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In My Opinion

The Colors of Quail Science

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ABSTRACT Humans engage in 2 modes of thinking: an associative mode and a reasoning mode. Institutions and scientific education primarily have focused on reasoning, even though the associative mode is linked to creativity and has been actively nurtured and used by influential scientists. The inattentiveness by scientific institutions toward associative thinking is such that it has been called the forgotten half of scientific thinking, and few opportunities exist for its professional exercising. I was fortunate to have been granted such an opportunity through an invitation to speak at a symposium honoring the retirement of a noted quail scientist. The symposium directive was simple: complete intellectual freedom to explore any quail topic as long as it was grounded in science. These were ideal and welcomed conditions for engaging in associative thought and nurturing dual thinking—that is, thinking engaging both association and reasoning. Here I provide my scientific reflections. The general themes range from psychology to chaos to dialectical philosophy. Although the topics may seem far removed from quail, I highlight their potential relevancy. I offer these reflections in the spirit of stimulating scientific curiosity in the natural world, as an encouragement to push the boundaries of quail science, and, ultimately, with the hope of encouraging further opportunities for dual thinking in science.

KEY WORDS chaos, creativity, dual thinking, ecological thresholds, quail, reproductive cues, resilience, scientific thinking, tipping points, umwelt.

"*This is not easy to understand*
For you that come from a distant land
Where all the colours are low in pitch–
Deep purples, emeralds deep and rich,
Where autumn's flaming and summer's green–
Here is a beauty you have not seen…"
— Dorothea Mackellar, The Colours of Light

Humans engage in 2 basic modes of thought. Cognitive psychologists have broadly termed these modes System I and System II (Kahneman 2011, Evans and Stanovich 2013). System I operates fast and automatically, with little effort, self-awareness, or control. It is responsible for the formation of impressions, intuitions, and complex patterns of ideas and could be thought of as an associative mode (Kahneman 2011). System II, on the other hand, is slow, deliberate, and analytical. It allocates attention to mental activities that demand effort such as complex computations; it could be thought of as reasoning (Kahneman 2011). Although both modes of thought are critical to science (Root-Bernstein 1989, 2003), institutions and science education have focused almost entirely on reasoning (Glatzeder 2011, Scheffer et al. 2015).

The inattentiveness of scientific institutions toward the associative mode is such that this intuitive, experiential mode has been called the "forgotten half of scientific thinking" (Scheffer 2014: 6119). Such inattentiveness is unfortunate because imagination and the capacity to make novel associations is linked to creativity (Kahneman 2011), a quality that describes many if not all scientific breakthroughs (Robinson 2010). Dual thinking—that is, the use of both the associative and reasoning modes of thought—is integral for creativity (Allen and Thomas 2011, Sowden et al. 2015), and history informs us that some of the most creative and transformative scientists nurtured dual thought (Robinson 2010, Scheffer et al. 2015). Even today, the most impactful investigations are those that are well-grounded in science but possess an infusion of atypical knowledge and unconventional links to other fields (Uzzi et al. 2013). Unfortunately, little opportunity exists for scientists to nurture associative, experiential thought and professionally engage in dual thinking. Convention resists it, and a publish imperative discourages it (Doubleday and Connell 2017, Paasche and Österblom 2019). Yet, calls for broader latitudes in scientific expression continue (Wiens 2016, Freeling et al. 2019).

I was fortunate to have been granted such an opportunity to engage in dual thinking a few years ago. Fred S. Guthery, a noted quail scientist, was nearing retirement, and colleagues were organizing a scientific symposium as his swan song to the quail world. The symposium directive was simple—presenters had complete intellectual freedom to explore any quail topic or issue of their liking, as long as it was grounded in science. It was the ideal mix of association and reasoning—dual thinking—called for by many scientists

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(Uzzi et al. 2013, Scheffer et al. 2015), and I was fortunate to be one of the invited presenters.

I took the symposium theme of complete intellectual freedom to heart, both in thought and in writing. What follow are 3 essays containing perspectives on quail ecology whose general themes range from psychology to chaos to dialectical philosophy. The themes may seem far removed from quail, but they are not. My goal is to highlight their potential relevancy. I offer these reflections in the spirit of stimulating scientific curiosity in the natural world, as an encouragement to push the boundaries of quail science, and, ultimately, with the hope of encouraging further opportunities for dual thinking in science.

