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Photo: C. R. Hill

The author examines a ring-billed gull nest site on May 19, 1980, the day after Mount St. Helens's ashfall. The nest and eggs were completely buried beneath the volcanic ash.

LEARNING *Firsthand*

BY JAMES L. HAYWARD

The following article is from the book, Dinosaurs, Volcanoes, and Holy Writ: A Boy-Turned-Scientist's Journeys from Fundamentalism to Faith *(Resource Publications, 2020).*

Charlie Amlaner and I landed our boat at the south edge of Harper Island on Sprague Lake. We scrambled out, climbed the volcanic ash-covered slope, and hiked the short distance to the gull colony. I had not set foot here since the previous year when Mount St. Helens emptied its fury on the colony. The eruption had buried nests and eggs and sent my research into a tailspin.

As we made our way to the nesting area, anxious gulls flew up and circled about. Hundreds of nests, most containing from one to three eggs, punctuated the pale, dusty colony surface. But we were not here to observe living birds—there would be plenty of time for that later. We were here to look for last year's nests and eggs buried beneath the ash.

I recently had talked with a geologist friend who told me that a fossilized dinosaur nesting colony had been discovered in northern Montana. Nests, eggs, and baby

Photo: C. J. Amlaner

A volcanic ash-buried ring-billed gull nest is uncovered on May 16, 1981, one year after Mount St. Helens's eruption. In addition to fragmented eggshell, an unbroken egg can be seen at the center of the photo.

dinosaurs had been buried by sediments eroded from the Rocky Mountains, which were then rising to the west. Volcanic ash deposits were also present in the region.[1] I wondered if my study site could serve as a modern-day analog to the Montana dinosaur colony. That's what Charlie and I were here to find out.

We walked over to where there had been a high concentration of ring-billed gull nests the year before. I got down on my knees and carefully scraped away the layer of volcanic ash. Charlie was poised to capture any finds on film. Within minutes my spade struck an ash-coated, brownish-green structure with a convex surface—an eggshell! Then another and another! Soon I had uncovered an entire buried nest with three eggs. As I continued to dig, more nests with eggs were uncovered. We had hit pay dirt.

The eggs were not fossilized, but they had been protected by the overlying ash. Had they not been completely covered, they would have been eaten by predators. The year-old insides contained a smelly paste of decomposing fats and proteins. Despite the fact that these gull eggs were not yet fossils, they would teach us important things about events that lead to egg fossilization, as well as about the process of fossilization itself. And because bird and dinosaur eggs are very similar, preservation of the gull eggs would help us understand processes leading to dinosaur-egg fossilization.[2]

As it turned out, our dusty find opened up an entirely new research arena in paleontology, and it connected me with some of the top people in dinosaur research. Like most scientific discoveries, ours was the result of curiosity, initiative, knowledge, and plain-old good luck converted to action.

This chapter is about scientific discovery of physical reality, which has played a crucial role in my journey from fundamentalism to faith. For me, nothing is more satisfying than uncovering a hitherto unknown corner of the universe, and then sharing that corner with the rest of the world. To illustrate the excitement and joy of discovery, I share several of my own long-term research projects that have opened new areas of inquiry in paleontology and

Photo: J. L. Hayward

Karl Hirsch and his dog, Maggie, at the Devil's Coulee, Alberta dinosaur-egg site in 1993

ecology. But first, I will mention a few reflections on the nature and value of scientific research.

First of all, I think that physical reality should serve as a control on the contours of belief and faith. People who

Despite the fact that these gull eggs were not yet fossils, they would teach us important things about events that lead to egg fossilization, as well as about the process of fossilization itself.

Photo: S. M. Henson

Photo: J. L. Hayward

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(Left) The author and Joe Galusha (right) in 2006, at the cabin where they lived on Protection Island, Washington. The converted van served as their "mobile blind." (Middle) Glaucous-winged gulls, common residents along the Pacific Northwest coast, have served as the author's primary research subjects for nearly a half century. (Right) The author, on the Protection Island gull colony, is dressed in protective gear—for reasons obvious in the photo.

undervalue physical reality are vulnerable to all sorts of spurious ideas—that the earth is flat, that flying saucers bring aliens to earth, that water filtered through lava cures cancer, that prayer cloths perform miracles, that vaccinations cause autism, that global warming is a myth, that dinosaurs and humans walked together. Faith does not involve believing in things falsified by evidence from the physical world. This is not to say that science provides a foolproof basis for understanding; in fact, science does not employ the idea of proof. Scientific perspectives shift over time, but generally our understanding of the universe shifts closer to reality as evidence accumulates. Advances in technology and medicine, practical applications of scientific understanding, provide powerful support for the idea that the scientific method is an effective way to progressively illuminate physical reality.

