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Criar y Dejarse Criar: Trans-Situ Crop Conservation and Indigenous Landscape Management through a Network of Global Food Neighborhoods

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Abbreviations and Terms

There are several Quechua and Spanish terms utilized in this document that have no direct translation. Brief descriptions are provided below:

Ayllu—Quechua concept which describes the organization of actors (human, natural, and/or divine) into communities, bound by common, equal, and reciprocal obligations to one another.

Ayni—Quechua concept of reciprocity and balance, which obliges all actors within an *ayllu* to fulfill certain obligations. *Ayni* is the basis for harmony in the world.

Campesino—Spanish word which can most closely be translated to the English "peasant." In Peru, *campesino* typically implies Quechua-speaking smallholder farmers and, additionally, is a legal designation. Registered *comunidades campesinos* [*campesino* communities] are given certain rights, most notably the right to collective land titles, though these rights are lesser than those granted to registered indigenous communities. For a variety of socio-political reasons, nearly all indigenous communities in the Peruvian Andes, including the communities of the *Parque de la Papa*, are registered as *comunidades campesinos*.

Parque de la Papa—Spanish name for the area of study which directly translates to "Potato Park." While the translation of this name is straightforward, I have chosen to use the original Spanish throughout the text given that it is a proper noun (name).

Sumaq Kawsay—Quechua concept of harmonious or correct living, which is achieved when there is *ayni* and balance amongst and between the human, natural, and divine realms. In the past several decades, *Sumaq kawsay* has been mobilized as a political ideology in several South American countries (most notably Ecuador), where harmonious living is advocated as an alternative to the economic indicators of progress and prosperity typically valued in western and international organizations (Thomson, 2011).

Yanantin—Quechua concept of duality, in which any whole is made up of two distinct but equally valued parts. The most obvious example is male/female, which have different but equally important roles that must be realized with harmony and respect in order for society to truly function.

Abbreviations:

Asociación ANDES……………………………………………………………………..ANDES

Crop Wild Relatives…………………………………………………………………....CWRs

Food and Agriculture Organization of the United Nations……………………………………FAO

Geographic Information System………………………………………………………..GIS

International Potato Center……………………………………………………………..CIP

Sustainable Development Goals……………………………………………………...SDGs

Abstract

As climate change progresses, global food security is likely to become increasingly threatened and crop biodiversity will be a significant source of resiliency and adaptability. However, these adaptations will only be fully realized through cooperative *in situ* and *ex situ* conservation and cultivation of domesticated crops, crop wild relatives, and wild foods. This conservation is best realized in places where communities have the cultural resources to invest meaningfully in the cultivation of native crops, and where the cultivation of those crops can reinforce place-specific livelihoods and identities. To this end, the principal objective of this research is to propose a framework for understanding, modeling, and managing zones of agrobiodiversity which are found in centers of crop origin and/or diversification, building upon understandings of biocultural heritage to create a global vision of sustainable, equitable, and innovative Food Neighborhoods. This study takes the *Parque de la Papa* [Potato Park] in Cusco, Peru as an ideal example of a Food Neighborhood, and uses the site to parameterize a spatial model and recommendations for up-scaling the Food Neighborhood concept. I provide an overview of the current status and trends in agrobiodiversity conservation, as well as an introduction to key concepts for the case study. I propose "Food Neighborhoods"—areas with deep linkages between indigenous ways of being and the cultivation of emblematic food products—as biocultural units to achieve *trans-situ* agrobiodiversity conservation. These neighborhoods are characterized by strong interactions between food crops or livestock, their wild relatives, and native farmers, and active management can promote the conservation of plant genetic resources, as well as the maintenance of indigenous food sovereignty and territorial rights to land and water.

1. **Objectives:**

In the era of anthropogenic climate change, global food security and crop biodiversity are increasingly threatened. Western scientific initiatives of genetic seed banking have successfully preserved a large percentage of crop genetics for hypothetical future use, but many of these preserved crops have been entirely lost from cultivation (FAO, 2019; Graddy, 2014). Indeed, though there are 30,000 edible plant species in the world, 80% of the world's calories are produced from only 12 crop species (Food Forever, 2019). As climate change progresses, global food security is likely to become increasingly threatened and crop biodiversity will be a significant source of resiliency and adaptability. However, these adaptations will only be fully realized through cooperative *in situ* and *ex situ* conservation and cultivation of domesticated crops, crop wild relatives, and wild foods (FAO, 2019). This conservation is best realized in places where communities have the cultural resources to invest meaningfully in the cultivation of native crops, and where the cultivation of those crops can reinforce place-specific livelihoods and identities (Argumedo and Stenner, 2008; Graddy, 2014).

In the past several decades, there has been a global focus on development, and more recently sustainable development, most notably borne out in the United Nations (UN) Millennium Development Goals (MDGs) (2000-2015) and the Sustainable Development Goals (SDGs) (2015-2030). Both international accords have at their core a mission of poverty-reduction, disease reduction, and equal opportunities for all; the SDGs integrate environmental targets into the language of development. However, both sets of goals fail to meaningfully address the underlying causes of the poverty they seek to ameliorate and neither do they recognize the importance of biocultural heritage, which is to say the intrinsic links between culture, ecology, and the ability to live well (Poole, 2018; Sterling, et al., 2017b). Increasingly, indigenous and local knowledge, epistemologies, and ways of being are recognized as a source of resilience and adaptation in a changing world, but indigenous rights and livelihoods are increasingly threatened by land insecurity, industrialization, and globalization (Adger, et al., 2011; Brandenburg & Carroll, 1995; Gavin, et al., 2015; De Wit, 2016). In order to preserve the agrobiodiversity upon which the world's food security depends, the erosion of indigenous rights must be halted, and conservation and development projects alike must strive for co-management which prioritizes, integrates, and acts upon the indigenous knowledge which has preserved food cultures for centuries.

To this end, the principal objective of this research is to propose a framework for understanding, modeling, and managing zones of agrobiodiversity which are found in centers of crop origin and/or diversification, building upon understandings of biocultural heritage to create a global vision of sustainable, equitable, and innovative Food Neighborhoods. This study takes the *Parque de la Papa* [Potato Park] in Cusco, Peru as an ideal example of a Food Neighborhood, and uses the site to parameterize a spatial model and recommendations for up-scaling the Food Neighborhood concept. First, I provide an overview of the current status and trends in agrobiodiversity conservation, as well as an introduction to key concepts for the case study. Second, I define Food Neighborhoods. Third, I describe the methodology for both the ethnographic and quantitative aspects of the project. Fourth, I present the results and discussion. I conclude by providing recommendations for the implementation of a global network of Food Neighborhoods.

2. Background to the Issue and Case

2.1 Agrobiodiversity Status and Trends

Climate change has begun to dramatically alter precipitation regimes, storm patterns, and average temperatures (IPCC, 2014), which in turn increases uncertainty and decreases yields in global agriculture (Beddington, et al., 2012). Both droughts and flooding are projected to increase in frequency and severity, sea level rise is expected to reduce arable land in coastal contexts, and average temperatures will rise by between two and five degrees Celsius by the end of the century (IPCC, 2014). Even the most conservative projections for climate change impacts in the next several decades will have severe consequences for food cultivation, with previously productive lands experiencing such radical changes as to necessitate dramatic shifts in agricultural practices (Nelson, et al., 2015). Given its inevitable consequences for agricultural production, climate change poses an acute threat to global food security (Beddington, et al., 2012; Nelson, et al., 2015; Pretty, et al., 2003). Agriculture is both a part of the problem and a part of the solution to climate change: current agricultural practices contribute between one quarter and one third of global greenhouse gas emissions (Beddington, et al., 2012, p.12). Thus, there is an urgent need for adaptation and resilience-building in agricultural practice, both to ensure global food security and to meet global greenhouse gas reduction goals.

Resilience in agricultural products relies upon the genetic diversity present in a population: populations with higher diversity are more likely to realize evolutionary adaptation to changing environmental pressures. Identifying populations with the highest levels of genetic diversity has been of global interest since the pioneering work of N.I. Vavilov, a Russian botanist who, in the early twentieth century, identified eight global centers of crop genetic origin, where he expected that diversity would be greatest. Vavilov's concept of centers has been debated and refined in the intervening century, and the notion that there are global agrobiodiversity hotspots—or centers of origin and diversity—has been validated by advances in science, linguistics, and archeology (Harlan, 1971; Hummer and Hancock, 2015). Today, these centers of origin are hotspots not just for crop diversity, but also for gene banks, scientific inquiry, and biocultural innovations. However, the world's food system is becoming increasingly homogenous, driven by growing human populations, ongoing economic development and globalization, the rise of supermarkets and refrigeration, urbanization, industrial food technologies, and facilitated global trade agreements (Khoury, et al., 2016). As homogenization progresses, the global importance of the genes found in centers of crop origin also increases, and thus, the protection of agrobiodiversity in centers of origin and diversification is a priority for all humanity.

Efforts to increase crop yields and pest resistance have long focused on the improvement of seeds and crop genetics. Genetic diversity, and the biodiversity which it underpins, is the basis of resilient and adaptable populations, and genes with demonstrated advantages in given conditions can be leveraged to improve the resiliency of a given crop (Fernie, et al., 2006; Maxted and Kell, 2009).Crop wild relatives (CWRs)—wild species closely related to domesticated crops—have been recognized as an essential source of genetic diversity since the early twentieth century, and advancements in technology and science in the 1980s and 1990s lead to a significant focus on preserving the genetic material of CWRs (Maxted and Kell, 2009; Meilleur and Hodgkin, 2004). Nearly every modern agricultural crop includes genes derived from CWRs, and they have come to be seen as an essential tool in ensuring global food security, economic stability, and environmental sustainability (Maxted and Kell, 2009). In terms of the conservation of both CWRs and landraces—local cultivars that have been domesticated and improved through traditional practices—there are two inter-related concerns: 1) How much diversity has disappeared from cultivation, and now exists only in gene banks?; and 2) How much diversity is threatened by a lack of *ex situ* conservation?

Much of the preservation of crop genetic material has taken place via *ex situ* seed banking, but biological difficulties in the preservation of some material, expense of preservation, and difficulties in repatriating genetic material reduce the efficacy of seed banking for guarding against food insecurity and biodiversity loss (Fernie, et al., 2006; Graddy, 2013, 2014; Meilleur and Hodgkins, 2004). Additionally, complex adaptations which arise from multi-gene interactions are difficult or impossible to isolate and/or simulate in laboratory conditions, and uncommon alleles are likely to be absent from gene-banked material (Bellon, et al., 2017). The genetic diversity of *ex situ* collections is likely to be well below the genetic diversity of crops which exists in cultivation, given the impracticality of storing sufficiently large samples to capture the genetic diversity of a population (ibid). Thus, in the past twenty years, there has been a growing focus on *in situ* conservation of CWRs and landraces and a corresponding need for improved management strategies at the local, regional, and global scales.

In situ conservation broadly refers to the practices of protecting and/or cultivating CWRs and landraces through active growing, as opposed to the *ex situ* practices of safe-guarding genetic materials for presumed future use (Brush, 1993; Maxted and Kell, 2009; Meilleur and Hodgkin, 2004). As Graddy (2014, p.2) notes, "a myopic focus on *ex situ* preservation will stockpile and store germplasm—but not keep alive agricultural biodiversity, which thrives when actually cultivated in fields, on farms, in practice." *In situ* conservation offers a variety of benefits in terms of agricultural adaptation and resiliency, including real-time testing of climate and pest resistance, the expression of genetic traits difficult to isolate in lab conditions, and increased biodiversity within ecosystems (Fernie, et al., 2006; Graddy, 2014; Maxted and Kell, 2009). Crops cultivated in fields undergo a continuous process of evolution driven by both natural pressures and human tastes, with domestication as a spectrum of innovations rather than a fixed historical incident (Bellon, et al., 2017).

Aside from its genetic advantages, the repatriation and revitalization of native crops can be a source of community empowerment, poverty reduction, and citizen science (Argumedo and Stenner, 2008; Graddy, 2013, 2014; van Etten, et al., 2019). Seed saving networks, which are essential to the maintenance of agrobiodiversity in fields, strengthen social networks and the social capital gained through these seed networks can be leveraged to improve many aspects of family and community life (Phillips, 2016). Additionally, where traditional agricultural systems are maintained, other aspects of cultural life—cosmologies, rituals, traditional economies, etc.—tend to be maintained as well (Meilleur and Hodgkin, 2004). Cultivation of CWRs and landraces is inherently linked to traditional agricultural systems, many of which are still practiced by indigenous and peasant farmers (Altieri, et al., 1987; FAO, 2019), and the prioritization of *in situ* conservation should thus ideally engage indigenous epistemologies and management strategies.

The intrinsic links between traditional cultivation strategies and *in situ* conservation make indigenous communities natural leaders in the development of agricultural and ecosystem management strategies for protecting crop biodiversity (Altieri, et al., 1987; Argumedo and Stenner, 2008; Graddy, 2013). Successful examples of indigenous management of *in situ* conservation exist across the globe (e.g., Adebooye and Opabode, 2004; Altieri and Merrick, 1987; Backes, 2001), but indigenous knowledge is nonetheless underrepresented in climate change resiliency and adaptation planning for agriculture (Adger, et al., 2001; Altieri and Merrick, 1987; Graddy, 2014; Heyd, 2014; Robbins, 2003). Thus, an understanding of indigenous management strategies of CWRs and landraces is imperative for effective *in situ* conservation of the world's food resources (Altieri, et al., 1987; Graddy, 2014).

2.2 Biocultural Heritage Landscapes

The study of indigenous knowledge and cosmology has been pursued for at least the last two centuries within the academic context of anthropology, but the indigenous land management strategies which these knowledges inform has rarely been treated as actionable and legitimate (Graddy, 2013; Robbins, 2003; Walley, 2010; Whyte, et al., 2018). However, within the context of a rapidly changing climate and a host of other challenges in the Anthropocene, from rapid population growth to globalization, indigenous knowledge has come to be of great interest as an alternative to the Western systems which have given rise to these challenges (e.g., Adger, et al., 2011; Balram, et al., 2004; PRATEC, 2009). Indigenous knowledge broadly refers to the epistemologies, practices, and beliefs of indigenous and/or local individuals and groups, and typically includes geographically-specific understandings of connections between peoples and the environment (e.g. Basso, 1996; UNEP, 1999; Whyte, et al., 2018). *In situ* agrobiodiversity conservation requires relevant knowledge of local growing conditions, as well as resilient methods for cultivation within particular landscapes, both of which are readily found in indigenous and peasant agricultural communities (Altieri, et al., 1987; Alteiri and Merrick, 1987). However, *in situ* conservation projects may necessarily rely upon resources found only in international centers of seed-banking, so westernized land management narratives and scientific dialogues are inevitably engaged as the dominant framework for decision-making about which seeds are repatriated and to whom (Graddy, 2013, 2014). The exceptional challenges of assuring food security for growing populations in the context of global climate change demand adaptive, place-based solutions which must foreground indigenous knowledge in bottom-up, collaborative management and conservation.

There is an appreciable correlation between biological and cultural diversity, and an interdependence between linguistic, cultural, and biological diversity due to processes of coevolution and geographic overlap (e.g. Heckenberger, et al., 2007; Loh & Harmon, 2005; Reyes-García, et al., 2014). This relationship has given rise to the concept of biocultural diversity, or the diversity of a given area measured in terms of both ecological and cultural diversity, which are interrelated and inseparable. Biocultural diversity is intrinsically linked to the landscapes where species, cultures, and ecosystems converge, termed biocultural heritage landscapes (iied, n.d., 2018). These landscapes are made up of a mosaic of land uses, which are deeply linked to the cultural traditions embedded in the memories and experiences of indigenous peoples (iied, n.d.). As a strategy for land management, biocultural heritage landscapes engage traditional knowledge and culture—world views, spiritual values, customary laws, institutions, and stewardship practices—to maintain both biodiversity and indigenous cultural practices, which increases the resiliency and adaptability of both human populations and ecosystems (iied, 2018; Gavin, et al., 2015).

Most development models advocate infinite growth and reliance on markets as the route to well-being, and development indicators tend to be overtly economic in nature (i.e. GDP), but biocultural heritage provides an alternative vision for both cultivating and measuring well-being (iied, n.d.; Gavin, et al., 2015; Sterling, et al., 2017b). Biocultural heritage and its related indicators assert that poverty and inequality are best addressed through culturally-grounded notions of socio-ecological reciprocity and equilibrium which support food sovereignty, biodiversity, and local economies (iied, n.d., 2018; Sterling, et al., 2017a, 2017b). Biocultural approaches are inherently systems-based in that they are concerned with the feedbacks that exist between human and ecological actors—it is impossible for human well-being to be conceived of without the existence of healthy ecosystems (Sterling, et al., 2017b). Contrary to decades of conservation thinking which has conceived of humans as the enemies of nature, human actors and cultures can be as important in maintaining healthy ecosystems as ecosystems are in maintaining human well-being (Bélair, et al., 2010; Caillon, et al., 2017; Pascual, et al., 2017; Sterling, et al., 2017a).

