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Narrating agricultural resilience after Hurricane María: how smallholder farmers in Puerto Rico leverage self-sufficiency and collaborative agency in a climate-vulnerable food system

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Abstract

Climate change is a threat to food system stability, with small islands particularly vulnerable to extreme weather events. In Puerto Rico, a diminished agricultural sector and resulting food import dependence have been implicated in reduced diet quality, rural impoverishment, and periodic food insecurity during natural disasters. In contrast, smallholder farmers in Puerto Rico serve as cultural emblems of self-sufficient food production, providing fresh foods to local communities in an informal economy and leveraging traditional knowledge systems to manage varying ecological and climatic constraints. The current mixed methods study sought to document this expertise and employed a questionnaire and narrative interviewing in a purposeful sample of 30 smallholder farmers after Hurricane María to (1) identify experiences in post-disaster food access and agricultural recovery and (2) reveal underlying socioecological knowledge that may contribute to a more climate resilient food system in Puerto Rico. Although the hurricane resulted in significant damages, farmers contributed to post-disaster food access by sharing a variety of surviving fruits, vegetables, and root crops among community members. Practices such as crop diversification, seed banking, and soil conservation were identified as climate resilient farm management strategies, and smallholder farmer networks were discussed as a promising solution to amass resources and bolster agricultural productivity. These recommendations were shared in a narrative highlighting socioecological identity, self-sufficiency, community and cultural heritage, and collaborative agency as integral to agricultural resilience. Efforts to promote climate resilience in Puerto Rico must leverage smallholder farmers' socioecological expertise to reclaim a more equitable, sustainable, and community-owned food system.

Keywords Smallholder farmers · Climate change · Natural disasters · Resilience · Food security · Socioecological knowledge

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Abbreviations

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NASS National Agricultural Statistics Service

SD Standard Deviation

US United States

USDA United States Department of Agriculture

Introduction

Global environmental changes are a major threat to food system stability, driven, in part, by an increased occurrence of extreme weather events, loss of agrobiodiversity, and adverse weather pattern shifts (Myers et al. 2017; Vermeulen et al. 2012). Food security in small islands may be disproportionately affected by climate change, with local food sources increasingly threatened by seed shortages, coastal flooding, and ocean acidification (Tompkins et al. 2005) as

well as increases in the frequency and intensity of natural disasters (Aalst 2006). In the Caribbean, smallholder farmers and other low-income food producers also face major resource constraints that can limit adaptation to a volatile climate, including fragmented food and resource distribution systems, farm labor shortages, and high restart-up costs (Gould et al. 2015).

Puerto Rico, a United States (US) territory, has a diminished agricultural sector, making up just 0.68% of its Gross Domestic Product (World Bank 2019) and mostly composed of smallholder farmers in the island's interior mountainous region, with 83% of farms in Puerto Rico having less than 50 *cuerdas* (about one acre) and 53% generating less than \$5000 in earnings per farm per year (USDA 2012). Although small-scale local food production in a largely agrarian society once supplied the majority of food consumed on the island, twentieth century governmental policies favoring industrialization, tourism, and reliance on federal food assistance programs destabilized the local food sector (CarroFigueroa 2002). Regulatory maritime restrictions, including US cabotage laws, have also dampened the competitiveness of local agribusiness due to the high costs of importing raw materials and exporting manufactured food (Suarez 2018). As a result, more than 85% of Puerto Rico's food supply is imported, contributing to poor diet quality and competing with local smallholder farmers. Coupled with diminished local food intake, food importation in small islands increases energy and processed food availability (e.g., sugary beverages, canned meats, sweets, and salty snacks) and has been associated with obesity and chronic disease risk (Lin et al. 2018).

Food import dependence also exacerbates food insecurity after natural disasters and in an increasingly climate-vulnerable global food supply (Gould et al. 2015). Puerto Rico relies heavily on a single port of entry and less than a handful of maritime companies for food transport, exacerbating disaster vulnerability and increasing imported food product prices. Locally, hurricanes and other extreme weather events can severely disrupt food importation and distribution systems, including port shutdowns, road and highway impasses, and energy and communication system outages. Without internal food sources, regional ports must resume full operations within 1–2 weeks after a natural disaster to avoid severe food supply depletion and potential malnutrition (Gould et al. 2015). Shocks to global food supply chains—including market, political, and climatic instability—can also have ripple effects back on the island, with imported fresh fruit and vegetable availability particularly susceptible to external market and regulatory disruptions (Suarez 2018).

Against this backdrop, climate resilient, self-reliant food systems are of increasing sociocultural and public health interest in island settings, with

local food sources serving to bolster post-disaster food security and diet quality. In Puerto Rico, small-scale farming, fishing, and home gardening have long contributed to localized social networks of exchange, providing fresh produce and staple foods among family and community members that seldom enter the formal economy. The island has ample fertile yet uncultivated land, with 471,215 acres (21% of Puerto Rico's total land mass) suitable for agriculture, and ecological resources to augment agricultural productivity (Gould et al. 2017) and has seen increases in hydroponic fruit and vegetable production (USDA 2012). Local food production has also supplied the majority of locally consumed green bananas, plantains, squash, and peppers (González and Gregory 2012) and currently contributes to higher intake of fruits, vegetables, dietary fiber, and plantbased protein (Marrero et al. 2020). Food autonomy and agroecology are also of increasing interest on the island, with local food production serving as a cultural emblem of self-sufficiency, rural quality of life, and environmental sustainability in the face of continuing global environmental change (Garriga-López 2019; Manuel-Navarrete and Buzinde 2010). However, whether smallholder farming can effectively act as a platform for collective action in the food system and in the face of unfavorable trade policies, climate change, and food insecurity remains to be determined.

Hurricanes and other natural disasters are typical in Caribbean ecosystems, and the occurrence of these high-intensity weather events will likely continue to increase (Aalst 2006), highlighting the urgency to identify and address challenges and opportunities for agricultural resiliency among local farmers. Hurricane María tested the strengths and climate vulnerabilities of Puerto Rico's food system. Making landfall as a Category 4 hurricane in September of 2017, the hurricane devastated an estimated 80% of the island's crop value, with plantains, bananas, and coffee crops as well as livestock production among the most strongly affected (USDA 2018). Inadequate federal responses also led to significant delays in addressing food and water shortages, particularly in remote rural areas (García-López 2018), while emergency aid increased access to processed foods high in sodium, saturated fats, and added sugars (Colón-Ramos et al. 2019). In an island-wide survey, food insecurity was shown to increase acutely among farmers, with 59.1% reporting difficulties in obtaining food the month after the hurricane (Rodríguez-Cruz and Niles 2018). Although two-thirds of participants reported that they had prepared for Hurricane María, a smaller percentage utilized climate resilient agricultural management practices such as crop diversification (19.6%) and rotation (21.2%). Less is known about how other, less formal knowledge systems and community support networks impacted food access and agricultural recovery.

Documenting the local expertise of smallholder farmers in reestablishing food production can offer insight into already built-in climate resilience in Puerto Rico and, moreover, can contextualize these practices in their broader cultural, political, and ecological environments (Folke 2006). Identifying collective strategies undertaken by rural farming communities to promote food self-reliance can also serve to decolonize post-disaster resiliency efforts in Puerto Rico, which can otherwise ignore the agency, collective power, and resource networks individual actors and communities rely on during recovery (Borges-Mendez and Caron 2019). Thus, “decolonizing” the Puerto Rican food system captures approaches that not only resist structural barriers to food security (e.g., inequitable trade policies) but also seek to reclaim and revitalize traditional, autonomous, and eco-centric food production (Figueroa-Helland et al. 2018). Through a combination of quantitative measures and narrative recall, this mixed methods study aimed to (1) identify experiences in food access, community support, and agricultural recovery among smallholder farmers after Hurricane María and (2) reveal underlying socioecological knowledge systems that can contribute to a more culturally-informed and climate resilient food system in Puerto Rico.

