Citizen science is a powerful tool for connecting members of the public with research and for obtaining large amounts of data. However, it is far less commonly implemented in developing countries than in developed countries. We conducted a large-scale citizen-science program monitoring honey bee (Apis mellifera) colony losses in Argentina to examine how a national consortium composed of local coordinators and two different recruitment strategies influenced volunteer participation. These strategies consisted of online questionnaires and face-to-face interviews with beekeepers to record bee health issues. We found that use of both recruitment strategies was necessary because they reached different volunteer profiles and different locations, and therefore influenced the survey’s results. Furthermore, public participation increased when the number of local coordinators was higher, regardless of recruitment strategy. These findings could also apply to other developing countries, where lack of internet access for some potential volunteers, logistical constraints such as long distances, and poor infrastructure hamper implementing large-scale citizen-science programs.

In a nutshell:

- Citizen-science programs are far more common in developed than developing countries
- The lack of volunteer participation is the main reason why there are so few citizen-science programs in developing countries
- A national consortium that includes numerous local coordinators increases volunteer participation
- Collecting bee health data through internet-based questionnaires and face-to-face interviews results in the highest levels of coverage and representativeness
- A large-scale consortium and a combination of several recruitment strategies improves participation and establishment of citizen-science programs in developing countries

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The number of citizen-science publications per country was found to be positively associated with its human development index (HDI; HDR 2018). (b) The global distribution of honey bee colony loss publications produced through citizen-science programs. Data were collected through an exhaustive synthesis of 39 papers (complete list in WebPanel 1). The Argentinean colony loss publications produced through citizen-science programs. (c) The global distribution of honey bee colony loss publications per country was also positively influenced by its HDI, and was correlated with the number of citizen-science publications (see WebFigure 1).

Figure 1. Global map of where citizen-science studies are conducted. (a) The global distribution of citizen-science studies published over the past 30 years (1987–2017); 7774 studies were identified following Follett and Strezov (2015), based on Web of Knowledge searches. (b) The number of citizen-science publications per country was found to be positively associated with its human development index (HDI; HDR 2018). (c) The global distribution of honey bee colony loss publications. (d) The number of colony loss publications per country was also positively influenced by its HDI, and was correlated with the number of citizen-science publications (see WebFigure 1).

Methods

Citizen-science program in Argentina

We implemented a citizen-science program to record the rate of honey bee colony loss in Argentina during 2015–2016...
were extracted and inspected against fitted values (residuals between fit and complexity (WebTable 1). Pearson residuals rank the candidate models to identify the best compromise. The Akaike information criterion (AIC) was used to evaluate their respective contributions to data collection. All possible combinations of one or more variables were evaluated. The Akaike information criterion (AIC) was used to rank the candidate models to identify the best compromise between fit and complexity (WebTable 1). Pearson residuals were extracted and inspected against fitted values (residuals versus fitted plot and normal quantile-quantile [Q-Q] plot) to assess the suitability of the statistical models.

National Beekeeping Consortium

We built a national organization – the National Beekeeping Consortium (NBC) – to represent the interest of beekeepers in Argentina. Because beekeeping activity is distributed heterogeneously across the Argentinian provinces (Figure 2a; RENAPA 2018), we ensured that the composition of the NBC reflected differences in provincial beekeeping activity levels (that is, with more members of the consortium in provinces that contained more beehives) (WebFigure 2). Members of this organization included a coalition of beekeeping coordinators from governmental agencies, beekeeping associations, and research institutes (Figure 2b); these were recruited based on their fieldwork involvement. Each coordinator has his/her own network of 10 to 60 beekeepers, and so the national network included a contact list of 1191 beekeepers. To evaluate the benefits of the NBC, we analyzed whether the number of responses to the bee colony loss survey varied with the number of coordinators across provinces. To do so, we fitted a generalized linear model (GLM) with Poisson error structure (glm function in the R base package; R Core Team 2017). This model included the recruitment strategy as a categorical predictor (two levels: face-to-face interview or online questionnaire), the number of coordinators as a quantitative predictor, and the interaction between the recruitment strategy and the number of coordinators. Because data collection in each province can be affected by both the number of coordinators and the level of beekeeping activity (both correlated; WebFigure 2), we determined which of these two variables was more likely to support improvements in data collection. To disentangle direct versus indirect effects of the consortium and beekeeping activity, we fit GLMs with Poisson error structures to compare their respective contributions to data collection. All possible combinations of one or more variables were evaluated.

