School of Biological Sciences

BIOL20212

DARWIN’S FINCHES COURSEWORK

HOW CAN DATA ON CHANGES IN BILL MORPHOLOGY OF DARWIN’S FINCHES DURING A POPULATION CRASH BE USED TO ILLUSTRATE THE FOUR POSTULATES OF EVOLUTION BY NATURAL SELECTION AND MICROEVOLUTIONARY CHANGE?

1876793

**Abstract (150 words)**

Peter and Rosemary Grant conducted research exploring the microevolutionary changes among Darwin’s finches in the Galapagos archipelago for forty years. The islets act as a microscope whereupon adaptive radiation and the pressures of natural selection can be documented and quantified by observing the many tagged finch species native to the islands such as *Geospiza fortis*. This paper navigates the four postulates of evolution: variability within species, variation heritability, more offspring being produced than surviving to breed, and survival being non-random. By interpreting subsets of the Grants’ contemporary data on the finches of islets Daphne Major and Santa Cruz, variation, heritability, and selection pressures are quantified and attributed evolutionary significance. In focus, a positive directional selection event occurred as a consequence of a “La Niña” drought in 1977 and favoured the *G. fortis* populations with deeper bill depths over small billed finches reliant on scarce small seeds as a food source.

**Introduction**

Peter and Rosemary Grant alongside a team of volunteers and co-workers conducted one of the most recognized studies on evolution and natural selection pertaining to Darwin’s finches in the Galapagos islands (Grant and Grant, 2006). Darwin’s finches are a core example of adaptive radiation which occurs when a singular common ancestor diversifies rapidly and evolves into distinct species. The diversification is typically a result of a change in the environmental factors such as climate, competition, and resources (Reaney et al. 2020). The Galapagos archipelago provide the environment appropriate for investigating adaptive radiation, as closely related species are scattered across the islands to separate and be reintroduced over time. The islands are located by the equator and regular witness dramatic interannual climate events with years of rain or drought that alter the ecological conditions for the finches (Grant, 2004). Furthermore, the islands are almost entirely exempt from human inhabitation and the introduction of new animals and plants, providing a controlled environment to observe the selected species of medium ground finch *Geospiza fortis* (Grant, 2004). “What an extraordinary triumph for the Grants, to have followed in Darwin’s footsteps and to have seen Darwin’s process unfold not in the lapse of ages but in the lapse of weeks and months- and in Darwin’s islands with Darwin’s finches” (Weiner, 1999, xii). Nearly all these finches on islet Daphne Major were marked and measured over forty years to subsequently reveal the rapid and intense directional and oscillating natural selection forces they experience in their beaks (Grant and Grant, 2002). The beak of a bird is instrumental in maneuvering food. Differences in feeding technique and success can be attributed to the diversity of detail in birds’ beaks size, length, shape, skull structure, curvature, and musculature (Grant and Grant, 2011). Collecting nutrition from flowers, insects, nuts, and seeds, even among finches alone, beak morphologies are diversified to perform their individualistic feeding systems. *G. fortis*, a medium ground finch feeds on small and softer varieties of seeds with typical beaks deep at the base to crack the shells. Within the species, a difference in diet is observed, where populations with larger beaks additionally, access a selection of bigger, harder seeds which allowed them to survive the 1977 drought event.

