Landscape multifunctionality, agroecology and smallholders: A socio-ecological case study of the Cuban agroecological transition

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Research Article

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Abstract

Context.

After the fall of the Soviet Union, Cuba was plunged into an economic crisis with devastating effects on the agricultural system. With few options, the government restructured its agricultural system from an industrial model to a model based on smallholders and agroecology. After several decades, the results of this transition have been far reaching.

Objectives.

This research aims to elucidate some of the social, economic and ecological dynamics of this process. In so doing, it produces a more holistic and multi-dimensional perspective of how these changes have transformed landscapes and livelihoods in rural Cuba.

Methods.

To accomplish this, this paper presents a case study of a smallholder community which has undergone a shift from industrial sugarcane to small-scale agroecology. This research makes use of mixed methods, including remote sensing analysis, semi-structured interviews and archival work to understand how these this shift has changed landscapes and livelihoods in the region.

Results.

The result of this work reveals that while agricultural extent has plummeted, the production of staple crops has increased dramatically. This increased production has been accompanied by a doubling of food markets. Additionally, on-farm incomes have risen steadily. At the same time, strong environmental protections have greatly improved forest cover in the region. Together, these results demonstrate the process of replacing an extractive agricultural economy with one based on smallholder livelihoods.

Conclusions.

In the context of strong social, economic and environmental protections, such a transition can produce a number of concurrent benefits, leading to more multifunctional landscapes capable supporting livelihoods alongside ecological recovery.

1. Introduction

On a clear day, looking down from the Lomas de la Canoa in central Cuba, one can see the ocean some fifteen kilometers to the north. From here, the contours of the coastal landscape gently taper away from the forested highlands of the Sierra de Jatibonico in a patchwork expanse of agricultural fields, towns and smallholder communities. Beyond them are the semi-deciduous trees of Caguanes National Park, located along the coastline between mangrove forests and the wetlands of the Ciénaga de la Guayabera.

Just offshore, the tropical Caribbean waters of the Jardines de la Reina host an array of cays and skerries that provide habitat for permanent and passing bird species as well as vacation destinations for migrating tourists. Between the ocean and the dense woodlands, the smallholder fields and rocky highlands, the vista from the *lomas* is one of a dynamic landscape, as picturesque as it is diverse and heterogeneous.

This is the view of north central Cuba from the town of La Picadora, located on the Sancti Spiritus side of the province's border with neighboring Ciego de Ávila. Geographically, this region is set apart from the rest of the island, nestled between a modest range of karst mountains to the south and the forested coastal peninsula to the north. While tourists frequent the offshore beaches of Cayo Coco to the east and the urban centers further south, few ever venture into this narrow strip of land that runs one hundred kilometers between the cities of Remedios and Morón. Despite these unique regional attributes, however, what is most interesting about La Picadora are not the things that make it distinct from the rest of Cuba, but rather what it shares with the island as a whole.

As with many other agricultural areas in Cuba, La Picadora was once the site of a thriving sugarcane industry, entailing vast monocultures of the perennial grass that occupied most of the lowland areas along the coast. A majority of La Picadora's sugarcane, once harvested, was sent to any number of regional mills where it was processed and prepared for export. Since the times of Spanish colonialism, this had been a familiar pattern for rural Cuban communities and landscapes, one that not even the radical politics of the 1959 revolution was able to change completely. But from the heights of the Canoa hills these days, the only evident pieces of this history are fading linear patterns that once designated breaks in the massive fields of sugar and roads for heavy machinery.

The agroecological landscape that has come to dominate this territory is today very different from the agroecological landscapes of the past. After the fall of the Soviet Union in the early 1990s, the Cuban economy, and in particular, the heavily-industrialized agricultural sector, which for decades had been tied directly to subsidies and special trading agreements with the USSR, became economically and practically unsustainable almost overnight (Alvarez 2004). In the vacuum of Soviet support and in the face of a persistent US embargo, the Cuban state had few options but to dramatically restructure its entire agricultural sector from a predominantly petroleum- and input-dependent model based on export-oriented monoculture crops, especially sugarcane, to a more diversified, localized system of smallholders, many of them implementing the low-input methods of agroecology (Wright 2009). All over Cuba, in places such as La Picadora, these policy shifts have induced fundamental socio-ecological changes, resulting in both landscapes and communities that have come to reflect three decades of radical agrarian transition. In this sense, La Picadora represents a microcosm of the national-scale agrarian transition that has occurred in Cuba since the early 1990s, one whose implications, while profound, remain understudied and misunderstood.

This paper uses La Picadora as a case study to interrogate some of the more nuanced and complex dynamics of Cuba's agroecological transition in the hopes of creating a more holistic perspective of both

the landscape and livelihood changes that have occurred since the Special Period (1990-1994). More specifically, this research uses mixed methods, including semi-structured interviews, archival work and satellite imagery analysis, to visualize and contextualize the social, economic and ecological changes that occurred in La Picadora. Using the lens of landscape multifunctionality, this work explicates the relationship between changes in livelihood practices at the household-scale and broader processes of landscape change within the context of the Cuban agroecological transition. In doing so, this paper will not only help to fill empirical gaps in the literature on Cuban agroecology, particularly in terms of landscape-level analysis, but will also contribute a novel case study about the role of smallholders and public policy in pursuing socio-ecological sustainability and resilience at multiple scales.

