CITIZEN SCIENCE:
THEORY AND PRACTICE

The Diversity of Participants in Environmental Citizen Science

RESEARCH PAPER

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ABSTRACT

Reported benefits of environmental citizen science include the collection of large volumes of data, knowledge and skills gained by participants, local action, and policy influence. However, it is unclear how diverse citizen science participants are, raising concerns about representativeness of data and whether individual, societal, and environmental benefits are evenly distributed. We surveyed 8,220 people representing a cross section of the population in Great Britain to ask whether they had participated in environmental citizen science, allowing us to examine who is and who is not participating. Using logistic regression, we examined relationships between demographic variables, and crucially the interactions between these variables, and the likelihood of participation and whether participation was repeated. Men were more likely to participate than women. People identifying as from white ethnic groups were more likely to participate than those identifying as from minority ethnic groups; participation by women from minority ethnic groups was particularly low. Participation by those from white ethnic groups declined with socio-economic status, but this was not the case for those from minority ethnic groups. Participation was highest amongst those in education (studying at school, college, or university) and lowest amongst the unemployed. We recommend citizen science practitioners carefully consider the aims of projects and thus the diversity of participants they wish to attract. We discuss potential mechanisms for widening participation, for example, engaging participants through third parties already embedded in communities and providing a variety of tasks for people with different amounts of time and types of skills to offer. Finally, we encourage practitioners to document and publish participant demographics to monitor diversity in citizen science.

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INTRODUCTION

Many benefits of citizen science methods have been discussed, including benefits for scientific research, such as collecting large amounts of data (Hochachka et al. 2011) and drawing on local knowledge (Lidskog 2008); for environmental monitoring and decision-making at local (Ballard, Dixon, and Harris 2017), national (Hayhow et al. 2019) and international (Turbé et al. 2019) scales; and for participants, including the ability to gain knowledge (Bonney et al. 2016) and skills (Stedman et al. 2009), build communities (Fernandez-Gimenez, Ballard, and Sturtevant 2008) and use data for advocacy (Johnson et al. 2014). However, there are doubts as to whether citizen science participants are representative of wider society, with biases in age, gender, ethnicity, and socio-economic status all reported (NASEM 2018), and this has important consequences for many of these reported benefits. However, our understanding of who is participating in citizen science is still limited. Previous research focusses largely on participants in individual projects, is geographically restricted, and examines demographic characteristics independently rather than looking at how they interact with each other to affect participation. We begin here by discussing how diversity is relevant to many aspects of the purported benefits of citizen science and how inequalities might arise through a lack of diversity in participants. Our focus is on environmental citizen science as one of the largest and most established fields in citizen science. We then present results of a large study of a cross-section of the population in Great Britain that examines who is and who is not participating in environmental citizen science. Our aim is to generate a clear understanding of the demographics of participation to start to address arising inequalities.

BENEFITS AND INEQUALITIES IN CITIZEN SCIENCE

There are many reported benefits that a citizen science approach may have for science and decision-making. These benefits vary depending on the aims of a project but can include data generation across broad spatial and temporal scales and/or at fine spatial and temporal resolutions, and data collection from otherwise inaccessible areas that enables insights that would not be possible without citizen engagement (Bonney et al. 2016; Fritz et al. 2019). Citizen science data provide the evidence base for thousands of scientific papers (Kullenberg and Kasperowski 2016) as well as for official environmental reporting (e.g., UK Biodiversity Indicators used for assessing progress towards Aichi biodiversity targets; Hayhow et al. 2019) and policy-making (Turbé et al. 2019). However, if some sectors of society are not participating in citizen science and there is a correlation between environmental variables and population demographics, the data generated may not reveal the true state of the environment (Purcell, Garibay, and Dickinson 2012). This in turn could have important consequences for the reliability of scientific conclusions as well as decision- and policy-making.

Citizen science can also have many benefits for participants. These include gaining knowledge (Evans et al. 2005; Jordan et al. 2011; Bonney et al. 2016; Phillips et al. 2019) and skills, for example in environmental monitoring or in the communication of results (Stedman et al. 2009). These benefits could result in greater employability; Geoghegan et al. (2016), for example, found that 10% of survey respondents had participated in citizen science to help their future career. Citizen science participation can increase a participant's sense of place (Evans et al. 2005), reduce stress (Coventry et al. 2019), and lead to the formation of new relationships and communities (West et al. 2020) with the potential for social learning, whereby people learn from each other via observation and imitation (Becker et al. 2005; Fernandez-Gimenez, Ballard, and Sturtevant 2008; Dickinson et al. 2012). Those who do not have the opportunity to participate in citizen science will be excluded from receiving these myriad benefits.

Finally, the process of bringing scientists and citizens together is also purported to have numerous benefits that, again, will be limited by a lack of diversity in participants. Participants can gain a better understanding of the scientific process and the relevance of science to their daily lives, as well as develop critical thinking skills (Trumbull et al. 2000; Bonney et al. 2016; Merenlender et al. 2016), which can help in scientifically relevant decision-making (Dickinson et al. 2012). In addition, scientists and other citizen science project leaders often aim to raise awareness of environmental issues, change participants' environmental values and perspectives, and in turn influence behaviour (Fernandez-Gimenez, Ballard, and Sturtevant 2008; Couvet and Prevot 2015; Bonney et al. 2016; Ballard et al. 2017). Through increased scientific literacy, project leaders also aim to generate a greater acceptance of outcomes of science (Stone 2015; Brouwer and Hessels 2019). Exclusion of some sectors of society will limit the reach of these impacts for participants and scientists. Engagement between citizens and scientists can also challenge the traditional expert-citizen hierarchy. Working with citizens can open scientists' eyes to new questions and considerations (Burke and Heynen 2014), potentially creating more relevant and democratic science (Irwin 1995). Working together can also give scope for incorporating local, often place-based, knowledge into the scientific process (Bäckstrand 2003; Lidskog 2008; Cigliano et al. 2015; Ramirez-Andreotta et al. 2015; Kimura and

Kinchy 2016), which is important for ensuring science is relevant to society and can lead to local action (see Lidskog 2008 for some examples). However, only the priorities of groups who are participating in citizen science will be represented. Innovation, invention, and creativity are more likely to be fostered when people of diverse backgrounds are brought together (Woolley et al. 2010; Dickinson et al. 2012; NASEM 2018) and this opportunity will be lost if there is a lack of diversity in citizen science participants.

