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Synergies of Microecology and Macroecology Elicit Insights for Creation Care

David P. Warners and John T. Wertz

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This article reports on a collection of microecological and macroecological insights that emerged from extended conversations between Calvin University professors David Warners, a botanist concentrating in restoration ecology, and John Wertz, a microbiologist specializing in microbial ecology. Classic descriptions of ecology identify biological interactions as happening at the ecosystem, community, or population level. And yet, ecological interactions are very much occurring at the microbial level as well. Furthermore, microbial-level interactions frequently influence the quality and character of macroecological relationships and vice versa. Allowing ecological principles to be applied across all life forms broadens our comprehension of interactions that are happening throughout creation. And when we consider macroecological principles for microbial ecosystems, we quickly see the importance of cultivating healthy microbial interactions to promote healthy macrobiological populations, communities, and ecosystems.

Using a case study that has emerged over the course of a decade, this article describes reciprocal understandings that arise when the subdisciplines of ecology and microbiology avail themselves to each other. Reflecting the perichoresis of the Creator God, these understandings elicit theological insights for (1) living in ways that protect and promote balanced relationships (between us and our microbiome, within macroecosystems, and with one another); (2) acknowledging that humans have been abusive in their relationship with nonhuman creation, pursuing selfish gains at great cost to creation's well-being; (3) recognizing that as embedded rulers of creation our responsibility is to ensure the thriving of our co-creatures; and (4) realizing humans are part of, not outside, God's general revelation. These insights shed fresh light on how we can better live within and care for God's expansive, beautiful creation at all levels.

Keywords: creation care, ecology, microbial ecology, perichoresis, relationships, restoration

I. Introduction

Ecology is the study of interactions between living organisms, and between living organisms and nonliving elements of their environment. Classic descriptions of ecology identify these interactions as happening at the ecosystem level, community level, or within populations.¹ And yet, ecological interactions are also very much occurring at the microbial level—between microbes and their host environments, between different species of microbes, as well as within same-species microbial populations.² Therefore,

David P. Warners has been at Calvin University since 1997, teaching courses and doing research in the areas of evolution, ecology, and botany. In 2019, Dave co-edited *Beyond Stewardship*, exploring new ways to understand creation care. In 2024, he co-authored *Reconciliation in a Michigan Watershed*, detailing the work of *Plaster Creek Stewards*, a watershed initiative he directs.

John T. Wertz has been teaching courses in microbiology and ecology/evolution at Calvin University since 2007. Since 2009 he has been co-director of the Science Education Alliance: Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) undergraduate student research initiative at Calvin. His research interests include the role of symbiotic bacteria in nutrient provisioning in ants and termites. He loves writing, talking, and thinking about the intersections of symbiotic microorganisms (both mutualistic and pathogenic) and the Christian faith.

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there is value in exploring how macroecological principles can shed light on microecological interactions and vice versa.

Recently, advances have been made to better appreciate the intimate connection between environmental health and human health. These insights continue to be explored under the emerging fields of “Health Ecology”³ and “One Health.”⁴ However, most considerations of this human-environment relationship fall short in appreciating the myriad interactions occurring between microbial species concurrent with larger organisms, including humans. “Macroecologists” and “microecologists” rarely interact when it comes to human or ecosystem health. This gap is exacerbated by exclusively relegating species as either microscopic or macroscopic; this is a false and somewhat damaging dichotomy.⁵ Although the discipline of ecology arose from considering macrobiological interactions,⁶ allowing ecological principles to be applied expansively over all life forms broadens our understanding of interactions that are happening at a microbial level. As we will discuss, we have found that applying ecological principles to microbial ecosystems illuminates the importance of cultivating healthy microbial interactions for promoting the health of macrobiological populations, communities, and ecosystems.

This article reports on some micro- and macroecological insights that have emerged from interactions between Calvin University professors Dave Warners, a botanist who specializes in restoration ecology, and John Wertz, a microbiologist who specializes in microbial ecology. In December of 2011 Dave received a knee replacement, which six months later needed to be removed due to an infection. Multiple problems and subsequent infections ensued.

During the succeeding years of health struggles, Dave was well supported by his departmental colleagues at Calvin University. In particular, John provided consistent insight, counsel, and encouragement. Through numerous discussions over the years, these friends came to appreciate multiple areas of overlapping conceptual resonance between their two subdisciplines. New insights were gained when each scientist considered their subdiscipline through the lens of the other.

This article represents further development of the reciprocal understandings that emerged from their interactions, with fresh insights these conversations elicited for how we can better care for all of God’s expansive creation.

II. Micro- and Macroecological Insights into Human and Environmental Health

A. *Species out of place can cause significant problems*

In June 2012, six months after his initial knee replacement, Dave woke up one morning feeling nauseous with a swollen, inflamed, and painful knee. The cause was Staphylococcus aureus, a common bacterial member of many people’s nasal passages that can cause serious disease outside the context of the nose. Surgery was needed to remove the implants, which had been colonized and overwhelmed by the bacterium. Several weeks of antibiotics were administered, after which a subsequent replacement was performed. In 2020, a third replacement was needed because the components had loosened. Seven months after this most recent replacement, another infection suddenly arose in Dave’s knee, this one caused by Granulicatella adiacens, a bacterium that is a normal constituent of most people’s mouths and gastrointestinal microbiome.

A common misconception is that the word symbiosis connotes a positive relationship between two living things. However, its etymology from the Greek *σύν*, *sýn*, “together” and *βίωσις*, *bíosiς*, “living” means nothing more than cohabitation.⁷ This cohabitation can be parasitic (one benefits, one is harmed), commensalistic (one benefits, and there is no harm or benefit to the other), or mutualistic (both benefit). Another common misconception is that these relationships are unchanging throughout the life of two organisms. In fact, life is far more complex. A mutualistic relationship can easily shift and become parasitic, or vice versa.⁸ Whether a symbiosis is mutualistic, commensalistic, or parasitic depends on the two organisms involved as well as the biotic and abiotic environmental context in which the organisms exist.⁹ Change the context, and the entire nature of the relationship can change.¹⁰

Approximately 20–30% of humans harbor the bacterium *Staphylococcus aureus* in their nasal passages.¹¹ Whether this relationship between our species and *S. aureus* is commensalistic or mutualistic is not well understood, but we do know that it is not harmful.¹² However, should *S. aureus* exit the nose and colonize another type of bodily tissue or enter the human body through contaminated food, the relationship between bacterium and human can become parasitic very quickly. On skin, *S. aureus* can cause impetigo, boils, and tissue death; one strain is known colloquially as the “flesh-eating bacterium.”¹³ In food, *S. aureus* can produce a toxin that, when ingested, can cause severe nausea, vomiting, and diarrhea. Should *S. aureus* get into the bloodstream, it

can cause internal disease of replacement joints (this is what Dave experienced), toxic shock syndrome, or scalded skin syndrome.¹⁴ Why the bacterium is benign in the nose but not elsewhere appears to be a result of multiple factors.¹⁵ Since the nasal passages are lined with many other bacteria and bacteriophages (viruses that can invade and kill bacteria), it is possible that this surrounding microbiome plays an important role in suppressing the virulence of *S. aureus*. If there is a dissociation of the bacteria from the surrounding microbes, it could become free to grow and invade other areas of the body unchecked.

Genetic variants of *Staphylococcus aureus* can produce a number of different toxins that make disease in certain areas of the body possible.¹⁶ For example, only *S. aureus* variants that carry a gene to make an exfoliating toxin are able to cause scalded skin syndrome. Variants that carry a gene that generates the enzyme hyaluronidase can cut through layers of skin. Those that contain a toxic shock syndrome protein can cause rapid decrease in blood pressure and shock, coma, and death. Some strains can carry up to forty different genes that help it evade the human immune system.¹⁷ Whether any given strain of *S. aureus* has these genetic variants is dependent on its evolutionary history within the nose of its host, including interactions with the host's immune system and whether or not antibiotic therapy has been administered.¹⁸

Far less is known about *Granulicatella adiacens*. This bacterium is thought to be a commensal of human mucosal surfaces (mouth and gastrointestinal tract).¹⁹ However, should the bacterium be introduced into the bloodstream through a cut, abrasion (even from flossing), or an ulcer, it can cause serious infections such as bacteremia, endocarditis, subcutaneous abscesses; it is also capable of growing on artificial hip and knee joints.²⁰ As with *Staphylococcus aureus*, it is likely that *G. adiacens* interacts with other microbes that may suppress its virulence in locations where it does not cause problems. Removed from those surroundings in which balance is maintained, it is capable of immune evasion, although little is known about how *G. adiacens* does this and how and when that capability is acquired.²¹

It is clear that bacteria like *Staphylococcus aureus* and *Granulicatella adiacens* are capable of causing disease, yet most of the time they do not. When they do become problematic, the reason is that they have been relocated to an area where they are not normally found. In this new context, for reasons that are not yet entirely clear, they can behave aggressively, to the detriment

of other microbes and the host organism. Therefore, to treat diseases caused by "out-of-context" bacteria that subsequently become opportunistic, we need a much better understanding of what keeps their virulence suppressed in their healthy environment and what activates their virulence when that environment changes.

