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Research Article

Interviews with farmers suggest negative direct and indirect effects of the invasive green iguana (*Iguana iguana*) on agriculture in Puerto Rico

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Abstract

Agricultural communities and crop production are negatively impacted by invasive species, with the effects of pathogenic fungi, parasitic insects and weedy plants being well studied. Mammals and birds are also recognized as impacting crops, but reptiles, such as non-native green iguanas (*Iguana iguana*), are typically not considered agricultural pests. Research on non-native green iguanas has largely focused on the lizard's interactions with native species with little attention given to its impact in the agricultural landscape. We conducted semi-structured interviews with farmers from 20 farms in Puerto Rico to explore the effect of the invasive green iguana on the production of crops and how farmers manage impacts, if any. A total of 34 of 55 crop species reported by farmers were negatively affected by the green iguana. We found that green iguanas were absent from 20% of farms, did not consume crops in 10% of the farms and caused negative impacts in 70% of the remaining farms. Negative impacts included crop loss and infrastructural damage, which had behavioral, emotional, and economic effects on farmers. Specific outcomes of these effects were revenue loss, refurbishing costs, changes in crop selection, management costs and emotional stress. Farmers considered management strategies as mitigation measures that needed to be constant to produce any positive effects on crop yield. They reported use of mesh fencing, hunting, and domestic animals as attempts to reduce negative effects of green iguanas on crop production. Recognition of this species as an agricultural pest is warranted in Puerto Rico and perhaps elsewhere in its introduced range. Agricultural extension agents should consider providing guidance on strategies to reduce negative impacts of green iguanas including cultivating less susceptible crops when possible.

Key words: agricultural pests, agricultural planning, agricultural policy, crop management, invasive species, social science in ecology, novel pests

Introduction

Plant pests encompass the spectrum of faunal, floral and microbial species that are pathogenic or harmful to agricultural plants and their products (FAO 2010). As commercial trade has increased and expanded, so too has the reach of agricultural plant pests. Invasive plant pests are a global concern for food security and can lead to billions of dollars of crop loss and management expenses (Paini et al. 2016). In a study of six African countries, estimates of crop loss were approximately US$ 1 billion due to only five agricultural pests (Pratt et al. 2017). In the European Union (EU) and in the United States (US), agencies and projects were established to monitor agricultural pests, manage them, and conduct research to increase food security. In 2015, the EU allocated US$ 8.2 million for the management of plant pests through a 10-country collaboration (Agricultural European Innovation Partnership 2020) while in 2017 the US spent US$ 53.2 million to fund their own projects (Animal and Plant Inspection Service 2018).

Recent work by Ireland et al. (2020) highlights the importance of classifying and prioritizing plant pests based on a set of common metrics. The authors designed and developed a framework that defines and classifies the impact of both native and non-native plant pests based on economic, socio-political, and management-related metrics. To classify pest species, information about their impact is needed. Invasive pest monitoring has engaged farmers (e.g., Dangles et al. 2010), scientists (e.g., Gotzek et al. 2012) and practitioners (Animal and Plant Inspection Service 2019a). Through continuous monitoring, plant pest species lists can be readily updated to support a reduction in further spread (Animal and Plant Inspection Service 2019b).

Viruses, fungi, insects and pathogens are the main focus of invasive pest management because of their negative impacts on food production. Rodent and bird species have also garnered attention as invasive agricultural pests that cause post-harvest losses in Asia, Latin America and Africa (Brooks and Fiedler 2001). Reptile species are not typically considered pests from an agricultural standpoint, though they are invasive alien species in over two dozen countries (Fritts and Leasman-Tanner 2001; Kraus 2009; Meshaka 2011). The invasive green iguana (*Iguana iguana* Linnaeus, 1758), a reptile from Central and South America, may become a pantropical agricultural pest and thus require the same concerted management action as other agricultural pests (Falcón et al. 2012; Knapp et al. 2020; van den Burg et al. 2020).

The green iguana is considered invasive in Asia and the Caribbean where it has spread through the pet trade (van den Burg et al. 2020; De Jesús Villanueva et al. 2021). Where introduced, this species is a concern due to its potential impact on local wildlife. In the US, there is concern over competition for nesting sites with the Florida burrowing owl (McKie et al. 2005). On the islands of Grand Cayman and in the Lesser Antilles, invasive green iguanas hybridize with endangered, endemic iguanids (Vuillaume et al. 2015; Moss et al. 2018; van den Burg et al. 2018). What has received far less attention is how the green iguana interacts with humans across its introduced range. Numerous countries cite invasive green iguanas as a threat to agricultural production (Kern 2009; Van Veen 2011; López-Ortiz et al. 2012; Thomas et al. 2013), yet qualitative or quantitative analyses of the potential impact of green iguanas on agriculture are lacking. As the green iguana spreads (Falcón et al. 2012, 2013; van den Burg et al. 2020) and increases its range, the need to understand its potential impact on agricultural food production becomes even more pressing.

