Citizen Science: Impacts on health and wellbeing outcomes in older South Australians

University of South Australia

Final Report Prepared for Office for Ageing Well by the University of South Australia

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Table of Contents

1. Executive Summary

Citizen Science Impacts on Health and Wellbeing Outcomes in Older South Australians was a project supported by Office for Ageing Well, SA Health. The project's central aim was to assess the impact of participating in a community Citizen Science project on several physical and psychological wellbeing outcomes.

The project is presented here in three parts:

1. A scoping review of literature to determine the existing evidence base for the health benefits of citizen science and environmental volunteering generally
2. A retrospective study, whereby participants were recruited from both citizen science active and inactive groups and evaluated for health and wellbeing indicators
3. A prospective study, whereby participants were enrolled in a clinical trial and exposed to an eight (8) week program of nature-based citizen science

An additional section of this report is also included as an Appendix, and comprises a related research article we published recently regarding the possible use of natural environment exposure as a public health intervention in urban areas.

The data collection period of the project ran from April 2020 to November 2021 and comprised both a retrospective and prospective study. Whilst COVID-19 did see a pivot of some of the project's procedures i.e., Zoom meetings rather than face-to-face visits and ensuring all social distancing protocols were in place during interventions, the overall impact was minimal.

Overall, trends towards positive physical and psychological changes were noted for individuals who participated in Citizen Science projects. The complex and heterogenous nature of the evidence base makes it difficult to draw definitive conclusions. However, the evidence appears to suggest that participating in community Citizen Science projects is not detrimental, and in fact may be beneficial for an individual's health and wellbeing.

Major findings reported here are as follows:

- A review of literature demonstrates that whilst the **health and wellbeing impacts of environmental volunteering/citizen science are likely to be positive**, there has been a lack of quantitative evidence to demonstrate impacts. Psychosocial positive outcomes are most commonly reported.
- A retrospective study showed that **participation in citizen science projects was associated with higher quality of life, lower loneliness, and higher levels of physical activity**. However, data variation resulted in a lack of significant statistical differences.
- A prospective clinical trial produced no conclusively demonstrated impact on physical activity or medication usage, or overall quality of life when participants were exposed to an eight (8) week citizen science intervention. An increase in moderate-vigorous physical activity was observed in the treatment group, but it was not statistically significant. We believe that inherent recruitment bias for citizen science activities, which select for participants with high education levels, minimised our ability to detect significant effects.
- **An eight (8) week intervention is an insufficient 'dose' of nature-based citizen science to generate clinical changes in participants.**

- Participants reported overwhelmingly positive experiences in citizen science, citing ‘exploring’, ‘talking’, ‘sharing’ and ‘new knowledge’ as highlights
- Participants explained that longer term programs were likely to be more beneficial and likely to impact behavioural change.

The above findings are consistent with the previously published literature, as described in the Scoping Review presented in Section 6.

Whilst we were aspiring to find more conclusive effects of the intervention, the mixed results reflect what others have found: namely that participation in nature-based citizen science is not harmful for older people, and is associated with marginal improvements in life quality, physical activity and loneliness reduction.

2. Key Recommendations

Here we make the following recommendations to Office for Ageing Well:

Recommendation 1

Consideration of future support for programs that engage older South Australians in activities that cause:

- *a) exposure to natural environments (either inside or outside of urban areas)*
- *b) social connection*
- *c) have a time course of at least 12 months for participants*
- *d) involve the use of digital technologies*

We do not necessarily recommend that such activities involve citizen science. Exposure to natural environments in a social context may be sufficient.

Recommendation 2

Consider how enhanced natural environmental exposure in social settings can become part of public health policy for older South Australians, without committing significant resources.

Recommendation 3 *(This is only presented in the case that Office for Ageing Well wishes to seek a more definitive evidence base for the health and wellbeing benefit of such programs.)*

Consider supporting future studies to determine health and wellbeing benefit with the following design features:

- *should include participants with a longer time course of citizen science exposure,*
- *using a case-control design*
- *selection of participants with lower baseline physical activity and lower educational status*
- *be designed so that ‘case’ participants are already taking part in citizen science, with a longer time-course engagement of at least 12 months to determine the clinical effective dose of participation.*

3. Background to this report

This project was supported by Office for Ageing Well, SA Health and stemmed directly from our previously completed study, 'Activating Citizen Scientists' for Office for Ageing Well. In that study, we reviewed previously published evidence on the wellbeing benefits for older people participating in citizen science. We also ran a series of citizen science workshops for older South Australians. This work demonstrated that 1) older South Australians are willing and able to participate in environmentally based citizen science excursions; and 2) there is some published evidence of the benefits of such participation, but the results are mixed and focus very little on physical activity, wellbeing, and medicine usage outcomes.

The two key elements of this project were a retrospective and prospective study to measure changes to physical activity, medicine usage, social connection, and self-worth as a result of participating in Citizen Science excursions; work commenced in April 2020. For this report, we also include a Scoping Review of the literature, synthesizing published findings concerning the health benefits of citizen science in natural environments.

The report concludes with a published paper produced by our team, which reviews current knowledge about the health benefits of natural environment exposure generally, unlinked to citizen science or volunteering. We then propose a potential public health policy advance with regards to the use of natural environments as a public health measure in urban areas.

ELEMENT 1: Scoping review of literature (Section 6)

Here we sought to bring together all of the available published literature reporting on changes to health and wellbeing as a result of citizen science, and in broader terms, environmental volunteering in general.

In preparing this review, we sought to illustrate the sum total knowledge in the field, to illustrate commonalities, and further clarify knowledge gaps.

ELEMENT 2: Retrospective cohort study (Section 7)

From the brief: " A trial that will involve recruitment of older people already participating in citizen science projects, along with matched control people who are not involved in citizen science. Physical activity and medicines use in both groups will be measured through questionnaires developed for the Australian Longitudinal Study of Ageing (ALSA). Cognitive performance and a 'depression score' will also be measured using ALSA instruments. Furthermore, we propose to use the Assessment of Quality of Life AQoL-8D questionnaire."

Recruitment of participants: Following the establishment of the overall study design and the creation of the visit system, advertising occurred via Facebook promotion through the 'Activating Citizen Science Facebook Page', electronic mailouts through various organizations with known older memberships (e.g. Royal Societies, Rotary groups etc), known citizen science groups, and WeekendPlus, the Seniors Card digital magazine. Recruitment was for individuals who were already involved in citizen science, compared with a matched control group.

ELEMENT 3: Prospective cohort study (Section 8)

From the brief: "A trial that focusses on physical activity measures (through research standard accelerometers) and psychosocial and cognitive measures (through tests and questionnaires) would help to identify new interventions to improve or maintain the health and wellbeing of older people. Measuring medicines use as part of this trial leveraged existing research strengths in the Quality Use of Medicines and Pharmacy Research Centre at UniSA, the Alliance for Research in Exercise, Nutrition and Activity (ARENA)."

Guiding principles for intervention design: Objectives of this project were aligned with the recommendations detailed in the *Future Directions to Support Ageing Well*[1] document. **We aimed to tackle ageism** by demonstrating the value of engagement of older citizens for important biodiversity data. We aimed to demonstrate how citizen science could promote the development of **meaningful connections** for participants and **reduce loneliness**. Furthermore, as highlighted in the '*Future Directions*' document, older South Australians value actions that promote self-determination and control over their lives. The aims can be achieved by engaging with older South Australians in citizen science activities that are accessible, impose no costs, and are inherently appealing to their personal interests.

Recruitment for participants: Following the establishment of the overall study design and the creation of the visit system, advertising occurred via Facebook promotion through the 'Activating Citizen Science Facebook Page', electronic mailouts through various organizations with known older memberships (e.g. Royal Societies, Rotary groups etc), known citizen science groups, and WeekendPlus, the Seniors Card digital magazine. Recruitment was for individuals who were not currently engaged in citizen science, half of whom undertook a citizen science project, with the other half not to be involved in a project.

Post-excursion evaluations: We used a combination of paper-based surveys, and accelerometry (measure of human movement) data for determining change in wellbeing outcomes following participation in citizen science excursions.

4. Aims of This Work

Purpose: to measure changes in health and wellbeing indicators in older South Australians participating in nature-based citizen science activities.

Outcomes:

1) To determine the impact of citizen science participation on physical activity in older people;

2) To determine the impact of citizen science participation on social connectivity and sense of wellbeing in older people;

3) To evaluate wellbeing benefits for citizen science participants at the individual level through integration of measured changes in physical activity, medication use, and social connectivity.

5. Project Personnel

[1] The Australian Centre for Social Innovation 2018. Future Directions to Support Ageing Well. Prepared for the Office for Ageing, Government of South Australia.

Personnel	Role
Investigators	
Prof Craig Williams UniSA: Clinical and Health Sciences	• Overall project coordination • Intervention design • Lead author (citizen science and health in urban areas) • Staff line management
A/Prof Katherine Baldock UniSA Allied Health and Human Performance	• Project coordination • Contributing author (citizen science and health in urban areas) • Staff line management
Dr Michelle Rogers Research Associate, UniSA Clinical & Health Sciences	• Project Advisor • Project design, planning and implementation • HREC Application and submission • Data collection, collation, and analysis • Participant management • Contributing author (citizen science and health in urban areas)
Dr Tom Wycherley UniSA: Allied Health and Human Performance	• Advisor for physical activity level measurement and tracking
A/Prof Lisa Kalisch-Ellett UniSA Clinical and Health Sciences.	• Advisor for medication use and change, record and tracking
Dr Sylvia Clarke Murraylands and Riverland Landscape Board, Landscapes SA	• Advisor for Citizen Science program development
Casual Project Staff	
Stephen Fricker	• Nature walk excursion coordination and scheduling • Location risk assessment and safety preparation • Excursion leadership and designated First Aid Officer • iNaturalist educator
Kylie Dankiw	• Project implementation • Data collection & collation • Participant management
Brett Tarca	• Accelerometer data analysis
Gennaro D'Elia	• Scoping literature review analyst and writer
Sophie Burnell	• Data analyst for Retrospective Cohort Trial

<u>Members of the External Project Advisory Group</u>:

Name	Organisation	Role
Prof David Harley FRACGP	University of Queensland	External advisory group member
Linda Millison	Citizen Science participant and older South Australian	External advisory group member
Stephen Merrett	Council of the Ageing (COTA) Policy Council	External advisory group member

6. Volunteering, citizen science and wellbeing in older adults: a scoping review

Craig Williams, Gennaro D'Elia, Katherine Baldock

Introduction

The practice of engaging volunteer participants for scientific data collection, Citizen Science, has a long history. From enduring projects such as the Christmas Bird Counts in the northern hemisphere that commenced in 1900 (Stewart 1954, Silvertown 2009), and the Climatological Observers Link that commenced in 1970 (Menne et al. 2012) through to the profusion of new projects starting every year, Citizen Science projects have served to enhance understanding of natural phenomena. There has been a strong focus on rapid assessment of animal abundance and distribution, such as birds, frogs, and marine life, along with observations of meteorological data and environmental quality measures. Citizen scientists have also been engaged in complex computational tasks through multi-player online games (Cooper et al. 2010).

Notwithstanding its rich history, Citizen Science is also an emerging field of practice and research, as evidenced by a rapid growth in projects available (e.g. https://scistarter.com/, a searchable online database of projects), together with a developing research literature. The benefits of citizen science for data collection in partnership with communities are being increasingly documented (e.g. Evans et al. 2005, Dickinson et al. 2012). Benefits for participants are also being demonstrated. Educational outcomes for participants are a commonly stated aim for citizen science projects, and advances are being made in developing frameworks to categorise and measure them (Phillips et al. 2018). Some studies have documented knowledge gains in participants (Jordan et al. 2011), although the results can be equivocal (Williams et al. 2017). Social connectivity and environmental gains have also been reported from citizen science projects (Bonney et al. 2014).

