Exploring Indigenous Permaculture for Land Management Strategies:

Combining People, Food and Sustainable Land Use in the Southwest

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Abstract

Indigenous peoples of the Southwest have adapted and persisted in the dry southwestern climate long before first contact from colonial settlers. By use of traditional ecological knowledge, Indigenous people developed permaculture structures to enhance the edible food landscape of the Southwest. These permaculture structures of water weirs, terrace and waffle gardens and the use of rock mulch are a few examples of applied traditional ecological knowledge which established microclimates for Indigenous foods (wild and cultivated) to thrive in. The location of structures maximizes potential of precipitation, such as in washes, arroyos and along canyon edges. Studies have shown that the impact of Indigenous permaculture structures increase topsoil depth, bank overflow, herbaceous cover, water saturation, and nutrients available in the soil. In contrast, the impact of non-Indigenous settlers and land managers has resulted in desertification and loss of native vegetation on the Colorado Plateau and the Southwest. In addition, climate change is impacting these regions with higher temperatures and lower precipitation. I propose for southwestern land managers to utilize Indigenous permaculture strategies that are adapted to the arid region in restoration and conservation efforts. Additionally, I propose decolonizing Indigenous land management by applying and reclaiming ancestral Indigenous methods of permaculture in order to reestablish and strengthen the food security and food sovereignty.

Table of Contents

Introduction

Land use prior to European contact

In the Southwest, food security and land management are dependent upon each other. Historically, Indigenous people were completely reliant on the landscape for food, fiber, medicine, dyes, and other natural materials. In order to sustain healthy ecosystems and communities, Indigenous cultures cultivated a symbiotic and familial bond with the land (Salmón, 2012). Self-sufficiency stems from observing the landscape and recognizing ecological relationships and patterns. Traditional ecological knowledge is the textbook of sustainable land management and Indigenous science. With this knowledge, Indigenous people tapped into the energy of the ecosystem and cultivated their landscape.

In addition to cultivated foods of corn, beans and squash, the wild foods found throughout the landscape were "systematically rummaged" to provide additional flavors, nutrients and diversity to the Indigenous diet (Price & Morrow, 2008, p. 22). These foods have hybridized and are genetically adapted to the region. They provide an abundance of nutrients for Indigenous health and add to the biodiversity of the ecosystem (Nabhan, 2013; Salmón, 2012). A wide range of wild foods are found in Indigenous diets, which includes yucca, osha, pinyons, mushrooms, amaranth, cactus, mesquite, acorns, wild onions, sunflowers, currants, and chokecherries (Price & Morrow, 2008; Salmón, 2012). This list is limited, with value and utility placed on every element, mineral, animal and plant in the environment.

Yet this reciprocal connection between land and people was disrupted once colonization occurred in the Americas. Sustainable land management values of Indigenous people were viewed as primitive, with little connection from colonizers of the abundance of the environment and how Indigenous communities guided the bountiful landscape (Salmón, 2012). Nearly 500 years of disassociated land management has been implemented, which correlates with the degraded health of ecosystems and Indigenous communities.

Spanish influence

The arrival of Spanish settlers reshaped resource management with the introduction of domesticated livestock and grazing. In the early 1500's, Spanish explorers began importing cattle, horses, sheep, goats and other livestock into the Southwest, with their populations increasing from the abundance of forage in the rangelands (Holechek, 1981; Holchek, Pieper & Herbel, 2011). The rangelands were historically covered in tall grasses, with Spanish explorers describing "grasses high enough to tickle the bellies of their horses" (Salmón, 2012, p. 87). But as Spanish missions and settlement expanded, wild horses became prevalent on the landscape and livestock ownership soared. Herd populations varied, with many landowners recording their herds to range from 5,000 to half a million animals (Holechek, 1981; Holchek, Pieper & Herbel, 2011). In addition to grazing by native animals such as elk, bison and deer, the capacity of the landscape was challenged by the arrival of domesticated livestock and the carefree perspective of infinite rangelands.

Forest health was also impacted by grazing. A recent study conducted on the Chuska Mountains in the Navajo Nation recorded a longer period of fire exclusion starting from 1830's compared to other regions where fire exclusion started around the 1870's. (Whitehair, Fulé, Meador, Taracón & Kim, 2018). This correlates with the presence of grazing, with Navajo people valuing sheep herding and that contributing to a change in the frequent fire regime (Guiterman et al. 2019).

Spanish settlers also introduced new crops and fruit trees such as peach, apricot and apples. The surviving orchards are now considered heirloom species and are adapted to the dry climate of the Southwest (Salmón, 2012). The integration of orchards and grazing with livestock added complexity to the use of land. Additionally, flood irrigation and the use of canals became primary methods for agriculture. Some of these land use practices were negative, and began to alter and degrade watersheds (Webb & Leake, 2005).

Western influence

Following the 1846-1848 Mexican-American war, the Southwest became part of the United States. Exploitation of natural resources and land expanded dramatically, with primary industries focused on mining, timber and grazing operations, supported by transcontinental railroads constructed in the 1880s. Populations of livestock continued to grow, with little oversight in regards of sustainable land management. Livestock surveys in the late 1800's estimated cattle populations peaking at 40 million, with overgrazing and desertification becoming alarmingly evident on the landscape (Holchek, Pieper & Herbel, 2011). Additionally, invasive species such as tamarisk began to thrive in disturbed habitats and monopolize southwestern riparian ecosystems, the construction of extensive water diversion structures impeded flood regimes, and keystone species such as beaver were removed from the ecosystem (Webb & Leake, 2005).

During this time period, Indigenous communities and cultures were at risk, with genocide and assimilation efforts used in federal oversight and policy. In addition to relocation and forced settlement onto reservations, federal regulation of land through the Homestead Act of 1862, the Dawes Allotment Act of 1887, and the Taylor Grazing Act of 1934 added to efforts to exploit Indigenous lands (Hibbard, 2006; Holchek, Pieper & Herbel, 2011). Not only did these acts continue to break up Indigenous lands but patrilineal ownership of land and livestock was formalized, which conflicted with traditional matrilineal cultures (Corntassel, & Witmer II, 2008). The Taylor Grazing Act was established in response to inventories from rangeland science indicating the deterioration of ecosystems due to overgrazing (Holechek, 1981; Holchek, Pieper & Herbel, 2011). Yet federal oversight through the Bureau of Indian Affairs utilized these regulations to decimate livestock populations on tribal lands, such as Navajo Nation, and drastically reduced herd sizes in another effort to assimilate Indigenous communities (Hibbard, 2006). The degradation of the ecosystem coincided with the devastation of Indigenous communities.

Currently in the Southwest

Despite scientific studies on natural resources and improvement in land management in the Southwest, wear and tear is evident on the landscape. The accumulation of prior colonial land management decisions, or lack thereof, have led to springs drying up, groundwater and aquifer depletion, and arroyo cutting (Salmón, 2012; Webb & Leake, 2005). The overexploitation of water and natural resources has contributed to woody plant encroachment, fire suppression, pest and disease outbreaks, invasive species and land degradation (Webb & Leake, 2005). Climate change is also prevalent with increasing temperatures and unpredictable weather patterns.

For example, on the Navajo Nation, a report for the United Nations recorded "trends of increasing temperature and lower amounts of snowfall (and precipitation) have led to increasingly arid conditions" (Margaret Redsteer et al., 2011). Additionally, with several centuries of open grazing of cattle, sheep, goats and horses, biodiversity on Navajo rangeland is reduced with vegetation cover ranging from 9.5-17% (Thomas & Redsteer, 2004). The combination of vegetation loss, higher temperatures and lower precipitation has led to an increase of active sand dunes which threatens Navajo homes and livelihoods (Magill, 2014). Measurements of dune migration located near Grand Falls, Arizona reveal that the average sand dune moves 115 feet per year (Redsteer, 2011). The encroachment of sand dunes are indicators of climate change on the Navajo Nation.

The consequences of climate change are uncertain and questions are being asked in scientific communities of what the landscape will look like in the near future. Recent climate modeling research predicts drastic changes in forest conditions on the Navajo Nation in the next century: "climate changes are projected to reduce the current conditions of Dine forest basal area by 65–89%" (Yazzie, Fulé, Kim & Meador, 2019). This radical change in forest density will threaten the biodiversity and functions of the ecosystem. The misuse of natural resources has accumulated into climatic forces beyond our control.

These extreme ecological transitions are alarming. What could one person do to combat climate change and protect our ecosystems? How can sustainable land management provide food security? Ecosystems and species need our help and protection in adapting to climate change. The functions and services of ecosystems need to be restored and humans need to be integrated into sustainable land management practices in the face of climate change.

This paper will explore strategies in sustainable land management with a look at 1) traditional farming practices and modern permaculture, and 2) Indigenous permaculture practices in the Southwest. Indigenous farming techniques are unique because they are adapted to the arid climate of the Southwest, require little machinery and can be applied across entire landscapes and watersheds. The implementation of Indigenous permaculture can create ecological resiliency, conserve biodiversity and is a natural resource and sustainable land management approach in response to climate change. These practices reclaim Indigenous techniques of sustainable land management by restoring ancestral relationships with the land, and revitalizing access to nutritional traditional foods. In addition, this paper serves as an example of asserting Indigenous sovereignty by decolonizing unsustainable land management practices in order to incorporate food and cultural security.

Chapter 1: What is Permaculture?

Permaculture is a practice of traditional farming that "works with nature and takes natural systems as models to design sustainable environments that provide for basic human needs and the social and economic infrastructures that support them" (Morrow, 2006, p.5). This "cultivated ecology of permaculture is designed to integrate people and land in a reciprocal relationship" (Morrow, 2006, p. 17). The Merriam Webster Dictionary (2019) defines permaculture as "an agricultural system or method that seeks to integrate human activity with natural surroundings so as to create highly efficient self-sustaining ecosystems." Additionally, Enrique Salmón provides an Indigenous perspective of cultivating an edible landscape, which focuses on blending "community, culture and land management for sustainable use and benefit for the ecosystem and the people" (Salmón, 2012, p. 101). Themes of connecting people and nature thread through these definitions of permaculture.

The concept of permaculture is to have a self-sustaining system that mimics natural ecosystems, ensuring that the needs of the site are met internally (Morrow, 2006). It is even noted that in permaculture design, one should "think like a forest" (Morrow, 2006; Hemenway, 2009). Everything in the forest has a role and waste is recycled into energy to contribute to another function. Alan York, a traditional farming consultant, stresses to "emulate how natural ecosystems work, they regulate themselves through diversity so you don't get epidemics of pests and diseases" (Chester, 2018). Permaculture strives to match the functions of a healthy ecosystem with the use of biomimicry in nutrient cycling, watershed management, soil building, pest management, and resilience in biodiversity (Figure 1.1).