Scientific research forces investigators to become intimately familiar with the systems they study. My research on the fossilization of eggs and on the behavioral ecology of gulls has provided me with insights about life in the past and present that I never could have obtained from reading or classroom work. Intimate and long-term connection with nature, especially in association with the rough and tumble of the scientific peer-review process, is a prerequisite for anyone hoping to speak intelligently about the complexities of life and its history. Research involves the combined skills and drama of Curious George, Indiana Jones, and Sherlock Holmes, but scientific research also involves tedium, innumerable trips down blind alleys, and countless failures. Patience, and lots of it, is required for the successful researcher. The folly of attempting to be seen as an expert in matters of science without an active research program is illustrated by the life and work of George McCready Price. Price disliked fieldwork, set himself up as an armchair critic of geology and evolutionary biology, wrote extensively on these topics—and has been thoroughly discredited, even by other creationists.[3] But lest we become overconfident about our knowledge, we need to keep in mind the cautionary remark by Scottish biologist, D'Arcy Thompson, that we can "never know all, about the smallest, humblest thing."[4]

We must also recognize that every scientist has bias. But scientific methodology, carefully applied, helps us minimize, as much as possible, the effects of bias on scientific conclusions. In science, the philosophical assumptions behind a hypothesis should be relatively unimportant; what is crucial is that the scientific method is applied rigorously as one tests that hypothesis. In fact, philosophical background and interests can be an important creative force in shaping one's research hypotheses, and indeed career. In an earlier chapter, I described the first research project I tackled as a student—development of a simple mathematical model to define factors necessary for the upright flotation of trees. The motivation for this project was the belief that the Genesis flood ripped trees from the ground, floated them about, and eventually left them in an upright position once the flood waters receded. I no longer consider a worldwide flood to be a viable explanation for the data, but that does not negate my conclusions about the factors necessary for the upright flotation of trees. In the same way, my more recent work in experimental paleontology has been motivated by curiosity about the past, curiosity inspired by my fundamentalist roots, even though my perspectives on what that was like have shifted since my youth.

Field research, my specialty, combines white-collar cognition with blue-collar grunt work. I enjoy physical labor—assembling an elevated observation blind, pounding nest stakes into the ground, building camera platforms. It's fun to figure out ways to use limited resources in creative ways. For nearly all my career I have worked on remote islands, places where you have to make do or lose opportunities to obtain important data. Learning to use what is at hand—scrap lumber, driftwood, an old piece of umbrella or tripod, a clothespin—to do what needs to be done is an important skill to develop.

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These days, good research almost always involves collaboration. Scientific research generally requires the knowledge, ideas, and skills of a variety of experts. Collaboration has been a crucial aspect of my research career. I cannot overstate the advantages I have enjoyed as a result of collaboration. In most cases, my collaborators became good friends and introduced me to other helpful people.

Good research also involves good storytelling. Humans love stories, and scientists are no exception. The scientist who makes ripples on the pond of knowledge needs to be able to communicate effectively. Narratives in science need to be presented, not only factually and with integrity, but also in ways that motivate continued listening or reading. I work hard on both my technical and popular writing. Good writing happens in concert with good reading, so each day I try to read well-written literature.

Photo: J. L. Hayward

Mathematical ecologist Shandelle Henson has just been shot with hot "white-wash" from the bowels of an angry gull. Gulls "shoot" with remarkable accuracy.

Mount St. Helens' ashfall happened the year before I began teaching at Union College. As much as I enjoyed working at Union, my teaching load was so intense that it was difficult to think about research. I did, however, manage to publish a report on the effects of the ashfall on the nesting gulls. Don Miller, my dissertation advisor at Washington State, and Calvin Hill, the friend who was with me when the ashfall occurred, were coauthors. Our paper appeared as the lead article in the October 1982 issue of *The Auk*, a prominent ornithological journal.[5] In 1989, Charlie Amlaner and I published the results of our discovery of ash-buried eggs and nests in the *Journal of Vertebrate Paleontology*.[6]

These two papers formed the basis for a productive research tangent—a tangent, because most of my research would continue to focus on the behavior and ecology of living animals. Yet this foray into historical biology and paleontology would remain a point of interest during the remainder of my career and provide many students with research projects. It would also give me firsthand experience and insights into the geologic column and history of life as I continued to shape my philosophical perspectives.