By using a multi-scalar approach, this research also presents empirical evidence to argue that the social, ecological and economic benefits associated with agroecology at the household-level (see Chan & Roach 2013; Altieri et al. 2012; Altieri et al. 2015) are scalable to the landscape- and even regional-scale. This supports the work of scholars including Lovell et al. (2010), Dalgaard (2009), Wojtkowski (2003) and others who have written about the cross-scalar synergies of both agroecology and landscape multifunctionality. As this paper argues, however, the scalability of agroecology from the household to the landscape is not a foregone conclusion of implementing agroecological practices, but rather one that is dependent on the political, economic and policy environment in which such practices are situated. As the case of La Picadora illustrates, in a context with strong social, economic and ecological protections in place, the functional benefits of agroecology not only accrue within rural farms and communities, but also within rural landscapes.

1.1 Landscape Multifunctionality

At the broadest level, landscape multifunctionality is the idea that landscapes serve multiple “functions” simultaneously. While particular functions are diverse and geographically specific, they can be grouped into four categories: 1) production functions (eg. food, fodder crops, (bio)energy, livelihoods), 2) regulatory functions (eg. soil production, water filtration), 3) habitat functions (eg. plant and animal biodiversity, ecological structures/processes), 4) informational functions (social/cultural values of a landscape and, more generally, landscape aesthetics) (Brandt & Vejre 2004; Waldhardt et al. 2010; Bolliger et al. 2011).

Within the framework of landscape multifunctionality, some scholars make an additional distinction between structures, functions and values (Selman 2009). *Structures* include both natural features, such as topography, or artificial features, such as land use patterns or buildings; *functions* consist of the provisioning of ecosystems operations, for instance soil and water filtration and agricultural production, among others; and *values* entails a diverse category that includes the historical, cultural, aesthetic, spiritual, and recreational ‘worth’ of a particular landscape (Parris 2004). Regardless of the specific framework, these approaches all understand landscape multifunctionality not as the static product of discrete processes, but rather an emergent property of hypercomplex, coupled socio-ecological systems (Selmen 2009).

Research indicates that in more multifunctional landscapes “a more diverse set of ecosystem services is accessible to a broader range of beneficiaries” (Selman 2009: 59). Rather than being more homogeneous or monofunctional, as in industrial agricultural systems designed for optimized crop production, multifunctional agricultural landscapes are instead more heterogeneous in terms of physical diversity, including patterns of land-cover and land-use, and also more diverse in terms of plant and animal biodiversity and ecological opportunity (Selman 2009). Additionally, the ecological and functional benefits that flow from these more diverse agricultural landscapes are “usually experienced more locally, and local people are more likely to be in charge of landscape management” (Fischer, Meacham & Queiroz 2017: 59).

Due to its holistic approach, the landscape multifunctionality framework is useful in revealing the relationships between social, economic, and ecological systems across space and scale. As such, landscape multifunctionality has also proved useful in creating policy recommendations and ‘tool-kits’ for land-use planning at a number of scales, from the community/local (Lovell et al. 2010) to the regional (Peng et al. 2017), in both rural (Estrada-Carmona et al. 2014) and urban (Lovell 2010) contexts, and for a number of purposes, including agriculture (Galler, Haaren & Albert 2015), conservation (Reyers et al. 2012) and energy (de Boer & Zuidema 2015).

In rural areas especially, many of the policy recommendations that emerged from landscape multifunctionality reflect the priorities and principles of agroecology, which as it is applied in Cuba and elsewhere, generally seeks to increase self-provisioning and resilience of smallholder households. As such, agroecology represents one potential framework capable of increasing social, ecological and economic functionality at the household-scale with potential implications for landscape multifunctionality at larger spatial scales.

1.2 Agroecology and the multifunctional framework

Agroecology is a loosely-defined set of low-input agricultural practices that “apply ecological concepts and principles to the design and management of sustainable food systems” (Gliessman 2011: 369; see also Altieri 1995; Francis et al. 2003). Over the past several decades agroecology has also grown to constitute its own academic discipline, concerned with the ecological dimensions of agricultural systems, as well as its own social movement (Wezel et al. 2009). This paper deals primarily with agroecology as a discipline and as set of policies and practices, however, it is important to note that Cuba, in particular, has been a world leader in the agroecological social movement since the 1990s and works closely with international organizations such as *La Via Campesina* and the *Latin American Scientific Society of Agroecology (SOCLA)* to promote ecological forms of agriculture as a means of addressing social, economic, political and ecological aspects of food systems (Rosset et al. 2011).

Like landscape multifunctionality, agroecology is a diverse concept, borrowing ideas from related disciplines such as agronomy, ecology, and permaculture (Wezel & Soldat 2009; Ferguson & Lovell 2014), while also paralleling efforts to make agricultural systems more sustainable, including climate smart agriculture (Lipper et al. 2018), ecological agriculture (Wezel et al. 2015) and sustainable intensification

(Tilman et al. 2011). Generally, agroecology is contrasted with conventional agriculture, which is heavily petroleum- and input-dependent and which typically occurs on larger, industrial scales (*see Table 1*).