DIVERSITY IN CITIZEN SCIENCE

Given the potential impacts of citizen science and the injustices that may arise from some sectors of society not participating, it is vital to explore who is, and who is not, represented in citizen science so inequalities can begin to be addressed. Those studies that have examined participant demographics have shown higher rates of participation in people who are of middle or older age (Crall et al. 2013; Wright et al. 2015; Domroese and Johnson 2017; Mac Domhnaill, Lyons, and Nolan 2020), have higher levels of education (Trumbull et al. 2000; Evans et al. 2005; NASEM 2018; Mac Domhnaill, Lyons, and Nolan 2020), have higher household incomes (Overdevest, Orr, and Stepenuck 2004; Mac Domhnaill, Lyons, and Nolan 2020), are in areas with lower levels of deprivation (Hobbs and White 2012), are employed (Crall et al. 2013; Mac Domhnaill, Lyons, and Nolan 2020), are in rural areas (Evans et al. 2005; Mac Domhnaill, Lyons, and Nolan 2020), and who identify as being from white ethnic groups compared with those identifying as from other ethnic groups (e.g., Wright et al. 2015; Merenlender et al. 2016; Domroese and Johnson, 2017; NASEM 2018). Participation by gender is less straightforward, with some studies finding higher participation rates in men (Wright et al. 2015; Ganzevoort et al. 2017; NASEM 2018), others in women (Crall et al. 2013; Merenlender et al. 2016; Domroese and Johnson 2017), and others finding no difference (Mac Domhnaill, Lyons, and Nolan 2020), which may be a result of the type of project or location of participants being examined. In their meta-analysis, for example, Pandya and colleagues (NASEM 2018) found that the male bias in participation was stronger in projects focussed on physical science compared with biological science, in online projects, and in roles with increasing levels of competition and responsibility.

AIMS OF THE STUDY

Although this literature provides some insights, a recent review of citizen science (including non-environmental citizen science) literature (NASEM 2018) found that only 10% of papers presented any data relating to participant demographics, and most projects that did present data (75%) were based wholly or partially in the United States (US), with nearly a quarter of these relating to online-only projects. The aim of the study we present here is to describe the demographics of environmental citizen science participants in Great Britain. We have focussed on Great Britain because it has a long history of citizen science (Pocock et al. 2015) and is a major contributor to citizen science globally (an estimated 7.5 million volunteer hours are spent annually on biodiversity monitoring alone in Great Britain and Northern Ireland; Hayhow et al. 2019) but has received very little attention when it comes to the demographics of participants (Hobbs and White 2012 is an exception to this).

Unlike previous surveys, which have either looked at the demographics of participants in individual projects (e.g., Evans et al. 2005; Domroese and Johnson. 2017) or used purposive sampling (i.e., targeting known citizen science participants) to survey the characteristics of participants in particular fields such as biological recording (Ganzevoort et al. 2017; Mac Domhnaill, Lyons, and Nolan 2020), we conducted a national survey of people for whom we have no prior knowledge of their engagement with citizen science, thus avoiding the partiality of a self-selecting sample (Berk 1983). This allowed us to understand diversity in citizen science participants, i.e., how representative the pool of citizen science participants is of the wider population (Brouwer and Hessels 2019). By conducting a survey through a third party, we also reduced the risk of social desirability bias (where participants try to give an answer they think would please the questioner) (Nederhof 1985), compared with a situation in which an interview was conducted by, for example, a citizen science organisation.

Furthermore, in contrast to previous studies, we also examine how different participant characteristics interact to affect participation in order to consider intersectionality. This is important because social categorisations such as ethnicity, gender, and age do not operate alone but interact with each other and can create overlapping systems of disadvantage (Cho, Crenshaw, and McCall 2013). By giving an overview of who is and who is not participating in citizen science, we hope to encourage practitioners to consider how to address this in their project design, including seeking understanding of potential barriers to excluded groups and how these can be overcome.

METHODS

NATIONAL SURVEY VIA A MARKET RESEARCH COMPANY

We commissioned TNS UK Ltd (*www.tnsglobal.com/united-kingdom*), a data provider that is now part of the Kantar market research group (*www.kantar.com*), to deploy a national survey to understand who has participated in environmental citizen science in Great Britain. The survey was undertaken as part of TNS UK's weekly Omnibus survey of a stratified sample of UK households to which anyone could pay for questions to be included (see Supplemental File 1 for full details of how households are selected). Selected households were visited by interviewers who explained TNS, the purpose of the interview, and why the household had been selected for participation. If residents agreed to participate, interviews were conducted immediately, face-to-face, using Computer Assisted Personal Interviewing, whereby the interviewer used an electronic device to record answers to questions. Our survey ran for two consecutive weeks in May 2015. Interviews were conducted only with people 16 and over and no incentives were offered for taking part.

QUESTIONS ASKED

For our study, interviewees were asked, "Have you ever taken part in any type of project that involved collecting any environmental scientific information or data?" For clarification, the interviewer added, "By this we mean national projects that help scientists like the RSPB Big Garden Birdwatch, one of the OPAL Surveys on worms, climate, tree health, biodiversity, bugs or water, or a local project." We chose this wording because all citizen science projects include an element of data collection (Cooper and Lewenstein 2016) and we wanted people to think about both national and local projects, and contributory and co-created forms of citizen science. However, we may have missed people who are involved in citizen science projects in other ways, for example analysing data or disseminating results. Respondents could answer "Yes, once," "Yes, more than once," "No," or "Don't know/can't remember." TNS UK also collected a wide range of demographic information from all interviewees. Interviewees could refuse to provide any or all of this information. The variables we used in our analysis are described in the "Data analysis" section below. Because we asked people if they had *ever* taken part in citizen science, their demographic characteristics at the time of the survey may not have been the same as those during the period in which they did the data collection, which may affect the interpretation of results.