When I searched for someone who knew something about eggshell fossilization, I came up with only one name—Karl Hirsch. He was connected with the University of Colorado Museum of Natural History. In late-summer 1983, I wrote to him and described my experience with Mount St. Helens ashfall. I mentioned that I was a novice in paleontology, included a copy of our *Auk* article, and asked for any information he might be able to provide on eggshell fossilization. He quickly responded, saying that as far as he knew, he was the only person in North America working on fossil eggs. Moreover, no one anywhere was working on eggshell taphonomy.[7] He was delighted to find someone else with an interest in fossil eggs. The following year, he called saying he would soon be visiting Lincoln, Nebraska, where

Using only three environmental variables, Shandelle Henson's mathematical model predicted the number of gulls loafing on this pier at any hour of the day with uncanny accuracy.

I was living at the time, and he wanted to get together.[8]

Karl was a strong extrovert, smoked tobacco, loved cognac, and spoke with a thick German accent. By contrast, I'm a strongly introverted, non-smoking, teetotaling, monolingual American, yet we hit it off immediately. As a young man, Karl was conscripted as a Nazi soldier. During Hitler's invasion of Russia he suffered three wounds, one of which nearly cost him a leg. "Out of two hundred twenty men in my unit," he said, "only ten were left after the war was over." In 1945, he was captured by the Russians and spent the next two-and-a-half years as a starving prisoner of war at a Siberian labor camp. After his release, he and his wife, Hildegard, immigrated to the United States, where they became rock hounds. In 1973, they found a fossil bird egg in the Nebraska badlands, and this got Karl interested in these ancient relics. No one seemed to know anything about fossil eggs, so he decided to learn about them himself.

Except for two courses at the University of Colorado, Karl had no formal training in geology or paleontology. In Germany, he had been trained in accounting and management, but here in the States he worked as a maintenance technician at Rocky Flats Weapons Plant in Denver.[9] He had taught himself what he needed to know about geology and paleontology, and he even learned scanning electron microscopy for the purpose of imaging and describing eggshell microstructure. He eventually published thirty-three technical papers on fossil eggs, including one in the prestigious journal *Science*, thus establishing himself as the world's expert on the topic. In 1990, the University of Colorado awarded him an honorary doctorate in recognition of his groundbreaking work, and, in the same year, The Paleontological Society honored him with its prestigious Strimple Award.[10] When I met him, Hildegard had recently died, leaving him depressed and lonely. His fossils and his friends were all he had left.

Karl was anxious for someone to maintain an interest in fossil eggs after he was gone. He was most interested in eggshell microstructure, and we published a paper together on the microstructural changes in gull eggshells buried by Mount St. Helens ash.[11] I was more intrigued, however, by the taphonomy of whole eggs and large-scale taphonomic features such as fracture patterns and fragment orientation, which could tell us important things about ancient environments and dinosaur behavior. Following Karl's death in 1996, several younger paleontologists continued to pursue his eggshell microstructure studies, and I continued with my studies on the taphonomy of whole eggs and eggshell fragments.

Karl and I enjoyed two extended trips together, during which we visited fossil egg sites and consulted with various paleontologists. In August 1992, we visited the Museum of the Rockies at Montana State University. There, Jack

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Horner showed me the museum's extensive dinosaur nest and egg collection, all cataloged and neatly stowed on heavy-duty metal shelves. We then traveled to Egg Mountain—really only a large mound—near Choteau, Montana, where, fourteen years earlier, Horner had discovered the first evidence of nesting dinosaurs in North America. Karl took me to several sites in the vicinity of Egg Mountain where dinosaur nests with eggs had been uncovered.

In 1993, Karl and I once again traveled to Egg Mountain. When we arrived, the site was bustling with paleontologists instructing volunteers who had paid for a chance to dig up dinosaur remains. An extensive dinosaur bone bed had been found, and enthusiastic volunteers were exposing the bones. Other volunteers were marking locations where concentrations of eggshell fragments had weathered out at the ground surface. All personnel were housed in large teepees—the site looked like a nineteenth-century Native American village.

The next morning we drove to Dinosaur Provincial Park, Alberta, where we enjoyed a tour of the dinosaur-infested badlands. From Dinosaur Provincial Park we traveled southwest the next day to Devil's Coulee, near the little town of Warner, Alberta. Here, in 1987, a high-school student and fossil enthusiast, Wendy Sloboda, found some pieces of dinosaur eggshell exposed in the eroding badlands. This led to further exploration, which revealed the presence not only of duck-billed dinosaur eggs, but also bones of juvenile duck-bills. Sloboda, it turned out, had discovered a dinosaur nesting site similar to the one at Egg Mountain further south.[12]

These two trips networked me into the paleontological community. Karl knew just about everyone working in the area of dinosaur paleontology. During our trips to field sites, museums, and professional meetings, he introduced me to many of the top people in the field, some of whom ended up as collaborators. Now that he is gone, I miss his friendship, his thickly accented phone calls ("Hi Chim! This is Karl!"), his cheerful enthusiasm, and his professional guidance.

