Chapter 5
The necessary give and take of complementary diversity

Does your farm, county or state have diverse enterprises, markets and sources of inputs? Are those enterprises working together, or against one another? Do your own enterprises complement each other? Are you burdened by the waste your enterprise creates? Do you feel like you're stretched too far managing your businesses? This chapter is meant to help you determine the right amount and types of diversity for your unique system.

In nature, diversity is not valued for its own sake as we see in some politically correct sectors of Western societies. In nature we see a myriad of autonomous species that are competing with each other but, in effect, working together to create a resilient ecological system. A species survives in an ecosystem because it fits well within the systems' network of subsystems, both producing and breaking down nutrients within the system. However, ecological resilience requires limits to diversity—all diversity must be complementary.

We begin this chapter by exploring how complementary diversity exists in nature. In the complex relationships and networks that arise out of these self-organizing systems, resilience emerges as the interaction of local species and systems, sheltering the system from disturbances natural to any landscape. Through this understanding of how complementary diversity manifests in ecological systems we can begin to build a framework for thinking about how those principles apply to agricultural systems.

The second half of this chapter will look at applying complementary diversity to the farm, field and greater networks that comprise our food systems. We'll look at how to think about diversity and how to seek out complementary relationships and enterprises. For now, let us step into the forest, meadow and field to see how nature has, for billions of years, been generating the resilient and robust ecosystems that we enjoy today.

Complementary Diversity in natural ecosystems

Diversity often seems to be an unalloyed good. Beginning with Darwin and shown experimentally by Tilman[176], many have shown that increased species richness is associated with increases in efficiency and stability of some ecosystems. Removal of species or addition of missing species support this observation. When all species that can perform a function are wiped out, big problems result. The

[176] Darwin C. 1859. On the origin of species by means of natural selection or the preservation of favoured races in the struggle for life [reprinted 1964]. Cambridge (MA): Harvard University. Tilman D, Wedin D, Knops J. 1996. Productivity and sustainability influenced by biodiversity in grasslands ecosystems. Nature, 379:718–20.

extinction of mega herbivores by aboriginal hunters caused a switch from grassland to tundra in the Northern latitudes.[177] Man can recreate this diversity of function by managing large grass-eating animals just as predators managed the large herbivores before man developed the capacity to create the extinction.

However, observing the correlation between diversity and resilience can give an incomplete picture. A more complete picture requires understanding that **all species must eat and be eaten.**

All species consume and are consumed by others. In ecological systems, everything is consumed and transformed into alternate materials for alternate uses. It is this recycling process that manages to construct huge redwood trees with solar energy and soil minerals as the only external output. How does a forest manage to build such great structures with seemingly so little input, particularly when we consider the vast inputs required for modern agriculture?

Ecological diversity exists only because one species uses waste products it receives from other species and provides useful nutrients to others. A species which only takes and never gives will destroy the system. Even the parasite in nature is also food for another species. Why don't we see ecosystems with selfish species who take and never give? Because those systems die. Only the complementarily diverse systems survive. Take the asteroid that destroyed the majority of life on the planet, wiping out the dinosaurs and much of the plant life of the time. In the wake of the impact, light from the sun hardly penetrated the layers of ash and debris held in the atmosphere. The only life forms capable of handling such a unique challenge were the fungal kingdom[178]. Before the atmosphere cleared and the dust settled, the fungus continued to decompose dead plants, clearing the way for seed ferns that survived in the soils below. What would have become of the surface of the planet without the fungi covering the surface, perpetuating the decay of plant matter?

The second and equally important thing to realize about the fungal/fauna partnership is that the fungi also needed the plants to survive. Though the mushrooms could survive without direct sun, they needed continual plant decay and the sugars produced. Therefore, we see that selfish or non-complementary systems die, and often young, because they don't realize that giving builds up the system which can then provide the inputs it needs. Whenever a selfish species arises, its lifecycle eventually decays because it destroys the system supporting it. Appreciating that sort of relationship is what we intend to help you develop over the course of this chapter, those complementary systems that keep you and your systems thriving and prospering even in the wake of a metaphorical asteroid.

Stable ecosystems such as a tract of mature oak hickory forest are often see as sustainable, lasting or self-managing. These forests are in fact in the K phase, having converted and stored nutrients into trees, and have low and decreasing diversity. A contiguous tract of mature forest has much less diversity than a patchy landscape composed of dense woods and meadows, shrubby areas and young trees. These patchy landscapes provide habitat for animals and plants at every stage of forest succession from new growth after a forest fire to long standing trees that harbor particular species. Traditional forest

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[177] Zimov SA, Chuprynin VI, Oreshko AP, et al. 1995. Steppe–tundra transition: an herbivore-driven biome shift at the end of the Pleistocene. Am Nat 146: 765–94.
[178] http://www.sciencemag.org/content/303/5663/1489.citation

management tends to produce more homogeneous growth than those forests disturbed naturally and increases the likelihood of unexpected catastrophic change.

Make no mistake though, there are limits to beneficial diversity. Many see the high diversity of resilient systems and conclude that increasing diversity will increase resilience. In fact, the opposite is often true over the long term.

Short term diversity can destroy long term diversity. In today's modern societies diversity is about inclusion. In ecosystems, resilience requires exclusion as well. Before we explore the immense diversity of ecosystems and the value of diversity for agricultural resilience, we must address one myth of diversity: more diversity is *always* good.

Increasing diversity by adding new species to an existing ecosystem can destroy multiple species and thus reduce diversity. Species which don't complement existing life can destroy systems where they are introduced. For instance, when the rabbit was introduced in Australia[179] it certainly increased diversity of species—momentarily. Then, because there were no natural predators for rabbits, they began to expand exponentially. Rabbits are very good at finding the seedlings of shrubs when they are very small and grazing them out to the extent where the native shrubs are completely unable to regenerate. Rabbits also threaten some of the native burrowing animals, such as the bilby and the burrowing bettong, by moving into their existing burrows and competing for food. Rabbits are responsible for serious erosion problems, as they eat native plants, leaving the topsoil exposed and vulnerable to sheet, gully, and wind erosion.

When the Asian chestnut blight fungus virtually eliminated American chestnut from over 180 million acres of eastern United States forests in the first half of the 20th century, it was a disaster for many animals that were highly adapted to live in forests dominated by this tree species. For example, ten moth species that could live only on chestnut trees became extinct.