ETHICS

TNS UK abides by the Market Research Society Code of Conduct (MRS Evidence Matters 2019), which regulates all market research activity in the UK in compliance with data protection and human rights legislation. Details of TNS UK's quality assurance and ethics protocols are given in Supplemental File 1. The survey was also approved by the University of York Department of Environment and Geography's Ethics Committee.

DATA ANALYSIS

We used chi-squared tests to test for relationships between demographic variables and (1) whether people had participated in citizen science and (2) if they repeated this participation. First, people who responded "Don't know/can't remember" were removed from the sample. Then, for each demographic variable in turn, we carried out separate tests where the inputs were the number of people who had and the number of people who had not participated in citizen science in different groups of the variable. We then used data only from respondents who said they had participated in citizen science and carried out tests for each demographic variable where the inputs were the number of people who had participated once and the number who had participated more than once in each group of the variable. Where chi-squared test results were significant, adjusted residuals were calculated, and groups for which the value was greater than 2 were considered to be drivers of the significant result.

The demographic variables we considered were age, gender, ethnicity, social grade, work status, and area as these have all been identified previously as factors that relate to participation (see Introduction). Groupings within these are shown in ***Table 1***. For ethnicity, interviewees could select from 16 groups, plus an option to decline providing this information. We initially present participation rates for all these groups; however, owing to the small numbers of interviewees for some groups (14 groups had fewer than 10 interviewees who had participated in citizen science), for our analysis we combined interviewees into the following broader groupings: white, mixed white and other ethnic groups, Asian, Black, and other. For the repeated participation test, because of small numbers in some groups, we combined the mixed ethnicity, Asian, Black and other ethnicity groups into a single minority ethnic group. Although these categories are far from perfect (for example, this potentially excludes those identifying as from minority white groups), they are used in similar demographic studies in the UK (e.g., The Royal Society 2014; DCMS 2018). Social grade is a socio-economic classification used in the UK based on occupation. Groups are defined by the Market Research Society (MRS Evidence Matters, undated) as higher managerial, administrative, and professional occupations (A); intermediate managerial, administrative, and professional occupations (B); supervisory, clerical and junior managerial, administrative, and professional occupations (C1); skilled manual occupations (C2); and semi-skilled and unskilled manual occupations, unemployed, and lowest grade occupations (DE). Area categorises people as being from rural or urban settings, with rural being defined as outside of settlements with more than 10,000 people.

VARIABLE	GROUP	ESTIMATED % GB 16+ POPULATION[1]	% (NUMBER) IN SAMPLE[2]	% (NUMBER) WHO PARTICIPATED IN CITIZEN SCIENCE[3]	PARTICIPATION χ^2 TEST RESULT[4]	% (NUMBER) WITH REPEATED PARTICIPATION[3]	REPEATED PARTICIPATION χ^2 TEST RESULT[4]
Total			**8,220**	**7.5 (613)**			
Gender	Male	48.5%	47.8% (3,931)	8.3% (323)*	**χ^2 = 6.323 *P* = 0.012**	55.1% (178)	χ^2 = 2.059 *P* = 0.151
	Female	51.5%	52.2% (4,289)	6.8% (290)*		49.3% (143)	
Age	16–24	14.4%	15.1% (1,238)	7.1% (88)	**χ^2 = 35.175 *P* < 0.001**	38.6% (34)*	**χ^2 = 25.620 *P* < 0.001**
	25–34	16.1%	17.5% (1,438)	4.1% (58)*		44.8% (26)	
	35–44	17.6%	14.6% (1,199)	9.2% (109)*		41.3% (45)*	
	45–54	17.5%	14.8% (1,215)	8.3% (100)		53.0% (53)	
	55–64	11.9%	12.5% (1,024)	9.3% (94)*		64.9% (61)*	
	65+	22.4%	25.6% (2,106)	7.5% (164)		62.2% (102)*	
Ethnicity	White	85.6%	85.6% (7,057)	8.1% (565)*	**χ^2 = 24.821 *P* < 0.001**	53.5 (302)*	**χ^2 = 4.104 *P* = 0.043**
	Mixed	1.5%	1.4% (114)	7.0% (8)		37.8 (17)*	
	Asian	7.6%	7.3% (615)	3.4% (21)*			
	Black	4.5%	4.5% (367)	3.9% (14)*			
	Other	0.5%	0.5% (37)	5.6% (2)			
Work status	Full time employed	51.2%	32.2% (2,650)	8.1% (214)	**χ^2 = 37.682 *P* < 0.001**	49.5% (106)	χ^2 = 7.951 *P* = 0.093
	Part time employed		14.3% (1,172)	7.9% (92)		48.9% (45)	
	Unemployed	48.8%	17.3% (1,420)	3.9% (55)*		49.1% (27)	
	Retired		28.4% (2,334)	7.9% (184)		60.9% (112)	
	In education		7.8% (644)	10.6% (68)*		45.6% (31)	
Social grade	A	3.5%	2.8% (227)	15.9% (36)*	**χ^2 = 27.537 *P* < 0.001**	66.7% (24)	**χ^2 = 11.458 *P* = 0.022**
	B	18.6%	14.6% (1,202)	16.7% (199)*		57.8% (115)	
	C1	33.4%	26.4% (2,166)	8.9% (191)*		52.4% (100)	
	C2	20.3%	20.8% (1,708)	5.4% (91)*		40.7% (37)*	
	DE	24.2%	35.5% (2,917)	3.3% (96)*		46.9% (45)	
Area	Urban	80.9%	79.7% (6,767)	7.3% (488)	χ^2 = 0.020 *P* = 0.069	50.2% (245)*	**χ^2 = 4.478 *P* = 0.034**
	Rural	19.1%	20.3% (1,453)	8.7% (125)		60.8% (76)*	

Table 1 Participation in citizen science by demographic group.