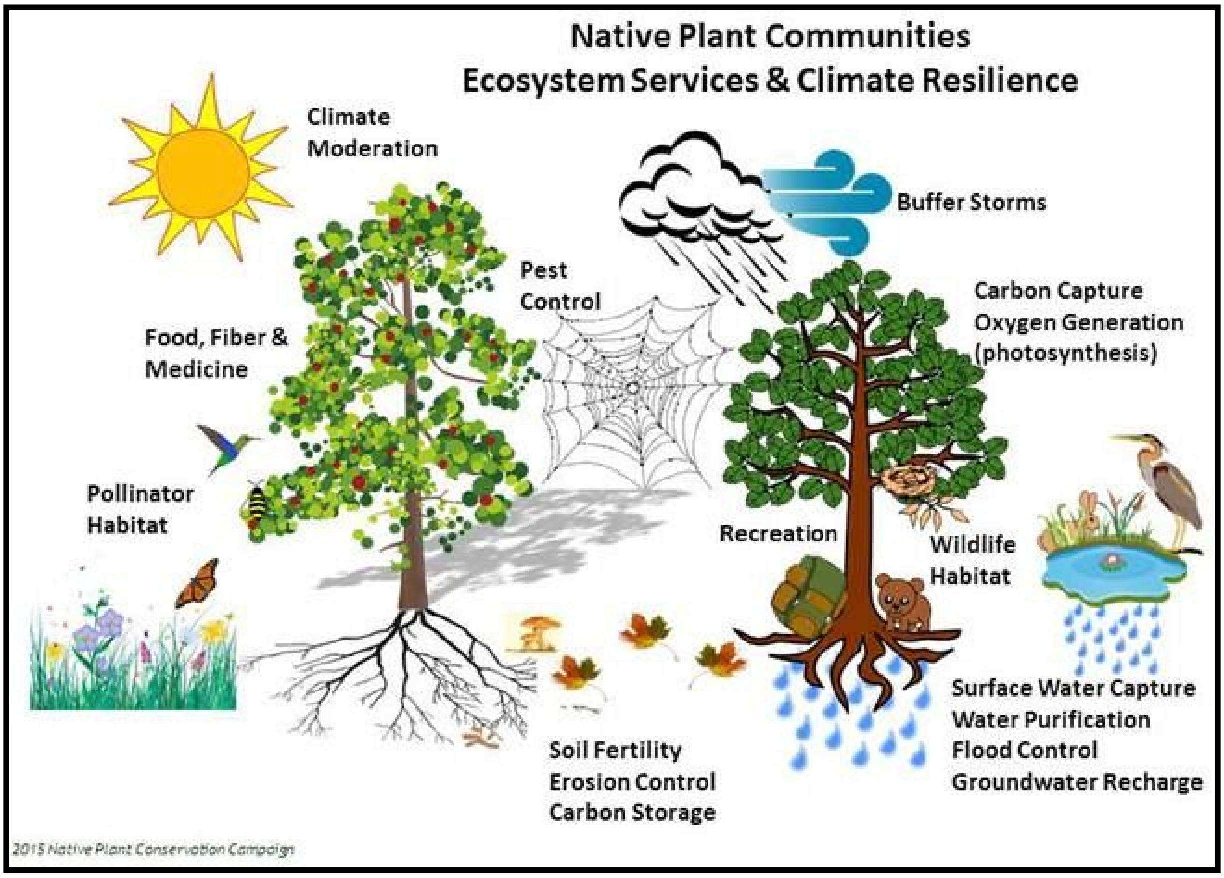

Figure 1.1: Ecosystem functions and services that permaculture replicates in order to create a sustainable farming and land management system. Image created by Dan Feldman, Native Plant Conservation Campaign, [*http://nativeplantsocietyofus.org/ecosystem-services-resources/*](http://nativeplantsocietyofus.org/ecosystem-services-resources/)

Successful permaculture requires knowing your bioregion, the characteristics of the climate and strategically planning in order to maximize energy use. Observation of a landscape and recognizing seasonal and climatic patterns is essential to permaculture, allowing practitioners to capture renewable energy. Beyond that, the permaculturists are harnessing the energy of the ecosystem. Alan York compares traditional farming to surfing, in which you are tapping into this flow of energy (Chester, 2018). Conserving this flow of energy is key, therefore any implementation in permaculture has more than one purpose, is multifunctional, and reciprocal.

In the 1970's, Australian researchers Bill Mollison and David Holmgren are known for coining the term "permaculture" and cultivating the ethics, principles, and practices that guide modern sustainable living (Grayson, 2007). They advocated for permaculture, or "permanent agriculture," in response to industrial agricultural and the destruction of natural ecosystems for modern food security. It was the combination of observations and ecological research in old-growth forests in Tasmania, Australia, and a 1929 book by Joseph Russell titled *Tree Crops: A Permanent Agriculture,* that influenced Mollison and Holmgren to establish permaculture (Allen, 2019; Grayson, 2007). Therefore, ecology and forestry terms such as pioneer species, succession, understory, ecotones, edge effect and microclimates are commonly found in the permaculture vocabulary (Box 1.1).

Box 1.1: Permaculture terms and themes

- *Guild:* A diverse selection of plants that are grouped together to match ecosystem functions, such as fixing nitrogen into the soil or providing shade and wind protection. Guilds can maximize vertical space and have various canopy layers. For example, the Three Sisters is a plant guild of corn, beans, and squash. Corn provides a trellis for the beans, beans fix nitrogen into the soil, and squash provides ground cover to minimize evaporation.
- *Solar energy:* In addition to capturing water energy, the observation of where solar radiation concentrates can create microclimates for plants. Cool and warm thermal zones may be more suitable for various plant species. Areas can be altered in order to

create an optimal growing site. For example, a south facing wall is suitable for plants that like warm, dry growing conditions.

- *Succession:* Ecological pattern of changes in species composition and ecosystem characteristics following disturbance. A dry, exposed piece of land may transition into a cool shaded forest after the use of thoughtful permaculture design. Pioneer species may have reshaped the space for understory species to flourish or for the integration of grazing animals.
- *Edge effect:* The transitional zone between distinct ecosystems such as a pasture to a riparian zone or an orchard. These transitional zones are complex and have higher rates of biodiversity, which can strengthen resiliency in the landscape. To maximize edge, permaculture uses patterns of curves, spirals, circles and other shapes when creating microclimates. Living fences also add to the edge effect and can be strategically used as windbreaks, to minimize evaporation and damage.
- *Incorporation of animals:* Guilds include the interaction with pollinators, wildlife and livestock which adds to the permaculture system by providing a natural fertilizer, controlling pests, pollination, and distributing seeds.

Mollison and Holmgren developed permaculture ethics and principles in order to achieve a healthy ecosystem (Figure 1.2). These principles developed place-based ecological knowledge, with the practitioner gaining an intimate perspective of the landscape and utilizing microclimates to nurture plant establishment. In order to encourage plant establishment, soil is manipulated to maximize water retention. Earthwork structures such as swales, which are trenches that are dug along the contour of a hillside, reduce water runoff and erosion. Perennial plants are placed on the outer berms of the swales, stabilizing the soil with the plant roots. Regardless of the size of the slope or the property, or the climate, permaculture practices can be used to transform an area into a fertile food landscape.

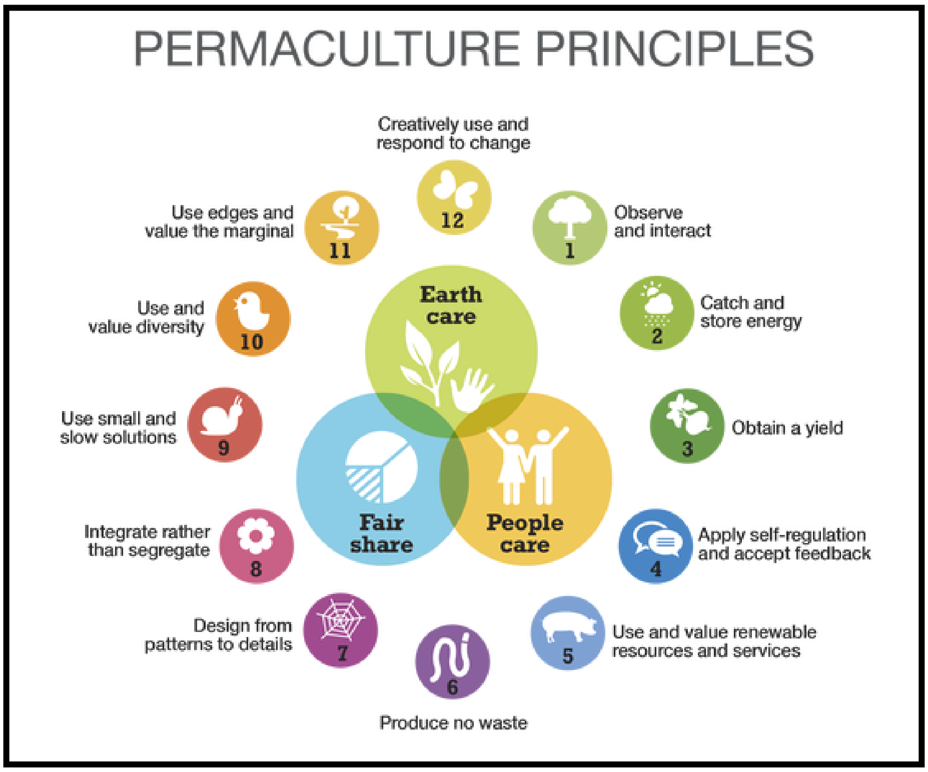

Figure 1.2: Permaculture ethics of earth care, people care and fair share. The principles in the smaller circles guide the permaculture process of replicating an ecosystem and providing a sustainable food source. Retrieved from: *https://theseedlingatsagada.wordpress.com/permaculture/*

Traditional Global Examples

The permaculture concept of "living with the land and not against it" is not new and is rooted in a global synthesis of Traditional Ecological Knowledge (TEK). Farmers from around the globe, and throughout the past, have developed their own place-based land management strategies to live harmoniously with the environment. With the use of TEK, farmers also played the role of land managers and found ways to sustainably cultivate in diverse regions across the world.

For example, terrace gardening can be found throughout the world in response to steep farming landscapes (Beach & Dunning, 1995; Brevik, Homburg & Sandor, 2018; Bruin, Evenari & Nessler, 1986;Nabhan, 2013; Wei et al., 2016). Ancestral terrace gardens are located in various climates, ranging from tropical to arid regions. Each of these regions have adapted terrace gardening into their traditional farming methods in order to capture the precipitation that is going downhill, to control erosion and reduce flood risks (Wei et al., 2016). Terrace gardens shaped microclimates into slopes, and enhanced the natural resources available in order to nurse agricultural landscapes. Ancestral terrace gardens are still evident and show the resiliency of the long lasting design (Figure 1.3).