**Postulate 1: Individuals Within Species are Variable**

The first postulate addresses the occurrence of variation among individuals within a species. Variation in a population is generated by or recombination between chromosomes or migration. Synonymous or silent mutations change a nucleic base but do not alter the amino acid produced and thus remain visibly “quiet” in an organism’s phenotype and evolutionarily neutral (Chu and Wei, 2019). In contrast, non-synonymous mutations do change the amino acids produced and incur variation and natural selection pressures. Mutations create new alleles, and the shuffling of alleles upon chromosome crossover results in a source of new variability. Variation occurs continuously or discretely, with either multiple genes or a singular gene affecting the expressed trait, respectively (Griffiths et al. 2000). The length of bill depths (mm) is observed as continuous variation among the species *G.fortis*. Variation can also be driven by environmental forces such as climate and diet as applies in the case of Darwin’s finches. Following a “La Niña” drought in 1977 on the islets Daphne Major and Santa Cruz, the variation and means for bill depth (mm) were observed among *G. fortis*. On Daphne Major the *G. fortis* group that survived had a mean bill depth of 10.09mm, and the group that died had a mean bill depth of 9.59mm (Table 1). The standard deviation was 1.03mm for the *G. fortis* finches that survived and 1.05mm for the *G. fortis* finches that died on Daphne Major. Figure 1 demonstrates the variation in bill depths (mm) and its frequency within individuals of the species *G. fortis* on Daphne Major and Santa Cruz (A). The variation in bill depths among surviving *G. fortis* on Daphne Major was between 5.82-13.82mm (B). Among deceased *G. fortis* on Daphne Major the bill depth ranged between 5.85-13.88mm. The *G. fortis* finches on Santa Cruz (dead and survived) had a mean bill depth of 10.77 mm, a standard deviation of 1.02mm, and variation ranging from 8.47-13.49mm (C). Mean bill depth of the population (dead and survived) on Daphne Major was 9.65mm while the population on Santa Cruz had beaks of 10.77mm. The variability within *G. fortis* beak morphology across the archipelago can further be attributed to reduced food resources, environmental diversity, and the energetic reward for feeding on small vs. large seeds between Daphne and Santa Cruz (Boag and Grant, 1983). The 1977 drought shed light on *G.fortis’* diet and its relationship with variability among the population. The finches’ food resource, predominantly seeds, depends on rainfall for proliferation. The finches hold a preference toward small seeds when in abundance and consequentially struggle upon these seeds becoming scarce at the occurrence of drastic climatic events such as a “La Niña” drought. It is only the larger-beaked individuals within the same species that are able to crack or rip the woody tissue of the larger and sturdier seeds available in the dry climate (Grant and Grant 2006). Therefore, individuals within a species vary, and it was the individuals with larger beaks (deer bill depths) over smaller ones that did not suffer a population crash as severe.

**Postulate 2: Variation Heritability**

Upon the 1977 population crash, it was the finches with deeper bill depths that survived to produce offspring and pass on unique traits. Microevolutionary responses to directional selection can be predicted based on heritable variation of quantitative traits such as bill depths (Grant and Grant, 1995). Heritability occurs when genes are passed to offspring and often independently of other genes. Only mutations occurring in the germline are passed to next generation offspring, not those occurring in somatic cells (Griffiths et al. 2000). To determine heritability of certain bill depths (mm), the midparent bill depth was plotted against the offspring bill depth in Figure 2. The midparent bill depth had a positive correlation against the offspring bill depth (General Linear Model, =0.52, F1,20= 21.93, p<0.001). The slope of the regression line ( measures narrow-sense heritability, the genetic resemblance between *G. fortis* parents and offspring, where 1 is a perfect value for heritability. The trait for bill depth resulted in a high probability of heritability at 77% and thus strongly suggests it occurs at the germline. The slope at 0.77 > 1 represents positive natural selection, the tendency for an increased frequency in advantageous traits among a population during adaptive evolution, as Darwin’s finches experienced (Schaffner et al. 2008). The trait is both heritable and beneficial to this species*,* as it allows for protecting and securing food, and thus accounts for positive selection among *G. fortis. G. fortis’* large body size and bill depth are two traits that are genetically correlated (Grant and Grant, 1995). A large body size and pertaining large beak are favourable to defend food, especially in scarcity events such as the 1977 drought. Yet, energy and forces concentrated into narrow bills among smaller birds provide an evolutionary advantage as well. (Grant and Grant, 2006). These traits thus respond to selection pressures together but can’t arrive at an optimum for both bill width and depth as they are evolutionarily contradictory. The evolutionary trade-off that smaller finches with short bill depths inherited in comparison with their larger-bodied and deep billed counterparts attributed to their population crash. The smaller finches conserved energy in a compact body, but were entirely unable to feed on larger seeds, excluding themselves from a food source and leading to a mass starvation episode. Meanwhile, larger finches exceeded necessary energy expenditure to sustain a bigger body but inherited the deep bill depth to access the only available food source and survive: large seeds (Hairston et al. 2005).

