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Biodiversity: Patterns, Processes, Loss and Value

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Ecological science originated from the observations of 18th and 19th century naturalists. These naturalists participated in exploratory voyages of the Americas, Asia, Africa, and isolated island groups. The journeys, which typically involved travel through several latitudes, enabled naturalists such as Alexander von Humboldt, Charles Darwin, and Alfred Wallace to observe the relationships between climate and plant forms, between latitude and species richness, and the effects of isolation on island biotas. In addition to recording their observations in extensive journals, naturalists also collected samples of regional flora and fauna for transport back to museums. The collections greatly increased the number of scientifically described species.

Some of the most basic observations and questions considered by these early naturalists are still explored and debated today. At present, biologists lack consensus regarding estimates of global species richness and mechanisms underlying biodiversity patterns. If these issues were simply subjects of academic debate, only specialists would find them interesting, but this is not the case. There is considerable public debate regarding the estimates and causes of biodiversity loss and the value of biodiversity. As an ecologist studying the structure of island communities, I have been particularly intrigued the subject of biodiversity. As a Christian ecologist, I continually reflect upon issues related to biodiversity origins, values, and stewardship through the lens of my faith.

Biodiversity - Definitions and Estimates

Biodiversity, a now familiar term, was coined less than 20 years ago at the National Forum on BioDiversity sponsored by National Academy of Sciences and the Smithsonian Institution (Wilson 1997). Although most have a general idea of what biodiversity means, the eminent biologist E.O Wilson (1997) defines it as “all hereditarily based variation at all levels of organization, from the genes within a single local population or species, to the species composing all or part of a local community, and finally to the communities themselves that compose the living parts of the multifarious ecosystems of the world.” Environmental scientists and ecologists typically subdivide to biodiversity into three types:

Genetic diversity – referring to the amount of genetic variation observed within a population or a species,

Species richness – referring to the number of species occupying a defined region,

Functional diversity – referring to the number of roles played by species in a community.

These scales of biodiversity are nested and interactive. High levels of genetic diversity within a population result in greater variation among members of that population. This increased variation in form and function may contribute to a population's or species' ability to withstand environmental change, whether that change is an abnormally cool August, a newly formulated pesticide, or the introduction of a pathogen such as the West Nile virus. High levels of genetic diversity also increase the chances of population or species survival by counteracting the impacts of inbreeding depression. Higher levels of species richness in a community typically result in greater functional diversity and stability within that community.

When most of us think of biodiversity, we consider species richness, and the following discussion focuses on this level of biological diversity. The biological definition of species is somewhat problematic, but can be thought of as groups of organisms that can interbreed and

produce viable fertile offspring. A biological species is assumed to be genetically and reproductively isolated from other species and is therefore on a unique evolutionary path. In practice, taxonomists rarely test the assumption of reproductive isolation, but rather consider a suite of morphological characteristics when making species determinations.

Estimates of the number of extant species on earth are widely divergent. At present, the number of scientifically named and described species stands at approximately 1.7 million (Becher 1998). This figure gives the most conservative estimate of Earth's species richness. The overwhelming majority of biologists acknowledge that the majority of Earth's species have not been scientifically named or described. Exploration of previously inaccessible environments (e.g. deep ocean trenches, oceanic rift zones, deep terrestrial environments), remote terrestrial regions, and incompletely sampled habitats (e.g. tropical forest canopies) continually yield "new" species. In fact, the rate of collection of these organisms greatly outpaces the ability of specialists to name, describe, and catalog them (approximately 15,000/ year, Stork 1997). In addition, there is considerable variability with respect to degree in which various groups of organisms are known and described. Taxa of large and/or immobile organisms, such as vertebrates and plants, tend to be more thoroughly described than small mobile organisms, such as invertebrates. As a group, invertebrates have the highest recorded levels of richness and numerically dominate the most poorly explored habitats (tropical tree canopies, soil, ocean floor). Therefore, most undescribed species are likely to be invertebrates and it is likely that there will be many new records.

