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Citizen science in Australia's waterways: investigating linkages with catchment decision-making

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ABSTRACT

Citizen science can be a viable mechanism to foster productive linkages between community and government for sustainable water resource management. In Australia, this potential has longstanding policy support but research into program extent, characteristics or impact on decision-making processes has been lacking. This article draws on a temporal analysis of data records from two citizen science programs and a nationwide survey of 47 program coordinators representing 43 freshwater and estuarine citizen science programs to examine these knowledge shortfalls. Results indicate that program activity has contracted in Victoria but increased in the ACT, with additional evidence indicating a nationwide contraction. Survey results revealed programs operating nationwide and largely implemented as a community-government partnership, combining data and educative priorities. Despite 70 per cent of programs having goals to inform catchment decision-making, data use was verified for less than half of programs. Program coordinators reported several social, organisational and technical barriers that limit this uptake. In highlighting these issues, we make three recommendations for enhancing linkages between citizen science and catchment decision-making: (1) increasing institutional support; (2) improving coordination and embracing new possibilities for collaboration; and (3) demonstrating and communicating program achievements.


KEYWORDS

Citizen science; community-based water monitoring; natural resource management; policy

Introduction

The need for practical and effective links between the public, science and policy is a widely discussed theme in sustainability and water resource management literature (Carr 2015; Reed 2008). In Australia, the past three decades have witnessed the emergence of diverse participatory programs and strategies that include the public in the management of natural resources (Curtis et al. 2014). These initiatives range from those that provide information to, or seek input from, interested or affected stakeholders, to more resource-intensive programs that build active and connected communities (Dean et al. 2016). Part of this broader development are longstanding efforts to support public involvement in the collection and analysis of water condition data, commonly referred to as

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'citizen science' (Bonney et al. 2009; Irwin 1995). In recent years, citizen science has grown in prominence as a viable mechanism to improve water resource management and foster productive linkages between community and government (Buytaert et al. 2014; McKinley et al. 2016; Nascimento et al. 2018; Turrini et al. 2018). However, whether and how these linkages form is an under-researched area, particularly in Australia.

In water environments, citizen science has historically functioned to build skills and raise community awareness around waterway issues through a combined process of participatory learning and scientific inquiry. This form of citizen science is otherwise labelled 'volunteer monitoring' or 'community-based monitoring' (Buckland-Nicks, Castleden, and Conrad 2016; Deutsch and Ruiz-Cordova 2015), and has been informed by the principles and practices of 'participatory action research' and 'community science' (Carr 2004; Cooper et al. 2007). In recent years, the popularity of citizen science has brought about a wide array of new projects in a variety of environmental contexts (Pocock et al. 2017), largely driven by advances in technology to support data collection, management and dissemination (Newman et al. 2012). The current suite of citizen science projects reveals a diversity of approaches, methods of data collection and multifaceted objectives, including the provision of data, policing environmental threats or education and engagement (Kinchy, Jalbert, and Lyons 2014). Projects enlist participants at varying levels of engagement, ranging from 'contributory' projects that involve volunteers in data collection, to 'collaborative' and 'co-created' forms, which involve participants in more steps of the research process and tend to produce deeper engagement due to their focus on local issues (Shirk et al. 2012).

Despite an increasing body of research demonstrating citizen science can make significant achievements in advancing ecological research (Dickinson et al. 2012), its uptake in environmental decision-making has been slow (Conrad and Hilchey 2011; Hecker et al. 2018). Accordingly, the issues and opportunities of citizen science at the science-policy interface have become a critical point of exploration and review (Ballard et al. 2017; Carlson and Cohen 2018; Chapman and Hodges 2016; Hecker et al. 2018; Hyder et al. 2015; McKinley et al. 2016). A central focus in this research is on the potential for data collected by volunteers to shape policy and resource management outcomes. If volunteer data collection is supported by sufficient training, data validation and effective quality control, then the data have the potential to identify environmental problems, assess conservation activities, inform and evaluate policy, and meet legislative and statutory agreements (Stepenuck and Genskow 2018). While not all citizen science projects will have such goals, nor will they be suitable for these purposes (Bonney et al. 2016), emerging research shows particular promise for contributions within place-based projects aiming to affect local decision-making (Newman et al. 2017).