On a macroecological level, invasive species can be described as species that have been displaced and subsequently become problematically opportunistic. There is nothing wrong with invasive species per se; they are simply species that have been moved from their place of origin to a novel environmental location. The Indigenous range in which a species has evolved includes many ecological checks on its uncontrolled growth. Over time, these checks (temperature, moisture, pathogens, herbivores, competitors, et cetera) have kept them in some form of balance. As one example among many possibilities, purple loosestrife (*Lythrum salicaria*) is an invasive species in wetlands of the northern United States, but in its home range (which includes central Europe), this plant does not cause problems. Instead, it is a well-behaved member of open wetland communities.²² Once out of place and free from the ecological constraints that are present in the place where it evolved, purple loosestrife can spread exponentially (at least for a time) and cause native ecosystems to lose diversity and resiliency.²³ In other words, context matters. The factors that keep this plant from achieving problematic abundances in Europe, including some insect herbivores, are not present in North America.

Invasive species can also arise from unaggressive members of a species picking up a particularly aggressive genotype, similar to how bacteria may pick up certain virulence factors.²⁴ Genetic diversity across individuals from the same species can vary widely, but all species display genetic diversity at some level—in fact, variance within species is a precondition of Darwinian evolution. Sometimes invasive species arise because they have undergone a mutation or have been selected for a particular trait that gives them a sudden advantage over competitors in particular habitats. Plants used in gardening may be subjected to drought conditions when gardeners go on vacation or forget to water. Garden plants may face intense weed competition that favors those weeds that grow fast and tall, or they may develop chemicals that keep insects away and keep the plant looking beautiful to the gardener. Such traits are preferred and may be perpetuated intentionally or unintentionally (selected, for example, via seed collection, cuttings, plant exchanges) by gardeners.

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These preferred garden traits can “pre-adapt” a genotype to becoming ecologically problematic if it escapes the confines of a formal garden. Once released into a more natural environment, the traits that made them highly desirable to the gardeners may convey competitive advantages over native species that have not gone through artificial “cultivation” selection pressures.²⁵

A fundamental responsibility of *Homo sapiens* (a Latin name which quite literally means “the wise member of the genus *Homo*”) is to learn as much as possible about creation and all its interactions. In Genesis 2:15, Adam is told to “tend the garden.” The Hebrew word here is “*abad*,” which elsewhere in the Old Testament is translated as “to serve.” To serve well, one must understand the intricacies and interactions of those being served. To serve creation well, it is important to understand that the world is much less a collection of individual species than it is a tapestry of interwoven fibers. When an organism becomes disconnected from its interwoven fibers, problems can arise. This happens when *Staphylococcus aureus* becomes disconnected from its interactions in the nose, when *Granulicatella adiacens* becomes disconnected from its interactions in the gastrointestinal tract, and when purple loosestrife becomes disconnected from its interactions in central Europe. Once released from their interwoven community fibers, these entities and so many others can cause great harm to humans and to ecosystems. Working to maintain a healthy balance in both micro- and macroecological systems and minimizing the opportunities for species to become displaced to novel environments is an important task of earthkeeping.

B. Biodiversity loss results in vulnerable landscapes

Treatment for Dave’s Granulicatella infection included another knee surgery that removed infected tissue, irrigated the joint with antibiotics, and was followed by months of heavy intravenous antibiotic treatment. During this time Dave developed “pseudomembranous colitis” a dangerous gastrointestinal disease caused by the bacterium Clostridioides difficile (formerly known as Clostridium difficile). This gastrointestinal infection required a shift away from the antibiotics that were treating Granulicatella, to a new antibiotic that was focused on treating the C. difficile infection. Fortunately, the new treatment did control Dave’s C. difficile infection without causing a flare-up of the Granulicatella infection in his knee. However, after switching back to the antibiotic that was being used to treat his knee infection, Dave had a recurrence of the C. difficile infection, and the antibiotic exchange had to be repeated.

Antibiotics have been a panacea for bacterial diseases. However, no antibiotic is so selective that it will kill only invading bacteria and not the myriad of beneficial microbes that inhabit our bodies. Some antibiotics are selective to certain small groups of bacteria, but most are lethal to a broad range of bacteria.²⁶ Therefore, when an antibiotic is taken systematically for a bacterial disease, inevitably some of our beneficial bacteria will be killed.²⁷ Typically, after ceasing antibiotic treatment, our normal bacteria will re-establish much as they were before, but not always.²⁸ Reducing the diversity of bacteria through antibiotic treatment can leave open niches that become inhabited by bacteria normally competitively excluded, such as the bacterium *Clostridioides difficile*.

Clostridioides difficile is an uncommon inhabitant of the human gastrointestinal tract. Rarely a problem before the year 2000, sometime between then and 2007, the bacterium developed a duplication of the gene that encodes a toxin, underwent mutations in the gene responsible for regulating toxin production, and subsequently became resistant to several different antibiotics.²⁹ Infection with *C. difficile* is extremely unlikely if the normal gastrointestinal bacteria are intact and functioning, but if the gastrointestinal microbiome is disrupted with antibiotics—a situation known as dysbiosis—a condition occurs in which *C. difficile* can become established in the colon and cause serious problems.³⁰

Clostridioides difficile is a spore-forming bacterium whose spores can make it past the harsh acids in the stomach and bile salts in the small intestine to take up residence in a dysbiotic colon, where the bacterium secretes toxins.³¹ The toxins are imported into the cells that line the colon, where they disrupt the normal function of these cells, causing them to die. This disruption leads to ulcerations in the lining of the colon and severe inflammation, leading to a buildup of fibrin, white blood cells, and bacteria that together form what is known as a pseudomembrane.³² Frequent diarrhea and severe abdominal pain result, leading to the infected individual being home-bound or hospitalized. Treatment of *C. difficile* presents an ecological paradox.³³ Dysbiosis due to antibiotics is the reason this bacterium was able to establish itself in the first place. Treatment with antibiotics may kill *C. difficile*, but it does not restore the original microbiome to a healthy state. About 20% of individuals who become afflicted with *C. difficile* will experience a recurrence,³⁴ which is what happened to Dave. The best course of treatment when repeated infections happen is restoration of the normal microbiota, discussed in part II.D below.

At a macroecological level, a healthy, fully functioning ecosystem is amazingly resilient to the ill effects of invasive species. However, once a disturbance has happened to an ecosystem (removal of important species, increased or decreased intensity or frequency of wildfires, or careless forest clearing), the landscape becomes much more vulnerable to infiltration by nonnative invasive species.³⁵ This dynamic is an example of dysbiosis on a macroecological scale, and the economic and ecological costs of invasive species are steadily rising as human perturbations continue to advance.³⁶ Because there is so much human activity across the globe that causes ecological disturbances, it is now estimated that 1/6th of already preserved natural areas are vulnerable to invasive species.³⁷

If we consider the earth to be a living creature itself, areas of this earth organism that have been mistreated—where biodiversity has been sacrificed, and where environmental health has been compromised—are sites where invasive species can come in and do further damage. It should be noted that ecological disturbances are a natural part of any ecosystem, and when a disturbance is of the magnitude, frequency, and extent of “normally occurring” disturbances, the ecosystem within which the disturbance occurs will likely be resilient and able to recover. But when the disturbance is uncharacteristic in terms of intensity, frequency, and extent, the ecological recovery mechanisms can be insufficient to recolonize and reset the ecosystem. In such situations, alternative ecosystem states can arise that are of lower quality and support much less biodiversity.³⁸

One example with which many North Americans are familiar is garlic mustard (*Alliaria petiolata*). Garlic mustard is a plant that is native to Europe and Asia and was intentionally brought to the United States initially as a culinary herb in the mid-1800s. This plant grows best in shady, moist forests, and its ability to germinate early in the season prior to most native species means that it can outcompete many of the classic spring wildflowers, such as common trillium (*Trillium grandiflorum*), spring beauty (*Claytonia* spp.), trout lily (*Erythronium* spp.), and Dutchman’s breeches (*Dicentra cucullaria*). Garlic mustard has also been shown to have a dramatically negative effect on the recruitment of new tree seedlings in a forest.³⁹ Furthermore, once it produces seeds, those seeds exhibit differential dormancy, meaning that some will germinate the next year, but others can remain dormant in the soil for multiple years.⁴⁰ One distinct advantage employed by this highly successful invasive plant is that it gives off chemicals into the soil that disrupt the growth of healthy soil fungi; these fungi normally

provide beneficial mycorrhizal connections between forest plants, including trees. Therefore, the infiltration of garlic mustard into a forest ecosystem can have a profoundly disruptive effect for a long period of time.

