Citizen science in developing countries: how to improve volunteer participation

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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.

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Traditional ecological data collection methods are limited in the amount of data that can be gathered across large areas. Such limitations can be reduced by developing citizen-science programs (Devictor *et al.* 2010; Theobald *et al.* 2015; Chandler *et al.* 2017), which involve volunteer participation by members of the public in collecting information following a protocol provided, designed, or validated by experts in the field of study (Dickinson *et al.* 2010). Citizen participation not only assists scientists in collecting large amounts of data over broader spatiotemporal scales, but also connects members of the general public to science, which may potentially increase public awareness of conservation and environmental issues (Van Rijsoort and Jinfeng 2005; McKinley *et al.* 2017; Ryan *et al.* 2018). Citizen science may also spur innovation through the exchange of ideas, information, and inspiration (Herrick *et al.* 2018), and therefore can potentially advance scientific knowledge across a wide range of disciplines (Silvertown 2009; Devictor *et al.* 2010; Follett and Strezov 2015).

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

Benefits derived from citizen-science programs often promote human well-being, for instance through education, better management of ecosystems, greater support for stakeholders' activities, and more effective policy making (Conrad and Hilchey 2011; Follett and Strezov 2015). Although developing countries need to improve human livelihoods, they often lack the resources to develop citizen-science programs (Danielsen *et al.* 2005; Chandler *et al.* 2017; Pocock *et al.* 2018), especially in Africa and Latin America (Figure 1a). Indeed, most citizen-science programs have been developed and conducted in countries that have a high human development index (HDI; Figure 1b). For instance, popular voluntary biological surveys (eg breeding bird surveys, Christmas bird counts, butterfly monitoring programs) collect a wealth of data on bird and butterfly populations in the developed countries of Europe and North America (eg Schmeller *et al.* 2009; Sullivan *et al.* 2009; Devictor *et al.* 2010).

One reason for the success of citizen-science programs is their extensive use of internet-based platforms, whereby in-person interviews and other traditional methods of data collection are replaced by self-participation via online question-

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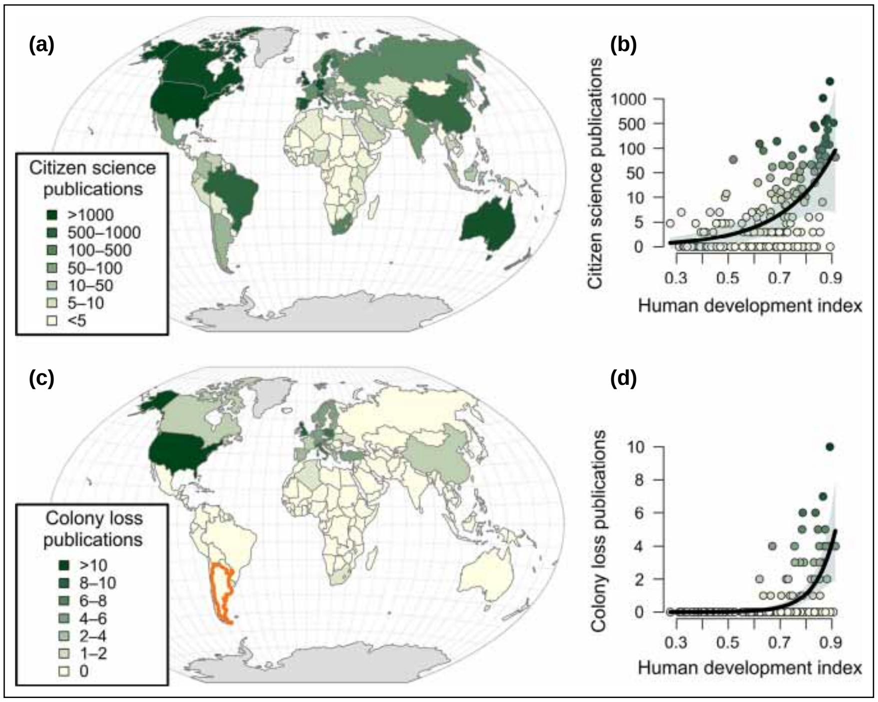