On the island of Puerto Rico where the green iguana was first documented in 1964 (De Jesús Villanueva et al. 2021), there is no shortage of complaints about these reptiles. Articles published in Puerto Rico's news outlets (ElNuevoDia.com 2009; Roman Vargas 2016) have made the public aware that green iguanas are consuming local agricultural crops and reducing revenue for farmers. This claim was recorded in local management plans for the species (López-Ortiz et al. 2012) despite a lack of data to support it. Here, we sought to describe and quantify the impact of the green iguana on food production by determining the diversity of crops affected, the relative impact among different crops and the approaches farmers use to mitigate these effects. We hypothesized that crops in the plant families that are part of the green iguanas native range diet (Rand et al. 1990; Lara-López and González-Romero 2002; Benítez-Malvido et al. 2018) would be more susceptible to impacts by the green iguana. We completed interviews with 20 farmers throughout the island to assess both the direct and indirect interactions between farmers and green iguanas. By studying the potential impacts of the green iguana in Puerto Rico, we expect to provide the farming community with a list of impacted crops and mitigation methods used. Furthermore, our findings will provide invasive pest management agencies with data that will allow them to evaluate whether the green iguana should be deemed an agricultural pest. The applicability of this work is therefore expected to reach beyond the boundaries of Puerto Rico and be useful to other governments and farmers within the reptile's widespread invasive range.

Materials and methods

Farmers throughout the island of Puerto Rico were interviewed to gain a broad understanding of the potential impact of invasive green iguanas on the island's agriculture. We used semi-structured interviews to understand the relationship between farmers and the green iguana. We found this approach to be well suited for identifying common themes among respondents that could be otherwise missed if responses were limited to multiple choice questions. We built questions based on our interest in identifying the type and magnitude of negative impacts the green iguana may cause, how farmers manage those impacts and the perceived outcomes of their management efforts.

Respondents were recruited at local farmer's markets, through cooperative farming organizations, local agricultural extension officers, and peer-to-peer recommendations (i.e., snowball sampling). We also recruited respondents through email when their contact information was available on public databases published for research purposes and through postings on social media pages focused on agriculture in Puerto Rico. Guest et al. (2006) provided a methodological report where they found that a sample size of 12 is sufficient to reach data saturation through semi-structured interviews. To reach data saturation in our study and represent multiple municipalities in the island, we chose a sample size of 20 informants. We did not expect to get an in-depth representation of the whole population of farmers on the island; rather we endeavored to identify common themes (Rusell Bernard and Gravlee 2015).

Our pilot questions, final interview questions and informed consent process were all approved by the Institutional Review Board at the University of Rhode Island (IRB-REF # 1050203-12). Each participant was given, or read, an informed consent form to sign, and an opportunity to ask questions before the interview began. We designed and tested our semi-structured interview questions during six pilot interviews (Figure 1) between June and August 2017. We modified those questions based on the feedback we received from informants and from further consultation with our research team. As an example, our informants suggested questions regarding farming techniques should be added, since they believed that having enclosed (i.e., greenhouses) versus open field crops may affect how green iguanas would impact the farmers. We also made modifications to improve clarity and remove leading questions. For example, before asking questions about the green iguana as a problem, we added a question asking if they were a problem or not.

After making all the suggested changes to our questionnaire we came to a final questionnaire consisting of six categories: demography, information about the farm, green iguana presence/absence, knowledge about the green iguana, green iguana impact, and green iguana management. The first four categories (i.e., demography, information about the farm, green iguana presence/absence, and knowledge about the green iguana) included questions that would be asked to all the participants, whereas questions in the remaining two categories were specifically for farmers who said both that the green iguana was present on their farm and caused negative impacts. The length of the interviews thus varied based on whether the green iguana was present and if the green iguana was considered a problem. The number of questions participants were asked varied as follows: if green iguanas were absent from the farm, then participants were asked 11 questions; if the green iguanas was present but not considered a problem, then participants were asked 12 questions; and finally, if the green iguana was present and considered a problem, then participants were asked 25 questions. Interviews

ENTREVISTAS CON AGRICULTORES

Gracias por tomarse de su tiempo para reunirse conmigo en el día de hoy. Aprecio su disposición a contribuir sus pensamientos a este proyecto de investigación. Estoy estudiando las interacciones entre los(as) agricultores(as) y la Iguana Verde en este proyecto. Sus comentarios nos ayudarán a entender los efectos de la Iguana Verde sobre la agricultura en Puerto Rico además de ayudar a otros a manejar la especie.

1) ¿Ha tenido a la Iguana Verde en su finca?
2) ¿Qué usted conoce acerca de este reptil?
3) ¿Hace cuanto usted comenzó a notar que habían Iguanas Verdes en su propiedad? ¿Cómo eran las cosechas antes de que las Iguanas Verdes comenzaran a aparecer en su finca?
4) ¿Están afectando su cosecha de alguna manera? De ser así, ¿Cuál(es) cosecha(s) y de qué forma(s)?
5) ¿Toma usted alguna acción para manejarlas? De ser así ¿Qué hace?
6) ¿Cuánto tiempo invierte usted al día manejando la iguana? ¿Cuánto tiempo invierte a la semana? ¿Qué otros recursos invierte sobre el manejo de la Iguana Verde?
7) ¿Ha observado algún cambio en su(s) cosecha(s) desde que comenzó con el manejo de la Iguana Verde? De ser así, ¿cuál(es) cambios?
8) ¿Hay alguna otra información que le gustaría brindarme que no se me haya ocurrido preguntarle?

INTERVIEWS WITH FARMERS

Thank you for taking the time to meet with me today. I appreciate your willingness to contribute your thoughts to this research. I am studying interactions among farmers and the Green Iguana in this project. Your comments will help us understand the scope of the effects of the Green Iguana in agriculture on Puerto Rico, and help others manage the species.

