Introduction

The Earth's systems are interconnected. The hydrosphere, atmosphere, and biosphere are engaged in a complex interplay that ultimately governs life on Earth. The connection between the El Niño Southern Oscillation and the genetic changes that have occurred in populations of Darwin's finches on the Galápagos Islands is a case study that highlights how deeply Earth's systems are interconnected.

Background Information

El Niño Southern Oscillation refers to the irregular-yet periodic alternations of atmospheric Walker circulation convection cells that generate the prevailing equatorial surface flows known as the trade winds. The trade winds push water in the equatorial Pacific from the east, off the west coast of South America, to the western Pacific, Indonesia and Australia. As the water is moved to Indonesia it is warmed by the direct solar angle of incidence and when it arrives in Indonesia it rises, expands, cools, condenses to form clouds, and precipitation occurs. This explains why tropical rainforests that are emblematic of this region. Then the air, after releasing its moisture in the western Pacific flows back east in the high altitude component of the Walker circulation cell. Finally, the now cool dry air descends back onto the west coast of South America and the eastern equatorial Pacific, completing the circle. Tropical rainforests with heavy annual precipitation in the western Pacific and cool semi-arid to drought conditions in the eastern Pacific characterize what are referred to as normal, or non-El Niño conditions. Every two to seven years this circulation reverses bringing torrential rains to the eastern equatorial Pacific, this is known as an El Niño event. (Ahrens, 2003; Smith & Southard, 2005)

During the past 100 years considerable morphological and genetic changes have occurred in populations of Darwin's finches on the Galápagos Islands (Farrington & Petren, 2011). Peter and Rosemary Grant, along with Lisle Gibbs, have observed populations of Darwin's finches on the Galápagos Island of Daphne major for more than 40 years (Grant & Grant, 2014; Gibbs & Grant, 1987a). On frequent and regular intervals they collected data on six measurable traits based upon body size, beak size, and beak shape, giving them valuable insights into the adaptive radiation (diversification of organisms; filling of different ecological niches) of several species of finches (Grant & Grant, 2002).

Important ecological and evolutionary changes in populations of Darwin's finches have been observed as a result of climatic variations that are associated with prominent El Niño events in the equatorial Pacific (Gibbs & Grant, 1987b; Farrington & Petren, 2011). Microevolutionary changes in populations of Darwin's finches were shown to result from ecological shifts in assemblages of plant communities, resulting in environmentally selective pressure on finch populations (Grant & Grant, 1993). In their research Gibbs, Grant, and Grant observed changes in the highly heritable traits of body and beak size in populations of *Geospiza fortis* commonly known as medium ground finches (Gibbs & Grant, 1987a; Grant & Grant, 2002). These changes in *Geospiza fortis* body and beak size were the direct result of a shift in type and abundance of food supplies that stemmed from the changes in plant communities on Daphne major (Grant & Grant, 1993). El Niño Southern Oscillation has influenced gene flow of heritable

traits in *G. fortis* by exerting environmental directional pressure on populations of medium ground finches, thus influencing the evolution of the species.

During a prolonged drought (non-El Niño conditions) that occurred essentially from 1976 to 1982 natural selection favored larger body and beak size (Seger, 1987). This is due to the fact that plant communities of the Galápagos, characterized by small ground-hugging cacti, that produced large hard seeds, are generally well adapted to arid conditions and can withstand prolonged periods of drought that are prevalent during non- El Niño conditions in the Eastern Pacific (Grant & Grant, 1993). During drought conditions when food supplies are low and large hard seeds are the most abundant food source, large adult body and beak size are favored because only large birds can crack open these large, hard seeds (Gibbs & Grant, 1987a). During this drought period there was heavy mortality among the small beaked finches resulting in a larger mean beak size in the succeeding generations of the *G. fortis* population (Grant & Grant, 2006). As such, when selected heritable traits are transferred to the next generation, evolution occurs (Grant & Grant, 1993).

In November 1982 an extraordinarily strong El Niño event brought eight months of substantial precipitation to the eastern Pacific lasting until July 1983, resulting in rapid vegetation growth from generally unrepresented species, during drought conditions (Grant & Grant, 1993). In response to the abnormally high rainfall, plant growth increased intensely, unrestrained growth of vines smothered cacti triggering a decline of the dry season food supply (large hard cactus seeds) and resulted in a corresponding increase in new seed production, in this case, small soft seeds (Gibbs & Grant, 1987b; Grant & Grant, 2002). Since small birds with smaller beaks are more efficient in handling small seeds, birds of this phenotype were favored in terms of natural selection (Seger, 1987).

A large die-off, comprised mostly of larger birds that could not effectively mange to eat the abundant smaller seeds, occurred during and after this El Niño period (Gibbs & Grant, 1987a). Due to the enormous seed production that occurred during the this El Niño event small seeds were abundant in the two years that followed, initiating a great breeding increase within bird populations that continued into the post El Niño period from 1984-1985 (Seger, 1987). During this post El Niño period small adults with smaller beaks survived more than large adults with larger beaks (Gibbs & Grant, 1987a). Therefore, highly heritable traits such as small beak size were selectively favored, as large seeds became limited, and Grant and Grant (1993) observed succeeding generations of *G. fortis* inheriting and transmitting these traits to their offspring. Thus, populations of surviving medium ground finches (*G. fortis*) were characterized by small body size and small beak size (Grant & Grant, 1993).

The populations of Darwin's finches on the Galápagos Islands offer are an ideal natural system in which to study adaptive radiation and natural selection (Farrington & Petren, 2011). The work of Gibbs, Grant, and Grant demonstrates natural selection occurring in response to environmental pressure in a relatively short period of time (Grant & Grant, 2002). In the face of a changing global climate understanding how species populations adapt to environmental pressure is imperative.