Research has shown that garlic mustard has been moving westward across North America from the northeast and that, as its range expands, it is particularly adept at gaining presence in forests that have been disturbed.⁴¹ Beyond the fact that today’s human-caused disturbances are increasing in frequency, many of them are also unlike the disturbances that natural ecosystems have evolved to accommodate. Wide-scale land conversion and habitat loss, species declines, and climate change are themselves opening up large areas of the planet to disturbances and combinations of disturbances to which native species have not been previously exposed and are therefore poorly equipped to tolerate. When native species fail to respond to these extreme disturbances, invasive species can proliferate. Novel wounds are damaging in and of themselves, but they also invite further degradation by displaced and potentially damaging species, making it even more difficult for the restoration of a healthy ecosystem to be achieved.

Dysbiosis in ecosystems creates the same imbalance that dysbiosis brings about in the human body, inviting problems that a healthy ecosystem typically does not encounter, whether caused by *Clostridioides difficile* or *Alliaria petiolata*. These two examples illustrate how understanding the interactions among species is certainly important, but not sufficient for both macro- and microecologists. We must also recognize that species interact with each other in the context of environments that are dynamic. Change is a constant in living systems, and it is an element of life that living organisms are adapted to deal with. But unprecedented changes can provide a welcome mat for invasive species, resulting in seriously compromised health to individuals and ecosystems.

C. Resistance emerges from overuse of control agents

Staphylococcus aureus, and to an extent *Clostridioides difficile* are notorious for their ability to develop resistance to antibiotics. In fact, before advances in discovering new antibiotics, methicillin-resistant *S. aureus* (MRSA) was virtually untreatable. To best treat Dave’s infection, physicians had to culture the *S. aureus* from his knee and the *C. difficile* from his intestine. Once in culture, the bacteria can be exposed to a battery of antibiotics in a microbiology lab. This testing ultimately generates a list of antibiotics to which

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the bacteria that made Dave sick were either susceptible or resistant. Thankfully, Dave's bacteria were susceptible to several different antibiotics, so the physicians could choose and administer the best option for recovery.

Literally, the term “anti-biotic” means “against life”; in other words, these agents try to stop something from living. Similarly, the term “pesti-cide” literally means “killer of a pest” (and “herbi-cide” means “killer of plants”). Like antibiotics, pesticides are utilized to kill certain life forms that are deemed detrimental to human well-being. When antibiotics and pesticides are used at their respective scales, many of the same population ecology dynamics play out in their wake, and reciprocal insights can be gained by each when considering the other.

Antibiotics save lives, but only when prescribed and used properly. Since the discovery of penicillin from a group of soil fungi (*Penicillium* spp.) in the 1940s, antibiotics tended to be prescribed even if a patient was suffering from a viral or parasitic disease—diseases for which antibiotics are completely ineffective.⁴² In some countries outside the U.S., antibiotics are readily available without a prescription—leaving the door open for widespread misuse by an under-informed public.⁴³ Furthermore, today a majority (80%) of antibiotics are used in the livestock industry to prevent disease in crowded barns, conditions favored for economic reasons so that animal meat can be brought to market more quickly.⁴⁴ According to the Centers for Disease Control and Prevention, this practice has led to more than 2.8 million antibiotic-resistant infections in humans in the U.S. each year, with more than 35,000 deaths as a result.⁴⁵ In 2019, the World Health Organization estimated that bacterial antimicrobial resistance was directly responsible for 1.27 million human deaths globally and was a contributing factor in 4.95 million deaths.⁴⁶

Bacteria are wonderfully gifted at sharing genetic information and developing mutations at a higher rate than eukaryotic cells. They also tend to reproduce much quicker than eukaryotic cells, all of which means that bacteria can incorporate genetic change into their genomes at a faster rate than eukaryotes. While this ability has allowed researchers to use bacteria for studying evolutionary processes within human time constraints,⁴⁷ the outcome of all this rapid genetic change is that in any given population or community of bacteria there are likely some that have acquired, by chance, antibiotic target-site point mutations, genes for multidrug efflux pumps, enzymes that degrade antibiotics, or enzymes

that modify antibiotics and render them ineffective.⁴⁸ When the microbial communities in which these modified bacteria reside are inundated with an antibiotic, the susceptible bacteria will be wiped out, leaving only the resistant ones. With plenty of space and resources and less competition, the resistant bacteria can now thrive. It is important to note that humans did not create antibiotic-resistant bacteria—they have existed for as long as bacteria and fungi have produced antibiotics. However, when antibiotics are used indiscriminately, we artificially increase the ratio of resistant-to-sensitive bacteria, making drug-resistant bacteria more plentiful. We have become selective agents in a rapidly evolving population of microbes.

A bit more complexity arises when we realize that antibiotic resistance itself can be an ecological matter. Not only do antibiotics remove healthy bacteria and create a dysbiotic environment, but bacteria can be resistant or sensitive to antibiotics depending on their surrounding environment.⁴⁹ In one study, *Escherichia coli* were grown with varying levels of antibiotics in large batches. Every so often, a sample of bacteria from the batch culture would be grown, but now as individual, disconnected isolates. The isolates grown alone were not nearly as resistant to the antibiotic as the batch cultures were. It turns out that when in community, a few *E. coli* secrete a substance known as indole, which acts to up-regulate multidrug efflux pumps in the entire *E. coli* population, as well as other related bacteria like *Salmonella*.⁵⁰ When grown in isolation, each bacterium finds itself devoid of indole, downregulates its multidrug efflux pumps, and becomes very susceptible to even low levels of the same antibiotic. Understanding population and community dynamics matters when it comes to disease management of resistant bacterial infections.

Similar to antibiotics, pesticides are used in an attempt to eliminate unwanted species that threaten plants preferred by humans, such as domesticated crop plants. An especially interesting and informative herbicide case study is glyphosate, a chemical readily available and widely used today. This chemical was first synthesized in 1950, but its potential use as a herbicide was not identified until 1970 by a chemist employed by the Monsanto Corporation (which was purchased by Bayer in 2018).⁵¹ Within four years, Monsanto had been given approval to sell their glyphosate product under the trade name of “Roundup.”⁵² The use of Roundup was somewhat limited early on because it was so effective—it did a great job of killing plants, but it did so indiscriminately. Without carefully targeted application,

it would kill crop plants along with weeds, and so its agricultural use was relegated to killing plants between rows of crops or before planting or after harvesting.⁵³

This all changed in 1996 when Monsanto (the same company that benefits from Roundup sales) genetically modified soybeans, corn, and cotton to be resistant to Roundup.⁵⁴ This development gave Monsanto the ability to sell seeds that grew into plants that were not killed when sprayed with Roundup. Therefore, in fields with these new genetically modified crops, farmers did not need to be so careful when spraying Roundup herbicide. Instead, Roundup in these fields can be broadcast-sprayed 1–3 times during the growing season over the entire field of Roundup-ready (RR) crops. Since the introduction of RR crops, Roundup sales have soared, and its use has increased 15-fold.⁵⁵

Although Monsanto downplayed the possibility of Roundup resistance developing in weeds that grow in areas that experience heavy application rates, before the release of RR crops, resistance to Roundup had already been discovered in a grass species in Australia. With wide-scale application of Roundup in the aftermath of RR crop introductions, several other weed species developed resistance to this herbicide, and more are certainly on the horizon.⁵⁶ The emergence of these “superweeds” is also being accelerated because of the increasingly casual way that Roundup is used by homeowners as an easier alternative to kill unwanted plants compared to physical weed removal or home remedies such as boiling water. As more Roundup-resistant weeds emerge, next-generation herbicide-tolerant crops are, or soon will be on the market.⁵⁷ These crops will be able to tolerate additional herbicides that are more likely to kill Roundup-resistant weeds. The agricultural chemical arms race against resistance-evolving weeds is taking us into an increasingly chemical-driven agricultural future.

One big concern with this chemical-based way of growing food crops is that several of the next generation of herbicides are expected to pose greater human health risks than Roundup does.⁵⁸ And yet, studies have shown that Roundup itself may be carcinogenic to humans.⁵⁹ Cautionary measures have been taken by the European Union, with several countries imposing partial bans on the use of Roundup. Additionally, lawsuits have been filed against Monsanto claiming that Roundup has caused cancer in users. As of October 2024, Monsanto had settled nearly 100,000 of these lawsuits with approximately \$11 billion in settlement payouts. Over 50,000 lawsuits are still pending.⁶⁰ All the while,

Roundup continues to be heavily used in agricultural landscapes and is readily available to homeowners at local supermarkets and hardware stores.