There are other potential health and wellbeing benefits for participants beyond educational and social outcomes. For Citizen Science projects that involve observation of the natural world, participants would typically be required to go outdoors and conduct observational activities. It follows that a number of benefits for participants may result. These may include physiological benefits through increased activity, and intrinsic psychological benefits due to participation and 'contributing to a cause'. These benefits may be difficult to measure and distinguish from one another.

Perhaps unsurprisingly, the literature describing the health benefits of citizen science is sparse. However, there is a more extensive literature on the benefits of volunteering and participation in community activities, of which Citizen Science is but one example (e.g. Jenkinson et al, 2013).

Furthermore, there has been extensive interest in improving the health of older people, variously identified as those aged over 50y or 60y. There are numerous policies, programs and interventions established by every level of government to enhance the wellbeing of older citizens. The World Health Organisation Global Network for Age-Friendly Cities (https://extranet.who.int/agefriendlyworld/) provides information on how governments globally are nominating volunteering as a key component of improving lives of older people. Examples abound from the European Union states (EuroHealthNet 2012), and in Australia and New Zealand many state and provincial governments have developed strategies and priorities to enhance the lives of older people. Examples can be found from various jurisdictions: e.g. New Zealand (Associate Minister of Health 2016), South Australia (Office for Ageing Well 2020), Victoria (Victorian Government 2016) and these invariably include objectives regarding improving health literacy, increasing physical and social activity, and participation in community activities. Opportunities to engage in meaningful social activities have been identified as important for older Australians (Mckercher & O'Brien, 2018), and the South Australian Government has identified 'Making a Contribution' – supporting opportunities for older adults to participate through lifelong learning and making positive contributions – as one of the five key priorities around healthy ageing (Office for Ageing Well 2020). Within this strategy aimed at promoting the active engagement in community of older adults, Citizen Science activities have been identified as an avenue for achieving benefit for older people.

This effort has been partially in response to global population age structure changes in recent decades. By 2030, the proportion of the global population aged over 60y is predicted to more than double from 2015 levels. Furthermore, whilst economically developed nations are currently the most aged, significant growth in the older persons population will occur in almost all countries (United Nations, Department of Economic and Social Affairs, Population Division (2015). Such changes draw attention to many aspects of older people's wellbeing, such as employability, continued education, psychological and physical health.

In addition, 'healthy ageing strategies' are commonly recognising older people as an asset that can be utilised, by activating their accrued skills and experiences. The involvement of older people in citizen science projects, in which they use not only their existing skills, but their time, is seen as an opportunity to not only enhance scientific data collection, but also to improve older people's wellbeing.

There are several reports associating volunteering with positive health and wellbeing outcomes, such as improvements with depression and life satisfaction, but not always with physical health (Jenkinson et al. 2013). However, in a recent randomised control trial, volunteering has been recently associated with increased physical activity levels in older people (Pettigrew et al 2019), but not with improved psychological outcomes. Gains in social connectivity alongside environmental benefit have previously been reported from citizen science projects (Bonney et al., 2014). However, the evidence base remains mixed and the consistency and intensity of effects unclear.

Here we present a structured scoping review reporting on the extent, range and nature of scientific literature reporting health, social and wellbeing outcomes of environmental volunteering, including Citizen Science, among older adults. Despite an abundance of literature on citizen science activities, to date there has been no structured review which has mapped the evidence base for benefits of engaging specifically in environmental volunteering and citizen science activities among older adults. Given the ageing population in many developed countries, and anticipated benefits of providing opportunities for older adults to engage in meaningful activity, the time is ripe to identify what, if any, are the benefits to older adults of engaging in volunteer and citizen science activities.

This review will fill a gap in current knowledge regarding the benefits of citizen science and related activities for older adults. Key learnings from this review will aid in decision-making processes regarding future investment in citizen science activities for this population.

Methods

Search Strategy

The following electronic databases were searched: Medline, Scopus, Web of Science, PsychINFO, and AgeLine All data bases were searched in October of 2018 (search updated May 2020). The search strategies were drafted in consultation with an academic librarian. A grey literature search was performed using a modified version of the search strategy for Trove and Google, with Google searching limited to the first 100 results (Archambault et al., 2012). The references of relevant articles were also searched to identify potential additional articles (pearling). The following search terms were used with relevant Boolean Operators and MeSH terms identified for individual databases:

"Citizen science", community based participatory research, public participation in scientific research, crowdsourcing, participatory action research, community-based research, public science, civic science, surveillance

Volunteer, volunteering, civic engagement, participation, environmental monitoring, environmental volunteerism, ecology, ecosystem, conservation, restoration, regeneration, preservation,

old* adult*, aged, elderly,

health, wellbeing, quality of life, mental health, connectedness, psychological, self-worth, fulfillment, education, social, physical activity, physiological

No limits were set for publication date. Only studies available in English language were eligible for inclusion.

Study designs

Qualitative, quantitative and mixed-methods studies were eligible for inclusion in this scoping review. Editorials, reviews and commentaries were excluded. The inclusion and exclusion criteria for the population-exposure-outcome (PEO) are outlined below.

Population: The included participant population was older adults aged 50 years or older, based on the definition for 'older people' proposed by the South Australian Government (n.d.).

Exposure: Studies were included if the exposure or intervention involved participation in Citizen Science or broader environmental volunteer activities (determined as being tasks involving outdoor activities). Studies to have investigated volunteering beyond environmental volunteering were excluded.

Outcome: Studies with objectively or subjectively measured outcomes were included. Studies measuring at least one relationship/outcome from exposure to Citizen Science/environmental volunteering were included, such as but not limited to physical, psychological, cognitive or social domains of health and wellbeing.

Study Selection

Literature selection was underpinned by a three-stage process. Stage 1 included importing all search results into EndNote X9® (2019, Clarivate Analytics, Toronto, Canada), where duplicates were removed. Stage 2 involved exporting the studies from EndNote X9® into the online Covidence™ software (2019, Alfred Hospital in Melbourne Australia, Instituto de Efectividad Clinica Y Sanitaria (EROS) in Buenos Aires, Argentina). The screening of title and abstracts was conducted in duplicate by two independent reviewers (GD, KB, CW) using Covidence™. One reviewer screened all studies (GD) and the remaining two reviewers (KB and CW) divided all studies between them. Eligibility for inclusion was based on the inclusion and exclusion criteria. Disagreements were resolved through discussion until consensus was achieved. Stage 3 involved assessing the eligibility of article full text according to inclusion and exclusion criteria. Disagreements were resolved through discussion and consultation with a third reviewer where necessary.

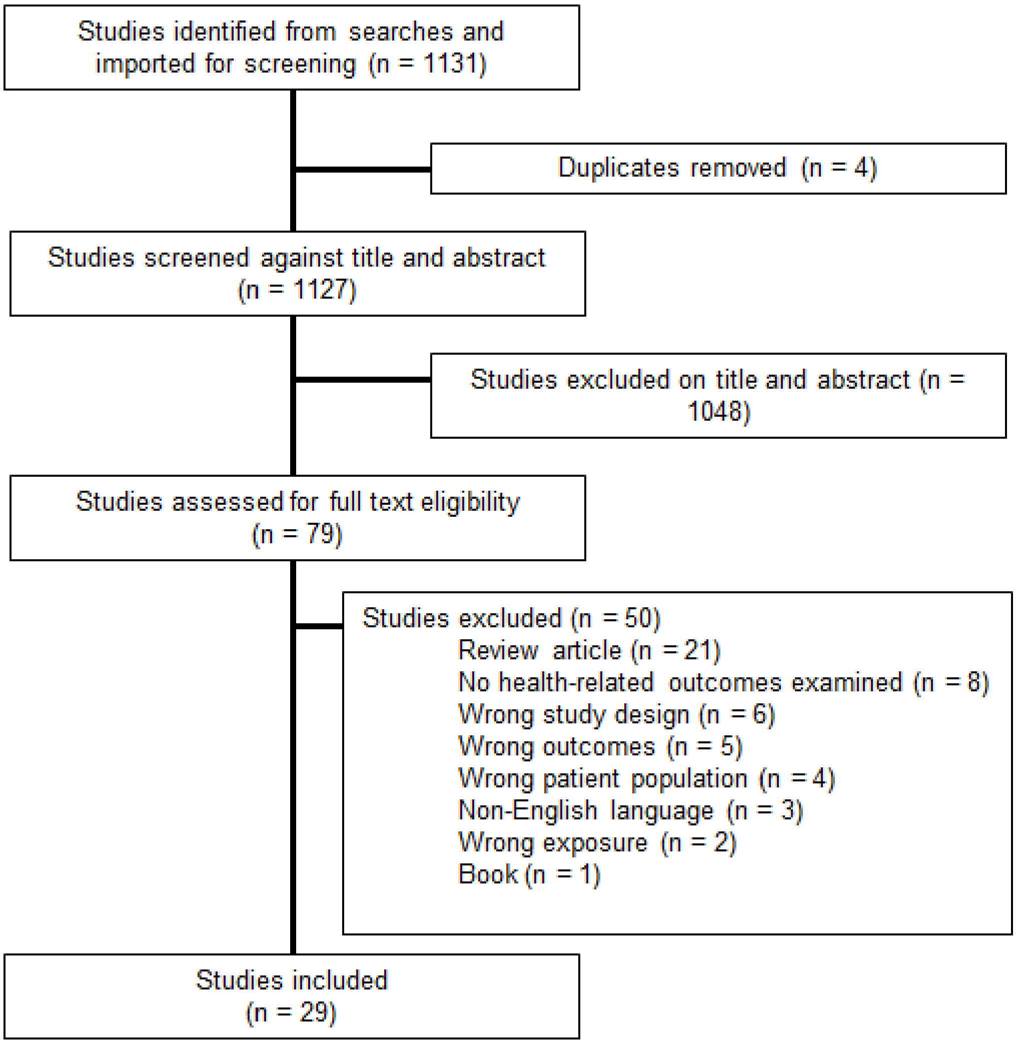
Data extraction

Data extraction from all included studies was conducted by GD using a pre-determined data extraction proforma in Microsoft Excel (version 1811, © Microsoft Cooperation 2018). Duplicate data extraction was conducted by KB for 20% of the included studies (n = 6), with no discrepancies in extracted data identified. Extracted data included: study design, participant characteristics, sample size, exposure/intervention, and outcomes. Some additional data extracted included outcome domains (physical, psychosocial, cognitive) and outcome results (statistical significance and descriptive data) where reported as related to benefits of participating in citizen science or broader volunteer activities.

Results

From 1131 abstracts, and following the exclusion of 4 duplicates, we screened 1127 results from Scopus, Web of Science, Medline, PsychInfo, and AgeLine. Of these, 79 were included for full-text review. Of these, 17 articles came from the grey literature and a further six articles were identified through pearling citations of included articles. In total, we identified 29 eligible studies (Figure 1).

Figure 1. Flowchart depicting study screening and selection process.



Overall, we found a modest body of published scientific literature that has examined the benefits to older adults of participation in environmental volunteering and citizen science activities. The vast majority of our included studies (n=23 of 29) were quantitative, with few qualitative (n=3) or mixed-methods (n=3) study designs. There was great diversity across these studies in terms of the volunteering or citizen science activity implemented, and the outcomes that were measured. The n=29 studies were published between 1978 and 2018, with almost two-thirds (n=17) having been published in the last 10 years. Most studies (n=20) evaluated psychosocial outcomes, and half (n=14) studied physical health (either measured or self-reported) outcomes. Just n=2 studies assessed cognitive outcomes among older adults. Table 1 provides a broad summary of findings from this review. Appendix 1 contains a summary of all included studies. Of the n=20 studies that examined psychosocial outcomes, such as life satisfaction, depressive symptoms, and quality of life, n=15 (75%) reported benefits for older adult volunteers. Of the n=14 studies to have examined physical health outcomes such as mortality and self-rated health, around two-thirds (n=9) reported benefits to older adult volunteers. In the n=2 studies that evaluated cognitive outcomes, such as memory, both reported benefits among older adult volunteers.

