)
   2. Genetic change in critical photoperiod of *Wyeomyia smithii* changed over 5 years (Bradshaw & Holzapfel 2001)
   3. Lake whitefish: differential expression between liver transcriptomes of sympatric dwarf and normal whitefish. Normal increased expression of protein synthesis and dwarf increased expression of energy metabolism, immunity, and DNA repair and replication. There was an absence of a correlation between sequence divergence at polymorphic sites and gene expression diversity. The gene expression divergence mirror life history trade-offs: dwarf have high metabolic rate; normal put more energy into growth. The higher immune gene expression in dwarf could be the underlying mechanism of population divergence and speciation (Jeukens et al. 2010)