Broadcast spraying a field of RR corn with Roundup three times a year is similar to regularly taking preventative antibiotics. In the short term, there may be benefits, but evolution is relentless, resulting in unwanted outcomes in those chemical-doused fields, not to mention the ancillary consequences of chemical residues that drift into adjacent areas or that end up in the bodies of unprotected workers or people who ingest pesticide-tainted foods. Because of the recognition of emerging antibiotic resistance in pathogenic agents, antibiotic use has become more carefully administered,⁶¹ certainly over the course of the past decade. Those who grow plants in agriculture, landscaping, and even home gardens should take notice. A field of corn is like a human body. Lots of antibiotics introduced into lots of human bodies has shown us the downside of this practice—disease agents have become resistant to the point of total resistance in some microbes. Isn't it much better to promote good health, to live carefully in ways that minimize the likelihood that we will need antibiotics? Keeping stress low, spending time in nature, eating healthy foods, staying active, and living in healthy communities of love and support are things we all know promote well-being. Antibiotics may still be needed at times, but when needed, they can be used judiciously, and in the meantime, alternatives should continue to be explored.

In contrast to an agricultural future increasingly dependent on a chemical arms race, the promise of regenerative agriculture looks amazingly refreshing and environmentally kind.⁶² Regenerative agriculture takes a similar approach to environmental health that wellness programs take to human health. When soil is healthy and plants are thriving, they are much less susceptible to pathogens. Fewer chemicals used on agricultural fields means healthier soil communities and fewer chemicals getting into local waterways and onto food that we eat. Growing crops in ways that promote the well-being of plants and reduce their need for chemical inputs improves the health of farm workers and consumers. Furthermore, taking good care of people, plants, and the places they inhabit will result in much less need for antibiotics or pesticides. The planet will be healthier, the food we eat more nutritious, the water we drink more trustworthy. Although shifting paradigms requires courage and always encounters resistance, one has to wonder, what's not to like about such a future?⁶³

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D. Restoration ecology is medicine at the macro and micro level

John was quite worried about Dave's *Clostridioides difficile* infections, knowing that *C. difficile* was difficult to treat and has a high recurrence rate. In addition, it was critical to control the *C. difficile* infection, but that could only be done by switching off the antibiotic that was addressing the *Granulicatella* infection, which put Dave at higher risk of having that infection return. At this point John informed Dave of a different kind of treatment for *C. difficile*—one that involves bringing back the “normal” bacteria—the microbial ecosystem that can become degraded by extended antibiotic treatment.

Successful treatment with antibiotics may kill *Clostridioides difficile*, but it does not restore the original microbiome to a healthy state; therefore, approximately 20% of individuals will experience a recurrence.⁶⁴ What can be done when antibiotics fail to stop a dangerous bacterial disease? The answer, at least for *C. difficile* disease, is to re-establish the normal microbiota to a pre-antibiotic state, or in other words, restoration ecology at the microbial level. The bacteria that have evolved within animal hosts tend to be hard to displace. They have perfected how to attach to tissues, interact with the immune system, and provide nutrients to the host and other bacteria nearby.⁶⁵ So, when they are displaced by antibiotics or other means, successful reintroduction can lead to interlopers like *C. difficile* becoming competitively excluded. For cases of *C. difficile*, the most successful type of this microbial restoration ecology is called Fecal Microbial Transplant or FMT.⁶⁶

The FMT starts with a stool sample, donated by a relative or from a company that collects fecal samples from screened donors. Medical staff will then sedate the patient, liquify the stool, and inject it into the colon through a colonoscopy tube. Soon, billions and billions of bacteria in the stool sample begin to establish themselves and force *Clostridioides difficile* out. The efficacy of this treatment is extremely high—92% of individuals are cured of *C. difficile* after one treatment.⁶⁷ Further, studies have shown that after an FMT, the number of bacterial antibiotic resistance genes decreases dramatically—suggesting that the normal human microbiota can out-compete not only *C. difficile*, but other antibiotic-resistant bacteria as well.⁶⁸

Restoration ecology at the macro level is a field within the discipline of ecology that works with damaged, degraded, or destroyed ecosystems and attempts to return environmental health to these compromised habitats.⁶⁹ An important element of doing an ecologi-

cal restoration project is to find a “reference ecosystem” which can guide the restoration work.⁷⁰ Reference ecosystems provide a model that informs a restoration practitioner of what species to use, and in what densities and spatial arrangements to use them. Restoration ecologists may also use reference ecosystems in a more direct way by literally collecting seeds from the reference site as propagules for growing new plants to be used in restoring the degraded ecosystem.⁷¹ In this way, local genotypes and genetic lineages are preserved and incorporated into these newly restored habitats.

Using native plants, and even native genotypes of native plants in a restoration project, may, by itself, not be enough to jumpstart a new ecosystem. If the soil has been significantly compromised, then natural processes will not automatically resume. However, if plants are used that were rescued from a location before the area was degraded, these transplants will act as an inoculant in the new site. Not only are the plants introduced into the restoration project, but Indigenous microbial soil ecosystems are brought to the new restoration site, too. The Indigenous soil will have invertebrates, macro and micro, as well as all kinds of soil bacteria, fungi, and algae. This same benefit can be conveyed by directly incorporating healthy soil or compost into a restoration project. In these ways, the new restoration site becomes inoculated with good microbes that, if cared for well, can spread and begin contributing to the growing health of the formerly degraded site. Transplanting rescued plants with their soil into a restoration project offers a direct parallel to using fecal microbial transplants from a healthy patient to a patient whose gut microbiome has been significantly compromised.

III. Insights for Creation Care

This extended case study re-emphasizes to us that God designed all of creation to be made of diverse, constantly interacting, relational-rich communities.⁷² A world composed of complex webs of interactions should not surprise us, given that it was brought into being by a highly interactive God—Father, Son, and Holy Spirit.⁷³ Theologian Colin Gunton describes the interconnect-edness of the trinity as a reflection; just as God is one being, so too is God's creation—an integrated whole.⁷⁴ Yet the Father, Son, and Holy Spirit are also defined by their unique activities, and so too is God's creation—each part serving an essential function to the others. Significantly, then, just as the Father, Son, and Holy Spirit are God only in integration with one another, all the parts of creation should be defined and understood by their relationships to other beings—a universal

“giving to and receiving from.”⁷⁵ Understanding ourselves as co-creatures who also inhabit and depend upon this complex web of relationships elicits several insights for creation care.

A. Functioning and balance

One insight is that our purpose as human creatures embedded within creation is to live in ways that protect and promote balanced relationships that keep all of creation, from the macro- to the microlevel, functioning as God intended.

1. *Balance between us and our gut microbiome.* It is becoming increasingly clear that the relationships that occur microbially in our human microbiome have a profound effect on human health. In fact, the relationship between us and our gut microbiome is one so deeply intertwined that humans could not survive without a gut microbiome. In this way, our microbes can be considered an organ, as essential to the proper function of the human body as the liver, lungs, or kidneys. This perspective calls us to extend intentional creation-care activities to our microbial communities by only taking antibiotics when absolutely necessary, eating low-fat, high-fiber diets that include fermented foods, yogurts, and other sources of potential probiotics, and by including regular exercise and other mindfulness activities that help keep stress levels low.

2. *Balance between us and natural macroecosystems.* Research is increasingly identifying the many benefits to human health conveyed by frequent and prolonged exposure to healthy natural ecosystems. Critically, when there is peace and goodwill among people, those people are more likely to value the places in which they live and be willing to care for them. When people work together to care for those places, human and nonhuman relationships are strengthened in a positive relational feedback loop.⁷⁶

Bringing healthy macroecosystems back into urban spaces requires the re-establishment of interactions among a wide diversity of species that knit them together in the first place.⁷⁷ College and university campuses are wonderful landscapes for activating this type of restorative creation-care practice. On Calvin University’s campus, we now have twelve native gardens, the most recent addition being a native meadow that was planted as part of the outdoor landscaping for a remodeled library (fig. 1). Integrating native gardens into our campus landscaping has provided multiple benefits, including carbon sequestration, stormwater absorption, reduced maintenance costs, fewer chemical

inputs, increased biodiversity, and improved human well-being. These gardens, in a manner similar to fecal microbial transplants, are wonderful examples of how increasing biodiversity enhances the overall well-being of creation.⁷⁸

3. *Balance between us and other humans.* At its best, creation care will also involve promoting mutual understanding and appreciation between different cultural groups. Work in the areas of anti-racism and international peacekeeping are excellent examples of promoting healthy relationships between people-groups. Promoting balance within a cultural group or population is important too—working for a healthy blend of appreciation for science, ethics, and art, where all three work together to promote overall well-being.⁷⁹ Finally, working for human health and well-being involves proper balance in the interactions of the emotional, spiritual, physical, and psychological needs within individual people. Though not typically thought of as creation-care activities, if human beings are recognized as interactive creatures within an interactive creation, initiatives that promote peace, cultural flourishing, and human well-being can also be recognized as expressions of creation care. Ultimately, social and environmental justice efforts should merge so that as people learn to better care for each other, they will come together



Figure 1. Calvin students planting a native meadow as part of the outdoor landscaping for a remodeled library at Calvin University.