Beyond its scientific dimensions, citizen science is regularly promoted as a tool for empowerment and behaviour change, with the potential to lead to more transparent and inclusive government processes (Nascimento et al. 2018). Public engagement in research and monitoring activities can raise environmental awareness, strengthen connection to 'place', improve scientific literacy and build social capital, among other benefits (Haywood 2016). These opportunities can empower communities to use the tool of science as an effective and structured method for communication of local environmental concerns (Pfeffer and Wagenet 2007). For example, a study by Storey et al. (2016) on

volunteer stream monitoring in New Zealand showed participants became more confident and better equipped to engage in conservation action as a result of their participation. In addition to enhanced civic engagement, volunteers are increasingly recognised as possessing valuable local knowledge that can guide program operation, such as choosing relevant and accessible sites for monitoring, and influencing the development of research questions in a way that aligns with community interests, needs and expectations (McKinley et al. 2016).

The data- and engagement-related benefits of citizen science described above represent two distinct, but mutually reinforcing, pathways through which citizen science can influence environmental decision-making (McKinley et al. 2016). However, the realisation of each pathway is not supported by a substantial body of evidence, leading several researchers to call for more focused attention on the contributions of citizen science decision-making, including the factors that permit meaningful and effective citizen participation and data contributions (Conrad and Hilchey 2011; Stepenuck and Green 2015). These knowledge shortfalls are particularly acute in Australia, despite longstanding investment and strong rates of participation in community-based monitoring (Thomson 2007). Australia, therefore, provides a rich case study to examine the issues and knowledge gaps identified above and is the focus of this article.

The historical context of freshwater and estuarine citizen science in Australia

In Australia, the history of freshwater citizen science is largely a story of Waterwatch,¹ a community-based water monitoring initiative that has operated for about three decades. The national Waterwatch program emerged in 1993 due both to rising public environmental concern and government policy to educate and engage the community in water management issues. The program was underpinned by two interconnected themes: participatory learning for sustainability and community-based monitoring of water quality and aquatic habitats (Thomson 2007). It was built on a flexible framework so that it responded to the local biophysical and social contexts in the respective region of implementation, with regional coordinators employed to support monitoring activities.

Waterwatch has maintained a longstanding commitment to educate and involve the public in the management of water resources by raising environmental awareness and promoting positive stewardship behaviours. Program goals extended beyond these educative dimensions to include the collection of useful, credible and accepted data to underpin catchment decision-making several years after its establishment (Waterwatch Victoria 2000). Interest by scientists and government agencies in exploring the utility of volunteer-collected data can be traced to as early as the year 1999. For example, Finlayson and Mitchell (1999) advocated for wetland conservation to explore the use of community participation in monitoring wetland condition, not only to act as an early warning for pollution impacts but also to improve communication between wetland researchers, managers and the local communities. More recently, government environmental policy at all levels explicitly states a commitment to support community-based water monitoring initiatives for its knowledge generation benefits (ACT Government 2014; DEPI 2013). However, efforts to link data with management actions and policy development have

been hindered historically by perceptions that community-collected data is inferior to professional data (Wilson 2002). In response, Waterwatch has worked to improve the alignment between community and professional data by implementing data confidence plans, regular training and quality assurance and quality control (QA/QC) procedures. Moreover, the level of resistance to the use of volunteer-collected data does not align with emerging evidence demonstrating citizen science water quality data can be comparable to professional approaches (Fore, Paulsen, and O’Laughlin 2001; Nicholson, Ryan, and Hodgkins 2002; Storey et al. 2016).

In 2008-09, changes to federal natural resource management funding arrangements meant Waterwatch programs were supported through a regional delivery model, which had a significant initial impact on program stability (Thomson 2007). These changes were felt across the spectrum of community-based natural resource management programs, weakening engagement and reducing support from natural resource management (NRM) bodies (Robins and Kanowski 2011). Ongoing funding challenges have highlighted the necessity of strong partnerships with local, regional and state government agencies, non-government organisations and industry (Hardie, Tilleard, and Wealands 2009). These partnerships not only assist in funding opportunities; they also provide programs with greater credibility and capacity to integrate within monitoring and decision-making frameworks.