Table 1 Comparisons between the practices and principles of agroecological production and conventional agriculture

Agroecology	Conventional Agriculture
<i>(Agro)biodiversity</i>	<i>GMO's</i>
<i>Polyculture</i>	<i>Monoculture</i>
<i>Organic (Low-Input)</i>	<i>Synthetic Fertilizers (High-Input)</i>
<i>Integrated Pest Management</i>	<i>Synthetic Pesticides, Herbicides</i>
<i>Water Conservation/Management</i>	<i>Industrial Irrigation</i>
<i>Seed/Food Sovereignty</i>	<i>Corporate control</i>
<i>Local Markets/Economies</i>	<i>Global Markets/Economies</i>
<i>Short supply chains</i>	<i>Long supply chains</i>

Rather than contributing to carbon emissions and global climate change like conventional agriculture, an expanding body of research suggests that agroecology has the potential for achieving both food production and climate change adaptation/mitigation goals (see, for example, Horrigan, Lawrence & Walker 2002; Lin et al. 2011; Altieri et al. 2012) while also improving farmer resilience (Chan & Roach 2013; Altieri et al. 2015). This is achieved by integrating ecological principles into the management and design of farming systems, which allow agroecosystems to mimic natural processes in regards to pest management, water and soil cycling, and biodiversity. This has been shown to improve agricultural yields (Chan & Roach 2013; Rosset & Altieri 2017)—though it must be noted, these yields still lag behind the yields of conventional agriculture—and improve energetic efficiency and sustainability over conventional agricultural practices (Altieri & Toledo 2011; Rodriguez et al. 2017). Indeed, apart from food production, many of the primary and secondary benefits of agroecological practices also come with improved ecosystem services, particularly in their maintenance of natural resources, biodiversity and agrobiodiversity (Liere, Jha & Philpott 2017).

In this respect, agroecology and agricultural multifunctionality are convivial concepts. While each approaches agroecosystems from different spatial perspectives, they share a multi-dimensional understanding of coupled socio-ecological systems at their core. Understanding the connections between agroecology and landscape multifunctionality therefore, not only produces an improved understanding of the relationship between smallholder livelihoods and socio-ecological change at larger spatial scales (see Zimmerer & Vanek 2016), but also provides a practical basis for developing sustainable agricultural policy for rural areas. As other scholars have noted, integrating the principles of agroecology and

landscape multifunctionality allows for the exploration of applied solutions to complex social, ecological and economic problems while also addressing sustainability (Lovell et al. 2010).

In the case study that follows, the cross-scalar synergies of agroecology and landscape multifunctionality are evident as are their implications for rural development and policy. Through the unique combination of strong social, economic and ecological protections with a governmental commitment to subsidizing and supporting a transition from the industrial production of export crops to the small-scale production of staple crops, the functional benefits of agroecological practices can be seen not only on farms and in households in La Picadora, but also in the increasing multifunctionality of the rural landscape writ large.

1.3 Agroecological landscapes in Cuba

Following the success of the Cuban Revolution in 1959 and with the implementation of the Cuban embargo by the US in 1961, Cuba turned to the Soviet Union for material and political assistance. This relationship with the USSR was decisive for the Cuban agricultural sector technologically and politically, but at the same time, it still maintained many of the same social and ecological contours that had defined the sector to date. After the nationalization and redistribution of large-land holdings through a series of agrarian reform laws in 1959 and 1961, the political structure of the Cuban agricultural sector was also reformed, collectivizing and centralizing agricultural production into large, state-run operations based on the Soviet agricultural development model. Like the American industrial agricultural model before it, the Soviet model was incredibly technologically- and input-dependent, a reality which would make Cuban agriculture under the USSR some of the most unsustainable and industrialized in the world with terrible environmental consequences (Diaz-Briquets & Jorge-Lopez 2000).

After decades of dependence on this unique political economic relationship, the collapse of the Soviet Union in the early 1990s spelled great changes for the Cuban agricultural sector (*see Fig. 1*). In the face of economic crises and large-scale food shortages, the Cuban government introduced a number of reforms aimed at decentralizing large-scale, state-run operations and connecting farmers and would-be farmers with available land (Alvarez 2004). From these broken-up state enterprises, most of which had been industrial sugarcane monoculture a new type of agricultural cooperative, the Basic Units of Cooperative Production (UBPC) were formed, joining Agricultural Production Cooperatives (CPA) and the Cooperatives of Credit and Service (CCS) that had been present since the collectivization efforts of the 1960s.

[FIG. 1]

The transition from state-run farms to UBPCs, many of which were cooperatives based on smallholder livelihoods and agroecology, is important for understanding the land-use dynamics of Cuba's agrarian transition for two key reasons. First, the collapse of industrial farming in Cuba meant that huge areas of cropland were quickly abandoned. Second, smallholder farmers soon found themselves working some of that same land which had been subsequently granted to them under the state's expanded usufruct laws (Alvarez 2004). Estimates vary, but recent work indicates that across Cuba upwards of 1 million hectares

of cropland were abandoned in this process while some 500,000 hectares were reclaimed by farmers and cooperatives (Machado 2018) (*see Fig. 2*). Additionally, these new smallholders were not engaged in the same type of industrial agriculture, but rather small-scale, low-input forms of production that largely focused on subsistence agriculture and local production for newly formed agricultural markets.

To account for these new scales and modes of agricultural production, the Cuban state gradually adopted agroecology as policy framework that could speak to these new realities. In one respect, such a move makes sense given the petroleum- and input-limited context of post-Special Period agriculture in Cuba, which curtailed the ability of the state to re-orient its agricultural sector along more conventional lines of development. In another respect, however, the way that the framework of agroecology is deployed in Cuba means that it by nature lumps together a diversity of agricultural practices which, due to the characteristics of the post-Soviet era, are low-input by necessity.