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to care for their place and vice versa. Martin Luther King Jr.'s vision for "the beloved community"⁸⁰ offers a shalomic image for us all when we imagine this notion of community to include all species who exist together in a shared space.⁸¹ The inclusion of social and environmental justice efforts together as critical elements of creation care deserves further thought and elucidation because it challenges traditional notions that focus creation care explicitly on nonhuman creation.

B. Restraining our destructive nature

A second insight is that our species has a strong tendency to pursue selfish gains, blinded to the costs incurred on the health of the broader creation. War is one example, with the impact on the land sometimes felt for centuries after the war has ended.⁸² In most urban areas, human presence has been imposed onto the earth with little regard for nonhuman life, decimating local ecologies. In turn, the lack of functioning ecosystems and loss of their ecological services often degrade the lives of people who are living in those places.⁸³ Failure to understand the necessity of healthy relationships across creation has resulted in a reduction of complexity, extensive loss of diversity, and serious incidents of dysbiosis. This destructive pattern extends from the global environmental scale down to the ecology of the human microbiome. Global climate change, forever chemicals, the emergence of resilient superbugs, and unprecedented rates of species loss are all indicators that our relationship with the rest of creation is far too one-sided and abusive. We need to learn new, more generous, and more careful ways of inhabiting God's good world. A solution? Bring restoration ecology into all areas of life that have been damaged, including international relations, neighborhood revitalization, habitat renewal, reforestation, urban green infrastructure, and microbial recolonization. The task before us is to bring healing to all disrupted relationships, from microbes to ecosystems.

The diversity of species in God's creation is immense. Therefore, protecting and promoting healthy relationships is no small task. At the end of God's creative activities in Genesis 1, the profound declaration made is that what had emerged was good; indeed, it was very good. And what emerged (in terms of the world we live in today) is approximately 30 million species – potentially as many as 20 million invertebrates and at least 4 million different species of fungi; avian life from 2-inch bee hummingbirds (0.01 oz) to 9-foot-tall ostriches (over 320 pounds); and plants from 5000-year old bristlecone

pinus to minute floating water meal that is barely visible without a microscope.⁸⁴ When God created, God created a diverse, mesmerizingly varied garden, not a swath of a single or handful of species. Diverse ecosystems are more stable and more resilient to disruptions, while ecosystems with low diversity (corn fields, suburban lawns, compromised human microbiomes) are highly vulnerable and need almost constant monitoring and intervention.⁸⁵ Restoring and maintaining ecosystems with high diversity requires understanding and nurturing the plethora of ways the species in those ecosystems interact. This is a monumental task, but it is absolutely essential to protecting and restoring God's creation.

C. Rulers as promoters of flourishing

A third insight comes from an articulation of humankind's unique responsibility to the rest of creation as being *rulers over* this vast array of diversity (Gen. 1:26). We are distinct from every other creature because of the relationships we are capable of having with the creator, each other, and the nonhuman creation.⁸⁶ And yet, being tasked with ruling creation ("*radah*" in the Hebrew) is not a mandate for exerting control, nor does it provide permission to do whatever we please. On the contrary, as is frequently seen in the Old Testament, God judges rulers ("*radah*-ers") as good or bad depending on how the subjects under their rule have fared. For example, Solomon (1 Kings 3, 1 Kings 9–11), Rehoboam (1 Kings 12), Ahab (1 Kings 21), the shepherds of Israel (Ezekiel), and the kings of Judah (2 Kings, 2 Chronicles) demonstrate that God expects rulers will govern in ways that ensure the flourishing of those who are being ruled.⁸⁷

Our task of ruling creation is a directive to make sure that creation can flourish as God intends it to flourish – in all its expansive diversity and with all its complex interactions at the macroecological and microecological levels. And when we ensure that relationships within creation are protected, our own lives will be blessed by those healthy relationships, too. Therefore, good earth-keeping should include diminishing our own impact so that creation can do what it was created to do.⁸⁸ While antibiotics and pesticides can be beneficial in specific circumstances, indiscriminate and careless use can cause severe damage. Therefore, these agents need to be used with deep respect for creation's interconnectedness, and sometimes the choice *not to* use them is the best option. A "*radah*-er" who benefits from the consistent destruction of those being ruled is certainly at odds with God's mandate for humans to be good rulers.⁸⁹

By emphasizing the embedded, relational reality of human existence, theologian Colin Gunton references Irenaeus and Coleridge, among others, who reacted against enlightenment thinking that promoted notions of human exceptionalism and an instrumental view of nonhuman creation.⁹⁰ Richard Bauckham's contemporary voice echoes this theme: "We belong *within* the complexly interrelated diversity of God's extraordinarily different creatures" (emphasis ours).⁹¹ However, it is important to recognize that long before these insights, most Indigenous cultures have been teaching the importance of paying attention to relationships, emphasizing that human well-being is inextricably dependent on creational well-being. Robin Wall Kimmerer says, "how we think about our relationship to the living world matters deeply."⁹² Randy Woodley, author and theologian, explains that Indigenous teachings of striving for and working toward "the good life" (which is referred to as "Bimaadiziwin" by the Anishinaabeg in the Great Lakes region) have much in common with Hebrew teachings about shalom.⁹³ Whether by choice or by necessity, as we transition into a more sustainable future, guidance from long-held Indigenous teachings will provide helpful guidance.

D. An expanded notion of God's general revelation

While we have highlighted many reasons for taking good care of the earth, a fundamental motivation for many Christians to care for creation is that the creation is understood to be one means by which we come to know God.⁹⁴ A thriving, relationally integrated world is what God created and through which God reveals God's self. When relationships become unraveled, species are lost and biodiversity erodes; our source of learning about and being drawn close to God is compromised.⁹⁵ Anthropocentrism has disarranged creation, but not so badly that we cannot see what God's creation was intended to look like. We can certainly learn about God by observing a polluted creek with half as many species as it formerly supported, but the lessons are muted, the insights simplified, and much of God's grace and love for the world that was intended to be conveyed by that creek is constrained.

Theologian G. C. Berkouwer describes God's tainted general revelation as a mirror that is covered in mud. While still a mirror, it is not able to accurately reflect God's revelation the way a clean mirror does. However, when we recognize the harm we have caused creation, lament our complicity in muddying the mirror, and

then begin working toward its restoration, we are being drawn into a reconciliation process that helps to heal our relationships with the earth, other people, and the Creator. Berkouwer emphasizes that human beings are not simply creatures who happen to form relationships, but that to be human is to be relational. He writes, "Man is never a 'thing' in himself; he is always a man-in-relation—to God, to his neighbor, and to the world."⁹⁶ When creation care is done well, a positive feedback loop results—the relationships we are involved in become healthier, and a restored earth is better able to reveal God's goodness and care.

We have also found it curious that God's special revelation is understood to be Scripture, and God's general revelation is typically relegated to nonhuman nature. However, by focusing general revelation solely on nonhuman creation, we miss an important channel through which God has much to convey. If human beings are embedded creatures *within* creation, not *outside* it,⁹⁷ then one important way we learn about God through God's general revelation is by paying attention to one another. While humans are not usually envisioned as part of God's general revelation, this notion aligns with teachings that humans are created in God's image and that at least some measure of God's goodness flows through each individual person.⁹⁸ By including humans and their healthy relationships as part of God's creation, the scope of God's general revelation becomes more expansive.

This paradigm shift requires recovering humanity back from the flawed Enlightenment notion of human versus nature. Human beings as part of God's creation means that God's general revelation includes the way humans interact well with each other and with the land. It means that God reveals God's self through the precious, innocent insights of children and the encouraging words of friends. To us, it also means that we can learn about God and how best to live in God's world through the careful discoveries of scientists, including psychologists, geneticists, sociologists, and climatologists who "read" God's general revelation and help interpret it. Humans as part of general revelation also means that we can learn about God's desire for all creation to exist in shalomic harmony from the wisdom of Indigenous people, many of whom emphasize the importance of carefully tending to the many relationships in which we are necessarily entwined.⁹⁹

Berkouwer explains that the image of God is, first and foremost, "in-relation-to" the Creator. And because we are created in the image of a relational God, we are

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inherently directed toward the “other.” Isolation is, in Berkouwer’s view, a contradiction of our created nature.¹⁰⁰ Neil Plantinga emphasizes that one important aspect of bearing God’s image is that we are communal beings, intended to be in mutual, reciprocally flourishing relationships.¹⁰¹ Cultivating healthy relationships among people and between people and the land gives us a clearer picture of the great three-in-one relationally complex Creator and that Creator’s loving desire for all creation to flourish together.¹⁰²

IV. Conclusion

Over the past 50 years, Christian Environmental Stewardship (CES) has provided a helpful paradigm for creation care.¹⁰³ However, the limitations of a traditional notion of stewardship have become increasingly apparent and new approaches are being suggested.¹⁰⁴ The contributions of restoration ecology to this ongoing dialogue include the importance of recognizing that creation exists at many different levels—many much larger than us, but also many much smaller. Caring for the human microbiome (let alone the microbiome of a tree or a chipmunk) is typically not considered under the purview of CES. However, these diverse microbial communities are certainly part of God’s good creation and, if neglected or treated poorly, can have reverberatingly negative effects that will degrade larger aspects of creation’s beauty and integrity. Furthermore, God’s good creation at all levels is intended to be diverse, interactive, and dynamic. And this good creation includes human beings, creatures who themselves thrive best within healthy relationships and through which we gain deeper insight into God’s goodness and grace. Christian environmental stewards, then, should be less regarded as keepers of a vineyard and more understood to be promoters, protectors, and restorers of diverse ecosystems with their myriad micro- and macroecological interactions.