**Postulate 3: More Offspring are Produced than Survive to Breed**

Selection favoured traits that enhanced foraging success among the finches. The mortality rate was 88.02% among *G. fortis* finches on Daphne Major following the 1977 drought, where finches alive n= 90, and dead n= 661. The small bill depth was selected against and caused for a population crash as the finches’ generation starved to death and could not compete with size for resources. Thus, in most generations, more offspring are produced than can survive to increase the chances of securing reproduction within the constraints of limited food resources, lodging space, and mates (National Academy of Sciences, 1999).

**Postulate 4: Survival and Reproduction are Non-Random**

The individuals with the highest reproductive success demonstrate evolutionary fitness and carry the most favourable variations resulting in their “natural selection”. Differences in bill depth between Daphne Major finches that survived the population crash versus those that died were tested. The differences between the means of the independent sample of alive and deceased populations were calculated at U= 20156, N1=751, N2= 43, P<0.001 with a Mann-Whitney test because both datasets were not normally distributed. The means of the samples differed from 9.59mm in the deceased sample to 10.09mm in the alive sample. Positive selection took place among *G. fortis* with a strength of selection of 0.44 mm following the drought. The selection favoured the finches with deeper bill depths as they could feed on larger seeds whereupon the small and soft seeds that short billed finches were dependent on were depleted. Evolution is a response (R) to selection occurring between generations, calculated by the quantified strength of selection (0.44 mm) combined with the genetic variation of the bill depth trait (77%), where R=0.33mm. Therefore, the next generation’s offspring should reflect an increase in 0.33 mm. As droughts bring scarcity in food and seed diversity, the diets of Daphne Major finches diverge further apart as represented by the populations’ different bill depths. These dietary differentiations are not as distinct within a species as among two sympatric species but can still be observed among *G. fortis’* small and larger bill depth populations. (Grant, 1999). Future studies may observe whether speciation occurs with the appearance of sympatry among these two populations as their competitive interaction for food is subdued with divergence in beak morphologies in a character displacement event (Grant and Grant, 2011).

**Additional Exercise No. 1**

The mean bill depths differed between the finches (dead and alive) on the two islets, where 9.65mm occurred on Daphne Major and 10.77mm occurred on Santa Cruz, and with standard deviations of 1.06mm and 1.02mm respectively. U= 6782, N1=751, N2= 43, P<0.001 applying a Mann-Whitney test because one dataset was not normally distributed. On Santa Cruz *G. fortis* coexists with *G. fuliginosa*, a smaller species with the tiniest beak and bite force. This co-habitation affects beak morphology of *G. fortis* in competition for food as the two have some dietary overlap and must compete over dependence on small seeds, this could select for a bigger body size in *G. fortis* or selection for a deeper bill depth in *G. fuliginosa* (Leon et al. 2020).

**Additional Exercise No. 2**

For finches (dead and alive) on Daphne Major the coefficient of variation (CV) = 10.99%, while for finches (alive) on Daphne Major CV= 10.2%. The CVs highlight there was 0.79% higher variation among finches (dead and alive) over solely finches (alive). This suggests natural selection reduces genetic variability with population crashes such as that in 1977.

**Conclusion**

The Grants analysed quantitative microevolution of *G. fortis* after extreme weather events to assess their responses and measure evolution in action. “La Niña” drought of 1977 triggered a population crash among small billed *G. fortis*, while deep billed variations in the population survived to breed and pass on the highly heritable bill depth trait. Selection produces a change in trait distributions within a generation and evolution produces this change in trait distributions between generations. The Grants’ research documented a positive directional selection force in action and saw the next generation *G. fortis* naturall*y* selected for deep bills that crack open larger seeds and outcompete other finches when food loses its abundance in dry seasons. “Only now, to work like the Grants’, are we realizing the full fascination and importance of untouched places and biotas- even as we watch so many of them disappear forever” (Weiner, 1999, xiii). The four postulates were computationally analysed and frame the importance of Darwin’s finches and the isolated Galapagos in contribution to the most acclaimed research in contemporary evolution.

