***Monarch Chrysalis:*** The monarch butterfly inside this chrysalis is in essence an outgrowth of the milkweed plant it is attached to. The caterpillar grew by transforming the biomass of milkweed leaves into itself before using the energy and substance of the plant to metamorphosize into the butterfly.

## BIODIVERSITY IS ESSENTIAL

Roger Hangarter

For many, biodiversity is something seen through a window, on television, or perhaps at a museum or zoo, yet all of our basic needs - the food we eat, the air we breathe, and the water we drink - are reliant on robust and biodiverse ecosystems. By closely observing Indiana's biodiversity through the lens of my camera, I have come to see biodiversity as a living tapestry in constant flux, weaving and reweaving threads spun from the cyclic birth and death of a diversity of interdependent life forms.

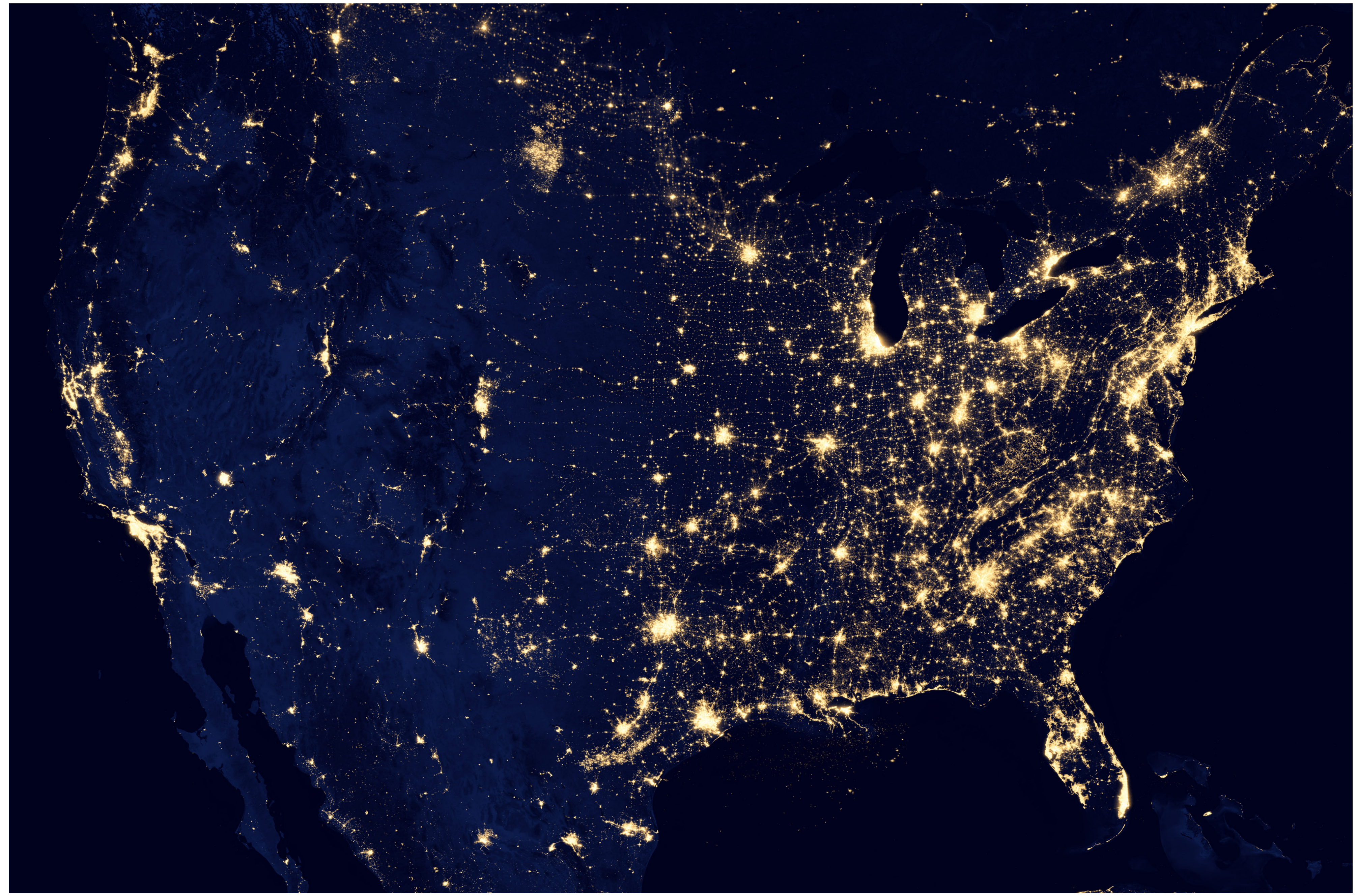
By definition, biodiversity encompasses all life on our planet from genes, species, and communities of organisms, to ecosystems that span all landscapes. Biodiversity is local and surrounds us no matter where we live. Biodiversity lives within us and on us. Biodiversity is rich in beauty, extraordinarily dynamic, and depends on complex orchestrated interchanges between the different life forms and their physical environment.