Methods

Study design and recruitment

This study was designed as a concurrent transformative mixed methods study consisting of a quantitative questionnaire and narrative interviews within the same sample, an approach chosen to aid identifying opportunities to initiate social change, empowerment, and advocacy (Creswell and Clark 2011). The study was conducted using a nonprobability multi-stage sampling approach with the goal of recruiting agricultural workers residing in Puerto Rico. First, purposive sampling was employed to (1) select individuals with key insights in the research areas of interest and (2) facilitate intensive case study in their cultural and agricultural expertise (Bernard 2017). Recruitment was carried out at community sites purposefully selected based on rural location or direct involvement with farmers, including a partner non-profit agricultural organization as well as community farmers’ markets. Second, snowball sampling was used by asking participants to

recommended other agricultural workers in the population, with whom study information was shared (Bernard 2017). Recruitment strategies were designed to attract general interest and a diverse range of perspectives. For example, the wording of study information was generalized (e.g., “to document experiences among farmers after Hurricane María”) to limit self-selection bias. Interested individuals contacted the study and were screened for eligibility: (1) had lived in Puerto Rico during Hurricane María and at least 6 months afterwards, (2) aged 21 years or older, and (3) able to answer questions without assistance. A total of 41 individuals contacted the study and were screened as eligible, of which 7 later declined participation and another 4 were unable to be recontacted. Thirty eligible individuals were scheduled for a 2-h interview at an office or other private location in one of the community partner sites or at the participant’s establishment; all attended as scheduled. Participants received a small (\$25) monetary incentive, refreshments, and reimbursement for transportation expenses, if requested. This study was approved by the Institutional Review Board of Harvard TH Chan School of Public Health and Ponce Health Sciences University (Protocols IRB19-0034 and 1903007592, respectively). All participants provided written informed consent.

Quantitative questionnaires

The day of the interview, a trained, bilingual research assistant administered a quantitative questionnaire to assess participant’s sociodemographic characteristics, hurricanerelated risks, and food product inventory before and after the hurricane (Supplement). Questions on farm characteristics (e.g., production type, extent) were also included and adapted from information collected in the USDA NASS Census of Agriculture (USDA 2017), with open-ended components added to accommodate non-standard responses specific to small-scale agriculture in Puerto Rico. This questionnaire served to systematically gauge important participant and farm characteristics from all participants that might otherwise be missed or not quantified in the qualitative narrative interview. These data were stored using the electronic data capture tool ‘Research Electronic Data Capture’ (REDCap) (Harris et al. 2009). Descriptive statistics were calculated, including means (SD) for continuous variables and frequencies for categorical variables.

Narrative interview

Qualitative narrative interviews were moderated by a trained English- and Spanish-speaking research assistant. The narrative interview was audio recorded to ensure the accuracy and completeness of gathered information. A

moderator's guide was developed in Spanish with input from the research team to openly ask about the participant's recalls of experiences after Hurricane María regarding resource access, social support, emotional responses, and future agricultural development (e.g., "Tell me about your experience finding the resources to restart operations again after Hurricane María") (Supplement). Specific concepts (i.e., "How did you get those resources?" "Who helped you?") were probed by the moderator when not offered by the participant to elicit further information.

Narrative interviewing was selected over other types of interviews (e.g., structured or semi-structured) due to its focus on the participant's storytelling, gathering information not as disjoint observations, but as an integrated collection of perceived events and feelings experienced after the hurricane (Anderson and Kirkpatrick 2016). For example, participants could choose to contextualize personal experiences of agricultural disaster recovery within broader social, cultural, or political circumstances and constraints; thus, through an uncomplicated storytelling process, this quasi-ethnographic approach was able to preserve interrelated and complex perspectives smallholder farmers may have of the entire food system in Puerto Rico. Additionally, by capturing sequences of events, the specific achievable and purposeful actions taken by participants could be documented to inform more relevant, holistic, and community-owned program design in response to a disaster (Greenhalgh 2016). Finally, narrative interviewing limited pre-defined theories and assumptions and facilitated capturing information inductively.

Upon asking open-ended questions, participants were allowed to take control of the pace, content, and direction of the interview within the specified queries, without interruption. At the end of the interview, the interviewer summarized and confirmed the participant's recounted narrative, while minimizing researcher-imposed interpretations. During the interview, interviewers took note of the participant's body language, expressions, mood, and ability to understand and respond to questions. Transcripts were prepared *verbatim* from the audio-recordings in the original language of the interview, mainly Spanish, and were validated for content, syntax, and fidelity to the local vernacular by comparing the transcript to the original recording and revising at least twice by three research assistants.

Interpretive thematic analysis was carried out without translation to preserve the meaning and

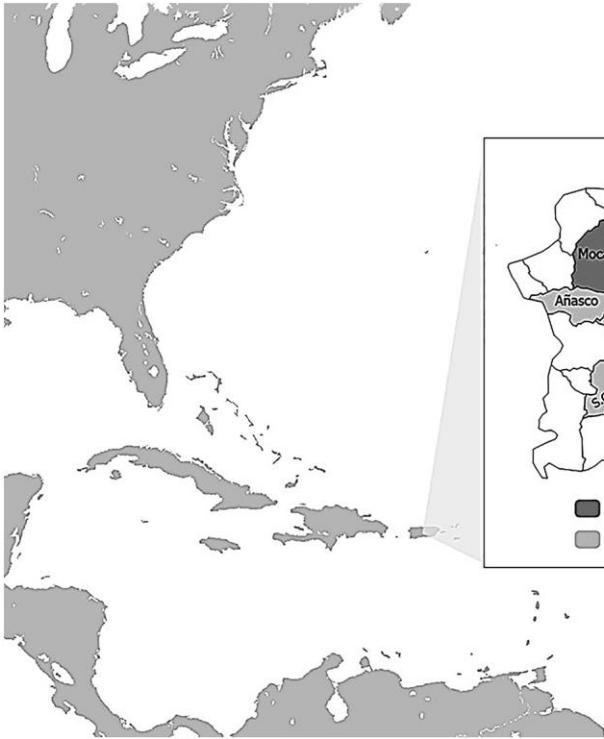
sociocultural context of the text (Regmi et al. 2010). In analyzing the transcripts, participants' narratives served as the basis in identifying the latent interpretive frameworks underlying common experiences and meaning-making processes (Clarke et al. 2015). Bilingual members of the research team familiarized themselves, reviewed, and delineated information in each validated transcript as codes, and similar codes within and across transcripts were identified and merged under the same code. Coding synchronously and inductively informed codebook development, including the specification of code descriptions, inclusion, and exclusion criteria. Codebook development was also informed by the National Institute of Minority Health and Health Disparities research framework (Alvidrez et al. 2019), adapted for this study by considering multiple health determinants across sociocultural, economic, political, and ecological domains. Additionally, by assessing how codes could be classified across individual, community, and societal levels of influence, this framework aided in informing actionable, multi-tiered recommendations. Domains were used to organize sets of similar codes inductively in the codebook. Codes and domains were continually refined (e.g., added, separated) based on codebook performance against transcripts during coding, and transcripts were iteratively recoded based on the updated codebook until saturation was reached (Ando et al. 2014). Intercoder reliability for a random subset of the interview transcripts ($n = 7$) was assessed using Cohen's kappa coefficient and percent agreement to evaluate coding consistency and ensure unambiguous and mutually exclusive codes (Decuir-Gunby et al. 2011).

Themes were developed as descriptive and analytic central organizing concepts, informed by coherent clusters of codes to identify salient patterns (Clarke et al. 2015). Searching for themes involved cutting across identified codes and domains to capture overarching relationships between concepts and meaning-making processes. Thematic development was also informed by research questions of interest, emphasizing solutions to food access, community support, and agricultural recovery through the lens of socioecological knowledge systems. Deidentified quotations from various participants serve as examples for each theme in the findings, translated into English with an emphasis on preserving literal source equivalence where possible (Regmi et al. 2010) and denoted by participant number. All analyses were carried out in NVivo v12 (Bazeley and Jackson 2013).

Findings

Farmer characteristics and

subsistence), and annual farm revenue (36.7% making less than \$10,000 annually vs. 36.7% making at least \$40,000). Most farmers reported using governmental (68.0%) and



hurricane- related descriptive statistics

Farmers were surveyed from 15 municipalities in the central mountain range of Puerto Rico, with most located in the central and western areas of the island (Fig. 1). Based on the quantitative questionnaire, most participants were Puerto Rican (96.7%), lived in a rural area (96.7%), and were the primary owner of the farm or agricultural establishment (83.3%) (Table 1). Balanced representation was obtained in terms of sex (56.7% male), age [mean (SD) = 47.2 (14.3)], production extent (i.e., 50.0% commercial vs. 43.3% plants (50.0%) and supermarkets (23.3%) in the local food supply chain. However, a diversity of direct-to-consumer sale strategies were also observed, including farmers' markets or roadside vending (40.0%) as well as sales to restaurants (33.3%) and individuals (23.3%).