Figure 1.3: Ancestral terrace gardens located in Colca Canyon, Peru. Terraces are still in use and have been cultivated for over 1,500 years (Brevik, Homburg & Sandor, 2018). Photo by Doug McMains, image courtesy of Smithsonian National Museum of American Indians.

Many methods of ancestral permaculture practices center around water, by harvesting the water into the soil or diverting water. In arid regions such as the Negev Highlands desert in Israel, ancestral farming practices rely on rain runoff (Wieler, Avni & Rosensaft, 2016). Fields or *wadis* are strategically placed near slopes to receive rain runoff, which are lined with perennials and rock mulch used to stabilize soils (Wieler, Avni & Rosensaft, 2016). Another farming tactic in the Negev Highlands desert is to remove the natural stone mulch areas above the *wadis* in order to increase and divert rain runoff towards the gardens (Wieler, Avni & Rosensaft, 2016). Watershed observation and management are critical disciplines in TEK in order to establish microclimates in arid regions.

Other practices include slash and burn, which can open up an agricultural area in a dense tropical forest. Burning of crop residues can clear a field at the end of the season. Traditional Ecological Knowledge recognizes the benefits of the ash, which provides additional nutrients to the soil (Ba, Lu, Kuo & Lai, 2018; Brevik, Homburg & Sandor, 2018). In addition, intercropping and integrating animals are traditional farming practices that promote biodiversity and fertilize the soil with manure (Miller & Marston, 2012; Brevik, Homburg & Sandor, 2018). Ancestral evidence of agropastoralism and incorporating domesticated livestock with crops, dates back to over 9,000 years ago with symbiotic relationships utilized in order to maximize productivity (Miller & Marston, 2012; Brevik, Homburg & Sandor, 2018). The use of TEK in ancestral farming practices expands the capacity of the edible landscape.

Permaculture and Land Management

The ethics and principles of permaculture are compiled with traditional ecological knowledge from all over the world and Western ecological science in order to formalize and map out sustainable living strategies for current societies. Themes of observation and conserving energy percolate throughout permaculture and sustainable land management. Additionally, sustainable land use terms are affiliated with permaculture such as: agroforestry, agroecology, agropastoralism, alley cropping, food forests, food landscapes, foodsheds, holistic rangeland management, integrated aquaculture, forest gardening, garden farming, edible landscaping, silvopasture, sustainable agriculture, watershed management, wildlife gardening and wild harvesting (Miller & Marston, 2012; Holmgren, 2012; Nabhan, 2013; Udawatta & Jose, 2012). Sustainable land management practices and permaculture strive to limit and reverse the harmful impacts on ecosystems caused by modern civilizations.

Scientific research in sustainable land management is slowly accumulating. Agroforestry houses many of these sustainable land management specialties, with studies ranging from silvopasture, alley cropping, windbreaks, riparian buffers to forest farming (Schoeneberger, Bentrup & Patel-Weynand, 2019; Udawatta & Jose, 2012). Trends indicate an improvement in soil health, and water and air quality from these practices (Jose, 2009; Jose, 2012; Jose & Bardhan, 2012; Kumar & Jose, 2018). The intercropping of perennials adds to the complexity of the layers of roots in agroforestry, accumulating minerals and nutrients and cycling them as an organic mulch on the surface for the benefit of other plants (Jose, 2009; Kumar & Jose, 2018). Additionally, species richness and biodiversity conservation improves, creating a more resilient landscape that can recover quickly from damaging natural forces (Jose, 2012; Jose & Bardhan, 2012; Schoeneberger, Bentrup & Patel-Weynand, 2019).

The use of windbreaks modifies nearby microclimates by limiting the effect of winds drying out crops and creating thermal zones that pocket solar radiation. Studies of windbreaks on the Great Plains show an increase in crop yields ranging from 10-16%, with other studies showing a 56% increase in crop yield (Schoeneberger, Bentrup & Patel-Weynand, 2019; Watts, 2019). In addition to increased crop yield, agroforestry can provide renewable biomass production. Strategic management can sustainably harvest the trees in agroforestry to replace some of the need for fossil fuel production (Udawatta & Jose, 2012;Watts, 2019). To also mitigate fossil fuel production, agroforestry has a high capacity for long term carbon sequestration (Jose, 2009: Udawatta & Jose, 2012). The Intergovernmental Panel on Climate Change ranked land use strategies in relation to potential carbon sequestration, with agroforestry significantly leading (Figure 1.4).

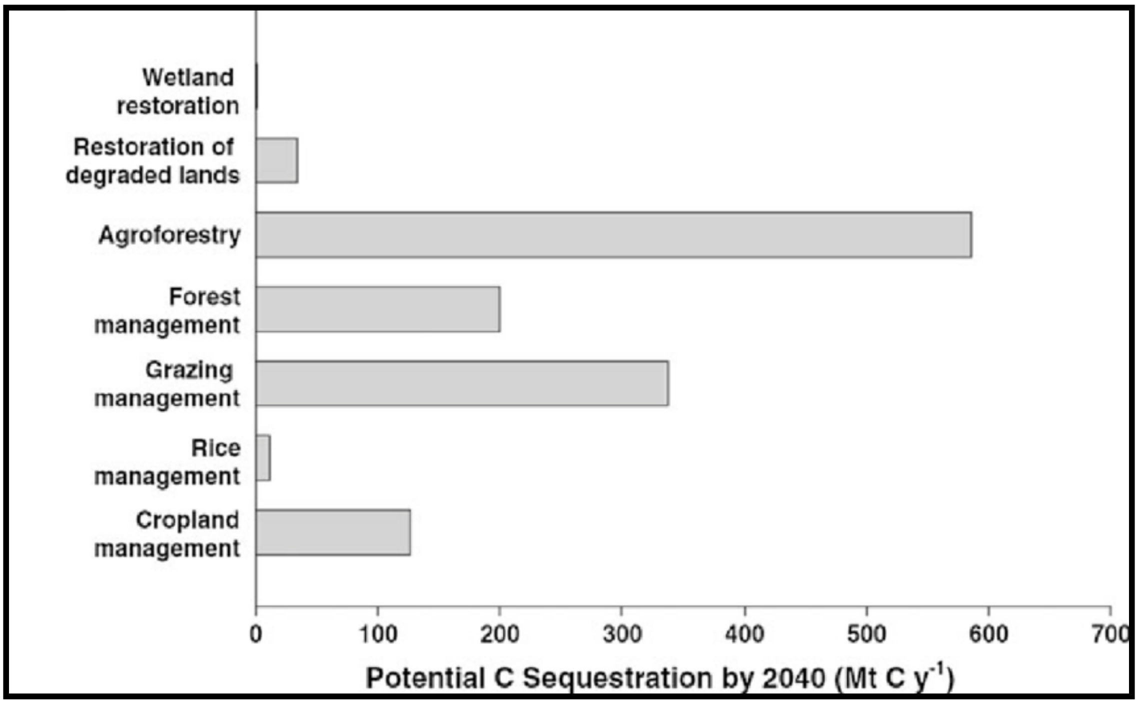

Figure 1.4: Agroforestry has the highest potential in carbon sequestration, as indicated by a report by the Intergovernmental Panel on Climate Change. (adapted by Jose & Bardhan, 2012)

The benefits of agroforestry counter prior land management decisions that have disrupted ecosystems and diverse habitats. Habitats and microclimates are created, adding to the biodiversity of the landscape. Crops and animals are being integrated and rotated, and pollinators are finding refuge in biodiverse areas. Western scientific research is backing traditional ecological knowledge and what ancestral farmers observed in mimicking and enhancing ecosystem functions. Additionally, modern sustainable land management and permaculture align in ethics of caring for the environment, caring for people and renewable distribution of resources.

Social

Permaculture not only focuses on farming, wildlife, and ecosystems, but integrates people with sustainable living concepts like rainwater and greywater harvesting, use of passive solar design, reusing and recycling, and using natural building materials (Holmgren, 2012). These practices build upon with permaculture principles of observing an area and influencing microclimates, but now for the benefit of human habitat. Additionally, permaculture strives to incorporate communities by supporting local economies, advocating for place-based education, and improving health and wellness (Figure 1.5). The principles of permaculture can also be applied in management and business strategies, in order to achieve long-term sustainability.

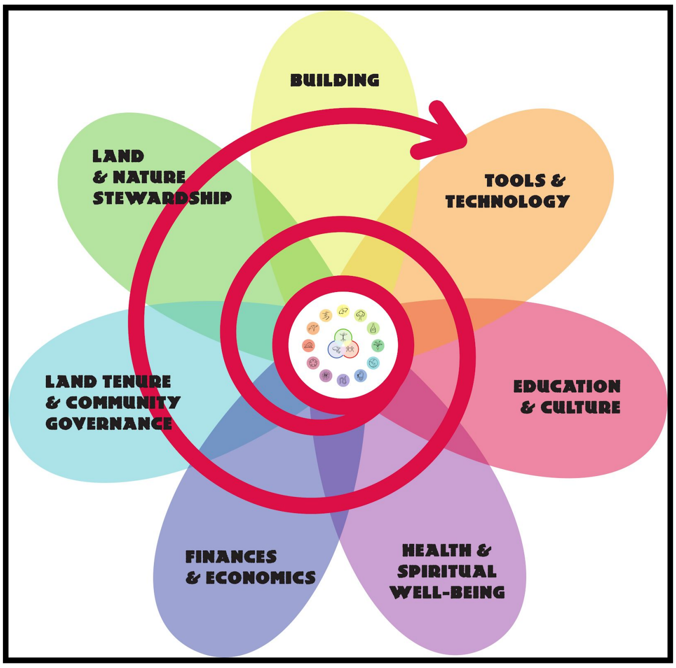

Figure 1.5: Social integration of permaculture principles identified by David Holmgren. (Holmgren, 2012).

The result of permaculture brings in an abundance of food and natural resources. Food security and ecosystems are stabilized. In communities that have been impacted by colonization, warfare and environmental injustices, permaculture promises an oasis. For example, in Africa the use of traditional ecological knowledge and ancestral practices of rainwater harvesting are being used to combat periods of drought and famine (Bruins, Evenari & Nessler, 1986). Additionally, with the incorporation of agroforestry, these farming practices add to the resiliency of the ecosystem and reforestation efforts (Castro, 1991).

Farmers are restructuring their practices and adapting sustainable land management practices to revitalize the fertility of their soils by incorporating diverse species of plants and animals. There are countless people throughout the world who are practicing small scale permaculture designs, including those who have been maintaining ancestral land practices, and those who have combined the practices of both (Box 1.2).