Figure 1. Global map of where citizen-science studies are conducted. (a) The global distribution of citizen-science studies published over the past 30 years (1987–2017); 7774 studies were identified following Follett and Strezov (2015), based on Web of Knowledge searches. (b) The number of citizen-science 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 produced through citizen-science programs. Data were collected through an exhaustive synthesis of 39 papers (complete list in WebPanel 1). The Argentinean study case is shown in orange. (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).

naires (Goodchild 2007; Sullivan *et al.* 2009; Bonney *et al.* 2014). This approach provides numerous advantages, including increased capacity for public outreach, reduced material costs, and the development of large-scale networks with real-time information-sharing capabilities (Sullivan *et al.* 2009; Newman *et al.* 2012; Herrick *et al.* 2018). Limited internet access in many parts the developing world (Gulati 2008) may therefore at least partially account for why these countries are currently underrepresented in citizen-science programs (Silvertown 2009; Newman *et al.* 2012; Pocock *et al.* 2018). It has been suggested that limited networking, organizational, and collaboration capacities are the most common factors that slow the implementation of large-scale citizen-science programs in developing countries (Conrad and Hilchey 2011; Maggi *et al.* 2016; Pocock *et al.* 2018). Although these difficulties are recognized (Chandler *et al.* 2017; Pocock *et al.* 2018), there is a critical lack of field assessment on how to improve participation and establish citizen-science programs in developing countries.

We used, and assessed the effectiveness of, a participatory method – specially adapted for developing countries – for organizing and connecting local networks of volunteers at large scales. This approach was based on the assumption that volunteers and stakeholders who share a common interest in a specific issue are regionally organized and structured but lack connections between regions. We therefore established a national consortium to facilitate interregional connections, improve the dissemination of standardized questionnaires (Danielsen *et al.* 2005), and enhance the collection of large-scale datasets. We also assessed whether face-to-face survey interviews could be used to offset limited internet access and to what extent such interviews could influence responses. Some studies suggest that face-to-face interviews and online questionnaires could vary in terms of response success, spatiotemporal range, and content of answers (Goodchild 2007; Schmeller *et al.* 2009).

As a case study, we developed a program to monitor the loss of honey bee (*Apis mellifera*) colonies, in which beekeepers recorded losses and health issues among the honey bees (vanEngelsdorp *et al.* 2012). The program was initiated because of concerns about the ecological, agronomic, and social consequences of global honey bee declines (Goulson *et al.* 2015; Potts *et al.* 2016). However, as with the global discrepancies in citizen-science programs generally (Figure 1a), bee colony loss monitoring programs have been widely implemented in the Northern Hemisphere (eg Europe and the US; Figure 1c) but are largely absent in developing countries (Figure 1d; WebPanel 1). The lack of nationwide colony loss monitoring programs in these countries prevents assessment of the current status of bee colony collapse disorder. Beekeeping also plays important socioeconomic roles in many developing countries; in Latin America, for example, beekeepers manage ~8 million honey bee colonies, which produce more than 200 million tons of honey per year (Requier *et al.* 2018a). The absence of monitoring programs is therefore of great concern throughout Latin America, and especially in Argentina, which has the largest number of beekeepers and the highest levels of honey production and exportation (Requier *et al.* 2018a). We therefore initiated a monitoring program focusing on honey bee colony losses in Argentina and evaluated whether (1) the establishment of a National Beekeeping Consortium – as a large-scale organization – enhanced voluntary participation of beekeepers and (2) whether methodological differences between recruitment strategies (online questionnaires and face-to-face interviews) influenced volunteer profiles or survey results.

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

(Figure 1c; Requier *et al.* 2018b). To estimate summer colony losses, beekeeping management, and bee health in Argentina, we selected questions commonly used in similar monitoring programs, including the Prevention of Honey Bee Colony Losses (COLOSS) questionnaire used to estimate winter colony loss in European countries (van der Zee *et al.* 2013), and questionnaires used by the Bee Informed Partnership (Kulhanek *et al.* 2017) and the EPILOBEE consortium (Jacques *et al.* 2017) – programs that were developed in the US and Europe, respectively (for more details see WebPanel 2). We adapted the questions to account for differences in Northern and Southern Hemisphere seasonal phenology, types of diseases, and botanical origins of honey (in order to make the questionnaire more compatible with South American biogeographic conditions), and prepared a Spanish translation.