Hurricane María resulted in significant destruction in surveyed farms, with all participants reporting losses of crops or animals and many citing damaged infrastructure (70.0%) and machinery (53.3%) (Table 2). With Puerto Rico's agricultural sector already burdened by significant labor shortages (Gould et al. 2015), approximately one third of participants (36.7%) also had farm laborers move to the mainland US in the months following the hurricane. Approximately two thirds (60.0%) had no farm products available for immediate sale after the hurricane, and the

nongovernmental assistance (63.2%). Most farms produced land-based crops (76.7%) while a smaller proportion were involved in animal (23.3%) or hydroponic (13.3%) production. To sell their products, many of the farms surveyed relied on intermediaries such as distributors or processing

Fig. 1 Map of 15 municipalities in Puerto Rico where 30 participating farms were located. Location of farms are shown in light gray for municipalities with 1–2 farms represented, and in dark gray for municipalities with 3–8 farms represented. Most were located in central mountainous municipalities of Puerto Rico, where smallholder farmers typically produce food for both market and personal consumption, support rural communities, and face similar land and resource constraints

majority lacked resources and were unable to produce food for longer than a year. One fifth of surveyed farmers continued to lack farm resources (e.g., seeds, fertilizer) (20.0%) and were unable to produce food (23.3%) at the time of the interview, nearly 2 years after the hurricane. Communication services on farms were inoperative for approximately one month after the hurricane and electric utilities, for more than 6 months. Despite these hardships, examples of self-sufficiency in the hurricane's aftermath point to the possibility of amplifying locally resilient natural disaster recovery. For example, although water shortages were widespread and government-led repairs to the electric grid were delayed, most surveyed farmers never lost access to potable water due to private or communitymanaged wells and natural springs. Farmers with generators and self-

maintained, renewable energy sources such as solar panels were also able to promptly restore electricity.

A variety of food products were produced in surveyed farms, with 38 unique items reported, including starchy fruits, root crops, coffee, vegetables, tropical fruits, herbs, and animal products (Table 3). The most reported crops produced were plantain (70.0%), green banana (63.3%), and *yautía* (i.e., a species of taro root) (46.7%). The ability to reestablish farm products after the natural disaster varied substantially, largely relating to crop cycle length, seed access, and plant structure. Most farmers were able and chose to continue producing plantain, green banana, *ñame* (i.e., a yam), *malanga* (i.e., a species of taro root), *apio* (i.e., a species similar to celery root), chili pepper, passion fruit, and papaya after the hurricane. In contrast, high proportions of permanent food product loss were observed for orange and lemon, trees requiring several years to bear fruit, as well as coffee, which relied on government-regulated seed banks (Borges-Mendez and Caron

Table 1 Characteristics of farms and smallholder farmers surveyed about experiences during Hurricane María in Puerto Rico

Participant characteristics ^a	All (n = 30)
Age, years	47.2 (14.3); 27.0–76.0
Male	17 (56.7%)
Puerto Rican ethnicity	29 (96.7%)
Rural area of residence	29 (96.7%)
Owner ^b	25 (83.3%)
Farm characteristics ^c	
Production type	
Land-based crop	23 (76.7%)
Animal or mixed (crop and animal)	7 (23.3%)
Hydroponics	4 (13.3%)
Other ^d	4 (13.3%)
Production extent	
Commercial	15 (50.0%)
Subsistence	13 (43.3%)
Major product purchasers	
Supermarkets	7 (23.3%)
Distributors and/or processing plants	15 (50.0%)
Restaurants	10 (33.3%)
Farmers' markets and/or roadside vendors	12 (40.0%)
Individuals	7 (23.3%)
Average annual revenue \$0–9,999	11 (36.7%)
\$10,000–39,000	7 (23.3%)
> \$40,000	11 (36.7%)
Use of governmental aid	17 (68.0%)
Use of non-governmental aid	12 (63.2%)

^a Data shown as n (%) except for age, which is shown as mean (SD); range of minimum to maximum

^b Others include supervisors, managers, and spouse of owner^c Sums may exceed or not add up to 100% due to multiple or not

applicable responses, respectively ^d Includes greenhouses, agroecology, and ecotourism

2019). Some farmers took opportunities to add new food products to their farms after the hurricane, including cacao in farms previously producing coffee as well as lettuce and cilantro in newly established hydroponic greenhouses. Although most participants had no farm products immediately available for sale, many recounted supplementing their diets with their crops and sharing them with family and local community members as fresh alternatives to the otherwise limited selection of processed foods available in supermarkets and aid packages. Apart from being readily available and having longstanding uses in traditional cuisine, these fruits and vegetables could also be a significant source of essential micronutrients and dietary fiber (Dilworth et al. 2007; Lopez 2008; Truesdell et al. 2018; Marrero et al. 2020).

Table 2 Self-reported damages and service disruptions to farms after Hurricane María in Puerto Rico

Damage ^a	All (n = 30)
Crops and/or animals	30 (100.0%)
Buildings and infrastructure	21 (70.0%)
Machinery and other equipment	16 (53.3%)
Permanent island abandonment of farm laborers	11 (36.7%)
No product immediately available after hurricane	18 (60.0%)
Service losses, days	
Electricity	210 (150–270)
Communication	30 (29–113)
Drinking water	0 (0–7)
Without farming resources, days	365 (120–540)
Currently ^b	6 (20.0%)
Unable to produce food, days	365 (154–540)
Currently ^b	7 (23.3%)

^a Data shown as n (%) or median (25th–75th) ^b Defined as still being without farming resources and/or unable to produce food at the time of interview (> 630 days)

Themes

The saturated codebook consisted of 35 codes, organized under four domains: (1) personal and community food access, (2) farm recovery, (3) psychosocial experiences, and (4) agricultural resilience (Appendix). Metrics for intercoder reliability suggested substantial agreement, with Cohen's kappa = 0.77 and percent agreement = 98.9%. Four major themes arose from the clustering of codes across several domains and were identified as follows: (1) socioecological identity, (2) self-sufficiency, (3)

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availability^b after the hurricane (%)

Socioecological identity

The theme of socioecological identity captured how the participants' sense of self was largely rooted in the farms and natural ecology around them. Participants were often overwhelmed with emotion during the narrative interview—unable to speak, in tears, or with raised goosebumps—when recounting their experiences first entering their land immediately after the hurricane. Initial feelings of homelessness and helplessness upon seeing a lifeless landscape were pervasive across narratives, with a personal sense of control lost in the aftermath of the hurricane.

You could see all the mountains brown, as if they had burned. That was the state of Puerto Rico, and we would go to see the farm like that, completely on

Table 3 Food product availability in 30 farms in Puerto Rico before and after Hurricane María

Product (count of farms) ^a	Immediately	available		
		Unchanged (%)	Lost (%)	Added (%)
Starchy fruits and roots				
Plantain (21)	38.1	71.4	23.8	4.7
Green banana (19)	10.5	68.4	21.1	10.5
<i>Yautía</i> (14)	21.4	42.9	42.9	14.3
<i>Ñame</i> ^d (12)	33.3	58.3	41.7	0.0
Pumpkin (8)	12.5	37.5	37.5	25.0
<i>Malanga</i> (7)	14.3	57.1	28.6	14.3
<i>Apio</i> ^d (6)	16.7	50.0	16.7	33.3
Coffee (10)	20.0	60.0	40.0	0.0
Cacao (4)	0.0	25.0	0.0	75.0
Vegetables				
Chili pepper (12)	0.0	83.3	8.3	8.3
Beans (7)	0.0	14.3	42.9	42.9
Pepper (5)	0.0	20.0	40.0	40.0
Lettuce (5)	0.0	20.0	40.0	40.0
Tropical fruits				
Lemon (9)	0.0	11.1	44.4	44.4
Passion fruit (8)	12.5	75.0	0.0	25.0
Papaya (7)	0.0	57.1	0.0	42.9
Orange (5)	0.0	40.0	60.0	0.0
Cilantro (7)	0.0	28.6	28.6	42.9
Others^{c,d}				
	Cassava, sweet potato, corn, avocado, eggplant, tomato, cabbage, broccoli, pineapple, <i>acerola</i> , <i>guanábana</i> , mango, starfruit, grapefruit, tamarind, culantro, ginger, oregano, eggs, cheese			
	Post-hurricane	change	in	

^a Includes all food products under production or available for sale currently, before, and/or immediately after the hurricane

^b Refers to change in food product availability related to the hurricane among participants who reported the respective product. 'Unchanged' denotes proportion of farms who had products before Hurricane María and at the time of interview (> 630 days after the hurricane). 'Lost' refers to proportion of farms who had products before the hurricane but did not have them at the time of interview. 'Added' denotes proportion of farms who did not have products before the hurricane but had them at the time of interview ^c

^c Includes roots, vegetables, fruits, herbs, and animal products reported by less than 5 out of 30 participants ^d *Yautía* and *malanga* are traditional terms for two different species of taro roots; *ñame*, for a species of yam; *apio*, for a species similar to celery root; *acerola*, for a species similar to cherry; and *guanabana*, for soursop

the ground, completely burned. Nothing, you had to stay and do nothing. (7)

The feeling around you became inhospitable because in the absence of trees, the atmosphere becomes heavy. (27)

Farms were similarly described as vulnerable entities, and losses in the natural environment after the hurricane often mapped onto farmers' own sentiments about losing a part of themselves—their passion, sustenance, and years of physical and economic efforts.