Despite undergoing various developmental phases (Figure 1), Waterwatch has not been supported by sufficient research attention on program characteristics, spatial extent and influence within catchment decision-making. Some early studies investigated the principles and conditions of effective environmental stewardship, including community-based monitoring programs (Carr 2002), the experiences and empowerment of volunteers in catchment groups (Gooch 2004), and the community-agency interactions that influence community research activities (Thomsen 2008). However, these studies predate the recent and widespread interest in citizen science (e.g. Pecl et al. 2015), including the associated advances in technology to support participation and improve data management

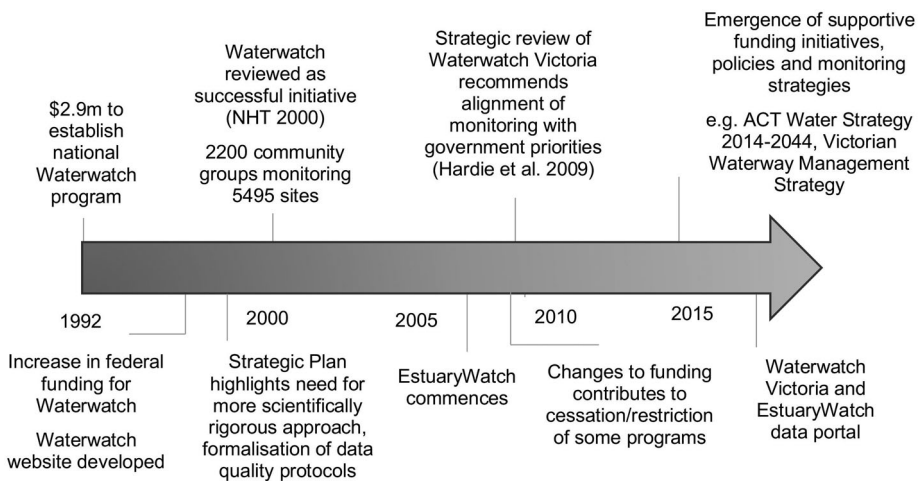


Figure 1. A timeline of major events in the history of the community-based water monitoring program, Waterwatch.

(Newman et al. 2012). Therefore, renewed investigation into the extent and influence of freshwater and estuarine programs is critical if programs are to realise their full potential in contemporary water resource management that is increasingly characterised by community partnerships and multi-actor coordination.

Methods

The central aim of this research was to conduct a comprehensive assessment of freshwater and estuarine citizen science programs in Australia using an approach comprising two methods. First was an analysis of program data records from two freshwater citizen science programs to establish how program activity and volunteer participation has changed over time. The second was an online survey distributed to all freshwater and estuarine citizen science program coordinators with three key aims:

- (1) to build a baseline understanding of the extent, characteristics, diversity of objectives and partnership structure across the network of programs in Australia;
- (2) to document and review examples of data contributions to catchment decision-making, including factors that influence data uptake; and
- (3) to explore the extent to which volunteers, through their participation, influence program operation and actively participate in catchment decision-making.

Program activity analysis

An initial investigation to determine how program activity has changed over time was conducted on two longstanding freshwater citizen science programs, in Victoria (*Waterwatch Victoria*) and the Australian Capital Territory (*Upper Murrumbidgee Waterwatch*). Both programs consist of multiple sub-programs hosted by regional natural resource management (NRM) bodies, water utilities or catchment coordinating committees. The ten sub-programs in Victoria and the four sub-programs in the ACT provide their data to centralised databases for storage and analysis. We collated these data and examined temporal trends in monitoring activity for each program using the total number of data records and unique monitoring sites annually since program inception as a proxy for program activity and volunteer participation over time. Data records were analysed only if they were from natural waterbodies e.g. lakes, rivers, wetlands and estuaries. Sites were excluded if they were marked as groundwater sites, household dams, rainwater tanks, constructed channels or stormwater drains.