Some of these diverse practices can be seen in the general categories used to define agricultural producers in the Cuban context. The first category of producers in Cuba are those that are non-agroecological. This entails industrial and conventional farms, which despite the nation's general transition to small-scale agriculture, still maintain a presence within the Cuban agricultural system, especially in the sugarcane industry (see Fernandez et al. 2018). The second category is for producers who are transitioning to more agroecological forms of production. Farmers in this category are often referred to as being "*en el camino*" (on the path) towards agroecology, having implemented some, but not all of the measures listed in Table 1.

The third category is for farmers that complete the transition and produce almost entirely according to the principles of agroecology. These farmers, whose practices still vary significantly, are said to be producing agroecologically "*por convicción*" (with conviction) and are held up as representing model farms. As such, for the purposes of this research and analysis, the agroecological framework is used not in a normative sense, but as a stand in for a variety of low-input practices that accompany the transition from large- to small-scale forms of agricultural production in Cuba.

[FIG. 2]

In the intervening years, and under the continual pressure of the US embargo, this new model of agroecological development, rooted in smallholder livelihoods and agroecological principles, steadily improved agricultural production on the island while also lowering the impact of the agricultural sector on the environment (see Fernandez et al 2018). This combination of processes—decreased agricultural extent alongside increased, sustainable agricultural intensification—entailed a large-scale shift of Cuban agrarian landscapes into multifunctional landscapes. While extensive swathes of rural land have been spared, whether through passive abandonment or active conservation efforts (see Galford et al. 2018), areas that remain productive have diversified and intensified, sharing the burden of food production with the improved provisioning of ecosystem services and at a larger-scale, landscape functions.

1.4 Contemporary agroecological landscapes

The impacts of the smallholder transition have been wide-reaching for Cuban landscapes. Recent landscape work by Stuhlmacher et al. (2020) uses a time-series of satellite imagery to conduct national-scale land-use/land-cover change (LULCC) analysis of Cuba between 1985 and 2010. This work shows a steady decrease in cropland extent during the study period as agricultural lands were abandoned. The researchers also note that the average patch size of cropland also decreased while increasing in shape complexity, indicative of a shift from “larger, compact agricultural patches” (i.e. industrial agriculture) to “many irregularly shaped patches” (i.e. small-scale agriculture) (Stuhlmacher et al. 2020: 13).

In addition to these dramatic changes in cropland, there have been a number of studies that show similar shifts in forest cover. Prior to Spanish colonization, Cuba had the largest extent of native forests in the region, which covered 88-92% of the island (Geblein 2011). When Spanish colonial rule ended in 1898, Cuban forests had been reduced to covering only 15-18% of the national territory (Diaz-Briquets 2000; Alvarez 2004; Funes-Monzote 2009), trends which continued during the first half of the 20th century. Since the early years of the revolution, however, the Cuban government has engaged in large-scale reforestation efforts. Especially since the mid-1990s as Cuba’s sustainable development and agroecological policies emerged, such state-led efforts have increased and improved considerably (Lambert 2008).

As with other ecosystems in Cuba, forests have benefitted from both relative isolation from development pressures and a strong national network of protected areas (Roman & Kraska 2016). Of Cuba’s nearly 4,330,800 hectares of land area, almost a quarter is contained within 211 protected areas (Galford et al. 2018). Outside of these protected areas, a number of policies were introduced aimed at increasing forest cover by promoting agroforestry practices among smallholders (Diaz-Briquets & Jorge-Lopez 2000). The results of these efforts are readily apparent. Today, Cuba maintains approximately 39% of its land as forest cover, a significant increase from its historical lows during the last century (Galford et al. 2018).

The ecological impacts of Cuba’s agroecological transition are also reflected in other recent empirical work. Bierman et al. (2020) conducted extensive sampling and analysis of river water across central Cuba, as a way to gauge the state of Cuban riparian and watershed conditions. According to this research, “concentrations of dissolved nitrogen are far lower [in central Cuba] than other areas where intensive agriculture is practiced, such as the Mississippi River Basin” (Bierman et al. 2020: 4). The authors credit the Cuban agricultural system as being one of the primary reasons for Cuban water having less contamination. Another source indicating Cuba’s unique agroecological context is from the Wildlife Conservation Society’s Human Footprint Index (Venter et al., 2016; <http://wcshumanfootprint.org/>). This index indicates that Cuba experienced a dramatic decrease in its overall human footprint between the early 1990s and mid-2000s, a result of shifting agricultural patterns and increases in forest cover (see also Machado 2018).

This unique socio-ecological trajectory since the 1990s has occurred within a political economic context that has maintained a commitment to strong social safety nets including universal access to healthcare, education, food and housing. The intersecting results of Cuba’s ecological and socio-economic context is

evidenced in part by the World Wildlife Foundation, who have found that Cuba is the only country in the world to have met its obligations towards sustainable development (Cabello et al. 2012). Cuba is also one of the only countries in the world to be considered “sustainable” according to the UN’s Human Sustainable Development Index (Bravo 2014). At the same time, Cuba is also unique in its ability to score highly on the UNDP’s Human Development Index, especially when compared with the US, while also maintaining a low carbon footprint (Latouche 2009; Kallis 2011).

As this research will demonstrate, despite continuing challenges surrounding food security and nutrition in Cuba (see Chan & Roach 2013; Bono & Finn 2017), the implementation of agroecological policies resulted in increased multifunctionality of landscapes in Cuba, which is to say, landscapes that are better able to support the social and economic needs of their inhabitants while also improving ecosystem services.