Box 1.2: Indigenous Food Forest

During the summer of 2018, I had the privilege of participating in the Indigenous Sustainable Communities Design Course. This course features Indigenous permaculture and sustainable land management practices, with various field trips to visit ancestral and modern demonstrations. The following is a reflection of a field trip to a successful permaculture site that was cultivated on Indigenous lands (Figure 1.6).

The Flowering Tree Permaculture Institute is an 1/8th of an acre food forest oasis which defies the dry and neglected landscape of northern New Mexico This 30-year-old mini forest immediately protected us from the harsh sun on that hot summer day. Outside of the food forest, the red sandstone dirt was compacted and crawling with red ants. The Indigenous owner gave us a tour of the forest, pointing out a partially buried boulder that was the start of the permaculture design. It was placed there to slow down water flow and to provide a nurse habitat for initial seedlings. The topsoil was dense with nutrients and organic matter, which was built up 6 inches in height from her neighbor's property. Not only did the food forest seedlings have to survive intense sunlight, they had to ensure harsh wind cycles and freezing temperatures.

As the succession of the food forest proceeded, the canopy of the trees provided shade from the sun and protection from frost (Hemenway, 2009). Within 8 years into the permaculture project, over 500 species were recorded on the small plot of land (Hemenway, 2009). Now, in the 30-year-old forest, we ate grapes from the walls of the hand built adobe home and admired the bamboo forest that was being nursed into cultivation. Bamboo is not native to an arid New Mexico ecosystem but the forest had progressed into a cool, shaded and moist enough environment for the bamboo to thrive in. Permaculture is a critical tool to counter climate change and restore ecosystems.

Figure 1.6: The dense food forest, located to the left of the driveway, is a diverse oasis that has cultivated multiple microclimates in the dry landscape. Photo courtesy of G. Kie, 2018.

Permaculture in the Southwest

In addition to the Flowering Tree Permaculture Institute, there is a web of researchers, land managers and community members who are cultivating various forms of permaculture and sustainable land management in the Southwest. The edible food landscape has been rediscovered and Indigenous knowledge is being incorporated to simulate the utilities and functions of a dry climate. Indigenous techniques that are adapted to the dry landscape and native plant species are valued for establishing food forests in the Southwest.

There are permaculture institutes sprinkled across the region, offering educational spaces to share practices and build local sustainable communities, such as the Hopi Tutskwa Permaculture Institute, Central Rocky Mountain Permaculture Institute and Mission Garden.

Certificates in permaculture design are offered to provide an experience of regional food forests, with the 72-hour courses loaded with effective hands-on permaculture strategies. Additionally, there are networks focused on bioregional food systems and sustainable land management strategies such as the Southwest Agroforestry Action Network, Linking Edible Arizona Forests, Native Seeds/SEARCH and the Traditional Native American Farming Association (Allen, 2019). These associations advocate for edible landscapes and the preservation of heirloom species that have adapted to the dry climate.

Conclusion

With the careful cultivation of ecological observation and knowledge, permaculture design is an effective approach to sustainable homes, communities and ecosystems. Simple ancestral farming practices are valued for being functional, efficient and climate adapted. By tapping into the natural cycle of the ecosystem, the health and productivity of the landscape improves. In the Southwest, land managers have the opportunity to utilize permaculture techniques and designs to maximize a watershed and increase biodiversity in conservation and restoration areas while strengthening the landscapes resiliency to the impacts of climate change.

Chapter 2: Indigenous Permaculture in the Southwest

Literature Overview

The resources used in this chapter range from books and peer-reviewed articles to personal communications. The research locations ranged throughout the Southwest and into Central America (Figure 2.1). The disciplines of the published sources come from archaeology, agroecology, biogeochemistry, geology, anthropology, landscape architecture, ethnobotany, natural resource management, hydrology, conservation, sustainable land management and human ecology. Out of these sources, only the Zuni tribe has collaborated with researchers on Indigenous farming practices with publications from 1998-2011. The majority of the sources were obtained from archaeological evidence and research into restoration practices. Additionally, few Indigenous authors are identified on the published sources list (Table 2.1). The primary research that is published on Southwest Indigenous permaculture and dry farming techniques has been largely non-native up to now.

Indigenous permaculture perspective through personal communication is obtained from Permaculture Design Courses. The information shared in this chapter comes from Indigenous-led guest presentations and class lectures. I attended the Indigenous Permaculture Design Course, offered by the Native American Traditional Farming Association, in the summer of 2019. The organizers of the course identify from the Mohawk Nation and Tesuque Pueblo, with a variety of local Indigenous guest speakers from Navajo, Santa Clara, Taos, and Hopi. Additionally Indigenous guest speakers for the Fall 2019 NAU Sustainable Communities Permaculture Design Course provided insight on Indigenous permaculture techniques.

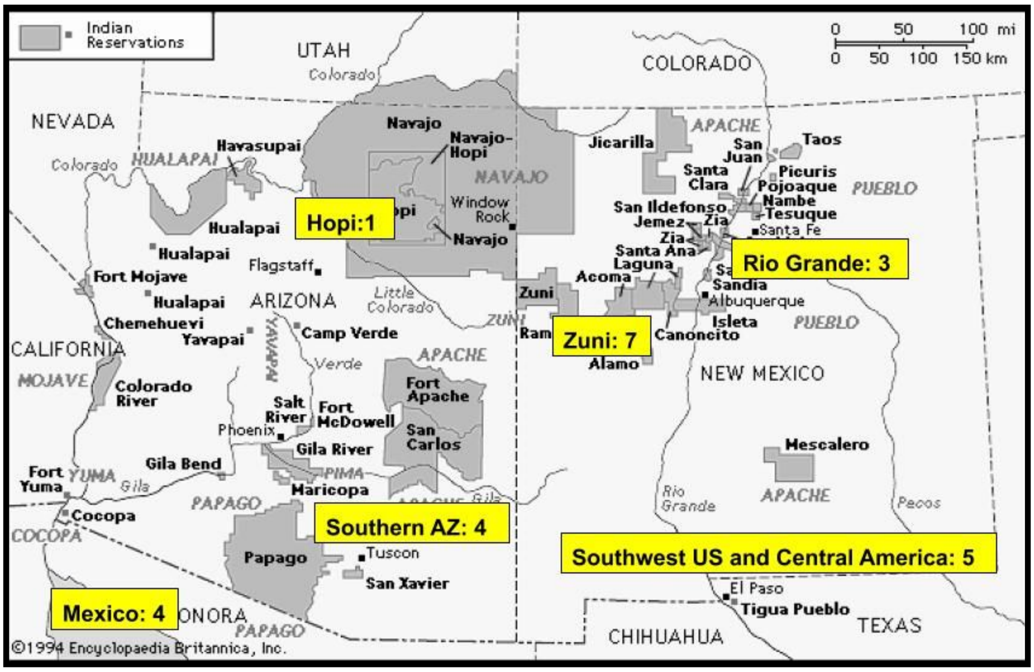

Figure 2.1: Locations of publications about Indigenous permaculture design or affiliated research. Original map retrieved from: https://www2.palomar.edu/users/scrouthamel/ais100/traditional_cultures.htm

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Table 2.1: A list of sources used in this chapter researching Indigenous permaculture strategies. Out of 24 published sources on the list, three sources have Indigenous authors, highlighted in blue.

	Source	Discipline	Research Location
1)	Hack, J. T. (1942). *The changing physical environment of the Hopi Indians of Arizona: Reports of the Awatovi expedition*. Cambridge, Massachusetts: Peabody Museum of American Archaeology and Ethnology.	Archaeology	Hopi, Arizona
2)	Homburg, J.A. & Sandor, J.A. (2011). Anthropogenic effects on soil quality of ancient agricultural systems of the American Southwest. *Catena, 85*, 144-154. doi:10.1016/j.catena.2010.08.005	Agroecology and biogeochemistry	Zuni, New Mexico

3)	Lightfoot, D. (1993). The cultural ecology of Puebloan pebble-mulch gardens. *Human Ecology*, *21(2).* 115-143.	Geology and anthropology	New Mexico
4)	Lightfoot, D., & Eddy, R. (1994). The agricultural utility of lithic-mulch gardens: Past and present. *GeoJournal, 34*(4), 425-437.	Geology and anthropology	New Mexico
5)	Lightfoot, D., & Eddy, R. (1995). The construction and configuration of Anasazi pebble-mulch gardens in the northern Rio Grande. *American Antiquity, 60*(3), 459-470.	Geology and anthropology	New Mexico
6)	Moreno-Calles, A., Casas, A., Rivero-Romero, A., Romero-Bautista, Y., Rangel-Landa, S., Fisher-Ortiz, R., … Santos-Fita, D. (2016). Ethnoagroforestry: Integration of biocultural diversity for food sovereignty in Mexico. *Journal of Ethnobiology and Ethnomedicine, 12*(1).	Human ecology	Mexico
7)	Morrow, B. H. & Price, V. B. (1997). *Anasazi architecture and American design.* Albuquerque, NM: University of New Mexico Press.	Landscape architecture	Ancestral pueblo villages, Southwest U.S.
8)	Nabhan, G. P. (1977). Living fencerows of the Rio San Miguel, Sonora, Mexico: Traditional technology for floodplain management. *Human Ecology, 5(2)*, 97-11. Nabhan, G. P. (2013). *Growing food in a hotter, drier land: Lessons from desert farmers on adapting to climate uncertainty*. White River Junction, Vermont: Chelsea Green Publishing.	Ethnobotany and natural resource management	Mexico
9)	Nichols, M. H. & Polyakov, V.O. (2019). The impacts of porous rock check dams on a semiarid alluvial fan. *Science of the Total Environment*, *664*, 576-582.	Hydrology	Southern Arizona
10)	Nichols, M. H., Polyakov, V.O., Nearing, M.A. & Hernandez, M. (2016). Semiarid watershed response to low-tech porous rock check dams. *Soil Science*. doi: 10.1097/SS.0000000000000160	Hydrology	Southern Arizona
11)	Norton, J.B., Bowannie Jr., F, Peynetsa, P., Quandelacey, W. & Siebert, S.F. (2002).	Agroecology and conservation	Zuni, New Mexico