Table 1. Summary of associations reported between volunteering / citizen science and psychosocial, physical and cognitive outcomes for older adults

Included Studies	*Outcomes Assessed*		
	Psychosocial	*Physical*	*Cognitive*
Berman & Noone 1978	+	+	
Fengler & Goodrich 1980	NA		
Fengler 1984	~		
Oman, Thoresen & McMahon 1999		+	
Dulin & Hill 2003	+		
Morrow-Howell et al. 2003	+		
Greenfield & Marks 2004	+		
Liu 2004	+	+	
Harris & Thoresen 2005		+	
Larkin et al. 2005	+		
Lum & Lightfoot 2005	+	+	
Warburton et al. 2008		+	
Barron et al. 2009		~	
McMunn et al. 2009	+		
Dabelko-Schoeny, Anderson & Spinks 2010	~	NA	
Pillemer et al. 2010	+	+	
Tang et al. 2010	+		
De Souza, Lautert & Hilleshein 2011	+	NA	
Kim 2013	NA		
McDonald et al. 2013	+		
Flatt 2014			+
Krageloh & Shepherd 2015	+		
Labegalini et al. 2015	+		
Burr, Sae Hwang & Tavares 2016		~	
Varma et al. 2016		~	
Griep et al. 2017			+
Pillemer et al. 2017	~		
Huang 2018	+	+	
Ryu et al. 2018	+	+	

+ Positive association, ~ Equivocal association, NA No association

Discussion

This scoping literature review sheds new light on previously published works reporting on the benefits to older adults of participating in volunteering and citizen science activities. Overall, there appears to be positive benefits to volunteering among older adults across psychosocial, physical and cognitive dimensions of health and wellbeing. Due to the complex and heterogeneous nature of the evidence base, it is difficult to draw unequivocal conclusions. However, the evidence appears to suggest that volunteering is not harmful and may in fact be broadly beneficial for older adults' health and wellbeing.

We identified nine studies of environmental volunteering in older people that demonstrated a positive association with physical health measures. This finding is in contrast to a previous systematic review of health and survival of volunteers (Jenkinson et al. 2013) that reported no significant associations with physical health. This discordance in findings may be related to the difference in our study (only being a scoping review compared with a systematic review and meta-analysis). Also, we restricted our scoping review to 'environmental' volunteering, with a specific focus on activities (including citizen science) that involve some form of outdoor physical activity.

Whilst participation in environmental volunteering had positive effects on older people, future research could address more specific questions to generate evidence to support new strategies. For instance, quantifying different types of physical activity involved with environmental volunteering through time budget analysis and GPS-tracked movements would add greater depth to physical performance data associated with participation. Such data would also enable better resolution between different kinds of environmental volunteering and the level of physical work involved in each. The benefits of exercise for improving cognition and mortality in later life is well described (e.g. Middleton et al. 2008). The extent of exercise resulting from environmental volunteering and citizen science is not as well described.

In addition, studies of medicines usage in older people participating in such activities could predict not just immediate physical benefits but could illuminate other medical and economic consequences of volunteering; not just for individuals but for populations. To illustrate the scale of such benefit, recent studies have shown that volunteering activities in older people may reduce dementia risk, and decrease rates of anti-dementia medication prescribing (Griep et al. 2017).

In order to develop more specific policies regarding citizen science and environmental volunteering for older people, more specific information is required about the benefits of participation. Future trials that focus on older people in the environmental volunteering could pave the way for more specific interventions led by governments.

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Scoping Review: Appendix. Description of study design and measured exposures for included studies in this work.

Author, year	*Location*	*Design*	*Volunteers (n)*	*Age range*	*Exposure*	*Primary outcomes*	*Description of study*
Barron et al. 2009	USA	Descriptive	174	60-86	Volunteering in a school setting	Self-reported health and functional status	Volunteers in the Experience corps completed questionnaires about their physical activity and functional status, and completed objective tests of their grip strength, four-minute-walk time, time to complete five STS, and flight of stair walking speed. Tests were completed prior to commencing volunteering and at the end of the year.
Berman & Noone 1978	USA	Mixed methods	84	66-95	Volunteering in a residential care facility	Morale, self-esteem, social relations index (SRI), feelings of usefulness, perceptions of health	Describes the role of volunteering within an institutional setting for elderly persons. Volunteers are members of the Retired Senior Volunteer Program (RSVP). Compares residents who volunteer with RSVP to non-volunteers, and specifically looks at the effects of volunteering on self-esteem, morale, social relations, and health perceptions.
Burr, Sae Hwang & Tavares 2016		Retrospective cohort	7803	51-104	General volunteering	CVD risk	Assessed whether volunteering was associated with five risk factors (central adiposity, hypertension, lipid dysregulation, elevated blood glucose levels, and high inflammation) for CVD and Metabolic syndrome. Data were taken from the 2004 and 2006 waves of the Health and Retirement Study, a survey of adults age 51 and over.
Dabelko-Schoeny, Anderson	USA	Pilot, non-equivalent switching	43		Participation in a civic-engagement intervention	Well-being	A pilot study exploring the feasibility of an intervention to promote civic engagement in older adults. Adults were recruited from

& Spinks 2010		replications design					day health centres and took part in a multicomponent intervention comprising of an education, service and recognition phase. Participants overall wellbeing through purpose in life, self-esteem, usefulness, and perceived physical health were assessed.
De Souza, Lautert & Hilleshein 2011	Brazil	Cross-sectional	166	Mean= 68.2 (5.8)	Volunteering with an NGO	Self-reported health and quality of life	
Dulin & Hill 2003	USA	Cross-sectional	115	65-90	Volunteering with Foster Grandparent and Senior Companion Program	Self-reported health and quality of life	
Fengler 1984	USA	Cross-sectional	1400	Mean=72	Volunteering with Retired Senior Volunteer Program	Life satisfaction	
Fengler & Goodrich 1980	USA	Mixed-methods	19	60-83	Volunteering at a men's workshop	Life satisfaction	
Flatt 2014	USA	Cross-sectional	1735	50+	Engagement in social activities (altruism)	Memory performance	
Greenfield & Marks 2004	USA	Cross-sectional	373	65-74,	General volunteering	Psychological well-being	assessed through negative affect, positive affect, and purpose in life
Griep et al. 2017	Sweden	Longitudinal	1001	65+	General volunteering	Risk of self-reported cognitive complaints and dementia	Self-reported cognitive complaints, likelihood of being prescribed anti-dementia treatment
Harris & Thoresen 2005	USA	Cross-sectional	7496	70-99	General volunteering	Mortality	
Huang 2018	International	Cross-sectional	3767	Mean=59.35 (9.661)	General volunteering	Well-being	life satisfaction, happiness, health, life mastery,
Kim 2013	Korea	Cross-sectional	1250	65+	General volunteering	Life satisfaction	
Krageloh & Shepherd 2015	New Zealand	Cross-sectional	399	65-96	General volunteering	Quality of life	domains of the WHOQOL-bref

Labegalini et al. 2015							
Larkin et al. 2005							
Liu	USA		17	"two were under age 60, seven were in age between 60-69, four were in age between 70-79, and four were older than 80."	Volunteering in an intergenerational environment program	Personal impact on attitudes towards children and environment	
Lum & Lightfoot 2005	USA	Prospective cohort	7322	Mean=77	General volunteering	Physical and mental health	Self-reported health, depression levels, functioning levels, mortality rate, nursing home residency rate, and number of physician diagnosed medical conditions
McDonald et al. 2013	USA	Cross-sectional	451	43-97	Participation in the Retired and Senior Volunteer Program	Physical health, mental health, and perceived quality of life	
McMunn et al. 2009	England	Cross-sectional	5384	60+	Participation in socially productive activities: caring for someone, voluntary work, and paid work	Well-being	Quality of life, life satisfaction, depression
Morrow-Howell et al. 2003	USA	Prospective cohort	1669 at baseline	60+	General volunteering	Well-being	self-rated health, functional dependency, depressive symptomology
Oman, Thoresen & McMahon 1999	USA	Prospective cohort	2025	55+	General volunteering	Mortality	
Pillemer et al. 2010	USA	Longitudinal	2630	Mean=44.7	Environmental volunteering	Physical activity, mental and physical health	

Pillemer et al. 2017	USA	Mixed	125	49-93 Mean=68	Environmental volunteering through Retirees in Service to the Environment	Self-efficacy, social integration, feelings of attachment to others, generativity, pro-environmental attitudes	
Ryu et al. 2018	Korea	Cross-sectional	188	60-90	General volunteering	Life satisfaction, dispositional optimism, health perception	
Tang et al. 2010	USA	Cross-sectional	207	56-89	General volunteering	Socioemotional benefits, physical and mental health	SES, time commitment, socioemotional benefit, physical and mental health
Varma et al. 2016	USA	RCT	114	Mean = 67.4 (6.0)	Volunteering with experience corps	Daily walking activity	
Warburton et al. 2008	Australia	Case-control	126	Mean 82.5 (6.9)	General volunteering	Risk of hip fracture	

7. Retrospective Trial

Study Design

A Retrospective cohort study design was utilised, whereby older South Australians, some of which take part in citizen science were recruited and assessed for physical activity, loneliness and quality of life.

Study setting

All participants attended the University of South Australia Clinical Trial facility for a once off appointment (60 mins duration) to complete health and wellbeing questionnaires.

Participants and recruitment

A total of 102 individuals enquired about participating in the trial, with 89 agreeing to take part (87% translation rate).

Outcome measures

The following outcome measures were collected:

Depression Anxiety Stress Scales 21 (DASS-21): This is a 21-item version of the DASS, a self-report instrument designed to measure the three related negative emotional states of depression, anxiety and tension/stress.

International Physical Activity Questionnaires (IPAQ): The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available.

Assessment of Quality of Life (AQOL-8D): The 35-item questionnaire takes approximately 5 minutes to complete and covers the following dimensions: Independent Living, Happiness, Mental Health, Coping, Relationships, Self-Worth, Pain, Senses

UCLA: A 20-item scale designed to measure one's subjective feelings of loneliness as well as feelings of social isolation. Participants rate each item as either O ("I often feel this way"), S ("I sometimes feel this way"), R ("I rarely feel this way"), N ("I never feel this way").

DeJong Gierveld: An 11-item loneliness scale that can be applied as a unidimensional loneliness scale.

Health Questionnaire: A multi question document covering topics of general health and medication use.

Data Analysis

Data analysis was conducted by Investigator Rogers, with assistance from Sophie Burnell. SPSS version 20 was utilised for statistical analysis; with associations between demographic factors measured via t-tests, and association between Citizen Science involvement and health outcomes examined via Mann Whitney U tests ($P < 0.05$).

Results

The study had a sample population of 89, with ages ranging from 51-80 years. A higher socioeconomic status is disproportionally represented in the sample population [Table 1]. Most participants were not citizen scientists, amongst respondents who were, neither active nor passive involvement appears to be heavily favoured (Table 2).

TABLE 2- DESCRIPTIVE STATISTICS SUMMARISING DATA OUTPUT FOR DEMOGRAPHIC, SOCIOECONOMIC AND EXPOSURE VARIABLES.

Category	N	%
Gender		
Male	32	36.0
Female	57	64.0
Age Groups		
50-59 yrs.	20	22.5
60-69 yrs.	41	46.1
70-79 yrs.	26	29.2
80+ yrs.	2	2.2
SES Status		
Low	17	23.3
Medium	19	26.0
High	37	50.7
Independent Variables		
CS Involvement		
Yes	36	40.9
No	52	59.1
Type of Participation		
Active	16	44.4
Passive	20	55.6

(N=89) MISSING VALUES: SES STATUS N=16; CS INVOLVEMENT N=1.

CS: Citizen Science; n: number/frequency; SES: Socioeconomic Status

Table 3 outlines the results of t-test investigations of age, gender, and CS participation.