PSYCHOLOGY

A few years ago, I read an article discussing human psychology and behavior. The article, *Why Cleaned Wastewater Stays Dirty in Our Minds*, discussed why people in California were refusing to drink cleaned waste water even though it was safe to drink (Spiegel 2011). The public was opposing a proposition that would build treatment plants to clean and reuse waste water to address the state's perennial water problem. Public reluctance was centered around a phenomenon called psychological contagion, which describes the human habit of linking objects to each other once they have been in contact (Rozin et al. 2015). Treated waste water, no matter how clean, remained dirty in the public's mind because it was once in contact with sewage. Carol Nemeroff, a psychologist from the University of Southern Maine collaborating on the research, noted, "It is quite difficult to get the cognitive sewage out of the water, even after the real sewage is gone" (Spiegel 2011).

The article underscored for me the significant role that psychology plays in the life of humans, and it made me ponder if psychology could play such an important role in the rest of the animal kingdom. I was reminded of research by Roger S. Urlich, a professor in the Department of Landscape Architecture and Urban Planning at Texas A&M University, who had been the graduate council representative on my graduate committee. Dr. Urlich investigated the influence of urban design on human well-being. His research had documented that patients assigned to hospital rooms with windows to nature had shorter postoperative stays, received fewer negative evaluations from nurses, and took fewer potent analgesics than patients with windows facing a brick building (Urlich 1984). In revisiting his research, I discovered that extensive literature existed on the influence of natural settings such as gardens, parks, and lakes on human psychology, behavior, and well-being (Cox et al. 2017). For example, Rachel Kaplan, a psychologist with the University of Michigan, documented that employees with views to nature reported greater job satisfaction, greater enthusiasm, and fewer ailments than employees lacking such views (Kaplan 1993). Exposure to nature also alleviated mental fatigue, physical tiredness, and irritability associated with focused, intense office work that exposure to man-made structures could not. Frances E. Kuo, a psychologist with the University of Illinois, noted that green space such as trees and grass cover in inner-city neighborhoods contributed to a greater sense of safety and adjustment, healthier patterns of children's play, and greater use of neighborhood common spaces (Kuo 2003). Green space also contributed to fewer incivilities, fewer property crimes, and fewer violent crimes. The pronounced nature-human phenomenon led me to ponder,

> *If green space has such a profound impact on humans, a species that has been removed from the natural environment for hundreds of years, can a similar effect be present in wild animals, species that still inhabit nature today?*

I wondered whether nature could be influencing quail behavior and, specifically, if green space could explain the highly variable reproductive effort that quail exhibit in semiarid environments of near complete reproductive failure during drought but extraordinary reproductive effort during abundant rain (McMillan 1964, Campbell 1968, Heffelfinger et al. 1999, Hernández et al. 2005).

Birds are thought to rely on 2 basic types of environmental information to time breeding: initial predictive and supplementary (Fig. 1; Wingfield et al. 1992). Initial predictive information provides predictive, long-term information that activates the reproductive system in anticipation of the upcoming breeding season. Photoperiod is considered the primary source of initial predictive information used by birds. Supplementary information, on the other hand, provides predictive, short-term information that

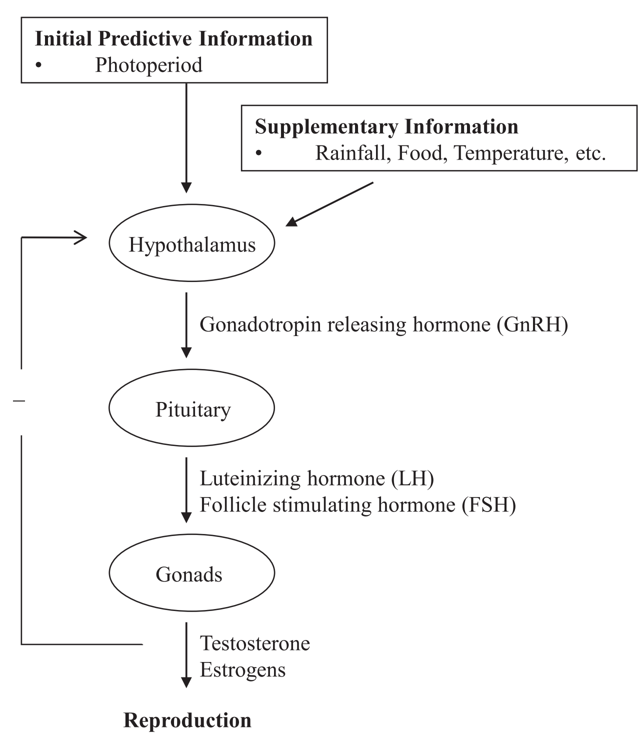

Figure 1. Birds rely on environmental information (initial predictive and supplementary) to time breeding, and they transduce this information via the endocrine system into reproductive behavior (figure adapted from Hau 2001).

fine tunes reproductive effort according to local conditions. Information such as temperature and nesting conditions accelerate or inhibit reproductive development depending on prevailing conditions. Birds receive the information contained within initial predictive and supplementary cues and transduce it into physiological responses that affect reproduction via the endocrine system (Hau 2001). The information provided by these cues is prioritized in a hierarchal fashion: wherein initial predictive information initiates the physiological state in which reproduction can occur, and supplementary information induces the actual reproductive effort (e.g., egg laying; Wingfield et al. 1992).