2.3 Food Neighborhoods

Biodiversity for food and agriculture, the percentage of global biodiversity which contributes to agriculture and food production, including terrestrial and aquatic microorganisms, pollinators, plants, and animal species, is declining (FAO, 2019). Decline is precipitated by global, regional, and local factors, and will have serious consequences for global food and nutrition security. The FAO (2019) advocates that the conservation of CWRs should be a global priority, realized through linked *in situ* and *ex situ* conservation efforts. *Ex situ* conservation can safeguard the genetic stock of the world's CWRs and landraces to assure the resiliency of future peoples, and it opens a world of possibilities for crop breeding and improvement programs, both today and in the future. On the other hand, *in situ* conservation benefits communities in real-time, increasing resiliency and adaptation, and validating indigenous and local knowledges as the source of innovation, while providing nutritious food products and diversifying livelihoods. Thus, a *trans-situ* approach aims to realize partnerships between *ex situ* genetic collections and scientists and *in situ* cultivators and innovators, such that the innovations, successes, challenges, and ideas of actors within each sphere are made freely available to the other. *Trans-situ* conservation aims to circumvent the tensions between *in* and *ex situ* conservation programs, making the knowledge of both available for the good of all humanity.

I propose "Food Neighborhoods" as biocultural units to achieve such *trans-situ* agrobiodiversity conservation. Food Neighborhoods, defined broadly, are areas with deep linkages between indigenous ways of being and the cultivation of emblematic food products; members of food neighborhoods are both producers and consumers whose identities are grounded in place-based relationships between cultivation and culture. These neighborhoods are characterized by strong interactions between food crops or livestock, their wild relatives, and native farmers, and active management can promote the conservation of plant genetic resources, as well as the maintenance of indigenous food sovereignty and territorial rights to land and water. Food Neighborhoods are areas of landscape management which protect both human and ecological diversity in order to fortify resilience and adaptation to a rapidly changing climate, provide roadmaps for indigenous-driven conservation efforts, and prioritize *trans-situ* collaborations for agricultural innovations. I draw upon theories of landscape ethnoecology, as well as the biocultural heritage landscape model, to elaborate a definition of Food Neighborhoods.

In landscape ecology, it is widely acknowledged that the proximity of features as well as their spatial arrangement in a heterogeneous landscape has significant impacts on the processes and compositions of the space (Hersperger, 2006). Similarly, in urban planning, the proximity of features and their interactions are believed to be key drivers of processes and interactions, amongst and between both individuals and spaces (e.g. Gustafson & Parker, 1994; Matsuoka & Kaplan, 2008; Sugiyama, et al., 2010). The neighborhood has been used as a unit of analysis in both ecological and anthropogenic landscapes to describe these interactions. Ecological neighborhoods are typically defined by three inter-related characteristics: a given ecological process, the timescale of that process, and the influence(s) of an organism during the period considered (Addicott, et al., 1987). In anthropogenic landscapes, neighborhoods are more loosely defined, not by given processes or timescales, but rather by interactions between human actors and spaces which give rise to specific types of human communities, defined by vicinity (Hersperger, 2006; Silver, 1985). Neighborhoods are not only about space, but also about the place-making activities which take place within them, which is to say that they are characterized by the specific human meanings which individuals and societies impart to them (Hersperger, 2006; Silver, 1985). Food Neighborhoods bridge these similar but divergent understandings of ecological and anthropogenic communities, proposing that the ecological processes, timescales, and organisms within an agricultural space are intrinsically connected to the place-making activities and identities of the human communities who cooperatively inhabit it. Thus, as a spatial unit, a Food Neighborhood can be understood as an area where the ecological processes of food cultivation are the key mechanisms for place-making by the human population(s) who inhabit it, and where the activities of those human populations are essential for the success of those same ecological processes.

However, because neighborhoods are defined culturally as much as spatially, it is difficult to determine their geographic extent. Food Neighborhoods are not mere spatial units which can easily be drawn on maps, but rather dynamic communities of producers and consumers engaged in continuous biocultural innovation and place-making. It is thus essential to consider the biocultural patrimony of a neighborhood as well as its spatial dynamics. In some cases, a food neighborhood may have constantly shifting boundaries, as with pastoralist communities; despite changes in size and even geographic location, its identity is retained through relationships amongst and between human, animal, ecological, and spiritual actors.

Further, in order for Food Neighborhoods to serve as useful units for ecological planning and management, I define them by certain common cultural characteristics and agricultural practices.

Most significantly, Food Neighborhoods are characterized by the cosmovision[1] of resident populations, which connects local ways of being with food production and/or consumption. Food Neighborhoods are the residencies of place-based cultural practices which engage in traditional and low-carbon agriculture, agrobiodiversity conservation, and the promotion of indigenous rights and identities. While it is not possible to generalize the specifics of various indigenous cosmologies which give rise to Food Neighborhoods, they do tend to share in common understandings about harmony between human, natural, and sacred spheres and typically place high importance on reciprocity between these three distinct types of actors (UNEP, 1999). The agrobiodiversity of Food Neighborhoods is inseparable from the cultural practices of their residents, and the indigenous cosmologies which underpin the social and agricultural practices of these populations are the basis for sustainable and resilient landscape management and the maintenance of biodiversity. Thus, Food Neighborhoods should be developed according to the cosmovision and values of indigenous populations who have safeguarded the world's agrobiodiversity for centuries.

Additionally, Food Neighborhoods should be located in important global centers of crop origin and/or diversification, where the linkages between cultures and food cultivation are likely to have the deepest histories of resilience and innovation. A given Food Neighborhood should have an emblematic crop related to that center of origin and/or diversification, though it is assumed that a wide variety of food products may be cultivated within the area. Because it has

[1] I use the term cosmovision to refer to the way in which a given group collectively conceives of and organizes the world. Cosmovision most obviously includes religious and spiritual beliefs, but also includes the mythologies, enculturation processes, and socio-cultural rules which guide the ways in which individuals act towards one another and as members of a group. (See: Eliade, 1959).

proven all but impossible to pinpoint the exact centers of origins for domesticated plants and animals (e.g. Harlan, 1971), I do not propose a strict adherence of Food Neighborhoods to the Vavilov centers of crop origin, which would unnecessarily limit the number, extent, and locations of Food Neighborhoods. Instead, I propose that a viable Food Neighborhood site must host a significant percentage of the total agrobiodiversity of an emblematic species, and that it must have a demonstrated historical record of doing so. It is useful to reference centers of origin and diversification in identifying such sites, as these centers host the highest incidents of agrobiodiversity on the planet (Hummer and Hancock, 2015; Khoury, et al., 2016).

The Food Neighborhood model shares similarities with various concepts of agrobiodiversity conservation and place-based cultivation, but is distinguished by its foregrounding of indigenous rights and knowledge and its strong commitment to integrated co-management. Geographical Indications (GIs) are an internationally recognized form of intellectual property granted to products that have a specific geographic origin and qualities or reputations related to that origin; well-known examples are Roquefort cheese and Darjeeling tea (WIPO, 2017). While GIs recognize the importance of place-based cultivation strategies in food products, they are an explicitly economic system and given their relationship to the complex world of intellectual property law, have been largely inaccessible to indigenous populations (Brush, 1993; Frankel, 2011; Paterson & Karjala, 2003). Food Neighborhoods, in contrast, reject the idea that food systems—including seeds, farming techniques, and agricultural products—can be commoditized as the intellectual property of any individual, corporation, or group. Similarly, the French have developed a sense of the place-based characteristics of food over centuries, known as *terroir*, which describes the particular taste, odor, and/or quality of foods grown in given regions (Trubek, 2008). However, *terroir* is about ecological characteristics above cultural ones—the variables of importance have to do with rainfall, soil types, etc. Food Neighborhoods, on the other hand, recognize that the specific characteristics of place-based foods are borne not only of ecology, but critically of human cultures.

The Food Neighborhood model is a landscape management approach which engages indigenous rights and management at all stages of the food system. Crucially, the concept of Food Neighborhoods is built upon notions of integrated management which engage all available forms of knowledge, from indigenous to scientific, in order to realize agricultural innovations, sustainability, and resilience. By engaging multiple ways of knowing, Food Neighborhoods protect the territories and patrimonies of indigenous peoples and the agrobiodiversity of their lands while working towards solutions to some of the 21st century's most difficult challenges. Integrated bottom-up management not only increases equity in conservation and agriculture, but also fortifies adaptation and resilience (Agrawal & Gibson, 1999; Brown & Kothari, 2011; Walley, 2010).

I conceptualize Food Neighborhoods as units of landscape management, and thus propose four related objectives which their management should fulfill. First, to strengthen and protect the rights of indigenous peoples to their territories, cultures, and health, Second, to conserve agrobiodiversity using a *trans-situ* approach in order to assure food security for both present and future populations. They should ideally include conservation efforts for both CWRs and landraces, though this will depend on the target species and the state of CWR conservation in a given geographical area. Third, to provide innovative, sustainable, and culturally-relevant livelihood options for resident populations, who cannot be expected to contribute to agrobiodiversity conservation for the good of humanity at the expense of their own ability to live healthy, productive, and fulfilling lives. Fourth, to contribute towards resilience and adaptation in the face of global climate change. Ultimately, a worldwide network of Food Neighborhoods will contribute to a global food system which is sustainable, resilient, equitable, and healthy, while protecting the rights and territories of the world's indigenous peoples.

2.4 Climate Change in the Peruvian Andes

More than fifty percent of the world's population depends on freshwater that originates in mountain ecosystems and, from an ecological point of view, mountain ecosystems are hotspots for biodiversity (Grêt-Regamey, Brunner & Kienast, 2012). However, mountain ecosystems are among the most vulnerable to climate change, given the fragile balance of elements at high altitudes, and mountain populations are some of the world's most vulnerable (Galloway McLean, et al., 2011; Grêt-Regamey, Brunner & Kienast, 2012). The erosion of mountain ecosystems is an issue of global concern, particularly in regards to water and food security, both for people living in mountainous regions and populations that rely upon the resources originating in high altitudes (Chevallier, et al., 2011; Mark, et al., 2010; Messerli, Viviroli & Weingartner, 2004). The rapid disappearance of high latitude glaciers, precipitated by increasing average global temperatures, is the main driver of vulnerability in mountainous regions and will have far-reaching consequences for global food and water security (Chevallier, et al., 2011; Messerli, Viviroli & Weingartner, 2004). Indigenous peoples living in mountain regions warrant particular attention in resiliency and adaptation planning because the climate change impacts they will experience are expected to be severe, given the sensitivity of their high altitude environments and livelihoods which rely on biodiversity in these fragile ecosystems (Galloway McLean, et al., 2011; Kothari, et al., 2012).

The Andes Mountains contain the highest elevation peaks in the Western hemisphere and complex interchanges between climate, topography, and biology have imparted a great diversity of ecosystems to the area, making the mountain range a biodiversity hotspot of global importance (Hutter, Guayasamin & Wiens, 2013). Proximity to both the Pacific Ocean and the Amazon Basin results in a complex system of verticality with hundreds of ecological niches (Murra, 2002). Cultural diversity is also high in the Andes—45% of the population of Peru, for example, identifies as indigenous (Minority Rights Group International, 2007). Additionally, the Andes are home to 99% of the world's tropical glaciers, with the highest concentration being found in Peru (Dyurgerov and Meier, 2005). However, climate change has precipitated dramatic changes in glacial stability in the region: rapid glacial retreat has been recorded in the past fifty years (López-Moreno, et al., 2014; Rabatel, et al., 2012; Vuille, et al., 2008). Major cities and rural populations alike throughout the Andes depend on glaciers for both freshwater and energy, provided in large part through hydroelectric dams, and Andean populations are thus highly vulnerable to climate change (Chevallier, et al., 2010; Cometti, 2015).

Andean ecosystems are also highly vulnerable to the water insecurity precipitated by melting glaciers, and shifting water and temperature regimes have begun to dramatically alter biological conditions for plants and animals alike (Vuille, et al., 2008). The fertile soils of the Andes depend upon specific balances of organic materials, pH, and various minerals, and are particularly affected by changes in precipitation and deglaciation (Cometti, 2015). As temperatures rise, pests and diseases are moving into higher altitudes, forcing agricultural activities higher and higher into the mountains, where there are both poorer soils (due to high rates of erosion) and less growing space (Sayre, Stenner, & Argumedo, 2017). Agricultural activity at high altitudes in turn increases the threat of erosion (Cometti, 2015). Crops which have long been staples of the Andean diet, such as potatoes, are becoming more difficult to grow, and there is thus urgent need for research and innovation for agricultural resilience to climate change (Sayre, Stenner, & Argumedo, 2017).

The Andean region is one of the important global centers of crop origin and domestication, giving the world crops including the potato (the third most important crop in the world in terms of calories consumed), quinoa, kiwicha, olluco, and oca (Khoury, et al., 2016; Sayre, Stenner, and Argumedo, 2017). Today, the region harbors the highest diversity of potatoes in the world, and Andean farmers have 8,000 years of experience in adapting potato cultivation to the extreme conditions of high altitude and the highly variable climate caused by the El Niño phenomenon (Sayre, Stenner, and Argumedo, 2017).

The Andes are an area of both great adaptability and great vulnerability. Given high dependence on small-scale agriculture and natural resources, rural highland communities are especially vulnerable to the effects of climate change and climate-linked natural disasters (Reyes, 2002). However, climate change is not a new phenomenon in the Andes, though the current climactic changes are progressing at a faster rate and with different consequences than historical transitions (Branch, et al., 2007; Chepstow-Lusty, et al., 2009; Vuille, et al., 2008). The influences of El Niño—a regular climactic occurrence which takes place roughly every five years when the cold waters of the Humboldt current, which flows north from Antarctica along the coast of Chile and Peru, is replaced with warmer, southern-flowing waters from the tropics—have been shown to have effects on both the ecosystems and cultures of the Andes for several thousand years (Chepstow-Lusty, et al., 2003, 2009; Keefer, et al., 1998; Reyes, 2002; Sandweiss, et al., 2001, 2009). There is compelling evidence that the rise of the Incan Empire was facilitated by climactic change which improved growing conditions in the Andes, as well as evidence that Incan agriculture was heavily influenced by shifts in the climate (Chepstow-Lusty, et al., 2003, 2009). This long history of climactic changes in the Andes has given rise to highly adaptable populations with cultural traditions of innovation, particularly related to agricultural practices.

Quechua-speaking peoples—the indigenous groups of the Central Andes—have lived with these fragile ecosystems for generations, and their cultures are intimately connected to the mountains which they inhabit. Climate change poses acute threats to the environments upon which Quechua peoples depend, as well as threatening symbolically laden sites, and thus erodes the traditional knowledge upon which these populations depend (Heyd, 2014; Paerregaard, 2013). As Heyd (2014, p. 356) notes, “space is more than the container of physical things but, rather, a grid of opportunities, needs, memories, worries, and so on, communally and individually constructed and re-constructed in a dynamic environment of encounters among humans, and between humans and non-human elements of the landscape.” In this context, climate change does not just threaten the functioning of ecosystems as it alters landscapes, but also erodes entire ways of knowing and being. Indigenous understandings of climate change in the Andes are premised upon generations of experience living with particular spaces, and thus frame global change in a distinctly local way and, because the experience of this change is local, there is strong conviction that there must be local solutions (Paerregaard, 2013). Thus, indigenous knowledge in the Andes, and around the world, is highly threatened by global climate change, but is also a source of resiliency and adaptation.

Quechua cosmovision is agrocentric and based on several interlinked relationships between humans, nature, and the spiritual world. There are three concepts which are especially key to the management of agricultural landscapes in the Andes. First, *Ayni*, or reciprocity, which exists between all things—humans, animals, nature, and spirits—creates harmony in the world

(Walshe and Argumedo, 2016). Translated to Spanish, the concept of *ayni* is understood as *criar y dejarse criar*—to nurture and to allow oneself to be nurtured—a deceptively simple concept that is the basis for all social and ecological harmony and justice (Graddy, 2014). Second, *Ayllus* are social units or communities which include concepts of common responsibilities and duties to ensure equality for all group members (Walshe and Argumedo, 2016). Third, *Yanantin* is equilibrium which is realized through complementary dualism, and asserts that opposites (such as male/female) are equal and interdependent parts of a harmonious whole (ibid). Additionally, landscape features, and mountains in particular, can be sacred deities and community leaders both; these *apus* (sacred mountains) oversee and govern many elements of Andean life, including planting and harvesting (Sayre, Stenner, and Argumedo, 2017). There is no epistemological distinction between nature and culture in the Quechua worldview (Paerregaard, 2013), and *ayllus* thus include human, natural, and sacred actors; *ayni* and *yanantin* exist between all types of members in these communities. Reciprocity and equilibrium are achieved through the observation of rituals according to calendars based upon natural indicators (rains, harvest, etc.) (Mulla, 2002; UNEP, 1999).