	Native American methods for conservation and restoration of semiarid ephemeral streams. *Journal of Soil and Water Conservation*, 57(5), 250-258. ● Contributions from Zuni Sustainable Agricultural Project		
12)	Norton, J.B., Pawluk, R. R., & Sandor, J. A. (1998). Observation and experience linking science and indigenous knowledge at Zuni, New Mexico. *Journal of Arid Environments, 39,* 331-340.	Agroecology and soils	Zuni, New Mexico
13)	Norton, J. B., Sandor, J. A., & White, C. S. (2003). Hillslope soils and organic matter dynamics within a Native American agroecosystems on the Colorado Plateau. *Soil Science Society of American, 67,* 225-234.	Agroecology and biogeochemistry	Zuni, New Mexico
14)	Norton, J. B., Sandor, J. A., White, C. S., & Laahty, V. (2007). Organic Matter Transformations through Arroyos and Alluvial Fan Soils within a Native American Agroecosystem. Soil Science Society of America Journal, 71(3), 829–835. doi: 10.2136/sssaj2006.0020	Agroecology and biogeochemistry	Zuni, New Mexico
15)	Polyakov, V. O., Nichols, M.H., McClaran, M.P., & Nearing, M.A. (2014). Effect of check dams on runoff, sediment yield, and retention on small semiarid watersheds. *Journal of Soil and Water Conservation, 69(5),* 414-421. doi:10.2489/jswc.69.5.414	Hydrology	Southern Arizona
16)	Price, V. B., & Morrow, B. H. (2006). *Canyon gardens: The ancient Pueblo landscapes of the American Southwest.* Albuquerque, NM: University of New Mexico Press. ● Contributions from Santa Clara Pueblo author	Ethnobotany and sustainable land management	Pueblo Villages, Southwest U.S.
17)	Rodriguez, V.P. & Anderson, K.C. (2013). Terracing in the Mixteca Alta, Mexico: Cycles of resilience of an ancient land-use strategy. *Human Ecology, 41*, 335-349. DOI: 10.1007/s10745-013-9578-8	Human ecology	Mexico

18)	Salmón, E. (2012). *Eating the landscape*. Tucson, Arizona. University of Arizona. ● Rarámuri author	Ethnobotany	Southwest U.S. and northern Mexico
19)	Sandor, J.A. & Homburg, J.A. (2017). Anthropogenic soil change in ancient and traditional agricultural fields in arid to semiarid regions of the Americas. *Catena, 85,* 144-154.	Agroecology and biogeochemistry	Southwest U.S., Central and South America
20)	Sandor, J. A., Norton, J. B., Homburg, J. A., Muenchrath, D. A., White, C. S., Williams, S. E., … Stahl, P. D. (2007). Biogeochemical studies of a Native American runoff agroecosystem. *Geoarchaeology,* 22(3), 359–386. doi: 10.1002/gea.20157	Agroecology and biogeochemistry	Zuni, New Mexico
21)	Sandor, J. A., J .B. Norton, R. R. Pawluk, J. A. Homburg, D. A. Muenchrath, C. S. White, S. E. Williams, C. L. Havener, and P. D. Stahl. (2002). Soil knowledge embodied in a Native American Runoff Agroecosystem. *Transactions of the 17th World Congress of Soil Science*, Bangkok, Thailand.	Agroecology and soils	Zuni, New Mexico
22)	Webb, R.H. & Leake, S. A. (2005). Ground-water surface-water interactions and long-term change in riverine riparian vegetation in the southwestern United States. *Journal of Hydrology, 320,* 302-323. doi:10.1016/j.jhydrol.2005.07.022	Hydrology	Riparian areas in southern Arizona
23)	Wei W., Chen D., Wang, L., Daryanto, S., Chen, L., Yu, Y., … Feng, T. (2016). Global synthesis of the classifications, distributions, benefits and issues of terracing. *Earth-Science Reviews, 159*, 388-403.	Human ecology	Global
24)	Wilken, G. (1987). *Good Farmers*. Berkeley, California. University of California Press.	Agricultural and natural resource management	Mexico and Central America

Indigenous permaculture in the Southwest

Indigenous people of the Southwest have coexisted, adapted and cultivated the natural landscape for food security. The entire landscape was assessed and used as an edible landscape. Any area that promised to host and nurse Indigenous wild foods and crops was nurtured with slight alterations to capture additional nutrients and water. These microclimates rely on seasonal precipitation from monsoon rains and winter storms, ranging from 5-20 inches per year depending on elevation (Arizona State Climate Office, 2019; DuBois, 2019). In addition to the challenges of growing food in a dry landscape that receives low annual precipitation, there is intense sun exposure with an average of 300 sunny days per year in the Southwest and cycles of wind storms that can dry out edible plants (Arizona State Climate Office, 2019; DuBois, 2019). To counter these climatic challenges, Ancestral Indigenous people of the Southwest have implemented dry farming techniques adapted with traditional ecological knowledge.

The range of dry farming practices in the Southwest is broad and many tribes have connections to ancestral practices that range from the Colorado Plateau to the Sonoran Desert in Mexico (Figure 2.2). These tribes have ancestral roots to dry farming and have been cultivating the landscape for over 3,000 years (Norton, Sandor, White & Laahty, 2007). More currently, tribes such as Zuni, Hopi, Taos, Tesuque Pueblos and others have continued to practice and revitalize their dry farming practices. Additionally, there are tribes farther south who are connected to dry farming practices such as the Tohono O'odham and the Rarámuri people in Mexico. This vast region of evidence of current and ancestral Indigenous farming techniques can be connected through ancestral trading routes, and in addition to exchanging goods, there was a trading of knowledge and farming practices (C. Brascoupe, personal communication, July 2018).

Figure 2.2: General area of study in Indigenous permaculture techniques.

Image retrieved from: https://www.tes.com/lessons/tUylgDIl28EzKA/1-2-desert-southwest

Indigenous farming practices can be viewed through the lens of permaculture, as there is a primary focus on integrating "community, culture and land management for sustainable use and benefit for the ecosystem and the people" (Salmón, 2012, p. 101). These practices of permaculture and living in relationship of the land is how Indigenous people have sustained their livelihoods and cultures for many generations. There is a constant balance of reciprocity for Indigenous people to live successfully on a dry landscape. Reciprocity identifies a harmonious relationship between people and nature, and promotes stewardship and responsibility for Indigenous peoples to care for the landscape so that it will care for their communities.

In the Southwest, dry farming and Indigenous permaculture practices center on harvesting water and watershed management. Since Indigenous communities are dependent on the runoff of seasonal precipitation, it is critical to capture this periodic flow of water on the landscape. Therefore, as an Indigenous farmer from Hopi Tutskwa Permaculture Institute commented, one must "plant the water first" (J. Marcus, personal communication, October 17, 2019). In order to do this, Indigenous people utilize minimal permaculture structures of water weirs, terrace gardens, waffle gardens, and rock mulch to disperse the flow of water and retain soil moisture within the watersheds (Homburg & Sandor, 2011; Price & Morrow, 2006; Salmón, 2012). Location is essential in water harvesting, by observing and using traditional ecological knowledge, the Indigenous farmer needs to identify areas on the landscape that are frequently saturated by seasonal precipitation. This runoff agriculture not only retains water on the landscape but it is multifunctional in minimizing erosion and dispersing sediment throughout the watershed.

Location

Observation of the land and how it receives precipitation allows for the utility of permaculture techniques to maximize water availability. Methods have been identified as manipulation of water catchment and managing slope in order to capture rainfall during the monsoons seasons (Wilken, 1987). Location is critical for these methods and tools which slow down storm water that may be rushing on the landscape and to have that water fully saturate strategic planting areas. The slopes and angles of location are key when considering water catchment concentration of precipitation which help channel ephemeral tributaries and runoff onto floodplains. Indigenous peoples have observed and placed their gardens in arroyos and washes and next to angled canyon walls that promise a concentration of water during precipitation periods (Morrow & Price, 1997; Price & Morrow 2006; Salmón, 2012). Additionally, an expedition by Harvard University in the 1940's and other studies have noted that the water table is closer to the surface of an arroyo and that Indigenous farmers strategically placed their fields in arroyos in order for their plants to have closer access to that source of water (Figure 2.3; Hack, 1942; Webb & Leake 2005).

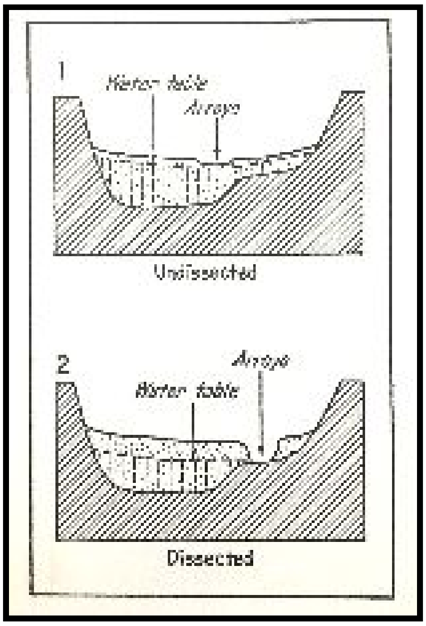

Figure 2.3a: Depiction of water table in relation to arroyo by Hopi, Arizona. (Hack, 1942).

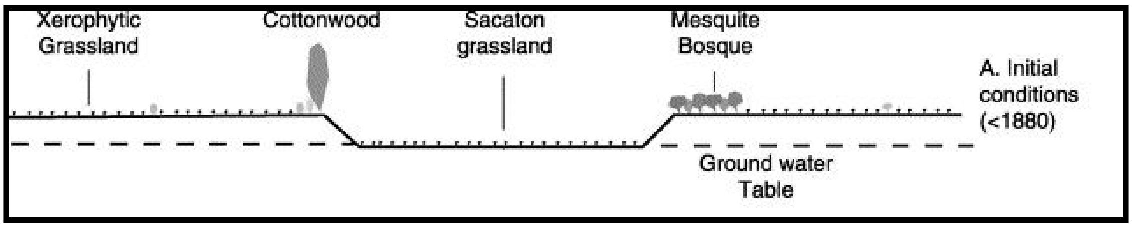

Figure 2.3b: Historical depiction of water table level in an arroyo, prior to 1880. (Webb & Leake, 2005).

Other natural angles of location include beneath cliffs along the edges of valleys and mesas where springs seep out, and naturally forming terraces such as benches of streams, arroyos and valley floors (Hack, 1942; Price & Morrow, 2006; Salmón, 2012). These observed locations of water disbursement create microclimates which provide extra nutrients and protection to gardens and native plant guilds. There is evidence left behind in Ancestral Indigenous sites of manipulating a landscape in order to direct the water flow and precipitation to specific agricultural locations (Hack, 1942; Price & Morrow, 2006; Salmón, 2012).

An Ancestral Indigenous example is of the Tsankawi site, which is located on a mesa in northern New Mexico between the Rio Grande and Bandelier National Monument. This Ancestral Pueblo site is recognized by the Tewa people as homelands and still provides demonstrations of watershed manipulation around the mesa (L. Hena, personal communication, July 2018). These channels are carved into the sandstone, collects precipitation along the top of the mesa and its edges, and transports the water flow to permeate the alluvial soils below the mesa (Figure 2.4). Rocks could be temporarily and strategically placed in the channels to block the direct waterflow and encourage bank overflow to saturate a nearby garden or field (L. Hena, personal communication, July 2018). Once the field has been irrigated, the rocks in the channel would be removed to allow for the flow of water to continue downstream to other strategically placed agricultural areas.