Aquatic plants such as South American water hyacinth now in Texas and Louisiana and marine algae such as Australian Caulerpa in the Mediterranean Sea have decreased diversity in vast areas by replacing formerly dominant native plants.

Other examples of increased diversity leading to decreased diversity[180]:

1. Man migrated to North America and wiped out megafauna, after he had done the same in Eurasia.
2. The predatory brown tree snake, introduced in cargo from the Admiralty Islands, has eliminated ten of the eleven native bird species from the forests of Guam.
3. The Nile perch, a voracious predator introduced to Lake Victoria as a food fish, has already extinguished over one hundred species of native cichlid fish there.
4. The sea lamprey reached the Great Lakes through a series of canals and, in combination with overfishing, led to the extinction of three endemic fishes.
5. The first sailors to land on the remote Atlantic island of St. Helena in the 16th century introduced goats, which quickly extinguished over half the endemic plant species.

[179] http://www.columbia.edu/itc/cerc/danoff-burg/invasion_bio/inv_spp_summ/Oryctolagus_cuniculus.htm
[180] McGinley, M. (2011). Invasive species. Retrieved from http://www.eoearth.org/view/article/153902/

Of all 1,880 imperiled species in the United States, 49% are endangered because of introduced species alone or because of their impact combined with other forces.[181]

It's important to realize that it is the addition of non-complementary diversity which creates destruction of diversity. Without these alien additions, high levels of diversity are invariably associated with resilience of ecosystems.

Before America was colonized by Europeans, the Eastern forests and Deep South were prime examples of how one species, humans, could live in complement with natural ecosystems. The native people worked for generations with the forest[182], developing clearings using slash and burn techniques to create savannahs and open prairies around the old growth forests where deer and other creatures found shelter. This provided them with ample hunting ground and a diverse food supply due to the varied nature of their forests. By creating every level of forest succession they developed vitally healthy, diverse forests and prairies. To develop a better sense of working with nature be sure to read the chapter on working with nature (ecological integration) filled with practical techniques and guidelines.

The pre-colonization forests of America (and some pristine forests such as ours at Meadowcreek) were a network of species in different stages of succession. Dense old growth forests were paired with shade tolerant plants and herbs colonizing the forest floor with a few seedlings waiting for light to emerge with the death of an older tree. As you inspect the forest floor, digging your hand into the dirt, you would find salamanders, worms, and a variety of other insects churning through the last year's leaves, breaking down the layer of nuts and dead twigs. The herbs and flowers would be prolific as many of them were as older, or older, than the trees they surrounded, sometimes 100's of years old growing roots underground to generate new stems. Moving on you would find a small patch of white pine, an indicator of where an old prairie used to be as this tree is sun loving, growing in clumps as a colonizing species in open clearing. Further, a new savannah with large trees surrounded by charred ground, new seedlings of grasses and other shade tolerant species peeking through the dark surface. Finally, an opening revealing a prairie with tall grasses, a few shrubs and wildlife abounding in the open area.

All along your forest walk, if you looked carefully, you would have seen a variety of birds and large mammals, each in their own unique habitat. These creatures need the diversity of shelter as well as the diverse plant life that supports them. Moreover these forests maintain a stock of seeds, unique to each section of the forest acting as a reserve in the face of inevitable forest fires or floods.

On a larger scale, this diverse forest acted to slow down high winds and absorb intense flooding, mitigating the damage from these disruptions. With a little imagination and adaptation this complementary diversity is applicable to your own systems as you mimic what this once great forest was able to accomplish. What, then, does that look like?

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[181] http://www.actionbioscience.org/biodiversity/simberloff.html

[182] http://www.wildlandfire.com/docs/biblio_indianfire.htm , http://whyfiles.org/2012/farming-native-american-style/

Two models of complementary diversity. Two models from ecology help us relate these large scale, forest ecosystems to our fields, farms and gardens.

Rivet model. Ehrlich and Ehrlich's[183] rivet hypothesis, which is similar to Frost and colleagues' model of compensating complementarity,[184] likens the ecological function of species to the rivets that attach a wing to a plane. Several rivets can be lost before the wing falls off. This model proposes that the ecological functions of different species overlap, so that even if a species is removed, ecological function may persist because of the compensation of other species with similar functions.

In the rivet model, an ecological function will not disappear until all the species performing that function are removed from an ecosystem. Overlap of ecological function enables an ecosystem to persist. Unfortunately, compensation masks ecosystem degradation, because while a degraded system may function similarly to an intact system, the loss of redundancy of species decreases the system's ability to withstand disturbance or further species removal. The same way that as rivets attaching a wing to a plane breaks it is necessary to replace, or repair, the broken ones. Unless these rivets are repaired, the safety and long term structure of the plane is sabotaged.

Though an ecosystem can decrease in its species diversity and still survive, its overall ability to recover from disasters is greatly hindered over the long term.

Drivers and Passengers model. Walker's ''drivers and passengers'' hypothesis accepts the notion of species complementarity and extends it by proposing that ecological function resides in ''driver'' species or in functional groups of such species.[185] It is similar to Holling's ''extended keystone hypothesis.''[186] Walker defines a driver as a species that has a strong ecological function. Such species significantly structure the ecosystems in which they and passenger species exist. Passenger species are those that have minor ecological impact. Driver species can take many forms. They may be ''ecological engineers''[187] such as beavers or gopher tortoises, which physically structure their environments. Or drivers may be ''keystone species."

What is the driver of your business that forms the way you operate and the decisions you make? What passenger projects can you create that bolster the whole business by aiding and supporting the function of the driver? Moreover how can those passenger projects work together, overlapping in their functions to mitigate waste products from the driver? This is how we can begin to develop an agricultural system that is ecologically resilient. For an ecosystem to be resilient, each component species feeds back into the others. The "waste" of one is the

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[183] Ehrlich, P.R. & Ehrlich, A.H. 1981: Extinction: the causes and consequences of the disappearance of species. Random House, New York, New York, USA.
[184] Frost, T.M., Carpenter, S.R., Ives, A.R. & Kratz, T.K. 1995: Species compensation and complementarity in ecosystem function. In: Jones, C.G. & Lawton, J.H. (Eds.); Linking species and ecosystems. Chapman and Hall, New York, New York, USA, pp. 224–239.
[185] Walker B. 1992. Biological diversity and ecological redundancy. Conserv Biol 6:18–23; Walker B. 1995. Conserving biological diversity through ecosystem resilience. Conserv Biol 9:747–52
[186] Holling, C.S. 1992. Cross-scale morphology, geometry and dynamics of ecosystems. Ecol Monogr 62:447–502
[187] Jones, C. G., Lawton, J. H. and Shachak, M. 1994. Organisms as ecosystem engineers. Oikos 69: 373-386

resource of another. Fossil fuels, the waste of dead dinosaurs, are a resource to us. What resources can you create for yourself?