To analyze and compare the effects of the two recruitment strategies on data collection, we first calculated the geographical distance between each location of response (distsm function in the R geosphere package) as an estimation of the spatial distribution of the responses. We calculated a random accumulating distance function between response locations, for which we ran 10,000 iterations for each recruitment strategy to mitigate the variation in sample size (see Results section). The spatial distribution in responses between the face-to-face and online strategies was compared using GLM with Gaussian error structure. We then modeled the temporal accumulation of responses during the 2 weeks after recruitment for each

Figure 2. A citizen-science program, implemented in 2015–2016, focusing on honey bee colony losses in Argentina. (a) National distribution of managed honey bee colonies. (b) Number of beekeeping consortium coordinators per province. (c) Number of answers per province.
online recruitment strategy (ie email, journal, social network, and website) as a spline function of time using generalized additive models \((\text{gam function in the R mgcv package})\).

Methodological effect assessment in answers
We analyzed the response success rate (ie the proportion of beekeepers answering a question) and the content of the responses to evaluate the potential methodological differences between the two recruitment strategies. The response success rate per question was compared between strategies using generalized linear mixed-effects models \((\text{glmer function in the R lme4 package})\) with a binomial error structure and the province as a random factor to account for the spatial non-independence of provincial repeated measurements. We used the same modeling approach for analyzing the content of the responses but implemented a Gaussian error structure for quantitative responses and a binomial error structure for binary responses (eg “yes” or “no”).

Results

Consortium effect on data collection
A total of 104 beekeepers (8.7% of the beekeepers in our contact list), managing 582 apiaries (4.6% of the apiaries registered in Argentina) and 22,945 beehives (2.7% of the beehives registered in Argentina), participated in the monitoring program. The distribution of responses covered 16 of the 23 Argentinian provinces (Figure 2c); provinces without participation contained less than 6% of the national stock of honey bee colonies. AIC analysis indicated that the amount of data collected per province (ranging from 0–11 responses × participant recruitment strategies) was better explained by the number of consortium coordinators than by provincial beekeeping activity (relative importance weights were 1.0 and 0.88, respectively), suggesting that the number of consortium coordinators had a direct effect on improving data collection. The number of responses per province was positively influenced by the number of consortium coordinators per province \((n = 48, Z = 0.302, P < 0.001; \text{Figure 3a})\). Interestingly, the significant interaction between the number of consortium coordinators and the participant recruitment strategies \((n = 48, Z = 0.203, P = 0.044)\) showed a higher ratio in data collection for the online strategy in provinces with more consortium coordinators (Figure 3a).

Participant recruitment strategies
Data collection was carried out by means of 56 traditional face-to-face interviews and 48 self-reported online submissions. Over the period of data collection (1 Jul 2016 to 1 Dec 2016; that is, after the end of the Argentinean 2015–2016 season of beekeeping; Figure 3b), there were significantly more daily collected responses from the face-to-face strategy \((5.6 \pm 7.0 \text{ responses per day, mean ± standard deviation})\) than for the online strategy \((1.7 ± 1.1 \text{ responses per day})\) \((n = 48, t = 35.28, P < 0.001)\). Among online recruitment strategies, email invitations elicited significantly more responses than face-to-face interviews (WebFigure 3). The spatial distribution of responses was compared among the recruitment strategies for the 39 online respondents and the 52 face-to-face respondents who had reported the location of their beehives at least at the municipal scale (of 48 and 56 total respondents, respectively). For the same number of responses (ie \(n = 39\)), spatial distribution was greater for the online strategy than the face-to-face strategy \((n = 10,000 \text{ iterations, } t = 9335.38, P < 0.001; \text{Figure 3c})\).