Given the above, landscape appearance may be providing supplementary information to quail thereby influencing their boom-and-bust dynamics. A landscape characterized by brown, crisp vegetation may be providing a negative reproductive cue and inhibiting reproduction, whereas a landscape characterized by green, lush vegetation may be providing a positive reproductive cue and stimulating reproduction (Fig. 2A,B). If vegetation color is providing a breeding cue to quail, then a change in vegetation color from brown to green, as occurs following rain, should cause an increase in circulating levels of reproductive hormones in quail and induce breeding. The hypothesis is plausible. Rainfall is known to be correlated with elevated levels of reproductive hormones in rufous-winged sparrows (*Aimophila carpalis*; Small et al. 2007), and green vegetation has been documented to stimulate nesting in the red-billed weaver (*Quelea quelea*; Marshall and Disney 1957).

The existence of such a psychological element in the animal kingdom may seem strange; however, it has been a recurring concept in animal ethology for many years. Jakob von Uexküll, a Baltic German biologist studying animal behavior in the 1900s, coined the term umwelt to describe the relation between the objective world and the world as an animal perceives it (Uexküll 1957). According to von Uexküll, animals were not machines, not a mere conglomeration of sensory and motor organs perceiving and responding to stimuli. Animals, rather, possessed an operator which was built into the organism, just as humans. In *A Stroll Through the Worlds of Animals and Men*, von Uexküll (1957:5) wrote,

> *"This little monograph does not claim to point the way to a new science. Perhaps it should be called a stroll into unfamiliar worlds; worlds strange to us but known to other creatures, manifold, and varied as the animals themselves. The best time to set out on such an adventure is on a sunny day. The place, a flower-strewn meadow, humming with insects, fluttering with butterflies. Here we may glimpse the worlds of the lowly dwellers of the meadow. To do so, we must first blow, in fancy, a soap bubble around each creature to represent its own world, filled with the perceptions it alone knows. When we ourselves then step into one of these bubbles, the familiar meadow is transformed. Many of its colorful features disappear, others no longer belong together but appear in new relationships. A new world comes into being…the world as it appears to the animals themselves, not as it appears to us."*

How different ecological inquiry would be, in design and interpretation, if we considered that animals might perceive the world through a psychological lens.

CHAOS

In the spring of 2009, I was assigned to teach a population ecology course as a result of departmental reorganization. Although the new assignment meant preparation for another course, the additional work turned out to be a blessing in disguise that bore fresh and unexpected fruit. Reading for the new course permitted me to become reacquainted with the remarkable work of Robert M. May, a theoretical ecologist from Oxford University, and, more importantly, introduced me to the world of chaos. As most wildlife

(A)

(B)

Figure 2. A) Landscape appearance may be providing supplementary information to quail such that a landscape characterized by brown, crisp vegetation (as occurs during drought) may provide a negative cue and inhibit reproduction, whereas B) a landscape characterized by green, lush vegetation (as occurs during abundant rain) may provide a positive cue and stimulate reproduction. (Photographs by Fidel Hernández).

scientists today, I was largely unaware of the phenomenon and its implications for the biological world.

The discovery of chaos involved chance and a scientist astute enough to recognize the significance of aberrant findings (Gleick 2008). Edward Lorenz was a meteorologist during the 1960s at the Massachusetts Institute of Technology. As told by Gleick (2008), Lorenz was investigating weather prediction and developed a set of 12 equations to model weather. The equations represented the rules of the system and established the precise relationships among a suite of weather variables. To model the weather, Lorenz would define the initial conditions of the system and allow his computer to run the simulation. Computers were slow in those days, and simulations took hours or even days. One day, Lorenz wanted to observe a particular simulation again but over a longer time period. In order to save time, he decided to start the simulation from the middle of the sequence instead of from the beginning. Lorenz noted the numbers from the mid-point of the calculations and entered these as the initial conditions for the new simulation. In theory, the 2 simulations should have been identical given the exact rules of the weather system. However, much to Lorenz's surprise, the second simulation diverged wildly from the original. Lorenz eventually discovered the reason: the computer printout only reported numbers to 3 decimal places, whereas the computer memory stored numbers to 6 decimal places. Lorenz, who had obtained the input numbers from a computer printout, entered 0.506 as the initial conditions for the rerun. The computer, however, had used 0.506127 in the calculations of the original simulation. Such small difference should have been inconsequential, but it was not. The phenomenon—dramatic differences resulting from small changes in initial conditions—came to be known as the butterfly effect (Hilborn 2004). The terminology partly arose from a presentation where Lorenz remarked, "The question which really interests us is whether… two particular weather situations differing by as little as the immediate influence of a single butterfly will generally after sufficient time evolve into two situations differing by as much as the presence of a tornado" (Lorenz 1972). Scientifically, the phenomenon was termed sensitive dependence on initial conditions, and it came to represent the essence of chaos.