Survey

To understand the characteristics and contributions of freshwater and estuarine citizen science programs, a survey of individuals in coordinating roles was conducted between March and April 2018. Coordinators were chosen as participants since they occupy a central position in citizen science networks and hold comprehensive insights into project issues and opportunities. To recruit participants, emails were sent either to organisations supporting freshwater or estuarine citizen science initiatives or directly to coordinators, as identified through an extensive web search and existing professional networks.

These were the most effective recruitment methods since, at the time of the survey design and implementation, a comprehensive list of known freshwater and estuarine citizen science projects in Australia was not available. The study was also promoted through other channels, including natural resource management email lists and newsletters and through the professional networks of program coordinators. In cases where a coordinator or organisation did not answer the survey request, two rounds of follow-up requests were sent via email at two-week intervals after initial survey deployment. The survey was available online using the software LimeSurvey (LimeSurvey GmbH).

Survey requests were sent to 61 freshwater and estuarine citizen science programs across Australia. Of these, 47 coordinators representing 43 programs from all states and territories in Australia responded to the survey, for a response rate of 77 per cent. It was most common for a program to have one coordinator facilitating monitoring and research activities. However, one program had five dedicated coordinators (four of whom took part in this study) each coordinating activities in separate regions. Another program involved a network of four subprograms located within separate catchment groups.

The survey comprised 38 questions seeking coordinator responses on three categories: (1) general program characteristics, (2) program interactions and partnerships, and (3) program and volunteer contributions to catchment decision-making (Table 1). The program characteristics analysed included monitoring duration, goals, number of volunteers, number of monitored sites, water condition indices collected, geographic focus and training and quality assurance and quality control (QA/QC) protocols. Questions related to interactions and partnerships sought information from coordinators about the organisations and institutions with whom their program interacted in the past year. For the purpose of this study, an interaction was defined as a 'one-off' or ongoing exchange of

Table 1. Survey categories and questions for coordinators of freshwater citizen science programs in Australia.

Survey category	Survey questions
General program characteristics	Monitoring years Goals Number of active volunteers Number of sites monitored in the past year Geographical focus Biological, chemical or physical indicators collected Level of volunteer involvement in monitoring steps Implementation of training, QA/QC protocols
Interactions and partnerships	Program interactions with organisation or institution (federal or state environmental management department, local council non-government organisation (NGO), NRM board or Catchment Management Authority (CMA), other community or citizen science group, TAFE or University, museum or zoo, primary or secondary school, and 'no interactions') Nature of interaction (exchange of ideas or advice, training, collaboration on projects, sharing data and resources or receiving funding) Importance of interactions and partnerships for achieving goals
Contributions to catchment decision-making	Data uptake in decision-making Type(s) of data uptake Perceived influence on decision-making Barriers to data uptake Volunteer participation in decision-making processes Volunteer influence on program operations

ideas or advice, training, collaboration on projects, sharing data and resources or receiving funding. Respondents were asked to name up to three organisations within seven organisational categories and report the importance of these interactions for achieving their program's goals. We limited responses to three organisations per category to reduce survey burden and expected this would capture a majority of their interactions. The final questions assessed the ways in which volunteers influence program design and implementation, and actively participate in decision-making processes.

Data contributions to catchment decision-making were assessed using three measures. First was the assessment of claims of data uptake from coordinator reports as part of the survey. Second, the provision of evidence of data uptake (in the form of documentation, links to web pages etc.) was sought from coordinators. This provided a mechanism to overcome the potential influence of social desirability bias among respondents (Nederhof 1985), which was identified as a methodological issue in a similar study on citizen science uptake in natural resource management (Stepenuck and Genskow 2018). Social desirability is the tendency for respondents to report positively about their program's impacts on decision-making even if no, or tenuous, linkages were achieved. The third measure was an independent web search of program websites and program-specific documentation to investigate additional instances of data uptake. The purpose of this third measure was to (1) cross-validate statements about data use by coordinators that lacked detail or were not supported by any form of documentation and (2) ensure the capture of a comprehensive assessment of the use of volunteer data for water and catchment decision-making. To explore factors important in determining data uptake, we established relationships between the uptake of program data in decision-making (i.e. yes versus no) and (1) number of volunteers per program, (2) number of sites monitored per program, (3) longevity of monitoring and (4) number of organisational interactions. We excluded schools from this assessment because these interactions were not considered important in determining a program's capacity to contribute data to inform decision-making. We did not undertake statistical testing to confirm these relationships as this was an exploratory study, and we lacked adequate statistical power given the limited sample size.