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. 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

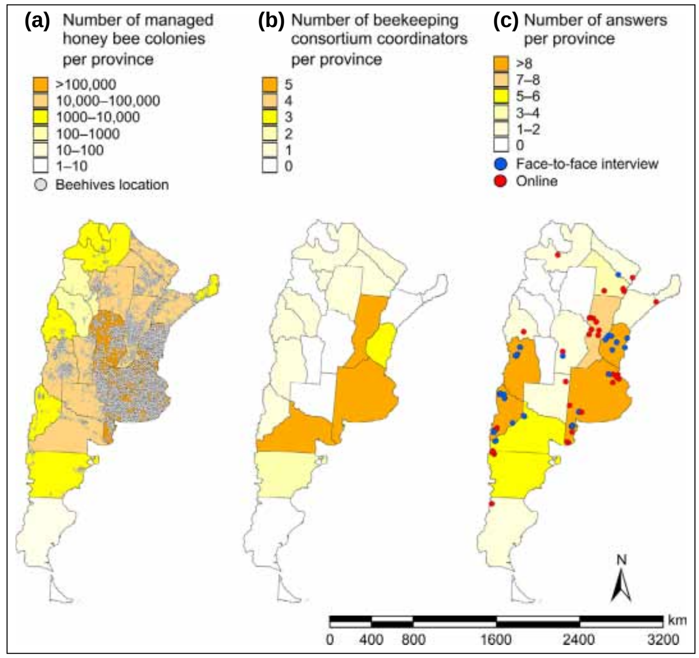

Figure 2. A citizen-science program, implemented in 2015–2016, focusing on honey bee colony losses in Argentina. (a) National distribution of managed honey bee colonies. (b) Number of coordinators associated with the National Beekeeping Consortium in each province. (c) Spatial distribution of beekeepers' participation; traditional face-to-face interviews are shown in blue circles and online questionnaires are shown in red circles.

versus fitted plot and normal quantile-quantile [Q-Q] plot) to assess the suitability of the statistical models.

Participant recruitment strategies

We implemented two participant recruitment strategies. In the "online strategy", beekeepers were invited to self-report their answers using a web-based questionnaire. This invitation was distributed by email to the beekeepers on the consortium contact list, as well as to beekeeping social networks and national beekeeping journals. In the "face-to-face strategy", we provided a printed version of the questionnaire used in the online strategy to beekeepers in Argentina who did not have internet access or preferred not to respond online, and conducted face-to-face interviews with these individuals. Interviews were performed by consortium coordinators during regular meetings of local beekeeping associations.

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 (*distm* 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 online recruitment strategy (ie email, journal, social network, and website) as a spline function of time using generalized additive models (*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 (*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; 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 ± 7.0 responses per day, mean ± standard deviation) than for the online strategy (1.7 ± 1.1 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 iterations, t = 9335.38, P < 0.001; 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