In a mathematical context, chaos is stochastic behavior arising within in a deterministic system. Stochastic means random. A deterministic system is one governed by precise rules, which imply repeatability and predictability. In a deterministic system exhibiting chaos, therefore, randomness arises despite exact rules. The phenomenon is not limited to meteorology but appears to occur throughout the universe. It has been investigated in a wide variety of systems ranging from celestial movements to magnetic fields to cellular metabolism (Gleick 2008). The characteristic pattern of chaos is an irregularity of highs and low, much like the boom-and-bust dynamics of many organisms such as lizards (Barrows 2006), rodents (Previtali et al. 2009), ungulates (Simpson et al. 2007), and plants (Tilman and Wedin 1991). The pervasiveness of chaos in nature and the erratic dynamics of quail populations led me to inquire,

Does chaos occur in quail populations?

In contemplating such a question, it is helpful to first address whether chaos can occur in biological populations. The answer, in a theoretical context, is yes. May (1974) discovered chaos in the logistic-growth equation while a professor at Princeton University during the 1970s. The logistic equation models the growth of a population in an environment with finite resources. The equation produces an s-shaped population trajectory that gradually increases towards an equilibrium (carrying capacity) and is the characteristic behavior of the logistic equation. Professor May, however, discovered that the equation was capable of producing a wide spectrum of population behavior through mere changes in the growth-rate parameter. As growth rate increased, population behavior progressed from equilibrium to cyclic oscillations to chaos (Fig. 3A–C). May also documented that the equation exhibited sensitive dependence on initial conditions; populations with the same growth rate but different initial population sizes exhibited drastically different population trajectories. May (1974: 645), recognizing the importance of his finding, remarked, "the implication is that even if the natural world were 100 percent predictable, the dynamics of populations with 'density dependent' regulation could nonetheless…be indistinguishable from chaos, if the intrinsic growth rate r was large enough."

Quail are species with a high reproductive potential (Brown 1989, Gutiérrez and Delehanty 1999, Brennan 2007). Although rare, populations can double from one year to the next under favorable conditions. Density-dependent processes are known to occur in quail populations (Roseberry and Klimstra 1984). Quail therefore represent a biological system in which chaotic dynamics could occur (Fig. 3D).

Investigation of chaos in quail populations is limited. Ralph L. Bingham and Fred S. Guthery, at the time professors of statistics and wildlife, respectively, with the Caesar Kleberg Wildlife Research Institute, reported on unusual dynamics of a simple, quail population model (Bingham and Guthery 1998). Boom-and-bust population dynamics arose from their model in alternate years despite a constant mortality rate and identical recruitment function. Bingham and Guthery's (1998) description of the population behavior is reminiscent of cyclicity, which is the population behavior that precedes chaos in the logistic-growth model (May 1974) and which has been documented in quail (Williams 1963, Roseberry and Klimstra 1984, Thogmartin et al. 2002). The analysis, however, was not a direct evaluation of chaos. A more formal evaluation was conducted by John G. Milton, a physiologist with McGill University, and Jacques Bélair, a mathematician with the University of Montreal. Milton and Bélair (1990) explored noise and chaos in population models using field data from a long-term study conducted by Paul L. Errington on northern bobwhite (*Colinus virginianus*) in Wisconsin (Errington 1945). They reported that, although the population