It was difficult to see a green nature so beautiful and so powerful reduced to nothing. (6)

Why the hell did I put myself into this, of developing the land, if this is so vulnerable? I cried a bunch because more than seeing it as a business, I am passionate about this. (16)

[It was as] if your worst nightmare was a reality. The farm is what sustains us and what you work for, and you have no tools to stop or save anything. You just have to let it happen. (17)

To see your own sacrifice, that of the laborers, and that everything is gone. I went to bed with everything, and I woke up with nothing. (20)

Due to a personal identification within their socioecological systems, the natural environment's destruction took an apparent toll on their emotional health, trauma that was sometimes still present at the time of the interview almost 2 years after the hurricane.

A lot of anxiety, more sadness—sadness to see the land destroyed. (25)

All the economic investment, all the physical labor was gone in a few hours. But all of that, you can recover— but the emotional aspect, no. (10)

Although a source of stress after the hurricane, farms were also often referred to as extensions of their families, capable of harboring the same feelings of strength, happiness, and spirituality more often associated with emotional wellbeing.

It is a fruit. It is something that depends on you, that you feed. It becomes a part of you. And the satisfaction, maybe, [is] not so much monetary, more so spiritual. It is a peace. (13)

Agriculture is a thing that is equal to a child. One enjoys it, one enjoys it. One makes it a part of one's own family, of seeing her grow, of seeing her give birth, of seeing her give that product. (22)

Positive emotions arising from their socioecological identities mirrored reflections on the resilience that many participants expressed is needed in agriculture, after a

natural disaster and otherwise. Just as the natural environment is complex and variable, with periods of scarcity and abundance, so too must farmers be able to have patience, persevere, and adapt to unpredictability.

In agriculture, you have to be very positive. That is a characteristic of the farmer because here, the most that you are going to have are constant and consecutive situations that are difficult: droughts, rain, low prices, illnesses, government. It is a complexity that nature herself gives us, but what we have left is to learn to work with her [nature] because she will always be there. (14)

One must wait. One must sow, one must sow. And if a wind knocks it down, one must wait again fourteen months more. That is the basis of us, farmers. (22) Well, I thought that agriculture does not need a roof. I needed it, but agriculture does not. So, I lifted my spirits myself, 'To plant, it has been said!' (6)

Self-sufficiency

Along with their perceived place in the natural environment, the theme of self-sufficiency surfaced as an essential facet of farmers' socioecological identities during the narrative interview. Participants largely expressed pride in their capacity as farmers to work laboriously in their fields and provide essential nourishment for themselves, their families, and their community. Agriculture was discussed as fundamental to the local food supply and food security, perspectives that were also often rooted in sentiments towards farming as integral to cultural and national identity. To be a farmer, one must be born for this. One must work their entire life to know what daily bread is. (12) A *pueblo* [community] without agriculture is a *pueblo* without food. A *pueblo* without food is a *pueblo* dead of hunger. (20)

Perspectives from mothers and caretakers also highlighted the benefits of farming as an autonomous source of income, simultaneously enabling them to remain in the household with children, aging parents, or family members with chronic health conditions. These benefits were especially pronounced for greenhouse and hydroponic production, which—although relying heavily on initial economic and infrastructural investments—were generally less laborintensive, climatically controlled, and more frequently harvestable.

The greenhouse, what I like most is that I can do it myself alone. Sometimes, it is very difficult to find someone to help you, including paying them. [But] this is what I want to do, and it is easy for me. I have the

girls that can be there, or they can stay here in the house. (5)

That is an advantage of entering into hydroponics. You can work it during the day, at night, rains, thunders, lightnings, because that does not get wet. You can even put young people and women to work it as well. Normal agriculture requires more labor. (14)

Recounted experiences after Hurricane María highlighted the desire of local farmers to build more self-sufficient farming operations, minimizing dependence on external aid for both food and agricultural resources in the aftermath of a natural disaster. Participants recalled relying on their own crops as a fresher, healthier, and more reliable food source than processed foods available in food aid packages or at intermittently stocked supermarkets. Solar

panels, wells or natural springs, and a diversity of food crops were pointed to as possible efforts to more efficiently reestablish personal and community food and water access after a storm, among other climate resilient farming strategies (Table 4).

My dad would tell me his stories, and that is why I always have planted products underground, a little bit of *yautía*. I plant *apio*. I plant *malanga*, a little bit, to have something in case a storm passes. (3)

We are looking for alternatives to diversify our products. We have to find alternatives so that we are harvesting weekly and so that that becomes monthly payments for us farmers. (11)

[The hurricane] has its good part and its bad part. Its bad part obviously because no one wants to live in fear.

Table 4 Climate resilient farming practices and their perceived benefits discussed by smallholder farmers in Puerto Rico

Practice	Description and examples	Perceived benefits
Crop diversification	Increase variety of food crops cultivated on farm and lag planting times	Access greater diversity of starch roots, fruits, and vegetables for personal and/or local community consumption; effectively recover crops that quickly mature while other stakeholders reestablish (e.g., coffee); obtain more frequent and consistent income throughout the year
Soil conservation strategies	Implement practices such as contour plowing, drainage water management, and use of cover crops	Promote soil health, minimize soil erosion, and diminish the risk of landslides after a natural disaster
Seed banking	Create seed banks in individual farms and/or with local farmers; invest in on-site greenhouses	Amplify and localize seed access after a natural disaster; reduce risk of seed shortages; decentralize seed management and decrease government dependence
Farm laborer action plan	Prepare action plan with farm laborers in the case of a natural disaster occurrence	Can harvest surviving product before spoilage in field; recover remaining plants and seeds to minimize reliance on entirely new planting cycle; and increase likelihood of retaining farm laborers
Hurricane farm preparedness	Prepare crops and farm structures by pruning trees and shrubs; reinforcing greenhouses with concrete (and cutting plastic covers immediately before a disaster) and maintaining vehicles/gasoline stores up-to-date	Minimize wind and water damage to crops and built infrastructure; retain local transportation capacity for resource access during gas and lines outages or road closures
Household food preparedness	Prepare for food shortages by establishing 2-week stores of nonperishable foods; installing solar panels for refrigeration and cooking appliances; accessing wells or natural springs; learning food safety practices of farmer crop consumption	Minimize dependence on super market access, restaurants, or food aid packages for food and water during a food supply chain breakdown; increase self-sufficiency access to electricity
Collaborative smallholder farmer networks	Amass agricultural and economic resources for economies of scale Engage in training and information sharing Bolster direct-to-consumer marketing and sales strategies via informal farmer-to-farmer agreements Prepare for and respond in community to natural disasters	Can interexchange farm resources such as seeds, fertilizers, small equipment at low or no cost; coinvest in value-added production strategies (e.g., banana flour); coinvest in expensive or otherwise inaccessible farm machinery; and efficiently coordinate work of farm laborer Can communicate information on governmental and non-governmental financial assistance, agricultural training, and other resources as well as best practices for novel or unregulated practices (e.g., hydroponics, agroecology) Can organize local farmers' markets; own or connect with local food vendors; engage in informal agreements with commercial farmers to bring products to market; participate in agrotourism routes; share resources for bulk delivery to community members, super markets, restaurants, and urban centers; coinvest in shared shipping containers for export markets; and set food product prices more resistant to supply and demand as well as extreme weather events Can maintain collaborative seed banks; establish community action plans after a disaster (e.g., reestablish road access, identify community centers for distribution of food and other basic necessities); and create networks of socioemotional support

But it also taught me that I must prepare myself for everything. I do not want to depend anymore on external factors to continue my normal life. And now, while I can, I put everything in solar energy, I make a well, drinking water, recycle everything I can, compost. Everything that I can reuse, sow, and have a diversity of plants. (24)

Discussed efforts to create a more secure and self-sufficient food system extended to the participants' sociopolitical realities, intersecting with cultural desires to diminish dependence on governmental assistance. Although some farmers recognized the importance of some current or proposed agricultural policies—including farmers' markets for beneficiaries of the Nutritional Assistance Program, financial support for farm laborers' wages, incentives for sustainable practices, and food import restrictions—most felt that access to government resources was highly inequitable and ineffective. Seed access among coffee growers, for example, was severely delayed after the hurricane due to government mismanagement, inspiring a few participants to collaborate with local organizations to create community-based seed banks. Participants with more commercialized production also recounted difficulties in accessing resources due to delayed claims for governmental agricultural insurance, while small, subsistent farmers did not have the financial capacity to obtain coverage to begin with. Some farmers pointed to government aid in agriculture as entrenched in longstanding colonial histories on the island and perceived subsistence farming as an act of political resistance and self-reliance. Most participants agreed that interventions should be offered not to reinforce government dependence and control but, instead, should only exist to facilitate farmers helping themselves and their communities.