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Notes

- ¹Rick Relyea, *Ecology: The Economy of Nature*, 9th ed. (W.H. Freeman and Company, 2021).
- ²Michael T. Madigan et al., *Brock Biology of Microorganisms*, Global Edition, 16th ed. (Pearson Education, 2021).
- ³Jean Lebel, *Health: An Ecosystem Approach* (International Development Research Centre, 2003).
- ⁴Sarah J. Pitt and Alan Gunn, “The One Health Concept,” *British Journal of Biomedical Science* 81 (2024): 12366, <https://doi.org/10.3389/bjbs.2024.12366>.
- ⁵Although “holobiont theory” is seeking to rectify that. See M. A. O’Malley, “From Endosymbiosis to Holobionts: Evaluating a Conceptual Legacy,” *Journal of Theoretical Biology* 434 (2017): 34, <https://doi.org/10.1016/j.jtbi.2017.03.008>.
- ⁶Ernst Haeckel is generally credited as first using the term “ecology”; in 1866, he wrote: “By ‘ecology’ we understand the comprehensive science of the relationships of the organism to its surrounding environment, where we can include, in the broader sense, all conditions of existence.” Ernst Haeckel, *Generelle Morphologie der Organismen* (Druck und Verlag von Georg Reimer, 1866).
- ⁷Bradford D. Martin and Ernest Schwab, “Symbiosis: ‘Living Together’ in Chaos,” *Studies in the History of Biology* 4, no. 4 (2012): 7–25, <https://shb.nw.ru/wp-content/uploads/2018/07/SHB-2012-4.pdf>.
- ⁸Sonya Purin and Matthias C. Rillig, “Parasitism of Arbuscular Mycorrhizal Fungi: Reviewing the Evidence,” *FEMS Microbiology Letters* 279, no. 1 (2008): 8–14, <https://doi.org/10.1111/j.1574-6968.2007.01007.x>; and Benjamin M. Titus et al., “Phylogenetic Relationships Among the Clownfish-Hosting Sea Anemones,” *Molecular Phylogenetics and Evolution* 139 (2019): 106526, <https://doi.org/10.1016/j.ympev.2019.106526>.
- ⁹Elizabeth G. Pringle, “Orienting the Interaction Compass: Resource Availability as a Major Driver of Context Dependence,” *PLoS Biology* 14, no. 10 (2016): e2000891, <https://doi.org/10.1371/journal.pbio.2000891>.
- ¹⁰The case study of fungal endophytes is especially fascinating—these are fungi that grow inside plants; an early documentation of such a fungus being both detrimental and beneficial depending on the environmental context was described by Jan L. Cassin, “Balancing Costs and Benefits in a Mutualism: Conditionality in the Interaction of the Grass, *Hystrix patula* Moench. (Poaceae: Triticeae) and Its Fungal Endophyte” (PhD diss., University of Michigan, 1997), <https://deepblue.lib.umich.edu/handle/2027.42/130435>.
- ¹¹Millling Yan et al., “Nasal Microenvironments and Interspecific Interactions Influence Nasal Microbiota Complexity and *S. aureus* Carriage,” *Cell Host & Microbe* 14, no. 6 (2013): 631–40, <https://doi.org/10.1016/j.chom.2013.11.005>.
- ¹²Yan et al., “Nasal Microenvironments and Interspecific Interactions.”
- ¹³Zahra Rashki Ghalehnoo, “Diseases Caused by *Staphylococcus aureus*,” *International Journal of Medical and Health Research* 4, no. 11 (2018): 65–67, https://www.researchgate.net/publication/330183444_Diseases_caused_by_Staphylococcus_aureus.
- ¹⁴Morgan Brazel et al., “Staphylococcal Scalded Skin Syndrome and Bullous Impetigo,” *Medicina* 57 (2021): 1157, <https://pdfs.semanticscholar.org/6306/221057012eebaf9450c1af50e857df222191.pdf>.
- ¹⁵Yan et al., “Nasal Microenvironments and Interspecific Interactions.”
- ¹⁶Ghalehnoo, “Diseases caused by *Staphylococcus aureus*.”
- ¹⁷Nour Ahmad-Mansour et al., “*Staphylococcus aureus* Toxins: An Update on Their Pathogenic Properties and Potential