Results

Program activity

Trends in program activity over time were found to differ between Waterwatch Victoria and Upper Murrumbidgee Waterwatch. For Waterwatch Victoria, total records and number of monitoring sites showed an initial increase from program inception in 1993 to 1998, then plateaued for approximately eight years before reaching a peak in 2007 for 10,063 total records and 1571 unique sites monitored across the state (Figure 2a). During the past decade, program activity has declined and, as of 2017, Waterwatch Victoria is operating at approximately 40 per cent of the peak period. In contrast, the Upper Murrumbidgee Waterwatch program had relatively slow uptake in its first ten years of development showing a notable increase in total records and sites monitored after 2006, reaching 1887 total records and 231 sites monitored in 2017 (Figure 2b).

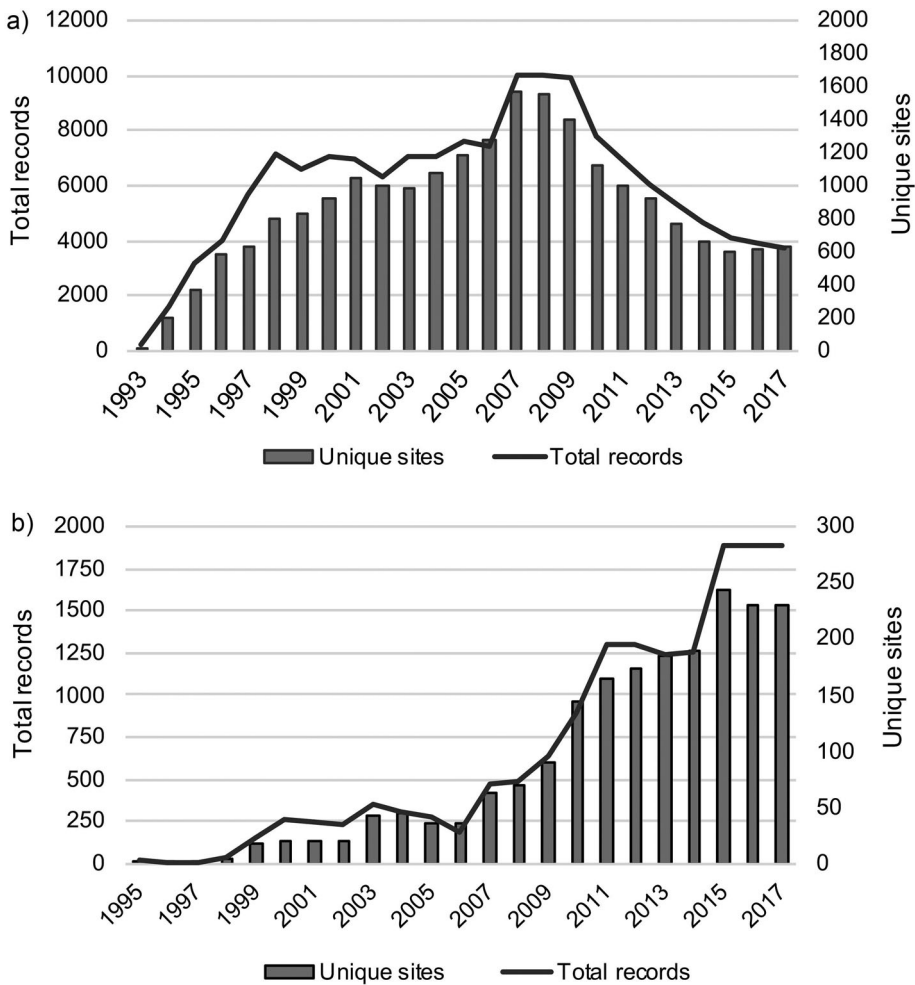


Figure 2. Total number of records and unique sites monitored per year for (a) Waterwatch Victoria and (b) Upper Murrumbidgee Waterwatch since inception.