Quechua landscape management is a complex system of balance between human, natural, and sacred needs which strives to achieve *sumaq kawsay*, or harmonious and correct living. *Sumaq kawsay* presents an alternative model for development which relies on biocultural indicators as opposed to economic ones (Thomson, 2011; Zimmerer, 2012). *Sumaq kawsay* is intrinsically linked to both the rights and ability of indigenous communities to produce and consume a customary diversity of agricultural products, and has thus been a key concept in agrobiodiversity conservation in the Andes (Zimmerer, 2012). Because *sumaq kawsay* depends on harmony between human, natural, and spiritual elements of a community, Quechua landscape management is a holistic system in which no single element can function in isolation; the maintenance of agrobiodiversity and cultural identity are codependent. The *Parque de la Papa* in Cusco, Peru provides a particularly robust example of Quechua landscape management, and is the emblematic case which I will use to elaborate a theory of Food Neighborhoods.

2.5 The *Parque de la Papa*[2]

The *Parque de la Papa* (*Parque* hereafter) is an agrobiodiversity conservation initiative located in the Sacred Valley of Peru, 50 kilometers from the city of Cusco. Comprised of about 10,000 hectares, the *Parque* is a high-altitude landscape (with altitudes ranging from 3,000 to 4,500 meters above sea level) jointly managed by a cooperative of 7,000 members from six indigenous communities—Amaru, Chawaytire, Cuyo Grande, Pampallaqta, Paru-Paru, and Sacaca. The area celebrates and protects indigenous biocultural heritage in a unique mountain agroecosystem, and provides a model for sustainable, resilient, and adaptable agriculture in the context of a rapidly changing climate. In collaboration with the Cusco-based NGO Asociación ANDES, the *Parque* has worked to repatriate native potatoes to the fields of *campesinos* from the gene bank at the International Potato Center (CIP) and to maintain the existing diversity of crops in the landscape, and there are currently nearly 1,500 varieties of potato landraces cultivated within the *Parque,* along with three CWRs of potato. The area is also home to a wide range of other crops and CWRs, including several native tubers (most notably, there is a high diversity of ocas and mashuas) and Andean grains (like quinoa and kiwicha). The *Parque* has the highest diversity of potatoes of any site in the world, and is a Food Neighborhood that serves as an exemplar of *trans-situ* conservation, bridging divides between indigenous and westernized knowledge, and creating productive feedbacks between *in situ* and *ex situ* methodologies.

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[2] The following description of the *Parque de la Papa* is elaborated according to both bibliographic review and ethnographic investigation in the area. For greater detail on data collection processes, see Section 4.1.

The *Parque* was founded in 2002 with the official merging of territories and the formal initiation of a biocultural heritage reserve. The *Parque* is an embodied and fully realized project of biocultural patrimony, where the place-making undertaken by indigenous groups throughout centuries has given rise to a tremendous diversity of potatoes, which are not simple biological products, but also spiritual and cultural ones. A typical plot within the *Parque* contains up to 150 distinct varieties of potato, all named and known by growers in the area, and each with their distinct stories and benefits (Argumedo, 2008; Walshe and Argumedo, 2016).The indigenous *campesinos* of the *Parque* assert that the agrobiodiversity of their fields is not an ecological coincidence, and that the highly valued genetic traits found within their native crops are not simply natural resources to be extracted; instead, both the landscape and the potatoes it contains are as cultural and political as they are biological (Graddy, 2014). In 2005, the *Parque* and ANDES reached a landmark agreement with CIP to repatriate more than 200 varieties of native potatoes to the fields of indigenous *campesinos* from the gene bank in Lima. Today, the *Parque* exists as a "living library" of potato diversity and continues to engage in collaborative *trans-situ* conservation through the management of their own seed bank, sending of genetic material to CIP, and the maintenance of various festivals and rituals throughout the year to support the potato harvest (Graddy, 2013; Walshe & Argumedo, 2016).

The *Parque* is premised upon the existence and management of three distinct *ayllus*: *Runa Ayllu* (the human sphere), *Sallaqa Ayllu* (the natural sphere), and *Auki Ayllu* (the sacred sphere) (see figure 1). *Runa ayllu* includes the economic and social activities of the *Parque*, which are realized through a system of collectives which undertake a variety of economic and administrative activities, including a restaurant and the organization of tourist visits. It also includes the organization of farming activities, realized by each family in their *chacras*, or plots of cultivation. *Sallaqa ayllu* includes the non-domesticated elements of the landscape, including wind, water, and plants and the ecological indicators found within this community are the basis for all agricultural activity. *Auki ayllu* includes the *apus* (sacred mountains) and other sacred landscape features, and governs the functioning of the other two *ayllus* on the basis of spiritual authority. According to the principle of reciprocity, the *Pachamama* (mother earth) gives crops to the farmers and, in return, farmers give elaborate offerings and payments to the earth, mediated by spiritual authorities (Argumedo, 2008). This ecosystem-based approach to managing traditional agricultural systems is the basis for maintaining both the diversity and health of domesticated and wild plant and animal species, and protecting the diverse ecosystems upon which they rely (ibid).

Figure 1 A visualization of the *Ayllu* system. The above diagram is a part of the presentation materials used during educational visits in the *Parque de la Papa* and demonstrates that harmony between the spiritual, human, and wild realms are needed to achieve harmonious living (*Sumaq kawsay)*. Image credit: Asociación ANDES.

As a crop, the potato boasts tremendous diversity and high resilience, but it is threatened in its Andean homeland by warming temperatures, glacial retreat, shifting precipitation regimes, and increased pest and disease loads (Pradel, et al., 2017; Sayre, Stenner, and Argumedo, 2017). In the face of climate change, the indigenous *campesinos* of the *Parque* have been forced to plant potatoes at higher and higher elevations in order to cultivate frost-tolerant varieties and to avoid the increasing pest loads of lower elevation plots (Sayre, Stenner, and Argumedo, 2017). The highest recorded elevations for potato cultivation have been realized in the *Parque*, near 4500 meters above sea level (ANDES, 2016). Despite the many challenges of climate change, the significant agrobiodiversity of the *Parque* will ensure that its members are able to maintain diverse and local food sources, and the many training and collaboration opportunities in which the communities engage will increase their ability to adapt and react to change. Additionally, due to the strong ties which exist between the member communities and the importance of *ayni* in cultural life, there is a custom of sharing seeds, food supplies, and knowledge, which will further increase resilience (Sayre, Stenner, and Argumedo, 2017).

The *Parque* engages in co-management of the landscape, merging indigenous knowledge with western scientific inquiry. Indigenous methodologies for investigating climate change impact in particular have been significantly elaborated within the *Parque,* based upon various *capacitaciones* (capacity-building workshops) carried out through Farmer Field Schools within the park and through collaborations with ANDES and CIP. Transects have been implemented throughout the *Parque* as a means of observing, cataloging, and experimenting with biodiversity in vertical space—a simple technique for recording species diversity, transects have provided indigenous *campesino* growers and scientists alike with invaluable data about the ecological conditions and agrobiodiversity of the space. Various collaborative mapping activities have been carried out within the *Parque*, resulting in detailed information about the locations of CWRs, the areas of highest agrobiodiversity, and altitudinal effects on potato cultivation. Community members in the *Parque* have been trained in the collection of genetic material, and in the creation of “true seeds” for potatoes, typically achieved by hand-pollination of varieties carefully selected for desired traits, and routinely pass these materials to *ex situ* collections to be safeguarded for future generations. Throughout the *Parque*, experimental plots exist where potato varieties are being exposed to a variety of conditions to test for climate resilience and adaptability. These collaborative approaches make the *Parque* a truly *trans-situ* initiative, utilizing scientific and indigenous approaches side-by-side to create both *in situ* and *ex situ* collections of potato diversity, and contributing to the global base of knowledge about potato cultivation in the context of climate change.

As with all landscape management schemes, a key challenge in the *Parque* has been securing livelihoods for community members and balancing the need for economic growth in the region with biodiversity conservation. The *Parque* has undertaken a variety of initiatives to both bolster and diversify livelihoods, creating a variety of cooperatives within the park that contribute towards value-added products. For example, the medicinal plants co-op produces teas and infusions for sale and are currently learning how to make soaps and shampoos as well. The gastronomy co-op runs a restaurant in the *Parque*, where they showcase the agrobiodiversity of the *Parque* through typical *campesino* recipes as well as creating innovative new potato-based recipes. Most significant to the economy of the *Parque*, undoubtedly, is the ecotourism initiative comprising homestays, an agrobiodiversity hike, and typical meals. While the site remains off the radar of many tourists, it benefits from its proximity to some of the most popular destinations in Peru (such as Machu Picchu) and from growing global interest in “new” Peruvian cuisine which makes use of wild and native ingredients (CBD, 2019). Within the framework of the *Parque*, so-called pro-poor agendas are conceptualized and carried out on collective scales, with the health, prosperity, and happiness of entire communities being the relevant scale as opposed to the individual. The *Parque* is not primarily an economic initiative, but it has undoubtedly increased the well-being of its members according to economic and biocultural indicators alike.

Given the success of the *Parque* in preserving agrobiodiversity, strengthening indigenous claims to territories and culture, and providing sustainable livelihoods for indigenous *campesino* populations, it will be taken as the ideal case for elaborating a model of Food Neighborhoods. I consider ecological, spatial, and cultural variables to describe variables of significance and to produce a set of recommendations for the up-scaling of the management model to other areas around the globe.

3. Research Question

In order to facilitate the upscaling of the Food Neighborhoods concept, this study aims to characterize the key characteristics of a Food Neighborhood, using the *Parque de la Papa* as an ideal case. The study addresses two key questions: 1) What are the significant variables of success in the *Parque de la Papa*, in terms of both agrobiodiversity and cultural conservation? and 2) How can these variables be used to identify sites for the development of Food Neighborhoods around the globe? In order to answer these questions, I combine ethnographic, geographic, and mathematical techniques to elaborate a modeling approach for site suitability analysis. Site suitability analysis is a geographic modeling technique in which a set of predetermined criteria are used to identify and rank suitable sites according to goodness of fit, calculated by intersecting the rank of each unit of measure (in this case, pixels) for each variable.

Additionally, the study aims to define the key goals of a Food Neighborhood and lay the groundwork for elaborating a monitoring and evaluation process, based on the successes realized in the *Parque* and on theories of biocultural indicators. The key question in monitoring and evaluation is: what characterizes the success of a Food Neighborhood and how can it be measured? The characterization of the *Parque* was the key activity for both the modeling approach and for evaluation recommendations, though both approaches generalize the results with an aim of universality—the results are not intended to be a complete characterization of the *Parque*, but rather a model parameterized to the successes realized there.

4. Methods

The *Parque de la Papa* is a geographical area, a community united by shared culture, and an ecosystem characterized by potato cultivation, making it a complex system which must be evaluated using cross-disciplinary approaches. Ethnographic methods can result in rich descriptions of lived systems, and capture the nuances of differing experiences and opinions, but it is difficult to replicate or scale-up projects based on ethnographic descriptions alone. On the other hand, spatial and mathematical modeling methods are tremendously useful in up-scaling, but they are necessarily a gross-oversimplification of the complex lived systems which they represent. The ultimate goal of this project is the elaboration of a spatial model for site selection of Food Neighborhoods, but the elaboration of this model is not based on math alone. I invested significant time in bibliographic review and ethnographic research at the *Parque* prior to any modeling activities, both to collect necessary data and, perhaps more importantly, to understand the nuances of the area. The results of this study are modeling-based, but they would have been impossible to realize without substantial investment in ethnography.

Towards the ultimate goal of up-scaling Food Neighborhoods, it is essential to recognize the importance of ethnographic expertise. Several variables which enter into the modeling approach rely on relevant knowledge about culture, lifestyles, and agricultural practices in an area. While my ultimate goal is to create a modeling approach which can handle larger data sets and data sets that contain greater uncertainty, a major challenge in developing such a tool is the difficulty of systematizing ethnographic understandings. Even the most sophisticated machine learning algorithms cannot capture the understandings gained from ethnographic study of an area. Further, Food Neighborhoods rely on collaborative management and knowledge generation, management, and distribution, which should begin with local experts. Aside from the limitations of systematizing knowledge, the inclusion of ethnographic elements in the modeling approach also facilitates the participation and collaboration of those without training in mathematics or geography.

4.1 Ethnographic methods

I carried out a variety of ethnographic activities both within the *Parque* and with Asociación ANDES during a period of ten weeks. I volunteered with ANDES and completed activities from translation to capacity-building trainings; my time working with ANDES gave me invaluable access to government officials, expert visitors both from Peru and abroad, and subject experts in agronomy, indigenous rights, and landscape management working for ANDES. I informally interviewed several ANDES staff members in order to gain historical information about the *Parque* as well as to gain detailed information about the context of indigenous agriculture and *in situ* conservation in Peru. I also visited the *Parque* many times and engaged in both participant observation and informal interviewing. Often, my visits coincided with formal educational visits organized for foreign and domestic researchers, policy makers, and volunteers; these visits were invaluable in understanding how the *Parque* characterizes itself for external audiences.

I met with eight local experts from the *Parque*, called *técnicos locales*, who act as official representatives of their communities to carry out the conservation work of the *Parque* (i.e. working in the seed improvement center, coordinating the seed bank, and planting and harvesting transect plots) as well as acting as the main representatives of the *Parque* for all educational and political activities. I had numerous informal conversations with the *técnicos*, and also had the opportunity to hear them explain all aspects of the *Parque* during educational visits. Towards the completion of the modeling approach, I also held a formal workshop with the *técnicos* designed to create a list of variables which characterize the *Parque*. During the workshop, participants discussed at length the beliefs, practices, and ecological characteristics that exist within the *Parque*, and divided them into five categories: 1) climatic (any weather or climate related phenomenon), 2) spiritual (any religious or cosmological beliefs impacting the functioning of the *Parque*) , 3) social (any governance-related features of the *Parque* and all political structures like healthcare, schools, etc.), 4) cultural (all cultural practices relating to the function of the *Parque*), and 5) ecological (the biological factors which exists within the *Parque*'s boundaries). These categories were decided based upon meetings held with ANDES staff, in which these dimensions were agreed upon as the key defining features of the *Parque* model. However, because these categories are inter-related and impossible to entirely divide, many variables were assigned to more than one category. Participants were then asked to identify the most important variables in each category (no limit was set on the number of variables that could be chosen). All fieldwork with the *técnicos* was conducted in Spanish, with Quechua translation as necessary.

4.2 Modeling approach

Any modeling approach is only as strong as the data which underpins it, so I began my modeling process by collecting, reviewing, and organizing all data held by ANDES, which has been collected throughout their nearly twenty years of work with the *Parque*. Most of this data was qualitative and contributed to an understanding of the national, regional, and local context within which the *Parque* functions, as well as guiding the selection of variables for inclusion in the final modeling approach. For example, while ANDES may hold limited quantitative data about climate change in southern Peru, they have ample evidence of the preoccupation of local farmers with the issue as well as rich ethnographic descriptions of local strategies for resilience and adaptation (e.g. Sayre, Stenner, and Argumedo, 2017).

In addition to reviewing the data held by ANDES, I also sought to use as many freely available data sources as possible, including national and international genebank databases, satellite data, and open-source spatial data (a complete list of data sources can be found in Appendix 1). Satellite data suffers from issues of downscaling (the scale at which areas like the *Parque* exist requires finer resolution data than many satellites collect) but is nonetheless the most widely accessible source of climate and land-use data and does not require that potential Food Neighborhood sites invest in their own data collection. Genebank databases and other national and international databases provide both historical and contemporary information about agrobiodiversity, growing suitability, and crop yields. However, it was my observation that these databases dramatically underestimated the diversity of potatoes that exists in Peru, again underlining the importance of ethnographic data in the project. Open-source spatial data is particularly useful in analyses of topography, as well as in establishing national and regional boundaries, locating landscape features, and examining large-scale natural resources (such as watersheds).

The data collected through ANDES archives as well as through satellite and database sources were matched to the variables identified in the ethnographic process. The variables identified through bibliographic review, interviews, workshops, and observation were combined and simplified where possible (for example, precipitation and rainy season/dry season were combined into annual mean precipitation, and seasonality was added as a secondary climate variable). After simplification, variables were ranked according to two dimensions: (1) relative importance to the functioning of the *Parque*, in terms of agrobiodiversity conservation and cultural value (this ranking was done in collaboration with the *técnicos locales*), and (2) ability of those variables to enter into a geographic and/or quantitative approach. Where variables could not be quantified, they were either assigned as binary variables (i.e. indigenous population=true/false) or proxy variables were assigned (i.e. sacred sites were chosen as a proxy variable for *Anyi* and altitudinal range was used for verticality). In some cases, no data was available for a given variable, in which case it was not included in the mapping characterization, though it is included in the fuzzy logic system (see figure 2).