2. Methods

This research uses mixed-methods, both qualitative and quantitative, to produce a more holistic perspective on how the socio-ecological dynamics of Cuba’s agriculture transition have played out in a specific rural community. La Picadora, which was the focus of this research, is a farming community in the Yaguajay municipality of Sancti Spiritus province. Traditionally, La Picadora and the surrounding region engaged almost exclusively in large-scale sugarcane production, however, over the past two decades have seen the community embark on a rapid, far-reaching transition from livelihoods based on monoculture sugar production to livelihoods based on small-scale agroecological production. The surrounding landscape, which includes a number of important conservation areas, has also come to reflect such drastic livelihood changes. As a result, La Picadora is an exemplary case study of the transition from monoculture sugarcane to small-scale agroecology that has defined much of the Cuban agricultural trajectory over the past several decades.

[FIG. 3]

To better interrogate these dynamics in La Picadora, three principal methodological components were employed: 1) remote sensing analysis of satellite imagery using random forest sampling procedures, 2) semi-structured interviews on the socio-ecological history of La Picadora and 3) evaluation of archival data, including agricultural and economic statistics from Yaguajay municipality, where La Picadora is located (see *Fig. 3*). By combining archival data with remote sensing and semi-structured interview data, this research creates a more holistic and triangulated picture of socio-ecological change in La Picadora and surrounding areas. Together, these methods not only produce visualizations of social and landscape changes in this region over the past several decades, but they also demonstrate how changes in agroecological policy and practice in La Picadora have translated into increases in the functional diversity of the surrounding landscape.

2.1 Remote Sensing

The remote sensing component of this research made use of 30-meter resolution Landsat satellite imagery that was filtered to minimize cloud cover over the area of interest in Yaguajay and Chambas municipalities. Images were selected to be seasonally-comparable—all images were from March or April, the height of the dry season, and right after harvest which allowed cleared fields to be more easily identified. The images were also used to produce a time series that corresponds to major shifts in the agroecological transition in La Picadora. In order to visualize the dynamics of small- and large-scale agriculture on the landscape, these images were analyzed using the random forest classification available in the software TerrSet. Random forest sampling was considered most appropriate because it allowed for the soft classification of single land-cover classes, in this case agriculture, while also increasing classification accuracy through the use of a decision-tree ensemble (see Pal 2005; Rodriguez-Galiano et al. 2012).

2.2 Semi-structured interviews

The remote sensing analysis results were compared with data derived from semi-structured interviews conducted in the community of La Picadora during the summer of 2019. The community of La Picadora was selected as a research site for reasons both intellectual and practical. From an intellectual perspective, La Picadora is representative of the Cuban agrarian transition as it transitioned from large-scale sugarcane production to small-scale agroecological production. Additionally, the community's close association with the Buenavista Biosphere reserve, which occupies the coastline to the north of La Picadora, created an interesting contrast to areas with recently established environmental protections. Thus, the area surrounding La Picadora contains both of the most transformative land change forces at play in rural Cuba.

From a practical perspective, La Picadora was unique in that it had recently received permission through the Cuban government to begin hosting tourists as part of a growing agrotourism industry. This was important because, under normal conditions, conducting fieldwork on farms in Cuba is incredibly challenging. Due to the residual effects of Cold War-era hostilities, agriculture on the island is considered an arena of national security and as a result, it was challenging to get access to farms in Cuba. Even though La Picadora was allowed to host tourists, local permission to conduct qualitative research was still necessary.

Eight semi-structured interviews were conducted in La Picadora. These interviews were informal and included snowball sampling of eight different farming families in the community. Each interview lasted between thirty minutes and an hour, with roughly half accompanied by visits to agricultural fields along with the farmers being interviewed. Due to the limited number of interviews conducted, this information was not systematically analyzed using traditional quantitative methods, but rather was used to develop a socio-ecological history of La Picadora and the surrounding regions, which could then triangulate the results of remote sensing and archival work.

2.3 Archival research

The combination of socio-ecological history and remote sensing data was further enhanced with municipal-level archival data to evaluate a number of social and economic factors, including agricultural production and employment. This data was sourced from the Cuban Office of National Statistics (ONEI), which collects and publishes a number of publicly available, annual reports on agriculture at the national-, provincial- and municipal-scale. While ONEI data is not cross-validated, it generally follows data reported by the United Nations Food and Agriculture Organization (FAO), which, due to the nature of its data collection process, includes some amount of verification and cross-checking (see Garibaldi 2012).

3. Results

3.1 Remote Sensing

Figures 4 through 6 represent the results of random forest analysis of active agricultural lands surrounding La Picadora between 1986 and 2018. This time series spans two distinct political and economic inflection points that are key for understanding the socio-ecological processes being observed: the Special Period between 1990-1993; and, the agroecological shift starting in 2005. In each map, the locations of regional sugar mills in the towns of Nela, Punta Alegre, and Fella are indicated. While all three mills were operational in 1986 and 1996, by 2018 both the Nela and Punta Alegre plant had been decommissioned with only the Fella plant remaining.

[FIG. 4]

[FIG. 5]

[FIG. 6]

Figures 4 through 6 show the dramatic land-use change taking place around La Picadora. However, between 1986 and 1996 this change was relatively minor, with a 14 percent increase in agricultural extent overall, a gain of approximately 4000 hectares. Based on cross tabulation results in *Figure 7*, agricultural losses tend to occur on the periphery while agricultural gains tend to occur at the core of the agricultural area.