Nematodes (small un-segmented worms) serve as a good illustration of this point. At present, the number of described and named nematodes hovers near 20,000. Several well known species of nematode are parasites of humans, domesticated animals, and crop roots. However,

the vast majority of nematodes are free-living, found in soil and in aquatic sediments, where their densities may approach 1-4 million individuals per square meter (Pechenik 2005). These free-living members of the phylum are poorly studied and are largely un-described. Estimates of actual nematode biodiversity range from a few hundred thousand to few million species (De Lay 2000, Lamshead and Boucher 2003).

A more spectacular example, and one nearer to my heart, is that of insect richness. Insects comprise almost 80% of described species, comparatively, mammals account for only 0.3% (Becher 1998). As a subgroup of insects, the number of described beetle species approximates 350,000 (Nielsen and Mound 2000). This incredible beetle richness accounts for over 20% of the described species on earth. When asked what could be inferred of the Creator from observations of nature, J.B.S. Haldane is said to have quipped “an inordinate fondness for beetles” (Gould 1993).

Research indicates that actual number of beetle species may range from near 900,000 to over 30 million (Erwin 1997, Nielsen and Mound 2000). The high estimates are largely related to Terry Erwin’s work in the tropics. Erwin sampled insect communities of tropical forest trees by fogging their canopies with insecticide, collecting the falling insects, and identifying them (Erwin 1988). His original study focused on a single species of tree, *Luehea semannii*, with a sample size of 19 trees. From 19 individuals of this single species of tree, he collected over 1200 species of beetles. He estimated that 163 of these species were specialists occurring only on *Luehea* trees. By extrapolating these data from a single species of tree to the estimated 50,000+ species of tropical trees and considering that 40% of arthropods are beetles, he arrived at his rather controversial estimate of 30 million species of arthropods (Ødegaard 2000). This estimate

has since been lowered to 2.5 – 10 million arthropod species (Stork 1997, Ødegaard 2000, Novotny et al. 2002).

What is the estimated species richness of our planet? Extrapolation of Terry Erwin's work with tropical beetles leads to rather high estimates of 30-50 million species (1997), while more conservative estimates of total richness range from 5-15 million species (Thomas 1990, Stork 1997, Ødegaard et al. 2000). Given that only 10-30% of earth's species are named, it should be no surprise that even less is known regarding the genetic and functional biodiversity of the vast majority of described organisms. Lawton (1993, cited by Stork 1997) tellingly writes, "Intriguingly, I have never seen anybody discuss what we actually know about the 1.7 million (species) that do have names. Overwhelmingly the answer will be nothing, except where they were collected and what they look like."

Biodiversity - Patterns and Processes

Although "precise" information regarding many aspects of global biodiversity are lacking, general patterns of biodiversity have been documented. At a global scale, one of the earliest patterns recognized by 19th century naturalists was tendency of terrestrial biodiversity to increase with decreasing latitude. Since the mid 1900's, over 30 explanatory hypotheses for this pattern have been proposed, but few of these hypotheses have been tested at large scales (Willig et al. 2003). Attempts to test some of these hypotheses at smaller scales have proven interesting, however, extrapolation of small scale observations and experiments to account for large scale phenomena is often problematic.

The Species Area Relationship

At local scales, the positive relationship between habitat area and species number has been extensively investigated. Botanists recognized species-area relationship (SAR) as early as the 1920's, observing a linear relationship between species number (Gleason 1922), or logarithm of species number (Arrhenius 1921), and the logarithm of area. This relationship has been confirmed by numerous studies in different habitats (tropical, temperate, montane, aquatic), at different scales (continents, large islands, woodlots, individual stones), and within various taxonomic groups (mammals, birds, plants, reptiles, insects, fish, molluscs).

Hypotheses explaining the significance of the SAR take 3 forms. Preston (1962a, 1962b) suggested that the SAR could result from a sampling effect, reflecting the tendencies of species abundances to follow log-normal distributions (species richness plotted against the log of abundance per species approximates a normal curve). He proposed that if species having different abundances are distributed randomly across the landscape, then greater numbers of species will be found with increasing sample area.