**Figures and Tables**

Table 1. Mean bill depths and standard deviations of three groupings of medium ground finches, *G. fortis*, observed on islets Daphne Major and Santa Cruz in 1977.

|  |  |  |
| --- | --- | --- |
|  | Mean Bill Depth (mm) | Standard Deviation in Bill Depth (mm) |
| Daphne Major *G. fortis* that Survived | 10.09 | 1.03 |
| Daphne Major *G. fortis* that Died | 9.59 | 1.05 |
| Santa Cruz *G. fortis* | 10.77 | 1.02 |

Chart, histogram

Description automatically generated

Figure 1 (A, B, C). Bill depth frequency distribution occurring in Medium Ground Finches (*Geospiza Fortis*) following the 1977 drought on the islet of Santa Cruz (C) (N=13), and on the islet of Daphne Major split into individuals that survived (A) (N=90) and died (B) (N=661).

Chart, scatter chart

Description automatically generated

Figure 2. Heritability relationships between offspring bill depth and midparent bill depth on the islet of Daphne Major fitted with a regression line (N=22).

**References**

BOAG, P.T. and GRANT, P.R. (1984). The classical case of character release: Darwin’s finches (Geospiza) on Isla Daphne Major, Galápagos. *Biological Journal of the Linnean Society*, 22(3), pp.243–287.

Chu, D. and Wei, L. (2019). Nonsynonymous, synonymous and nonsense mutations in human cancer-related genes undergo stronger purifying selections than expectation. *BMC Cancer*, 19(1).

De León, L., Podos, J., Gardezi, T., Herrel, A. and Hendry, A., 2014. Darwin's finches and their diet niches: the sympatric coexistence of imperfect generalists. *Journal of Evolutionary Biology*, 27(6), pp.1093-1104.

Fitch, W.T. (2012). Evolutionary Developmental Biology and Human Language Evolution: Constraints on Adaptation. *Evolutionary Biology*, 39(4), pp.613–637.

Gibbs, H. and Grant, P., 1987. Ecological Consequences of an Exceptionally Strong El Nino Event on Darwin's Finches. *Ecology*, 68(6), pp.1735-1746.

Grant, P., 2002. Unpredictable Evolution in a 30-Year Study of Darwin's Finches. *Science*, 296(5568), pp.707-711.

Grant, P.R. (2006). Evolution of Character Displacement in Darwin’s Finches. *Science*, 313(5784), pp.224–226.

Grant, P.R. (2017). *Ecology and evolution of Darwin’s finches*. Princeton, New Jersey: Princeton University Press.

Grant, P.R. and B Rosemary Grant (2011). *How and why species multiply : the radiation of Darwin’s finches*. Princeton, N.J. ; Woodstock: Princeton University Press.

Grant, P.R. and Grant, B.R. (1995). PREDICTING MICROEVOLUTIONARY RESPONSES TO DIRECTIONAL SELECTION ON HERITABLE VARIATION. *Evolution*, 49(2), pp.241–251.

Grant, Rosemary. (2003). Evolution in Darwin’s Finches: a review of a study on Isla Daphne Major in the Galapagos Archipelago. *Zoology*, 106(4), pp.255–259.

Griffiths, A., Miller, J. and Suzuki, D. (2000a). An Introduction to Genetic Analysis. *NCBI*, 2nd Edition.

Griffiths, A., Miller, J. and Suzuki, D. (2000b). Somatic versus germinal mutation. *NCBI*, 7th Edition.

Hairston, N.G., Ellner, S.P., Geber, M.A., Yoshida, T. and Fox, J.A. (2005). Rapid evolution and the convergence of ecological and evolutionary time. *Ecology Letters*, 8(10), pp.1114–1127.

HERREL, A., PODOS, J., HUBER, S.K. and HENDRY, A.P. (2005). Bite performance and morphology in a population of Darwin’s finches: implications for the evolution of beak shape. *Functional Ecology*, 19(1), pp.43–48.

National Academy of Sciences (US) (1999). *Evidence Supporting Biological Evolution*.

NCBI.Reaney, A., Bouchenak‐Khelladi, Y., Tobias, J. and Abzhanov, A., 2020. Ecological and morphological determinants of evolutionary diversification in Darwin's finches and their relatives. *Ecology and Evolution*,.