1) Have you had Green Iguanas on your farmland?
2) What do you know about the reptile?
3) When did you first start to see iguanas on your property? What were your crops like before the Green Iguanas began to appear on you property?
4) Are they affecting your crops in anyway? If so, which crops and how?
5) Do you do anything to mange them? If so, what?
6) How much time do you invest on this issue a day? Or a week? What else do you invest into the Green Iguana management?
7) Have your noticed any changes in your crops since you began management efforts? If so, what changes?
8) Is there anything else you would like to offer that I didn't think to ask about?

Figure 1. Pilot interview questions. These questions were modified to include farmers that did not have green iguanas on their property or did not consider it to be an issue. Questions regarding the size of the farm, its location and farming strategies used were added based on farmer's feedback.

lasted between five to 40 minutes based on the content and length of the informant's answers.

We sought to compile and quantify information on the green iguana's impact provided by informants. Interviews were transcribed and coded using 28 code categories in the program DEDOOSE (version 8.3.20). A code was assigned to each response by sentence (Supplementary material Table S1).

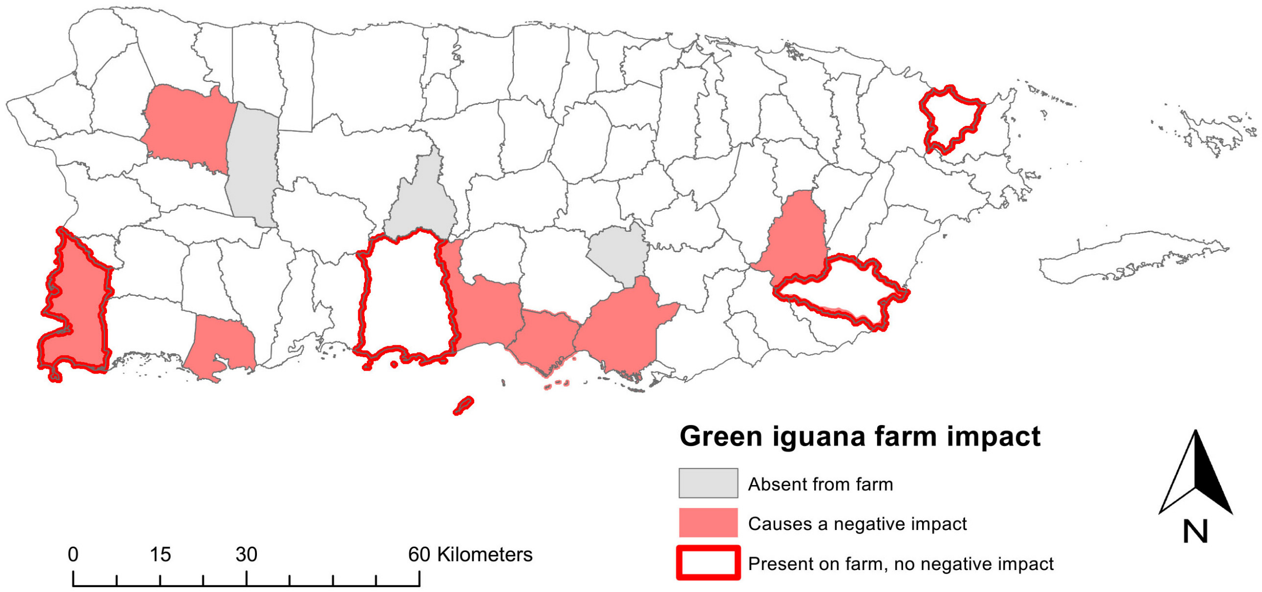

Figure 2. Municipalities in Puerto Rico where farms were located indicating the presence/absence of green iguanas and whether negative impacts were reported by farmers.

The information from these interviews allowed us to identify the crops impacted and the methods used to mitigate such impact. We compiled the information for each interview in Microsoft Excel to quantitatively explore the impact of the green iguana and the management strategies reported.

Results

Using semi-structured interviews as our approach, we were able to gather ecological, economic and management information about the green iguana on farms in Puerto Rico. Semi-structured interviews were an effective means of gaining a foothold within the agricultural community on the island. Participants who were not able to read, for example, were able to contribute valuable information on crop preferences of the green iguana that would have otherwise been lost. However, the length of the interviews and how informative they were depended heavily on the farmers time constraints. Farmers who sat down in a relaxed manner to speak about their experiences shared more detail about their farms and experiences (or lack of it) with the green iguana. Even though confidentiality was discussed and understood by all participants, there was still mistrust when it came to recording the interviews. Using recorded interviews as our data collection method led participants to ask if it was "ok" for them to share information with us that the participant may have considered controversial. During recording, one participant chose not to share information about green iguana management because they believed that there are "some things you just can't say".