[FIG. 7]

Between 1996-2018, the land-use change is more extensive with a 74.5% decrease in agricultural extent, which represents a loss of almost 25,000 hectares. The land-use change during this time period shows spatial patterning remaining persistent in parts of the agricultural core, but being lost across large swathes of the periphery (*see Fig. 8*).

[FIG. 8]

Interestingly, by 2018 large-scale agriculture becomes almost non-existent west of the Rio Jatibonico del Norte, which serves as the boundary between the Yaguajay and Chambas municipalities, as well as the

boundary between Sancti Spíritus and Ciego de Ávila provinces.

Figures 9 through 11 are false color composites of satellite imagery for the region surrounding La Picadora between 1986-2018, highlighting both vegetation and agriculture. While vegetation is bright green, agriculture varies in color depending on the presence or absence of crops. It is bright green where crops are present and tan and dark brown where crops have been recently harvested or soils tilled, respectively. These figures visually demonstrate significant changes in both agricultural extent and forest cover, notably along the Lomas de Canoa in the southwest and on the peninsula to the northeast where Caguanes National Park is located.

[FIG. 9]

[FIG. 10]

[FIG. 11]

[FIG. 12]

Figure 12 depicts landscape features between 1986-2018 that were extracted from false color composites providing a more detailed view of localized dynamics of land-use and land-cover change. In Comparison 1 (*Fig. 12*), it can be seen that in the countryside surrounding La Picadora, large-scale agriculture is being abandoned while small-scale agriculture is becoming more concentrated around the agricultural core of the community. In some cases, it is possible to see that smallholders are expanding into these abandoned lands, turning large-scale agricultural tracts into as small-scale agricultural plots. These same dynamics as well as substantial amounts of reforestation can also be seen in Comparison 2 (*Fig. 12*), which shows the wetland area along the Rio Jatibonico del Norte. Lastly, in Comparison 3 (*Fig. 12*) dramatic changes are evident on the Caguanes peninsula between 1986 and 2018. During this time period, as agriculture and other types of land-use disappear from the peninsula, a substantial amount of reforestation occurs.

3.2 Semi-structured Interviews

Semi-structured interview data was particularly helpful in elucidating the socio-ecological history of La Picadora since the Special Period. It also provided a number of insights on the household- and community-scale perspectives of these recent transitions and the socio-economic impacts they have had on producers in the region. As this data indicates, the main source of livelihood for the 84 farming families in La Picadora has traditionally been agriculture. While the Special Period impacted the sugarcane industry throughout Cuba starting in the early 1990s, the regional impacts in Yaguajay were not felt until almost a decade later. Sugarcane production in the municipality remained at its height with a number of local wetlands remaining drained and previously-forested areas kept clear to support industrial-scale, monoculture production (see also Ramenzoni et al. 2020) until the early 2000s. After the closure of several regional sugar mills the local sugarcane industry in Yaguajay finally ended. This

sparked the community of La Picadora, and others in the region, to shift away from large-scale industrial agricultural livelihoods to smallholder subsistence and commercial production livelihoods.

From a technical perspective, several community members explained this shift was facilitated through an ongoing partnership with the University of Havana and involved substantial agricultural extension and educational outreach in La Picadora and other surrounding communities. From an ecological perspective, this shift was facilitated by the fact that within the municipality, large areas of gleysol and vertisol soils, which once made this region ideal for mechanized sugarcane agriculture, are juxtaposed with the presence of phaeozem soils, which are very fertile and suited for small-scale agriculture (FAO 2003). From a political perspective, this shift was facilitated by a dramatic change in public policy which entailed the adoption of a national-scale sustainable development framework largely based on the ideas of agroecology.

Concurrent with these state-led initiatives to promote agroecology and smallholder livelihoods in La Picadora, there have also been a number of regional conservation efforts along the coastal and inland areas of Yaguajay province. Most notable among these is the Buenavista Biosphere Reserve which was established after the closing of regional sugar mills in the mid-2000s (see also Ramenzoni et al. 2020). The reserve itself is a socio-ecological complex which includes the Jardines de la Reina marine reserve offshore and the forested peninsula of Caguanes National Park. Both of these protected areas have substantial ecological and anthropological significance and as such, the reserve was designated as a Ramsar site for the protection of wetlands and as UNESCO world heritage site. The forested coastal areas are also an important part of the Cuban government's 100-year initiative to combat climate change through creating coastal conservation areas (see Stone 2018). Coastal forests, such as those in Caguanes, as well as mangroves and wetlands, such as those in the Jardines, will play a central role in mitigating the impacts of climate change, including sea level rise, loss of biodiversity and increasingly powerful hurricanes (Planos-Gutiérrez et al, 2013; Galford et al. 2018)

3.3 Archival Data

Archival data was most helpful in supplementing the relatively limited number of interviews that were able to be conducted in the field. ONEI provided data sets focused on agricultural production, income, and number of grocery store outlets. In general, while this data was aggregated at the municipal scale, it nevertheless provided an important view into the changing agricultural economy in Yaguajay as it has played out over the past ten years.

[FIG. 13]

Figure 13 shows that the majority of growth in agricultural production in Yaguajay since 2010 has consisted of tubers and vegetables, with more modest growth seen in cereal, legume and fruit production. In contrast to the sugarcane production that these products have come to replace, these staples food are intended for domestic consumption rather than export. Within this new, more local agricultural economy,

not only has food production more than doubled over the past decade, so too have the number of grocery stores and markets across the municipality (*see Fig. 14*).