[1] Data provided by TNS UK Ltd as part of the survey results; work status data were available only for unemployed and employed).

[2] Group numbers for ethnicity do not add up to 8,220 because some interviewees did not provide this information.

[3] Groups for which adjusted residuals were greater than two (i.e., those considered to be driving the significant result) are starred.

[4] Significant results are in bold.

Considering each variable separately allowed us to interrogate more groups within each variable before moving on to include all variables in a single model, where sample sizes required us to combine some groups. Including all variables in single models, however, allowed us to examine the issue of intersectionality by determining whether different demographic variables had independent effects on citizen science participation or whether these variables interacted with each other. We used binary logistic regression, which requires a binary response variable and one or more explanatory variables and tests for a relationship between the explanatory variable(s) and the probability of a particular outcome of the response variable. In our first model, each of our interviewees was a data point, and whether or not they had participated in citizen science was the binary response variable. In our second model, each of the interviewees who had participated in citizen science was a data point, and whether their participation was one-off or repeated was the binary response variable. Our explanatory response variables were the categorical demographic variables described above, and all of their second-order interactions (e.g., interactions between age and ethnicity; social grade and gender, etc.). Work status was not included because of a lack of power in the model and an overlap between work status and age. For ethnicity, we used the combined minority ethnic group described above. We also combined the oldest two age groups into a single group of over 55, and social grades A and B into a single AB group.

To identify variables and interactions between variables that had a significant effect on likelihood of citizen science participation and likelihood of repeated participation, backward and forward stepwise regressions were performed on the initial models. This process retains only variables and interactions between variables that have a significant effect on the response variable in a minimal adequate model. Main effects were included in the final model if they were present in a retained interaction term. We used the stepAIC function in the MASS package (Venables and Ripley 2002) in the R statistical software (R Core Team 2017).

RESULTS

A total of 8,220 people were surveyed. ***Table 1*** shows the estimated percentage of the over-16 population of Great Britain in each of our demographic groups and the percentage of our sample of 8,220 in these groups, showing that our sample represented the wider population well. Of the 8,220 interviewees, 59 people (0.7%) responded "Don't know/can't remember" to our question about citizen science participation and were excluded from further analyses; 613 (7.5% of the remaining sample) said that they had taken part in a project that involved collecting environmental scientific information or data; and 321 (52.4%) of these had participated more than once.

INDIVIDUAL DEMOGRAPHIC VARIABLES

Results of chi-squared tests can be seen in ***Table 1***. There was a significant relationship between gender and participation in citizen science, with fewer women participating than men; but there was no significant difference in single versus repeated participation between genders. There was also a significant relationship between age and participation, driven by low participation in 25- to 34-year-olds and high participation in 35- to 44- and 55- to 64-year-olds. Repeated participation rates were significantly lower in younger than older age groups.

There was a significant relationship between ethnicity and participation, driven by high participation by people identifying as belonging to white ethnic groups and low participation in people belonging to Asian and Black ethnic groups. Rates of repeated participation were also significantly higher amongst those identifying as from white ethnic groups than those identifying as being from minority ethnic groups. Looking at participation in the 16 ethnic groups separately, however, shows variation within these combined groups (***Figure 1***). For example, participation appears higher in those identifying as white British and white Irish than those identifying as belonging to other white ethnic groups. Rates of participation amongst people identifying as from some mixed ethnic groups were also high, with those identifying as being from mixed white and Asian groups having the highest rates of participation of any ethnic group. There was some variation amongst Asian and Black ethnic groups, with the lowest rates of participation being in the Pakistani and African ethnic groups, respectively. It is important to note, however, that the small sample sizes in some of these groups makes it difficult to draw any firm conclusions.

There was a significant relationship between work status and participation, driven by low participation in the unemployed and high participation in those in education, but there was no difference in rates of single versus repeated participation between these groups. There was also a significant relationship between social grade and participation, driven by high participation in those from socio-economic groups A, B, and C1 (non-manual professions), and low participation in those in socio-economic groups C2 and DE (manual professions and the unemployed). Similarly, rates of repeated participation were lower amongst C2 and DE groups, with low participation in the C2 group driving the significant result. Finally, there was no significant relationship between whether people were in urban or rural areas and participation, but rates of repeated participation were significantly higher in rural than in urban areas.

INTERACTIONS BETWEEN DEMOGRAPHIC VARIABLES

In the logistic regression model that examined likelihood of participating in citizen science, the variables retained in the minimal adequate model were the interactions between age and ethnicity, social grade and ethnicity, gender and ethnicity, and age and area (***Table 2***). The significant interaction between age and ethnicity showed that participation amongst those identifying as from minority ethnic groups was highest in 16- to 24-year-olds (7.7%) and then fell to between 2.2% and 3.4% for all other