TABLE 3- RESULTS FROM T-TEST INVESTIGATIONS OF AGE, GENDER, AND CS PARTICIPATION

		n	Mean	Std. Dev.	Std. Error Mean	P-Value
Age (Years)						
Gender	Male	32	67.38	6.174	1.091	0.158
	Female	57	64.98	7.185	0.952	
CS Involvement	Yes	36	65.97	5.955	0.992	0.984
	No	52	65.94	7.477	1.037	
Type of CS Participation	Active	16	66.00	5.692	1.423	0.980
	Passive	20	69.95	6.304	1.410	

GENDER & CS INVOLVEMENT; MISSING VALUES: N = 1.

CS: Citizen Science; N: number/frequency; Std. Dev: Standard deviation of the mean; Std. Error Mean: Standard error of the mean.

There were no statistically significant effects of Citizen Science participation on overall quality of life or physical activity (Table 3). However, all loneliness scores were lower for those involved in citizen science projects. This was true for both social and emotional loneliness (Table 4).

TABLE 4 - MANN-WHITNEY U TESTING OF QUESTIONNAIRE DATA

CS Participation		n	Mean	Std. Dev.	Std. Error Mean	U-Value	P Value
AQOL							
Total score	Yes	36	66.36	15.329	2.555	873.5	0.502
	No	51	63.24	24.613	3.447		
DeJong							
Emotional Loneliness Score	Yes	36	1.28	1.830	0.305		0.073
	No	51	2.04	2.144	0.300		
Social Loneliness Score	Yes	36	1.78	1.914	0.319		0.341
	No	51	2.18	1.997	0.280		
Total Loneliness Score	Yes	36	3.06	3.447	0.575		0.161
	No	51	4.22	3.844	0.538		
IPAQ							
Weekly MET Minutes	Yes	36	7688.76	4349.93		789.0	0.266
	No	51	4119.54	4878.67			

(N=87) MISSING VALUES: N=2.

CS: Citizen Science; IPAQ: International Physical Activity Questionnaire; MET Minute: Metabolic Equivalent of Task in Minutes; N: number/frequency; Std. Dev: Standard deviation of the mean; Std. Error Mean: Standard error of the mean.

Summary of Findings

Participation in citizen science projects was associated with higher quality of life, lower loneliness, and higher levels of physical activity. However, data variation resulted in a lack of significant statistical differences.

The strongest statistical result was seen in the DeJong Emotional Loneliness Score, where the P value of 0.073 was close to significant (needing to be < 0.05).

Thus, a measurement at a single moment in time revealed that participation in Citizen Science Projects is associated with higher overall quality of life (based on the total AQOL score), lower loneliness (emotional, social and total; collected from the DeJong Greiveld Questionnaire) and is associated with increased Physical Activity (based on the total score from the International Physical Activity Questionnaire).

8. Prospective Trial

Study Design

A prospective randomised trial (PRT) design was utilised, where participants were assigned to one of two arms: a control and treatment. The control group received no intervention, whereas the treatment group experienced an 8 week nature-based citizen science experience. All participants were measured again after the 8 weeks.

Study setting

The study measurements were collected at the University of South Australia Clinical Trial Facility City East Campus in Adelaide South Australia. The study intervention experienced by the treatment group was in the form of Nature Walks, held at eight separate metropolitan Adelaide locations.

Participants, recruitment and randomisation

To be eligible to take part in the study participants had to be 50 years or older, able to understand English and able to complete a variety of questionnaires, have access to a smart device (iPhone, Samsung or something similar) and computer, and if no access to a smart phone or something similar they must have access to a computer and a digital camera, be able to undertake low-moderate physical activity (i.e. 60-minute walk) and be able to commit to an 8-week project period. Participants were screened against the inclusion/exclusion criteria by completing a confidential screening questionnaire.

Recruitment of participants began in January 2021 and continued until August 2021, yielding n = 48. Rolling recruitment was undertaken, meaning data collection occurred simultaneously. Participants were randomly allocated (i.e. by chance) into either the intervention or control group using a computer program.

Description of Intervention

The intervention involved 8 once weekly 60-minute nature walks hosted at a pre-determined location by a research team member. The locations of the nature walks varied week-to-week and took place in locations in metropolitan Adelaide readily accessible by car or public transport, feature paved pathways and easily graded landscapes to enable ease of foot traffic to cater for a variety of fitness levels and mobilities. In the event of inclement weather, the walk was postponed and/or cancelled for that week. Participants needed to complete a minimum of 4 walks for their data to be valid.

During the nature walks participants were required to record wildlife (flora and fauna) observations using the iNaturalist Application which could be used via a PC web browser or downloaded on to a smart phone or tablet device. The recording of wildlife observations was achieved by using the camera feature on the device to take pictures of flora or fauna witnessed by the participant. The participants were then asked to upload their observation to the iNaturalist application. In cases where the participant did not have access to a mobile or tablet device with a camera feature, they were required to use a digital camera to take pictures of their observations and upload their photo observations to the iNaturalist web browser.

Nature walk locations

The weekly nature walks were held in a pre-determined location and assessed by the research team for ease of accessibility and safety. A range of sites across Adelaide were used, including:

- Seacliff Esplanade + Coffee After
- Oaklands Park
- Dry Creek Trail
- Beaumont Common + Coffee After
- Gs Kingston Park/Wirrarninthi Pk23
- St. Peters Billabong
- Henry Codd Reserve + Coffee After
- Felixstow Reserve

Citizen science activity: iNaturalist

As described above the citizen science activity element of the intervention was use of the iNaturalist application for logging photo observations. iNaturalist is one of the world's most popular nature apps, helping identify plants and animals around the world. It allows individuals to get connected with a community of over a million scientists and naturalists, and by recording data allows them to create research quality data for scientists working to better understand and protect nature. iNaturalist is a joint initiative by the California Academy of Sciences and the National Geographic Society.

Procedure

Once deemed eligible by a member of the research team, participants were contacted via phone or email by the Clinical Trials Facilitator to book in a convenient time for their first study appointment.

Participants in the control group attended the Clinical Trials Facility at the University of South Australia City East Campus for one baseline visit and one final visit after 8-weeks. Participants in the intervention group underwent a baseline visit or zoom calls (60 minutes duration), a group session entitled "An introduction to iNaturalist", participated in the 8-week program (60-90 mins duration/week), and a final study visit or zoom call (60 minutes duration). A description of each of these visits can be found below.

Baseline visit

Visit 1 occurred at the participant's earliest convenience following eligibility confirmation and was held at the University of South Australia Clinical Trials Facility, Frome Road. This appointment involved:

- An explanation of the project, providing an opportunity for participants to ask questions, signing of overall study consent form.
- Completing a series of questionnaires relating to quality of life, physical activity, and mental well-being.
- Be loaned an activity monitor called GENEActiv to measure sleeping and physical activity patterns for 2 weeks.

Group session

Visit 2 occurred approximately 2 weeks after visit 1. This visit involved:

- Participants returning the GENEActiv
- Installation of iNaturalist App (key personnel: Mr Stephen Fricker)
- Supply of the dates for the 8-week intervention period, and education around the intervention.

8-week intervention

The intervention block involved:

- Weekly nature walks hosted at a pre-determined location by a research team member
- Wildlife observations which are recorded in the iNaturalist App.

Walks took place in locations in metropolitan Adelaide readily accessible by car or public transport, feature paved pathways and easily graded landscapes to enable ease of foot traffic to cater for a variety of fitness levels and mobilities. There were no more than 25 individuals per group. In the event of inclement weather, the walk was postponed and/or cancelled for that week.

Final visit

The final visit occurred as soon as practical following the conclusion of the 8-week intervention block. This visit involved:

- Completing a series of questionnaires relating to quality of life, physical activity, and mental well-being.
- Being lent an activity monitor called GENEActiv to measure sleeping and physical activity patterns for 2 weeks. Participants was supplied with a registered reply-paid envelope and sealed container to facilitate the return of the GENEActiv device to the study.
- An opportunity to provide feedback on the citizen science interventions
- Provision of trial honorarium

Outcome measures

Both questionnaires and direct physical activity measurements were used to detect potential health and wellbeing gains in participants (Table 5).

TABLE 5- ASSESSMENT TOOLS FOR THE PROSPECTIVE TRIAL

			Outcome Measure	Measured at clinic visit
1°		Questionnaires	Quality of life (QOL): QOL was assessed at baseline and at the end of the intervention/control period using the Assessment of Quality of Life (AQOL-8D). These data will be compared with control data and will be used when making future recommendations for ageing well projects. Questionnaires: International Physical Activity Questionnaires (IPAQ), Depression, Anxiety and Stress Scale 21 (DASS-21), UCLA, DeJong	Baseline and Final

			Gierveld, and Health questionnaire was assessed at baseline, and at the end of the intervention period. These measures will be included to describe the population and are validated, reliable and freely available.	
1°		Physical activity	14-day physical activity and sleep patterns were assessed using accelerometers (Geneactive). This data will be collected at baseline and at the end of the intervention period.	Baseline and Final

Accelerometry: Physical activity and sleep were measured using triaxial accelerometers (GENEActiv), which were worn on the non-dominant wrist on two separate occasions: at baseline (prior intervention), and at the end of the intervention/control period. Participants were asked to wear the monitor 24hr/d for 14 consecutive days, removing it for showering/bathing or any other water-based activities. Activity data was processed by GENEActiv software (version 3.2), and periods of sleep and non-wear time were calculated using custom filters. Total activity counts and the amount of time spent sedentary, engaged in light physical activity or moderate-vigorous physical activity were determined. To assess participants' levels of sedentariness and physical activity, the following variables were extracted: (1) average counts per day, excluding sleep; (2) average daily time spent sedentary, in light physical activity, and in moderate to vigorous physical activity (MVPA).

Questionnaires:

Depression Anxiety Stress Scales 21 (DASS-21): The DASS is a 21-item version of the DASS is a self-report instrument designed to measure the three related negative emotional states of depression, anxiety and tension/stress.

International Physical Activity Questionnaires (IPAQ): The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available.

Assessment of Quality of Life (AQOL-8D): The 35-item questionnaire takes approximately 5 minutes and covers the following dimensions: Independent Living, Happiness, Mental Health, Coping, Relationships, Self-Worth, Pain, Senses

UCLA: A 20-item scale designed to measure one's subjective feelings of loneliness as well as feelings of social isolation. Participants rate each item as either O ("I often feel this way"), S ("I sometimes feel this way"), R ("I rarely feel this way"), N ("I never feel this way").

DeJong Gierveld: An 11-item loneliness scale that can be applied as a unidimensional loneliness scale.

Health Questionnaire: A multi question document covering topics of general health and medication use.

Data Analysis

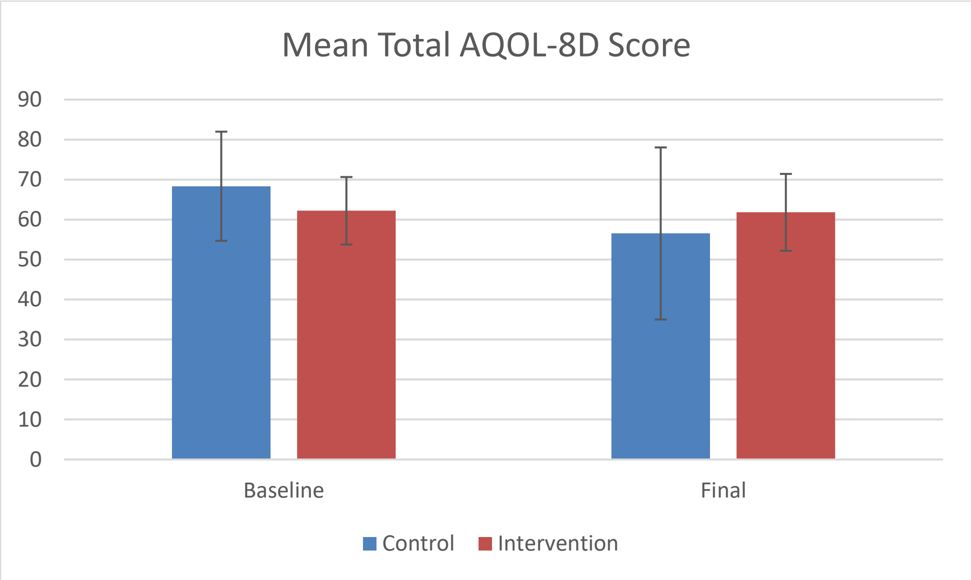
Data analysis was conducted by CI Williams and CI Rogers using SPSS version 20; with pre-post assessment for all outcome variables assessed via t-tests ($p < 0.05$).

