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Sex and Diversity

All species have genetic diversity—their biological rainbow. No exceptions. Biological rainbows are universal and eternal. Yet biological rainbows have posed difficulties for biologists since the beginnings of evolutionary theory. The founder of evolutionary biology, Charles Darwin, details his own struggle to come to terms with natural variation in his diaries from *The Voyage of the Beagle*.[1]

In the mid 1800s, living species were thought to be the biological equivalent of chemical species, such as water or salt. Water is the same everywhere. Countries don't each have water with a unique color and boiling temperature. For biological species, though, often each country does have a unique variant. Darwin saw that finches change in body size from island to island in the Galápagos. We can see that robins in California are squat compared to robins in New England, and lizards of western Puerto Rico are gray compared to the brownish ones near San Juan. Darwin recognized that the defining properties of biological species, unlike physical species, aren't the same everywhere. This realization, new and perplexing in the mid 1800s, remains at times perplexing today.

In Darwin's time, the Linnaean classification system, which is based on phyla, genera, species, and so forth, was just becoming established. Naturalists mounted expeditions to foreign places, collecting specimens for museums and then pigeonholing them into Linnaeus's classification system. At the same time, physicists were developing a periodic table for elements—their classification scheme for physical species—and chemists were classifying recipes for various compounds on the basis of chemical bonds. But the biological counterpart of physical classification didn't work very well. If Boston's robin is different San Francisco's, and if intermediates live at each gas station along Route 80, what do we classify? Who is the "true" robin? What does "robin" mean? Biological names remain problematic in zoology and botany today. Biological rainbows interfere with any attempt to stuff living beings into neat categories. Biology doesn't have a periodic table for its species. Organisms flow across the bounds of any category we construct. In biology, nature abhors a category.

Still, a robin is obviously different from a blue jay. Without names, how can we say whether it is a robin or a blue jay at the bird feeder? The work-around is to collect enough specimens to span the full range of colors in the species' rainbow. Then specialists in biological classification, taxonomists, can say something like, "A robin is any bird between six and seven inches in length with a red to orange breast."[2] No single robin models the "true robin"; *all* robins are true robins. Every robin has first-class status as a robin. No robin is privileged over others as the exemplar of the species.

DIVERSITY—GOOD OR BAD?

Rainbows subvert the human goal of classifying nature. Even worse, variability in a species might signify something wrong, a screwup. In chemistry a variation means impurity, a flaw in the diamond. Doesn't variability within a species also indicate impurity and imperfection? The most basic question faced by evolutionary biology is whether variation within a species is good in its own right or whether it is simply a collection of impurities every species is stuck with. Evolutionary biologists are divided on this issue.

Many evolutionary biologists are positive about the rainbow. They view it as a reservoir of genes that can come to the forefront at different times and places to guarantee a species' survival under changing conditions. The rainbow represents the species' genetic assets.[3] According to this view, the rainbow is decidedly good. This view is optimistic about the capability of species to respond to ever-changing environmental conditions. This view affirms diversity.

Other evolutionary biologists are negative about the rainbow, believing that all gene pools—even our own—are loaded with deleterious mutations, or bad genes. During the 1950s, studies claimed that every person has three to five lethal recessive genes that would surface if they chose the wrong marriage partner, causing their children to die.[4] This view is pessimistic about the future, suggesting that evolution has already reached its pinnacle and all variation is useless or harmful.[5] This school of evolutionists believed in a genetic elite, advocating artificial insemination from sperm banks stocked with genes from great men. This view represses diversity.

Darwin himself was ambivalent on the value of rainbows. Darwin argued that natural selection is the mechanism that causes species to evolve. On the one hand, because natural selection depends on variation, Darwin viewed the rainbow as a spectrum of possibilities constituting the species' future. A species without variability has no evolutionary potential, like a firm with no new products in the pipeline. On the other hand, Darwin viewed females as shopping around for mates with desirable genes while rejecting those with inferior genes. This view demeans the variation among males and implies a hierarchy of quality, suggesting that female choice is about finding the best male rather than the best match. Darwin both affirmed and repressed diversity at different times within his career.