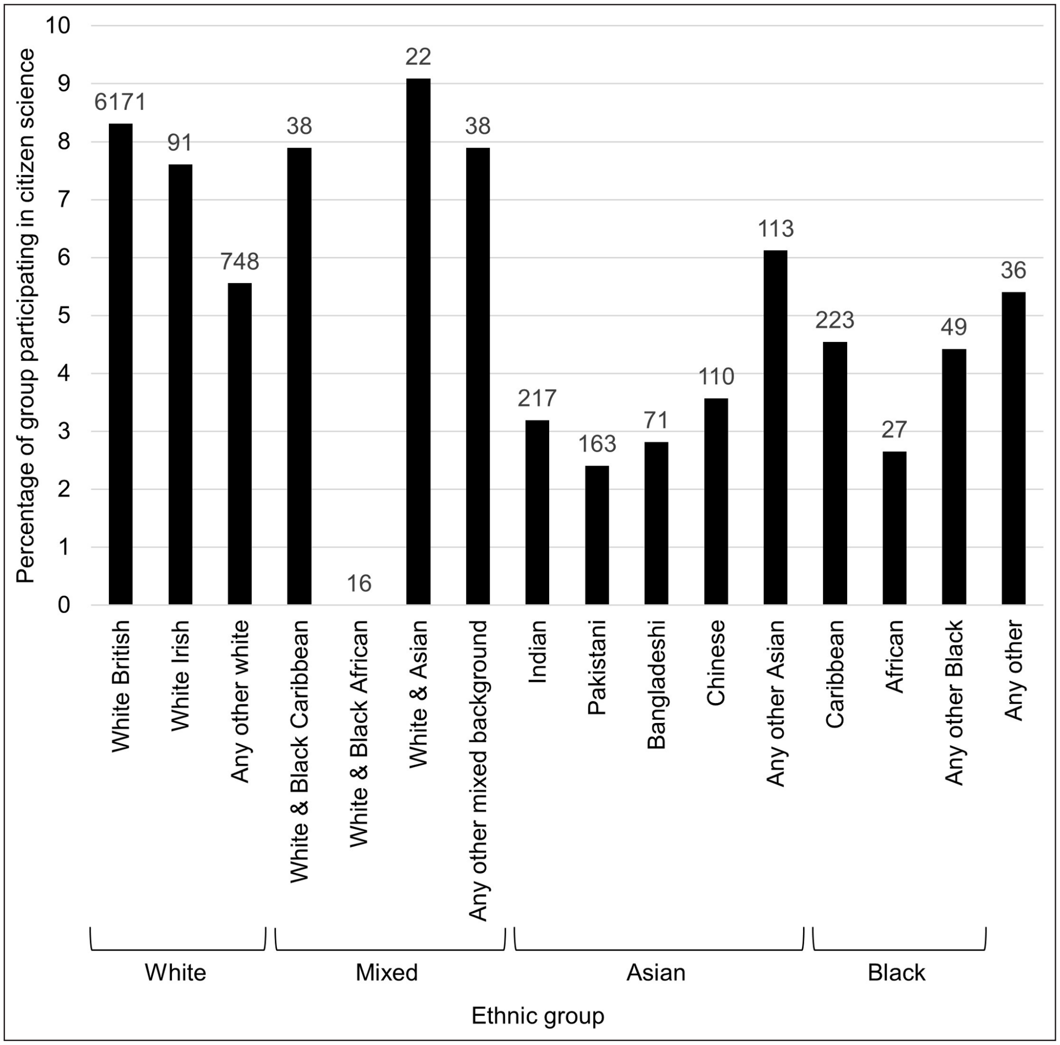

Figure 1 Percentage of interviewees identifying as being in each ethnic group who had participated in citizen science. Labels show the total number of respondents in each ethnic group.

age groups, whereas for respondents identifying as from white ethnic groups, participation was at 6.9% for 16- to 24-year-olds, dropped to 4.3% for 25- to 34-year-olds, and then rose to between 8.5% and 10.7% for all remaining age groups (***Figure 2a***). The significant interaction between ethnicity and social grade revealed that, amongst people identifying as from white ethnic groups, there was an increase in citizen science participation moving from social grade DE through to AB, but this did not follow amongst those identifying as from minority ethnic groups, where participation was highest in those in social grade C1 and lowest in C2, with AB and DE falling in between (***Figure 2b***).

A significant interaction between ethnicity and gender revealed that amongst those identifying as from both white and minority ethnic groups, women were less likely to participate than men, but this disparity was greater for those from minority ethnic groups (***Figure 2c***), where participation amongst women was very low. Finally, the significant interaction between age and area showed that amongst 25- to 34- and 45- to 54-year-olds, participation was higher in rural than in urban areas, whereas in 16- to 24-year-olds, participation was higher in urban than in rural areas (***Figure 2d***). In the repeated participation model, social grade, gender, ethnicity, age, and the interaction between gender and ethnicity were retained in the final model. The interaction between gender and ethnicity showed that not only is participation in women from minority ethnic groups less likely than those from other groups, but amongst those who had participated, repetition of this participation was also less common than for other groups (***Figure 2c***).

DISCUSSION

Our study of a large cross section of the population in Great Britain has revealed that environmental citizen science

	GROUP[1]	COEFFICIENT ESTIMATE (β)[2]	ODDS RATIO (EXP(β))[3]	STD. ERROR	Z VALUE	P VALUE
Citizen science participation						
Constant		–1.202	0.301	0.558	–2.154	0.031
Gender	Female	0.450	1.568	0.373	1.205	0.228
Age	25–34	–0.460	0.631	0.593	–0.776	0.438
	35–44	1.783	5.946	0.592	3.010	0.003
	45–54	0.885	2.422	0.600	1.474	0.140
	55+	2.579	13.183	1.077	2.394	0.017
Social grade	C1	–1.561	0.210	0.508	–3.075	0.002
	C2	–0.987	0.373	0.753	–1.311	0.190
	DE	–2.983	0.051	0.557	–5.352	0.000
Ethnicity	ME	–0.326	0.722	0.483	–0.675	0.500
Area	Rural	–0.414	0.661	0.387	–1.068	0.286
Age*Ethnicity	25–34*ME	–0.275	0.760	0.458	–0.599	0.549
	35–44*ME	–1.467	0.231	0.505	–2.904	0.004
	45–54*ME	–0.835	0.434	0.507	–1.646	0.100
	55+*ME	–2.445	0.087	1.042	–2.346	0.019
Social grade* Ethnicity	C1*ME	0.853	2.346	0.470	1.816	0.069
	C2*ME	–0.201	0.818	0.717	–0.281	0.779
	DE*ME	1.182	3.262	0.506	2.336	0.019
Gender*Ethnicity	Female*ME	–0.585	0.557	0.339	–1.726	0.084
Age*Area	25–34*Rural	1.097	2.996	0.497	2.206	0.027
	35–44*Rural	0.146	1.157	0.488	0.299	0.765
	45–54*Rural	0.742	2.101	0.462	1.607	0.108
	55+*Rural	0.388	1.473	0.419	0.926	0.355
Repeat participation						
Constant		–0.503	0.605	0.562	–0.896	0.370
Social grade	C1	–0.091	0.913	0.207	–0.439	0.661
	C2	–0.726	0.484	0.259	–2.803	0.005
	DE	–0.444	0.641	0.257	–1.730	0.084
Gender	Female	2.717	15.128	1.161	2.339	0.019
Ethnicity	ME	0.376	1.457	0.409	0.919	0.358
Age	25–34	0.276	1.318	0.357	0.773	0.440
	35–44	–0.055	0.946	0.309	–0.179	0.858
	45–54	0.520	1.683	0.315	1.652	0.099
	55+	0.942	2.565	0.276	3.413	0.001
Gender*Ethnicity	Female*ME	–2.821	0.060	1.120	–2.517	0.012

Table 2 Results of stepwise logistic regression models, showing the main effects variables and interactions retained in the minimal adequate models.