Everything eats and is eaten. To develop a clearer depiction of how biological systems work together and form nutrient supply systems, let us look briefly at how food or resources are created across living systems.

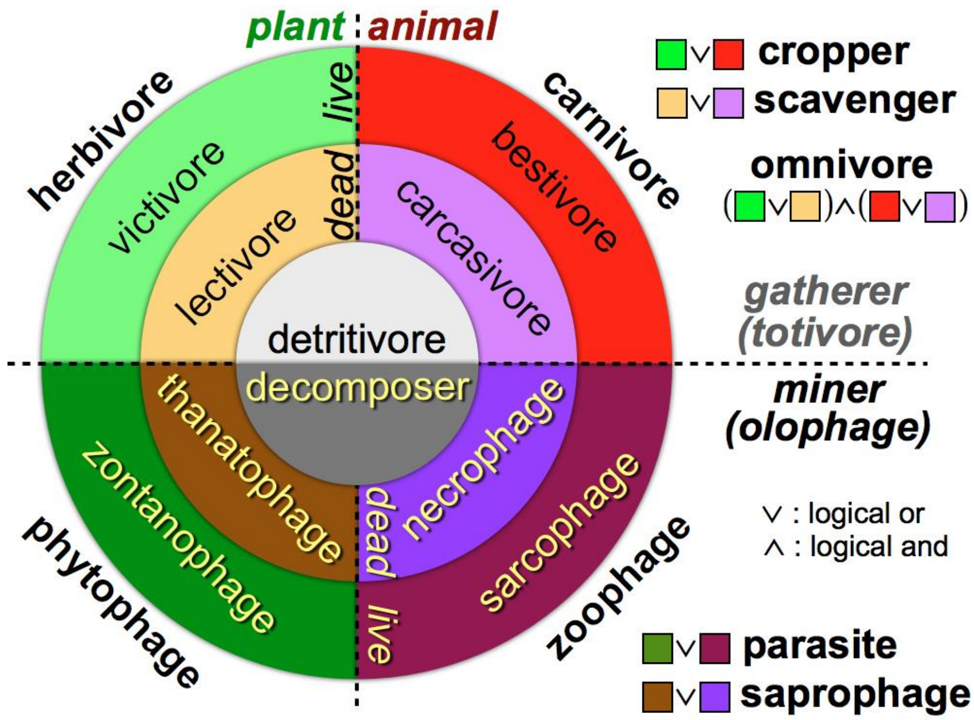

Figure 7. Consumer categories based on material eaten (plant: green shades are live, brown shades are dead; animal: red shades are live, purple shades are dead; or particulate: grey shades) and feeding strategy (gatherer: lighter shade of each color.

Plants and algae do not usually eat other organisms, but eat other predigested organisms as nutrients pulled from the soil or the ocean and manufacture their own food using photosynthesis. For this reason, they are called primary producers or autotrophs. It is energy from the sun that usually powers this base of the food chain. An exception occurs in deep-sea hydrothermal ecosystems, where there is no sunlight. Here primary producers manufacture food through a process called chemosynthesis.

What we call consumers eat other organisms more directly. In the adjacent diagram: green shades feed on living species of plants, brown shades on dead plants; those which consume live animals are in red shades, purple shades consume dead animals are dead; those species in grey shades provide nutrients from all species for primary producers. Feeding strategy is illustrated as: gatherer in lighter shade of each color and miners in darker shade of each color.

Consumers (heterotrophs) are species that cannot manufacture their own food and need to consume other organisms. Animals that eat primary producers (like plants) are called herbivores. Animals that eat other animals are called carnivores, and animals that eat both plant and other animals are called omnivores.

Decomposers (detritivores) break down dead plant and animal material and waste to then release it again as energy and nutrients into the ecosystem for recycling. Decomposers, such as bacteria and fungi (mushrooms), feed on waste and dead matter, converting it into organic chemicals that can be recycled as mineral nutrients for plants to use again.

Decomposers are often left off food webs, but if included, they make the food chain into a cycle. Thus food chains can be seen to start with primary producers and end with decay and decomposers. Since decomposers recycle nutrients, leaving them so they can be reused by primary producers, in the cycle they are neither beginning nor end. A resilient system has no end products, and no waste—due to complementary diversity.

These broad categories are functional categories to help us see how we can close the loop of waste and redefine these materials as what they are: products or outputs. Every organism within biological systems is working to develop fuel for the next stage of decomposition. How can your own enterprises anticipate the outputs, complementing them with ample need?

Ecosystems are resilient when ecological interactions reinforce one another and dampen disruptions. Such situations may arise when a species with an ecological function similar to another species increases in abundance as the other declines,[188] or as one species reduces the impact of a disruption on other species. However, different species operate at different temporal and spatial scales, as is clearly demonstrated by the scaling relationships that relate body size to ecological function.[189]

A scale is a range of spatial and temporal frequencies. Species that operate at the same scale interact strongly with one another, but the organization and context of these interactions are determined by the cross-scale organization of an ecosystem. Consequently, understanding interactions among species requires understanding how species interact within and across scales.

Many disturbances provide an ecological connection across scales. Contagious disturbances such as fire, disease, and insect outbreaks have the ability to propagate themselves across a landscape, which allows small-scale changes to drive larger-scale changes. For example, the lightning ignition of a single tree can produce a fire that spreads across thousands of square kilometers. Such disturbances are not external to ecological organization, but rather form integral parts of ecological organization. The disturbances are as much determinants of ecological resilience as are interactions among species.

Current models of the relationship between species richness and stability only model species and their ecological functions at the same scale; however, ecological systems are not scale dependent. A growing body of empirical evidence suggests that ecological structure and dynamics are primarily regulated by a small set of plant, animal, and abiotic processes.[190] Small and fast scales are dominated by biophysical processes that control plant physiology and morphology. At the larger and slower scale of patch dynamics, interspecific plant competition for nutrients, light, and water influences local species composition and regeneration. At a still larger scale of stands in a forest, processes of fire, storm, insect outbreak, and large mammal herbivory determine structure and successional dynamics from tens of meters to kilometers, and from years to decades. At the largest landscape scales, climate, geomorphological, and biogeographical processes alter ecological structure and dynamics across hundreds of kilometers and over millennia. These processes produce patterns and are in turn reinforced by those patterns; that is, they are self-organized.