- Treatments," *Toxins* 13, no. 10 (2021): 677, <https://doi.org/10.3390/toxins13100677>.
- ¹⁸Benjamin P. Howden et al., "Staphylococcus aureus Host Interactions and Adaptation," *Nature Reviews Microbiology* 21 (June 2023): 380–95, <https://doi.org/10.1038/s41579-023-00852-y>.
- ¹⁹Fanny Quénard et al., "Prosthetic Joint Infection Caused by *Granulicatella adiacens*: A Case Series and Review of Literature," *BMC Musculoskeletal Disorders* 18 (2017): 276, <https://doi.org/10.1186/s12891-017-1630-1>.
- ²⁰Quénard et al., "Prosthetic Joint Infection"; T. S. Shailaja et al., "Infective Endocarditis Caused by *Granulicatella adiacens*," *Indian Heart Journal* 65, no. 4 (July–August 2013): 447–49, <https://doi.org/10.1016/j.ihj.2013.06.014>; and Agnè Gièdratienè et al., "Antibiotic Resistance Mechanisms of Clinically Important Bacteria," *Medicina* 47, no. 3 (2011): 137–46, <https://doi.org/10.3390/medicina47030019>.
- ²¹Gièdratienè et al., "Antibiotic Resistance Mechanisms."
- ²²T. G. Tutin et al., eds., *Flora Europaea, Volume 2: Rosaceae to Umbelliferae* (Cambridge University Press 1968).
- ²³Connie L. Gaudet and Paul A. Keddy, "A Comparative Approach to Predicting Competitive Ability from Plant Traits," *Nature* 334 (July 1988): 242–43, <https://doi.org/10.1038/334242a0>; Mark G. Anderson, "Interactions Between *Lythrum salicaria* and Native Organisms: A Critical Review," *Environmental Management* 19 (1995): 225–31, <https://doi.org/10.1007/BF02471992>; and Gregory P. Grabas and Terence M. Laverty, "The Effect of Purple Loosestrife (*Lythrum salicaria* L., *Lythraceae*) on the Pollination and Reproductive Success of Sympatric Co-Flowering Wetland Plants," *Écoscience* 6, no. 2 (1999): 230–42, <https://doi.org/10.1080/11956860.1999.11682524>.
- ²⁴Carol Eunmi Lee, "Evolutionary Genetics of Invasive Species," *Trends in Ecology & Evolution* 17, no. 8 (August 2002): 386–91, [https://doi.org/10.1016/S0169-5347\(02\)02554-5](https://doi.org/10.1016/S0169-5347(02)02554-5); and Lua Xia et al., "Rapid Genetic Divergence of an Invasive Species, *Spartina alterniflora*, in China," *Frontiers in Genetics* 11 (April 2020): 1–19, <https://doi.org/10.3389/fgene.2020.00284>.
- ²⁵It is a curiosity that across the world most people who have home gardens plant non-native species in them; while many of these garden plants do not spread and become problematic, those that do can cause great harm; for a fascinating analysis of which traits help species "escape" home gardens, see Audrey Marco et al., "From the Backyard to the Backcountry: How Ecological and Biological Traits Explain the Escape of Garden Plants into Mediterranean Old Fields," *Biological Invasions* 12 (2010): 761–79, <https://doi.org/10.1007/s10530-009-9479-3>.
- ²⁶Rick van Saene et al., "Broad- and Narrow-Spectrum Antibiotics: A Different Approach," *Clinical Microbiology and Infection* 4, no. 1 (January 1998): 56–57, <https://doi.org/10.1111/j.1469-0691.1998.tb00338.x>.
- ²⁷Martin J. Blaser, "Antibiotic Use and Its Consequences for the Normal Microbiome," *Science* 352, no. 6285 (April 2016): 544–45, <https://doi.org/10.1126/science.aad9358>.
- ²⁸Drew J. Schwartz et al., "Understanding the Impact of Antibiotic Perturbation on the Human Microbiome," *Genome Medicine* 12 (September 2020): 82, <https://doi.org/10.1186/s13073-020-00782-x>.
- ²⁹Marc Monot et al., "Clostridium difficile: New Insights into the Evolution of the Pathogenicity Locus," *Scientific Reports* 5 (October 2015): 15023, <https://doi.org/10.1038/srep15023>.
- ³⁰Anne J. Gonzales-Luna et al., "Gut Microbiota Changes Associated with *Clostridioides difficile* Infection and Its Various Treatment Strategies," *Gut Microbes* 15, no. 1 (January–December 2023): 2223345, <https://doi.org/10.1080/19490976.2023.2223345>.
- ³¹Anna Maria Seekatz et al., "The Role of the Gut Microbiome in Colonization Resistance and Recurrent *Clostridioides difficile* Infection," *Therapeutic Advances in Gastroenterology* 15 (November 2022): 175628482221134396, <https://doi.org/10.1177/17562848221134396>.
- ³²Anna Maria Seekatz and Vincent B. Young, "Clostridium difficile and the Microbiota," *Journal of Clinical Investigation* 124, no. 10 (October 2014): 4182–89, <https://doi.org/10.1172/JCI72336>.
- ³³Seekatz and Young, "Clostridium difficile and the Microbiota."
- ³⁴Jessica E. Buddle and Robert P. Fagan, "Pathogenicity and Virulence of *Clostridioides difficile*," *Virulence* 14, no. 1 (2023): 2150452, <https://doi.org/10.1080/21505594.2022.2150452>.
- ³⁵Ildikó Orbán et al., "The Role of Disturbance in Invasive Plant Establishment in a Changing Climate: Insights from a Drought Experiment," *Biological Invasions* 23, no. 6 (June 2021): 1877–90, <https://doi.org/10.1007/s10530-021-02478-8>.
- ³⁶Christophe Diagne et al., "High and Rising Economic Costs of Biological Invasions Worldwide," *Nature* 592 (April 2021): 571–76, <https://doi.org/10.1038/s41586-021-03405-6>.
- ³⁷Regan Early et al., "Global Threats From Invasive Alien Species in the Twenty-First Century and National Response Capacities," *Nature Communications* 7 (August 2016): 12485, <https://doi.org/10.1038/ncomms12485>.
- ³⁸Richard Law and R. Daniel Morton, "Alternative Permanent States of Ecological Communities," *Ecology* 74, no. 5 (July 1993): 1347–61, <https://doi.org/10.2307/1940065>.
- ³⁹Kristina Stinson et al., "Impacts of Garlic Mustard Invasion on a Forest Understory Community," *Northeastern Naturalist* 14, no. 1 (2007): 73–88, [https://doi.org/10.1656/1092-6194\(2007\)14\[73:IOGMIO\]2.0.CO;2](https://doi.org/10.1656/1092-6194(2007)14[73:IOGMIO]2.0.CO;2).
- ⁴⁰Irene O. Sabin and Nicholas Polanin, "Identification, Control, and Impact of Garlic Mustard (*Alliaria petiolata*)," New Jersey Agricultural Experiment Station, *Rutgers University Fact Sheet FS1212* (September 2013), <https://njaes.rutgers.edu/fs1212/>.
- ⁴¹Victoria Nuzzo, "Invasion Pattern of Herb Garlic Mustard (*Alliaria petiolata*) in High Quality Forests," *Biological Invasions* 1 (1999): 169–79, <https://doi.org/10.1023/A:1010009514048>.
- ⁴²Tanvir Mahtab Uddin et al., "Antibiotic Resistance in Microbes: History, Mechanisms, Therapeutic Strategies and Future Prospects," *Journal of Infection and Public Health* 14, no. 12 (October 2021): 1750–66, <https://doi.org/10.1016/j.jiph.2021.10.020>.
- ⁴³Kerry Cullinan, "A Third of People Used Antibiotics Without Prescription, WHO Europe Survey Finds," Health Policy Watch: Independent Global Health Reporting, November 23, 2023, accessed March 11, 2026, <https://healthpolicy-watch.news/a-third-of-people-used-antibiotics-without-prescription-who-europe-survey-finds/>.
- ⁴⁴Vanmathy Kasimanickam et al., "Antibiotics Use in Food Animal Production: Escalation of Antimicrobial Resistance: Where Are We Now in Combating AMR?," *Medical Sciences* 9, no. 1 (February 2021): 14, <https://doi.org/10.3390/medsci9010014>.
- ⁴⁵Centers for Disease Control and Prevention, accessed March 11, 2025, <https://www.cdc.gov/antimicrobial-resistance/index.html>.
- ⁴⁶World Health Organization, accessed March 11, 2025, <https://www.cdc.gov/antimicrobial-resistance/index.html>.
- ⁴⁷Richard E. Lenski, "Experimental Evolution and the Dynamics of Adaptation and Genome Evolution in Microbial Populations," *The ISME Journal* 11, no. 10 (October 2017): 2181–94, <https://doi.org/10.1038/ismej.2017.69>.
- ⁴⁸Gièdratienè et al., "Antibiotic Resistance Mechanisms."
- ⁴⁹Nicole M. Vega et al., "Salmonella typhimurium Intercepts Escherichia coli Signaling to Enhance Antibiotic Tolerance," *Pro-*