Fuzzy logic is a logic operations method which allows for partial truth or degrees of fit. Unlike Boolean logic, which functions according to binary true/false logic, in a fuzzy logic system, the truth values of variables can be any value between 0 and 1 (Klir & Yaun, 1995). Traits are assigned to categories and then expert knowledge is used to set outcomes in if/then logical framing (i.e. "if distance to sacred sites is greater than 75km, then suitability is very low"). Fuzzy logic for suitability analysis is particularly useful because in geographic data, there are a wide range of unpredictable data present, making perfect suitability unlikely (Malczewski, 2006). Fuzzy logic allows for suitability analysis that analyzes degrees of fitness, creating a range of values based on many input values.

Three open-source data analysis programs were utilized: R statistical software, QGIS GIS software, and Diva-GIS GIS software. R and QGIS are very widely used and, being open-source, benefit from robust user community input as well as high accessibility. Diva-GIS is lesser-known, but specifically designed for biodiversity and climate mapping. Open-source software for analysis lowers barriers to replicating the modeling approach in other sites; it is my hope that the analysis carried out here is easily replicable and can be improved through collaborative implementation. The analysis proceeded in three phases: (1) descriptive statistics,

(2) mapping of the *Parque*, and (3) suitability analysis modeling. The suitability analysis model was parameterized using the *Parque* and tested using a hypothetical case from the Navajo Nation in Arizona, USA. More detailed descriptions of each of the phases follow.

4.2.a Descriptive Statistics

R statistical software was used to analyze and characterize the *Parque*, according to several quantitative features. All available variables were matched by geo-referenced coordinates, and then tested for correlation. Spatial data have several unique characteristics—as well as an enormous number of influencing factors—so correlations tended to be relatively weak, but nonetheless helped to establish patterns. Because all climate data was obtained via global-level datasets and satellites, the resolution of the data was too coarse to enter into data analysis at the level of the *Parque*. Instead, I tested climate factors (temperature and precipitation) using the EcoCrop model (DIVA-GIS; FAO) at the continental scale (see Figure 5).

4.2.b Mapping the *Parque de la Papa*

Spatial analysis of the *Parque* leveraged QGIS software to represent all variables in geographic space, and allowed for the visualization of some variables for which data was unavailable. Digital Elevation Models of the area were used to obtain slope, aspect, and hillshade models of the areas, which provide more nuanced information than altitude alone. Landsat data was used to create normalized difference vegetation index (NDVI) rasters for the area which, combined with GLOBCOVER data provided characterization of the land-use types present in the *Parque*. Once the area was mapped, some ideal parameters were extracted, such as distance from roads, population centers, and total area of conserved land. Note that all maps in this project were elaborated using WGS84 projection and units are in meters unless otherwise noted.

4.3.c Suitability Analysis

After the characterization and ranking of relevant variables based on the *Parque*, I created a suitability analysis model utilizing fuzzy logic, which unlike Boolean systems, can assign weighted values to distinct characteristics. First, the fuzzy logic rules were created (see figure 2). For spatial analysis, it is useful to think of suitability in terms of proximity, with a proximity of zero indicating that a characteristic falls within itself (i.e. proximity to river=0m indicates that the selected area is within the river). Thus, most map layers were converted to proximity rasters using the raster distance tool, with the distances corresponding to the fuzzy logic rules. Landuse, slope, and elevation rasters were not converted to proximity rasters, but rather reclassified according to suitability characteristics. Proximity rasters were reclassified to assign a numeric value to each distance, according to suitability. Finally, the raster calculator was used to create a suitability score, using the following formula:

$$(annual\ temp + annual\ precipitation + elevation + slope + landuse\ type + sacred\ sites + rivers + roads + population\ centers) * protected\ areas * indigenous\ land * center\ of\ origin * presence\ of\ CWRs = suitability\ score$$

The suitability formula sums ranked variables and multiples by binary variables, such that any binary variable with a score of 0 will mark the site as unsuitable. However, depending on the data which exist, it is also possible to simply pre-determine these binary variables and not enter them as map layers (i.e. centers of origin are recorded on a regional scale, and are widely debated, so one may wish to exclude this variable from the suitability analysis and instead only examine sites within the given geographical range of a given native crop).

CRITERIA	RULE		CONDITIONS		CONSEQUENCES	SCORE
1	1	**IF**	Indigenous population=False	**THEN**	Suitability is very low	0
	2		Indigenous population=True		Suitability is very high	1
2	1	IF	CWR=False	THEN	Suitability is low	0
	2		CWR=True		Suitability is very high	1
3	1	**IF**	Center of Origin=False	**THEN**	Suitability is low	0
	2		Center of Origin=True		Suitability is high	1
4	1	**IF**	Elevation is greater than 4500m	**THEN**	Suitability is very low	0
	2		Elevation is between 4000-4499m		Suitability is low	1
	3		Elevation is less than 4000m		Suitability is high	2
5	1	**IF**	Land use is ocean or wetland	**THEN**	Suitability is very low	0
	2		Land use is forest		Suitability is low	1
	3		Land use is mixed-use/ agricultural		Suitability is high	2
	4		Land use is agricultural		Suitability is very high	3
6	1	**IF**	Distance to sacred sites is greater than 75km	**THEN**	Suitability is very low	1
	2		Distance to sacred sites is between 31-75km		Suitability is low	2
	3		Distance to sacred sites is between 11-30km		Suitability is high	3
	4		Distance to sacred sites is between 0-10km		Suitability is very high	4
7	1	**IF**	Distance to population center is greater than 200km	**THEN**	Suitability is very low	1
	2		Distance to population center is less than 10km		Suitability is very low	1
	3		Distance to population center is between 150-200km		Suitability is low	2
	4		Distance to population center is between 75-150km		Suitability is high	3
	5		Distance to population center is between 10-		Suitability is very high	4
8	1	**IF**	Precipitation is less than x	**THEN**	Suitability is very low	1
	2		Precipitation is between x-x		Suitability is low	2
	3		Precipitation is greater than x		Suitability is high	3
9	1	**IF**	Area is less than 10,000 hectares	**THEN**	Suitability is very low	0
	2		Area is greater than 10,000 hectares		Suitability is high	1
10	1	**IF**	Slope is greater than 65%	**THEN**	Suitability is very low	1
	2		Slope is between 45-65%		Suitability is low	2
	3		Slope is between 25-45%		Suitability is high	3
	4		Slope is less than 25%		Suitability is very high	4
11	1	**IF**	Distance to river is greater than 3500m	**THEN**	Suitability is very low	1
	2		Distance to river is between 2500-3500m		Suitability is low	2
	3		Distance to river is between 1500-2500m		Suitability is high	3
	4		Distance to river is between 25m-1500m		Suitability is very high	4

Figure 2 The fuzzy logic rules which form the basis of the suitability model. Note that numeric values are bounded by each criterion, and not according to an objective scale. Scores of zero are assigned when a rule would result in complete unsuitability. If the lowest suitability in a category does not correspond to complete unsuitability, it is given a score of 1. The scale within a category always progresses linearly from the lowest score.

5. Ethical Concerns

Given that the communities involved in this study are indigenous peoples with limited economic resources, there is certainly a power differential between the researcher and study participants—every effort was made to allow conversations and projects to be guided by the opinions, insights, and priorities of the community members involved. Working with ANDES, the NGO which supports the *Parque*, helped to alleviate some ethical concerns. ANDES has a long-standing and positive relationship with the communities at the *Parque de la Papa*, and this project fit within the work that the organization does in collaboration with the park. The positive relationship helped to bring community members into the project as collaborators, rather than subjects, and the project aims to produce knowledge that promotes the goals of the communities and deliverables that may be useful for future activities (maps and text).

As previously mentioned, models are necessarily oversimplifications of the systems which they represent. Great care was taken to involve community members and ANDES staff in the selection and characterization of variables which entered into the spatial model, but it is nonetheless impossible to represent the nuance of expertise and opinions in the final modeling approach. For all its appearances of scientific objectivity, modeling relies upon many subjective choices and, when representing the fully realized system of living individuals, these choices have the potential to impact partner communities in both positive and negative ways. Community members identified some variables which were impossible to include in the model directly (such as continuous use of traditional dress) as the most important to the functioning of the *Parque*, and the final model presented here is a compromise between the realities of living individuals and the capacities of mathematical and spatial techniques.

Figure 3 Members of the *Parque de la Papa* wearing traditional dress. *Trajes típicos* (traditional clothing) were identified in conversations with the *técnicos locales* as a key source of identity and pride in the *Parque,* which contributes to the overall success of the area in terms of biocultural conservation.

Epistemological equality is a topic of frequent conversation at ANDES and within the *Parque*—how can traditional knowledge be maintained and actualized without becoming simply a means to enable western scientific analysis? This project, despite its concerted efforts to equitably include all kinds of knowledge nonetheless relies on western methodologies (statistics, GIS, climate science), which can far more easily integrate scientific and quantitative data than traditional knowledge. Ultimately, the goal of the project is to create guidelines and tools for replicating the *Parque de la Papa*, and spatial modeling is a powerful technique for the dissemination of these ideas to a broader audience. However, spatial modeling cannot capture much of the traditional knowledge upon which the success of the *Parque* depends—it proved impossible to adequately represent all ways of knowing equitably within the modeling approach. While the study design aimed to integrate the input of key informants in the selection and weighting of variables, the final decisions were my own, and I cannot escape my own biases as a westerner or academic. I have workshops scheduled to present this work to the communities of the *Parque* and will make adjustments to the model as needed based on feedback—my hope is that through active collaboration, this study can effectively bridge epistemological differences.

6. Findings and Discussion

The findings of the study can be divided into two discreet categories: results which help to characterize the *Parque de la Papa* and results which contribute to a scale-able model for the elaboration of global Food Neighborhoods.

6.1 Characterizing the *Parque de la Papa*:

Interviews and workshops with members of the *Parque de la Papa* revealed a long and varied list of key characteristics, which can be divided into four thematic categories: organizational/political; spiritual/cosmological; cultural; and biological (including ecological and climatic). Of these categories, biological variables entered the most directly into modeling approaches, while proxy variables were assigned as often as possible to political, cosmological, and cultural variables. Table 1 displays a complete accounting of the identified variables. Note that several variables are in more than one category, a reflection of the holistic nature of the Quechua worldview, in which human, biological, and divine aspects are mutually constituted through reciprocal relationships and obligations. Certain key variables proved impossible to meaningfully include in spatial models of the *Parque*, particularly cosmological concepts like *ayni* and *yanantin* and cultural practices like traditional dress. Figure 4 shows examples of spiritual and ritual practice in the *Parque*—while these variables don't enter into the spatial model, they were key in thinking through the Food Neighborhoods concept.

Organizational/ Political	**Spiritual/ Cosmological**	**Cultural**	**Biological**
Agreements with CIP	*Ayllu* system	Agricultural calendar	Agrobiodiversity (esp. potatoes)
Ayllu system	*Ayni* (reciprocity)	*Ayllu* system	Altitude
Collaboration with ANDES	Ceremonies (month of August is especially important)	*Ayni* (reciprocity)	Climate change
Community assemblies	*Ini (*faith, belief)	Indigenous and/or *campesino* communities	Clouds
Economic collectives	*Los apus* (sacred mountains)	*Munay* (learning with your heart)	Crop Wild Relatives
Governance structure	*Munay* (learning with your heart)	Music and dance	Glaciers
Indigenous and/or *campesino* communities	Offerings (annual cycle)	Organic agriculture	Periods of freezing (*heladas)*
Infrastructure in each community	Offerings (every day)	Quechua language	Pests and diseases
Intellectual propoerty and collective trademark	Organic agriculture	Seed network	Precipitation
Inter-community agreements	Stars (esp. Pleiades)	Traditional dishes/recipes	Rainy season/dry season
Inter-community directives	*Sumaq Kawsay* (harmonious living)	Traditional dress	Rivers
Los apus autoridades (elected mountain leaders)	*Yanantin* (duality; equality)	Traditional knowledge	Soil types
Seed bank		*Yanantin*	Stars (esp. Pleiades)
Seed network			Temperature
Social events (workshops, parties, etc.)			Verticality (*pisos ecologicos)*
Yanantin (duality; equality)			Winds

Table 1 Variables identified to characterize *Parque de la Papa* through interviews, workshops, and observation. Note that ecological and climactic variables were combined into a single category based in confusion about distinction between the categories on the part of *técnicos*.

Figure 4 Rituals in the *Parque de la Papa*. At left, a traditional welcoming ceremony is performed, using coca leaves and chicha. At right, a member of the *Parque* observes on of the *Apus* (sacred mountains) embedded in the landscape of the *Parque.* Image credits: Asociación ANDES.

The first step in both characterization and elaborating a spatial modeling approach was examining the *Parque de la Papa* in a regional context, in terms of both climactic variables (temperature and precipitation) and species richness of wild potatoes. EcoCrop models (Diva-GIS) indicated relatively low suitability for Potato cultivation in the Peruvian Andes, contradictory to observed data (figure 5).

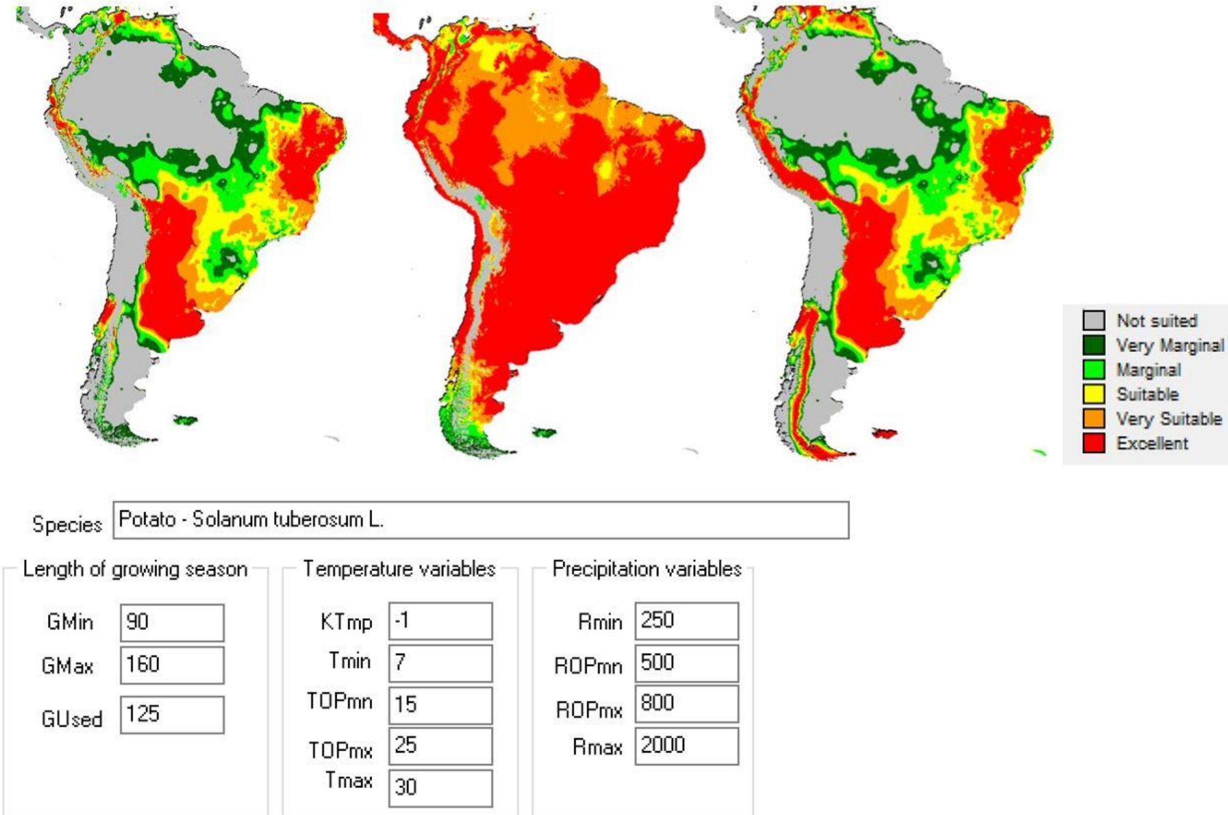


Figure 5 EcoCrop (FAO, Diva-GIS) models of Potato (*Solanum tuberosum*) using defaults from EcoCrop database (below), where KTMP is the temp that will kill the plant, Tmin/Tmax is the average min/max temp at which plant will grow, TOPmn/TOPmx is the min/max average temp for optimal growth, Rmin/Rmx is the min/max rainfall (mm) during the growing season, and ROPmn/ROPmx is the optimal min/max rainfall during the growing season. From left: (1) suitability determined as a function of annual temperature scores multiplied by annual precipitation score, (2) suitability determined as limited by annual minimum temperature, and (3) suitability determined as limited by annual precipitation. In cases factoring temperature, the Andes of Southern Peru are calculated to be unsuited for potato cultivation, contrary to the incredibly high diversity of potatoes found in the area.