Results

Quality Of Life (measured via AQOL-8D)

Quality of life remained stable in both the control and intervention groups across the course of the 8-week citizen science project (Figure 2).

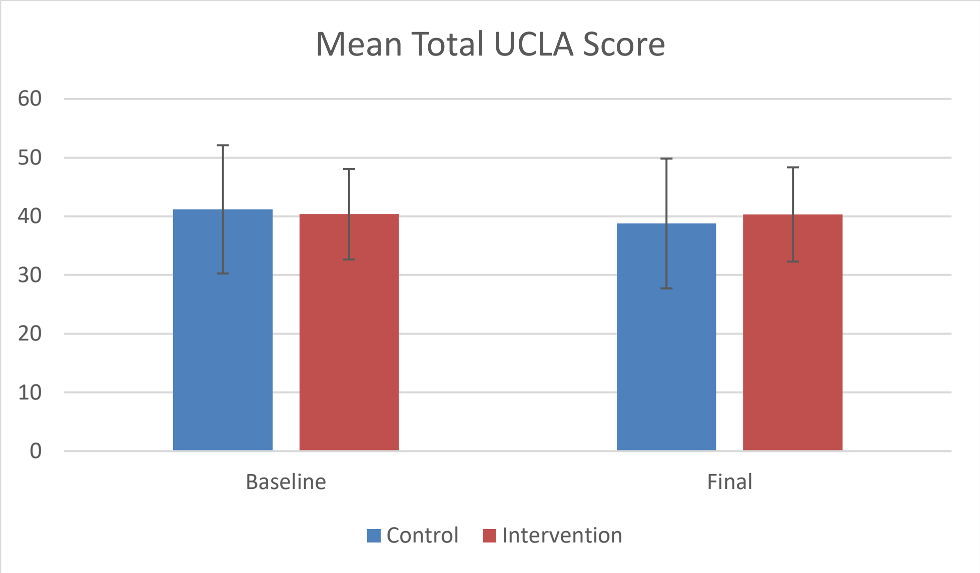
FIGURE 2- AQOL-8D SCORES FOR TREATMENT AND CONTROL ARMS IN THE PROSPECTIVE TRIAL.



Loneliness (measured via UCLA survey)

A loneliness score from 20 – 80 is calculated based on the sum of all responses, with a higher score indicating a higher level of loneliness. The scores calculated reflect no change post intervention in either the control or intervention group.

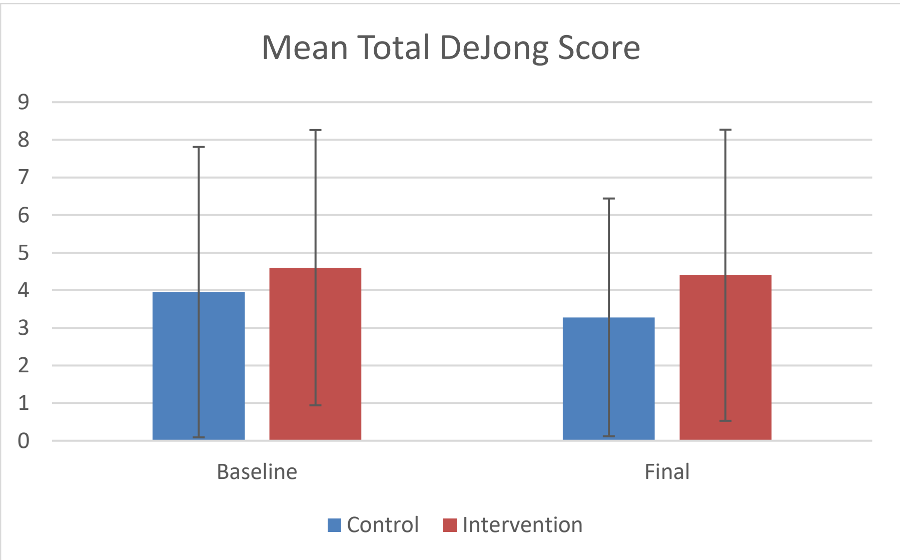
FIGURE 3- LONELINESS SCORES FOR TREATMENT AND CONTROL ARMS IN THE PROSPECTIVE TRIAL USING THE UCLA INSTRUMENT.

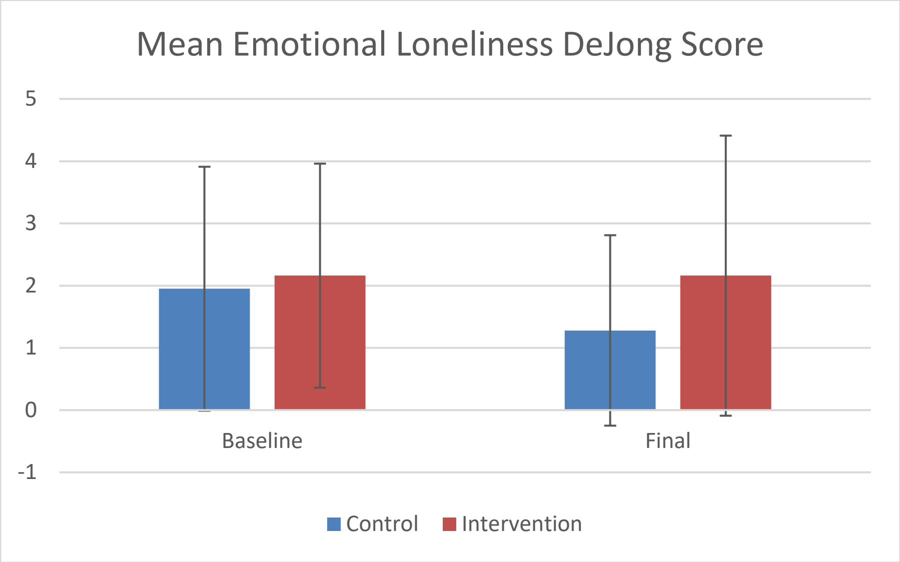


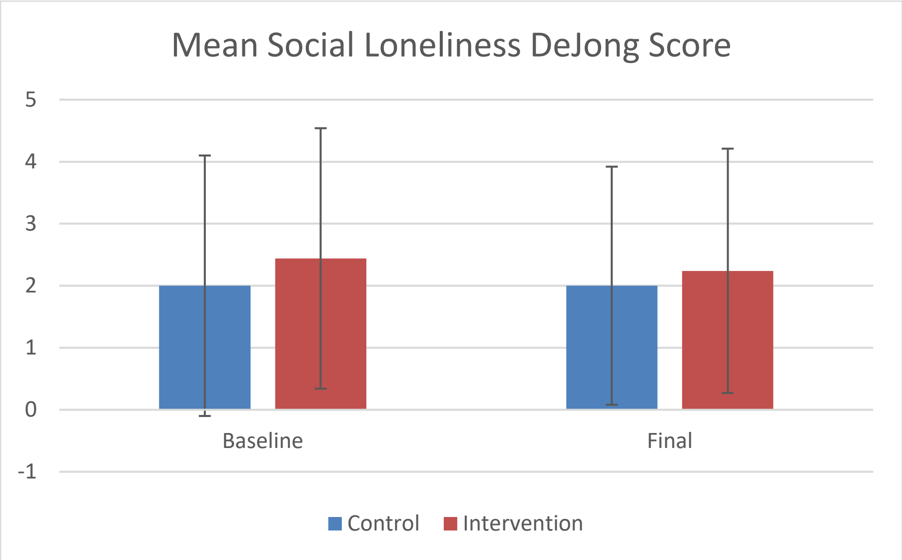
Loneliness (measured via DeJong survey)

The DeJong scale measures loneliness in both the social and emotional domains, and also returns a total loneliness score. In general, loneliness decreased in both domains in the intervention group after the 8 week trial. However, decreases were also seen in the control group, indicating no meaningful impact of the intervention on loneliness.

FIGURE 4- LONELINESS SCORES FOR TREATMENT AND CONTROL ARMS IN THE PROSPECTIVE TRIAL USING THE DE JONG INSTRUMENT, INCLUDING SUB-DOMAIN RESULTS







Medication Use

The amount and type of PRN (as required) medication use was analysed. Results showed that there was no difference in the amount, or type of PRN medication used in pre or post intervention.

TABLE 6 – MEDICATION USE COMPARISON FOR TREATMENT AND CONTROL GROUPS IN THE PROSPECTIVE TRIAL.

Study Group * Baseline PRN Medication Use Crosstabulation

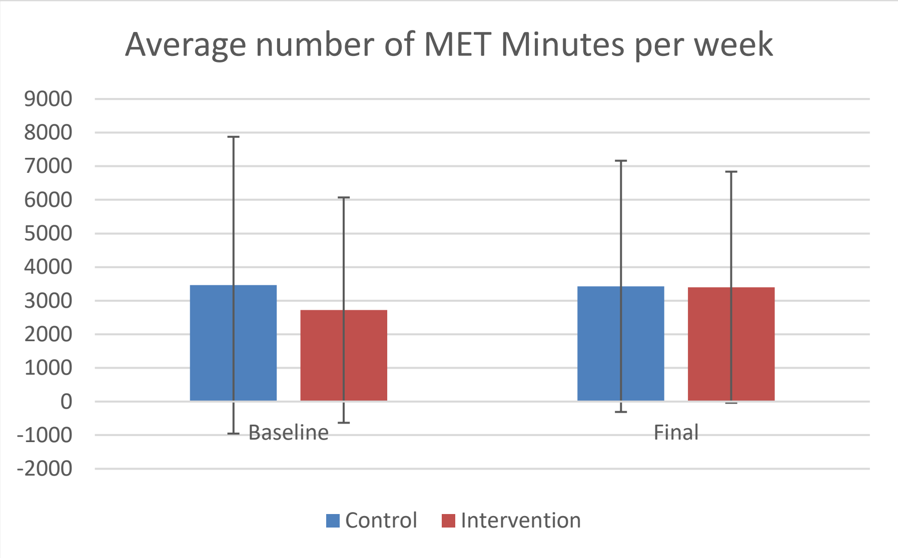
			Baseline PRN Medication Use						
			Vitamins	Lipid Modifying Agent	Dermatological	Antinflammatory and Antirheumatic Products, Non-Steroids	Analgesics	Antihistamine & Drugs for Obstructive Airway Diseases	Total
Study Group	Intervention	Count	6	1	1	8	10	5	31
		% within Study Group	19.4%	3.2%	3.2%	25.8%	32.3%	16.1%	100.0%
		% within Baseline PRN Medication Use	85.7%	100.0%	100.0%	72.7%	83.3%	62.5%	77.5%
		% of Total	15.0%	2.5%	2.5%	20.0%	25.0%	12.5%	77.5%
	Control	Count	1	0	0	3	2	3	9
		% within Study Group	11.1%	0.0%	0.0%	33.3%	22.2%	33.3%	100.0%
		% within Baseline PRN Medication Use	14.3%	0.0%	0.0%	27.3%	16.7%	37.5%	22.5%
		% of Total	2.5%	0.0%	0.0%	7.5%	5.0%	7.5%	22.5%
Total		Count	7	1	1	11	12	8	40
		% within Study Group	17.5%	2.5%	2.5%	27.5%	30.0%	20.0%	100.0%
		% within Baseline PRN Medication Use	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	17.5%	2.5%	2.5%	27.5%	30.0%	20.0%	100.0%

Physical Activity

IPAQ Questionnaire

Results from the self-reported International Physical Activity Questionnaire show that individuals in the control and intervention group, pre- and post intervention, undertake moderate physical activity. That is, 5 or more days of moderate intensity activity or walking of at least 30 minutes per day. When considering the average number of MET minutes per week, whilst there is no statistical difference between the two groups, there is a positive trend upwards for the intervention group following the intervention. Suggesting an increase of weekly moderate or intense physical activity following involvement in the 8-week citizen science project.