Robert MacArthur and E.O. Wilson (1963, 1967) applied the SAR to islands to describe variations in species richness on oceanic islands of varying sizes and proposed a mechanism for this pervasive relationship. Their equilibrium theory of island biogeography (ETIB) related the effect of island size to species immigration and extinction rates. The model assumed that over time species richness of an island will approach an equilibrium balance between immigration and extinction rates. In essence, the various species on an island may change, or turnover, but the number of species will remain stable. At equilibrium, smaller islands will support fewer species than large islands because they are smaller "targets" for immigration and will have higher

extinction rates due to their inability to support large populations (small populations are more extinction prone).

As a graduate student, Daniel Simberloff tested the ETIB on variously sized mangrove islands off the coast of Florida. Simberloff recorded the numbers of species inhabiting each of the sample sites and then fumigated the islands. Over the next year he chronicled the rates of subsequent immigration and extinction on mangrove islands of various sizes until the islands reached equilibrium (extinctions = immigration). He found that the equilibrium species richness approximated the prefumigation levels, with larger islands supporting more species than small islands (Simberloff and Wilson 1969). In further tests of the ETIB, Simberloff reduced the size of a subset of the mangrove islands and observed a subsequent decrease in the equilibrium number of species on those islands (Simberloff 1976). Although the SAR has been demonstrated for many islands and insular habitats, relatively few studies have successfully demonstrated that the SAR is the result of equilibrium between extinction and immigration rates (ex. Diamond 1969, Lynch and Johnson 1974, Diamond and May 1977, Rydin and Borgegård 1988).

Habitat Heterogeneity

From observations that forest communities with greater vertical structure support more species of birds, MacArthur and MacArthur (1961) proposed that increasing habitat heterogeneity is positively related to increased biodiversity. MacArthur and Wilson (1967) included this concept as a component of their equilibrium model, asserting that larger areas usually exhibit greater habitat diversity (more niches) allowing the coexistence of more species. Large islands typically exhibit greater habitat heterogeneity (more topographical variation and types of habitats) than small islands. Power's study of bird richness on the California Channel Islands indicated that plant richness was a more important determinate of bird richness than

island area, but island area was an important determinate of plant richness (1972). Separating out the importance of habitat heterogeneity from the importance of area has proven problematic in tests of these hypotheses (Power 1972, Whittaker 1998, Johnson et al. 2003).

The Intermediate Disturbance Hypothesis

In a conceptual break from the prevalent idea that communities exist in an equilibrium, whether equilibrium resulted from immigration/extinction or from species interactions (e.g. predation, competition, mutualism), Joseph Connell proposed that environmental fluctuations prevent communities from ever reaching equilibrium. He also noted that occasional environmental fluctuations are characteristic of communities with high species richness (Connell 1978). High levels of disturbance will allow only those species that can tolerate disturbance to persist at a site. Ecologically, these are called “r” type species. These organisms typically exhibit broad habitat tolerances, rapid reproductive capacities, short life cycles, and good colonization abilities. Conversely, lack of disturbance or rare disturbance will promote the persistence and dominance of a site by superior competitors. These organisms, the “K” type species, are habitat specialists, exhibiting relatively low reproductive output, longer life cycles, and poor colonization abilities. At intermediate levels of disturbance, “r” and “K” species may co-exist resulting in overall higher species richness. In addition, occasional disturbance may foster habitat heterogeneity by creating open space on rocks or gaps in forest canopies. Field tests of the intermediate disturbance hypothesis continue to yield results that appear to support its basic premises, at least at local scales (e.g. Sousa 1979, Hemphill and Cooper 1983, McAuliffe 1984, Whicker and Detling 1988, Vujnovic 2002, Riis and Hawes 2003, Roxburgh et al. 2004).