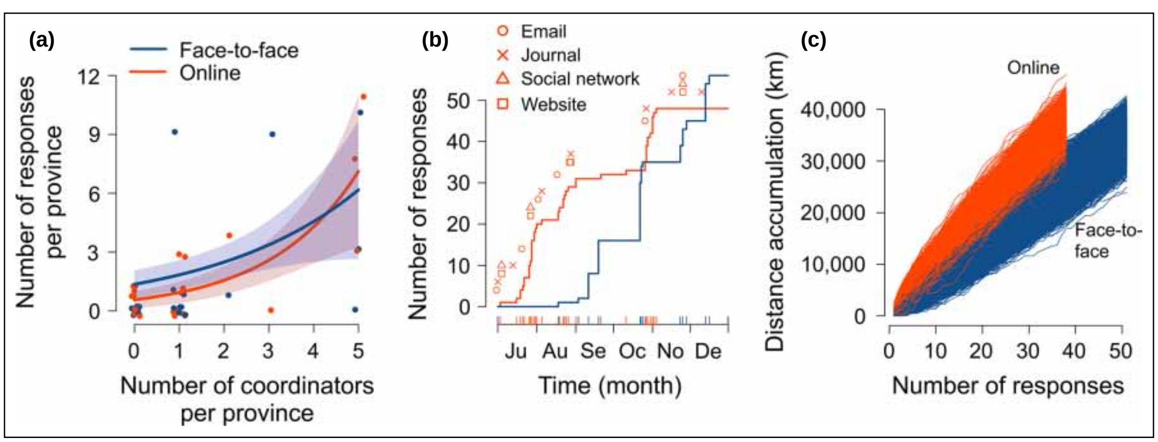

Figure 3. (a) Involvement of more consortium coordinators in a citizen-science project increases the number of responses, regardless of whether traditional face-to-face interviews or online questionnaires are used. The solid line is the prediction of the generalized linear model and the shaded area indicates the 95% confidence interval. (b) Cumulative time series of responses in traditional face-to-face interviews (in blue) and online questionnaires (in red). Symbols indicate the event timeline for each online recruitment strategy. (c) Spatial distributions of traditional face-to-face interviews and online questionnaire responses, calculated using a random accumulating distance function (see Methods).

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.

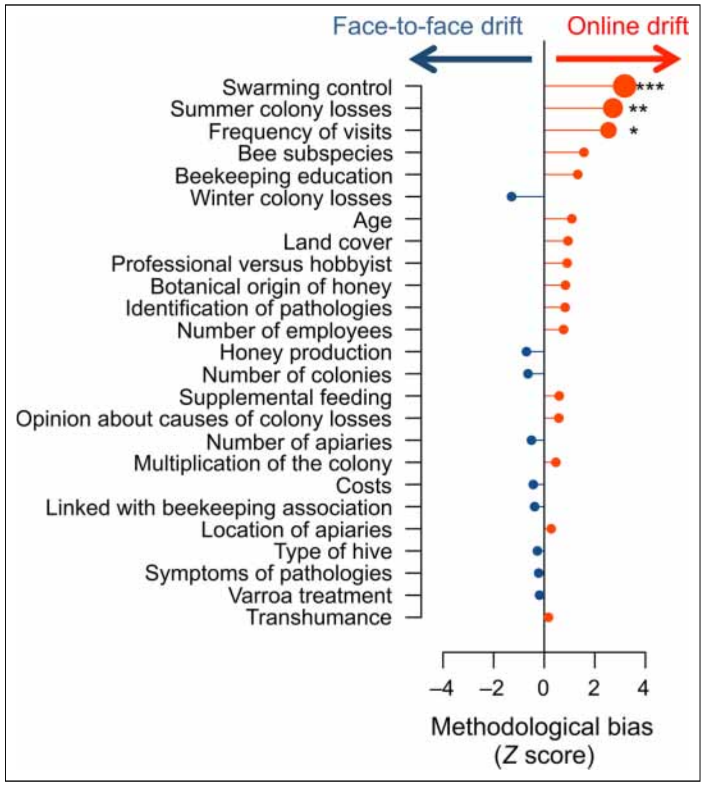

Figure 4. Differences in response values between traditional face-to-face interviews and online questionnaires. Positive values reflect trends in online questionnaires and circle sizes indicate the effect level; asterisks indicate the significance level (see Methods): ***$P < 0.001$, **$P < 0.01$, and *$P < 0.05$.

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 non-interested 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).

The NBC established local networks of volunteer citizen scientists over a large spatial scale, which seems to be a key factor in obtaining sufficiently representative amounts of data.

Figure 5. Beekeepers in northern Patagonia (Nahueve, Argentina) are isolated from cities, high-speed internet access, and transportation infrastructure.

A common feature of successful surveys regarding honey bee colony loss is the implementation of inter-institutional networks of beekeepers and consortiums (eg the Bee Informed Partnership [vanEngelsdorp *et al.* 2008; Kulhanek *et al.* 2017] in the US and COLOSS group [van der Zee *et al.* 2012, 2013; Brodschneider *et al.* 2016] and the EPILOBEE consortium [Jacques *et al.* 2017] in Europe). Therefore, investing in large-scale organizations and connections among local networks may promote the establishment of citizen-science programs in Latin America and Africa (Figure 1). The NBC is one example of a successful large-scale organization, but other approaches should also be tested and developed.