[FIG. 14]

The shift from monoculture sugarcane to small-scale family farming not only entailed changing agricultural production and distribution dynamics, it also included a shift from primarily wage-based labor arrangements to a mixed system of subsistence and commercial livelihoods. Despite this shift away from farm wage-labor, however, local agricultural salaries in Yaguajay municipality have actually increased over the past decade.

[FIG. 15]

Figure 15 shows monthly salary data for the state agricultural sector in Yaguajay since 2010. There has been a steady rise in monthly salaries among farmers in the state sector, so much so that as of 2018, agriculture has become the highest paying economic activity in the municipality (ONEI 2018). Again, the income data seen above refers specifically to the state sector, however, it is likely that agricultural incomes for non-state farmers are *even higher* in the municipality than for their state counterparts. Such a relative income difference is common in Cuba and is due in part to efforts towards limited liberalization in the agricultural sector (see Alvarez 2004).

4. Discussion

4.1 Socio-ecological changes

The combination of remote sensing analysis and semi-structured interview data reveal a number of trends across the study period. First, there was modest increase in industrial agricultural land between 1986-1996 despite these years representing a difficult time within the Special Period crisis. While substantial sugarcane production losses occurred across Cuba during this time period, the remote sensing analysis suggests that sugarcane production in the Yaguajay region was relatively unaffected. This is corroborated by the semi-structured interviews from La Picadora, which indicate sugarcane production continued throughout the 1990's and early 2000's until the closing of the regional mills between 2003 and 2005.

Between 1986-1996, there were also notable changes to the spatial patterns of agricultural extent. There is a loss of sugarcane production on the periphery and an increase around the core, relative to the sugar mills in both Nela and Falla. This change may be due to several factors, the most important being limited access to fossil fuels in Cuba which occurred after the Soviet collapse. It is perhaps unsurprising that, during this same time, sugarcane production in the region became more spatially concentrated around the towns where local sugar mills are located, thereby cutting down on prohibitive transportation costs. However, this trend does not seem to occur around the Punta Alegre mill in Yaguajay, which is located on

the Caguanes peninsula. This suggests other factors that are at play, especially since the Punta Alegre mill was physically located farther from active agricultural regions dating back to 1986.

Between 1996-2018 the change in cropland extent was more dramatic. This change, as the interview data confirmed, corresponded to the closure of the mills in Nela and Punta Alegre as well as La Picadora's transition to agroecological forms of production. As before, the changing spatial patterns reveal a clear trend of cropland loss on the periphery and persistence at the agricultural core surrounding Falla, the only remaining sugar mill in the region.

While the Special Period in Cuba resulted in certain universal consequences across the island, the spatiotemporal dynamics of agricultural change in La Picadora show that the specific impacts of the crisis played out unevenly, with different regions being subject to more-localized drivers of change. This observation is reflected in other recent remote sensing work, most notably by Stuhlmacher et al. (2020), which points to not only several distinct periods of agricultural loss, but also the uneven geographic distribution of this loss.

As the agricultural extent changed across Yaguajay, so did the extent of other land uses. This is particularly evident in the increase in forested areas along the Lomas de Canoa and on the Caguanes peninsula. Interestingly, as the false color composites indicate (*see Fig. 9 through 11*), regions which correspond with the most reforestation, are also areas where agroecological practices were implemented, such as along the Lomas de Canoa.

During one interview with a small-scale cattle farmer from La Picadora, the nature of this reforestation process in the *lomas* was explained in more detail. Previously, he had grazed his cattle on pasture, but with the closing of the sugar mills and the partnership with the University of Havana, he began to receive subsidies to allow his land to revert back into forest and technical training to facilitate a transition towards a silvipastoral system. The results of these incentives were seen on several field visits with this farmer, whose plot reflected a more multifunctional system, one that supported the grazing needs of his herd at the same time as improved forest cover supported various ecological functions such as erosion control, water filtration, and improved biodiversity. As other interviewees explained, state support was also available to farmers engaged in other reforestation practices on their land, most commonly through the planting of living fences (*cercas vivas*). In addition to this reforestation near La Picadora, there was also substantial reforestation in the regions where conservation efforts were undertaken, such as in Caguanes National Park (*see Fig. 11, northeast corner*).

4.2 Socio-economic changes

While to date a number of other remote sensing studies have analyzed the socio-ecological dynamics of this transition from a national-scale perspective (see for example, Gebelein 2012; Galford et al. 2018; Stuhlmacher et al. 2020), there is almost no published research on the more granular details of this transition. By combining regional remote sensing work with interview and archival data, this research provides such details to better explain the changing spatial patterns observed.

Together, these data sources reveal a regional economy in flux, one in which the local production and consumption of food is ascendent, taking the place of a more extractive model of monoculture production and export. In particular, the period between 1996 and 2018 reveal a profound shift from an export-oriented industrial agro-economy, one in which farmers are wage laborers, to an economy based on smallholder livelihoods and local food systems, one in which farmers are producing both subsistence crops for their households while also providing crops for sale at local markets and stores.