[1] ME refers to minority ethnic groups.

[2] 'Constant' shows the predicted coefficient estimate (β) when all variables are in their baseline groups: male for gender, 16–24 for age, AB for social grade, white for ethnicity and urban for area.

[3] For the participation model, the odds ratio represents the odds of someone participating in citizen science compared with the baseline group. For gender, for example, the odds of a female participating in citizen science is 0.873 that of a male. For the repeated participation model, the odds ratio is the odds of someone participating in citizen science multiple times compared with the baseline group.

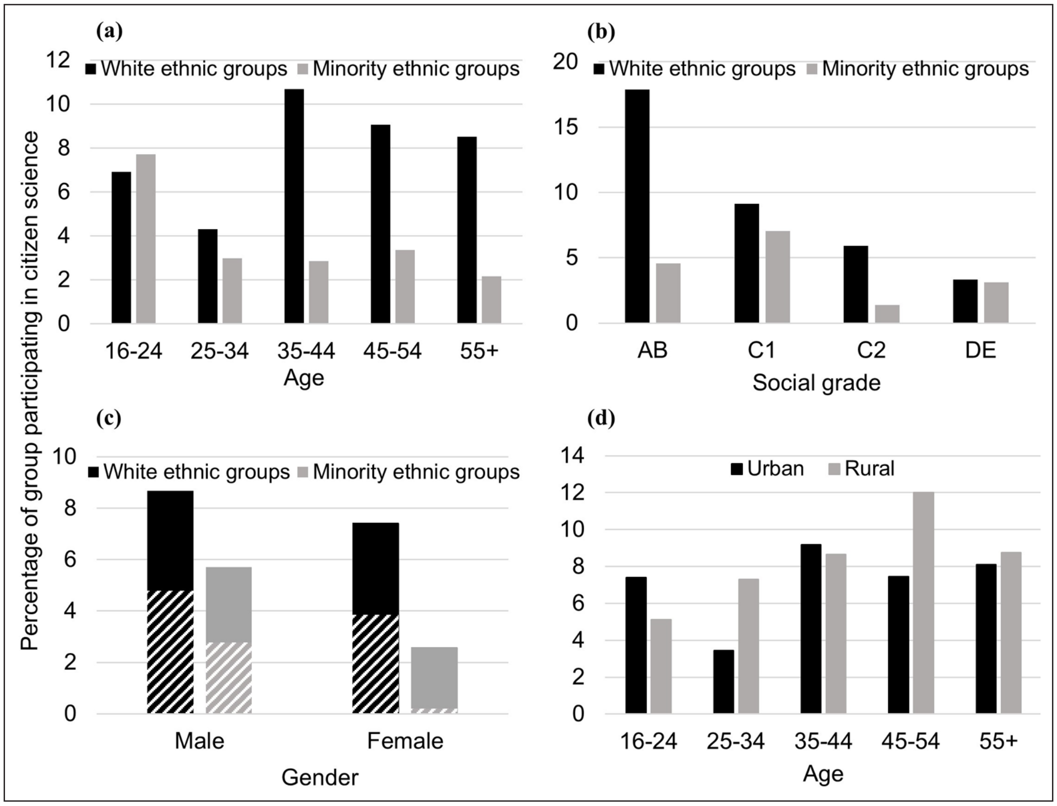

Figure 2 Interactions between participant characteristics on likelihood of citizen science participation. In each case, figures show the percentage of interviewees in each group who had participated in citizen science. Interactions are between **(a)** ethnicity and age, **(b)** ethnicity and social grade, **(c)** ethnicity and gender, and **(d)** area and age. In (c), the hatched areas show the percentage of the group that had participated in citizen science more than once.

participants are not representative of the wider population. While some of our findings echo those of previous studies in Europe and North America, our approach of looking across the population and at interactions between demographic variables means we are able to offer further insights.

PATTERNS IN PARTICIPATION

Overall, our results present a picture of typically marginalised groups in society also underrepresented in citizen science. These results reflect patterns in volunteering in general, where people with lower social capital (the ability to obtain benefits by being part of social networks (Portes 1998)), lower human capital (levels of education and skills), and lower economic capital are less likely to volunteer (Rutherford et al 2019; Southby, South, and Bagnall 2019). Although previous research has not found consistent patterns in participation by gender, perhaps due to differences in projects that have been examined (NASEM 2018), here we have shown that across environmental citizen science in Great Britain as a whole, women are less likely to participate than men (8.2% of men had participated compared with 6.8% of women). Also in line with previous studies (Wright et al. 2015; Merenlender et al. 2016; Domroese and Johnson 2017; NASEM 2018), we found higher rates of participation in those identifying as from white ethnic groups compared with those identifying as belonging to minority ethnic groups. We have also shown that participation amongst women from minority ethnic groups is particularly low (2.6% of respondents had participated in citizen science compared with 7.4% of women from white ethnic groups and 5.7% of men from minority ethnic groups, and less than 1% of this group had participated more than once). Unemployed people and those from lower socio-economic groups were also shown to be underrepresented, with 3.3% of the lowest socio-economic group compared with 15.9% of the highest having participated, confirming for Great Britain patterns observed in other countries (Trumbull et al. 2000; Overdevest, Orr, and Stepenuck 2004; Evans et al. 2005; Crall et al. 2013; Mac Domhnaill, Lyons, and Nolan 2020).