To appreciate the importance of biodiversity it is essential to understand how biodiversity functions. All forms of life require a reliable energy source and the raw materials that compose the biochemistry of life (carbon, water and minerals). The sun is our primary source of energy. The chemical elements of life come from the earth itself and need to be recycled for life to persist. In this essay I will attempt to describe in brief how solar energy, raw materials and the process of recycling are at the heart of the essentiality of biodiversity.

Energy is needed to power the basic metabolic reactions of all living things. Although there are some organisms capable of extracting energy from inorganic minerals to drive their metabolism, the vast majority of life ultimately derives its energy and substance from the process of photosynthesis, which is the foundational process behind the diversity of life on our planet. Organisms that carry out the process of photosynthesis use energy from sunlight to manufacture themselves from carbon dioxide, water, and minerals. To achieve this, chlorophyll in the photosynthetic apparatus captures the energy of sunlight and uses it to energize and extract electrons from water molecules while releasing oxygen into the environment. The energy and electrons are then used to create simple sugars from carbon dioxide captured from the atmosphere. Some of this solar energy is stored in the chemical bonds of the newly formed sugars. Plants then use the carbon and energy from these sugars, along with minerals obtained from soil water, to construct the many other molecules that make up the biomass of plants. Plant biomass is the substance and fuel upon which nearly all life on the planet depends.

The metamorphosis of a caterpillar into a butterfly is often touted as one of the most astonishing biological transformations that occurs in nature. However, prior to the caterpillar to butterfly metamorphosis, the energy-rich biomass of plants must be transformed into the caterpillar itself. When a female butterfly lays an egg on a plant, the caterpillar consists of just a single cell (zygote) inside the egg. The zygote then uses maternal food reserves to divide, grow and develop into a miniature multicellular larval caterpillar. After depleting the maternal food supply, the miniscule caterpillar then eats the plant and transforms the energy and substance of plant biomass into itself. Only after the caterpillar has transformed enough plant biomass into itself will it have the energy and material substrates needed to undergo the "most astonishing" metamorphosis by reorganizing and transforming the substance of the caterpillar body into the adult butterfly.

In nature, plant biomass is constantly being transformed into entirely different organisms, which may in turn then be consumed and transformed into yet another organism, and so on. Such organismal transformations of plants are known as food webs and are at the heart of the multiplicity of life forms that we refer to as biodiversity. My photograph, Common Grackle in Redbud Leaf, which accompanies Christoph Irmscher's essay in this volume, is a representation of how all animal biodiversity manifests itself from the photosynthetic power of plants.



***USA at Night:*** Images taken at night by NASA provide a striking visual illustration of human impact on earth. The first commercial electric light was patented just 142 years ago. Since then, humans have been transforming the energy of ancient photosynthesis (fossil fuels) back into light while releasing alarming amounts of carbon dioxide into the atmosphere. The resulting light pollution is wreaking havoc on many organisms that until 142 years ago could rely on natural photoperiods to anticipate seasonal change. Migratory and mating behaviors of animals, flowering time, and onset of dormancy of plants are among the many things artificial light is disrupting and is another way human activity is disrupting biodiversity. Note the large area of light to the west of Minneapolis. That light is not from a city. It is light from the burn off of uncaptured natural gas "waste" from the fracking fields in North Dakota.

Organisms in an ecosystem often have particular metabolic capabilities that others may not share. Such metabolic differences lead to critical co-dependencies among organisms that further drive the evolution of biodiversity. For example, most plants rely on mycorrhizal fungi that form intimate relationships with root cells. The plant provides the fungi with products of photosynthesis that the fungi need to grow. In exchange, the fungi send filamentous hyphae far into the soil beyond where the roots can reach and the hyphae take up minerals from the soil and share them with the plant. Mycorrhizal fungi can also link to other, sometimes unrelated, plants and provide a network through which other metabolites and chemical signals can be exchanged. These types of co-dependencies among organisms are commonplace and illustrate a central tenet of biodiversity.

Recycling raw materials back into the environment is vital for plants to continue producing biomass via photosynthesis. For the raw materials of life to be returned to the ecosystem, biological waste products and the biomass of dead organisms must be broken down to their constituent molecules by biological decomposition. Decomposition requires additional biodiversity that is also interdependent on specialized metabolic activities. The organisms that carry out the bulk of decomposition are often overlooked since most decomposition occurs out of sight in the rhizosphere (the upper regions of the soil where roots grow). The rhizosphere contains a tremendous diversity of life that includes a vast array of organisms that are able to consume decaying biomass. Bacteria and fungi, which are considered the masters of decomposition, are essential for returning essential mineral constituents like nitrogen back into the soil so that plants can continue to photosynthesize and grow.