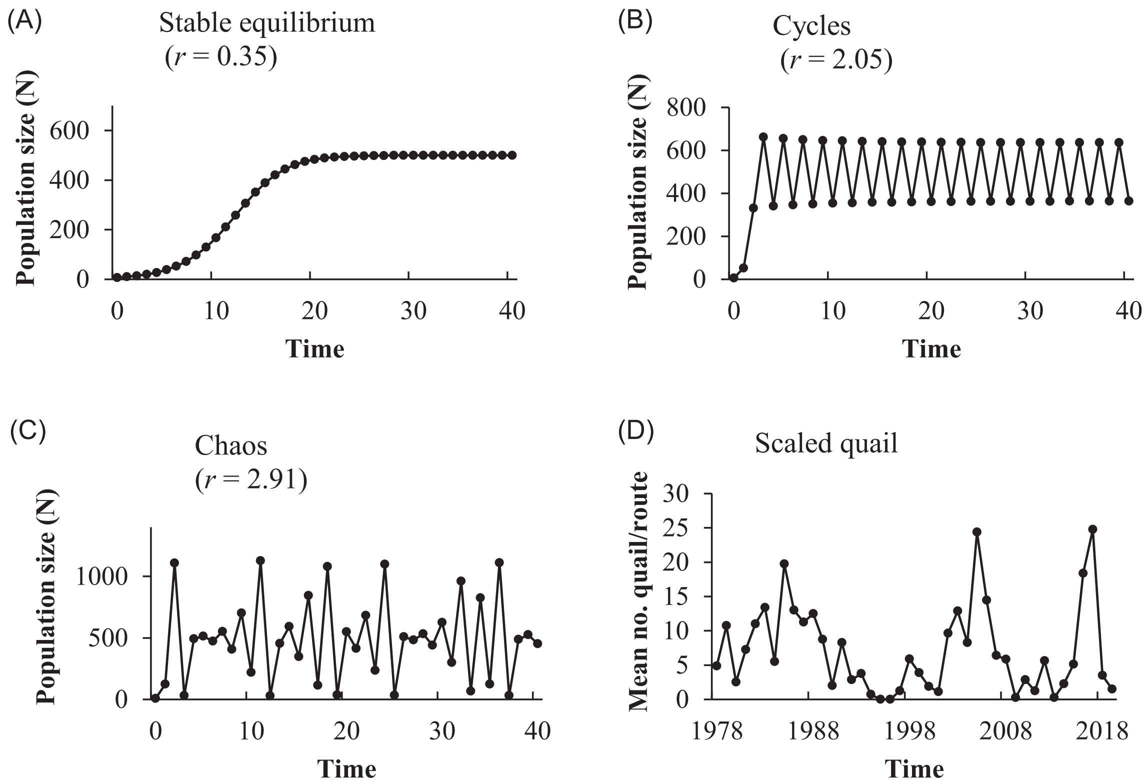

Figure 3. The logistic-growth model can produce a wide range of population behavior. Increases in the growth parameter (r) result in population behavior that progresses from A) stable equilibrium point to B) cycles to C) chaos. D) Quail possess a high reproductive capacity, and their populations exhibit erratic fluctuations that visually resemble chaos. Population simulations were produced using the discrete logistic growth model, $N_{t+1} = N_t e^{r(1-N_t/K)}$, where $N_1 = 7$ and $K = 500$. Data are for scaled quail (*Callipepla squamata*) in the Edwards Plateau ecoregion and were provided by Texas Parks and Wildlife Department.

model derived from Errington's data was capable of producing chaotic dynamics, the population fluctuations observed in the study likely reflected random perturbations. An interesting finding of the analysis was that chaos in the model could arise not only from changes in growth rate but also from changes in other parameters that were influenced by factors such as habitat or disease. Chaos, therefore, could arise even in populations with low growth rates under certain circumstances.

The question of whether chaos exists in quail populations is not purely an academic one. Chaos carries with it significant, real-world implications (May 1989). For example, normal or healthy body rhythms traditionally are thought to be simple, periodic, or homeostatic. However, research suggests that normal body rhythms may not be periodic but rather exhibit chaotic variability, and the loss of variability can represent the onset of disease (Pool 1989). Studies have compared the cardiac rhythm of patients in good health and patients suffering from cardiac diseases. A general finding, although debated, is that healthy cardiac rhythms exhibit chaotic dynamics whereas diseased rhythms exhibit precise periodicity (Goldberger et al. 2002). Other research suggests that the onset of Huntington's or Parkinson's disease can be detected by a change in walking gait or muscular tremors from chaotic to regular (Hausdorff et al. 1997). Ary L. Goldberger, a professor of medicine at Harvard Medical School, believes that chaos provides physiological systems with inherent, bounded variability and affords them robustness and flexibility to external stimuli (Goldberger 1996). In biological populations, chaos may provide similar benefits. For example, Milton and Bélair (1990) noted that quail populations operating in a chaotic regime would be less vulnerable to external perturbations and more resistant to extinction. More generally, Allen et al. (1993) documented that chaos decreased the probability of species extinction for metapopulations that were weakly coupled by immigration and subject to locally varying external noise. Such demographic resilience is analogous to the hypothesized robustness that chaos provides physiological systems. Thus, if loss of variability impairs system health, then attempts to control fluctuations of chaotic populations may weaken system resiliency. Ironically, the reduction of such erratic, population fluctuations is the goal of many quail management programs, and this type of control-and-command approach of reducing system variability characterizes much of natural-resource management today (Holling and Meffe 1996, Fuhlendorf et al. 2017).