Figure 2.4: Carved sandstone channels along the mesa of the Tsankawi historical site, which collects precipitation and directs it to fields located below.

Image retrieved from: https://www.nps.gov/band/planyourvisit/tsankawi.htm

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Soil

The quality of soil is also a significant value of location for Indigenous farming practices. Indigenous farmers are interested in loamy sandy soils that act as a sponge and allow for subsurface soils to maintain moisture (Sandor et al., 2007). These loamy sands can be found in alluvial fans, which are consistently saturated by seasonal precipitation and receive periodic waterflow from washes, canyons or channels from mesa tops. Not only do alluvial fans provide soft soils for planting but they are in the direct route of monsoon and winter storms and sediment deposits from upslope locations (Sandor et al., 2007).

Additionally, sandy deposits and sand dunes are used as dry farming locations. Some of these sand dunes can be found on top of mesas, or may be windblown against a sloped location (Hack, 1942). Precipitation is absorbed in the sand dunes and the top layer of loose sand acts as a mulch and limits evaporation (Hack, 1942; Price & Morrow, 2006). This choice of location is evident in Figure 2.5, where Hopi farmers have strategically placed their peach trees in sandy soil deposits found below a mesa top. During monsoons, the slopes above the peach trees will direct runoff and soak into the sandy deposits, saturating the roots of the fruit trees.

Figure 2.5: This photo was taken by Josef Muench in 1944 near a Hopi mesa. The peach trees are planted in sand, circled in yellow. Image: Cline Library, Special Collections.

In addition to an increase of water and the quality of soil in these locations, there is a "traveling compost slurry" of nutrients that flows with the water downstream and is deposited along the banks and in the washes (Nabhan, 2013; Norton, Pawluk., & Sandor, 1998; Salmón, 2012). This slurry consists of plant litter, duff and topsoil from higher elevation forest types, such as Pinyon-Juniper, is referred to as "tree sand" by the Zuni people (Sandor et al., 2007; Price & Morrow, 2006). This silt and sediment is filtered into strategically placed gardens.

Studies from Zuni farms in the early 2000's showed an increase of organic matter, nitrogen and phosphorus in runoff farming and in areas of agricultural practices (Price &

Morrow, 2006; Sandor et al., 2007; Norton, Sandor, White, Laahty, 2007). This natural fertilizer is critical in sustaining the Indigenous landscape diet in the dry Southwest. Additionally, there is an increase of mycorrhizae activity in the runoff sediments, which increases plant productivity with water and nutrient intake (Sandor et al., 2007). With periodic deposits of upslope sediment, this continual renewal of organic matter also builds the height of the soil (Norton, Sandor, and White, 2003; Sandor et al., 2007). The precipitation-based cycle of sediment deposit aids in soil renewal for agricultural areas and is very important to long-term sustained agricultural productivity, as well as watershed conservation (Sandor et al., 2007).

Water weirs

In the Southwest, water weirs or small dams are placed in ephemeral streams to slow down the flow of water and disperse it across the landscape. Indigenous water weirs vary in construction, with materials using either brush or rocks as a dam structure. They are typically staggered, with multiple water weirs strategically placed along a wash or arroyo (Wilken, 1987). Fields are placed below and alongside the water weirs, which benefit from the additional runoff from precipitation and the silt deposits traveling with it. Farmers strategically planned with water weirs by placing these low-impact dams a year before planting their fields near it, in order to collect nutrients and sediment deposits that accumulate behind the water weir (Polyakov, Nichols, McClaran & Nearing, 2014; Sandor et. al, 2002).

Brush water weirs

Brush water weirs take on various forms in the arroyos or washes as unstructured brush piles to more deliberate structures using brush. In a study done with Zuni farmers, they prune the lower branches of local Juniper and Pinyon, and harvest sagebrush and rabbitbrush to utilize for their brush materials (Norton, Bowannie, Peynetsa, Quandelacey & Siebert, 2002). Brush piles focus on the accumulation of brush in arroyos or washes laying parallel with the bank, with the goal to place "as much debris as possible into the channel with a minimum of additional strengthening" (Norton, Bowannie, Peynetsa, Quandelacey & Siebert, 2002, p. 252). In contrast, brush check dams concentrate on laying brush perpendicular across the arroyo with additional brush woven in to reinforce it.

Other brush weir structures demonstrated by Zuni farmers are more developed by partially burying branches in vertical rows upstream from a brush structure. The rows of the posts help reduce the velocity of water flowing downstream and "comb" or filter out large debris. Lastly, brush can be woven through the posts to reinforce and stabilize the water weir (Figure 2.6) (Norton, Bowannie, Peynetsa, Quandelacey & Siebert, 2002).

Studies of Zuni brush water weirs found that the structures trapped silt traveling with the water flow, with sediment deposition extending 100 meters upstream from the weir and an increase of water saturation in the watershed (Norton, Bowannie, Peynetsa, Quandelacey & Siebert, 2002). These conditions created nutrient dense microclimates which led to more herbaceous cover along the banks of ephemeral streams, which stabilized the banks and contributed to erosion control (Norton, Bowannie, Peynetsa, Quandelacey & Siebert, 2002; Sandor et. al, 2007). These brush water weirs are significant structures on the watershed by distributing and harvesting water and nutrients in deliberate locations.

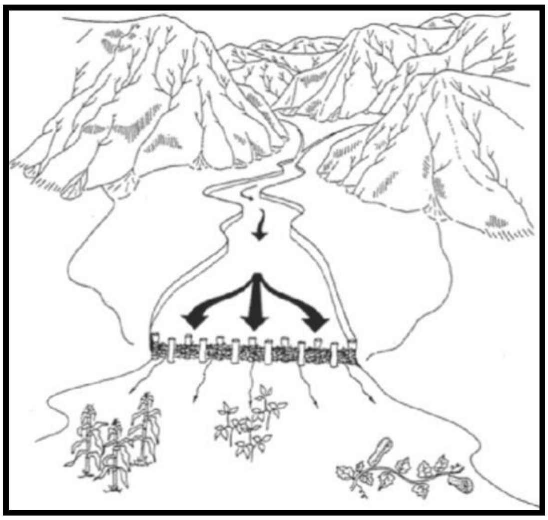

Figure 2.6a: Developed brush water weir is strategically placed above a field to slow down the flow of water and filter out large debris. (Sandor et. al, 2007).

Figure 2.6b: Brush weir example by Zuni farmers. (Norton, Bowannie, Peynetsa, Quandelacey & Siebert, 2002).

Rock water weirs

Another permaculture technique in the Southwest is the use of rock water weirs. The rock water weirs are hand built within the wash to create a small dam to slow down the flow of water downstream. The height of the dam allows for water to spill over after filling up the small reservoir and may flow downstream into other rock structures. These rock water weirs vary in complexity and labor requirements with single rock dams and rock check dams. Single rock dams are modest and utilize large rocks a row in a small drainage, whereas rock check dams are larger structures with multiple layers of loose rocks (Figure 2.7).

This technology is currently being used in watershed restoration efforts in order to control erosion and reduce incising of gullies, arroyos and washes (Nichols & Polyakov, 2019; Nichols, Polyakov, Nearing & Hernandez, 2016; Polyakov, Nichols, McClaran & Nearing, 2014). Studies using rock check dams for watershed restoration in southern Arizona had similar results as the brush water weirs in Zuni, with an increase of water saturation from monsoon runoffs and an increase of organic materials from sediment accumulation behind the check dams (Polyakov, Nichols, McClaran & Nearing, 2014; Sandor et. al, 2007). Additionally, studies of brush and rock water weirs in watershed restoration show a decrease in channel slope with the added soil from the silt deposits, a decrease in peak discharge with the energy of high flood waters slowing down and an increase of bank overflow and water saturation in the surrounding soils (Nichols & Polyakov, 2019; Nichols, Polyakov, Nearing & Hernandez, 2016; Norton, Bowannie, Peynetsa, Quandelacey & Siebert, 2002; Polyakov, Nichols, McClaran & Nearing, 2014).

Overall, the loose structures of the water weirs allow for seasonal water to continue flowing through the watershed, yet the water weirs impede the energy flow and the water slows down to permeate into the ground and deposit silt. With slight manipulation to a dry watershed, Indigenous dry farmers create microclimates to expand their edible landscape. The fertile deposits harvested from rock water weirs offer a natural agricultural site for Indigenous farmers.

Figure 2.7a: Single rock dam, image taken in 1972 near Hopi mesas. (Sandor et. al, 2007).

Figure 2.7b: Ancestral Pueblo rock check dam located in southern Colorado. Retrieved from: https://www.crowcanyon.org/EducationProducts/WOODS/karen.asp

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Terrace gardens

Terrace gardens take advantage of slopes and are flat garden beds that are dug slightly along the contour of a hillside. The walls of the terrace gardens can be reinforced with soil, rock, or perennial plants such as agave (Rodriguez & Anderson, 2013; Sandor & Homburg, 2017; Wilken, 1987). Check dams can be extended by terraces, with the strategically placed gardens taking advantage of the proximity of water overflow and sediment deposition (Nabhan, 2013;Sandor & Homburg, 2017). Terrace gardens maximize water saturation on a hillside by creating "many micro-watersheds" that not only reduce erosion but improves soil quality and plant productivity (Wei, et. al, 2016, p.392). Additionally, these microclimates create ideal environments to nurse seedling plants, and assist growing plants in providing soft, moist and fertile soils in an otherwise dry climate (Wei, et. al, 2016). Similar to the studies of water weirs, increase levels of nitrogen and other nutrients are retained in the soils of terrace gardens (Wilken, 1987).

Terrace gardens can cover entire landscapes and are long lasting. There are ancestral terrace gardens, also known as *trincheras*, located in the Sonoran and Chihihua deserts in Mexico that are over 500 years old (Figure 2.8a) (Nabhan, 2013; Rodriguez & Anderson, 2013; Wilken, 1987). Terrace gardens take advantage of any slope in a dry region and can be expansive in their size. A Hopi permaculturist shared that the Hopi mesas have been known to have a 50-mile radius of terrace gardens (Figure 2.8b) (L. Hill, personal communication, September 2019). The large spatial scale of these terrace gardens underscores the point that Indigenous people have a landscape-wide diet and observed with traditional ecological knowledge in order to enhance ecological functions for food security (Wei, et. al, 2016).