The climate suitability models, despite underestimating the growing range of potato in the Andes, do show small areas of excellent suitability which coincide with the location of the *Parque*, validating the choice of the site as an ideal Food Neighborhood. The model also suggests that climatic variables beyond temperature and precipitation may play a significant role in the suitability of a landscape for potato cultivation, which should be taken into account in future considerations about site suitability. An additional consideration in the use of climate data is the persistent issue of downscaling: when it comes to sites for landscape management as Food Neighborhoods, we are likely to be interested in areas much smaller than the average resolution of global-level climate data. Micro-climatic factors can be key determining factors in the survival of crops and in crop yields, so local climates warrant attention in site selection. In the case of the *Parque*, there is not currently climate or weather data available that has been collected on site, or even regionally, so I was only able to include coarse resolution data in the modeling. However, ethnographic data revealed that average temperatures are increasing in the area, and that droughts have become an issue of particular concern, indicating that both cultivation and management strategies must pay particular attention to resilience and adaptation to these conditions.

It is likely to be impossible to select sites with ideal climates, especially in the context of climate change. Instead, it is essential to be aware of the climate factors that exist so that management for adaptation and resilience can be as effective as possible. While it may be possible to exclude certain cultivars on the basis of climate factors, these crops are likely to be excluded by other variables in the model anyway (i.e. tropical fruits will be excluded in suitability analyses for temperate latitudes on the basis of centers of origin as well as climate mismatch). However, the analysis of temperature and precipitation in the *Parque* did reveal some useful parameters: data from the WorldClim model and the TRMM satellite were combined and mean temperature and precipitation was calculated for the *Parque* area. Mean annual temperature is $8.4^{o}C$ and mean annual precipitation is 673mm.

I consider both centers of origin and centers of diversification in elaborating the Food Neighborhoods model, supposing that conserving the greatest amount of plant genetic diversity is the final goal. In order to validate the site of the *Parque de la Papa*, I considered not just potential growing suitability, but also recorded presence of potato landraces. The Southern Andes are recognized as the center of crop origin for potatoes and, according to both ethnographic and scientific data, there are about 2000 varieties of potatoes grown in the Andes region today. Figure 6 shows records of all potato landraces from the Global Roots and Tubers Database, confirming that Peru is home to the greatest number of landraces in the world, and thus justifying it as the home of a potato Food Neighborhood (i.e. the *Parque de la Papa*).

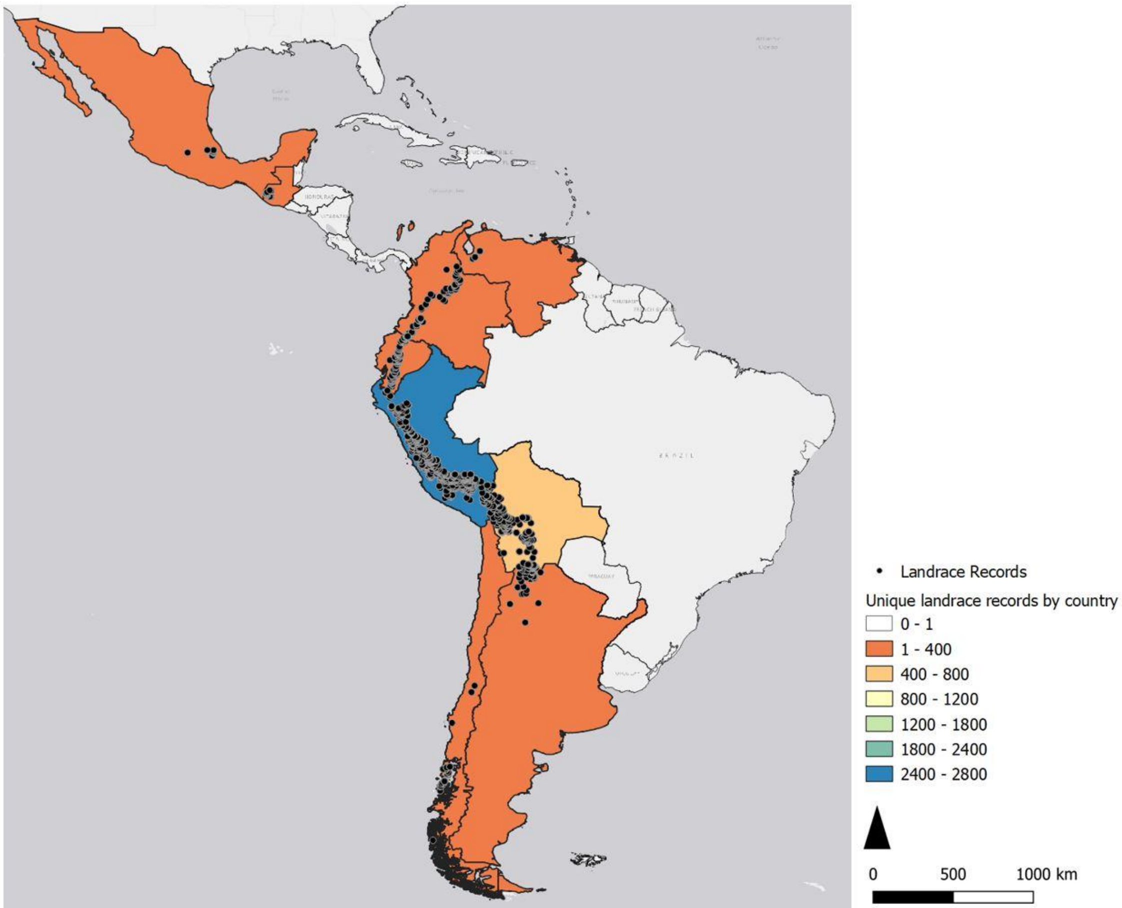


Figure 6 All georeferenced (i.e. including latitude and longitude) records from the Global Roots and Tubers Database (CIP) for landraces of Potato were mapped and then grouped by country. Peru has, by far, the most global records of Potato landraces in cultivation. It should be noted that these data are not identified to species level—the data represent unique records, not unique species.

Having considered climate and agrobiodiversity in in regional context in order to validate the site of the *Parque de la Papa*, I mapped all key variables in the area and calculated descriptive statistics for quantitative variables. It was not possible to establish correlation between climate variables and altitude, soil type, or crop types because the resolution of the climate data was too coarse. It should be noted that no time series data was available within the

Parque, from which it may be possible to establish correlations; all data which entered into the present analysis is spatial in nature. Mapping and statistical analysis revealed that the most key relationships within the *Parque* are those driven by verticality.

6.1.a Verticality in the *Parque de la Papa*:

Several dimensions of verticality were examined in characterizing the *Parque*, and in spatial, statistical, and ethnographic analysis the relationship of cultivation and culture to ecological zones defined by altitudinal ranges was the defining system of organization and success within the *Parque.* First, I examined the altitudinal range that exists within the *Parque*, and used the DEM to create a model of both slope (steepness) and aspect (directionality of sunlight). The *Parque* has a wide altitudinal range (about 3000-4800 meters above sea level), and is mainly characterized by moderate slopes (less than 50 degrees) and east/west facing slopes (figure 7). Ethnographic data emphasized the importance of this variability and range as the basis for high agrobiodiversity, as well as underpinning food sovereignty for the communities of the *Parque.* These conditions impact different crops differently, but provide ideal conditions for potatoes, which thrive in the sunny high elevation fields of the area and help to stabilize slopes against soil erosion.

I also analyzed the distribution of both CWRs (Figure 8) and soils (Figure 9) by elevation in the *Parque*. The boxplots for each of these analyses show the five number summaries (minimum, first quartile, median, third quartile, and maximum) for each of the variables by altitude. These boxplots clearly show the limited altitudinal range of most CWR species and soil types found in the *Parque.*

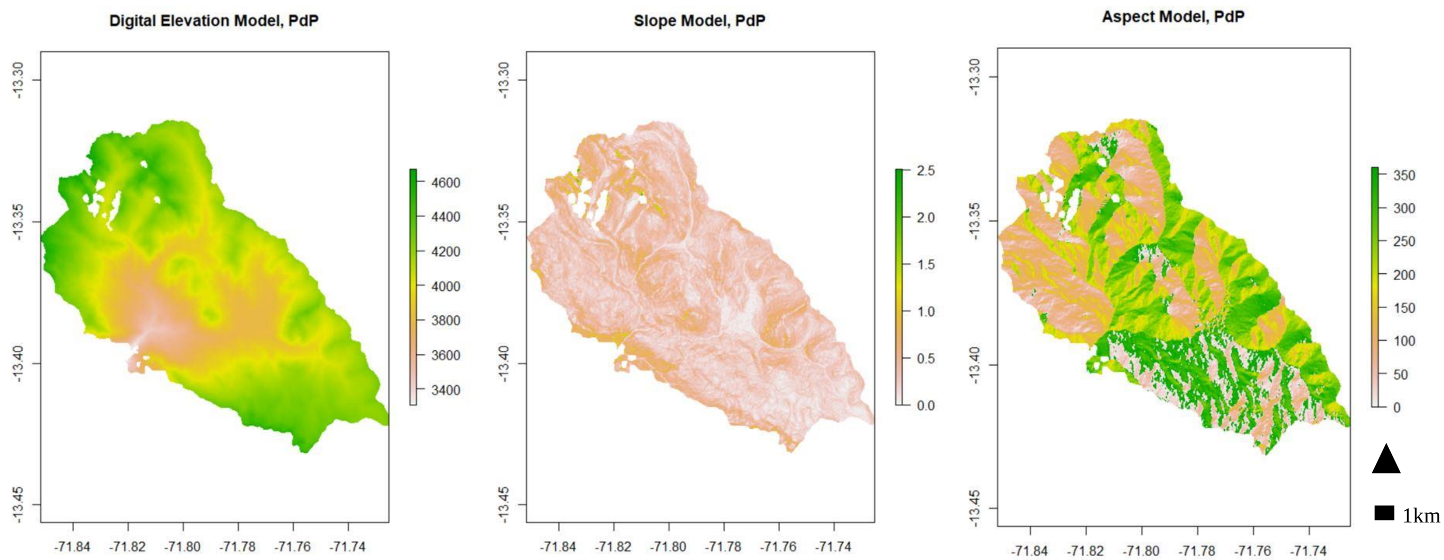
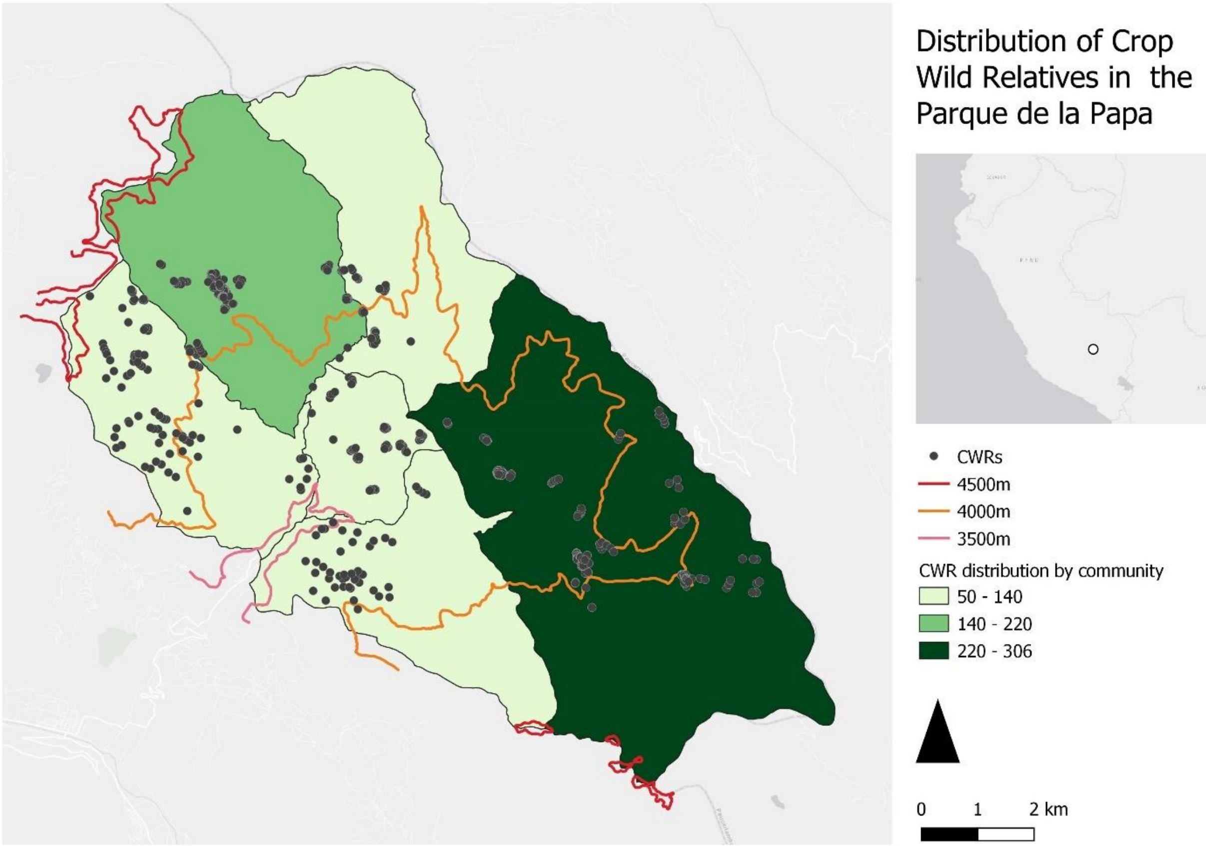


Figure 7 Understanding elevation in the *Parque de la Papa*. From left: Digital Elevation Model (DEM) of the *Parque*; slope model of the *Parque*; and aspect model of the *Parque.* Note that the scale for the DEM model is in meters, while the scale for the slope model is in degrees with a tangent transformation (for display clarity), and the scale for the aspect model is in degrees.

Verticality is well-established as a concept fundamental to Andean and Quechua agricultural and social systems, so it is unsurprising that it should have arisen as the key variable in the *Parque*. The Incan empire, for example, is said to have been able to thrive by exploiting vertical organization throughout the Andes in order to maximize production (Murra, 2002; PRATEC, 2009). Within the *Parque*, verticality is the underpinning for the level of agrobiodiversity which has been realized as it provides a tremendous number of ecological niches, and is also the basis for nutrition, food systems, and social organization. Depending on the location of a given individual *chakra* (cultivation plot), the farmer will have the ability to grow certain crops but not others; thus exchange takes place across vertical space so that families living and cultivating *chakras* at given altitudes are able to access the crops which thrive above and below their fields. Verticality leads to specialization, both in terms of cultivation strategies and crop genetics (see figures 8 and 9).