Lorenz's discovery of chaos remained unknown to science for many years, buried in the *Journal of Atmospheric Sciences* (Gleick 2008). Slowly, however, chaos found its way into the sciences. Some science historians contend that the 20th century will be known for 3 discoveries—relativity, quantum mechanics, and chaos—each resulting in a scientific revolution (Steward 2002, Gleick 2008). Startlingly, chaos remains a foreign concept to much of the natural-science community. In ecology, chaos has been explored (Tilman and Wedin 1991, Hanski et al. 1993, Cushing et al. 2003) but appears to remain largely unknown and under-appreciated. In wildlife science, chaos remains buried in the annals of a meteorological journal.

DIALECTICAL PHILOSOPHY

Some books arrive with perfect timing; they arrive at precisely the right moment and precisely the right place. When such events occur, they bring with them a certain sense of uniqueness and mystique. *The Tipping Point* by Malcolm Gladwell carried that sense of perfect timing and mystique for me. The book describes how small changes can lead to big differences (Gladwell 2002), as related by Gladwell in an account of New York City crime.

New York City was in the grip of a crime epidemic in the 1980s (Gladwell 2002). During this time, the city averaged more than 2,000 murders and 600,000 felonies per year. The subway system was in a state of disorder: walls and trains were covered with graffiti, floors were littered with trash, fare-beating was rampant, and harassment of subway riders was widespread. Felonies on the subway reached 20,000 per year by the end of the decade, and use of the subway sunk to its lowest point in history. From such a disordered state of affairs, however, things suddenly changed and crime underwent a precipitous decline. Within a span of about 5 years, felonies dropped by about 50% and murders by about 65%. Felonies on the subway declined by 75% by the end of the 1990s. What caused such an unprecedented and swift drop in crime?

Several explanations exist, but one of the most intriguing is outlined by Gladwell (2002), who believed that social phenomena such as ideas, fads, or fashion trends spread through a society similar to how a disease epidemic spreads through a population. A disease can exist in equilibrium within a population, affecting only a small percentage of individuals, until a small change in infection rate or some other parameter tips this equilibrium, and the disease transforms into an epidemic (Anderson and May 1991). Gladwell (2002) termed the point where a phenomenon goes from equilibrium to epidemic (and vice versa) as the tipping point. The tipping point is the threshold where a system toggles between 2 drastically different states, and small changes near this tipping point can push the system in either direction. For New York City, the small changes that led to a state of order appears to have been a clampdown on quality-of-life crimes such as graffiti, fare beating, public intoxication, and other minor crimes indicative of social disorder.

Tipping points exist in many sociological phenomena. For example, research suggests that teen pregnancy and dropout rates are influenced by the percentage of role models (e.g., professionals) in a community, and small changes in the percentage around the tipping point can drastically impact these rates (Crane 1991). Jonathan Crane, a sociologist with the University of Illinois, has documented that teen pregnancy and dropout rates remain relatively unchanged as the percentage of role models in a community decreases from 40% to 5%. However, when the percentage decreases below 5%, teen pregnancy and dropout rates increase dramatically. For African American children, a slight decrease in the percentage of role models in the community from 5.6% to 3.4% results in a near doubling of teen pregnancy and drop-out rates (Crane 1991). The tipping point for teen pregnancy and dropout rates relative to the number of professionals in a community therefore appears to be around 5%.

When I read Gladwell's book, I was reminded of the northern bobwhite decline occurring in the southern Great Plains. According to some local biologists and landowners, quail populations in the region have declined rapidly despite large amounts of habitat and bouts of favorable weather. Such circumstances have caused people to question why bobwhites have declined despite large tracts of habitat and what could have caused such a rapid decline. A popular hypothesis is disease (Dunham et al. 2014). However, I wonder whether a tipping point exists for quail regarding the amount of habitat necessary for population persistence and whether such tipping point has been crossed in the region. That is,

> *Could small amounts of habitat loss through time, imperceptible to humans, have accumulated and crossed a tipping point such that the quail system abruptly transitioned from a state of persistence to one of decline?*