We started a project of a coffee greenhouse to be able to supply coffee to farmers, using seeds or grains that we collected immediately after the hurricane. Because we knew that the government was not going to have coffee seedlings. (23)

[We have to] secure our food because I did not know what hunger truly was until [after the hurricane]. We must remove our dependence of importing so much here, and that they help us. First, I help myself and then after. Because, that way, I can help others. (24)

Perceived needs to promote self-sufficiency also revolved around reducing food import dependence; investing in innovative strategies such as agrotourism; and leveraging sociocultural support, solidarity, and pride in agriculture to promote the local food economy.

I think that more value has been given [to local agriculture] now. More conscientiousness was created after being with that dependence on what was outside coming in. I have seen more support. (16) A *chinchorro* [food kiosk-hopping] of farms where the people take advantage—they go and buy fresh products, products of the nation. You promote an economy of solidarity, of each of us helping the other. (27)

Community and cultural heritage

Although working of their own accord, the majority of participants placed self-reliance in agriculture within a broader sociocultural context. Farms and agricultural knowledge were often handed down generationally, and many participants expressed loyalty to a heritage of providing for family, farm laborers, and other community members. For some participants, familial and cultural heritage was a major motivator to work in agriculture and restart operations after the hurricane.

This farm has been in my family for a hundred and four years. These people have been working with our families for generations, so I feel a sense of responsibility. (17)

There are few young people in this country that believe in agriculture. One of the cultural things that, as I understand it, was horrible when we grew up was that they would tell me, 'Study so that you will not have to be under the sun. Study so that you do not have to work in agriculture.' And when I finished studying, I see that agriculture was one of those things that should [have] never be[en] abandoned. (18)

Others, however, had older family members so emotionally shaken after the disaster that they did not wish to return to their fields. Being unable to support their communities after Hurricane María was particularly painful for a few participants, a stress experience that persisted to the time of the interview.

The farm was run by my dad and me, although he became demoralized a lot after that and left me the reigns of the farm because he did not want to continue anymore. (16)

The hurricane passed, and you cannot give yourself the job even of crying because someone has to be strong. In this house, that is me, and I am strong for my parents [and] my laborers. And you telling everyone that everything is okay, that everything is going to recover. And you go to bed and try to close your eyes, and you cannot. For months, to be in that condition, one

reaches a moment at which, physically, one becomes drained and, mentally. I got to a point that I sat down one day and cried and cried and, still, there are times like that. But I must do it because I must be the ‘support’ for my family. But who is my support? (10)

The perceived inability to help those in need, along with insufficient social support for their own wellbeing, were major determinants of long-lasting negative emotionality after the hurricane. In contrast, many participants expressed a positive perspective shift towards empathy and gratitude upon observing communities coming together to aid those with greater needs than their own. Farmers coming together to amass resources—including establishing road access, sharing food crops with the community, and lending each other farm resources—was a source of spiritual wellbeing, resilience, and sociocultural pride after the hurricane.

The thing is, I cannot tell you that I had emotions because it was like, ‘Let us go to my [farm], let us go to the other, let us go to the other.’ I went with the brigades to open paths where the government had not been able to reach. I saw so many things worse next to me that I did not have time to stop myself and say, ‘Wait, how am I feeling?’ I think that what Puerto Ricans did—a lot of resilience to keep moving forward and, within everything, I am grateful. (19)

There was a coming together spiritually among the people themselves to share what little there was because, for example, the farmers, well, a family member would come, we would give them, if we had a little bunch of green bananas, we would give it to them. I would say that that was most important—the spiritual strength to be able to help each other. (3) Among the bad that occurred in the hurricane, what surprised me was how we would help others. It was something *brutál* [incredible] because I had never seen a union of community, of *pueblo*. And we, me as a farmer and two or three farmers and neighbors that had different types of businesses, we united and we were able to bring food to other *pueblos*, other people. (20)

The ability to provide food for the community was an important facet of their identities as farmers. Agroecology—apart from its direct benefits to the environmental sustainability of farming operations—was identified as an exemplary agricultural movement taking hold in Puerto Rico that could more equitably address health and food insecurity compared to other formally regulated and expensive foods.

What happens with organic agriculture is that, not that it is not good, but it is elitist. The common person does

not have access to buy those products. Agroecology [has] a different meaning, without any type of regulation. (27)

Collaborative agency

The ability for smallholder farmers to informally collaborate with and for themselves, their families, and their communities—a capacity intimately tied with perceived self-sufficiency, sociocultural heritage, and psychosocial wellbeing—was consistently discussed as an ideal that ought to be strived for in the local agricultural sector. Socioecological metaphors, linked to their physical identities as farmers, evoked images of a natural and inherent desire to work with the land and each other to serve the community after the hurricane.

After the hurricane, you saw people suffering in front of you, and one [feels] like one has no arms, one has no legs. What do I do? One cannot do anything. I was born to give. If I do not do that, for me, life is useless. (22)

The earth never keeps anything. It always gives something. (4)

We must organize, I would say, by community or by area in case something happens. How will we work? Because, maybe, I have a chainsaw, you have gasoline—let us use them. Uniting in a group is easier. (10)

Beyond the context of a natural disaster, coming together to create informal alliances and amass physical, economic, and dietary resources was identified as an important strategy to expand agency in an agricultural sector otherwise characterized by limited assets, reliance on government aid, and competition from heavy food import dependence. Importantly, participants expressed that the sociopolitical and economic benefits of collaboration between farmers should be informal, minimally regulated, and counterbalanced with the preservation of individual identity and financial interests. I think that what we should do is all help each other, [so] that there is more. Not help from outside, but instead, our own. (4)

[The collaboration] is not stipulated. Simply, that is how we behave. We need to educate ourselves as modern farmers and create alliances. Truly, help is help. And among all of us, we can succeed in Puerto Rico. If we would apply ourselves and row in one same direction, without trying to put obstacles on the colleague, we would definitely plant everything that is left. (18)

Throughout the interviews, participants provided recommendations for climate resilient farming practices and how to establish informal smallholder farmer networks, along with specific examples of their perceived benefits (Table 4). Climate resilient practices included crop diversification, soil conservation, establishing seed banks, creating actions plans with farm laborers, hurricane preparedness, and household food preparation. To facilitate some of these practices, many participants expressed the desire of establishing collaborative smallholder farmer networks within a local community or region. These networks, for example, could exchange seeds, fertilizers, and small farm equipment; coinvest in value-added production as well as expensive or otherwise inaccessible machinery; and coordinate with and distribute increasingly limited farm laborers between farms. Farmers could also communicate information on available assistance and resources as well as share best practices for novel or unregulated agricultural methods, including hydroponics and agroecology. Additionally, through farmers' markets, agrotourism routes, shared shipping containers, or bulk delivery to community members, supermarkets, restaurants, and urban centers, farming collaboratives may more effectively engage in direct-to-consumer marketing and sales, diffusing time and monetary expenses amongst each other and decrease intermediary costs. Farmers could also collaborate to set prices for locally produced agricultural products, which can vary considerably in Puerto Rico due to the competitive pricing of imported foods as well as unfavorable weather events. Finally, collaborative natural

disaster preparedness, such as shared seed banks and community action plans, could more efficiently mobilize resources in farming communities after a future extreme weather event.