Ecological processes produce a scale-specific template of ecological structures that are available to species. Ecological structure and patterns vary across landscapes and across scales. Many species may

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[188] Holling CS, Schindler DW, Walker BW, Roughgarden J. 1995. Biodiversity in the functioning of ecosystems: an ecological synthesis. In: Perrings C, Ma¨ler K-G, Folke C, Holling CS, Jansson B-O, editors. Biodiversity loss: economic and ecological issues. New York: Cambridge University. p 44–83
[189] Peters RH. 1983. The ecological implications of body size. Cambridge (UK): Cambridge University.
[190] Holling et al., ibid.

inhabit a given area, but if they live at different scales they will experience that area quite differently. For example, a wetland may be inhabited by both a mouse and a moose, but these species perceive and experience the wetland differently. A mouse may spend its entire life within a patch of land smaller than a hectare, while a moose may move among wetlands over more than a thousand hectares. This scale separation reduces the strength of interactions between mice and moose relative to interactions among animals that operate at similar scales.

This concept is reflected in the drivers and passengers model we visited earlier in the chapter. The drivers exist at an often larger scale, changing more slowly but generating larger and broader outcomes. The passengers are often working at a smaller scale, moving faster and generating outcomes more quickly.

These metaphors and examples of biological processes are meant to help you reflect on your own agricultural system. It requires us to consider what aspects of our business are moving fast, needing more consistent attention and change versus those attributes that are slower and more consistent. How can you then leverage that knowledge to operate your own business with more awareness to develop action plans and consistent outcomes in the face of outside changes?

Complimentary Diversity increase resilience to disturbance. Most important to resilience is coping with disruption, an inevitable occurrence. None of the Northern hemisphere mega-herbivores could cope with man and his new tools and social organization, so the entire ecosystem changed. Species such as American bison expanded into the niche and proved more resilient--until man came up with even better tools.

The variability in responses of species within functional groups to environmental change is critical to ecosystem resilience and known as "response diversity." It is defined as the diversity of responses to environmental change among species that contribute to the same ecosystem function.[191]

Nearly all ecosystems are subject to disturbances that operate across a range of temporal and spatial scales. Natural disturbances tend to be pulse disturbances with characteristic magnitudes and the frequency of disturbance is distributed. Human activities tend to create chronic disturbances stressing many aspects of the ecosystem often for prolonged periods. The role of biological diversity is to provide the capacity for renewal and reorganization of desirable ecosystems following change by providing a series of backups of species and plant varieties that can move in to recover freshly disturbed areas.

Many, beginning with Darwin, reiterated by MacArthur, modeled by May, and shown experimentally by Tilman and colleagues[192] show that increased species richness increases the efficiency and stability of some ecosystems. Removal of species or addition of missing species support this observation. When all species that can perform a function are wiped out, big problems result. The extinction of mega herbivores by aboriginal hunters caused a switch from grassland to tundra in the Northern latitudes.[193]

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[191] Elmqvist, T., C. Folke, M. Nystrom, G. Peterson, J. Bengtsson, B. Walker, and J. Norberg. 2003. Response diversity, ecosystem change, and resilience. Frontiers of Ecology and Environment 1(9):488-494.

[192] Darwin (1859), MacArthur (1955), May (1973) Tilman 1996; Tilman and others 1996)

[193] Zimov SA, Chuprynin VI, Oreshko AP, et al. 1995. Steppe–tundra transition: an herbivore-driven biome shift at the end of the Pleistocene. Am Nat 146: 765–94.

Man can recreate this diversity of function by managing large grass-eating animals just as predators managed the large herbivores before man developed the capacity to create the extinction.

Over and over again through history we can see that the loss of specialist species that perform certain functions means those functions may not be carried out at all – for example, the decomposition of particular substrates or the pollination of certain species. Systems where whole functional groups go extinct or become ecologically insignificant as a result of environmental change usually decreases resilience. The consequences of species loss may not be immediately visible, but is likely to appear with loss of ecological resilience upon disturbance or disruption. Species loss reduces the variety of possible alternative ecological organizations. Ecological resilience must be understood if humanity is to anticipate and cope with the ecological crises and surprises that accelerating global change will bring.[194]

Ecosystems can be strikingly conservative in their organization and function, despite differing histories and species compositions. For example, lake studies have demonstrated that similar ecological functions can be maintained over a wide mix of species and population densities.[195] Mediterranean climate regions are similar in ecological structure and function, despite the geographic and evolutionary isolation that has produced radically different floras and faunas.[196] Other work has shown that an ecosystem's patterns of function, diversity, and body mass can be conserved despite considerable species turnover.[197]

Relating ecological principals to farm, field and community

Thinking like an ecosystem. The first half of this chapter should have introduced you to the concepts of complementary diversity in forest, meadows and other naturally occurring landscapes and ecosystems. So, how does all of that relate to the organized, systematic realm of modern agriculture? How do we apply the principles outlined above into a meaningful strategy for building greater resilience in our agricultural systems to develop *ecologically* resilient agricultural systems? In this second half of the chapter we'll look at precisely that, in theory as well as application.

Today there is much talk of diversity on the farm. Diversity of plants, income streams, livestock, etc. But the quality of diversity is often overlooked. We must ensure that diversity is also complementary, building upon itself to become more robust, flexible, and resilient. In agricultural systems, one aspect of complementarity is evaluating our waste streams to develop added income and savings, Complementary diversity can be the key and it starts with thinking like an organism, a system, a forest or a community of microbes.