- ceedings of the National Academy of Sciences 110, no. 35 (August 2013): 14420–25, <https://www.pnas.org/doi/10.1073/pnas.1308085110>.
- ⁵⁰Vega et al., “*Salmonella typhimurium* Intercepts *Escherichia coli*.”
- ⁵¹G. M. Dill et al., “Glyphosate: Discovery, Development, Applications, and Properties,” chapter 1 in *Glyphosate Resistance in Crops and Weeds: History, Development, and Management*, ed. V. K. Nandula (Wiley, 2010), 1–33; and Camila Domonoske, “Monsanto No More: Agri-Chemical Giant’s Name Dropped in Bayer Acquisition,” National Public Radio, June 4, 2018, accessed March 18, 2025, <https://www.npr.org/sections/thetwo-way/2018/06/04/616772911/monsanto-no-more-agri-chemical-giants-name-dropped-in-bayer-acquisition>.
- ⁵²Stephen O. Duke and Stephen B. Powles, “Glyphosate: A Once-in-a-Century Herbicide,” *Pest Management Science* 64, no. 4 (April 2008): 319–25, https://www.researchgate.net/publication/228666854_Mini-review_Glyphosate_a_once-in-a-century_herbicide.
- ⁵³Charles M. Benbrook, “Trends in Glyphosate Herbicide Use in the United States and Globally,” *Environmental Sciences Europe* 28, no. 1 (February 2016): 3, <https://link.springer.com/article/10.1186/s12302-016-0070-0>.
- ⁵⁴Benbrook, “Trends in Glyphosate Herbicide Use.”
- ⁵⁵Benbrook, “Trends in Glyphosate Herbicide Use.”
- ⁵⁶Ian M. Heap, “Global Perspective of Herbicide-Resistant Weeds,” *Pest Management Science* 70, no. 9 (January 2014): 1306–15, <https://doi.org/10.1002/ps.3696>.
- ⁵⁷Jared White, “Bayer’s Next Generation of Soybeans Planned for 2027,” *Brownfield News*, June 20, 2024, accessed March 25, 2025, <https://www.brownfielddagnews.com/news/bayers-next-generation-of-soybeans-planned-for-2027/>.
- ⁵⁸David A. Mortensen et al., “Navigating a Critical Juncture for Sustainable Weed Management,” *Bioscience* 62, no. 1 (January 2012): 75–84, <http://www.jstor.org/stable/10.1525/bio.2012.62.1.12?origin=JSTOR-pdf>.
- ⁵⁹IARC Monographs Volume 112: Evaluation of Five Organophosphate Insecticides and Herbicides,” International Agency for Research on Cancer, World Health Organization (March 20, 2015), accessed March 25, 2025, <https://www.iarc.fr/en/media-centre/iarcnews/pdf/MonographVolume112.pdf>; and Michael DiBartolomeis et al., “An Assessment of Acute Insecticide Toxicity Loading (AITL) of Chemical Pesticides Used on Agricultural Land in the United States,” *PLoS ONE* 14, no. 8 (August 2019): e0220029, <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0220029>.
- ⁶⁰Zenebou Sylla and Elizabeth Wolfe, “Bayer Ordered To Pay \$2.25 Billion After Jury Concludes Roundup Weed Killer Caused a Man’s Cancer, Attorney Says,” CNN US, January 30, 2024, accessed March 25, 2025, <https://www.cnn.com/2024/01/29/us/roundup-cancer-verdict-philadelphia-bayer-monsanto/index.html>.
- ⁶¹This is true for most developed-world countries, while there are other countries who often allow antibiotics to be sold without a prescription at pharmacies and other outlets.
- ⁶²Ayana Elizabeth Johnson, *What if We Get It Right? Visions of Climate Futures* (One World, Penguin Random House, 2024), 66–85.
- ⁶³Both of these case studies reveal the need for a re-examination of the concept of “the good life,” often translated in the Bible as “to prosper” (Jer. 29:11–13). A re-examination of true prospering, and a fresh understanding for what it means to live the good life is needed and can be informed by Indigenous teachings and wisdom. The Anishinaabeg promoted a concept referred to as “Bimaadiziwin”; see Nicole Bell, “Anishinaabe Bimaadiziwin” in A. Kulnieks et al., eds., *Contemporary Studies in Environmental and Indigenous Pedagogies* (SensePublishers, 2013), https://doi.org/10.1007/978-94-6209-293-8_6.
- ⁶⁴Buddle and Fagan, “Pathogenicity and Virulence of *Clostridioides difficile*.”
- ⁶⁵Seekatz and Young, “*Clostridium difficile* and the Microbiota.”
- ⁶⁶Nathan Zev Minkoff et al., “Fecal Microbiota Transplantation for the Treatment of Recurrent *Clostridioides difficile* (*Clostridium difficile*,” *Cochrane Database of Systematic Reviews* 4, no. 4 (April 25, 2023): CD013817, <https://doi.org/10.1002/14651858.cd013817.pub2>.
- ⁶⁷Minkoff et al., “Fecal Microbiota Transplantation.”
- ⁶⁸Sam Nooij et al., “Long-term Beneficial Effect of Faecal Microbiota Transplantation on Colonisation of Multidrug-Resistant Bacteria and Resistome Abundance in Patients with Recurrent *Clostridioides difficile* Infection,” *Genome Medicine* 16, no. 1 (February 2024): 37, <https://doi.org/10.1186/s13073-024-01306-7>.
- ⁶⁹See the homepage of the Society for Ecological Restoration at <https://www.ser.org/>.
- ⁷⁰See Principle 1, “Ecological restoration practice is based on an appropriate local Indigenous reference ecosystem,” in *National Standards for the Practice of Ecological Restoration in Australia*, edition 2.2, Standards Reference Group, Society for Ecological Restoration Australasia. In consultation with key partners (Society for Ecological Restoration Australasia, September 2021), 4–6, https://www.seraustralasia.com/standards/NationalStandards2_2.pdf.
- ⁷¹Gail G. Heffner and David P. Warners, *Reconciliation in a Michigan Watershed: Restoring Ken-O-Sha* (Michigan State University Press, 2024), 157–70.
- ⁷²Claus Westermann writes, “It is quite impossible to view Creation otherwise than as a whole in intimate relationship to the parts ...” Claus Westermann, *Creation* (Fortress Press, 1974), 46.
- ⁷³Colin E. Gunton, *The One, the Three, and the Many: God, Creation, and the Culture of Modernity* (Cambridge University Press, 1993).
- ⁷⁴Colin E. Gunton, *Christ and Creation* (Paternoster Press, 1992).
- ⁷⁵Uche Anizor, “A Spirited Humanity: The Trinitarian Ecclesiology of Colin Gunton,” *Themelios* 36, no. 1 (2011): 26, https://www.academia.edu/70285700/Spirited_Humanity_The_Trinitarian_Ecclesiology_of_Colin_Gunton.
- ⁷⁶Gretel Van Wieren, *Restored to Earth: Christianity, Environmental Ethics and Ecological Restoration*, (Georgetown University Press, 2013); and Heffner and Warners, *Reconciliation in a Michigan Watershed*.
- ⁷⁷Mark A. Goddard et al., “Scaling Up from Gardens: Biodiversity Conservation in Urban Environments,” *Trends in Ecology and Evolution* 25, no. 2 (February 2010): 90–98, <https://doi.org/10.1016/j.tree.2009.07.016>.
- ⁷⁸Eric Jaffe, “This Side of Paradise: Discovering Why the Human Mind Needs Nature,” *Observer*, American Psychology Society, May/June 2010, <https://www.psychologicalscience.org/observer/this-side-of-paradise>.
- ⁷⁹Gunton, *The One the Three, and The Many*, 151.
- ⁸⁰Martin Luther King Jr., <https://www.religion-online.org/article/martin-luther-kings-vision-of-the-beloved-community/>.
- ⁸¹Aldo Leopold’s words are worth repeating here: “We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.” Aldo Leopold, *A Sand County Almanac: And Sketches Here and There* (Oxford University Press, 2020), foreword, viii.
- ⁸²Neta C. Crawford, *Pentagon Fuel Use, Climate Change, and the Costs of War* (Watson Institute for International and Public

Affairs, Brown University, 2019), <https://costsofwar.watson.brown.edu/sites/default/files/papers/Crawford-Pentagon-Fuel-Use-Climate-Change.pdf>; and Neta C. Crawford, *The Pentagon, Climate Change, and War* (MIT Press, 2022).

⁸³Christopher J. Walsh et al., "The Urban Stream Syndrome: Current Knowledge and the Search for a Cure," *Journal of the North American Benthological Society* 24, no. 3 (2005): 706–23, <https://doi.org/10.1899/04-028.1>.

⁸⁴Walter S. Judd et al., *Plant Systematics: A Phylogenetic Approach*, 4th ed. (Sinauer Associates, Inc., 2019) 119ff.

⁸⁵Shahid Naeem et al., "Plant Diversity Increases Resistance to Invasion in the Absence of Co-Varying Extrinsic Factors," *Oikos* 91, no. 1 (October 2000): 97–108, <https://doi.org/10.1034/j.1600-0706.2000.910108.x>; and Michael Kriss et al., "Low Diversity Gut Microbiota Dysbiosis: Drivers, Functional Implications and Recovery," *Current Opinion in Microbiology* 44 (July 2018): 34–40, <https://doi.org/10.1016/j.mib.2018.07.003>.

⁸⁶Gunton, *Christ and Creation*.

⁸⁷Steven Bouma-Prediger, *For the Beauty of the Earth: A Christian Vision for Creation Care*, 2nd ed. (Baker Academic, 2010).

⁸⁸Bouma-Prediger, *For the Beauty of the Earth*, 137ff.

⁸⁹Steven Bouma-Prediger, "The Character of Earthkeeping: A Christian Creation Care Ethic," in Kiara A. Jorgenson and Alan G. Padgett, eds., *Ecotheology: A Christian Conversation* (William B. Eerdmans, 2020), 119–52.

⁹⁰Gunton, *The One, the Three, and the Many*, 2–15.

⁹¹Richard Bauckham, "Being Human in the Community of Creation: A Biblical Perspective," in Jorgenson and Padgett, *Ecotheology: A Christian Conversation*, 15–47.

⁹²Robin Wall Kimmerer, "Reclaiming the Honorable Harvest," TEDx Talks, August 18, 2012, <https://www.youtube.com/watch?v=Lz1vfgZ3etE>.

⁹³Randy S. Woodley, *Shalom and the Community of Creation: An Indigenous Vision* (William B. Eerdmans, 2012); and Marc Kruse et al., "Educating in the Seventh Fire: *Debwewin, Mino-Bimaadiziwin*, and Ecological Justice," *Educational Theory* 69, no. 5 (2019): 587–601, <https://doi.org/10.1111/edth.12388>.

⁹⁴Belgic Confession Article 2: How God Makes Himself Known to Us (1561), <https://www.reformedontheweb.com/confessions/the-belgic-confession.pdf>.

⁹⁵See Eva van Urk, "The *Imago Dei* in a Time of Mass Extinction: Rediscovering the Spiritual Value of Biodiversity," (PhDiss., Vrije Universiteit Amsterdam, 2025), embargoed until June 8, 2026, <https://doi.org/10.5463/thesis.992>.

⁹⁶Gerrit Cornelis Berkouwer, *General Revelation*, vol. 6 of *Studies in Dogmatics* (William B. Eerdmans, 1955), 204.

⁹⁷Joseph A. Sittler, "The Ecological Commitment as Theological Responsibility," *Zygon* 5, no. 2 (June 1970): 172–81, <https://www.zygonjournal.org/article/id/14980/download/pdf/>.

⁹⁸Cornelius Plantinga Jr., "Reflections on the Image of God," *Conferences and Lectures* 155 (Calvin Theological Seminary, 1988), https://digitalcommons.calvin.edu/hh_av_conferences/155.

⁹⁹Robin Wall Kimmerer, *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge, and the Teachings of Plants* (Milkweed Editions, 2013).

¹⁰⁰Berkouwer, *General Revelation*.

¹⁰¹Plantinga, "Reflections on the Image of God."

¹⁰²David P. Warners and Larry Borst, "The Good of a Flourishing Creation: Seeking God in a Culture of Affluence," *Perspectives on Science and Christian Faith* 57, no. 1 (2005): 24–33, <https://www.asa3.org/ASA/PSCF/2005/PSCF3-05Warners.pdf>.

¹⁰³Loren Wilkinson et al., *Earthkeeping: Christian Stewardship of Natural Resources* (William B. Eerdmans, 1980).

¹⁰⁴David Paul Warners and Matthew Kuperus Heun, eds., *Beyond Stewardship: New Approaches to Creation Care* (Calvin College Press, 2019).



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