Farmer participation covered 13 municipalities, with 10 south of Puerto Rico's central mountain range (Figure 2). We had 21 informants, of which two were a couple and shared a farm, and one person had two farms. This

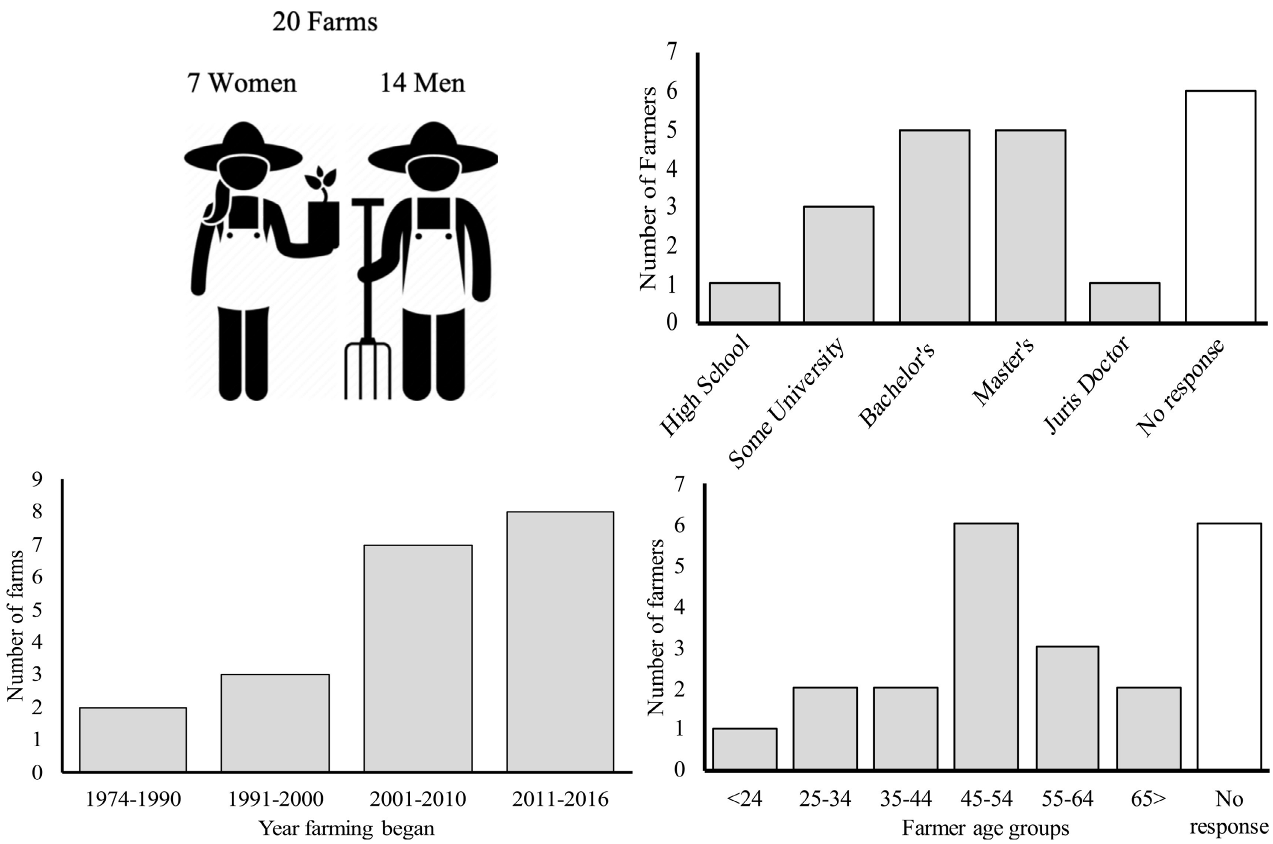

Figure 3. Demography and educational background of farmers interviewed as well as the farm history.

gave us a total 20 farms. Of our 21 informants, 14 identified as male while the remaining seven identified as female. Only 15 informants provided information regarding their level of formal education, one participant had reached a high school degree while all others had some university courses up to Master's and Juris Doctor degrees (Figure 3). Informant age ranged from 24 to 71 years and farm sizes ranged from 0.2 to 117.9 hectares (Figure S1). In total, these 21 farmers represented 579.5 hectares of farmland of which 320.4 hectares were being used to grow crops at the time of interview.

We did not limit our interviews to informants who had issues with the green iguana, but instead gathered information from all farmers who were willing to participate. Herein we provide informant responses at the farm level to avoid duplicating responses from couples about the same farm. Therefore, of the 20 farms represented by the informants, four (or 20% of farms) had not detected green iguanas on their land. All farms without green iguanas were over 480.0 meters above sea level (masl). Of the remaining 16 farms, informants representing two farms (or 10% of farms) mentioned that none of their crops were consumed by the reptile, while two more reported that their management efforts prevented them from having problems with green iguanas. The farms where informants reported not having problems with the green iguana represent 74.9 hectares of which 25.1 were used for cultivation. The remaining informants, representing 70%

of farms reported negative effects on their farms due to the green iguana. Of the 13 municipalities represented by these informants, seven had negative impacts associated with the green iguana (Figure 2). This represents a total of 504.6 hectares of affected farms of which 295.4 hectares were being cultivated.

We found that the green iguana had two principal impacts on farms: 1) crop loss (i.e., consumption of seedlings, plants, flowers or fruits) and 2) infrastructural damage (e.g., nesting that damages plastic mulch). These impacts had several effects and outcomes on farmers and their approaches to cultivating crops. We summarized these effects into three categories: behavioral, emotional, and economic. These effects encompass the indirect negative outcomes of green iguana activity on farms as well as the associated costs, modifications, and stressors that farmers endured because of these negative effects. Specific economic impacts were revenue loss due to crop loss (reported by nine participants), purchasing additional equipment or services (e.g., hunters in one case and paying for germinated nursery plants instead of directly sowing seeds into the ground in another case) or additional hours of labor. We considered behavioral impacts to be changes in the selection of crops grown or the location within the farm where crops were planted, though we recognize that this can also lead to economic impacts. Finally, we considered the stress associated with the crop loss and management of the green iguana, reported by three farmers, as an emotional effect associated with the species (Figure 4).