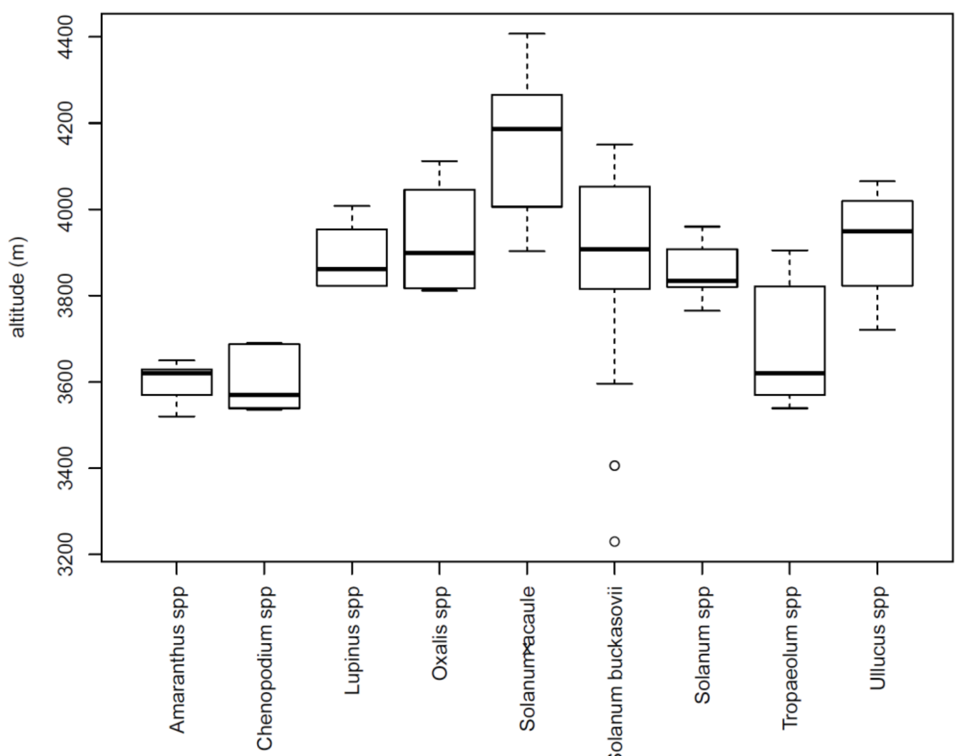
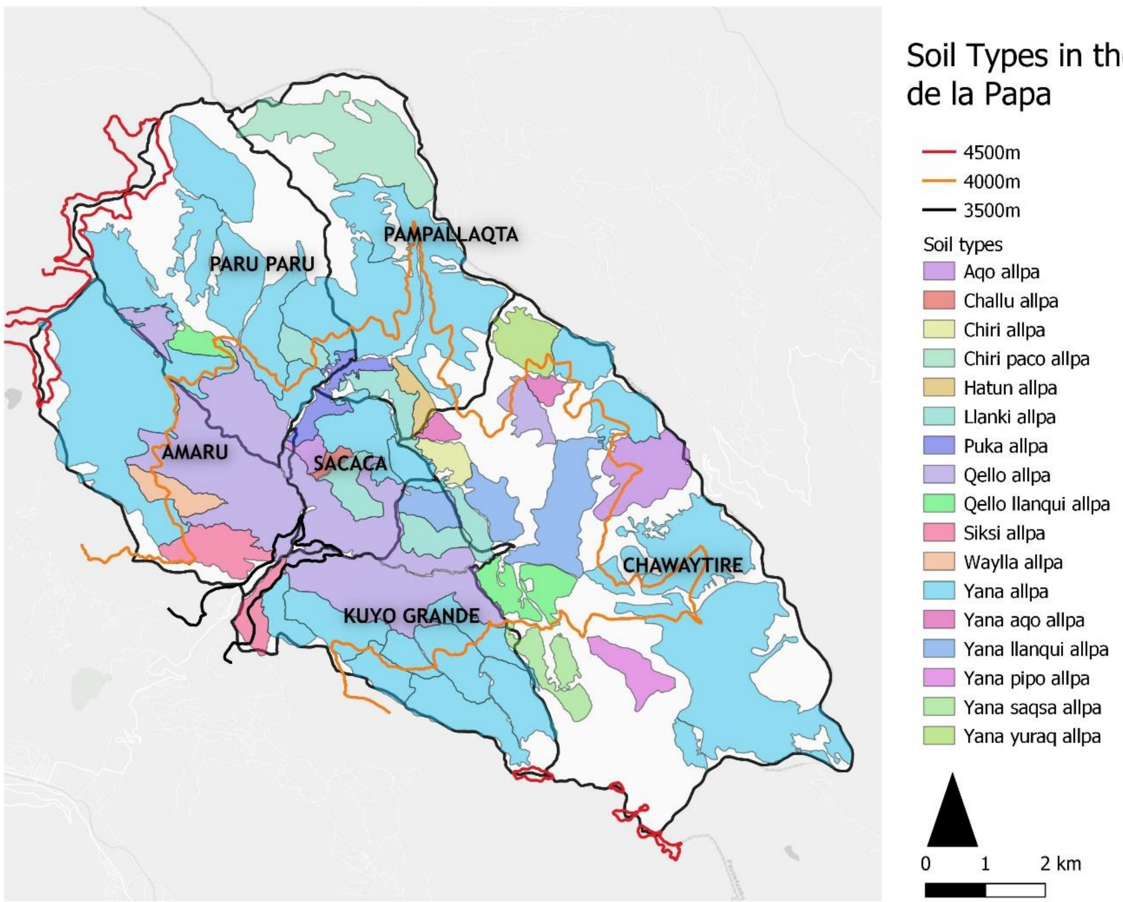


Figure 8 Distribution of Crop Wild Relatives (CWRs) by altitude in the *Parque de la Papa.* CWR data was collected in participatory mapping activities carried out in 2011-2012 by ANDES; here, georeferenced data points are intersected with communities and distribution by elevation is calculated. The two high elevation communities of the *Parque* (Paru Paru and Chawaytire) have the highest density of CWRs, and distribution shows clear altitudinal zones for each of the 9 CWRs present in the *Parque.*



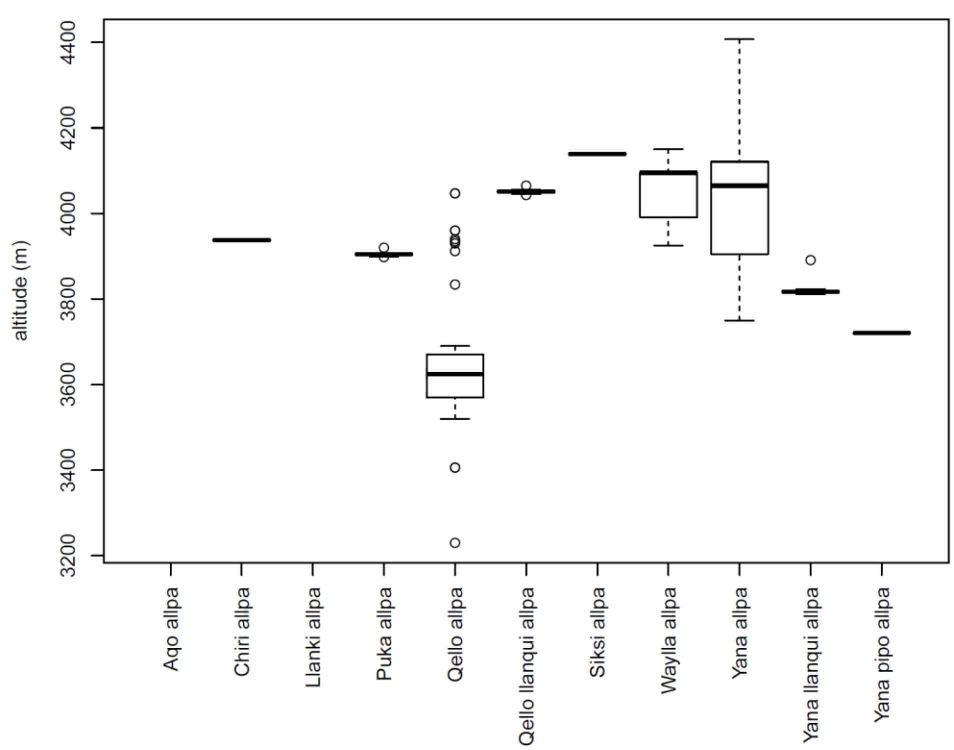


Figure 9 Distribution of Soil Types in the *Parque de la Papa*. Like CWRs, soil types show a correlation with altitudinal range. A list of the present soil types with brief descriptions can be found in Appendix 2. Soil conditions are a key determinant in the success of given crops, and the distribution of soils by altitude in the *Parque* is one of the main conditions considered during planting.

6.1.b Other variables in the *Parque de la Papa*

Aside from verticality, I mapped and analyzed data related to watersheds, population centers, roads, and land use type. One challenge of using land use data in the analysis is that agricultural land is often categorized as degraded landscape and, in some cases, the pixels for degraded land are not possible to distinguish from agricultural use land. The *Parque* shows land use pixels for both mixed use and agricultural land and, in NDVI modeling, bands corresponding to both degraded land and healthy vegetation. I thus used agricultural land, mixed-use land, and degraded land pixels to characterize the *Parque* and parameterize the suitability analysis (the goal of Food Neighborhoods is to create areas of conservation for agrobiodiversity, and this is best realized where agriculture is already being practiced). The main *Apus* (sacred mountains) were added to the map with the help of the *técnicos locales* and, while other sacred sites exist within the *Parque*, I added only four to the map because the represent the points of maximum distance between any given pixel and a sacred site.

Ultimately, the characterization of the *Parque* revealed the complex interplay of variables in the system. Several variables were impossible to map (i.e. the use of traditional dress, the Quechua language, and the ritual calendar), but nonetheless are included in my definition of Food Neighborhoods. Those variables that could be mapped were analyzed and intersected wherever possible, revealing the importance of a diversity of ecological niches (which in the *Parque* are formed vertically), the centrality of sacred sites to spatial organization, and the importance of access to water resources across the entire space. Roads and population centers did not enter into analysis of the space, but are included as parameters because access to Food Neighborhoods is a key part of their ability to provide improved livelihood options through ecotourism and gastronomy initiatives.

6.2 Suitability analysis

After collecting and analyzing the variables of importance in the *Parque de la Papa*, I used the results to parameterize a suitability analysis model. The Navajo Reservation of Northern Arizona was chosen as a test site for the model because I had previously completed ethnographic work in the area and had access to relevant data. It should be noted that, for several reasons, the site may not actually be an ideal choice for Food Neighborhood development. First, there isn't recorded evidence of CWRs in the area, though this doesn't necessarily mean they don't exist. Second, there is not evidence that the area hosts high agrobiodiversity, and traditional low-carbon agricultural practices have been substantially eroded through colonization and assimilation policies. However, despite these limitations, it provides a useful test case for the suitability model. The result of the model can be seen in Figure 10.

Currently, the model is significantly limited by processing power—the approach utilized is impractical for application to very large areas. For example, the model wouldn't work well to identify all suitable sites for Food Neighborhoods development at a country scale, but it is easy to apply and relatively quick at a community- or state-level scale, making it a significant first step in the scaling-up of the Food Neighborhoods model. For example, within the test case, the model effectively identifies two zones with very high suitability for Food Neighborhood development (areas with blue coloring in Figure 10), which would prove incredibly valuable if leaders of the Navajo community were to be interested in developing a management area. Ideally, machine learning approaches can be applied to the suitability analysis in the future to increase its efficacy for identifying Food Neighborhood sites at a country or global scale. Additionally, as with all modeling approaches, the suitability analysis requires the input of a significant amount of data, some of which is only available through ethnographic sources (like sacred sites), meaning that a certain level of regional expertise is required to effectively implement the analysis.

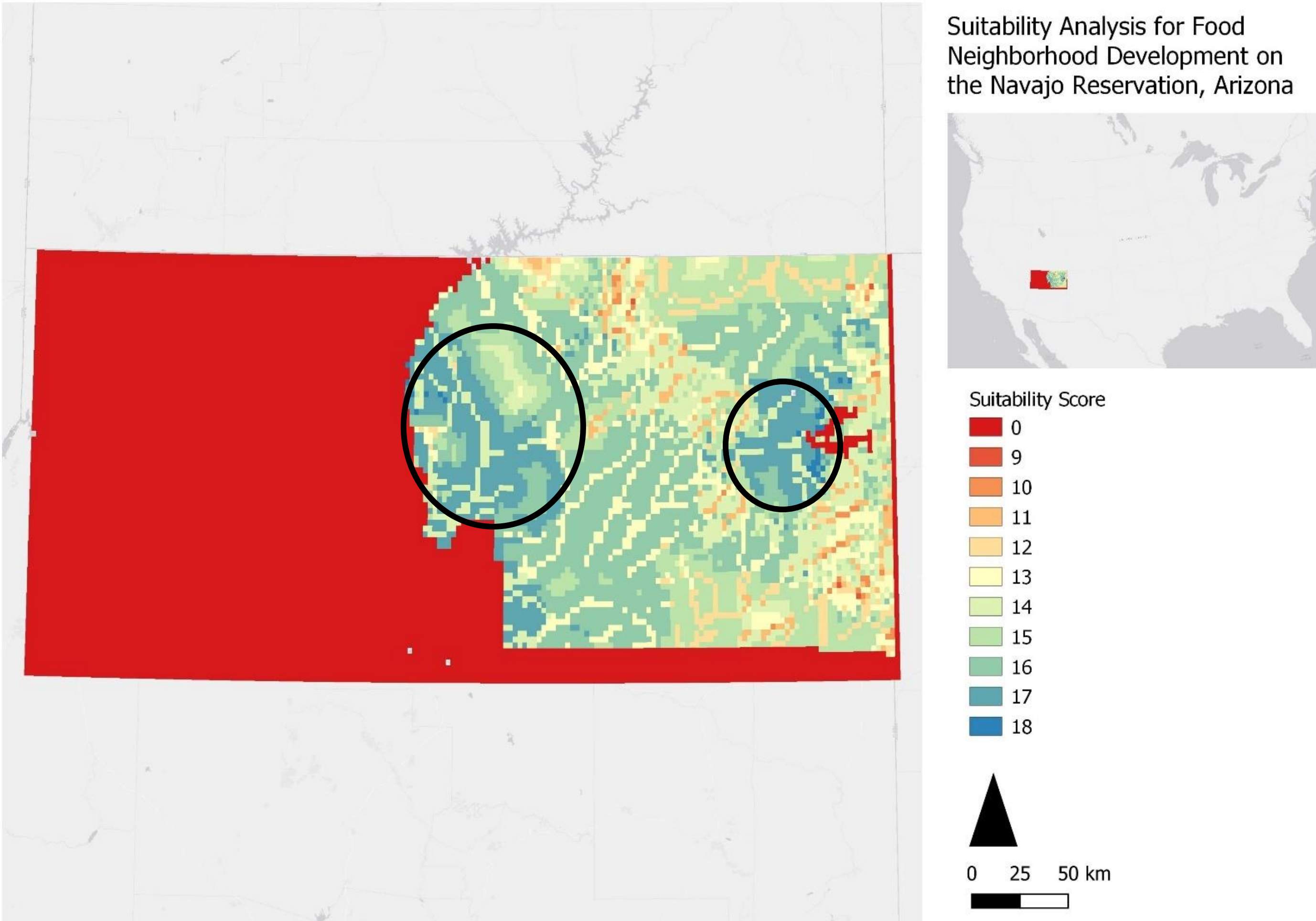


Figure 10 The output of the suitability analysis for the Navajo Reservation in Arizona, USA. Raster calculus resulted in a maximum suitability value of 18 (displayed in blue) and a minimum value of 0 (displayed in red). The analysis resulted in two highly suitable locations for Food Neighborhood development within the reservation (circled in black).

7. Conclusions and Recommendations

Taken together, the ethnographic and spatial characterizations of the *Parque de la Papa* create an actionable set of parameters for suitability analysis towards the up-scaling of the Food Neighborhoods model. Analysis reveals that ecological diversity and proximity to sacred sites are the two most important variables in the spatial organization of the area, as well as the driving forces behind biocultural management strategies. The *Parque* provides an impressive example of the potential of biocultural, indigenous landscape management to contribute to food security, food sovereignty, biological innovation, and cultural preservation. As an ideal example of a Food Neighborhood, the *Parque* is an important basis for thinking through how similar methodologies can be applied across the globe, especially in the context of a changing climate which increasingly threatens agricultural systems and mountain ecosystems.

No model is perfect, and this study underlines the difficulty of capturing the huge variety of variables and ways of knowing that enter into complex and lived systems. Nonetheless, it is my hope that the modeling approach elaborated here provides at least the basic tools necessary for undertaking the first steps in replicating the successes of the *Parque* in indigenous communities around the world. It is important to recognize that spatial and quantitative tools alone will never be sufficient on their own to identify Food Neighborhood sites: the on-the-ground knowledge and experiences of community members, and their academic and professional partners, are equally important in planning sites for agrobiodiversity landscape management. Ultimately, I conceptualize Food Neighborhoods as areas intimately linked to the place-ness of sites, and even the most sophisticated geographic analyses cannot truly capture the place-ness of a landscape.

It should be noted that, while I intend Food Neighborhoods to serve as a globally-applicable model of indigenous landscape management, the definition and model elaborated here are heavily influenced by the particulars of Andean and Quechua cosmology and landscape management. While indigenous people around the world tend to share certain values, beliefs, and practices related to nature and food systems, a significant component of the work in any future Food Neighborhood development project will necessarily be the identification of the salient local cosmovisions which underpin the sustainable food system of a given area. Mariano, one of the *técnicos,* always tells visitors that the members of the *Parque* are engaged in "*agricultura inteligente*" (intelligent agriculture), which doesn't rely on chemicals, or machines, or modified seeds. "Es la forma en que siempre habíamos cultivado nuestras papas ... cualquier otra forma, eso no es inteligente."[3] What Mariano refers to as intelligent agriculture is the entire system of the *Parque de la Papa*, ranging from the use of organic fertilizers to the community seed bank to the calendar of ritual offerings to *Pachamama* (mother earth). The task in upscaling Food Neighborhoods is not to identically replicate the *Parque*, which is built upon distinctly Quechua principles, but rather to identify intelligent agricultural practices within their cultural contexts and build from there. My hope is that the model I have elaborated here is a useful step in identifying potential sites for Food Neighborhood development, but there is no way to quantify or model the indigenous practices which underpin intelligent agriculture.