Karl's pioneering work in eggshell microstructure and Jack Horner's discovery of the dinosaur nesting ground at Egg Mountain stimulated great interest among paleontologists. This interest led to the first book on the topic, *Dinosaur Eggs and Babies*, edited by Kenneth Carpenter, Hirsch, and Horner. The introductory chapter referenced the two papers on taphonomy my colleagues and I had published to that point and predicted the results of our work would "shed light on dinosaur nesting sites,"[13] which is indeed what happened.

Lots of things can happen to an egg laid at a nesting site before it becomes a fossil. Burial by volcanic ash is an important one, but there are many others. Eggs, for example, can be predated, burned, crushed, attacked by bacteria, dissolved by acidic soil, or get washed into the sea. Eggshell fragments can be trampled at the nest site or transported by water, wind, or rising tides. None of these possibilities had been rigorously examined. Knowing how these factors affect eggs and eggshell fragments could provide "forensic evidence" about the behavior of dinosaurs and the types of environments in which they lived. Given the tremendous interest in dinosaurs, I decided this would be a fruitful area of research.

My students, colleagues, and I carried out an extensive series of experiments to find out what happens to eggs

Photo: J. L. Hayward

Over the years, more than sixty student members of the Seabird Ecology Team have contributed to the success of the research. Here, in 2008, Kelly McWilliams and Andre Moncrieff take a break beside an elevated blind. Kelly now teaches science at Wisconsin Academy, and Andre is a doctoral candidate in zoology at Louisiana State University.

Gulls make excellent subjects for animal behavior studies: they nest in large, open colonies with hundreds or even thousands of individuals; they are active during the day; they exhibit interesting and relatively complex behavior and communication patterns; they walk, run, fly, and swim with equal ease; and more than four dozen species of gulls make comparative studies interesting and feasible.

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under various circumstances. We used modern chicken, ostrich, and emu eggs for our experiments. These eggs served as excellent proxies for ancient eggs, both bird and dinosaur, because bird and dinosaur eggs share such similar physical properties. We lowered chicken eggs into the Pacific Ocean to a depth of about 2,000 feet from the oceanographic research vessel *New Horizon*, and demonstrated that eggs at those intense pressures don't crack. We found that when gulls build nests and lay eggs too low along the beach, high tides cause nests and eggs to float away from shore; eventually the eggs drop from the disintegrating nest to the ocean floor. We found that chicken eggs placed on the ocean bottom are not eaten, but gradually serve as substrates for the growth of bacteria and other microorganisms. We discovered that eggshell buried in soil laced with various species of soil bacteria, or placed in solution of different levels of acidity, develop characteristic patterns of pitting on the eggshell surface. We crushed whole eggs under sediment loads and found that the fracture patterns differ depending on whether the eggshell is hollow, freshly laid, or filled with plaster to mimic eggs that have fossilized. We heated ostrich and emu eggshell fragments at different temperatures for varying lengths of time, and showed that during a forest fire, eggshells turn various colors—some quite beautiful—depending on the type of egg and the amount of heat. Each of these experiments helped with the interpretation of the taphonomic histories of fossil eggs described from around the world.[14]

Our taphonomic work that attracted the most interest, however, were experiments on eggshell fragment orientation. We found that the ratios of eggshell fragments oriented concave-surface up versus concave-surface down vary depending on their transport histories. Fragments transported by wind or water tend to exhibit a concave-surface down orientation. By contrast, if transport has not occurred, the predominant orientation is concave-surface up. This simple test allowed us to infer that dinosaur eggshell fragments found at a site in northern Montana, and at another site at Devil's Coulee, Alberta, were in the locations of the ancient nest sites and had not been transported from other locations.[15]

Finding dinosaur eggshell fragments predominantly concave-surface up implied, among other things, that these sites had not been inundated by flowing water. Had these eggshell fragments been pushed around, for example, by the Genesis flood, they likely would have assumed predominantly concave-down orientations. Moreover, eggshell at some dinosaur sites occur at multiple levels, separated by one or more sediment layers. This suggests the sites were used for more than one nesting season, not just a single season in the year purported for Noah's flood.[16]

Our eggshell taphonomy work provided paleontologists with useful tools and concepts for reconstructing the original environmental conditions at dinosaur nest sites. It has been heartening to see our ideas and techniques adopted by other scientists. Moreover, research in taphonomy has taught me a great deal about the fossil record, and has supplied ample reason for me to reject the notions of flood geologists.