Together, the themes captured during the interviews demonstrated the wealth of socioecological knowledge farmers possessed as they coped with, adapted to, and leveraged their social and natural resources to recover after Hurricane María; these findings informed the development of an illustrative model of a climate resilient food system in Puerto Rico (Fig. 2). Despite a largely fragmented and underdeveloped agricultural sector, surveyed smallholder farmers consistently expressed the desire to capacitate food autonomy in local communities by providing locally sourced staple foods, reducing food import dependence, and incorporating environmentally sustainable practices. More than just a set of practical considerations, however, these sentiments overwhelmingly placed agriculture at the center of cultural and collective wellbeing. With multigenerational expertise serving as intermediaries between their unique social and natural environments, smallholder farmers consistently expressed pride in contributing to and preserving a community and agricultural heritage rooted in self-sufficiency and implicit mutual aid (Boger et al. 2019). As a concept capturing the tendency to place one's sense of self in the natural environment, efforts to preserve socioecological identity and related cultural values may also lend themselves well to the promotion of sustainable agricultural development, landscape

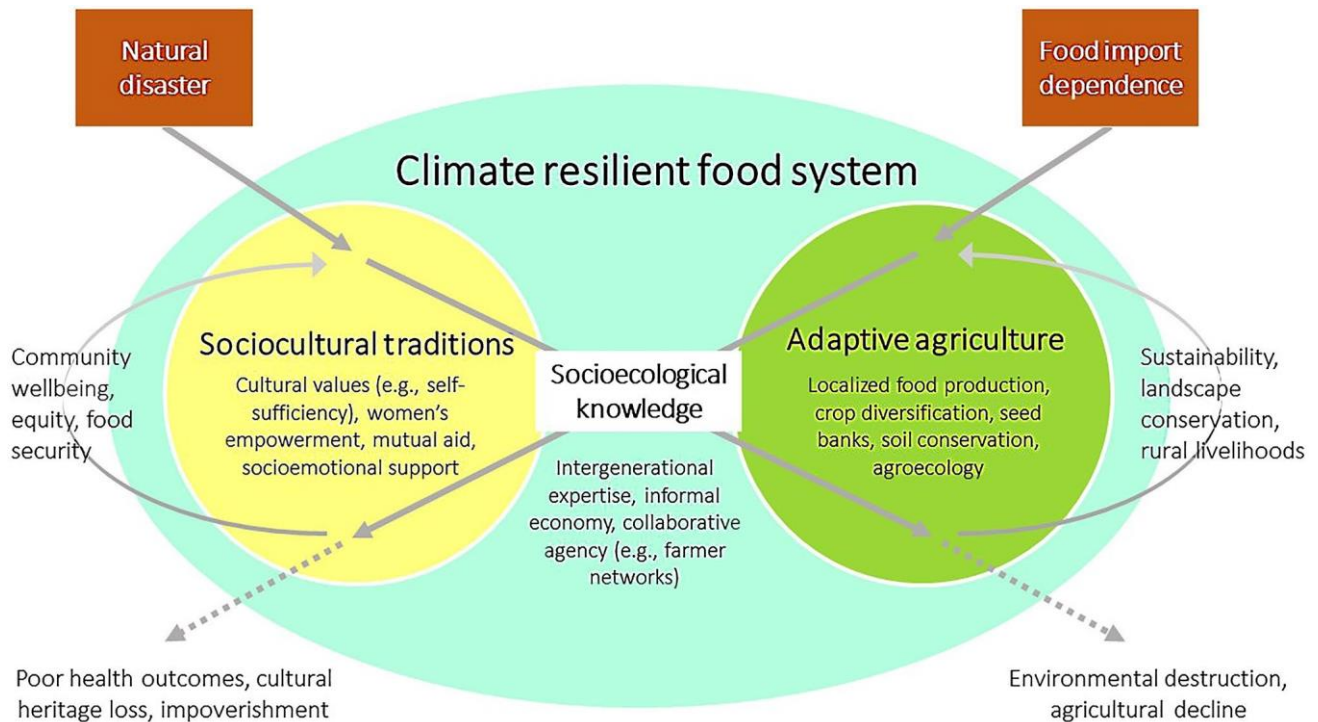


Fig. 2 Illustrative model summarizing smallholder farmer's perspectives of a climate resilient food system. Natural disasters, import dependence, and other disturbances can have adverse consequences, particularly in a small island food system. Serving as longstanding intermediaries between their communities and natural environments, smallholder farmers seek to prevent poor outcomes associated with these external shocks by leveraging traditions of social support and adaptive agricultural practices to bolster food access, farm recovery, and community-wide resilience. This local expertise, described here as socioecological knowledge, can inform the promotion of a healthier, sustainable, and more self-determined food system. Figure adapted from RIHN 2013

conservation, and rural quality of life. Finally, by emphasizing mechanisms of social support, this model highlights how collaborative agency can be leveraged in farming communities pursuing food sovereignty, recognizing strengths already present and ingrained in Puerto Rican sociocultural systems. With food security amid climate change as an ultimate goal, understanding agricultural practices within their socioecological contexts will be important in moving toward locally-informed community action and climate resilience.

Recommendations

Beyond a source of economic output, local agriculture is deeply imbedded in the social, cultural, and ecological fabric of Puerto Rico. Incorporating the sentiments and cultural expertise of smallholder farmers will be crucial in promoting a locally relevant and resilient island food system. Bolstering agriculture in rural Puerto Rican communities will rely on locally informed solutions and, according to surveyed farmers, can include climate resilient farming practices and informal, collaborative smallholder farmer networks. Traditional expertise on agroecological techniques such as contour plowing and agroforestry systems, for example, can contribute to climate resilience by improving soil quality, preserving local biodiversity, and diminishing the risk of erosion (Altieri et al. 2015). According to surveyed farmers, crop diversification can also diffuse natural disaster risk by providing products that can be harvested in months such as plantain and chili pepper—or in weeks such as hydroponic lettuce and cilantro—while tree and shrub crops like coffee take longer to reestablish. Diversifying food crops can have additional benefits to farm and food security, including contributing to more consistent year-round income and increasing local access to a variety of traditional fruits and vegetables (Ebert 2014; Lin 2011). Ensuring that these natural sources of food and potable water are safe to consume (e.g., filtration systems, food safety practices) should also accompany efforts to bolster rural food autonomy.

In these fragile and resource-limited island environments, collaboration will be increasingly necessary

to bolster a community-led local food system (Saint Ville et al. 2015). Smallholder farmer networks, for example, can more equitably share information on climate resilient management systems, best practices for hydroponic or agroecological production, and government aid. Collaboration among farmers can also amass physical and economic resources (Kangogo et al. 2020) to collectively invest in expensive farm equipment, bulk delivery, or value-added production, efforts that may contribute to gains in rural livelihoods. Cooperative direct-to-consumer sales such as local farmers' markets can shorten otherwise fragile distribution systems, lower intermediary costs, and leverage community interest in a self-reliant food supply (Samoggia et al. 2019). In collaborating to mitigate natural disaster risk, smallholder farmers can also choose to establish locally managed seed banks in order to reduce delays in start-up and decrease dependence on government aid (Borges-Mendez and Caron 2019). Developing farm laborer action plans for future natural disasters may also aid in quickly harvesting surviving food crops and increase the likelihood of retaining farm laborers who may otherwise leave the island or look for other employment. Finally, within larger neighborhoods and kin networks, farmers can participate in the development of community action plans to facilitate recovery, including strategies to preserve, distribute, and cook surviving food crops immediately after a natural disaster. Strengthening communal ties may also bolster emotional support, especially when needed to preserve mental health after a natural disaster (Shakespeare-Finch and Green 2013).

Despite farmers having and relying on a wealth of socioecological expertise, individual action alone may not suffice to overcome the broader structural constraints in Puerto Rico's economic and political systems. Institutions, infrastructure (e.g., transportation, housing and utilities, communication systems), and political context are important drivers of adaptation and recovery in disaster-prone agricultural systems (López-Marrero and Yarnal 2010). After Hurricane María, farmers in Puerto Rico most often cited government bureaucracy and insufficient support; delayed insurance payments; and lack of electricity, machinery, water, and accessible roads as major obstacles (Rodríguez-Cruz and Niles 2021). Island-wide governance within the agricultural sector must address these deficits and, beyond that, move towards policies that support farmer autonomy and agency. Instead of current production-oriented incentives (e.g., subsidies for agrochemicals, crop insurance programs)—which may provide small, short-term financial aid but have, ultimately and historically, distorted rural economic development—government policy must aim to reduce propensities towards dependence and make way for social movements that

uphold sovereign, culturally regenerative, and ecologically sustainable local food economies (McCune et al. 2019).