The Keystone Species Concept

The activities of community members may also suppress competitive exclusion and foster higher levels of species richness. The concept of the “keystone” species was first illustrated by Robert Paine and applied to top level predators (1966, 1969, 1971). Paine observed that subtropical intertidal food webs supported more species than those of temperate regions. In his analysis of food webs at each of these locations, he discovered that subtropical food webs had relatively higher predator to prey ratios than temperate food webs. He hypothesized that predator activity might foster greater richness via the prevention of competitive exclusion among prey species. Paine tested this hypothesis by experimentally removing the top-level predators (sea stars) from intertidal plots in Washington state. After 2 years, he compared the richness of the removal plots with those containing predators. In removal plots, he observed a significant decline in species richness due to strong competitive interactions among prey species. Paine repeated his studies in New Zealand, with similar results.

Subsequently, researchers have expanded the keystone species concept to include any organism having an inordinately strong effect on community structure relative to their biomass or abundance. From the perspective of species richness, the removal of the keystone results in a cascade of effects resulting in substantial losses of species from the community (e.g. Estes and Palmisano 1974, Lubchenko 1978, Duggins 1980, Power 1990, Mills and Soule 1993, Power et al. 1996).

Biodiversity Loss – Extinction

Species are thought to have finite “lifespans.” Speciation occurs, the number of individuals in the original population increases, and subsets of the population may disperse and

establish new populations, which effectively expands the range of the species. If individual populations experience decline, they may be “rescued” by immigration from other populations or they may eventually die out (local extinction). Global extinction refers to the loss of all populations and the irrevocable loss of all individuals of the species. Estimates from the fossil record indicate that the lifespans of species range from 7-25 million years for marine invertebrates to 1-4 million years for terrestrial animals (McKinney 1997). Interestingly, modern patterns indicate similar trends, with the greatest proportion of threatened species belonging to terrestrial rather than marine groups.

Fossil evidence also indicates that species extinctions have occurred at the average rate of approximately 9% per million years, or 0.000009% per year (Raup 1988). This would be equivalent to the loss of 1 species/year given the presence of 10 million species. This figure is problematic for a number of reasons. First, it is likely to be an underestimate of true extinction rates because the fossil record can only give estimates based upon organisms that fossilize well and will miss the presence and subsequent extinction of rare species (Raup 1988, Regan et al. 2001). In addition, this average does not give an accurate indication of the variability of the rate through time. Earth’s history has been punctuated by periods of high extinction rates (mass extinctions). Raup (1988) states:

“Phanerozoic time included a number of profound perturbations: the mass extinctions. The most serious of these, near the end of the Permian period (250 million years ago), eliminated an estimated 52% of the families of the marine animals then living and had significant though lesser effects on plants and terrestrial organisms.

Published attempts to interpolate the 52% rate of family extinction to the level of species kill have yielded estimates ranging from 77 to 96% extinction for the marine animal species then living. If these estimates are even reasonably accurate, global biology (for higher organisms at least) had an extremely close brush with total destruction.

Another four or five Phanerozoic events are also usually classed as mass extinctions, including the Cretaceous-Tertiary event 65 million years ago. Each of these large extinctions probably eliminated at least half the animal species then living.”

Although the precise causes of these mass extinctions are not known, evidence indicates that they were linked to catastrophic events (e.g. asteroid impact at the end of the Cretaceous Period) or large scale environmental change (e.g. climate change accompanying the formation of Pangea at the end of the Permian).

Periods of relatively low extinction rates, or background extinction, preceded and followed these mass extinction events. The background extinction rates for 2 well documented fossil groups, estimate the loss of 25% of marine invertebrates species and 40% of mammal species during any given million year period (Regan et al. 2001). Given present richness of mammals (4,327 species) this would be the equivalent of losing 1.7 species every 1000 years (0.0017 species/year). The last 400 years has witnessed the global extinction 60 mammal species (Regan et al. 2001). This represents a loss of 0.15 species per year; nearly 100 times the estimated background rate.