Most of my research has focused on the behavior and ecology of living animals, including gulls, harbor seals, marine iguanas, and bald eagles. As I mentioned earlier, I studied gull reproductive behavior for my PhD dissertation, and this was the reason I was on a gull colony in eastern Washington when Mount St. Helens erupted in 1980. I had already spent three field seasons working on another colony, studying gull communication for my master's degree, so I was well acquainted with these birds. Gulls make excellent subjects for animal behavior studies: they nest in large, open colonies with hundreds or even thousands of individuals; they are active during the day; they exhibit interesting and relatively complex behavior and communication patterns; they walk, run, fly, and swim with equal ease; and more than four dozen species of gulls make comparative studies interesting and feasible.

For my master's thesis research project, I determined how gulls use sequences of behavioral units and *body orientations* to communicate messages. From motion picture film and video recordings, I transcribed the sequences of behaviors and body orientations used during territorial disputes. I found that body orientation plays a significant role during aggressive encounters by these birds. For example, body orientation toward an intruder by a territory defender conveys a higher level of threat than orientation away from the intruder. Moreover, the communicative function of a behavior may be altered by the behaviors that precede it in sequence. Just as humans use body postures, orientation, and syntax when we communicate with one another, so do gulls.[17]

The philosophical implication of this to me is profound. Gulls use the same elements of communication—vocalizations, postures, orientations—as we do, albeit with considerably less complexity. Both gulls and humans modulate communicative signals by changes in vocalization amplitude and pitch, along with changes in the rate of movement. Especially fascinating to me is that communicative signals cross species boundaries. If I orient my body toward a gull, stare directly at it, or raise my arm to it, I communicate more threat than if I stand still and look the other way. Similarly if a gull orients toward me, raises the feathers on top of its head, and vocalizes an attack call, I know that I had better watch my head! Common rules of communication bond us together as social creatures. Although we humans may be more complex than gulls, each of us exists as part of the remarkable, interacting fabric of nature.

In 1987, the summer after I moved to Andrews University, Joseph Galusha invited me to participate at the research site he had established on the Protection Island gull colony, the largest seabird colony in Washington State's inland waters. I had become acquainted with Joe during the summer of 1971, when I was a senior biology major taking summer coursework at the Rosario Beach Marine Laboratory. Joe was completing his master's degree research on gull behavior under John Stout who, in turn, became my master's thesis advisor. Upon completion of his master's degree, Joe earned a doctorate at Oxford University with Niko Tinbergen, the "father" of gull studies. During the time Joe was his student, Tinbergen, Konrad Lorenz, and Karl von Frisch won the 1973 Nobel Prize in Physiology or Medicine for their pioneering work in animal behavior. When Joe returned to the States with a newly minted Oxford doctorate, he was hired to teach biology at Walla Walla College.

Joe understood gull behavior better than anyone I knew, and he had developed an excellent research setup on Protection Island, home to thousands of nesting glaucous-winged gulls. It was a generous offer to share

Photo: J. L. Hayward

Three Andrews University students who worked with the Seabird Ecology Team during 2014: left to right, WayAnne Watson, Ashley Reichert, and Sumiko Weir. All three women have completed, or are completing, MD degrees.

The egg cannibal has just touched down on its nest territory with a stolen egg. The egg will be immediately broken open and its contents devoured.

his field site with me—many researchers are protective of their productive research sites. Little did I know that I would spend the next thirty-three field seasons working on Protection Island where gulls, bald eagles, harbor seals, vegetation, and even geology would attract my focus. I would come to know and love this island better than any place on earth. Joe not only shared this outstanding research site with me, he also taught me much about gull behavior, research techniques, and how to mentor students.

Protection Island is located in the Salish Sea at the southeast corner of the Strait of Juan de Fuca, Washington. The island is about a mile and a half long and a half mile wide, and is shaped a bit like a plump, reclining comma with long, gravel spits forming its tips. The main part of the island consists of a grassy plateau, 100–200 feet above sea level. Two wooded areas also occur on the plateau. The northern edge of the plateau—the convex hump of the comma—forms a nearly vertical cliff, along which the island's geologic history is vividly exposed by the sediment layers. From a single location at the top of the island, the San Juan Islands to the north, Vancouver Island to the northwest, the Olympic Mountains to the south and west, Mount Rainer to the southeast, and the North Cascades to the east and northeast are all visible. I could not have asked for a more aesthetically pleasing site at which to do research.

Western Washington is famous for its lush, evergreen forests and abundant rainfall, but because of its position in the rain shadow created by the Olympic Mountains, much of Protection Island is a dry, tallgrass prairie. The temperatures are mild and mosquitoes, which plague denizens of the surrounding mainland forest, are mostly absent; a lack of standing freshwater and frequent sea breezes keep the pesky critters away. A research site on an island within an inland sea, surrounded by scenes of other islands and snow-covered peaks, and blessed with pleasing temperatures and a paucity of mosquitoes, is a rarity for field biologists. I had always dreamed of studying animals on an isolated island, like my boyhood hero, Sam Campbell, and that's what I was privileged to do on Protection Island for more than three decades.