The essentiality of recycling is most obvious in tropical rainforest ecosystems where slash-and-burn agriculture takes place. In rainforests, nitrogen and other minerals are continuously enmeshed in the forest biomass. As leaves fall and trees die, decomposers return the raw materials of life to the soil where mycorrhizal fungi and tree roots rapidly absorb the nutrients before the rain leaches them away. This allows photosynthesis to build new biomass. With slash-and-burn agriculture, however, forests are cut down and burned and the minerals that were in the biomass are left in the ash. In short order, rain leaches away the nitrogen and other soluble minerals. Crop yields plummet and the farmers abandon their fields and clear more of the forest. It takes decades before nitrogen fixing bacteria can replenish the ecosystem with enough nitrogen for forests to begin to recover.

Recycling is essential even at the level of a single cell. Cells rely on the biochemical process of respiration to provide the energy needed to carry out basic metabolism. At the heart of the respiratory process is a cyclic series of biochemical reactions known as the Krebs or TCA cycle which transforms the energy from carbohydrates into other chemical forms usable for cellular metabolism. If for some reason a critical molecule in that respiratory reaction cycle is depleted, respiration will stop and the cell will die.

The process of photosynthesis itself is, at its very core, also reliant on metabolic recycling. The molecule, ribulose-1,5-bisphosphate, which captures carbon dioxide from the atmosphere in order to make sugars, must continuously be remade as part of the carbon fixing process. If a photosynthetic cell runs out of this one key molecule, it will no longer be able to capture carbon dioxide from the atmosphere, photosynthesis will stop, and the plant will eventually run out of energy and die.

Nearly every high school and introductory college biology textbook explains the essentiality of the basic cycles that allow life to flourish and yet humans remain woefully inept at performing even the most basic types of recycling. Instead, humans excel at disrupting nature's cycles in fundamentally unsound ways. A macabre example is seen in how we deal with our own bodies, at least in the USA. We use the words "from dust to dust" at most burials while in practice we strive to prevent our biomass from entering that most basic recycling process of life. Typically, human bodies are required to be embalmed, which keeps decomposers from doing their job and also introduces toxins into the ecosystem. Most cemeteries also require bodies to be placed in coffins and the coffins to be enclosed in sealed concrete vaults before burial. I spent my summers during high school and college working in a cemetery and was appalled to learn that concrete vaults are merely an aid for lawn maintenance since without them coffins will eventually succumb to decomposers and collapse. The earth above will then sink making the ground too uneven for using large mowers.

Humans are also terrible at recycling what we produce and use. We entomb most of our "waste" in landfills where decomposers cannot function. We are also the only organism on the planet that has learned how to convert toxic fossil fuels into all kinds of "necessary" products that are resistant to recycling, with plastics being the most notable. Even though some plastics can be reused once or twice, this is not recycling. The manufacturing of plastics also results in toxic waste and a large carbon footprint, a primary source of climate destabilization. Sadly, we continue such practices.

How did humanity come to be the only species to disavow so many of the fundamental laws of biology? In many regards the answer is that we are the only species that learned how to obtain massive amounts of energy from fossil fuels, which led us to create an economy based on cheap energy. Instead of developing ways to recycle raw materials, we became adept at extracting raw materials from the earth at alarming rates. We also use fossil fuels to extract even more fossil fuels and we manufacture nitrogen fertilizer from atmospheric nitrogen, which disrupts the natural nitrogen cycle causing alarming ecosystem imbalances. In essence, we have collectively become masters at using this cheap energy source to proudly and foolishly consume and destroy more biomass than any other type of organism. Our fossil fuel dependence has effectively led humanity to falsely trust our future to unsustainable continued economic growth.

Little, if anything, of what I've said in this essay is new. The naturalist Alexander von Humboldt, after years of careful observation of a variety of natural systems wrote in the mid 1800's that "… organisms are connected to each other, not linearly, but in a net like entangled fabric." He also explained how humans were already altering the climate through agriculture and other manipulations of land. In the century and a half since von Humbolt, science has revealed to us a great deal about the fundamental natural processes on which life depends. As I've tried to emphasize in this essay, recycling is one of the fundamental concepts that applies across all scales, from the biochemistry of life up to the entirety of earths ecosystems. While complex in detail, the principle of recycling is simple at its core. The stories I've shared demonstrate that biodiversity is essential for recycling to occur and, likewise, recycling is essential for biodiversity to thrive.

Because humans are part of biodiversity, it is vital that we learn to embrace the fundamental processes, like recycling, that sustain biodiversity. Surely the creation of jobs that nurture the environment, foster biodiversity, curb climate degradation, and benefit the common good will be more satisfying than making and selling products that have little use beyond "growing our economy" and filling our landfills. Ideally, humanity will find ways to transition to an economy based on recycling in order to ensure that plants continue to turn into caterpillars, butterflies, and the myriad other organisms that make up our planet's rich and essential biodiversity.

The state of nature is precarious. Our growing awareness that humans are part of functional ecosystems is a hopeful sign that we will be able to turn back the tsunami-like impact humanity has inflicted on earth's natural systems. By all accounts, we are running out of time but if we are truly the superior organisms we claim to be, we surely ought to be able to learn how to live sustainably before we completely unravel the tapestry of life and find our thread in that tapestry so frayed that nature omits us from future iterations.