Similar figures for other taxonomic groups (birds, plants) and the overall loss of over 1000 plant and animal species over the last 400 years, have prompted many biologists to state that we are in the midst of a sixth mass extinction (Leakey and Lewin 1996, Pimm and Brooks 2000, Novacek and Cleland 2001). Unlike previous mass extinctions, “modern” events are well documented and their causes generally known. McKinney (1997) states that the study of fossil data provides “our only opportunity to study ‘natural’ extinction patterns. Human impacts have been so profound that not a single case of nonanthropogenic species extinction can be documented in the last 8000 years.” Although many associate anthropogenic extinctions to recent events, extinctions related to overexploitation of birds on Pacific, Caribbean, and Indian

Ocean islands prior to European contact actually exceed those occurring post-European contact (135 species vs. 87 species, Steadman 1997). Likewise, extinctions of Australian and North American megafauna may be linked to pre-European human overexploitation. Overexploitation continues to be an important threat to biodiversity; however habitat loss, fragmentation, and degradation are considered the primary causes of extinction today (Erhlich 1988, Shafer 1990, Novacek and Cleland 2001).

Anthropogenically induced habitat loss, fragmentation, and degradation counteract factors associated with high levels of biodiversity (see above). Large habitats are capable of supporting larger populations and large populations are less likely to experience extinction through stochastic or deterministic events. Instances of natural and experimental habitat reduction and fragmentation have illustrated the loss of species with decreasing habitat area (e.g. Brown 1971, Simberloff 1976, Shafer 1990, Fahrig 2003). In these cases, habitat loss and fragmentation resulted in local extinction, with the displaced species existing in other locations. Global extinctions of species due to habitat loss have also been documented. Deforestation in Ecuador provides an unfortunate example. Ecuador supports over 4000 endemic plant species, but during the last 50 years it has lost more than 40% of its original vegetative cover (Pitman et al. 2002). In the late 1970's, a botanical survey of an isolated Ecuadorian cloud forest yielded 90 previously undescribed plant species. Within a decade of the survey, the cloud forest had been converted to agriculture and the newly described endemics were gone (Leakey and Lewin 1995).

Additional human impacts associated with local and global extinctions include habitat degradation (e.g. cultural eutrophication, chemical pollution), alterations of natural disturbance regimes (e.g. flood prevention, fire suppression, overgrazing), and the expansion of opportunistic species. The last of these, the expansion of opportunistic species is particularly interesting. A

subset of species actually benefit from human activities. As anthropogenic impacts reduce or eliminate populations of organisms finely tuned to undisturbed habitats, other species fill the void. In general, opportunistic species with broad habitat requirements and tolerance of conditions associated with human impacts (“r” type species), are exhibiting range expansion. For example, two hundred years of fire suppression and overgrazing of California’s native grasslands has transformed them from “a palatable, nutritious, native perennial canopy to that of an annual grassland of primarily introduced species” with “about 90% of the biomass introduced from other continents” (Sims and Risser 2000). The majority of species dominating California grasslands are Eurasian in origin and well adapted to grazing pressures exerted by domestic livestock (also Eurasian in origin). A quick survey of our year around avian residents in Orange City includes, almost exclusively, house sparrows, starlings, and pigeons. These non-native species possess broad habitat tolerances and are well adapted for co-habitation with humans. Daniel Simberloff states that “the world’s biota is being rapidly homogenized” as purposeful and accidental introductions disrupt native ecosystems via competition with, predation on, and spread of disease to native species (2000).

In the face of continued pressures of expanding human populations and increased per capita resource consumption, biologists expect increased local and global extinction. At present, over 5000 species of plants and animals are listed as endangered or critically endangered (IUCN Red List 2003). These organisms are facing high (70%) or extremely high (80%) risks of extinction in the wild over the next 10 years. The number of species on the list increases yearly as biologists assess the status of additional species and as the impacts of human activity intensify.

In his excellent review of extinction, McKinney makes the case that extinction is rarely random (1997). Ecologists have long recognized that large animals require more resources and therefore larger habitats when compared to small organisms. Animals at high trophic levels also require a large resource base due to the entropy associated with energy exchanges through multiple trophic levels. Organisms that threaten or compete directly with humans are also subject to higher rates of local extinction. Therefore, as habitats are fragmented and human presence increases, large predators usually disappear first from the landscape. Most of the dominant predators of the U.S. prior to the western expansion have experienced marked population declines and often extirpation. Prior to western expansion, grizzly bear numbers were estimated at 50,000-100,000, with 10,000 in California alone. Their range extended from the Pacific coast to the western plains. At present, less than 1,100 individuals occur in the continental U.S. and they are restricted to 6 isolated areas in 4 northwestern states (Mattson and Merrill 2001). Only 1-2% of the pre-1850's population persists in only 2% of their original range.