From 1987 to 2001, I spent the field seasons getting acquainted with Protection Island. I engaged in a variety of disconnected projects—collecting gull chick carcasses for a gull bone development project, timing the duration of various gull behaviors, collecting and analyzing the contents of great-horned owl pellets, assessing bald eagle activity patterns, characterizing the diversity and distribution patterns of vegetation, and quantifying the taphonomic characteristics of eggs and eggshell. In the process I learned a great deal about the island and its tenants. Much of my time was spent perched atop a bluff overlooking Violet Point, the eastern gravel spit, and each hour for fifteen-hour days I counted the number of birds of each species in various habitats on the spit below. By 2001, I had accumulated a large data set which nicely showed contoured fluctuations of numbers of each species in the various habitats. When I plotted these fluctuations, I saw that they varied in complex ways, with environmental variables such as time of day, tide height, wind speed, and day of the year. My modest analytical skills, however, did not extend to understanding how to evaluate these complex relations. I needed something more than basic statistics to figure out the meaning of the fluctuating trends in the data.

In the fall of 2001, Shandelle Henson, a new professor in Andrews University's Department of Mathematics, gave a seminar in which she described how she analyzed fluctuations in lab populations of flour beetles. She was a member of the well-known "Beetle Team," an interdisciplinary group of mathematicians, statisticians, and biologists from Rhode Island, Arizona, California, Idaho, and now Michigan, that provided the first demonstration of the mathematical phenomenon of "chaos" in an animal population—a big deal theoretically and one that captured the attention of ecologists worldwide.[18] I didn't understand the mathematics she used, but I did understand that she possessed the mathematical tools to analyze fluctuations in animal numbers. After the seminar, I went up to her and briefly explained that I had an extensive data set that described rising and falling numbers of marine birds and mammals. I asked if she would be willing to take a look to see if her methodologies could be used to analyze these data. To my surprise, she agreed.

I sent my data to her, and after a few days she responded that she thought they were something with which she could work. Our first meeting, however, turned out to be a clash of "two cultures"—mathematics and biology. After I described the gull system, we agreed that fluctuations in the number of gulls "loafing" on the marina pier would work best for a first try at analysis. But when I began to list important environmental factors—time of day, windspeed, barometric pressure, air temperature, solar radiation, tide height, day of the year, and so on—she protested. "No, no, just give me the two most important factors!" Thinking she was terribly naïve, I said it would be impossible to list only two factors—ecosystems are complex, and any model worth thinking about would need to incorporate many factors. After a good-natured argument during which I continued to view her perspective as that of a hopelessly clueless mathematician, I skeptically compromised with a list of *three* factors: tide height, time of day, and day of the year. She said she would try to work with these three variables.[19]

Two weeks later, she announced she had developed a mathematical model that described the rises and falls of my loafing-gull counts. When I saw the graph that showed how beautifully her model described the number of gulls on the pier, I was astonished. I discovered that I was the one who was clueless and Shandelle was right: you don't need, or even want, to include all the environmental factors impinging on a system to model it effectively. She explained that the purpose of a mathematical model is to find the *main* factors that drive the system. If all the factors were included it would no longer be a model, it would be the system itself. In this case the main factors appeared to be tide height, time of day, and day of the year.

A research site on an island within an inland sea, surrounded by scenes of other islands and snow-covered peaks, and blessed with pleasing temperatures and a paucity of mosquitoes, is a rarity for field biologists.

Shandelle then explained that the real test of model effectiveness is whether it can *predict* the behavior of a system in the future. Now a believer in her technique, I constructed a spreadsheet listing the tide height forecast, available from the National Oceanographic and Atmospheric Administration (NOAA) website, for every hour of the day for each day we planned to work on Protection Island the following spring. Shandelle used her differential

Photo: J. L. Hayward

Jim Cushing and Shandelle Henson have spent extensive time creating and successfully testing computer-based mathematical models of gull behavior.

equation model to generate predictions of rises and falls of counts of gulls on the pier. All we had to do now was wait for the next field season and hire a couple students to help collect the data needed to test the predictions.

Shandelle, two students, and I arrived on Protection Island on May 8, 2002, got set up, and began counting the next day. From atop a bluff overlooking the colony, we counted gulls on the pier every hour, from 5:00 am until 8:00 pm for twenty-nine consecutive days. Each count was a time-consuming process, frustrated occasionally by fog, eagle disturbances, or caretakers cleaning the pier.