These patterns reflect barriers to participation in citizen science identified previously, which are likely to have a particular impact on marginalised groups. Lack of time, for example, has been repeatedly identified as a barrier (Everett and Geoghegan 2016; Merenlender et al. 2016; Domroese and Johnson 2017), which may explain underrepresentation of groups likely to have more caring responsibilities (i.e., women, particularly those from minority ethnic groups [Clark and Drinkwater 2007]), and those from lower socio-economic groups who may have multiple jobs and poorer transport options (Evans et al. 2005; Pandya 2012). This latter group may also be exluded by prohibitive participation costs, including those for transport and for equipment (Merenlender et al. 2016). Furthermore, a lack of previous experience of scientific methods has been identified as a barrier for those with lower levels of formal education (Evans et al. 2005; Merenlender et al. 2016). Although not all environmental citizen science projects take place in the countryside, where they do, a barrier for people from minority ethnic groups could be a lack of sense of belonging in these landscapes (Ward-Thompson et al. 2003) as they are seen to be places inhabited by white people (Agyeman and Spooner 1997). Feeling uncomfortable in (Levine, González, and Martínez-Sussmann 2009) and difficulties in accessing (Evans 2005) natural environments may also be a barrier for people from urban settings, which may explain our finding of lower rates of repeated participation in people from urban environments. Underrepresentation of certain groups may also result from projects not aligning with the motivations, interests, or needs of these groups (Pandya 2012). Poor alignment may be a result of lack of diversity in the science profession, which displays similar patterns of participation to those identified here (The Royal Society 2014). A lack of diversity amongst those setting research agendas and designing citizen science projects may mean they do not appeal to the priorities of marginalised communities.

Our study also offers new insights about participation amongst different age groups. We found 25- to 34-year-olds were less likely to have participated in citizen science than people in other age groups, in line with previous studies that have shown higher participation in middle-aged and older people (Crall et al. 2013; Wright et al. 2015; Domroese and Johnson 2017; Mac Domhnaill, Lyons, and Nolan 2020). Again, time constraints may explain the lower rates of participation we observed in this group as they are more likely to have young families and be investing time in building their careers (Merenlender et al. 2016). This may also explain the particularly low rates of participation in people from urban areas in this age group, for whom travel time may be more of a barrier than for people in rural areas. Unlike previous studies, however, we found higher rates of participation in 16- to 24- than in 25- to 34-year-olds. Although this may be driven in part by young people (particularly those under 18) being excluded from previous studies (NASEM 2018), it may also be a result of an increase in citizen science being used as an educational tool in schools and universities in the UK in recent years (e.g., through the OPen Air Laboratories [OPAL] [Davies et al. 2016] and Polli:Nation [*polli-nation.co.uk*] projects). For people identifying as from minority ethnic groups, the highest rates of participation were amongst 16- to 24-year-olds, and the upturn in participation in over-35-year-olds that is seen in those identifying as being from white ethnic groups is not present. In other activities, such as music, childhood experiences can facilitate a return to participation after a break in early adulthood (Lamont 2011). It may be, therefore, that recent inclusion of citizen science participation in formal education will eventually lead to an upturn in participation in older people from minority ethnic groups.

IMPLICATIONS

These findings have implications for the purported scientific and societal benefits of citizen science. The exclusion of marginalised groups is important because those who could have the most to gain from volunteering are the least likely to participate (Southby, South, and Bagnall 2019). For example, there are known links between deprivation and environmental quality, often with the most deprived areas also having the poorest environmental quality (Fairburn, Butler, and Smith 2009). Our finding, therefore, that those from the lowest socio-economic groups are less likely to participate in citizen science means that, in particular for those projects where participants are encouraged to collect data from their local areas, environmental quality could be overestimated. People living in areas of poor environmental quality and vulnerable to environmental injustice are those most in need of information about their local environment (Purcell, Garibay, and Dickinson 2012). Their lack of participation in citizen science may mean their local areas are invisible in environmental datasets and thus not considered in prioritisation for action or funding. Furthermore, these groups will not gain through participation the tools, skills, and support needed to campaign on issues relevant to them and to make sure their voices are heard in decision-making (Purcell, Garibay, and Dickinson 2012).

Clearly, as citizen science does not appear to be reaching diverse participants, other potential outcomes of citizen science, such as wellbeing benefits and the opportunity to be part of a community, will not be spread equitably in society. Some of the most frequently cited benefits of citizen science are that participants will gain knowledge, skills, and scientific literacy (Bonney et al. 2016), which in turn could help their career development. Our results have shown that the unemployed, who may benefit most from this if they are seeking work, are underrepresented in citizen science. In addition, women and people from socially disadvantaged groups are underrepresented in science careers in general (CaSE 2014), and people identifying as from minority ethnic groups are severely underrepresented in environmental science careers (The Royal Society 2014). Underrepresentation of these groups in citizen science is a missed opportunity to provide a path into scientific careers. The experiences and perspectives of these groups will not be included in the setting of research agendas, and the benefits for creativity and innovation that come from bringing together people with diverse backgrounds will be missed.

RECOMMENDATIONS

When designing projects, citizen science practitioners should carefully consider both the scientific and societal aims of a project, and the implications for these aims if participants are not diverse. This will help to define target participant groups, which can then be used to carefully inform various aspects of project design. Approaches that are successful for currently underrepresented groups will differ from those that work for typical participants. As Pandya explains,

> "there is *no* research to suggest that some groups of people are inherently less able to participate in citizen science projects because of some perceived deficit—cultural, social, educational, linguistic, or otherwise. Rather … *all* participants need some encouragement or scaffolding to participate in citizen science regardless of demography or prior experience." (NASEM 2018, p. 45)

Examples and experiences exist that practitioners can draw on. For example, which recruitment strategies are used affect who hears about and is recruited to projects (Brouwer and Hessels 2019). People from groups not widely represented in the current pool of volunteers may feel excluded, unwelcome, and like they don't fit in (Merenlender et al. 2016), or they may simply be unaware of opportunities. Traditional approaches to recruitment such as by word of mouth or through media channels are likely to recruit people similar to those already engaged. By contrast, targeted invitations to participate (Brouwer and Hessels 2019) and engagement through third-party organizations or through key individuals already embedded in and trusted by communities have been shown to be effective ways to reach underrepresented groups (Sorensen et al. 2019).