Management approaches for the green iguana were focused on preventing the entry of the reptile into the farm, protecting crops from the species, and reducing the population of green iguanas present on the farm. We divided these strategies into active or passive management approaches. Active management approaches reported were: (1) using chemical deterrents; (2) hunting with air rifles; (3) changing the crops chosen to cultivate; (4) changing the location of the crop to one where less damage is perceived to occur; and (5) preventing iguanas from reproducing by building trap nests or removing eggs when possible. Passive management strategies included the use of domestic cats or dogs, surrounding plants with mesh fencing or metallic sheets to protect crops, contracting hunters, or hiring people to make egg traps (Table 1). Three farms using either domestic cats or dogs, mesh fencing or hunting thought that problems associated with the green iguana were solved or at least avoided, while the remaining 12 considered problems to be ongoing and that their efforts led to a reduction in impacts (Table 2).

From our interviews, we collected information on 55 crops in 28 plant families (Table S2, Table S3). The most cultivated plant families were Cucurbitaceae (i.e., gourds, 29 mentions), Solanaceae (i.e., nightshades, 24 mentions) and Musaceae (i.e., bananas and plantains, 10 mentions) (Table 3).

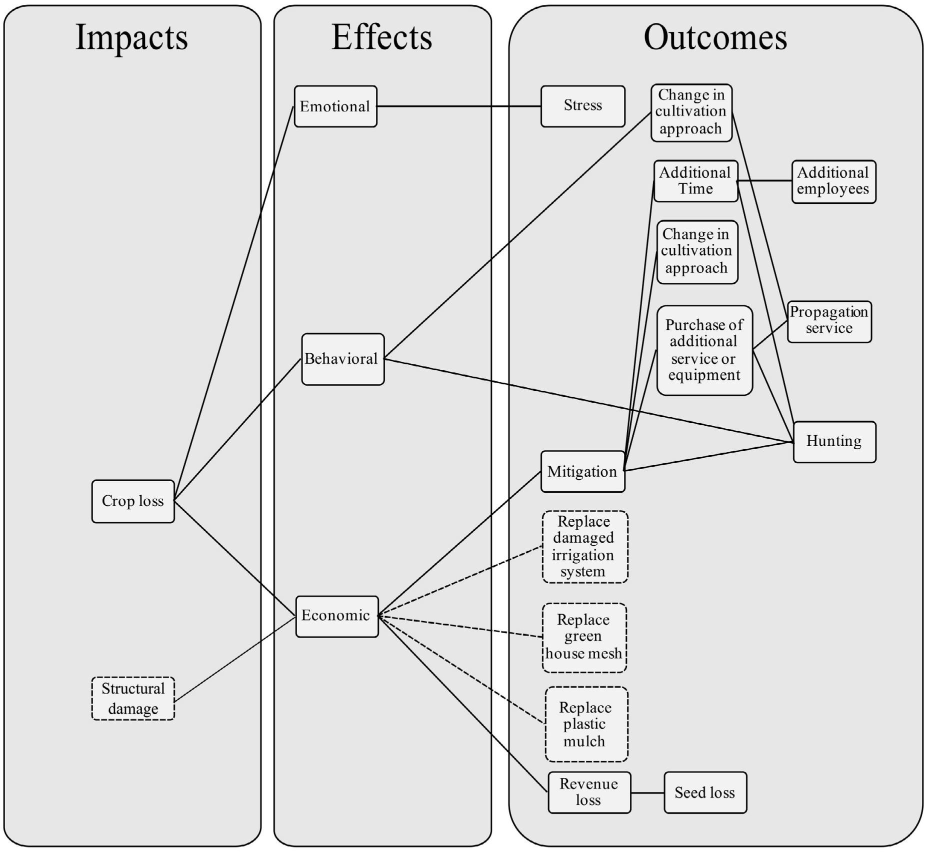

Figure 4. Impact network of the green iguana on agriculture in Puerto Rico. The direct impact of the green iguana on farming and the subsequent effects and outcomes of that impact. The causal relationship researchers identified between the reported impacts and these downstream outcomes is shown from the left panel to right panel flowing from impacts causing effects which then cause the outcomes. Solid lines represent effects and outcomes associated with crop loss, whereas dotted line represents those related to structural damage. These two impacts both have economic effects.

Table 1. Management approaches reported by farmers, divided into active and passive management practices.

Management approach		Mentions
Active		13
	Chemical	1
	Plant choice or plant location	1
	Reproduction prevention	1
	Hunting	10
Passive		11
	Dogs or cats	6
	Hired egg trap builders	1
	Hired hunters	2
	Mesh fence	1
	Metal screens	1

Out of these crops, 34 crops in 20 plant families were reported as negatively affected by the green iguana. The most affected crops were in the families Cucurbitaceae (27 mentions), Solanaceae (13 mentions) and equally the Asteraceae, Caricaceae, Fabaceae and Musaceae (4 mentions each) (Figure 5). In most instances, the effect on the plants was consumption and the loss of the plant due to herbivory. In one instance, a farmer reported losing 1.5 of the two hectares (75%) of watermelon (*Cucumis melo*) that they

Table 2. Management strategies reported by farmers and their perceived results. Farmers often had more than one strategy in place to attempt to reduce the impact of the green iguana (represented with plus signs).