In recognition of the deficiencies of quantitative approaches for replicating the *Parque de la Papa*, I conclude here by providing some sociological recommendations about the necessary characteristics and intended outcomes of a Food Neighborhood. By combining these guidelines with the spatial and physical characteristics analyzed above, it is possible to more fully understand, and evaluate the successes of a Food Neighborhood. Additionally, these characteristics and goals lay the framework for indicators that could be used in the monitoring and evaluation of future Food Neighborhood sites.

The essential characteristics of a Food Neighborhood are:

- Indigenous landscape management which arises from a cosmovision intrinsically related to natural landscapes and/or agriculture
- Strong, place-based relationships between cultural practices and food systems

[3] "This is the way that we have always cultivated our potatoes…any other way would be unintelligent." (Translation of author). *Presentation at an educational visit July 1, 2019.*

- The presence and management of CWRs
- High levels of agrobiodiversity, realized through ongoing innovation
- Strong and healthy interactions between flora, fauna, and humans
- *In situ* conservation of plant genetic resources
- Participation in agricultural systems across all genders and age groups
- Collaboration both within the participating communities themselves and with a global network of producers

The key intended outcomes of a Food Neighborhood are:

- Strengthening indigenous and farmers' rights to lands, culture, and health
- Conserving agrobiodiversity for adaptation, resilience, and food security
- Improved and innovative livelihood options
- Conservation, innovation, and knowledge related to CWRs
- Contribute to a global food system which is sustainable, resilient, equitable, healthy, and delicious
- Creating *trans-situ* conservation systems, which link *ex situ* collections with *in situ* practices

This project aims to provide an initial definition for Food Neighborhoods as a category of indigenous landscape management and agrobiodiversity conservation based upon biocultural methodologies. The *Parque de la Papa* provides a successful example of how a Food Neighborhood can be actualized at the community level and serves as the emblematic case for the elaboration of the suitability analysis presented here. However, there is still much to be done towards the development of a global network of Food Neighborhoods. As previously mentioned, this study is strongly influenced by the specifics of Quechua cosmovision which underpin the functioning of the *Parque*, and further work is needed to investigate how the Food Neighborhoods concept fits within other cosmovisions in different parts of the world. The suitability model presented here is a first step in elaborating a methodology for site selection, but there is considerable work to be done testing the model on other cases and parameterizing variables according to a wider range of experiences. There is need for additional theoretical investigation as well, to strengthen the analytical framework of the concept. In particular, further research is needed to more exactly define the spatial and human relationships which constitute "neighborhoods" in this case, and more research is needed to understand how the Food Neighborhoods concept dovetails with other indigenous landscape management methodologies.

I recognize that a major barrier in the modeling approach I have elaborated is the relatively high data density required—a vital step in the development of Food Neighborhoods will be the collection of relevant data in potential sites, which is not a small task. The current model relies on satellite data for climate variables, but issues of downscaling render the data insufficient to study the localized impacts of climate variability. Indigenous methodologies for the collection of relevant climate data need to be integrated into the approach so that the climate adaptation and resiliency potential of Food Neighborhoods can be more fully measured and realized. Additionally, the modeling approach used here is severely limited by processing power as it relies on manual data inputs and transformations, which are very time consuming—the approach is only appropriate for relatively narrow areas (i.e. it works for the Navajo Reservation, but would be impractical to apply to the entire U.S.). Thus, an important next step in the modeling approach is to apply machine learning techniques to increase the ability to analyze large geographic areas.

As evidenced by the *Parque de la Papa*, Food Neighborhoods can increase the climate change adaptability and resiliency of indigenous populations, while increasing their rights to land, water, and food sovereignty. They also have the potential to serve as sites of *trans-situ* conservation, which link the high agrobiodiversity found in the fields of *campesinos* to the technological capacities of gene banks, and vice versa. The world's population is increasingly vulnerable to food insecurity as climate change drastically alters growing conditions in fields everywhere, and an overdependence on a small number of crops increases this vulnerability. Food Neighborhoods present an alternative to industrial, global agriculture, recognizing the place-ness of cultivation as a key component of its sustainability. A global network of Food Neighborhoods would serve to not only protect the food security of some of the world's most vulnerable populations, but would also contribute to a global food system that is equitable, sustainable, and healthy.

References

Adebooye, O. C., & Opabode, J. T. (2004). Status of conservation of the indigenous leaf vegetables and fruits of Africa. African Journal of Biotechnology, 3(12), 700-705.

Addicott, J. F., Aho, J. M., Antolin, M. F., Padilla, D. K., Richardson, J. S., & Soluk, D. A. (1987). Ecological neighborhoods: scaling environmental patterns. Oikos, 340-346.

Adger, W. N., Barnett, J., Chapin III, F. S., & Ellemor, H. (2011). This must be the place: underrepresentation of identity and meaning in climate change decision-making. Global Environmental Politics, 11(2), 1-25.

Agrawal, A., & Gibson, C. C. (1999). Enchantment and disenchantment: the role of community in natural resource conservation. World development, 27(4), 629-649.

Altieri, M.A., Anderson, M.K., & Merrick, L.C. (1987). Peasant Agriculture and the Conservation of Crop and Wild Plant Resources. Conservation Biology, 1(1), 49-58.

Altieri, M. A., & Merrick, L. (1987). In situ conservation of crop genetic resources through maintenance of traditional farming systems. Economic Botany, 41(1), 86-96.

ANDES. (2016). Resilient Farming Systems in Times of Uncertainty: Biocultural Innovations in the Potato Park, Peru. London: IIED. http://pubs.iied.org/pdfs/14663IIED.pdf

Argumedo, A. (2008). The Potato Park, Peru: Conserving agrobiodiversity in an Andean indigenous biocultural heritage area. Protected landscapes and agrobiodiversity values, 1, 45.

Argumedo, A., & Stenner, T. (2008). Association ANDES: conserving indigenous biocultural heritage in Peru. International Institute for Environment and Development.

Asociación ANDES. (n.d.) *Acerca de ANDES.* Accessed April 6, 2019 at http://www.andes.org.pe/acerca.

Backes, M. M. (2001). The role of indigenous trees for the conservation of biocultural diversity in traditional agroforestry land use systems: the Bungoma case study: in-situ conservation of indigenous tree species. Agroforestry Systems, 52(2), 119-132.

Baied, C. A., & Wheeler, J. C. (1993). Evolution of High Andean Puna Ecosystems: Environment, Climate, and Culture Change over the Last 12,000 Years in the Central Andes. Mountain Research and Development, 13(2), 145.

Balram, S., Dragićević, S., & Meredith, T. (2004). A collaborative GIS method for integrating local and technical knowledge in establishing biodiversity conservation priorities. Biodiversity and Conservation, 13(6), 1195–1208.

Basso, K. H. (1996). Wisdom sits in places: Landscape and language among the Western Apache. UNM Press.

Beddington, J. R., Asaduzzaman, M., Fernandez, A., Clark, M. E., Guillou, M., Jahn, M. M., ... & Scholes, R. J. (2012). Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change. Research Program on Climate Change, Agriculture, and Food Security, Copenhagen.

Bélair C., Ichikawa K., Wong B.Y. L., and Mulongoy K.J. (Editors) (2010). Sustainable use of biological diversity in socio-ecological production landscapes. Background to the 'Satoyama Initiative for the benefit of biodiversity and human well-being.' Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 52, 184 pages.

Bellon, M. R. (2004). Conceptualizing interventions to support on-farm genetic resource conservation. World Development, 32(1), 159-172.

Bellon, M. R., Gotor, E., & Caracciolo, F. (2015a). Conserving landraces and improving livelihoods: how to assess the success of on-farm conservation projects?. International Journal of Agricultural Sustainability, 13(2), 167-182.

Bellon, M. R., Gotor, E., & Caracciolo, F. (2015b). Assessing the effectiveness of projects supporting on-farm conservation of native crops: evidence from the high andes of South America. World development, 70, 162-176.

Bellon, M. R., Dulloo, E., Sardos, J., Thormann, I., & Burdon, J. J. (2017). In situ conservation—harnessing natural and human-derived evolutionary forces to ensure future crop adaptation. Evolutionary applications, 10(10), 965-977.

Bennett, N. J. (2016). Using perceptions as evidence to improve conservation and environmental management. Conservation Biology, 30(3), 582-592.

Biggs, D., Abel, N., Knight, A. T., Leitch, A., Langston, A., & Ban, N. C. (2011). The implementation crisis in conservation planning: could "mental models" help?. Conservation Letters, 4(3), 169-183.

Branch, N. P., Kemp, R. A., Silva, B., Meddens, F. M., Williams, A., Kendall, A., & Pomacanchari, C. V. (2007). Testing the sustainability and sensitivity to climatic change of terrace agricultural systems in the Peruvian Andes: a pilot study. Journal of Archaeological Science, 34(1), 1-9.

Brandenburg, A. M., & Carroll, M. S. (1995). Your place or mine?: The effect of place creation on environmental values and landscape meanings. Society & Natural Resources, 8(5), 381-398.

Brown, J., & Kothari, A. (2011). Traditional agricultural landscapes and community conserved areas: an overview. Management of Environmental Quality: An International Journal, 22(2), 139-153.

Brush, S. B. (1993). Indigenous knowledge of biological resources and intellectual property rights: the role of anthropology. American Anthropologist, 95(3), 653-671.

Cabeza, M., & Moilanen, A. (2001). Design of reserve networks and the persistence of biodiversity. Trends in ecology & evolution, 16(5), 242-248.

Caillon, S., Cullman, G., Verschuuren, B., & Sterling, E. J. (2017). Moving beyond the human–nature dichotomy through biocultural approaches: including ecological well-being in resilience indicators. Ecology and Society, 22(4).

Chepstow-Lusty, A., Frogley, M. R., Bauer, B. S., Bush, M. B., & Herrera, A. T. (2003). A late Holocene record of arid events from the Cuzco region, Peru. Journal of Quaternary Science: Published for the Quaternary Research Association, 18(6), 491-502.

Chepstow-Lusty, A. J., Frogley, M. R., Bauer, B. S., Leng, M. J., Boessenkool, K. P., Caarcaillet, C., ... & Gioda, A. (2009). Putting the rise of the Inca Empire within a climatic and land management context. Climate of the Past, 5(3), 375-388.

Cheung, W., Pitcher, T. J., Cheung, W. W. L., & Pauly, D. (2005). A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. *Biological Conservation*, *124*(1), 97–111.

Chevallier, P., Pouyaud, B., Suarez, W., & Condom, T. (2011). Climate change threats to environment in the tropical Andes: glaciers and water resources. Regional Environmental Change, 11(1), 179-187.

Cometti, G. (2015). Lorsque le brouillard a cessé de nous écouter. Changement climatique et migrations chez les Q'eros des Andes péruviennes. Peter Lang: Berne, Switzerland.

Convention on Biological Diversity [CBD]. (2019). Peru - Biodiversity Facts. Retrieved June 2, 2019, from https://www.cbd.int/countries/profile/default.shtml?country=pe

de Agar, P. M., Ortega, M., & de Pablo, C. L. (2016). A procedure of landscape services assessment based on mosaics of patches and boundaries. Journal of environmental management, 180, 214-227.

De Wit, M. M. (2016). Are we losing diversity? Navigating ecological, political, and epistemic dimensions of agrobiodiversity conservation. Agriculture and Human Values, 33(3), 625-640.

Dyurgerov, M.B., & Meier, M.F. (2005) Glaciers and the changing earth system: a 2004 snapshot. Institute of Arctic and Alpine research occasional paper, vol 58. University of Colorado, Boulder, Colorado, USA.

Devaux, A. (2018). Potato technology and innovations as the critical bridge to respond to food security challenges and promote agribusiness in Latin America. Revista Latinoamericana de la Papa, 22(1), 1-4.

Dulloo, M. E., Labokas, J., Iriondo, J. M., Maxted, N., Lane, A., Laguna, E., ... & Kell, S. P. (2008). Genetic reserve location and design. Conserving plant genetic diversity in protected areas, 23-64.

Eliade, M. (1959). The sacred and the profane: The nature of religion (Vol. 144). Houghton Mifflin Harcourt.

Eoin, L. N., Owens, E., & King, R. (2013, October). Memories of Metolong: the challenges of archiving intangible heritage in development contexts. In 2013 Digital Heritage International Congress (DigitalHeritage) (Vol. 2, pp. 37-44). IEEE.

FAO. 2019. The State of the World's Biodiversity for Food and Agriculture, J. Bélanger & D. Pilling (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome. 572 pp. (http://www.fao.org/3/CA3129EN/CA3129EN.pdf)

Fazey, I., Evely, A. C., Reed, M. S., Stringer, L. C., Kruijsen, J., White, P. C., ... & Blackstock, K. (2013). Knowledge exchange: a review and research agenda for environmental management. Environmental Conservation, 40(1), 19-36.

Fernie, A. R., Tadmor, Y., & Zamir, D. (2006). Natural genetic variation for improving crop quality. Current opinion in plant biology, 9(2), 196-202.

Fick, S.E. & Hijmans, R.J. (2017). Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology.

Food Forever (Global Crop Diversity Trust). (2019). Food Forever | Biodiversity for Resilience. Retrieved July 26, 2019, from https://www.food4ever.org/

Frankel, S. (2011). The mismatch of geographical indications and innovative traditional knowledge. Prometheus, 29(3), 253-267.

Galloway McLean, K., A. Ramos Castillo, J. Rubis (Eds.). 2011. Indigenous peoples, marginalized populations and climate change: Vulnerability, adaptation and traditional knowledge. Mexico City, July 19–21. Compilation of presented abstracts. Accessed June 7, 2019 at: https://unesdoc.unesco.org/ark:/48223/pf0000265874

Gavin, M. C., McCarter, J., Mead, A., Berkes, F., Stepp, J. R., Peterson, D., & Tang, R. (2015). Defining biocultural approaches to conservation. Trends in ecology & evolution, 30(3), 140-145.

Graddy, T. G. (2013). Regarding biocultural heritage: in situ political ecology of agricultural biodiversity in the Peruvian Andes. Agriculture and human values, 30(4), 587-604.

Graddy, T. G. (2014). Situating in situ: A critical geography of agricultural biodiversity conservation in the Peruvian Andes and beyond. Antipode, 46(2), 426-454.

Grêt-Regamey, A., Brunner, S. H., & Kienast, F. (2012). Mountain ecosystem services: who cares? Mountain Research and Development, 32(S1).

Gu, H., & Subramanian, S. M. (2014). Drivers of change in socio-ecological production landscapes: Implications for better management. Ecology and Society, 19(1), 1-13.

Gustafson, E. J., & Parker, G. R. (1994). Using an index of habitat patch proximity for landscape design. Landscape and Urban Planning, 29(2-3), 117-130.

Harlan, J. R. (1971). Agricultural origins: centers and noncenters. Science, 174(4008), 468-474.

Heckenberger, M. J., Christian Russell, J., Toney, J. R., & Schmidt, M. J. (2007). The legacy of cultural landscapes in the Brazilian Amazon: implications for biodiversity. Philosophical Transactions of the Royal Society B: Biological Sciences, 362(1478), 197-208.

Hersperger, A. M. (2006). Spatial adjacencies and interactions: Neighborhood mosaics for landscape ecological planning. Landscape and Urban Planning, 77(3), 227–239. doi:10.1016/j.landurbplan.2005.02.009

Heyd, T. (2014). Symbolically Laden Sites in the Landscape and Climate Change. Ethics, Policy & Environment, 17(3), 355-369.

Hummer, K. E., & Hancock, J. F. (2015). Vavilovian centers of plant diversity: Implications and impacts. HortScience, 50(6), 780-783.

Hutter, C. R., Guayasamin, J. M., & Wiens, J. J. (2013). Explaining Andean megadiversity: the evolutionary and ecological causes of glassfrog elevational richness patterns. Ecology letters, 16(9), 1135-1144.

International Institute for Environment and Development [iied]. (n.d.). Biocultural Heritage Territories: Land use mosaics encompassing indigenous and traditional land tenure, production and exchange systems, cultural identity, community organisation and simultaneous goals of endogenous development and biodiversity conservation. Accessed April 1, 2019 at https://pubs.iied.org/pdfs/G03843.pdf.

International Institute for Environment and Development [iied]. (2018). Biocultural innovation: the key to global food security? Accessed April 1, 2019 at http://pubs.iied.org/17465IIED.

International Potato Center [CIP]. (2016). Global Roots & Tubers Base. Accessed July 23, 2019, at http://germplasmdb.cip.cgiar.org/index.jsp.

International Potato Center [CIP]. (2018). Accessed April 6, 2019 at https://cipotato.org/.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jarvis, D. I., Brown, A. H., Cuong, P. H., Collado-Panduro, L., Latournerie-Moreno, L., Gyawali, S., ... & Hue, N. T. N. (2008). A global perspective of the richness and evenness of traditional crop-variety diversity maintained by farming communities. Proceedings of the National Academy of Sciences, 105(14), 5326-5331.