The philosophical conflict over whether to affirm or to repress diversity is still with us today, permeating everything from the way biologists interpret motives for an animal's choice of a particular mate to how medical doctors handle newborn babies in the hospital.

THE COSTS VERSUS THE BENEFITS OF SEX

How, then, are we to decide whether rainbows are good or bad? Who is correct, the diversity affirmers or the diversity repressers? To answer this most fundamental question of evolutionary biology, let's compare species with full rainbows to species with very limited rainbows. Species who manage to reproduce without sex have limited rainbows. By sex, I mean two parents mixing genes to produce offspring. Lots of species propagate without sex. In such species, everyone is female and offspring are produced without fertilization. In addition, in many species offspring may be produced either with or without fertilization, depending on the season.

If you go to Hawaii, look at the cute geckoes on the walls. You're seeing an asexual species—all these geckoes are female.[6] Females in all-female species produce eggs that have all the needed genetic material to begin with. In sexual species, like humans, an egg has only half the genetic material needed to produce a baby; a sperm has the other half, so combining these yields the required material. In addition, eggs from an all-female species don't need fertilization by a sperm to trigger the cell divisions that generate an embryo. Females in all-female species clone themselves when they reproduce.

The Hawaiian all-female geckoes are locally abundant and widespread throughout the South Pacific, from the lovely Society Islands of French Polynesia to the Marianas Islands near New Guinea. More all-female species live in Mexico, New Mexico, and Texas—all varieties of whiptail lizards These small, sleek tan and brown-striped animals dart quickly along the ground looking for food. The all-female species of whiptail lizards live along streambeds, while sexually reproducing relatives typically live up-slope from the streams in adjacent woods or other vegetation. Every major river drainage basin in southwestern North America is a site where an all-female whiptail lizard species has evolved. More than eight all-female species are found in this area. Still more all-female species of lizards are found in the Caucasus Mountains of Armenia and along the Amazon River in Brazil. All-female fish occur too. Indeed, all-female animal species are found among most major groups of vertebrates.[7]

Also, some species have two kinds of females: those who don't mate when reproducing and those who do mate. Examples include grasshoppers, locusts, moths, mosquitoes, roaches, fruit flies, and bees among insects, as well as turkeys and chickens.[8] Fruit flies grow easily in the laboratory and are especially well studied. Over 80 percent of fruit fly species have at least some females that reproduce entirely asexually. Although the majority of females in these species reproduce through mating, selection in the laboratory increased sixtyfold the proportion of females not needing to mate, yielding a vigorous all-female strain.[9]

Thus all-female species are well known among animals. So why don't even more all-female species exist? Indeed, why aren't *all* species all-female? To answer this question, let's look at the costs and benefits of reproducing with and without sex.

Sexual reproduction cuts the population's growth rate in half—this is the cost of sex. Only females produce offspring, not males. If half the population is male, then the speed of population growth is half that of an all-female population. An all-female species can quickly outproduce a male/female species, allowing an all-female species to survive in high-mortality habitats where a male/female species can't succeed. (This result is also true in hermaphrodite species, in which the fifty-fifty allocation of reproductive effort to male and female function reduces the female allocation used to make eggs by half.)

The potential for doubling production in an all-female species hasn't escaped the attention of agricultural scientists. In the 1960s, turkeys and chickens were bred to make all-female strains.[10] Indeed, the cloning of a sheep in Scotland reflected a fifty-year-old aspiration to increase agricultural production by taking the sex out of reproduction. However, despite the big advantage in population growth rate that all-female species enjoy and the many examples of all-female species that do occur, clonally reproducing species remain a tiny minority. Far and away most species are sexual. Nature has experimented many times and keeps experimenting with clonal species, but with little success. Sex does work. Why?