Ecologists have been interested in the question of how much habitat is sufficient for population persistence for many years. Naturally, the answer varies by species, depending on the species' life history and ecology. A common assumption underlying the inquiry has been that the relationship between habitat area and population persistence is linear (Fahrig 2002, 2003). That is, a small amount of habitat loss results in a small decrease in the probability of population persistence, and a large amount of habitat loss causes a large decrease in the probability of persistence. However, research by Lenore Fahrig, a landscape ecologist with Carleton University, suggests that the relationship between habitat area and population persistence may not be linear but rather possess a threshold, where the probability of population persistence goes from 1 to 0 with a small amount of habitat loss near the threshold (Fig. 4; Fahrig 2001). Fahrig (2002) also has documented that habitat fragmentation increases the extinction threshold, such that more habitat area is necessary for population persistence in fragmented landscapes. Trisha L. Swift and Susan J. Hannon, ecologists with the University of Alberta, conducted a literature review of simulation and empirical studies on the concept of extinction thresholds (Swift and Hannon 2010). They reported that available evidence supports 2 general findings: non-linear ecological responses to habitat loss occur in nature, and habitat fragmentation (among other factors) influences the extinction threshold.

The extinction-threshold hypothesis (Fahrig 2002, 2003) may provide an alternative explanation for the rapid decline of northern bobwhite in the southern Great Plains. The region is characterized by vast amounts of rangeland. However, a considerable amount of rangeland has been lost

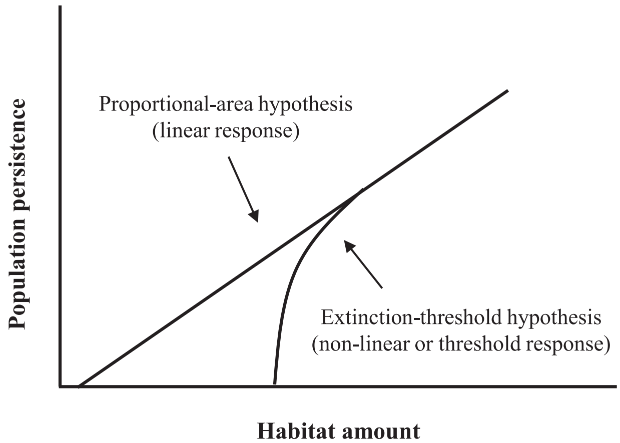

Figure 4. The relationship between habitat area and population persistence commonly is assumed to be linear. However, the extinction-threshold hypothesis suggests that the relationship may not be linear but rather possess a threshold, whereby the probability of species persistence drastically decreases with small amount of habitat loss near the threshold (figure adapted from Fahrig 2003).

due to conversion to cropland, particularly in the southernmost extent (Rollins 2007), and research indicates that bobwhite abundance in the region declines when the proportion of cropland in a county surpasses a threshold of 20% (Lusk et al. 2002). Habitat loss and fragmentation therefore have occurred, and continue to occur, in the southern Great Plains. If an extinction-habitat threshold exists for quail in the region, then small amounts of additional habitat loss near the threshold may have pushed the quail system into a decline within a relatively short period of time (Fig. 5A,B). Such circumstances could explain the general impression of biologists and landowners that nothing has changed in the region but that bobwhites have drastically and rapidly declined. As Fahrig (2001: 72) noted,

> *"Habitat loss typically occurs continuously in small increments. Intuitively, each additional hectare of forest cut, wetland drained, or beach front developed would seem to increase extinction probabilities by only a tiny bit. However, if there is a threshold in the extinction-habitat relationship, then even a small additional loss of habitat near the threshold will have a large impact on survival probability."*

Small changes can lead to big effects (Odum 1982). This idea is contained in the dialectical laws of the nineteenth-century German philosophers Georg W. F. Hegel, Karl Marx, and Frederick Engels (Woods and Grant 2002). These philosophers embraced a belief known as dialectical philosophy, which postulated that all things in the universe were in a constant process of change, motion, and development, even when they did not appear so. Their law of the transformation of quantity into quality stated that small changes, which individually were not sufficient to induce change, eventually accumulated to do so. Small quantitative changes eventually effected a large qualitative change. For example, small increases in temperature eventually changed water from liquid to gas; sustained discord eventually resulted in revolt. Alan Woods and Ted Grant in their book, *Reason in Revolt*, account how a dialectical perspective can facilitate understanding and interpretation of the world in both nature and society. In their book, Woods and Grant (2002) present a quote by Napoléon, who is describing the combat between the unskilled but disciplined French cavalry and the skilled but undisciplined Mamelukes (soldiers from Turkic tribes), to illustrate the law of transformation of quantity into quality,

> *"Two Mamelukes were undoubtedly more than a match for three Frenchmen; 100 Mamelukes were equal to 100 Frenchmen; 300 Frenchmen could generally beat 300*