Habitat specialists are more extinction prone than habitat generalists. McKinney found a strong link between specialist characteristics (specialized diet, narrow temperature tolerances, limited mobility, and tendency toward symbiosis) and extinction vulnerability (1997). These characteristics are typical of those observed in tropical rain forest communities. The high levels of biodiversity in the wet tropics are related to the high levels of specialization. In essence, specialists divide their habitat more finely allowing for greater species packing per unit area. Effective population sizes of these specialists are typically low, which also increases their risk of extinction.

Not only are these organisms more extinction prone, but they are also faced with increasing human impacts. Human population growth is relatively high in the wet tropics.

Economic support for these growing populations is tied to resource extraction. For example, over 13,000 species occur in Madagascar. Of these, approximately 85% are endemics (9700 species of plants, 771 species of animals) and most of these species are habitat specialists inhabiting Madagascar's western rainforests (Miller 2000). Unfortunately, Madagascar is experiencing increasing pressure from its growing and impoverished population to exploit its natural resources. At present, over 80% of Madagascar's native plant communities have been converted to agricultural land with native plant and animal species occupying smaller and smaller fragments of intact habitat. Even at lowest estimated human population growth rates and given the most optimistic conservation forecasts, Madagascar is likely to lose half of its species over the next 20 years (Miller 2000). Madagascar and other regions supporting exceptionally high levels of specialized endemic species and facing exceptional threats from human impacts are considered "biodiversity hotspots" (Mittermeier et al. 2002). These hotspots have been and will continue to be the foci of intense conservation efforts.

Value of Biodiversity

Why are conservationists concerned about biodiversity loss? Why are scientists scrambling to develop workable management plans for hotspots in Madagascar and Ecuador? They are concerned because biodiversity is a truly a non-renewable resource. Once a species experiences global extinction, it is gone. They are also concerned because biodiversity is valuable. Most obviously, organisms provide material benefits to humans; they have anthropocentric value. Humans are heterotrophic and are therefore dependent upon other organisms for energy and nutrients. We also depend upon biodiversity products for clothing, shelter, and medicines. We rely most heavily upon domesticated species to provide our

resources, but wild organisms also contribute to our upkeep. Many human populations continue to draw heavily upon wild organisms for sustenance (Committee on Noneconomic and Economic Value of Biodiversity 1999). The genetic resources of biodiversity are also valuable. Genetic material from a nearly extinct species of wild corn from Mexico has been incorporated into domestic species to increase disease resistance (Miller and Rossman 1997). Many medical compounds are based upon chemicals derived from wild organisms, primarily plants. At present, the medicinal value of only 0.3% of known plant species has been evaluated (Miller 2002). Rolston reminds us that *Penicillium* was a “useless mold” until its antibiotic capabilities were known and that “in some respects, human ingenuity makes nature an infinite resource” (1988). We should be wary of making short-term unsustainable demands upon our ecosystems without regard for the future benefits that may be provided by intact and diverse biota.

Organisms also provide innumerable “ecological services.” The activities of bacteria, fungi, and invertebrates are key to soil formation, waste decomposition, and nutrient recycling. Photosynthetic organisms not only provide energy for non-photosynthetic organisms, but also remove carbon dioxide from the atmosphere. Diverse arrays of insects pollinate important crop plants. Predatory arthropods control crop pests. Microbes purify water. All of these natural processes improve the quality of human life and the lives of organisms we rely upon for support.

Humans also appreciate and value biodiversity because of the satisfaction they derive from interactions with the natural world. Studies have shown that naturalistic experiences increase levels of relaxation, calm, and enhanced capacity for creativity (Kellert 1996). Biodiversity has an aesthetic value for most people. Kellert notes that the attraction of humans to diversity is more “than a simple reaction to the pretty” and may “reflect a recognition of the increased likelihood of finding food, safety, and security” (1996).