Your system, if at maximum ecological resilience, should support you based on the interacting agents within it. Whether it's a balance between livestock and crops, herbs and cheese, cotton and compost,

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[194] Peterson et al. 1998. Ecological resilience, biodiversity and scale. Ecosystems 1:6-18.
[195] Schindler DW. 1990. Experimental perturbations of whole lakes as tests of hypotheses concerning ecosystem structure and function. Oikos 57:25–41.
[196] Kalin Arroyo MT, Zedler PH, Fox MD. 1995. Ecology and biogeography of Mediterranean ecosystems in Chile, California, and Australia. New York: Springer-Verlag.
[197] Forys, E.A. & Allen, C.R. 2002: Functional group change within and across scales following invasions and extinctions in the Everglades ecosystem. Ecosystems 5: 339–347; Allen et al., 2011. Managing for resilience. Wildlife Biology, 17: 337-349.

there is a dynamic system within your grasp given some planning, imagination and a willingness to try something new. So many farmers today, perhaps yourself, are either considering or have already taken off farm jobs to support their families, receive healthcare or any number of reasons. The problem is that when we consider it from an ecological perspective, the ecosystem of the farm is effectively invaded by such actions. A farmer getting an off-farm job is much like introducing an alien species. Certainly it increases diversity of income streams, but usually in a non-complementary way. The increased income may help the farm stay alive, but decreases likelihood that the farm will last beyond the current generation. Loughrey[198] with Glauben[199], have concluded that working part time and building on-farm diversification lead to resilience in the current generation, but only diversification lead to trans generational resilience. Why is this?

Often it is the amount of work required to work both off and on the farm full time. Any child or fellow witnessing this balancing act is prone to wonder, what's the real payoff? Why would anyone work so hard? The bottom line is that choosing to working off the farm permanently divides your attention while sapping emotional, physical and mental resources over the long run. It's much like an invasive species in an ecosystem, forcing local organisms to work harder, stressing the nutrient reserves and eventually strangling out the once thriving and diverse ecosystem.

Of course, this is all too simple to just say "find complementary diverse enterprises on your farm. Good luck!" So let's lay down a few suggested guidelines and practices that have been shown to produce results.

First, it's true that too much diversity can also decrease resilience on the farm. Too much diversity of enterprises can be less efficient, consuming just as much time and energy as an off farm occupation. Hyper-diverse farms tend only to last because they are supported by off farm income. On the other hand, America relies on only 82 crop species to provide 90 % of the energy consumed by humans. This is equally unwise, and certainly unnecessary given that the world has at least 12,650 edible plant species and about 7,000 species that have been used to a significant extent by humans at some point in time.[200]

How it works on the ground. Let's take our first example from the rangelands of Australia where the significance of both functional diversity and response diversity in grass species were recognized.[201] The species distribution was typical, with the bulk of the biomass accounted for by a few dominant species and a long "tail" of minor species with low abundances.

Five functional attributes of each of the 22 perennial grass species in the rangeland – height, biomass, specific leaf area, longevity, and leaf litter quality – were measured or estimated. These attributes were involved in water and nutrient cycling and for which there were data or estimates. The species were

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[198] Loughrey, Jason Thia Hennessy, Kevin Hanrahan, Trevor Donnellan, 2013, Agricultural Labour Market Flexibility in the EU and Candidate Countries. Working Paper 49. Centre for European Policy Studies, Brussels, Belgium.
[199] Glauben, T., Tietje, H. and Weiss, C.R., (2003), Farm Exits: Evidence from German Census Data. Paper presented at 77th AES Annual Conference, April 2003, University of Plymouth, Seale-Hayne Campus, Newton Abbot.
[200] Prescott-Allen, R. and C. Prescott-Allen, 1990. How Many Plants Feed the World. Conservation Biology, 4:365-374; Kunkel, G. 1984. Plants for Human consumption. Koeltz Scientific Books. Koenigstein, Germany; Hammer, K. 1999. Species diversity of wild relatives to crop plants. Bot. Lithuan. Suppl. 2:31-35.
[201] Walker, B., A. Kinzig, and J. Langridge. 1999. Plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. Ecosystems 2:95–113

plotted in a five-dimensional space using a similarity index, such that species close together were very similar in terms of these particular attributes.

The dominant grass species were functionally dissimilar and therefore complementary; this is functional diversity. Most of these dominant species had one or more minor species that were very similar to them in terms of the function they performed. At a heavily grazed site, a number of the species that were dominant in the un-grazed community had been lost or substantially reduced. In four out of five cases, the minor species that replaced these lost ones were their functional analogues. Therefore, despite the fact that grazing reduced the populations of dominant grazing-sensitive species, formerly less dominant but functionally analogous grazing-tolerant species increased in abundance and contributed to the maintenance of ecosystem functions; this is response diversity.

Both functional and response diversity are important in the rangeland. Functional diversity increases the performance of the plant community as a whole, bringing together species that take water from different depths, grow at different speeds, store different amounts of carbon and nutrients, and thus complement each other. Response diversity enables the community to keep performing in the same complementary way in the face of stresses and disturbances such as grazing and drought.

This is something to bear in mind as you cover crop or choose grasses for your livestock to feed on. In the face of drought conditions and ever limited water resources we need to consider diversifying our grasslands. Consider including grasses that penetrate deep into the soil, pulling water up for use by other grasses that create more biomass or store nitrogen. These kind of diverse functions can, and do, develop soils that maintain moisture and biological life in the face of intense heat and lack of rainfall.

Lack of diversity underlies success of modern agriculture. A few species have small edge over other species. Farmers and later breeders selected the most productive genotypes. Then farmers and scientists created optimal conditions for those species and genotypes. Other regions saw the success and adapted the system to their conditions. So the ancestors of maize (Central America), potatoes (South America), wheat (Middle East), rice (Asia), sorghum and sweet potatoes (Africa) all gradually were selected and came to dominate and displace other species.

Farmers can counter this lack of diversity by increasing diversity within this limited group of crop species. Plant communities comprised of regional varieties that are responsive to various regional climates and conditions can be created. This ensures, or safeguards, against numerous crop failures from climate to cultural issues like pests and disease. Moreover having multiple types of similar, though distinctly different, plants develops a kind of competitive interaction that can develop into more robust responses to disturbance. Competitive interactions are strongest among species that have similar functions and operate at similar scales. These interactions encourage functional diversity within a scale, and the distribution of ecological function across scales, enhancing cross scale resilience. This is true among plants and other biological networks as well as marketing and distribution networks. One thing that capitalism has shown us over the years is the value of having market competition, a diverse array of competitors pushing the envelope on development and quality. Moreover, as more businesses, farms, markets and distribution channels join the market, a division of labor can develop with a net of complementary contributors to the overall system.

In the field, on the farm

Many of the practices we might suggest here are located in the Working with Nature chapter of this book. Here we present relevant concepts that demonstrate complementary diversity on the farm.

Annual vs perennial. Annual crops enable farmers to capture yearly the growth phase of the adaptive cycle. However, the benefits of maintaining perennial crops of local flora can outweigh this advantage. The amount of time and energy given to producing annual crops is one reason to look at what perennial crops you can include into your business model.