At one point, Shandelle had to travel to Rhode Island for a meeting with the Beetle Team, leaving the students and me to do the counts. During her absence a seasonal island resident, Warren Odegard, whom I knew from previous visits, appeared with his *Thor*, a forty-plus-foot landing craft which he tied up to the pier. That in itself would not have posed a problem for us; short gaps in our counts would not create difficulties for our analysis. The problem was that Warren decided it was a good time to make extensive repairs on the outside of his boat. His activity would seriously interfere with our counts. I called Shandelle and told her what was happening.

"You've *got* to find a way to keep him off the pier!" she exclaimed. I agreed, but this would be tricky—he had as much right to be on the pier as we did. So I decided to offer him a bribe.

"Hi Warren!" I said, as I approached him on the pier. "We're doing some research which requires us to count gulls on the pier at the top of each hour every day. I'll pay you one hundred dollars if you'll agree stay off the pier while you're here on the island." Warren thought a moment about my strange offer and then said, yes, he would be willing to stay off in exchange for my bribe. I reached into my pocket, pulled out five twenties, and handed him the cash. He kept his word and our counts continued unimpeded by repairs to the *Thor*.

At the end of the twenty-nine days, Shandelle compared our counts to her model predictions. The model accounted for 61% of the variability in the data.[20] Sixty-one percent may not sound spectacular, but for ecological and behavioral data from a wild population, this level of predictability is spectacular. Based on these results, we applied for a National Science Foundation (NSF) grant to extend our work to other parts of the gull colony system. Our proposal was successful, and we were awarded funds to support travel, salaries, equipment, and supplies for continued work. All those tiresome counts were paying off. Our work was novel—no one had ever made successful predictions like these for vertebrate animals in a natural population. Over the next nineteen years, NSF granted us $1.25 million to support research on the mathematical prediction of animal behavior in relation to environmental variables, including climate change.

With help over the years from more than sixty students, colleagues, and volunteers, we have used Shandelle's mathematical approaches to assess the behavioral dynamics of harbor seals, bald eagles, and four species of gulls in the United States, and of marine iguanas on Isla Fernandina in the Galápagos Islands. Her approach has worked well in every case. Since 2004, we have published more than thirty scientific papers on our joint work.[21]

Our most exciting project involved a complex interaction between gull-egg cannibalism and egg-laying synchrony. We began this project unknowingly in 2006. In 2005, we documented a dramatic failure of gull reproductive success on Protection Island. By the end of the breeding season, fewer than a dozen gull chicks had survived—there should have been thousands. In 2006, we decided to determine what factors were important to the reproductive success of these birds. We established five study plots, each containing thirty or more breeding territories. A numbered, wooden stake was placed by each nest when the first egg was laid. The first egg was marked "A," and subsequent eggs, if laid, were marked "B" and "C." Every day we checked each egg in each sample nest until hatching, or until some other fate such as predation eliminated the egg. We knew of only two species of egg predators on Protection Island—bald eagles and the gulls themselves. When bald eagles preyed on a nest, all the eggs were destroyed. When only a single egg was lost, it was usually because a gull had cannibalized it.

Over six field seasons, egg cannibalism by gulls accounted for 55% of the eggs lost. We had known that egg cannibalism played a role in the colony, but we were surprised at how large a role. Cannibalism turned out to be the most important factor determining the degree of reproductive success, or lack thereof, in the colony as a whole. The rate of cannibalism each year varied from about 14% of the eggs laid, to over 40%. What could cause such large year-to-year differences?

We considered a variety of environmental factors that might fluctuate with the rate of cannibalism. The only factor that stood out was sea surface temperature. When sea surface temperature is high—even by only a fraction of a degree—forage fish move to deeper water. In contrast with other seabirds such as puffins and cormorants, gulls can't dive. So if fish go to deeper water, gulls go hungry. Hungry gulls look around for other food, and eggs are the most nutritious non-fish foods available. An adult gull can obtain nearly all the calories it needs in a day if it devours only two of its neighbors' eggs. Some gulls do just that—and more.[22]

Sea surface temperatures are on the rise in most of the world's oceans. Will gull egg cannibalism rise as the seas get warmer? Our research suggests it might. What will this mean for populations of gulls and other seabirds? We don't know, because our unintentional climate change experiment is still ongoing. But though we don't know the ultimate fate of ocean warming on gull reproduction, we think we do know how female gulls combat the effects of cannibalism on their reproductive success.