Figure 5 – Physical activity expressed as MET minutes from the physical activity questionnaire

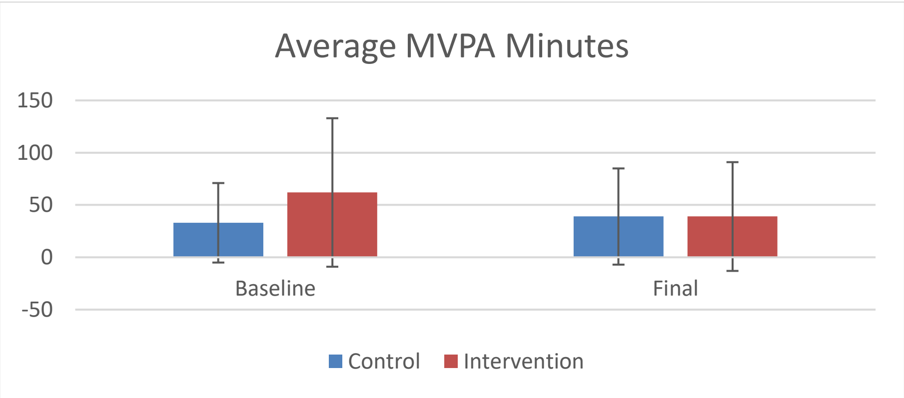


**MET Minutes: MET minutes represent the amount of energy expended carrying out physical activity. A MET is a multiple of your estimated resting energy expenditure. One MET is what you expend when you are at rest.

GeneActive Trackers

Analysis of the personal physical activity tracking devices showed no difference in the average moderate or vigorous physical activity (MVPA) minutes (as calculated by pre-determined cut off points) completed by individuals pre or post intervention.

Figure 6 – Vigorous physical activity expressed as MET minutes from accelerometer Gene-Activ devices



Summary of Findings

Within the achieved sample size, participation in Citizen Science activities across an 8-week time frame, did not result in any difference in overall quality of life (based on the total AQOL score), loneliness (emotional, social, and total; collected from the DeJong Greiveld Questionnaire) or Physical Activity (based on the total score from the International Physical Activity Questionnaire & GeneActive Data). As required medication use also did not change.

9. Participant evaluation of the prospective trial (Nature Walk intervention)

Participants in the intervention group were asked to complete a confidential feedback form during their final visit measures. Below are the questions asked in the feedback form along with the answers from participants.

How would you describe your overall experience of the nature walks?

''Enjoyable I learnt a lot and being involved helped me to share similar experiences with my grandchildren''

''Positive. Stephen knowledgeable and shared info with participants. Thabata and Larissa added freshness and a sense of fun. Helped to connect me with the smaller things in nature like bugs and mushrooms''

''Fantastic''

''It was good. The people were friendly, and Stephen was very knowledgeable about the wildlife''

''Very good – amiable company, approachable and interesting people and it created a learning atmosphere''

''Very good. Stephen even allowed grandchildren and interacted well with them''

''Most enjoyable''

''Enjoyable and interesting''

What were your most favorite/enjoyable experiences of the nature walks?

''Looking at our urban parks through fresh eyes''

''Finding critters and learning about flora and fauna we were finding. Great weather. Going to places I wouldn't have visited otherwise''

''Exploring, sharing and talking to like minded enthusiastic people. The events were stimulating''

''Chatting with people''

''Coming to grips with using phone camera and all the photos. The people, the conversations and observations''

''Feeling (almost) stupid as Stephen could see so much more''

''Visiting areas not known to me – learning about species of which I was unfamiliar''

''Finding things which I had never heard of before e.g. gall wasps and taking some great shots (esp. orb spiders as I hate spiders)''

What were your least favourite/enjoyable experiences of the nature walks?

''Having to squeeze the walks between two other events on Saturday mornings and not attending the soccer match of one grandchild due to the clash of times''

''Having to finish the event, not building friendships with other like-minded people to meet up at other times''

''The unfortunate fact that I could not find the time to attend all of them''

''One bout of hay fever – otherwise there were no 'least' favourites''

''Rainy and windy day in South Park Lands''

''Too short? Seeing the big picture and why? Where does my observation end up''

Suggested areas of improvement

''An occasional meal would have been good to share the mornings findings, highlights etc. A group that continues/expands with a monthly walk gathering to keep the enthusiasm and excitement up and share what/where we had been over the past month''

''It would be nice for Stephen to be provided with non-biological data on the areas visited''

''Maybe different visit times? 9am, 11am, 3pm and 4pm to see of different species appear?''

General feedback

''If the idea is to change behaviour, it would be useful to discuss with participants their ideas re what they might do differently now''

''My interest in the world in my own backyard piqued. No bug or strange growth can escape the camera lens''

10. Acknowledgments

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Appendix. Nature-based Citizen Science as a mechanism to improve human health in urban areas

This article was written in parallel with the work described in the above report, but does not include any data or intellectual property developed from the funded project. It is included here because it supports the findings made in the report, and is contemporary and peer-reviewed.

Citation:

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Review

Nature-Based Citizen Science as A Mechanism to Improve Human Health in Urban Areas

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Abstract: The world is becoming increasingly urbanised, impacting human interactions with natural environments (NEs). NEs take a number of forms, ranging from pristine, modified, to built NEs, which are common in many urban areas. NEs may include nature-based solutions, such as introducing nature elements and biological processes into cities that are used to solve problems created by urbanisation. Whilst urbanisation has negative impacts on human health, impacting mental and physical wellbeing through a number of mechanisms, exposure to NEs may improve human health and wellbeing. Here, we review the mechanisms by which health can be improved by exposure to NEs, as explained by Stress Reduction Theory, Attention Restoration Theory, and the 'Old Friends'/biodiversity hypothesis. Such exposures may have physiological and immunological benefits, mediated through endocrine pathways and altered microbiota. Citizen Science, which often causes exposure to NEs and social activity, is being increasingly used to not only collect scientific data but also to engage individuals and communities. Despite being a named component of scientific and environmental strategies of governments, to our knowledge, the intrinsic health benefits of Citizen Science in NEs do not form part of public health policy. We contend that Citizen Science programs that facilitate exposure to NEs in urban areas may represent an important public health policy advance.

Keywords: natural environments; urbanisation; public health; policy; Citizen Science

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1. Introduction

Human habitats have become increasingly urbanised, and these urban environments are strongly divergent from the habitats in which humans have spent most of their evolutionary history. Subsequently, human health has been affected by urbanisation including increased prevalence of allergic, autoimmune, inflammatory, metabolic and infectious 'urban-associated diseases' [1]. However, compared to remote and regional communities, income and access to health services are often higher for people living in cities, as are some health indicators such as longevity and total disease burden [2] demonstrating a complex relationship between urbanisation and human health. Within cities, living near green spaces and natural environments (NEs) typically confers health benefits ranging from better mental health and wellbeing to reduced overall mortality [3]. However, adding to this urban health complexity are findings from some studies showing increased mortality in cities with greater overall 'greenness' [4], and tensions between green space creation, urban gentrification and social inequity [5].

Categorising an environment as natural may be subjective, as it may have both natural and unnatural qualities. Indeed, 'nature' and 'natural' are conceptual terms that may be understood in different ways [6]. In reality, even environments perceived as natural may have some level of disturbance or modification, and thus exist on a spectrum between wild and pristine ('organic' NEs), through to partially natural (e.g., urban forest preserve with trails) or heavily disturbed (e.g., managed, grassy parkland). NEs may also be re-created through the establishment of community gardens and green roofs ('built' NEs). For this paper, we understand natural environments (NEs) to be any vegetated area with less built aspects and anthropogenic disturbance compared to surrounding areas; this definition includes both 'organic' and 'built' forms of green open spaces, gardens, parks, reserves and other forms of 'Metro Nature' as described by Wolf and Robbins [7]. Nature-based solutions (NBS), which include natural materials and processes, can also provide NEs in urban areas [8]. Following the modern taxonomy of NBS [8], they can be broadly categorised through their various uses: for stormwater management, soil and water remediation and bioengineering, greening systems to improve biodiversity in built environments, food and biomass production systems, and the provision of green space for human use.

In addition to intrinsic values, NEs have a number of extrinsic values, providing landscapes, flora and fauna that supply ecosystem services [9], resulting in breathable air, water, and food production. NEs also provide recreational spaces, cultural capital, and serve as a genetic and biochemical repository for novel materials and pharmaceutics [10,11]. Human redevelopment of natural environments is a predominant cause of habitat disruption and is expected to reduce current biodiversity by 20–30% within 100 years [12].

Interactions with NEs provide positive cognitive, emotional and physical health outcomes [7,11–15]. Health benefits are associated with both 'organic' NEs that pre-date human influence and extend to 'built' NEs within urban areas, including parks, gardens and man-made wetlands [7,13–18]. Human exposure to NEs can take the form of passive interactions such as viewing greenspace through building windows, or active interactions where there is an immersive physical presence [7,13–16,18,19].

Living in urbanised areas with scarce NE elements is increasingly common; by 2040, 85% of the population in developed countries is predicted to be urban [12,20]. Urban living may contribute to immunoregulatory dysfunction by reducing human exposure to biodiversity, microbial diversity especially [21–25], furthering the rise of inflammatory mediated chronic health issues [11,12]. Autoimmune diseases, allergies, cancers, obesity, and type 2 diabetes may be associated with inflammatory conditions [11,12,21,23,26], which may, in turn, impose burdens on individuals and healthcare systems [12,27]. For example, long term elevation of inflammatory markers such as C-reactive protein (CRP) is associated with an increased risk of cardiovascular complications and mental health issues such as depression [11,21]. The links between improved mental health and exposure to NEs are well established [28,29] though the mechanistic connections are not always clear.

Given the health benefits of nature exposure, programs that foster nature engagement have potential co-benefits for health. Citizen Science projects often span environmental science fields, empowering participants to monitor flora and fauna in an effort to map trends, gain conservation literacy, and aid conservation efforts [30–34].

The identification of environmental changes often requires large-scale observations, which make citizen scientists a valuable resource [30,31,35]. As an example, participants generate upwards of ten million bird count observations annually for the Cornell Lab of Ornithology in New York [35]. New technologies allow scientists to utilise streamlined data management tools including websites and mobile applications which are customisable to specific research designs and allow integration of input from multiple collaborators, with simplified interfaces suitable for large scale data collection of Citizen Science [30,32,35,36]. Effective Citizen Science programs have high levels of support and guidance for citizen participants, including reference materials, and multiple lines of communication to research scientists, where open discussions are encouraged [30,34–37].

Citizen Science is a highly collaborative, multidisciplinary endeavour which is designed to achieve mutual benefits for participants and researchers [35–39]. It provides a platform for education, building scientific literacy through engagement with local environments [30,31,34]. Citizen Science initiatives that increase scientific literacy, generate meaningful connections to local environments, and further understanding of community views can also contribute to improved environmental policy making [31,36,37]. Integrating Citizen Science projects into the school curriculum has great student and teacher learning benefits, whilst encouraging interaction and connection with NEs [31,39]. Alliances between professionals in education, environmental sciences, statistics, and social sciences allow for both scientific and educational aims to be met [35]. Involvement in Citizen Science programs sparks discussions about environmental research in social interactions, reinforcing participant learning and broadening scientific literacy within the community [30,33,34].