Evidence from Puerto Rico and other small islands have identified similar practical and cultural considerations in promoting local food production. In Jamaica, for example, efforts to promote household and national food security have looked to small-scale subsistence farming, with an emphasis on leveraging adaptive local knowledge and reducing food import dependence (Beckford et al. 2007). Identified strategies to capacitate local farmers have included diversifying field crops; maximizing traditional local food use; reducing food waste via post-harvest storage, marketing, and distribution systems; recognizing the role of and empowering women in agriculture; increasing community and household agro-processing; and utilizing organic and agroecological practices. In the Pacific, ethnobiological knowledge around indigenous agricultural practices—including agroforestry, fishing, and polyculture—is both intimately tied to social traditions and highly adaptive to extreme weather disturbances; many of these climate resilient systems are still used in modern food production (McMillen et al. 2014). Backyard farming in Puerto Rico's informal economy bolsters a community-led food sector sustained, not by external factors, but instead by extended community and kin networks (GarrigaLópez 2019). Other research after Hurricane María points to agroecology as the backbone of agricultural recovery, rural solidarity, and political will (Félix and Holt-Giménez 2017). Smallholder farmers' ability to successfully leverage natural (e.g., biodiversity, ecosystem services) and social resources (e.g., informal-horizontal networks, social mobilization, collective action, trust, reciprocity, exchange) will serve as a key determinant of adaptive capacity in this climate vulnerable food system (Rodríguez-Cruz and Niles 2021).

Limitations of study

This study is bolstered by several strengths, including a mixed methods approach which captured detailed quantitative data on smallholder farming characteristics, hurricane-related damages, and food product availability in an underserved, climate vulnerable food system. These findings were complemented by rich qualitative data offering a nuanced understanding of agricultural resilience and recovery in Puerto Rico. Some limitations, however, should be noted. Demographic characteristics of our sample contrast data from the 2018 Census of Agriculture in Puerto Rico, which documented 89.3% male, a mean of 59.2 years of age, and 22.0% making at least \$40,000 (USDA 2017). Selfselection bias in this nonprobability sample may also limit generalizability. Finally, although a diverse range of

perspectives, including those of female and younger farmers, were represented, qualitative analyses within economic and sociodemographic categories were not included due to small strata-specific sample sizes.

Conclusions

Natural disasters linked to climate change, including hurricanes, droughts, and coastal flooding, will continue to impact food systems in Puerto Rico and small island settings around the world. Historical declines in agricultural productivity, particularly in the rural mountainous region of Puerto Rico, and resulting food import dependence has contributed to a local food supply that is highly processed, vulnerable to climate change, and misaligned with a cultural heritage rooted in locally grown self-reliance and collective wellbeing. Nonetheless, the fortification of small-scale local food production has been identified as an important aim in promoting healthy, ecologically sustainable, and equitable food systems (Gonzalez 2011). Amid severe disruptions in agricultural production after Hurricane María, narrative interviews with smallholder farmers in Puerto Rico indeed demonstrated a deep-rooted desire to foster a more collaborative, self-determined, and climate resilient food system. Our findings suggest that the reinvigoration of local agriculture may hold promise in promoting food security, preserving cultural traditions, and serving as the foundation for sociopolitical autonomy in Puerto Rico. Importantly, efforts to promote climate resilience will need to leverage smallholder farmers' socioecological expertise—including self-sufficiency and collaborative agency—to ensure a more equitable, sustainable, and community-owned food system.

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Author contributions AM conceptualized the research question, conducted interviews, transcription, data analysis and interpretation, and wrote the manuscript. ALC assisted in data analysis and interrater reliability assessments. RBM assisted in data collection, community partnerships, and contributed to the manuscript. JM supervised conduct and management of the study and contributed to the manuscript. All authors read and approved the final manuscript.

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Data availability Due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data are not available.

Declarations

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

Consent to participate All participants provided written informed consent.

Consent to publish All participants provided written informed consent to publish.

Ethical approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Institutional Review Board of Harvard TH Chan School of Public Health and Ponce Health Sciences University (Protocols IRB19-0034 and 1903007592, respectively).

References

- Aalst, M.K.V. 2006. The impacts of climate change on the risk of natural disasters. *Disasters* 30: 5–18. <https://doi.org/10.1111/j.1467-9523.2006.00303.x>.
- Altieri, M.A., C.I. Nicholls, A. Henao, and M.A. Lana. 2015. Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development* 35: 869–890. <https://doi.org/10.1007/s13593-015-0285-2>.
- Alvidrez, J., D. Castille, M. Laude-Sharp, A. Rosario, and D. Tabor. 2019. The National Institute on Minority Health and Health Disparities Research Framework. *American Journal of Public Health* 109: S16–S20. <https://doi.org/10.2105/AJPH.2018.304883>.
- Anderson, C., and S. Kirkpatrick. 2016. Narrative interviewing. *International Journal of Clinical Pharmacy* 38: 631–634. <https://doi.org/10.1007/s11096-015-0222-0>.
- Ando, H., R. Cousins, and C. Young. 2014. Achieving saturation in thematic analysis: Development and refinement of a codebook. *Comprehensive Psychology*. <https://doi.org/10.2466/03.CP.3.4>.
- Bazeley, P., and K. Jackson. 2013. *Qualitative data analysis with NVivo*. Thousand Oaks: SAGE.
- Beckford, C., D. Barker, and S. Bailey. 2007. Adaptation, innovation and domestic food production in Jamaica: Some examples of survival strategies of small-scale farmers. *Singapore Journal of Tropical Geography*. 28: 273–286.
- Bernard, H.R. 2017. *Research methods in anthropology: Qualitative and quantitative approaches*. Lanham: Rowman & Littlefield.
- Boger, R., S. Perdikaris, and I. Rivera-Collazo. 2019. Cultural Heritage and local ecological knowledge under threat: Two Caribbean examples from Barbuda and Puerto Rico. *Journal of Anthropology and Archaeology* 7: 1–14. <https://doi.org/10.15640/jaa.v7n2a1>.
- Borges-Mendez, R., and C. Caron. 2019. Decolonizing resilience: The case of reconstructing the coffee region of Puerto Rico after Hurricanes Irma and Maria. *Journal of Extreme Events*. <https://doi.org/10.1142/S2345737619400013>.
- Carro-Figueroa, V. 2002. Agricultural decline and food import dependency in Puerto Rico: A historical perspective on the outcomes of postwar farm and food policies. *Caribbean Studies* 30: 77–107.
- Clarke, V., V. Braun, and N. Hayfield. 2015. Thematic analysis. In *Qualitative psychology: A practical guide to research methods*, 222–248. London: SAGE Publications.
- Colón-Ramos, U., A.A. Roess, K. Robien, P.D. Marghella, R.J. Waldman, and K.A. Merrigan. 2019. Foods distributed during federal disaster relief response in Puerto Rico after Hurricane María did not fully meet federal nutrition recommendations. *Journal of the Academy of Nutrition and Dietetics* 119: 1903–1915. <https://doi.org/10.1016/j.jand.2019.03.015>.
- Creswell, J.W., and V.L.P. Clark. 2011. Choosing a mixed methods design. *Designing and Conducting Mixed Methods Research* 2: 53–106.
- Decuir-Gunby, J.T., P.L. Marshall, and A.W. McCulloch. 2011. Developing and using a codebook for the analysis of interview data: An example from a professional development research project. *Field Methods* 23: 136–155. <https://doi.org/10.1177/1525822X10388468>.
- Dilworth, L.L., F.O. Omoruyi, and H.N. Asemota. 2007. In vitro availability of some essential minerals in commonly eaten processed and unprocessed Caribbean tuber crops. *BioMetals* 20: 37–42. <https://doi.org/10.1007/s10534-006-9012-4>.
- Ebert, A.W. 2014. Potential of underutilized traditional vegetables and legume crops to contribute to food and nutritional security, income and more sustainable production systems. *Sustainability* 6: 319–335. <https://doi.org/10.3390/su6010319>.
- Félix, G.F., and E. Holt-Giménez. 2017. Hurricane María: An agroecological turning point for Puerto Rico? Working paper. *Food First*.
- Figueroa-Helland, L., C. Thomas, and A. Pérez Aguilera. 2018. Decolonizing food systems: Food sovereignty, indigenous revitalization, and agroecology as counter-hegemonic movements. *Perspectives on Global Development and Technology* 17: 173–201.
- Folke, C. 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16: 253–267. <https://doi.org/10.1016/j.gloenvcha.2006.04.002>.
- García-López, G.A. 2018. The multiple layers of environmental injustice in contexts of (un)natural disasters: The case of Puerto Rico post-Hurricane maria. *Environmental Justice* 11: 101–108. <https://doi.org/10.1089/env.2017.0045>.
- Garriga-López, A. 2019. Puerto Rico: The future in question. *Shima: the International Journal of Research into Island Cultures* 13: 175–192.
- Gonzalez, C.G. 2011. Climate change, food security, and agrobiodiversity: Toward a just, resilient, and sustainable food system. *Fordham Environmental Law Review* 22: 493–522.
- González, G.M., and A. Gregory. 2012. Economic development plan for the agricultural sector. *Puerto Rico Planning Board*.
- Gould, W.A., F.H. Wadsworth, M. Quiñones, S.J. Fain, and N.L. Álvarez-Berríos. 2017. Land use, conservation, forestry, and