In the scriptures, we are told to partake in the goodness of creation and are also instructed to take an active role in its care (Genesis 1:28-31; 2:15). Hebrew law includes specific instructions for maintaining the integrity and fertility of the land (Leviticus 25:1-7, 18-21). Consequences for failure to follow these instructions are also given (Leviticus 26: 33-35). Prudent use of resources, including biodiversity, is well advised from a stewardship perspective that values creation's role in sustaining human life and from the perspective of obedience to our Creator. This type of value, although scripturally based, is also anthropocentric. Ultimately it benefits our species.

Does biodiversity have value apart from its usefulness to humans or future generations of humans? Is the primary "purpose" of non-human creation to serve as the means for our support? Is creation simply a stage for the human drama? Proponents of animal rights and deep ecology would answer with a resounding "no." These biocentric approaches to biodiversity would propose that all animals (animal rights) or all organisms (deep ecology) possess intrinsic value. At their most extreme, both movements would propose that human possess are of no more "value" than any other creature and that humans should not infringe upon the "rights" of other creatures to flourish.

Both of these movements look at organisms on an individual basis without addressing the ecological functions of species within their communities (Rolston 1988). An ecocentric perspective of biodiversity recognizes that all organisms participate in relationships with others. Plants and pollinators participate in mutualistic relationships. The bee receives nectar and pollen rewards from the plant. The plant benefits from the bee's deposition of pollen (sperm) on its female organs and the special delivery of its pollen to the female organs of another plant. Herbivores obtain nutrients from plants; carnivores obtain nutrients from herbivores. Fungi and

bacteria decompose dead organisms releasing nutrients to the soil. Plants require these nutrients for growth. Each organism in a community provides “goods” and/or “services.” From a community perspective, each species is valuable.

Scripture also indicates that creatures have value apart from human utility. Although the Bible primarily addresses the relationship between humans and their God, numerous references are made regarding the relationship between the Creator and non-human creation. The first chapter of Genesis repeats the refrain “and God saw that it was good” as myriads of creatures cover the land, teem among the waters, and fill the sky (Genesis 1: 9-31). In the account of the great flood, Noah is instructed to take every type of creature into the ark, clean and unclean, regardless of their utilitarian value to Noah and his family (Genesis 6:19-21). Following the flood, God covenants not only with Noah and his family, but also with “all living creatures of every kind on earth” (Genesis 9:12-17). Bouma-Prediger (2001) notes that, in contrast with the reciprocal Mosaic covenant, the Noahic covenant with the earth is “unilaterally and unconditionally” established and that it “rests solely on God’s commitment.”

While scripture does indicate that humans play a unique role in creation and participate in a special relationship with their Creator, a relationship also exists between the Creator and non-human creatures. His provision for and delight in wild organisms is vividly described in Job 38-41 and in Psalms 104. Christ sustains and reconciles all of creation (Colossians 1:15-20, Hebrews 1:3). This relationship is not one sided. Creation responds to its Creator with longing (Romans 8:19-22) and praise (Psalms 96, 98, 100, 148). From a theocentric perspective, biodiversity has value. While humans may appreciate the value of biodiversity from various utilitarian, biocentric, and ecocentric perspectives, we can also appreciate the value of

biodiversity from a theocentric perspective. We can value the many manifestations of creation as acts of obedience and thanksgiving.

*The earth is the Lord's and everything in it, the world, and all who live in it;
for he founded it upon the seas and established it upon the waters.*

Who may ascend the hill of the Lord, Who may stand in his holy place?

Psalms 24: 1-3.

Come let us sing for joy to the Lord; let us shout aloud to the Rock of our salvation.

Let us come before him with thanksgiving and extol him with music and song.

For the Lord is the great God, the great King above all gods.

In his hands are the depths of the earth, and the mountain peaks belong to him.

The sea is his, for he made it, and his hands formed the dry land.

Come, let us bow down before the Lord our Maker.

Psalms 95:1-6.

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