The benefit of sex is survival over evolutionary time. Lacking sex, clonal species are evolutionary dead ends. On an evolutionary time scale, almost all clonal species are recently derived from sexual ancestors. On the family tree of species, asexual species are only short twigs, not the long branches.[11] The advantages of sex are also demonstrated by species who can use sex or not, depending on the time of year. Aphids (tiny insects that live on garden plants) reproduce clonally at the beginning of the growing season, switching to sexual reproduction at the end of the season. Aphids benefit from fast reproduction when colonizing an empty rose bush, but the anticipated change of conditions at the end of the season makes sexual reproduction more attractive.[12]

Clonally reproducing species are "weeds"—species specialized for quick growth and fast dispersal, like plants that locate and colonize new patches of ground. The common dandelion of North America is a clonal reproducer whose sexual ancestors live in Europe.[13] Weeds eventually give up their territory to species who are poorer colonizers but more effective over the long term.[14] The geckoes who colonized the South Pacific and the whiptail lizards of New Mexico streambeds make sense in these contexts, where dispersal is at a premium or the habitat is continually disturbed.

Clonal reproduction is a specialized mode of life, not recommended for any species that fancies itself a permanent resident of this planet. But we haven't answered *why* sexual reproduction is good over the long term. Two theories have been offered for why sex benefits a species, one diversity-affirming, the other diversity-repressing. Both theories agree that asexual species are short-lived in evolutionary time relative to sexual species and that sex guarantees the longer species survival. Both theories therefore agree that sex is beneficial to a species. Both theories also agree that the purpose of sex isn't reproduction as such, because asexual species are perfectly capable of reproducing. But the theories have different perceptions of why sex is good. The diversity-affirming theory views diversity itself as good and sex as maintaining that diversity. The diversity-repressing theory views diversity as bad and sex as keeping the diversity pruned back.[15] Let's start with the diversity-affirming theory.

THE DIVERSITY-AFFIRMING THEORY

According to the diversity-affirming theory for the benefit of sex, sex continually rebalances the genetic portfolio of a species. Think of a savings account and jewelry—a rainbow with two colors. How much can both colors earn together? When demand for jewelry is low, one can't sell jewelry, even to a pawnshop, and earning 2 percent from a bank account looks great. When jewelry is hot, interest on a bank account looks cheap and selling jewelry turns a good profit. The overall earnings are the total from both investments.

A species earns offspring instead of money from its investments. The long-term survival of a species depends on being sufficiently diversified to always have some offspring-earning colors. Although biologists may talk about the rainbow as a source of genes for new environments, it is in fact more important for surviving the regular fluctuations between hot and cold, wet and dry, and the arrival and departure of new predators, competitors, and pathogens like the bubonic plague or AIDS.[16]

The social environment within a species is always changing too. Concepts of the "ideal" mate change through time. Among humans, men have sometimes preferred the amply proportioned Mama Casses among us, at other times the skinny Twiggys, as recorded in the portraits of women from art museums. Other aspects of our social environment have also changed over the centuries, like the fraction of time spent with others of the same sex or the opposite sex, or the number of sex partners a person has. Changes in the social setting within a species, as well as changes in the ecological and physical environment, all affect which colors of the rainbow shine the brightest at any one time.

A clonal species can accumulate diversity through mutation, or it may have multiple origins, thereby starting out with a limited rainbow. In fact, several genetically distinct clones have been detected among the South Pacific geckoes and dandelions. Still, these mutation-based and origin-based rainbows are nearly monochromatic.[17]