Management strategies used	Ongoing-Reduced crop impact	Solved-Impact is avoided	Total
Domestic pets	1	1	2
Egg destruction	1	0	1
Fencing-Netting	0	1	1
Hunting	4	1	5
Hunting + domestic pets	2	0	2
Hunting + domestic pets + fence-metallic	1	0	1
Hunting + domestic pets + pesticide	1	0	1
Hunting + egg destruction + change growing location	1	0	1
Hunting + fence-metallic	1	0	1
Grand total	12	3	15

Table 3. The crop species mentioned by farmers during interviews by plant family (N), scientific name and common name (n).

Plant Families	N	Most mentioned crop	n	Common name
Cucurbitaceae	29	*Cucurbita moschata*	10	Pumpkin
Solanaceae	24	*Solanum melongena*	8	Egg plant
Musaceae	10	*Musa* spp.	6	Banana
Araceae	9	*Colocasia esculenta*	4	Taro
Rutaceae	8	*Citrus sinensis*	3	Orange
Asteraceae	7	*Lactuca sativa*	5	Lettuce
Fabaceae	6	*Phaseolus vulgaris*	2	Beans
Apiaceae	5	*Coriandrum sativum*	4	Cilantro
Lamiaceae	5	*Ocimum basilicum*	2	Basil
Annonaceae	4	*Annona muricata*	2	Soursop
Brassicaceae	4	*Brassica oleracea*	3	Broccoli
Caricaceae	5	*Carica papaya*	5	Papaya
Passifloraceae	4	*Passiflora edulis*	4	Passion fruit
Anacardiaceae	3	*Magnifera* spp.	2	Mango
Bromeliaceae	3	*Ananas comosus*	3	Pineapple
Convolvulaceae	3	*Ipomoea batatas*	3	Sweet potato
Lauraceae	3	*Persea americana*	3	Avocado
Dioscoreaceae	2	*Dioscorea* spp.	2	Ñame
Malvaceae	2	*Abelmoschus esculentus*	1	Okra
Rubiaceae	2	*Coffea* spp.	2	Coffee
Amaryllidaceae	1	*Allium cepa*	1	Onion
Bixaceae	1	*Bixa Orellana*	1	Annatto
Cactaceae	1	*Hylocereus undatus*	1	Dragon fruit
Euphorbiaceae	1	*Manihot esculenta*	1	Cassava
Nyctaginaceae	1	*Bougainvillea spectabilis*	1	Bougainvillea
Poaceae	1	*Zea mays*	1	Corn
Sapindaceae	1	*Melicoccus bijugatus*	1	Quenepa
Zingiberaceae	1	*Zingiber officinale*	1	Ginger

sowed, which they estimated cost them US$ 32,000. Another two farmers reported the loss of squash (*Cucurbita moschata*) crops with one being 0.60 hectares at an estimated cost of US$ 21,839, while the other suffered a loss of 0.20 hectares worth approximately US$ 7,280 (these estimates were based on yields reported by Hernandez and Beaver 2015 and the average value of the crop between 2013–2016). One farmer noted that green iguanas crawling on their bananas left blemishes on the fruit that made them difficult to sell; although the reptile did not directly consume it, we consider this a negative impact on the crop's production value.