Survey

Program characteristics

Findings show programs are mainly affiliated with local, regional or state government (51 per cent) and catchment groups and coordinating committees (31 per cent). Approximately 10 per cent were community-led programs and one program emanated from a university. Programs were largely concentrated along the eastern and south-eastern coast of Australia (Figure 3).

Program size varied considerably, with total active volunteers and sites monitored reported to range from 2 to 240 and 1 to 300, respectively. Approximately half of coordinators reported their program had been collecting water condition data for more than 20 years while ten programs (21 per cent) had been in operation for five years or less (Figure 4a). Most programs were focused on monitoring at a local to regional level with no programs operating nationally or internationally at the time of data collection (Figure 4b).

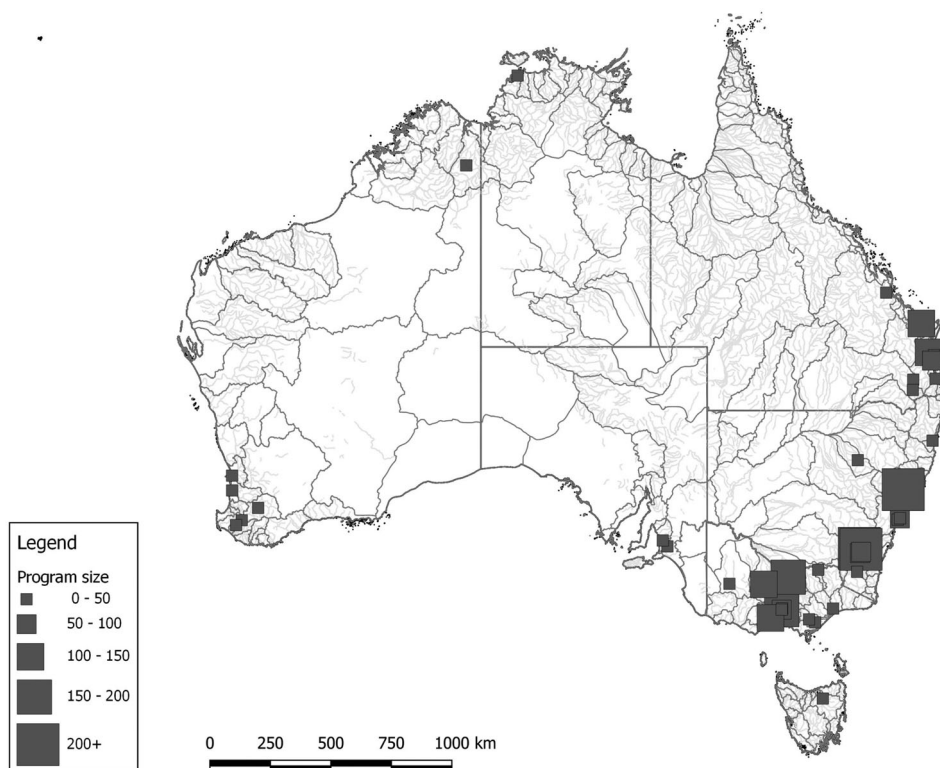


Figure 3. Location and size of programs across Australia by postcode. Size of squares represents the number of sites monitored in 2017.

Many programs monitored more than one type of waterway. Most programs were found to monitor rivers (89 per cent), followed by lakes/reservoirs (53 per cent), wetlands (51 per cent) and estuaries (23 per cent). There were also some reports of programs monitoring groundwater and constructed waterbodies. Coordinators reported data collection for a wide range of water condition indices, with the most common being physicochemical

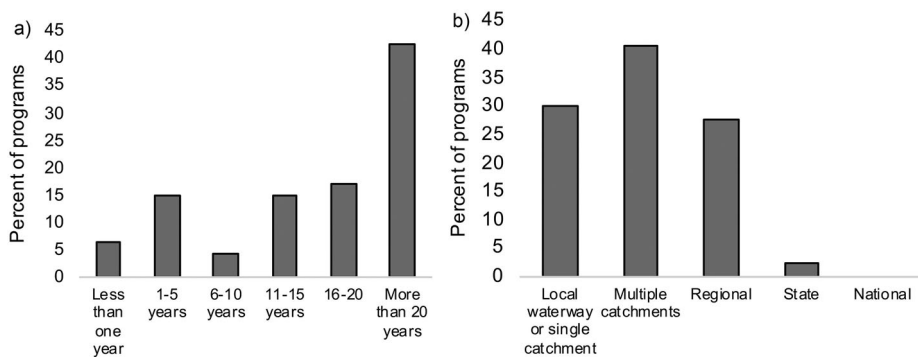


Figure 4. (a) Program longevity and (b) geographic focus of monitoring of freshwater and estuarine citizen science programs in Australia ($n = 47$).