Known barriers to participation can also be tackled in project design. For example, to overcome time barriers, projects can be designed to be modular so participants can do what is possible for them alongside existing commitments (Purcell, Garibay, and Dickinson 2012). One-off activities can facilitate the inclusion of the time poor (Everett and Geoghegan 2016), and activities can be targeted at families or incorporated into community events focusing on other topics of interest to local communities, such as gardening or the arts, to widen participation (Purcell, Garibay, and Dickinson 2012). Projects should be open to people with a breadth of previous experiences. For example, project designers should consider whether they are excluding people without previous scientific experience, and if particular skills are required, how these can be gained within a project (e.g., Purcell, Garibay, and Dickinson 2012). Project designers should also seek to recognise and to be inclusive of the different skills and types of knowledge that people with different backgrounds and experiences can bring (Hermoso et al. 2021). Compensation for participants should also be considered, especially when working in resource-poor settings and where participation may take time away from paid work (e.g., see West et al. 2020).

Co-design at every stage has been demonstrated to be effective in designing projects that appeal to the needs and motivations of previously underrepresented groups (NASEM 2018). There are a growing number of co-designed projects to be learned from. For example, Pandya (2012) outlines a five-step framework for co-designing projects, which was successfully implemented in the Baltimore Mosquito Study (Sorensen et al. 2019). The Celebrate Urban Birds project (Purcell, Garibay, and Dickinson 2012) and Project Harvest (Davis, Ramirez-Andreotta, and Buxner 2020) have also demonstrated the successes that can come from taking the time and effort to understand the needs, daily lives, and potential barriers to participation of a target community, and working with this community to co-design a project with mutual goals and appropriate methods. However, it should be noted that such approaches are resource intensive and so the strategies selected will need to be balanced with the other aims of a particular project.

It is also important to note that citizen science does not sit in isolation in tackling these issues. A wealth of lessons can be learned from experiences in related fields, including but not limited to environmental volunteering (as summarised by West and Pateman 2016), environmental justice (see Sorensen et al. 2019), and science communication (e.g., Humm, Schrögel and Leßmöllmann 2020).

As well as the practical steps that project designers can take to increase diversity of citizen science participants, further research is also required. This includes better documentation of the demographics of citizen science participants by practitioners (Theobald et al. 2015; Burgess et al. 2017), and reporting this in the literature (NASEM 2018). Our study is limited to environmental citizen science in Great Britain, and work is needed to understand patterns in other fields of citizen science and in other contexts. We are also unable to examine in our study if these patterns of participation hold for different project types (e.g., contributory, collaborative, and co-created) and different tasks within these projects (e.g., research design, data collection, and data analysis). Better documentation of participants will also allow examination of if and how patterns are changing over time (for example, if we begin to see older people from minority ethnic groups participating in citizen science because of exposure at a young age). Further work is also required to understand the relationship between ethnicity and participation. Although we have demonstrated a broad pattern of participants being dominated by those identifying as being from white ethnic groups, our data suggest variation within broad ethnic groups that warrants further attention. For example, participation amongst those identifying as from "other" white ethnic groups appears to be lower than those from white British and white Irish groups, which could imply underrepresentation of those from minority white ethnic groups. Our data also suggest variation within Asian, Black, and mixed groups, but our sample was not large enough to test for these. Different participant characteristics should also be included in further research. For example, disability is known to affect particpation in environmental volunteering (Ockenden 2008) and so could be an important factor in citizen science participation that needs to be understood.

Our work has also considered only the diversity of participants. Our questions did not reveal the quality of participants' experiences and so we cannot comment on how effective or meaningful participants' experiences of citizen science were, and as a result, our ability to address inclusivity or equity in citizen science is limited (NASEM 2018). There is some evidence to suggest that people identifying as disabled or from minority ethnic communities have a less positive experience of volunteering than other volunteers (NCVO 2019). Quality of experience affects the likelihood of repeated participation (NCVO 2019), so our finding that marginalised groups are also less likely to participate multiple times suggests they may also have less rewarding experiences. Qualitative studies will be critical to go beyond understanding who is participating to understanding how the quality of participation differs between groups.

Finally, identifying the underlying causes of underrepresentation is crucial for understanding how these can be overcome (Pandya 2012). Some of the potential barriers to participation are outlined above, but the relative importance of these different factors is unclear, and there may be other barriers that have not yet been identified. Further work is required to understand barriers for particular groups in more detail (for example, women from minority ethnic groups), and practitioners should seek to gain this understanding from potential participants and document the success and failure of different strategies used to overcome these barriers.

CONCLUSIONS

We have offered some new insights into citizen science participants; in particular, we have explored how different participant characteristics interact to affect likelihood of participation, and in line with previous studies, found that those already marginalised in society are the least likely to participate. There are scientific and societal implications of a lack of diversity in citizen science participants, which practitioners should consider, and we have offered some guidance on how projects can be designed to widen participation. Better documentation of who is participating in projects, further research, and a sharing of best practices around how to overcome barriers to participation are all required to tackle the issue of underrepresentation in citizen science.

DATA ACCESSIBILITY STATEMENTS

Data will be deposited with the UK Data Service.

SUPPLEMENTARY FILE

The Supplementary File for this article can be found as follows:

- **Supplemental File 1.** Survey methodology. DOI: *https://doi.org/10.5334/cstp.369.s1*

ETHICS AND CONSENT

This study gained approval by the University of York Department of Environment and Geography's Ethics Committee.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

AD and SW designed the survey methodologies, drafted sections of the manuscript, and critically revised other sections; RP analysed the data and led the writing of the manuscript. All authors gave final approval of the submitted version and agree to be accountable for aspects of the work they conducted.

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