Given the health impacts caused by urbanisation and the known health benefits of exposure to NEs, the development of initiatives to increase NE exposure in humans should be of public health benefit. Citizen Science is an increasingly used activity that may bring people into contact with NEs. In this review, we explore the current connections between NEs and human health and then interpret the potential value of Citizen Science as a mechanism for enhanced wellbeing. We then apply these findings to our argument for nature-based Citizen Science to be central to public health policy to enable systematic up-scaling of human exposure to NEs.

2. Methods

In order to develop a thesis that links urbanisation, natural environments and health, we conducted a narrative review. This focussed on two distinct sections: (a) urbanisation impacts on human health, and (b) NE interactions and human health. We then developed a schematic concept map that links these and illustrates the ways in which Citizen Science can foster NE preservation, and enhance human contact with NEs, and improve social interaction. Having established this, we then provide a discussion in which we propose the use of nature-based Citizen Science as a public health intervention in itself, which is ideally suited to those living in urban areas.

3. Results

3.1. Urbanisation and Human Health

Modifiable environmental risk factors are estimated to have accounted for 12.6 million deaths globally in 2010 and 22% of the worldwide disease burden in disability-adjusted life years [40]. Urbanisation has normalised sedentary routines and increased environmental pollutants, contributing to a rise in chronic and infectious diseases [10,11,15,18,26,40–43]. Built environments can contaminate waterways, and create excess noise that can be linked with adverse health outcomes beyond auditory effects [10,11,14,18,40], and generate air pollution which has robust associations with allergies, cancers, and mental health disorders [10,15,40]. Urban landscapes also generate a heat island effect attributable to a lack of vegetation and surface water, in conjunction with altered wind patterns, impermeable surfaces, heat generated from human activities, and air pollution which alters cloud cover [11,15,18,40–42,44–46]. Heatwaves are deadly natural disasters; for example, more than 70,000 people excess deaths were recorded in Europe due to the heatwave of 2003 [47]. Global surface temperatures are predicted to rise in the coming century [48] potentially amplifying existing health emergencies such as heat-related illnesses [10,41].

Mental health disorders affect one in five people globally each year [49], and are the biggest cause of disability worldwide [11]. Mental health disorders such as mood, anxiety and schizophrenic disorders have been associated with living in built, non-natural environments [1]. The psychological health of ageing populations in some countries (e.g., Australia, Sweden) is also an imminent issue, with an ever-growing risk of cognitive decline, increasing the strain on social support within communities along with the burden on the healthcare system [50,51]. Urban environments also generally contain fewer opportunities for people to engage with NEs which can impact health in many ways. The development of nature-based solutions for treating and remediating water and soils in cities [8] is acting to provide the range of Ecosystem Services [7] that facilitate exposure to NEs.

3.2. Interactions between NEs and Human Health

Humans may respond in physiological, psychological and behavioural ways to NE exposure. The characteristics of NEs that may facilitate health benefits are likely to be multi-faceted, directly related to exposure to increased sunlight, air quality, biodiversity [including microbial], and phytochemicals in NEs, and indirectly through the opportunities NEs provide for restoration, socialisation, and physical activity.

Research demonstrates that exposure to NEs can enhance human cognitive performance in multiple ways; they can improve success within school and workplace settings, and have been used as a therapy tool to promote physical and emotional healing [7,14,16–19,29,40,52]. According to attention restoration theory (Table 1), NEs are restorative through redirecting attention, specifically the use of a passive soft fascination, contrasting the conscious attention required to meet the demands of busy urban living, triggering a physiological response that reduces stress and anxiety [13,14,16,17,29,53]. Stress Reduction Theory (Table 1) proposes ancestral preferences for NE properties associated with safety and resources remain relevant to unconscious stress-related neural mechanisms [19,29,54,55]. As little as 15 min of NE exposure is associated with lowered stress responses that are measurable from blood pressure, cortisol levels and pulse rate, with the most stressed individuals experiencing the greater stress-relief effect [29]. Passive exposure to NEs also produces restorative effects, generating greater capacities to concentrate attention in urban settings when living spaces have natural views, compared to ones overlooking urban artificial landscapes [29].

Greater accessibility to NEs is acknowledged as a key factor in promoting physical activity [7,11,13,14,17,18,46,56], however, it is insufficient on its own to encourage such behavioural changes [46,52]. Physical activity has important healthcare implications, with inactivity being the fourth highest contributor to worldwide mortality [52]. Physical activity provides an increased capacity to navigate stress as well as improved overall mental wellbeing [7,11,46,56] and is a highly encouraged preventative health measure against cardiovascular diseases [26,56,57]. Physical activity has also been shown to increase regulatory T cell activity, thereby limiting the inflammation associated with cardiovascular complications and mental health issues [21,26]. It has demonstrated a protective role against cognitive decline in later life, with findings suggesting a need for as little as three weekly walks to elicit this effect [57]. A study of an adult cohort aged over 65 years over a 5-year period demonstrated an ability of physical activity, at a frequency of three times a week, to improve learning and memory functioning by 42.3%, in addition to a 34% reduced risk of developing dementia [51]. Older adults have also demonstrated improvements in sit-to-stand and fast pace walking due to involvement in low-level volunteering [58], benefits that could also arise from Citizen Science activities. Whilst these benefits are associated with any form of physical activity, evidence suggests a rise in positive psychological reactions when undertaken within NEs [17,18,52].

Microbial flora (Table 1) such as bacteria, fungi, and protozoans coevolved with humans; exposure to diverse microbiomes builds our immune memory and educates and modulates our immune response [12,21]. As the diversity of microbial flora is diminished in urban environments [59,60] the protection they once provided from allergy, bowel inflammation and autoimmune diseases is also reduced [11,12,17,21,23,42]. The link between exposure to less diverse microbial communities and human health is described by two related hypotheses: the biodiversity hypothesis and the 'old friends' hypothesis (Table 1). The human gut alone contains over 160 species of bacteria, with both commonality and variation in species across individuals [12,61]. Human skin can have commensal relationships with many types of microorganisms including bacteria, fungi, viruses and microscopic protozoans [12]. Diversity within commensal microbiota is hypothesised as a key protection mechanism against adverse inflammatory responses, with different microorganisms exciting varying levels of regulatory stimulation [22,23]. Studies of rural living have linked agricultural land to increased diversity of the microbiota on skin and surfaces, inversely associated with the prevalence of allergies and asthma [17,21,22,42,62].

A lack of microbial stimuli disrupts immunoregulatory actions as evidenced by reductions in the regulatory cell activity of dendritic cells, T cells, and cytokines such as IL-10 and transforming growth factor-beta [12]. Gammaproteobacteria have been identified for immunoregulatory properties, being positively associated with lower allergy risk when commensal microbiota diversity is improved, thought to be a product of increased stimulation of anti-inflammatory IL-10 cytokines secreted from peripheral blood mononuclear cells [22]. Reduced organism biodiversity within surface and mattress dust has been associated with a greater risk of asthma in several studies of childhood environments [21]. The addition of a dog within the household from an early age has been found to reduce immunoglobulin E (IgE) sensitisation, protecting against allergy, likely a function of an increased microbiota diversity of household dust [11,21].

NEs that support social interactions are commonplace worldwide [13,16,38], meaning they could become a plentiful resource as a therapeutic treatment (aka 'social prescription'), thus reducing the economic burden at the individual and community level [16]. This is one of the arguments for social prescribing [where medical professionals prescribe social services or activities rather than medical interventions] generally and 'green'/nature prescribing specifically. Citizen Science programs could fall into this category as they can be socially engaging, with the potential to alleviate anxiety and promote better mental health, in addition to improving cognitive outcomes particularly among older participants [36,51,63]. Isolation from NEs and a reduction in diverse human contact associated with older age and reduced mobility is associated with elevated inflammatory markers including IL-6, and a dramatically reduced diversity of gut microbiota [11,21]; a finding of great concern in an ageing population [40,58]. Additionally, a limited social network is associated with a 60% increased risk of developing dementia within retired populations [51]. Citizen Science provides an opportunity for the mutual benefits of shared knowledge across generations, with the young learning from the experience of older participants, and reciprocating with an ability to help older citizens to improve their technological literacy and engagement [51].

3.3. *Citizen Science, Natural Environments, and Urbanisation: Linkages Influencing Human Health*

The complexity and multi-faceted nature of NE exposure and human health, in the context of urbanisation, is schematically depicted (Figure 1). In this schematic, the negative consequences of urbanisation (depicted in red) are connected with NEs and human health. Urbanisation alters NEs, reduces biodiversity, and impacts human health. Conversely, exposure to NEs may improve human health. Citizen Science is shown as an agent to improve NEs through the generation of environmental research, gains in scientific literacy, and indirectly through policy change that acts to generate new NEs (such as through nature-based solutions in urban areas), or through preservation of existing areas. In addition, Citizen Science also promotes contact with NEs, which in turn may benefit human health (Figure 1). These benefits could be manifested through improved social connectivity, exposure to NEs directly impacting immune function, and increased exercise. Quantifying such benefits of NE exposure via Citizen Science has not been the subject of research thus far. By illustrating these links between NEs and human health, we propose future research (such as through clinical trials) that specifically links health gains with nature-based Citizen Science.

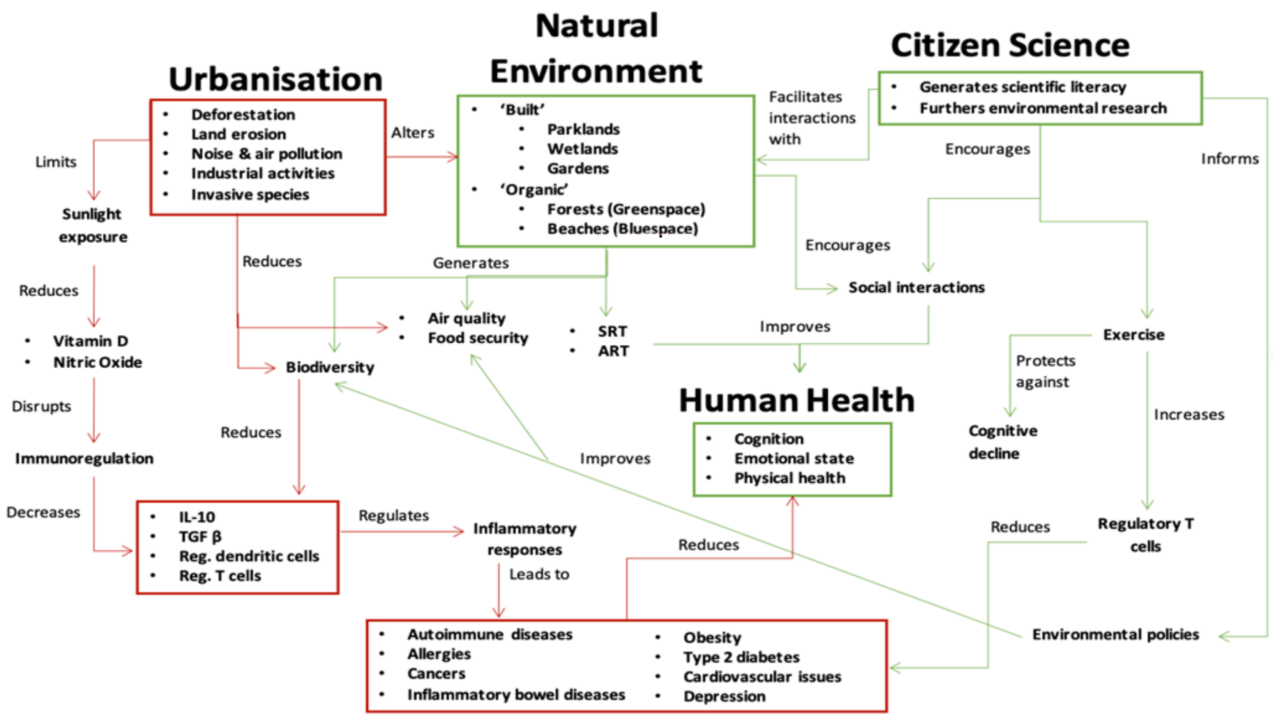

Figure 1. The complex relationships between Citizen Science, environmental exposure and human health. Evidenced and putative links are represented with arrows coloured in green (benefits), and red (harms). Abbreviations: ART: attention restoration theory IL-10: interleukin 10; SRT: stress reduction theory; TGF-β: transforming growth factor-beta.