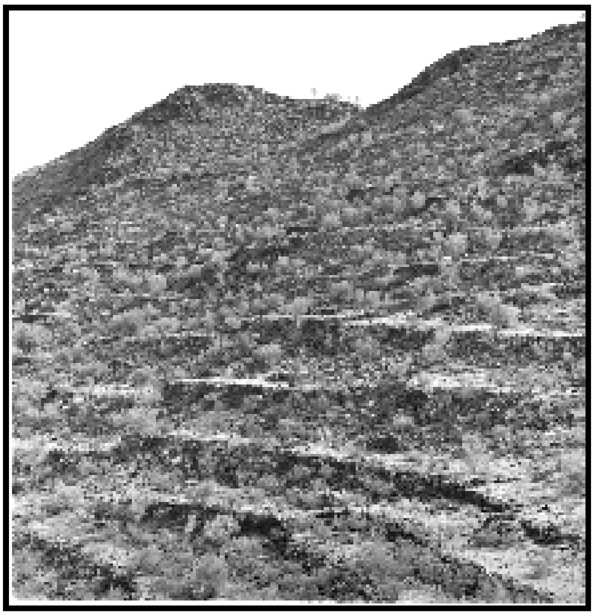

Figure 2.8a: Ancestral terrace gardens located in Sonora, Mexico. Image: U.C. San Diego, Harry Crosby collection.

Figure 2.8b: Wide terrace gardens with earthen walls, on a gentle slope. Image was taken in 1944 by Milton Snow near Hopi mesas. Cline Library, Special Collections.

Waffle gardens

Waffle gardens are compact grids with earth ridges that limit the loss of water flowing on the landscape (Figure 2.9). The waffle garden is dug and shaped into the soil, with the walls ranging in height from a few inches to as high as 15 inches (Price & Morrow, 2006; Salmón, 2012). Each segment or "hood" of the waffle garden creates individual microclimates for plants to establish (Nabhan, 2013). The developed walls of the waffle garden offer multiple functions such as providing partial shade from the sun, a wind barrier and water saturation in the soils (Salmón, 2012). These gardens benefit from seasonal precipitation, the walls are able to hold in precipitation and deliberately saturate the plants and its roots. Additionally, the structure of the waffle garden allows for easy accessibility for farmers to tend and care for the plants (Nabhan, 2013).

Figure 2.9a: Waffle gardens at Zuni Pueblo, photo taken 1911 by Jesse Nusbaum. Museum of New Mexico.

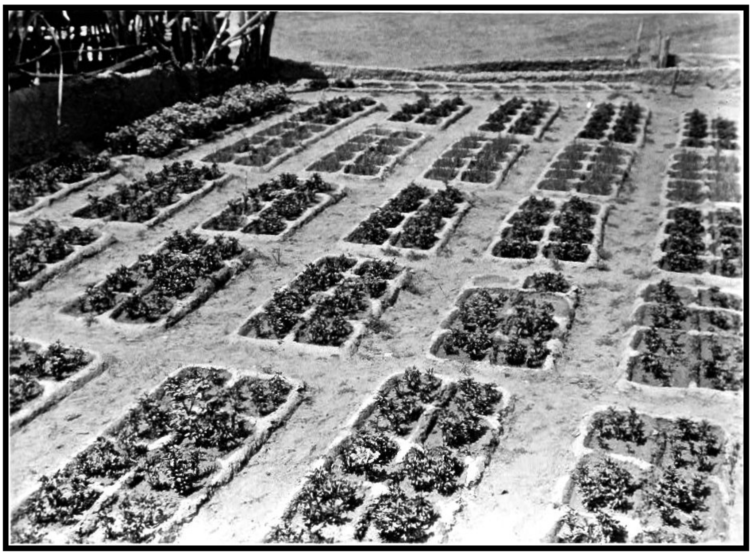

Figure 2.9b: Zuni waffle gardens in 1927, photographed by Edward Curtis. Library of Congress.

Rock mulch

Another Indigenous permaculture technique is the use of rock mulch. Traditional ecological knowledge has observed the collection of rain runoff in the sandy soils under the river pebbles and gravel, and Indigenous farmers mimic this water harvesting method with using rock mulch in their gardens (Salmón, 2012). Locally sourced stones, cobbles, or pebbles are collected and line garden grids. There are several ways that the rock mulch is utilized. Loose rocks can be placed as the border of gardens and can cover large areas (Figure 2.10). Rock mulch is also used as a pile that surrounds the base of plants, which adds protection from the wind and sun and minimizes evaporation (Nabhan, 2013). Additionally, the soil temperature is extended into the night when the rocks radiate passive solar heat (Lightfoot & Eddy, 1994; Lightfoot & Eddy, 1995; Salmón, 2012).

Another use of rock mulch are found in ancestral pebble gardens in northern New Mexico, along the Rio Grande. These are xeriscaped areas of harvested pebbles that are deliberately layered onto the majority of the surface of the gardens (Lightfoot & Eddy, 1995; Price & Morrow, 2006). This not only controls weeds, but studies have shown that the rough surface of the pebbles reduces the wind velocity and stabilizes the soil, reducing erosion from wind and runoff (Lightfoot & Eddy, 1995; Sandor & Homburg, 2017). The benefits of rock mulch include an increase of water infiltration and retention in the soil, and an increase of organic nutrients such as nitrogen and phosphorus which resulted in an increase of biomass and crop yield (Lightfoot & Eddy, 1994; Lightfoot & Eddy, 1995; Price & Morrow, 2006; Salmón, 2012; Sandor & Homburg, 2017).

Traditional ecological knowledge of rock mulch is still being utilized in dry farming communities in the Southwest. The benefits of partial shade, thermal mass, wind protection, and concentration of water that the rock mulch provides is used to nurse establishing plants for restoration efforts, which also enhances the biodiversity (L. Hena, personal communication, July 2018). Additionally, boulders and rocks were used in the first steps of building an Indigenous food forest at the Flowering Tree Permaculture Institute in New Mexico (Hemenway, 2009; R. Swentzell, personal communication, July 2018). The rock mulch helps stabilize the soils from rain runoff on a hillside, collected organic matter and established microclimates.

Figure 2.10: Rock lined ancestral gardens in southeastern Arizona. (Brevik, Homburg, Miller, Fenton, Doolittle & Indorante, 2016).

Living Fences

Living fences are used in floodplain management and as windbreaks to protect plants from drying out. The fences can vary with a single row of vegetation such as cottonwoods, willows or brush that is deliberately planted in rows on the edges of gardens (Figure 2.11), or additional branches can also be woven in between, strengthening the structure of the fence (L. Hill, personal communication, September, 2019; Nabhan, 2013). The location of the living fences may be on the perimeter of the field, in rows in the field, or placed on the outside of the field in the direct path of flood or wind patterns. These fences provide multiple benefits of protecting fields from floods, erosion, and animal grazing (Nabhan, 1977; Nabhan, 2013).

Similar to the brush water weirs, living fences slow down the flow of water from seasonal storms and trap silt that is traveling with flood waters (Nabhan, 2013). Sediment is deposited in the fields and adds a new layer of fertile topsoil for the fields and slowly expands the area of arable land (Moreno-Calles, et. al, 2016; Nabhan, 1977; Nabhan, 2013). Additionally, an organic mulch from the leaf litter of the living fences increases the level of nitrogen and other nutrients critical for plant development (Nabhan, 1977; Salmón, 2012).

Microclimates are created by living fences by providing shade and functioning as a windbreak, protecting drying out from the sun and wind (L. Hill, personal communication, September 2019; Salmón, 2012). Additionally, the living fences strengthen biodiversity by providing a habitat for birds, who contribute with natural pest management and eat insects that may be in the fields (Nabhan, 1977; Nabhan, 2013). Living fences also produce a renewable source of biomass. Willows and cottonwoods can be coppiced and periodically harvested, with the stumps of the living fence regenerating (Moreno-Calles, et. al, 2016; Nabhan, 1977; Nabhan, 2013)

Figure 2.11: Hopi farmers in 1949 planting rows of small brush windbreaks. Cline Library, Milton Snow Collection.

Digging Sticks

A critical tool for Indigenous permaculture is the digging stick. The digging stick varies among Indigenous tribes and the locally sourced wood used but it is typically in the form of a small staff with the bottom end of the staff narrowed and sharpened into a spade-like structure, that can easily puncture the soil (Figure 2.12). The simplicity of the digging stick allows for direct penetration into the soil to plant seeds, which is less destructive than mainstream agricultural practices of plowing and tilling the earth. The low impact trait of the digging stick allows for the structure and integrity of the soil and its moisture content to remain intact (Price & Morrow, 2006). Nutrient dense cryptobiotic soils and microfungi continue to thrive, and soil erosion is reduced (Lal, Reicosky & Hanson, 2007; Price & Morrow, 2006; Salmón, 2012).

In the harvesting of wild plant species such as wild onions, digging sticks create a limited amount of disturbance that has proved to "actually encourage plant diversity and further growth of some plants" (Salmón, 2012, p. 160). Sustainable harvesting of abundant and healthy plants allows for more growth space and reducing competition for weaker plants (Salmón, 2012). This reciprocal relationship benefits the humans who harvest the plants but also stimulates the growth and biodiversity of the landscape. The relationship between Indigenous people and the edible landscape maximizes the energy and growing space available in a dry region.

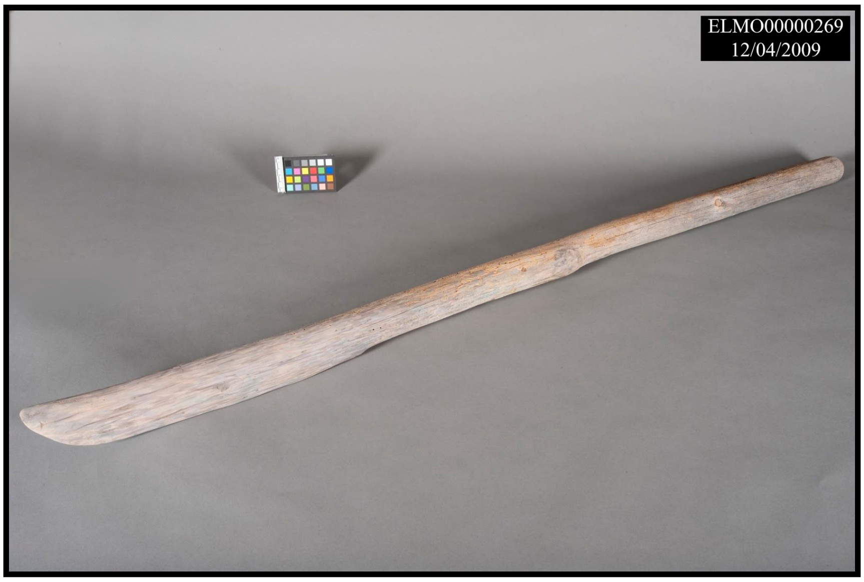

Figure 2.12: Replica of a digging stick, El Morro National Park Service. Retrieved from: http://swvirtualmuseum.nau.edu/photos/picture.php?/4639/category/827

Conclusion

Throughout the Southwest, there is evidence from Ancestral and current Indigenous communities that have cultivated place-based traditional ecological knowledge in order to provide a landscape wide and diverse diet for Indigenous people. Once considered primitive from the colonial perspective, these dry farming practices are simple and adapted to a sensitive dry environment. Traditional ecological knowledge focuses on finding ways to enhance the ecosystem functions of nutrient cycling, water harvesting, integration of wildlife and soil conservation which led to an abundant landscape.