Annual crops require at least some annual tilling to produce—even if only moving the soil aside to insert a seed in no-till systems—which means erosion is concern in all annual systems. Moreover if every one of your crops is an annual you're going to be putting time and energy into either purchasing or saving seeds, purchasing or starting transplants and the necessity of planting all those individual starts or seeds. The benefits of allowing the soil to maintain its structure and the time you're rewarded with are paramount in considering what and how many perennial crops you want to include in your farm plan. There is maintenance to consider, though in contrast to the energy exerted in soil preparation and planting annual crops every year, the comparison can be a stark one.

What berries, trees, flowers and herbs can you include in your business that can bolster the health of your land while also providing you with an income stream? The more annual flowering plants you have bolsters your pollinator population as well, further adding to your complementary diversity. The complementary effects of emphasizing perennial plants can be magnificent depending on how diverse you're willing to make your enterprise. Consider the honey you could produce from the added wildflowers and buds from fruit trees. Or, the boost in your annual crop production and the notable improvement of flavor in your produce from the added pollinators now safely harbored on your property. We cover this subject fairly extensively in the working with nature chapter but, again, it is valuable to highlight that when we work with nature we are presented with an opportunity to build an astonishing array of complementary relationships and therefor outcomes on a greater scale.

Lastly, annual species put all their energy and resources into seed or fruit or other portion which can be harvested. Perennials must put at least some energy into maintaining the living plant, and therefore the living soil. The added benefit to your soil of this mutualistic relationship between perennials and soil health is something that is hard to measure, but is nonetheless invaluable and in many ways truly remarkable.

Induced diversification of species in social agroecosystems. As we discussed earlier in this chapter, there are benefits to be had from ensuring adequate species variation in ecosystems and therefore also in agro ecosystems.

An interesting study[202] was conducted in the tropics by a group of soil scientists who wanted to understand how species diversity impacted forest recovery after clear cutting of a section. They clear cut an area of tropical forest and developed the following test plots to measure the impact of ecosystems on the soil:

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[202] Soule, D. and K. Piper. 1992. Farming in Nature's Image: An Ecological Approach to Agriculture. Washington, DC: Island Press

- A control plot where they prevented any regeneration
- A natural succession plot where they allowed the forest to grow back as it naturally would
- An enriched succession where they added seed stock to the natural successional sequence but took no plants away
- A maize (corn) and cassava crop treatment where they grew each species in monoculture
- And, of the most interest to this topic, an imitation of the natural succession created by the researchers. The imitation of succession was an attempt to build an ecosystem that resembled the natural secondary growth structurally and functionally, but using different species. In this study the investigators replace, as the plants appeared on the site, the naturally occurring species with morphologically similar ones (that is, annual for annual, herbaceous plant for herbaceous plant, tree for tree, vine for vine) not native to the site.

The outcome showed that the natural succession plot was successful in maintaining soil fertility while the mimic worked comparatively well, especially in regard to holding soil nutrient. After 4 years both the succession plot and the imitation plot showed similar successes in fine root structure and despite having no species in common both maintained proportionate soil structure.

What we can take from this is the awareness that we can induce and build ecosystems with proportionate soil building capacity. We have the tools and knowledge to construct models that mimic the miraculous nature of forest and other natural ecosystems! Consider then the value of incorporating these micro-climates into your hedgerows, creeks, rivers and drainage banks and in your forests. The species diversity that will naturally arise from this induced environment will inevitably provide your farm with the added, complementary systems that ensure pollination, pest mitigation and potentially added value.

Crop rotation, companion planting, guild planting.

These three practices all hinge on the principle of complementary diversity, generating better soil biota and in many instances increase groundwater retention.

> **Cover crops** enable groundwater retention by ensuring that there is always a living layer, pulling the water up to the surface and shading the soil from direct sunlight. Moreover by continually having plants growing in the soil you ensure plenty of microorganisms and mycelium can colonize the soil as they will continue to have root matter and plant decay to consume. These two elements alone hold moisture and nutrient in the soil providing them to whatever crops you plant by means of the mutualistic relationship that plant roots form with both microorganisms and mycelium below the ground.
>
> **Companion planting** has the potential to, again, raise the water table making groundwater more available to your plants. The potential here is incredible as we introduce radishes and other deep rooted plant species that break up the soil and literally pull moisture to the more shallow rooted plants. In addition through companion planting you can plant herbs and flowers that repel pests and harbor beneficial insects while also beautifying the space and potentially creating another avenue of cash flow for your farm.
>
> **Guild planting** is companion planting taken to another level. Often named after the tree that the guild is built around, guild planting takes a center point and builds around it, seeking to provide complementary species to a particular tree, or trees by planting flowers, shrubs and herbs that

will benefit those around itself. Similar to companion planting, but the intention is more centered around a particular focal point, say, an ash or walnut tree. Know that in three dimensions we are filling in all the spaces and niches from the over story or canopy tree down to the soil. In addition, the plant guilds have root systems that cover every depth –mimicking that which exists above the ground, below, and include the incredibly important functions of the fungi and mycelia.

A successful plant guild will naturally evolve over time and will have diversity, interdependence and good relationships, as is needed in our human relationships as well. Resilience naturally occurs in such systems, strengthening the whole community.

These practices are covered more extensively in the Working with Nature chapter. We mention them here to highlight their pertinence to complementary systems development. Bear them in mind as you consider the ecological niches you can fill as you're looking for opportunities to enact this principle on your own property.

Disturbance maintains diversity. We'll cover this topic more extensively in the periodic transformation chapter, but as we stated in the first half of this chapter, creating ecological disturbance is not only beneficial, it's imperative to developing a resilient system.

It's important to realize that deep or shallow tilling is not the kind of disturbance we're looking for. Even in the wake of a tornado, which tears open the surface of the ground, this is only in one strip and often times that strip is narrow leaving plenty of plant life around the affected area. The primary form of disturbance in natural systems is burning or grazing by large herd animals. Both of these disturbances, though, can cause monumental issues if left unchecked. Overgrazing can both deprive soil of that plant layer shading the ground and holding moisture while also compacting soil, exacerbating the problem of over grazing. Similarly burning for the sake of burning can also dry out soils and cause runoff as there is no grass to hold the soil.