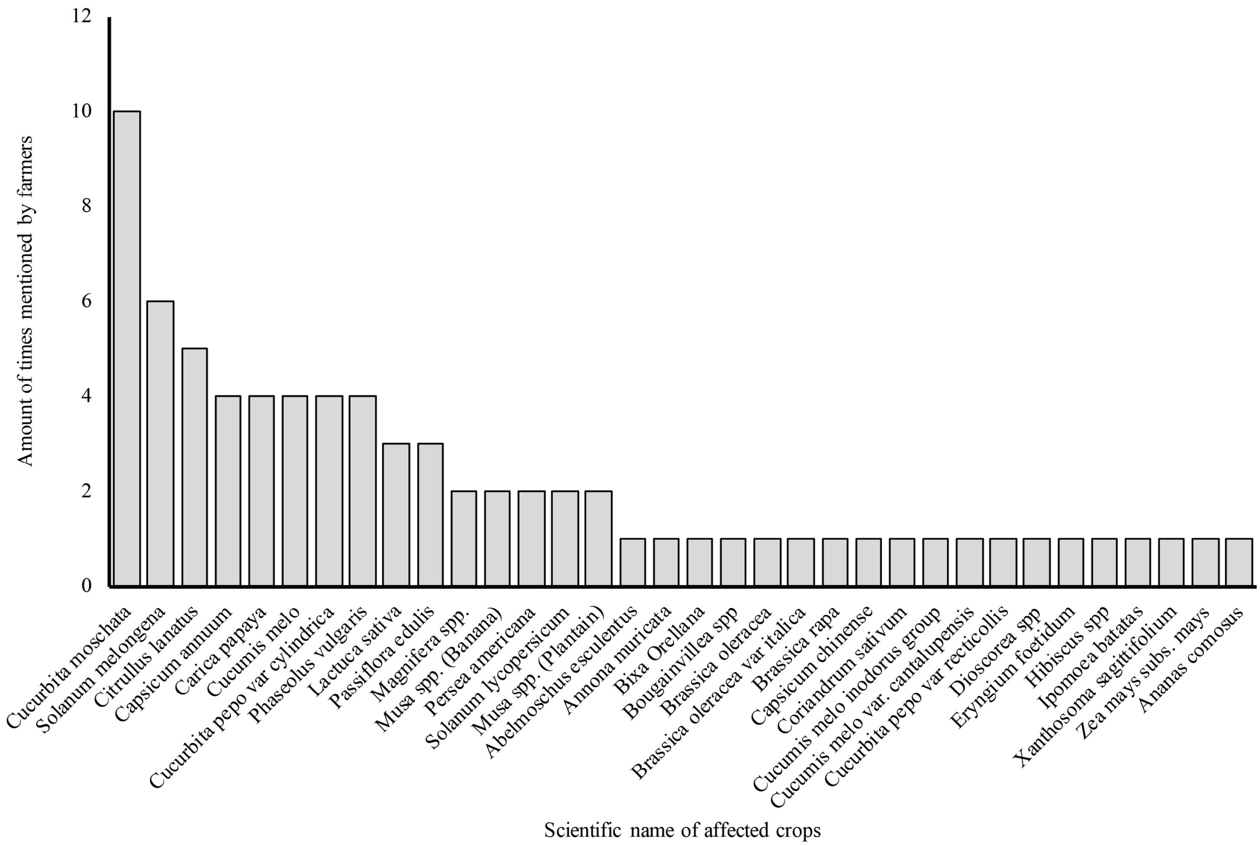

Figure 5. The frequency of 34 crops mentioned as impacted by green iguanas from interviews of farmers in Puerto Rico. Crops are displayed in descending order of frequency from the most reported to the least reported.

Farmers reported behavioral information about the green iguana related to their dietary preferences, habitat choice and activity. Vulnerability of a particular part of the plant to herbivory varied by crop. Leaves were thought to be the most vulnerable parts of the plant (six farmers), followed by flowers (four farmers); seedlings and shoots were each mentioned three times. Farmers thought green iguanas preferred areas in the farm with the following habitats: (1) bodies of water (e.g., rivers); (2) nesting sites in compost piles or stacks of accumulated vegetable material and soil; and (3) basking sites in surrounding trees. Some observed seasonally heightened activity, meaning they observed more green iguanas on their land from April to May (i.e., the breeding and nesting season). Others reported a loss in wariness by the green iguana toward humans or pets. One farmer also observed competition for space: after large adults were removed by hunting, smaller individuals came to occupy the same spaces.

Discussion

Our study suggests that the green iguana has a diverse array of negative effects on crop production from planning to harvesting. In this work, we sought the expertise of 21 farmers from 20 farms across Puerto Rico to explore the magnitude of the green iguana's impact on their crops. Farmers are documented in popular media as a group disproportionately impacted by green iguanas (Alicea-Torres 2020), although no previous research existed to measure the extent to which green iguanas impact the work of farmers.

The habitat breadth that the green iguana occupies throughout its Central and South American native range suggests that the species is capable of occupying forests from tropical dry to tropical moist habitats (Bughardt and Rand 1983; Muñoz et al. 2003). From this study, we found green iguanas were present in southern xeric climates of the island and moist forest in the northeast. The green iguana's occurrence at lower elevation habitats (Harris 1982; Campbell 1998) could explain why in our study we found green iguanas on farms from zero to 200 meters above sea level (masl) but not on farms above 400 masl. Past field surveys of the green iguana on Puerto Rico suggest smaller population sizes are possible at elevations > 500 masl, which could also explain their absence on these farms (Rodríguez Gómez et al. 2020). A host of microclimatic variables could also explain the presence of the reptile including temperature (i.e., higher at lower elevations), access to water, and availability of perching sites (Rodríguez Gómez et al. 2020). In the green iguana's native range, research showed a possible preference for perching near bodies of water (Greene et al. 1978). The overlap among potential habitat and farming activities is of particular concern since suitable habitat can be found throughout the island (Rodríguez Gómez et al. 2020). The few higher elevation farms unaffected by green iguanas may face future concerns as climate scenarios indicate warmer, drier conditions for the higher elevations in Puerto Rico (Henareh Khalyani et al. 2016; Bowden et al. 2020).

Affected crops show some overlap with the reported diet of the species in its native range. The calabaza or squash (*Curcubita maxima*) is a member of the Cucurbitaceae family and part of the green iguana's native diet (Rand et al. 1990; Lara-López and González-Romero 2002; Benítez-Malvido et al. 2018), as are sweet potatoes (*Ipomoea batata*) in the Dioscoreaceae family, beans (*Phaseolus vulgaris*) in the Fabaceae, and hibiscus (*Hibiscus* spp.) in the Malvaceae. Information about the diet of the green iguana in its native range is limited, which could explain why we identified numerous previously unreported plant families as part of the crops consumed by the reptile (Figure 5).

It is possible that the list of 55 plant species we acquired through our interviews (Table 3) may underrepresent the number of crops cultivated by the farmers in our study. Improved interview techniques could lead to a more comprehensive list of crops. We found that interviews could be improved by actively encouraging participants to generate lists with a minimum number of items (e.g., list at least three crops). For example, farmers were inclined to respond to the question "which crops do you grow?" with a category of crops (e.g., starch vegetable). Further probing for a list of starch vegetables would be more useful to our analysis. Another solution to this issue could be to write down each crop as it was listed and then ask about any effects on each crop if time allows.