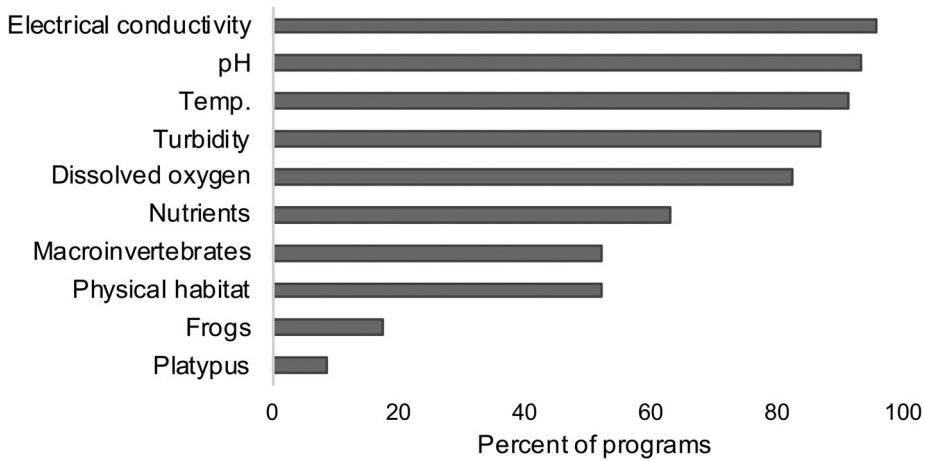


Figure 5. Water condition indices collected by freshwater and estuarine citizen science programs in Australia ($n = 47$).

parameters (Figure 5). Almost half of coordinators reported that their program monitored the physical and riparian habitat (e.g. flow, sediment size or riparian cover) (51 per cent) and macroinvertebrates (51 per cent), while the monitoring of other aquatic taxa (frogs and platypus) was less common.

Program goals

Table 2 shows the priorities of programs, with all but four coordinators reporting multiple goals. A majority of coordinators identified a combination of education and data-related goals. Educating and engaging the community was reported to be the main priority for a majority of programs (87 per cent), followed by goals relating to the collection and use of waterway monitoring data (Table 2). Nineteen coordinators reported their program had priorities to investigate the outcomes of a management effort (40 per cent) while answering a particular research question was reported by just seven programs (15 per cent).

Table 2. Goals of freshwater and estuarine citizen science programs as reported by program coordinators.

Program goals	Number of programs	Percent (%)
To educate and engage the community	41	87.2
To obtain data useful to inform management decisions and policy	33	70.2
To create long-term data sets on a particular waterway	29	61.7
To address a lack of monitoring/waterway data	25	53.1
To monitor a perceived environmental threat (e.g. pollution, impacts of a development)	22	46.8
To investigate the outcome of a restoration or other management efforts	19	40.2
To use monitoring data to obtain funding for natural resource restoration and protection	14	29.8
To answer a research question	7	14.9
To investigate an environmental crisis	4	8.5

Training, data quality assurance and control and monitoring protocols

Many programs had processes in place to ensure the collection and delivery of high-quality data. These included volunteer training (96 per cent) with its frequency varying across programs, from once per year to on a needs basis i.e. as new groups/projects begin. A high proportion of programs were found to implement data quality assurance and quality control procedures (83 per cent) and use of government (or government-endorsed) data collection standards (60 per cent).