When we began monitoring reproductive success in 2006, we noticed something very strange. We would check nests in our study plots one day, and there would be lots of new eggs; the next day, however, there would be just a few new eggs, but the day after that there would again be lots of new eggs. We thought, that's funny—it seems as though female gulls in our sample areas tend to lay their eggs together on alternate days. We graphed our data and sure enough, a distinct up-and-down, every-other-day, zig-zag pattern emerged. The graphs seemed to confirm our perception of what was happening: the females, which individually lay an egg every other day until they completed their clutch, were synchronizing their egg-laying. What looked like egg-laying synchrony only occurred in some but not in other years. It seemed to happen in years when both the sea surface temperatures and egg cannibalism rates were high.

We knew, however, how easy it is to see patterns in data when patterns don't really exist. This is because the human mind wants to see patterns everywhere—just think how the ancients saw constellations of stars in the night sky, which in reality have no intrinsic meaning. We had to come up with a way to determine if the up-and-down fluctuations were random—like constellations—or if they were nonrandom and held intrinsic meaning. It

Photo: J. L. Hayward

In 2012, Gordon Atkins, with graduate student Amanda Sandler, mounted "spy" cameras in lengths of PVC pipe. The cameras were deployed on the gull colony to study egg-laying behavior.

took us quite some time to come up with an objective way to do this, but we finally determined an effective method. In the end our perceptions were supported: statistically significant egg-laying synchrony occurred in years with high rates of cannibalism and when sea surface temperatures were high.[23] Why would this be?

The mathematicians on our team—Shandelle Henson and Jim Cushing from the University of Arizona—developed a series of models which provided an answer. The models showed that cannibalism confers an advantage to cannibals in the short term—it serves as a "lifeboat" mechanism to carry them through bad years when the food supply is poor. When good times return, they can resume non-cannibalistic behavior. At the same time, by engaging in egg-laying synchrony during years of high cannibalism, the females in the colony lower the chance their eggs will be cannibalized. This is because cannibals can eat only so many eggs on a given day; if most eggs are laid on one day, the chance that a particular egg will be eaten is reduced. Natural selection appears to have favored behavioral flexibility which allows gulls to switch between synchronous and non-synchronous egg-laying, depending on the rate of egg cannibalism in a given year.

What are the long-term effects of cannibalism on the population? The mathematicians developed other models demonstrating that in the long run, this ability to switch between high levels of cannibalism plus synchrony in bad years, and low levels of cannibalism and no synchrony in good years, allows the population to persist over the long haul. If, however, the string of bad years is too long, the population could experience a "tipping point" and completely collapse.[24]

One final question needed to be answered to complete our story about cannibalism, egg-laying synchrony, and climate change: What signal enables the female gulls to synchronize their behavior? Is it chemical, visual, auditory, or something else?

If you hang several identical pendulum clocks on a wall, with their pendulums swinging out of synch, after a while all the pendulums will swing synchronously. Slight vibrations generated by the clocks travel through the wall and function as synchronizing signals. Every synchronous system requires a synchronizing signal such as these vibrations.

Gordon Atkins, a physiologist on our team with extensive experience in the analysis of auditory signals in insects and birds, has worked hard to identify the signal that synchronizes egg-laying in our gulls. Through a clever series of experiments and observations, he may have discovered it. He noted that the copulation call emitted by males during the act of mating is loud and distinct. This call, emitted by a single male, can be heard throughout the entire colony. By playing recorded copulation calls back to a small group of nesting gulls isolated from the rest of the colony, he was able to stimulate courtship and copulation at will. He showed that the call alone, separate from the dramatic wing-flapping that occurs during the call, was a sufficient stimulus to elicit courtship and copulation.[25]

Atkins then mounted a series of automated cameras on posts in dense parts of the colony. Each camera was programmed to take a digital photo of a small area of the colony every five minutes. Each nest within view of the camera was monitored daily for the presence of new eggs. With this technique, Atkins demonstrated a strong, negative relationship between the occurrence of copulation and egg laying. On days when a female gull lays an egg, she seemed to exhibit no urge to copulate. Instead, she waited for the next day to copulate. Hormonal cycles account for the every-other-day egg-laying pattern in individual gulls, but the copulation call seems to synchronize the laying patterns of densely-nesting females during years of high cannibalism.[26]

So how do these research experiences relate to my journey out of fundamentalism into a more open view of reality? Participation in research demonstrates that natural patterns can be described, quantified, and predicted. Natural patterns tell us important things about reality. To deny the existence of patterns in, for example, the fossil record, or to ignore their existence because of so-called "faith commitments," amounts to an absurd and gross trivialization of the notion of faith. Serious and mature faith development requires careful attention to physical reality. Faith should be consistent with physical reality, not contradictory to it. Research offers firsthand glimpses into reality, which for me provide a meaningful and joyful context for real faith.

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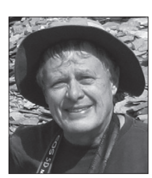

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