- agriculture in Puerto Rico. *Forests* 8: 242. <https://doi.org/10.3390/f8070242>.
- Gould, W.A., S.J. Fain, I.K. Pares, K. McGinley, A. Perry, and R.F. Steele. 2015. Caribbean regional climate sub hub assessment of climate change vulnerability and adaptation and mitigation strategies. *United States Department of Agriculture*: 67.
- Greenhalgh, T. 2016. *Cultural contexts of health: The use of narrative research in the health sector*. Copenhagen: World Health Organization. Regional Office for Europe.
- Harris, P.A., R. Taylor, R. Thielke, J. Payne, N. Gonzalez, and J.G. Conde. 2009. Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics* 42: 377–381. <https://doi.org/10.1016/j.jbi.2008.08.010>.
- Kangogo, D., D. Dentoni, and J. Bijman. 2020. Determinants of farm resilience to climate change: The role of farmer entrepreneurship and value chain collaborations. *Sustainability* 12: 868. <https://doi.org/10.3390/su12030868>.
- Lin, B.B. 2011. Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience* 61: 183–193. <https://doi.org/10.1525/bio.2011.61.3.4>.
- Lin, T.K., Y. Teymourian, and M.S. Tursini. 2018. The effect of sugar and processed food imports on the prevalence of overweight and obesity in 172 countries. *Globalization and Health* 14: 35. <https://doi.org/10.1186/s12992-018-0344-y>.
- Lopez, C.M. 2008. Cultural diversity and the renal diet: The Hispanic population. *Nephrology Nursing Journal* 35: 69–73.
- López-Marrero, T., and B. Yarnal. 2010. Putting adaptive capacity into the context of people's lives: A case study of two flood-prone communities in Puerto Rico. *Natural Hazards* 52: 277–297. <https://doi.org/10.1007/s11069-009-9370-7>.
- Manuel-Navarrete, D., and C.N. Buzinde. 2010. Socio-ecological agency: from 'human exceptionalism' to coping with 'exceptional' global environmental change. In *The international handbook of environmental sociology*. Cheltenham: Edward Elgar.
- Marrero, A., M. Tamez, J.F. Rodríguez-Orengo, and J. Mattei. 2020. The association between purchasing locally produced food and diet quality among adults in Puerto Rico. *Public Health Nutrition*. <https://doi.org/10.1017/S1368980020003134>.
- McCune, N., I. Perfecto, K. Avilés-Vázquez, J. Vázquez-Negrón, and J. Vandermeer. 2019. Peasant balances and agroecological scaling in Puerto Rican Coffee farming. *Agroecology and Sustainable Food Systems* 43: 810–826.
- McMillen, H.L., T. Ticktin, A. Friedlander, S.D. Jupiter, R. Thaman, J. Campbell, J. Veitayaki, et al. 2014. Small islands, valuable insights: Systems of customary resource use and resilience to climate change in the Pacific. *Ecology and Society* 19: 44. <https://doi.org/10.5751/ES-06937-190444>.
- Myers, S.S., M.R. Smith, S. Guth, C.D. Golden, B. Vaitla, N.D. Mueller, A.D. Dangour, and P. Huybers. 2017. Climate change and global food systems: Potential impacts on food security and undernutrition. *Annual Review of Public Health* 38: 259–277.
- Regmi, K., J. Naidoo, and P. Pilkington. 2010. Understanding the processes of translation and transliteration in qualitative research. *International Journal of Qualitative Methods* 9: 16–26. <https://doi.org/10.1177/160940691000900103>.
- Research Institute for Humanity and Nature (RIHN). 2013. *Vulnerability and resilience of social-ecological systems. Project E-04 (CR2)*. Kyoto: Research Institute for Humanity and Nature.
- Rodríguez-Cruz, L., and M. Niles. 2018. *Hurricane Maria's impacts on Puerto Rican farmers: Experience, challenges, and perceptions*. Burlington: University of Vermont.
- Rodríguez-Cruz, L.A., and M.T. Niles. 2021. Puerto Rican farmers' obstacles towards recovery and adaptation strategies after Hurricane Maria: A mixed-methods approach to understanding adaptive capacity. *Frontiers in Sustainable Food Systems* 5: 220.
- Saint Ville, A.S., G.M. Hickey, and L.E. Phillip. 2015. Addressing food and nutrition insecurity in the Caribbean through domestic smallholder farming system innovation. *Regional Environmental Change* 15: 1325–1339. <https://doi.org/10.1007/s10113-015-0770-9>.
- Samoggia, A., C. Perazzolo, P. Kocsis, and M.D. Prete. 2019. Community supported agriculture farmers' perceptions of management benefits and drawbacks. *Sustainability* 11: 3262. <https://doi.org/10.3390/su11123262>.
- Shakespeare-Finch, J., and J. Green. 2013. Social support promotes psychological well-being following a natural disaster. In *Proceedings of the Australian and New Zealand disaster and emergency management conference 2013: Peer reviewed papers*, 210–229. Nerang: AST Management Pty Ltd.
- Suarez, W., II. 2018. Cabotage as an external non-tariff measure on the competitiveness on SIDS's agribusinesses: The case of Puerto Rico. *CENTRO: Journal of the Center for Puerto Rican Studies* 30: 172–208.
- Tompkins, E.L., S.A. Nicholson-Cole, E. Boyd, L.A. Hurlston, G.B. Hodge, J. Clarke, N. Trotz, G. Gray, and L. Varlack. 2005. *Surviving climate change in small islands. A guidebook* 37.
- Truesdell, E., M. Schelske-Santos, C.M. Nazario, R.V. RosarioRosado, S.E. McCann, A.E. Millen, F.A. Ramírez-Marrero, and J.L. Freudenheim. 2018. Foods contributing to macronutrient intake of women living in Puerto Rico reflect both traditional Puerto Rican and western-type diets. *Nutrients* 10: 1242. <https://doi.org/10.3390/nu10091242>.
- USDA. 2018. Caribbean area agriculture, watershed recovery one year post María. In *Natural resource conservation service Caribbean area*. Washington: USDA.
- USDA National Agricultural Statistics Service. 2012. *2012 Census of Agriculture, Puerto Rico Island and Municipio Data 1*. Washington: USDA National Agricultural Statistics Service.
- USDA National Agricultural Statistics Service. 2017. *2017 Census of agriculture*. Washington: USDA National Agricultural Statistics Service.
- Vermeulen, S.J., B.M. Campbell, and J.S.I. Ingram. 2012. Climate change and food systems. *Annual Review of Environment and Resources* 37: 195–222. <https://doi.org/10.1146/annurev-environ-020411-130608>.
- World Bank. 2019. *Agriculture, forestry, and fishing, value added (% of GDP)—Puerto Rico*. Washington: The World Bank—IBRD IDA.

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Dr. Ramón Borges-Méndez was born in San Juan, Puerto Rico and has a professional career working in the United States, Latin America and Asia. He is currently Coordinator of the graduate Community Development and Planning Program, and Co-Coordinator of the dual degree (MA/MBA) program at Clark University (Worcester, MA). He holds a PhD and an MCP in Urban/City and Regional Planning from MIT, and a BA in Social Thought and Political Economy (STPEC) from the University of Massachusetts, Amherst. Prof. Borges-Méndez has held academic positions at UMASS-Boston, UMASS-Amherst, American University's School of International Service, The Johns Hopkins' School of Advanced International Studies (SAIS), and the University of Chile's Public Policy Graduate Program. He also has a broad career as a consultant working for the Ford Foundation, the World Bank, The Economic Commission on Latin American and the Caribbean of the United Nations (ECLAC), The United Nations' Department for Social and Economic Affairs, the Inter-American Development Bank, The Brookings Institution, the Japanese International Cooperation Agency, the Government of Chile, and SEIU-1199 Health Care Workers, NYC. Dr. Borges-Méndez has written on various public policy issues: workforce development; labor markets; poverty and community development in the United States; immigration; sustainability and governance in Latin America. His work has been published in the *Economic Development Quarterly*, *The Non-Profit Voluntary Sector Quarterly*, *Local Environment: The International Journal of Justice and Sustainability*, and *CENTRO-Journal of the Center for Puerto Rican Studies*. In 2005, he was chosen as William Díaz Fellow by Non-Profit Academic Centers Council. He has served in several advisory boards: The Mauricio Gaston Institute for Latino Community Development and Public Policy/UMASS-Boston; The Latino Education Institute at Worcester State University;

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