Currently there are traditional Indigenous farmers who have maintained and revitalized traditional permaculture techniques in an effort to promote food sovereignty and food security within their areas. The Hopi Tutskwa Permaculture Institute and the Flowering Tree Permaculture Institute, have combined traditional ecological knowledge from their

Indigenous communities with mainstream permaculture methods to create distinctive lush oases in the dry Southwest. Additionally, the Traditional Native American Farmers Association (TNAFA) networks throughout the United States and the globe in cultivating Indigenous permaculture practices and protecting Indigenous foods. Also, there are local movements that are scattered throughout the Southwest of reclaiming Indigenous permaculture design for community health such as the Red Willow Farm in Taos, New Mexico and the Española Healing Foods Oasis (Figure 2.13).

Figure 2.13a: Red Willow Farm located in Taos Pueblo, New Mexico. The high elevation farm utilizes a biomass furnace to heat a system of tunnels under the greenhouse in order to grow during the cold winters. Photo courtesy of G. Kie, 2018.

Figure 2.13b: Tewa Women United established a terraced community garden in Española, New Mexico. Image retrieved from: [*http://tewawomenunited.org/espanola-healing-foods-oasis/*](http://tewawomenunited.org/espanola-healing-foods-oasis/)

These permaculture centers are educational hubs that cater to knowledge sharing and application with the direct results in cultivation, sustainable harvesting, the use of medicinal plants, Indigenous food preparation, basket weaving, and other cultural practices that relies on the cultivated landscape. Beyond that, these Indigenous knowledge sharers, farmers and permaculturists are cultivating and nourishing cultures, and reconnecting people and communities to the land (C. Brascoupe, personal communication, July 2018; L. Hill, personal communication, September 2019).

These permaculture methods have fed and supported Southwest Indigenous communities before colonization. It is time to reclaim these practices in order to protect an edible landscape from the impending challenges of climate change. Indigenous nations and land managers have the opportunity to return to place-based traditional ecological knowledge and apply permaculture methods that have previously cultivated a landscape in order to revitalize and restore an edible landscape that has been disrupted since 1492.

Conclusion

Ethics: Sustainable land management

Incorporating food security into sustainable land management strategies are guided by the stewardship principles of forestry, agroforestry, and permaculture (Table 3.1). The benefits of responsible land management conserve and strengthen ecosystem functions, while meeting public needs for renewable resources (Society of American Foresters, 2019). In addition, agroforestry and permaculture utilize strategies of intercropping, soil building, windbreaks, water harvesting and the harmonious integration of livestock and wildlife, that conserves resources and supports resiliency in biodiversity and food systems (Wartman, Acker, & Martin, 2018). Not only are these principles ecologically based, but they also center around people. There is a responsibility to strategically manage natural resources for current and future communities and to communicate with integrity.

Table 3. 1: Ethics and principles of the Society of American Foresters, Permaculture and Agroforestry (Society of American Foresters, 2019; Wartman, Acker, & Martin, 2018)

Society of American Foresters	1. Foresters have a responsibility to manage land for both current and future generations. 2. Society must respect forest landowner's rights and correspondingly, landowners have a land stewardship responsibility to society. 3. Sound science is the foundation of the forestry profession. 4. Public policy related to forests must be based on scientific principles and social values. 5. Honest and open communication, coupled with respect for information given in confidence, is essential to good service. 6. Professional and civic behavior must be based on honesty, fairness, good will, and respect for the law.
Permaculture	1. Care of earth 2. Care of people

	3. Redistribution of surplus
Agroforestry *(adopted from agroecological principles presented in Table 2, Wartman, Acker, & Martin, 2018)*	1. Enhance the recycling of biomass, with a view to optimize matter decomposition and nutrient cycling over time. 2. Strengthen the "immune" system of agricultural systems through enhancement of functional biodiversity-natural enemies, antagonists, etc. 3. Provide the most favourable soil conditions for plant growth, particularly by managing organic matter and by enhancing soil biological activity. 4. Minimize losses of energy, water, nutrients and genetic resources by enhancing conservation and regeneration of soil and water resources and agrobiodiversity. 5. Diversify species and genetic resources in the agroecosystem over time and space at the field and landscape level. 6. Enhance beneficial biological interaction and synergies among the components of agrobiodiversity, thereby promoting key ecological processes and services.

There is growing interest from Western scientists in monitoring the effective qualities of Indigenous permaculture and dry farming techniques. Current efforts in watershed restoration, agroecology, conservation and forestry are revisiting ancestral ecological knowledge and methods that work with the dry ecosystems of the Southwest. The utility of Indigenous permaculture practices provide benefits of soil building, water harvesting, distribution of nutrients, and controlling erosion. With the perspective of permaculture, place-based ecological knowledge guides responsible land management to replicate and enhance ecosystem functions and services.

For restoration and climate change efforts, the techniques of Indigenous permaculture to manipulate microclimates can be incorporated in revegetation efforts, climate change adaptation, and assisted plant migration. This includes building conservation and restoration plans around watersheds. By applying ecological knowledge, locations on the watershed can be identified that are frequently saturated from seasonal precipitation and Indigenous permaculture structures can be utilized to create fertile microclimates for restoration treatments.

Ethics: Native nation building

Native nation building strengthens Indigenous nations by enhancing the effectiveness of the tribes or tribal entities in serving the community and its needs, while preserving culture, and providing economic development opportunities (Box 3.2) (Jorgensen, 2007; Native Nations Institute, 2019). Indigenous permaculture and native nation building adds further complexity to decolonizing land management, providing access to culturally appropriate foods, and strengthening sovereignty. Through strategic management, effective leadership and capable government, Indigenous permaculture techniques can provide an abundant edible and cultural landscape. By increasing self-sufficiency and food security on Indigenous lands, this reclaims sovereignty.

Table 3.2: Principles developed by the Harvard Project on American Indian Economic Development and the Native Nations Institute (Jorgensen, 2007; Native Nations Institute, 2019).

Native Nation Building	1. Reclaim sovereignty 2. Create a capable government 3. Culturally appropriate 4. Strategic planning 5. Having effective leadership

Additionally, the United Nations Declaration on the Rights of Indigenous Peoples supports Indigenous sovereignty and the right to cultural practices on traditional lands (Anaya, 2009). This includes the right to access and protection of traditional foods (Frisbie, 2018; Salmón, 2012). Land, culture and food security are all integrated in responsible land management and rely on the utility and protection of Indigenous traditional ecological knowledge.

Decolonize Indigenous natural resource management to include food security and food sovereignty

Indigenous permaculture techniques are tools of traditional ecological knowledge and sustainable land management solutions. These dry farming practices can recreate an edible landscape and revitalize the biodiversity of a deteriorated environment. Indigenous permaculture can address health epidemics that are linked to a divergence from traditional foods and food insecurity. The traditional Indigenous diet in the Southwest is "high in fiber and complex carbohydrates; is low in fat and cholesterol; and offers the full range of minerals, vitamins, and proteins required for human health" (Salmón, 2012, p. 78-79). Yet with the onslaught of colonization, access to traditional foods has become limited and assimilated foods have been incorporated into Indigenous diets.

Much of the landscape has transformed into food deserts, with fast food, restaurants, convenience stores and the sparsely scattered grocery stores providing the primary sources of food (Partnership with Native Americans, 2017). The shortage of healthy and nutritious foods has led to high rates of poor health, overweight and obesity, diabetes, and high blood pressure which are prevalent in Indigenous communities (Adakai, Sandoval-Rosario, Xu, Aseret-Manygoats., Allison, Greenlund & Barbour, 2018). In reclaiming the landscape with Indigenous permaculture techniques, this offers other opportunities in providing culturally appropriate foods and reclaiming health in Indigeous communities.

Indigenous natural resource management can provide government support in designing objectives that incorporates food security and strengthens tribal sovereignty. For example, the Confederated Tribes of the Umatilla Indian Reservation restructured their natural resource department in order to focus on traditional food management (Quaempts, Jones, O'Daniel, Beechie, & Poole, 2018). The tribal programs of water resources, fisheries, wildlife, range and forestry were restructured to protect the tribe's primary cultural foods of water, fish, big game, roots and berries (Quaempts, Jones, O'Daniel, Beechie, & Poole, 2018). Resource management is now prioritized to restore and enhance the ecological systems and functions in order to sustain the traditional food sources.

Additionally, interagency and intergovernmental collaboration is critical in order for tribes to assert their sovereignty and conserve their natural resources for food security. Collaborating creates strategic solutions that are effective and efficient, with shared accountability towards sustainable resource management. In order to address the security of the foodshed of the Confederated Tribes of the Umatilla Indian Reservation, they had to develop collaborative interagency relationships to restore lands located off their reservation boundaries (Quaempts, Jones, O'Daniel, Beechie, & Poole, 2018). Strategic collaboration can strengthen local restoration projects with the added support and investment from stakeholders.

Future research

The focus of this professional paper is on dry farming and rainfall dependent farming techniques. There are other Southwest Indigenous permaculture methods that rely on diversion canals, spring fed fields, hand watered gardening, as well as companion planting, sustainable harvesting and other manipulations of the landscape (Morrow & Price, 1997; Price & Morrow, 2006; Salmón, 2012). Additionally, research in the Southwest on Indigenous permaculture design could be expanded. There are opportunities to utilize waffle gardens, rock mulch and other strategies in revegetation and restoration efforts. Research in climate change adaptation and assisted plant migration with use of Indigenous permaculture techniques could provide transitional corridors that conserves biodiversity that is resilient in the challenges of climate change.

Indigenous *solutions for a sustainable future*

The ecological knowledge and utility of Indigenous permaculture in the Southwest is integral to sustainable land management practices. The disruption of these farming practices has contributed to an environmental imbalance. The once manicured landscape of the Southwest has been overrun by lawless land management for several hundred years and now we are revisiting Indigenous ecological knowledge to provide sustainable solutions. These farming practices are adapted to the climate and landscape, and are the most appropriate methods of incorporating responsible land management to restore degraded ecosystems. Additionally, Indigenous nations (and other governments such as municipal and state) can decolonize their natural resource management strategies to incorporate the conservation of culturally appropriate foods and ensure food security. As we approach the unknown consequences of climate change, we look to "Indigenous solutions for a sustainable future" (Traditional Native American Farming Association, 2018).

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