The outcomes of green iguana herbivory on each crop can lead to varying degrees of economic impact. Farmers noted that even with changing growing strategies from directly sowing seeds to transplanting seedlings, they would still face crop loss (Excerpt 1). For example, an estimate of the potential economic losses of two crops that farmers mentioned includes 302,300 Kg (3,023 quintales) of Soler pumpkins and 251,900 Kg (2,519 quintales) of Taina Dorada pumpkins in 3.93 hectares (Hernandez and Beaver 2015). The average value of this crop based on a survey conducted by the Puerto Rico Department of Agriculture between 2013 and 2016 was US $48.53 /100 Kg (or one quintal). This comes to a potential loss of US $146,706 of Soler pumpkins and US $122,247 of Taina Dorada (additional monetary estimates due to crop loss are included in the Supplementary material). We recognize that this is likely a conservative estimate since it excludes the cost of seeds, labor, and irrigation. We make these calculations as part of the process of beginning to quantify the economic cost of the invasive green iguana on Puerto Rican agriculture.

Invasive pest species are considered the cause of crop losses in a variety of food plants (Oerke 2006). Pests like the coffee berry borer (*Hypothenemus hampei*) (Wegbe et al. 2003) and *Cochliobolus* spp. fungi have led to global coffee production losses and decreased productivity. Similar to the case of coffee, long-term crop loss associated with the green iguana could reduce the amount and variety of crops brought to market by Puerto Rico's farmers. In addition to changing the strategies farmers use to cultivate crops, the reptile affected the farmers' choice as to what crop to cultivate (Excerpt 2) or to abandon a particular crop altogether (Excerpt 3).

Farmers noted that management had to be constant to prevent green iguanas from consuming their crops. They shared that actively excluding the reptiles or habitually culling them would give seedlings the opportunity to establish and to reach harvest. Farmers believed that once these management activities (e.g., hunting or egg removal) were discontinued, green iguanas would return to the farm and have the same level of impact as before these activities were begun. One farmer likened green iguana management to removing weeds (Excerpt 4). Information on the green iguana's population density on and around such farms could help explain the need for constant management. Future work should seek to estimate population densities as an additional variable to consider when planning farm management.

Unassisted or sporadic management on farms is unlikely to be effective. Management of invasive plant pests is a daunting task that requires multimillion-dollar investments and continuous monitoring. In 2005, Pimentel et al. reported the US spent $500 million annually on crop pest management. In the case of the green iguana, few studies have tested the effectiveness of management strategies. In one study, researchers removed nests across 20 nesting sites in the Cabezas de San Juan Nature Reserve (CSJNR) in Fajardo, Puerto Rico with the goal of reducing the green iguana population. After five years of harvesting green iguana eggs, researchers noted that population densities had not declined notably. They concluded that egg removal on its own was not an effective means of management in the short-term and recommended accompanying this practice with removal of adult green iguanas (Rodríguez Gómez 2013). In another study, the Cayman Islands Ministry of The Environment funded a multimillion-dollar effort to manage green iguanas by removing them through government-sanctioned hunting. In a single year, 874,252 green iguanas were culled from the island (Rivera-Milán and Haakonsson 2020). Even with this effort to remove green iguanas in the Cayman Islands, eradication was not seen as feasible. More work is needed to determine the effectiveness of various management strategies as alternatives for farmers.

Though further work in the invasive range of the green iguana is necessary, this study can serve wildlife managers and agricultural workers looking to understand the potential impact of this reptile once it reaches the establishment phase (Colautti and MacIsaac 2004). The green iguana is considered invasive in 21 countries, states or territories where it has been introduced (Iguana Specialist Group 2017). It is considered an invasive species, mainly due to its large population size (Meshaka et al. 2007; Arce-Nazario and Carlo 2012; López-Torres et al. 2012; Rivera-Milán and Haakonsson 2020) as well as its impact on native species and plants in ornamental gardens. The Puerto Rico Department of Natural Resources and the Environment classified it as an invasive pest species in a report published by their department and the Puerto Rico Department of Agriculture (López 2013). Nevertheless, there was no data from farms to substantiate this claim. This study filled the knowledge gap for agricultural agencies to decide if the green iguana should be considered an agricultural pest. Our data suggest that the large-scale impact of the green iguana on agricultural production could be severe and warrant treatment of the reptile as a pest.

Conclusions

In this study, we sought to explore the potential impact of the invasive green iguana on Puerto Rico's agricultural community. We found that not all farms were equally affected, with unaffected farms most often at higher elevations. Affected farmers reported crop loss and structural damage as direct impacts of the reptile. Indirect factors included spending more time and resources mitigating impacts of green iguanas on their farms. The efficacy of mitigation strategies should be assessed to determine their effectiveness. This could be done by increasing the number of farmers providing the results of their management efforts (through interviews or surveys) and by conducting field experiments. As the green iguana continues to expand in range, information on its potential impact is crucial for new territories. The potential impacts outlined in this paper could serve as the imperative for taking measures to prevent establishment of the species (Knapp et al. 2020).

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Authors' contribution

CDJV, CGQ and JJK contributed to the research conceptualization, sample design and methodology and ethics approval. CDJV, GMP contributed to investigation and data collection. Data analysis and interpretation were contributed to by CDJV, GMP, CGQ, and JJK. Funding was sought by CDJV, WG and JJK. Original draft was written by CDJV and JJK. All authors contributed to review and editing.

Ethics and permits

This research was approved by the University of Rhode Island Institutional Review Board (IRB Ref. #1050203-12).

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Supplementary material

The following supplementary material is available for this article:

Table S1. Codes used to categorize answers from farmer interviews.
Table S2. Crops reported in this study as not affected by the green iguana.
Table S3. List of crops used to evaluate the green iguana as a pest following the plant pest impact metric system to classify plant pests produced by Ireland et al. (2020).
Figure S1. Farm size and location of the 20 farms included in this study.