Effect of methodology on responses
The response rate for the 25 questions on the questionnaire ranged from 18.8% to 96.4% (WebFigure 4). Regardless of
the participant recruitment strategy used, beekeepers were largely unwilling to reveal the location of their beehives (18.8% and 26.8% response success for online and face-to-face recruitment strategies, respectively) and the economic details of their activities (62.5% and 58.9% response success). Significant differences in response rate between the two recruitment strategies (online versus face-to-face) were observed for nine of the 25 questions, with higher response rates for the face-to-face strategy (WebFigure 4; WebTable 2). Moreover, another methodological effect was observed within the survey results for several of the questions, with a trend toward higher values for the online strategy (Figure 4). Although methodological effects were not detected for questions about the age of the beekeeper, the number of colonies, or beekeeping-associated education, suggesting that the responder profiles were similar for the two recruitment strategies (see WebPanel 3), the values for “swarming control”, “frequency of visits”, and “summer colony losses” were higher for the online approach than for the face-to-face approach (Figure 4; WebTable 3). As an example, beekeepers reported 2.9% ± 4.8% versus 6.5% ± 6.9% of summer colony losses through face-to-face interviews and through the online questionnaire, respectively.

Discussion

Consortium matters in data collection

Although there is a general desire to foster citizen science in developing countries (Pocock et al. 2018) with a view to establishing international and global projects (Chandler et al. 2017), the techniques used to collect data through citizen-science initiatives in developed countries may not work in developing countries (Danielsen et al. 2005; Chandler et al. 2017; Pocock et al. 2018). We have demonstrated that the establishment of the NBC, which included provincial coordinators, was a key contributor to data collection about honey bee colony losses in Argentina. For one, collaboration between the NBC and numerous local beekeeping associations (that is, beekeeping technical coordination within each province through, for example, Asociación Apícola de la Comarca Andina, Sociedad Argentina de Apicultores, Programa Apícola Provincial Pro Miel, and Programa Nacional Apícola [PROAPI]) greatly increased access to survey material distributed via email. In addition, advertising the survey in national beekeeping magazines, in university and research institutes, and in networks of beekeeping associations further increased questionnaire distribution. Finally, conducting direct face-to-face interviews with beekeepers also improved the efficiency of the process.

At the same time, however, the relatively small number of beekeepers who responded to the surveys underscores the challenge of collecting data via citizen-science programs in South America as compared to programs in the US and Europe. Participation by Argentinean beekeepers was only about one-third (in absolute terms) that of participation in similar surveys in Europe and North America in the first year (vanEngelsdorp et al. 2008; Brodschneider et al. 2010; van der Zee et al. 2012). This low participation rate may be due to limited internet access (Gulati 2008) and a lack of organization at larger spatial scales (Conrad and Hilchey 2011; Maggi et al. 2016) or may reflect a lower level of interest among the citizens of developing countries (Pocock et al. 2018), possibly because potential respondents do not perceive any personal benefit from participation (eg no compensation) or due to a lack of personal resources or time to support participation. Additional social-science research is needed to more fully evaluate whether and how these social factors influence participation in developing countries. Given that the volunteers involved in our survey (ie beekeepers) have personal concerns about honey bee health and conservation, we expected the participation rate to be higher than that in citizen-science programs involving noninterested respondents, as Wilson et al. (2017) did in the US, measuring public understanding of bee diversity. However, the level of participation in Argentina was higher than that in several other countries, such as South Africa (Pirk et al. 2014), Uruguay (Antúnez et al. 2017), and China (van der Zee et al. 2012).
Citizen science can improve data collection for research and consequently can deliver social, economic, and ecological benefits (Conrad and Hilchey 2011; Theobald et al. 2015; Ryan et al. 2018). Our study focused on a large-scale citizen-science program in Argentina; as of now, such studies are a rarity in the Southern Hemisphere (Figure 1). We propose that citizen-science programs in developing countries be implemented via the development of a large-scale consortium to facilitate inter-regional connections between citizen-science participants and to expand their spatial coverage. Such a consortium also facilitates the standardization of questionnaires. Given that face-to-face interviews increase response rates and online questionnaires improve the spatial distribution, we recommend that these two participant recruitment strategies be used in tandem to improve future citizen-science programs. Furthermore, the data source must be included as a predictor variable in statistical analyses to mitigate any methodological effects.

We identified several matches between our results and suggestions from previous studies, including (1) establishing a national...
Citizen science in developing countries

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**Supporting Information**

Additional, web-only material may be found in the online version of this article at [http://onlinelibrary.wiley.com/doi/10.1002/fee.2150/suppinfo](http://onlinelibrary.wiley.com/doi/10.1002/fee.2150/suppinfo)