During an interview with one smallholder from La Picadora, the mechanics of this increasingly-localized agricultural economy could be seen in a number of ways. As the farmer explained, producers in the region were still required to sell quotas of certain crops to the state for redistribution at a regional- and national-scale. This includes commercial crops such as sugarcane, tobacco, coffee, and cacao as well as beef and milk. Apart from these select goods, however, smallholders are able to, but not obliged to, sell their agricultural products to the state or instead choose to sell at local markets. In these efforts, these farmers are helped by a doubling of food outlets over just the past ten years (*see Fig. 14*), providing a number of options for selling goods. This is particularly the case for smallholders in the non-state sector, and especially so for those selling fresh fruits and vegetables, which are difficult and costly to transport long distances.

In addition to these commercial opportunities, farmers are incentivized to produce crops as part of subsistence plots to improve household *auto-consumo*, or self-sufficiency. Crops grown for household consumption, such as coffee, or for forage, such as sugarcane, are exempt from the state quota system. The result, as this farmer elucidated in his interview, is a mixed food and agricultural system that provides a number of outlets and opportunities for commercialization while actively encouraging subsistence production and subsidizing smallholder initiatives at the household-scale.

5. Conclusion

On the most basic level, the case study of La Picadora is interesting for what it reveals about the changing spatial dynamics of the agroecological transition that has occurred in Cuba since the early 1990s. By triangulating of La Picadora's agricultural transition with several distinct data sources, this work illustrates how a combination of agroecological policy, environmental protections and political economic change have contributed to a radically changed socio-ecological landscape in the municipality of Yaguajay and in the community of La Picadora, more specifically.

In this sense, the case study of La Picadora shows how these factors have intersected within a particular regional context to impact the multifunctionality of a rural landscape. In La Picadora, we can see a rural landscape that is not only more ecologically diverse, but also one that seems better able to support the lives and livelihoods of local people. While much more research is needed to further quantify, elucidate and validate these findings, such conclusions echo more recent work by scholars such as Wilson et al. (2020), which points the emergence of a system of 'ecological public health' in Cuba. La Picadora, it can be argued, reveals the broad the contours of such a system in practice.

In addition, the Cuban context, the case study of La Picadora is also interesting for what it reveals about the potential synergies between agroecology, as a model for rural development, and landscape multifunctionality, as a framework for the management of rural landscapes. As this brief discussion about ecological public health illustrates, there are a number of inherent cross-scalar relationships between social, economic and ecological systems. In La Picadora as in many other rural areas, this is manifest in the relationship between livelihoods and landscapes, which co-produce each other in several material and immaterial ways (McCusker & Carr 2006; Carr & McCusker 2009).

What is perhaps most interesting about this case study are the ways in which it illustrates how a shift from wage-based, industrial agricultural livelihoods to smallholder livelihoods based on low-input agricultural practices can produce a radically different and more multifunctional landscape while also contributing to rural livelihoods. Interrogating these dynamics further, both in Cuba and more broadly, remains an important avenue for future research, one that is essential for addressing some of the most vexing challenges at the heart of many modern food systems, namely how to improve agricultural production and livelihoods while minimizing environmental externalities and mitigating climate change.

Declarations

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Compliance with Ethical Standards

This research includes semi-structured and informal interviews with farmers in Cuba. As per ethical standards, IRB approval was obtained for this work through Clark University for research involving human subjects. All interviewees provided informed, verbal consent as outlined in the Human Subject application and all responses and names were properly anonymized as stipulated by the approved IRB proposal.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study's overall conception and design. Marc Healy's contribution focused mainly on developing the technical and conceptual aspects of the remote sensing analysis. The material preparation, data collection, fieldwork and analysis were performed principally by Mario Reinaldo Machado. The first draft of the manuscript was written by Mario Reinaldo Machado and was revised with comments and edits from Marc Healy. Both authors read and approved the final manuscript.

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Figures

Figure 1

Sugarcane production in Cuba, 1989-2018. Source: Cuban Office of National Statistics (ONEI), Anuario Estadística de Cuba, 2018

Figure 2

Harvested Area in Cuba, State and Non-State Sectors, 1986-2014 from (Machado 2018)

Figure 3

Map of La Picadora and surrounding region. Included are both Yaguajay and Chambas province, as well as the Buenvista Biosphere Reserve, which contains both Caguanes National Park and the Jardines de la Reina

Figure 4

Agricultural extent in the area surrounding La Picadora in 1986

Figure 5

Agricultural extent in the area surrounding La Picadora in 1996

Figure 6

Agricultural extent in the area surrounding La Picadora in 2018

Figure 7

Results of cross-tabulation analysis showing the change in agricultural extent between 1986 and 1996 in La Picadora and surrounding areas.

Figure 8

Results of cross-tabulation analysis showing the change in agricultural extent between 1996 and 2018 in La Picadora and surrounding areas

Figure 9

False color composite of the area surrounding La Picadora in 1986

Figure 10

False color composite of the area surrounding La Picadora in 1996

Figure 11

False color composite of the area surrounding La Picadora in 2018

1986

2018

Comparison 1:

Countryside
surrounding La
Picadora

Comparison 2:

Wetland region
Jatibonico del
Norte river

Comparison 3:

Caguanes
National Park

Figure 12

Localized patterns of landscape change, 1986-2018

Figure 13

Agricultural production of staple crops in the non-state sector of Yaguajay municipality between 2013 and 2018 (ONEI 2014; 2018)

Figure 14

Number of grocery stores (Tiendas de productos alimenticios) in Yaguajay municipality, 2010 – 2018
(ONEI 2014; 2018)

Figure 15

Average monthly salary for state sector agricultural workers in Yaguajay municipality between 2010 and 2018 (ONEI 2014; 2018)