Furthermore, even the limited rainbow of a clonal species is continually endangered. The colors that shine brightly are always crowding out the colors that don't, causing diversity to contract over time. Recall the jewelry and the savings account. If diamonds are valuable for a long time, their value grows and comes to overshadow the savings account. If profits are automatically reinvested in the most immediately successful venture, the portfolio gradually loses its diversity. Then when the demand for jewelry drops—say because a new find of diamonds floods the market—the portfolio takes a big hit. This progression is similar to that of the clonal reproducer, which courts danger by concentrating on only a few investments. Instead, one should redistribute some earnings each year across the investments. If jewelry has a good year, sell some and put the proceeds in the savings account. If interest is high one year, then withdraw some funds and buy jewelry. Shuffling money across investments in this way maintains the portfolio's diversity, and a bad year for one investment doesn't cause disastrous losses in the portfolio. Wall Street investors call this shuffling "rebalancing a portfolio." This is the strategy of the sexual reproducer. Every generation when sexually reproducing animals mate, they mix genes with one another and resynthesize the colors in short supply. Thus, according to the diversity-affirming theory, sex serves to maintain the biological rainbow, which conserves the species.[18]

THE DIVERSITY-REPRESSING THEORY

According to the diversity-repressing theory for the benefit of sex, sex protects the genetic quality of the species. The diversity-repressing theory envisions that asexual species accumulate harmful mutations over time and gradually become less functional, as though asexual lizards gradually lost the ability to run fast or digest some food. Sex supposedly counteracts this danger by allowing family lines that have picked up harmful mutations to recombine, producing offspring free of bad mutations. According to this theory, some offspring will possess both families' mutations and will die even more quickly, but other offspring will have none of the mutations, and will prosper on behalf of the species. According to this theory, without sex each and every family line inexorably accumulates mutations, leading eventually to species extinction.

ENDING THE DEBATE

Although both the diversity-affirming and diversity-repressing views have a long history, the time has come for closure. The time has come to reject the diversity-repressing view as both theoretically impossible and empirically vacuous. The scenario envisioned by the diversity-repressing theory can't exist. In an asexual species, when a bad gene arises, the line where the mutation originated is lost to natural selection, whereas the lines without the mutation prosper. The entire stock never deteriorates, because natural selection doesn't look the other way while a bad gene spreads. Instead, natural selection eliminates a bad gene when it first appears, preserving the overall functionality of the species. No evidence whatsoever shows asexual species becoming extinct because of a progressive accumulation of disabilities and loss of functionality. A bad gene never gets going in an asexual species, and sex's supposed pruning of the gene pool is unnecessary and mythical.

On the other hand, the environment does change from year to year, and individuals who don't do well one year may shine when conditions change, and vice versa. Butterflies whose enzymes work at cold temperatures thrive in dark, damp years, while butterflies whose enzymes function best at hot temperatures do better in sunny drought years. All butterflies are perfectly good butterflies, even if the abilities of some don't match the opportunities currently supplied by the environment.

I don't see any grounds for dignifying the diversity-repressing view for the benefit of sex as a viable alternative to the diversity-affirming view. To be agreeable, one might say both theories are valid. But this compromise isn't true. Conceding, even slightly, that one function of sex is to prune diversity puts forth a view that hasn't earned its place scientifically. Accepting a diversity-repressing view of sex simply to be polite admits through the back door a philosophical stance that may later be used to justify discrimination.

Therefore, I accept as a working premise that a species' biological rainbow is good—good because diversity allows a species to survive and prosper in continually changing conditions. I further accept that the purpose of sex is to maintain the rainbow's diversity, resynthesizing that diversity each generation in order to continually rebalance the genetic portfolio of the species. I reject the alternative theory that sex exists to prune the gene pool of bad diversity.

Darwinists have to take a consistent stand on the value of diversity. They can't maintain on the one hand that most variation is good because it's needed for natural selection and on the other hand also maintain that females must continually shop for males with the best genes as though most genes could be ranked from good to bad. Instead, I argue that almost all diversity is good and that female choice is more for the best match than for the best male.

How then should we assess the rainbows in our own species? We should be grateful that we do reproduce sexually, although we probably take this gift for granted. I feel too that we should conserve and embrace our rainbows. Affirming diversity is hard, very hard. We must come to accept ourselves and love our neighbors, regardless of color in the rainbow.

Overall, sex is essentially cooperative—a natural covenant to share genetic wealth. Sexual reproduction is not a battle.