Participant recruitment strategies affect honey bee colony loss estimates

Colony collapse disorder of managed honey bees currently threatens honey production and crop pollination in many countries, which could have negative social, economic, and ecological effects (Potts *et al.* 2016). As there is a lack of data to identify the causes of this disorder – thought to be driven by the combined stress of parasites, pesticides, and lack of flowers (Goulson *et al.* 2015; Potts *et al.* 2016) – large-scale citizen-science programs have been initiated in many countries around the world to monitor honey bee colony losses (Figure 1; WebPanel 1). Data collected by these programs have revealed that up to 25–50% of honey bee colonies may be lost every winter in Europe (Brodschneider *et al.* 2016) and North America (Kulhanek *et al.* 2017). We found that reported estimates of summer honey bee colony losses in Argentina were higher among online questionnaire respondents than among those who participated in traditional face-to-face interviews; however, reports of winter colony losses did not differ between recruitment strategies. Although surveys of the colony losses of a given year occur during the beekeeping season of the subsequent year, beekeepers can be influenced by their personal experiences in voluntarily responding to the survey, suggesting that beekeepers who have been subject to colony losses may be more motivated to respond to colony loss surveys, and may also be more prone to search for such citizen-science programs online. Another explanation for the differences between face-to-face and online responses could be a bias toward people with internet access (Figure 5), which could, for example, explain the differences observed in responses for the two common beekeeping practices, "swarming control" and "frequency of visits".

Citizen-science programs are robust tools for collecting large amounts of data and as such have great potential to advance scientific knowledge, influence policy making, and guide resource management; however, this potential can only be realized if datasets are of high quality (Kosmala *et al.* 2016). Evidence of methodological effects on estimates of summer colony losses in honey bees calls into question the representativeness of the colony loss estimates presented in previous studies conducted in South Africa (Pirk *et al.* 2014), Uruguay (Antúnez *et al.* 2017), and China (van der Zee *et al.* 2012), where data sources were not identified. Moreover, in most surveys of colony losses, there has been no assessment of the potential effects of the participation recruitment strategies used (eg Brodschneider *et al.* 2016; Jacques *et al.* 2017; Kulhanek *et al.* 2017). Therefore, we recommend that the effects of the data source used in the statistical analyses be rigorously assessed prior to application in future surveys.

Lessons learned and recommendations

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 consortium to support networks and inter-regional exchanges (Conrad *et al.* 2011; Maggi *et al.* 2016); (2) coupling web-based surveys with traditional face-to-face interviews in order to mitigate the (common) problem of limited internet access (Pocock *et al.* 2018) and the potential loss of interest in responding to online surveys due to the ever-expanding amount of information available online and the large number of such requests; (3) performing face-to-face interviews as a means of reinforcing social links among volunteers and professionals/scientists (Van Rijsoort and Jinfeng 2005; Conrad and Hilchey 2011), and for mitigating the substantial distrust in public engagement in policy development that prevails in many developing countries; and (4) standardizing questionnaires for large-scale projects (Danielsen *et al.* 2005). We argue that these recommendations can serve as a generic framework for improving participation in citizen-science projects in developing countries.

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Body color evolution in predators and prey

Animals in the Qinghai-Tibet Plateau generally evolve coloration that protects them from predators. For example, lizards, such as this Theobald's toad-headed agama, *Phrynocephalus theobaldi*, and grasshoppers (*Bryodema* sp) have evolved body colors that are similar to the rocks in this environment, which helps them avoid predation by natural enemies. The protective colors can also help lizards hide themselves to prey on grasshoppers. Interestingly, predator and prey have evolved different colors, and can always find a favorable environment for themselves within the complex array of background colors. For example, the blue-gray grasshoppers mostly settle on blue-gray stones, which means that they can at least differentiate the color of objects that match their own body color; however, it is not known whether they can recognize other colors. If the lizards cannot distinguish the blue-gray color, then the grasshoppers have evolved a way to better protect themselves from this predator. Body color seems to have evolved depending on the organism's mode of locomotion. The lizards have evolved multiple body colors because they crawl across the environment, while the grasshoppers evolved a single body color because they can jump or fly to their chosen destination. In any case, it is interesting to explore whether the interrelationship between lizards and grasshoppers or other external factors have driven the differential evolution of their body colors and to understand how this happened.

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