The greatest benefits we can yield from grazing animals is through management intensive grazing, again this is covered more thoroughly in the working with nature chapter, but suffice to say that through mimicking the patterns of predators moving grazing animals from one pasture to another we can promote incredible regrowth rates for grasses while intensively fertilizing the soil with manure. Bringing fowl into the mix to break up manure and eat insects and larvae and you're developed a more complementary system than you had before while continuing to systematically "disturb" the ecosystem for its betterment.

Burning's greatest benefits are seen in the production of biochar to hold moisture and retain nutrients in the soil while also clearing the way for cover crops or that season's vegetable production. It's important to re-seed as soon as possible to ensure that the soil doesn't dry out immediately and you maintain that vital layer of microorganisms and fungi. Burning also can be beneficial in the woods to quickly remove layers of leaf mulch and free up seeds stored for generations beneath the deep layers of leaf mulch. This procedure should be done mindfully, and not all at once as many insects and beneficial organisms reside in the leaf mulch layer. It is suggested that you burn rotationally only disturbing one section of the forest at a time to allow a faster recovery. Though in natural ecosystems fires would be widespread, we want to achieve faster results than nature would provide alone.

Moreover, some people intentionally subject their plants to particular disturbances to breed in resistance by selecting the plants that responded well to the disturbance. Interestingly, when breeders use this tactic they choose the plant that performs nearly the best, not the one that shows the least disease or shock. What this does is ensure that there is still resistance to other disturbance left in the genome. If you breed a plant to be highly resistant to one disturbance, say drought, it is likely to have low resistance to many other disturbances as those genes have been either bred out or repressed in favor of the drought resistance. Here too, complementary diversity is present by preserving gene pool variety to produce a response to many disturbances rather than one.

The same thing happens when we utilize seed varieties that have been conditioned for generations to thrive in humid, dry, sunny or shady conditions. An example is a fig tree that, through successive breeding, can survive Minnesota winters, truly a remarkable trait as the common fig has trouble as far south as Missouri due to late or hard frosts. Through selective and disturbance targeted breeding we can diversify our seed supply to mitigate the challenges of widespread disease, harsh pests and shifting climate.

The larger system: Working in and with it. It is perhaps at a larger scale that we see complementary diversity having the most widespread effects. As we develop cooperative and complementary enterprises we stand to build a resilient food supply that is responsive to market shifts, shortages or fallouts. As we culturally build our systems in the pursuit of complementary partnerships, greater yield results from those partnerships.

Modularity, (covered more extensively in the modular connectivity chapter) can lead to complementary diversity, division of labor, efficiency and more productivity through specialization. Farmers who produce their own transplants won't get disease from transplants grown elsewhere. However, once a reliable system of transplant production is created, economies of scale may dictate the farmer use the external source. The same economy of scale is often seen in livestock and particularly poultry production with whole businesses dedicated to each stage of poultry development. Many resilient farmers, however, maintain their capacity to produce transplants or other inputs if needed to ensure a backup supply in case of fallout, yet another key element of resilient systems.

It is through the conscious pursuit of cooperative and transparent partnerships that we can develop complementarily diverse systems that respond to unforeseen changes in the market and planet. A challenge that many groups face, though, is adversity of all kinds that stifles willingness of certain groups to work with or cooperate with others. In publications[203] on promoting diversity in business it has been indicated that promoting diversity for the sake of diversity can backfire, breaking down the communication channels and the organizations ability to build trust or a sense of close bonding within members or associates. How do we overcome these challenges?

Diversity in your businesses. If it's true, and often it is, that a percentage of the community is unwilling to work with the other there exist a handful of things that can be done. It is also true that fellowship can

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[203] http://www.huffingtonpost.com/wray-herbert/does-diversity-undermine_b_4044853.html; http://www.boston.com/news/globe/ideas/articles/2007/08/05/the_downside_of_diversity/?page=full

be achieved when a common goal is realized and a common purpose established. Even the most divided groups can begin to find avenues to work together when there is a common belief or challenge that unites them.

You can also consider a reward system that encourages cross participation, creating win/wins for all people and groups involved. This takes a lot of imagination and a distinct feeling and understanding of the community you're in to begin to make this tactic work. What are the needs and desires of your community? What needs are particularly shared by everyone involved? And most paramount, is that need greater than the distrust of distaste that one or both sides has for the other?

Third is the concept of a lofty goal, or vision that can be attained only through unity. This is similar to that of the previous two tactics with a twist—it's not a challenge or problem to solve, but rather a goal greater than the anyone can achieve alone. This could be the funding of a community center, development of a job training program, after school programs, a low interest loan fund for participants or any number of other desires that the whole community holds. This can be a great motivator and a place to begin in the pursuit of building diversity that is productive and complementary.

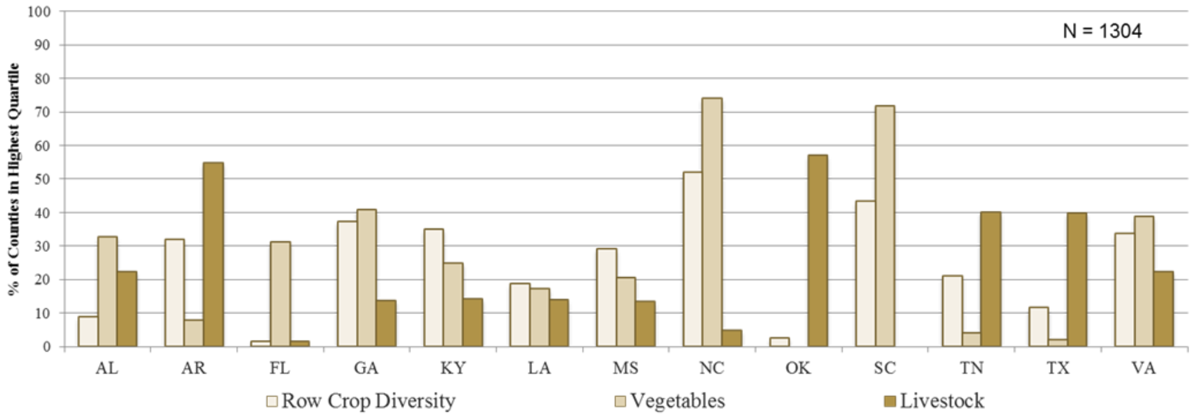
It is through the construction of a shared dream, goal or desire that people begin to find avenues for cooperation. If all else fails, separate organizations may be the only resolution, though it is advised to work towards partnership as all walks and perspectives have the potential to build more resilience into any organization by offering different perceptions and therefor different answers to unforeseen problems as they arise.