Jeanneret, P., Schüpbach, B., & Luka, H. (2003). Quantifying the impact of landscape and habitat features on biodiversity in cultivated landscapes. Agriculture, Ecosystems & Environment, 98(1-3), 311-320.

Johns, T., & Sthapit, B. R. (2004). Biocultural diversity in the sustainability of developing-country food systems. Food and nutrition bulletin, 25(2), 143-155.

Keefer, D. K., DeFrance, S. D., Moseley, M. E., Richardson, J. B., Satterlee, D. R., & Day-Lewis, A. (1998). Early maritime economy and EL Niño events at Quebrada Tacahuay, Peru. Science, 281(5384), 1833-1835.

Khoury, C. K., Achicanoy, H. A., Bjorkman, A. D., Navarro-Racines, C., Guarino, L., Flores-Palacios, X., ... & Ramírez-Villegas, J. (2016). Origins of food crops connect countries worldwide. Proceedings of the Royal Society B: Biological Sciences, 283(1832), 20160792.

Klir, G. J., & Yuan, B. (1995). Fuzzy sets and fuzzy logic: theory and applications. Upper Saddle River, 563.

Kothari, A. et al. (Eds.). 2012. Recognising and supporting territories and areas conserved by indigenous peoples and local communities: Global overview and national case studies. Montreal: Convention on Biological Diversity (CBD).

Leppik, E. E. (1970). Gene Centers of Plants as Sources of Disease Resistance. Annual Review of Phytopathology, 8(1), 323–344.

Loh, J., & Harmon, D. (2005). A global index of biocultural diversity. Ecological indicators, 5(3), 231-241.

López-Moreno, J. I., Fontaneda, S., Bazo, J., Revuelto, J., Azorin-Molina, C., Valero-Garcés, B., ... & Alejo-Cochachín, J. (2014). Recent glacier retreat and climate trends in Cordillera Huaytapallana, Peru. Global and Planetary Change, 112, 1-11.

Malczewski, J. (2006). Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. International journal of applied earth observation and geoinformation, 8(4), 270-277.

Mark, B. G., Bury, J., McKenzie, J. M., French, A., & Baraer, M. (2010). Climate change and tropical Andean glacier recession: Evaluating hydrologic changes and livelihood vulnerability in the Cordillera Blanca, Peru. Annals of the Association of American Geographers, 100(4), 794-805.

Matsuoka, R. H., & Kaplan, R. (2008). People needs in the urban landscape: analysis of landscape and urban planning contributions. Landscape and urban planning, 84(1), 7-19.

Maxted, N. & Kell, S. (2009). *Establishment of a Global Network for the In Situ Conservation of Crop Wild Relatives: Status and Needs*. FAO. 224 pages.

Meilleur, B. & Hodgkin, T. (2004). In situ conservation of crop wild relatives: status and trends. Biodiversity and Conservation, 13, 663–684.

Messerli, B., Viviroli, D., & Weingartner R. (2004). Mountains of the World: Vulnerable Water Towers for the 21st Century. AMBIO Special Report, 13, 29–34.

Minority Rights Group International, World Directory of Minorities and Indigenous Peoples - Peru, 2007, available at: https://www.refworld.org/docid/4954ce0b2.html [accessed 6 June 2019]

Mistry, J., & Berardi, A. (2016). Bridging indigenous and scientific knowledge. Science, 352(6291), 1274-1275.

Murra, J. V. (2002). El mundo andino: población, medio ambiente y economía. Lima, Peru: IEP.

Nedkov, S. (2009). Analyzing spatial dimensions of ecosystem services and their valuation using GIS: A case study in Smolyan municipality. Problems of Geography, 4, 53-61.

Nelson, M. C., Ingram, S. E., Dugmore, A. J., Streeter, R., Peeples, M. A., McGovern, T. H., ... & Spielmann, K. A. (2016). Climate challenges, vulnerabilities, and food security. Proceedings of the National Academy of Sciences, 113(2), 298-303.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. Science, 325(5939), 419-422.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., ... & Maris, V. (2017). Valuing nature’s contributions to people: the IPBES approach. Current Opinion in Environmental Sustainability, 26, 7-16.

Pascua, P. A., McMillen, H., Ticktin, T., Vaughan, M., & Winter, K. B. (2017). Beyond services: A process and framework to incorporate cultural, genealogical, place-based, and indigenous relationships in ecosystem service assessments. Ecosystem Services, 26, 465-475.

Paterson, R. K., & Karjala, D. S. (2003). Looking beyond intellectual property in resolving protection of the intangible cultural heritage of indigenous peoples. Cardozo J. Int'l & Comp. L., 11, 633.

Perales, H. R., Benz, B. F., & Brush, S. B. (2005). Maize diversity and ethnolinguistic diversity in Chiapas, Mexico. Proceedings of the National Academy of Sciences, 102(3), 949-954.

Phillips, C. (2016). Saving more than seeds: Practices and politics of seed saving. Routledge.

Poole, A. K. (2018). Where is goal 18? The need for biocultural heritage in the sustainable development goals. Environmental Values, 27(1), 55-80.

Prakash, T. N. (2003, December). Land suitability analysis for agricultural crops: a fuzzy multicriteria decision making approach. ITC.

Pretty, J. N., Morison, J. I., & Hine, R. E. (2003). Reducing food poverty by increasing agricultural sustainability in developing countries. Agriculture, ecosystems & environment, 95(1), 217-234.

Pradel, W., Hareau, G., Quintanilla, L., Suárez, V. (2017). Adopción e Impacto de Variedades Mejoradas de Papa en el Perú: Resultado de una encuesta a nivel nacional (2013). Centro Internacional de la Papa, Lima, Perú. pp. 48

Proyecto Andino de Tecnologías Campesinas (PRATEC) (2009). Cambio climático y sabiduría andino amazónica-Perú: Prácticas, percepciones y adaptaciones indígenas.

Paerregaard, K. (2013). Bare rocks and fallen angels: environmental change, climate perceptions and ritual practice in the Peruvian Andes. Religions, 4(2), 290-305.

Programme des Nations Unies pour l'environnement (UNEP). (1999). Cultural and spiritual values of biodiversity (p. 772). D. A. Posey (Ed.). London: Intermediate Technology.

Rabatel, A., Francou, B., Soruco, A., Gomez, J., Cáceres, B., Ceballos, J. L., ... & Scheel, M. (2012). Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change. The Cryosphere, 7(1), 81-102.

Reyes, R. R. (2002). Gendering responses to El Niño in rural Peru. Gender & Development, 10(2), 60-69.

Reyes-García, V., Paneque-Gálvez, J., Bottazzi, P., Luz, A. C., Gueze, M., Macía, M. J., ... & Pacheco, P. (2014). Indigenous land reconfiguration and fragmented institutions: A historical political ecology of Tsimane'lands (Bolivian Amazon). Journal of Rural Studies, 34, 282-291.

Robbins, P. (2003). Beyond ground truth: GIS and the environmental knowledge of herders, professional foresters, and other traditional communities. Human Ecology, 31(2), 233-253.

Sandweiss, D. H., Maasch, K. A., Burger, R. L., Richardson III, J. B., Rollins, H. B., & Clement, A. (2001). Variation in Holocene El Niño frequencies: Climate records and cultural consequences in ancient Peru. Geology, 29(7), 603-606.

Sandweiss, D. H., Solís, R. S., Moseley, M. E., Keefer, D. K., & Ortloff, C. R. (2009). Environmental change and economic development in coastal Peru between 5,800 and 3,600 years ago. Proceedings of the National Academy of Sciences, 106(5), 1359-1363.

Satterfield, T., Gregory, R., Klain, S., Roberts, M., & Chan, K. M. (2013). Culture, intangibles and metrics in environmental management. Journal of environmental management, 117, 103-114.

Sayre, M., Stenner, T., & Argumedo, A. (2017). You Can't Grow Potatoes in the Sky: Building Resilience in the Face of Climate Change in the Potato Park of Cuzco, Peru. Culture, Agriculture, Food and Environment, 39(2), 100-108.

Silver, C. (1985). Neighborhood planning in historical perspective. Journal of the American Planning Association, 51(2), 161-174.

Sterling, E., Ticktin, T., Morgan, T. K. K., Cullman, G., Alvira, D., Andrade, P., ... & Claudet, J. (2017a). Culturally grounded indicators of resilience in social-ecological systems. Environment and Society, 8(1), 63-95.

Sterling, E. J., Filardi, C., Toomey, A., Sigouin, A., Betley, E., Gazit, N., ... & Blair, M. (2017b). Biocultural approaches to well-being and sustainability indicators across scales. *Nature ecology & evolution*, *1*(12), 1798.

Sugiyama, T., Francis, J., Middleton, N. J., Owen, N., & Giles-Corti, B. (2010). Associations between recreational walking and attractiveness, size, and proximity of neighborhood open spaces. American Journal of Public Health, 100(9), 1752-1757.

Talen, E. (2000). Bottom-up GIS: A new tool for individual and group expression in participatory planning. Journal of the American Planning Association, 66 (3), 279-294.

Thomson, B. (2011). Pachakuti: Indigenous perspectives, buen vivir, sumaq kawsay and degrowth. Development, 54(4), 448-454.

Tripathi, N., & Bhattarya, S. (2004). Integrating indigenous knowledge and GIS for participatory natural resource management: State-of-the-practice. The electronic journal of information systems in developing countries, 17(1), 1-13.

Trubek, A. B. (2008). The taste of place: A cultural journey into terroir (Vol. 20). Univ of California Press.

Tse-ring, K., Sharma, E., Chettri, N., & Shrestha, A. B. (2010). Climate change vulnerability of mountain ecosystems in the Eastern Himalayas. International centre for integrated mountain development (ICIMOD).

van Etten, J., de Sousa, K., Aguilar, A., Barrios, M., Coto, A., Dell'Acqua, M., ... & Kiros, A. Y. (2019). Crop variety management for climate adaptation supported by citizen science. Proceedings of the National Academy of Sciences, 116(10), 4194-4199.

van Oudenhoven, F. J., Mijatović, D., & Eyzaguirre, P. B. (2011). Social-ecological indicators of resilience in agrarian and natural landscapes. Management of Environmental Quality: An International Journal, 22(2), 154-173.

Velásquez-Milla, D., Casas, A., Torres-Guevara, J., & Cruz-Soriano, A. (2011). Ecological and socio-cultural factors influencing in situ conservation of crop diversity by traditional Andean households in Peru. Journal of ethnobiology and ethnomedicine, 7(1), 40.

Verschuuren, B. (2012). Arguments for developing biocultural conservation approaches for sacred natural sites. In Sacred Natural Sites (pp. 88-98). Routledge.

Vuille, M., Francou, B., Wagnon, P., Juen, I., Kaser, G., Mark, B. G., & Bradley, R. S. (2008). Climate change and tropical Andean glaciers: Past, present and future. Earth-science reviews, 89(3-4), 79-96.

Whyte, K., Caldwell, C., & Schaefer, M. (2018). Indigenous lessons about sustainability are not just for ‘‘All Humanity’’. Sustainability: Approaches to Environmental Justice and Social Power, 149.

Walshe, R., & Argumedo, A. (2016). Ayni, Ayllu, Yanantin and Chanincha: the cultural values enabling adaptation to climate change in communities of the potato park, in the Peruvian Andes. GAIA-Ecological Perspectives for Science and Society, 25(3), 166-173.

World Intellectual Property Organization [WIPO]. (2017). Geographical Indications: An Introduction. (No. 952E). Geneva, Switzerland: WIPO.

Zimmerer, K. S., & Douches, D. S. (1991). Geographical approaches to crop conservation: the partitioning of genetic diversity in Andean potatoes. Economic Botany, 45(2), 176-189.

Zimmerer, K. S. (2003). Geographies of seed networks for food plants (potato, ulluco) and approaches to agrobiodiversity conservation in the Andean countries. Society & Natural Resources, 16(7), 583-601.

Zimmerer, K. S. (2012). The Indigenous Andean Concept of Kawsay, the Politics of Knowledge and Development, and the Borderlands of Environmental Sustainability in Latin America. PMLA, 127(3), 600–606.

Appendix A: Data Sources

Climate data

WorldClim

Fick, S.E. & Hijmans, R.J. (2017). Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology. http://worldclim.org/version2.

TRMM

NASA. (2018). TRMM: Tropical Rainfall Measuring Mission. Retrieved June 28, 2019, from https://trmm.gsfc.nasa.gov/

Land cover data

Landsat 8

NASA. (2019). Landsat 8 « Landsat Science. Retrieved June 28, 2019, from https://landsat.gsfc.nasa.gov/landsat-8/

GlobCover

ESA and UCLouvain. (n.d.). ESA GlobCover. Retrieved July 10, 2019, from http://due.esrin.esa.int/page_globcover.php

Elevation data

DEM – SRTM 1 Arc-Second Global

USGS. (2019). EarthExplorer. Retrieved June 28, 2019, from https://earthexplorer.usgs.gov/

Political and physical maps

Google Maps

Google. (2019). Retrieved July 2, 2019, from https://www.google.com/maps.

Potato distribution data

Global Roots and Tubers Base

International Potato Center [CIP]. (2016). Global Roots & Tubers Base. Retrieved July 10, 2019, from http://germplasmdb.cip.cgiar.org/index.jsp

Appendix B: Soil types in the *Parque de la Papa*

A wide variety of soil types have been identified, cataloged, and mapped in the *Parque de la Papa*. The following is a list of the present soils and brief descriptions, as described by Javier Llacsa Tacuri (unpublished, 2011) in collaboration with members of the *Parque* during the first phase of the Indigenous People's Climate Change Assessment Project.

1. Q'oñiallpa: "warm" soils – special microclimate
2. Jatunallpa: "grand" soils – fertile
3. Chiri allpa: "cold" soils – soils found where there are frequent hard freezes
4. Qaraqallpa: Uncovered soils – medium fertility
5. Waylla allpa: Marshy soils – wet
6. Yanaallpa: Black soils – fertile
7. Puka allpa: Red soils – clayey
8. Q'ello allpa: Yellow soils – clayey
9. Q'echa allpa: Soils of various colors (yellow, red, black) – clayey
10. Sacsa allpa: Mixed sand/clay soils
11. Aq'o allpa: Sandy soils
12. Challu allpa: Coarse soils – gravely
13. Chiri paco allpa: Cold soils used for rotation with grazing
14. Llanki allpa: Clay soils
15. Q'ello llanki allpa: Yellow clay soils
16. Siqsi allpa: Silty sandy soils
17. Yana aq'o allpa: Black sandy soils
18. Yana llanki allpa: Black clay soils
19. Yana pipo allpa: Black soils with a very high concentration of organic material
20. Yana sacsa allpa: Multi-colored soils, with predominance of black
21. Yana yuraq allpa: Black/grey soils

Appendix C: Interview and Focus Group Protocols

Elaboration of Interview Methodology

Interview subjects were identified with assistance from ANDES, with a goal of gaining insight from community members involved in crop cultivation about the *Parque de la Papa* project. Interview questions (below) are largely open-ended and aimed at understanding community perspectives about the factors of success in the park. Interviews were completed in Spanish, with Quechua translation as necessary. Note that interviews were informal and not every participant was asked every question.

1. For how long have you been involved with the *Parque de la Papa?*
2. What have been some of the greatest successes of the *Parque*?
3. What factors do you think have led to these successes?
4. Do you think there are unique features of this landscape which make it well-suited to potato cultivation and/or conservation?
5. Are there things that haven't worked well in the *Parque*?
6. What factors do you think contributed to these things not working?
7. In what ways is the *Parque* good for the community?
8. I am working on a project to advise other communities that might be interested in creating a similar TIBC based on the successes of the *Parque de la Papa*. What advice would you give to communities about starting and/or maintaining this kind of project?

Elaboration of focus group methodology

Focus groups were held with ANDES staff and with *técnicos locales* (local experts) from the *Parque de la Papa*. Participants were asked to identify key variables within the *Parque de la Papa*. Focus groups were scheduled for 1 hour each and were completed in the ANDES office in Cusco. 4 specific questions (below) were posed for discussion and follow up questions were posed as necessary. Participants were asked to brainstorm key characteristics of the *Parque de la Papa* in terms of what makes the area unique and successful. Then, participants were asked to rank the characteristics that they had identified by importance. Focus groups were conducted in Spanish, with Quechua translation as necessary.

1. How was this site identified by the community for the development of the *Parque de la Papa*?
2. What are the features—in terms of landscape and community/culture—that are important or unique at the *Parque de la Papa*?
3. What are the most important things to consider when planting a new crop?
4. What are some things that you think could be tried in the future at the *Parque de la Papa* in terms of agriculture, community involvement, and/or economic growth?