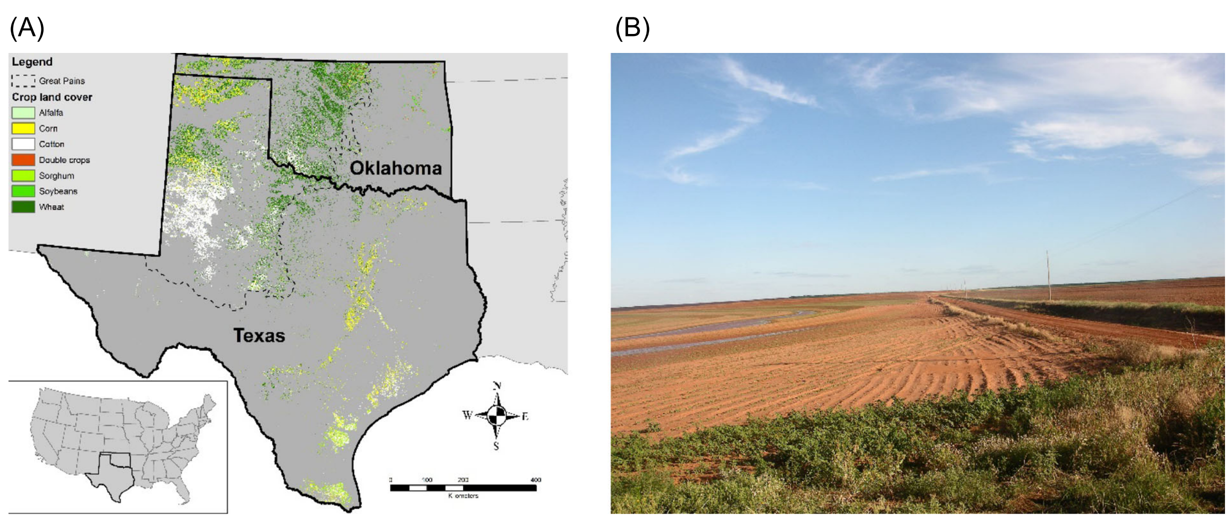

Figure 5. A) Considerable habitat loss and fragmentation have occurred in the southern Great Plains due to conversion of rangeland to cropland. B) If a threshold exists in the quail-habitat amount relationship, then even small increases in the amount of cropland near the threshold may have caused a transition in the quail system from stable to declining. (Crop cover 2019 data provided by Cropscape, National Agricultural Statistics, USDA. Photograph by Fidel Hernández).

Mamelukes; and 1,000 Frenchmen invariably beat 1,500 Mamelukes."

How few acres lost does it take for the decline of a quail population? How many additional acres conserved does it take to sustain one?

CONCLUDING REMARKS

Language influences human thought (Kramsch 2004). The existence of words such as tomorrow and north facilitates human comprehension of concepts such as time and space. Language does not constrain thinking or restrict thoughts to known vocabulary. It does, however, influence certain aspects of human cognition such as memory, classification, and perception (Boroditsky 2001). Thus, cultures with different languages may perceive the world in slightly different ways (Gleitman and Papafragou 2005, Deutscher 2010).

In an episode of Radiolab called Colors, Jad Abumrad and Robert Krulwich discussed how words depicting color such as green and blue facilitated human perception of color shades (Abumrad and Krulwich 2012). The authors referenced a demonstration conducted for illustrative purposes by Dr. Jules Davidoff, professor of neuropsychology with the University of London, who documented how English speakers could easily distinguish between green and blue because the English language contained separate words for these two color shades. However, people of the Himba tribe in Namibia, which lacked a word for the color blue, encountered difficulty. The lack of a word for the color blue somehow affected their ability to perceive the color, even though they had the physical capability to do so (Goldstein et al. 2009).

I wonder how the limited vocabulary of quail science may be influencing our perception of the quail world. Despite a long history of investigation, quail scientists themselves have birthed only a handful of ecological terms: doomed-surplus, inversity, usable space, and habitat slack. The first 2 were introduced in the 1930s by Paul Errington (Errington and Hamerstrom 1935, Errington 1945), and the latter 2 were added in the 1990s by Fred Guthery (Guthery 1997, 1999). Thus, in more than a century of research, our vocabulary has hardly changed, and our research trajectory reveals such limited language development. Studies have been repeated, ideas have been recycled. Predator control. Supplemental feeding. Pen-raised quail. Many studies are only slight variants of past research.

The language of quail science is poor, and we are left to perceive a steno-chromatic world. Who will open our eyes to the full color spectrum of quail science?

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