Self-assessment of diversity. Explore the following questions to determine the complementary diversity of your system.

a. Do your crop and animal enterprises require work at different times in your yearly schedule?
b. Do you have a variety of enterprises which each contributes to the others?
c. Do you have back-up markets for all your products?
d. Do you use many varieties of seed?
e. Are you producing a greater variety of products than when you began managing the farm?
f. Is the quality of your products increasing?
g. Do you hold another job? If so, is it related to agriculture?

Assessment of complementary diversity from secondary databases. We have identified several variables with available county-level data which shed light on levels of complementary diversity in the thirteen Southern states. The results are shown by state in the following chart according to methods described in more detail in the Appendix.

Complementary Diversity in Agrifood System by State
% of Counties in State Ranked in Highest Category



Sources: 2012 Census of Agriculture; extra calculations by the University of Mississippi Center for Population Studies. Scores based on standardized score rankings on: Row Crop Diversity = average % of operations producing across seven row crops; Vegetables = % of operations with harvested vegetables; Livestock = % of operations with livestock sales. Analysis based on 1304 counties.

Complementary Diversity Quality of Resilience

Table 5 shows state by state comparisons of the three county-level measures of complementary diversity and the combination of these measures in a diversity index.

The adjacent box show the rankings by state on the diversity index. Most striking is that that top four states on SRI are also the top four on diversity.

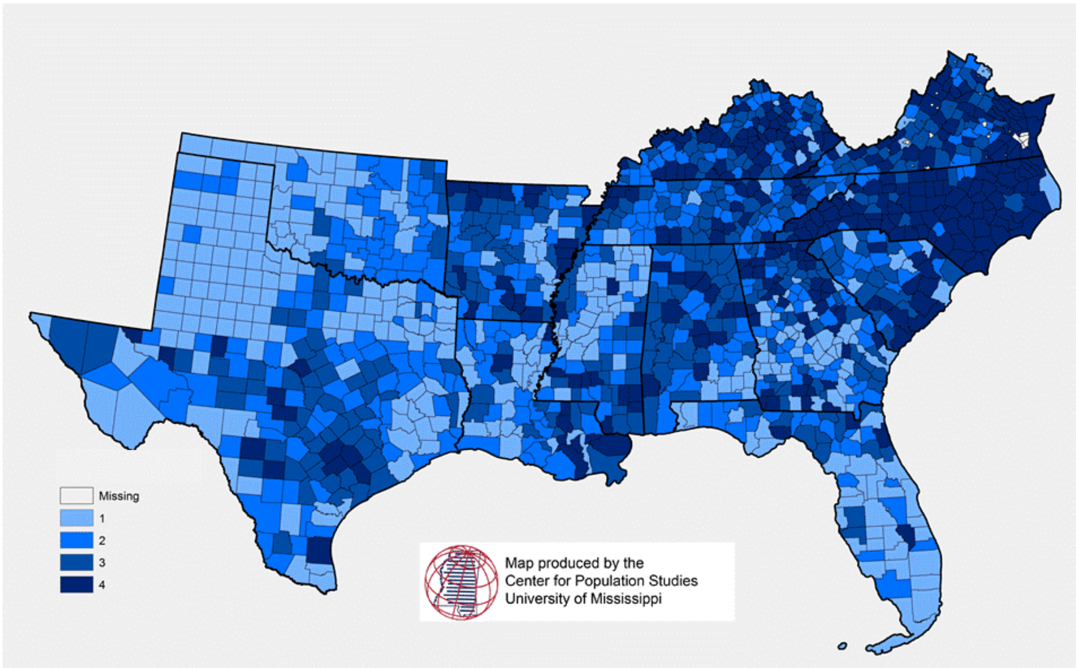
Also striking are the similarity of low scores on the overall SRI and low production diversity index scores for Oklahoma, Texas and Mississippi. Of those states with the lowest SRI rankings, only Alabama manages to rise to nearer the middle tier on diversity.

Florida is distinctive in being among the top five in overall SRI, but in the lowest three states in diversity, according to this index which compares extent of row crop, animal and vegetable diversities.

States ranked by % of counties in highest quartile on the production diversity index			
Production diversity	Overall SRI	State	%
1	2	North Carolina	83.0
2	1	Virginia	52.0
3	3	Kentucky	44.2
4	4	South Carolina	26.1
5	9	Georgia	25.2
6	8	Arkansas	22.7
7	7	Tennessee	21.0
8	12	Alabama	19.4
9	6	Louisiana	14.0
10	13	Mississippi	13.4
11	5	Florida	5.9
12	11	Texas	5.1
13	10	Oklahoma	0.0

The lack of any counties in Oklahoma to rank in the top quartile and the 83% of North Carolina counties in the top quartile also point to a vast disparity between Southern states in production diversity.

Cooperative, Complimentary Diversity: Row Crop, Vegetable, and Livestock Production Index (Quartile Ranks)



A higher quartile ranking indicates a higher level of resiliency on this measure. State of the South data sources: 2012 Census of Agriculture, 2013 Food Atlas, and 2014 review of state policies and regulations; extra calculations by the University of Mississippi Center for Population Studies. Analysis based on 1304 counties.

Summary

As everywhere in ecology, contradictory concepts must be embraced and united if resilience is to be born. Ecological diversity is born of conflict, though it also arises out of cooperative relationships. As life on this planet has morphed and changed and as ecological niches are made or filled, it is often through complementary diverse relationships that ecosystems are built. Looking at the soil system we see an amazing network of individual components (e.g. microorganisms, worms, ants, fungi, etc.) finding opportunities to aid one another by providing otherwise unavailable nutrients, aeration or soil moisture. Above the ground shade loving plants are complemented by large trees. Squirrels, birds and may other animals both feed on and transplant the nuts and fruit therefor propagating trees into new territories. Woodpeckers in their pursuit of bugs create dwellings for beneficial insects.

Though conflicting goals can result in diversity in resilient systems, cooperative or complementary goals achieve the same and often greater results!

It is up to you to look for those opportunities to build something greater than the sum of its parts. To find those connections on and off the farm that yield results that keep building on themselves, closing the real and metaphorical loop to eliminate wasted time, energy and inputs.

Though diversity can be a destructive force, when concepts, ideas, and systems are paired with complementary ones, the magnitude of the results can be truly remarkable yielding greater income, time and opportunities.