Table 1. Theories linking natural environments and human health, with details of key supportive experimental trials.

Theory	Participants	Study Design	Evidence	Reference
Kaplan's attention restoration theory [ART] Urbanised living demands high levels of directed attention, taxing neural pathways that maintain focus and attention, NEs are hypothesised to stimulate soft fascination, switching unconscious neural processes and restoring tired pathways [29,53,64]. Core concepts theorised to influence the attention restoration mechanism are: a sense of being away, extent, fascination, and compatibility [29,53,64].	N = 12 8 males, 4 females Mean age = 30 Edinburgh University students.	A walk through three distinct districts, representing urban living [zone 1], a natural environment [zone 2], and a busy commercial zone [zone 3]. A neural cap recorded Electroencephalgram (EEG) data.	The zone 2 to zone 3 transition had decreased levels of arousal, frustration and engagement. Indicating that the natural environment reduced directed attention.	[53]
	N = 110 Predominantly staff and students of Chung-Hsing University.	Viewing 4 sets of 3 images, representative of the core concepts of ART; being away, extent, fascination, and compatibility. Images were viewed in 10s intervals, with 10s of non-viewing, blue screen in between [64]. Electomyography (EMG), EEG and blood volume pulse (BVP) measurements were taken.	Statistically significant EEG elevations, and decreased BVP, occurred whilst observing natural elements. Supporting claims that humans generate a response to elements within NEs.	[64]

Table 1. *Cont.*

Theory	Participants	Study Design	Evidence	Reference
	N = 38 23 males, 15 females Age = 18+ All living, working or studying in an urban, west midlands region of the UK [65].	30 min walks along 3 different trails; quiet residential streets [urban], inner-city parklands [greenspace], and along a canal [bluespace]. Measurements were taken at baseline [T1], after walking [T2], and 30 min later [T3]. Measurements included participant rated scales, backward digit spans, cortisol levels from saliva sampling, and heart rate monitoring.	The green and blue NEs gave greater cognitive function improvements and restorative experiences. Improvements in cognitive function took time to exhibit, being measurable at T3 but not T2.	[65]
	N = 12 7 females, 5 males Age = 18–24 undergraduate students of McMaster university.	Participants took photos of elements, within a natural place of their choosing, which they believe to positively contribute to their mental health. In depth interviews were used to collect data.	All participants expressed a correlation between removing themselves from built environments and improvements in mental health.	[13]
Ulrich's stress reduction theory [SRT] The notion that elements of NEs can unconsciously trigger physiological and psychological stress reduction mechanisms, thought to be a remnant of survival instincts towards geographical preferences during human evolution [29,55].	N = 158 80 males, 78 females Age = 18–32 Long term US residents [55].	Self-reported stress was measured via Visual Analogue Scale. Stress was triggered with a Trier Social Stress Test. A personal viewing headset displayed one of ten 6-min 3D videos of street scenes with varying tree density.	Videos with higher tree density correlated with an increase in stress reduction. Tree cover at 62% density increased stress recovery by 60%, compared to a 2% density.	[55]
	N = 48 Young males.	15 min sitting in an urban and a forest landscape. Ongoing physiological measurements were taken as well as psychological self-reposts.	Forest areas significantly lowered diastolic blood pressure and heart rate and increased parasympathetic activity.	[54]
'Old Friends'/biodiversity hypothesis A reduction in immunoregulation from a limited exposure to the microorganisms humans coevolved with, depriving the immune system of the input needed for education [11,12,17,21–23].	N = 60 Age = 7–14 50% living on traditional Amish farms, 50% living on industrialized Hutterite farms	Blood samples were collected from children along with history of allergies and asthma. Dust samples were collected from childrens' bedrooms. Mice were exposed to the dust; immune and airway responses were monitored.	Amish children had 4–6 times lower prevalence of asthma and allergies and different innate immune cell composition. Amish dust had 6.8 times higher levels of endotoxin. Mice exposed to Amish dust had inhibited airway hyperreactivity; this protective effect was blocked in mice deficient in certain innate immune signals [MyD88 and Trif].	[66]
	N = 24 Healthy Canadian full term infants [61].	Gene sequencing, from stool samples taken at 3 months old, indicated microbiota composition. Mothers reported on the presence of siblings and household pets.	Microbiota quantity and diversity was increased for infants living with pets but not siblings. Siblings and pets altered the composition of the microbiota.	[61]

Table 1. *Cont.*

Theory	Participants	Study Design	Evidence	Reference
	GABRIELA N = 444 Age = 6–12 16% living on farms Rural Germany [62]	Settled dust in children's bedrooms collected for culturing, gram staining and microscopy. Lung function testing with spirometry.	Samples from farming households had a higher biodiversity of fungi and bacteria, which correlated to a reduced prevalence of asthma.	[62]
	PARSIFAL N = 489 Age = 6–13 52% living on farms Rural Germany [62]	Mattress dust collected for single-strand conformation polymorphism testing.		
	Human blood samples and live mice	Dust was collected from an urban house and a farm barn and the microbial diversity was quantified. Monocyte-derived human dendritic cells [moDCs] were exposed to dust then coculture with purified naïve T cells. Mice were exposed to dust via intranasal administration.	Urban house dust contained a lower diversity of bacteria than farm barn dust. Exposure to urban house dust drove moDCs towards an 'allergic' [Th1-dominated response] while exposure to the highly diverse barn dust drove these cells towards a Th2-type response. Mice exposed to urban house, but not farm barn dust developed allergic inflammation in lungs.	[67]
	Genetically similar piglets [23].	Grown in isolation. Environmental exposures; sterile indoor environment, with or without antibiotics, and outdoors.	Microbiota compositions were dramatically impacted by alterations of early life environmental exposures [23]. Indoor grown piglets displayed upregulation of MHC-class 1 and various chemokines. Many of the identified phylotypes from this study can be found in humans.	[23]

4. Discussion: Nature-Based Citizen Science as Public Health Policy: Enticing Urban Dwellers into NEs

Many benefits of NEs are subconscious [7,68], which may present as a barrier when encouraging the community to connect with NEs. Nature-based Citizen Science projects can provide motivation for people to engage with NEs and have co-benefits for health through social interactions, physical activity and exposure to greater biodiversity. Unfamiliarity or past negative experiences with NEs can elicit negative associations, such as anxiety, uncertainty, or fear of aggressive or poisonous wildlife [11,18,29]. Evidence indicates that intentions to engage in certain behaviours, such as physical activity, can be improved following positive experiences of those behaviours [52,68]. Citizen Science projects may provide a catalyst for initial contact with NEs to shape participant attitudes for enduring attachment and engagement with nature [30].

The perceived social normality of interacting with NEs also has a critical influence on the attitudes and behaviours of individuals. Implementation of Citizen Science programs may require simultaneous public marketing and education strategies that help shift and shape perceived norms regarding interaction with NEs. For instance, the health benefits of Citizen Science are not routinely publicised in participant recruitment for projects; yet, such publicity may in fact increase participation and subsequently perceived norms around NE engagement. The development of empirical evidence linking Citizen Science and participant health may ultimately inform public health policy and Citizen Science practice itself, and introduce a sense of social encouragement to engage with NEs [52].

Despite established links between human health and NEs, several variables of therapeutic potential remain unclear, such as required exposures (akin to 'dosages'), the duration of benefit after daily activities resume, and the impact of repeated exposure as familiarity with NEs are increased. The nature of interactions with NEs, and the influence they may have on protective health outcomes is also unclear. Finally, the impact of NE type (e.g., garden vs. park vs. forest) on therapeutic outcomes is unclear as is the wellbeing contribution of the NE exposure per se compared to the removal of negative urban stimuli. Answers for these questions would help inform more strategic and effective use of social/green/nature prescribing overall and the use of Citizen Science for health.

Nature-based Citizen Science provides a mechanism by which people may be exposed to NEs through systematic, organised and scalable activity. These activities provide multiple benefits and may be used to achieve a variety of scientific, conservation and educational goals. To the best of our knowledge, Citizen Science does not form an explicit component of health strategic planning.

Some jurisdictions, however, do have Citizen Science strategic plans and legislation, but not specifically for public health reasons. In Europe, there are a few national-level strategies emerging from a heterogeneous ecosystem of Citizen Science projects [69]. Links between Citizen Science and policy development are championed by COST (European Cooperation in Science and Technology, Available online: https://www.cost.eu/ (accessed on 7 December 2021)). In the USA, the American Innovation and Competitiveness Act (2017) contained provisions to utilise nationally coordinated Citizen Science to enhance scientific research, literacy and diplomacy. In Australia, the Inspiring Australia initiative (Available online: https://www.industry.gov.au/funding-and-incentives/inspiring-australia-science-engagement-in-australia (accessed on 7 October 2021)) aims to engage people with science, and as a consequence Citizen Science activities are enabled through this program. Amongst a diverse and highly contextualized body of Citizen Science projects, human health is often mentioned, but only in relation to particular projects that collect environmental data to improve health, not in the sense of Citizen Science activities being intrinsically healthy to do.

Therefore, whilst Citizen Science is becoming part of government policy and strategy, this seems to contribute principal evidence to enhance environmental and public health objectives. Citizen Science is not yet an explicit part of public health policy, and we contend that embedding Citizen Science into public health strategy, particularly projects that facilitate NE engagement, could result in diverse health improvements for participants (e.g., physical, social, cognitive, etc.), while advancing science engagement and our scientific knowledge of the Australian environment.

Linking nature-based Citizen Science to public health strategy could involve nominated targets for community involvement, set out in aspirational targets. Governments at both the state/provincial and national level are fond of establishing strategies that nominate key actions to improve health and wellbeing. We contend that this could include the explicit naming of nature-based Citizen Science as part of a strategy, with concomitant funding and directed recruitment of participants.

However, before any further public investment in nature-based Citizen Science, demonstrating the explicit health benefits obtained from such activities is a vital next step. If nature-based Citizen Science can be shown to have health benefits, and these can be quantified in terms that can be linked to government aspirational strategy, then recommendations can be made to health authorities for systematic investment and incorporation with policy. We contend that clinical trial research should demonstrate health improvements in the domains such as overall quality of life and social connection, physical activity and over-the-counter (non-prescribed) medication use. Indeed, to this end, there are trials currently being conducted in Australia examining the health benefits of nature-based Citizen Science (e.g., the authors conducting a study for the South Australia Office for Ageing Well).

5. Conclusions

The human health benefits of exposure to NEs are well established and can be achieved through participation in nature-based Citizen Science. This route of exposure to NEs could promote health through all three of the main pathways connecting health and nature: through increased (a) physical activity, (b) social interactions and (c) exposure to an increased quantity and diversity of microbiota. Exposure to diverse microbiomes is shown to aid in the development and maintenance of immunoregulation and changes to microbiomes and immune function can occur rapidly from exposure to NE. Long-term monitoring of C-reactive protein can determine the influence of NE exposure on inflammation over time, which can indicate levels of risk for cardiovascular diseases, inflammatory disorders, depression, and stress resilience and could be used to monitor the effectiveness of Citizen Science programs in reducing chronic stress and related conditions.

Nature-based Citizen Science projects have the potential to motivate communities to further engage with NEs, providing holistic benefits to human health and the healthcare system, whilst generating the scientific research needed to better sustain NEs. Incorporating Citizen Science into public health policy will make the links between Citizen Science participation and health more explicit, thereby encouraging Citizen Science uptake and creating benefits to both public health and science.

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