Program interactions and partnerships

Table 3 reveals the program interactions and partnerships with other organisations and institutions, including the purposes of these connections. Programs most commonly interacted with primary and secondary schools (81 per cent) followed by local councils (72 per cent), federal and state environment departments (60 per cent) and other community environmental groups or other citizen science programs (60 per cent). Less common interactions were with private companies (32 per cent) and museums and zoos (15 per cent). Three programs reported no interactions. Interaction purposes varied according to organisation type. For example, it was more common for programs to receive funding from federal or state environmental departments than it was for local councils to provide financial support. Moreover, programs exchanged ideas and advice with other community and citizen science groups to greater extents than with government departments.

Table 3. The extent and purposes of organisational interactions and partnerships.

Organisation	n	%	Purpose of interaction (as a percentage of n)				
			Exchange of ideas or advice	Training	Collaboration on projects	Sharing data and resources	Receiving funding
Primary or secondary school	38	80.9	31.6	55.3	34.2	42.1	0
Local council	34	72.3	67.6	17.6	50.0	52.9	23.5
Federal or state environmental management department	28	59.6	53.6	21.4	50.0	60.7	50.0
Other community or citizen science group	28	59.6	76.0	40.0	56.0	44.0	4.0
NRM board or Catchment Management Authority	25	53.2	57.1	17.9	53.6	46.4	32.1
TAFE or University	25	53.2	60.0	40.0	48.0	56.0	12.0
Non-government organisation (NGO)	23	48.9	53.6	25.0	53.6	46.4	3.6
Private organisation or company	15	31.9	47.8	17.4	43.5	39.1	13.0
Museum or zoo	7	14.9	20.0	0	20.0	20.0	0

Types and extent of data uptake

To investigate linkages between community data and decision-making, coordinators were asked questions about their program's contributions to, and perceived influence on, catchment management and policy development. For programs whose coordinator claimed

data-related priorities ($n = 45$), approximately half reported 'some' influence ($n = 23$) on catchment decision-making while 38 per cent reported having 'little' or 'no influence' ($n = 17$). No coordinators reported that their program had 'extensive' influence on catchment decision-making.

Coordinators from 24 programs claimed their program's data was used in catchment decision-making, while approximately 11 program coordinators reported no data uptake and eight coordinators were 'not sure'. After collecting and collating data use instances through documentary analysis and independent web searches, a revised total of 19 programs were found to have verifiable evidence of data uptake. Evidence of data use came in the form of management reports, internal and program-specific reports, policy and planning documents, monitoring frameworks and webpages. There were instances in which positive claims about data uptake were unsubstantiated ($n = 5$), as well as instances in which examples of data use were found for programs whose coordinators reported 'no' or 'not sure' when asked whether their program had achieved data uptake ($n = 5$). One respondent was unwilling to provide evidence of data use even though this program had on a number of occasions identified an environmental problem that was raised with stakeholders for resolution. Their reasoning was that it was not appropriate to publicise examples as it would undermine the 'pro-active, non-regulatory approach' undertaken by the organisation.

Instances of data uptake were categorised according to a typical adaptive management framework, with findings as follows: (1) strategy and planning (9 per cent of total programs with data-related priorities), (2) monitoring and implementation (27 per cent) and (3) reporting and evaluation (24 per cent) (Table 4, for full list see Supplemental Table 1.). In the evaluation and reporting category, volunteer data were used for resource condition reporting, impact evaluations against policy targets and annual reporting of management activities. Data uptake for monitoring and implementation related to the testing of assumptions and resource condition change due to external influences. Several examples were reported where findings from program investigations triggered action by authorities e.g. pollution impacts. Data uptake in strategy, planning and policy development was least common.

Factors influencing data impacts on decision-making

To understand which factors might influence the uptake of program data in decision-making, we explored the relationship between program data uptake and four factors: (1) volunteer numbers, (2) sites monitored, (3) program longevity and (4) extent of partnerships and organisational/institutional interactions. Our findings reveal that, generally, programs with greater numbers of volunteers and sites monitored have delivered more impacts on catchment decision-making than smaller programs (Figure 6a, b). Additionally, program longevity appears to be important in determining whether a program has achieved data uptake (Figure 6c). Of the 20 programs that have been in operation for more than 20 years, 80 per cent ($n = 16$) have achieved some form of data use in catchment decision-making compared to only one in nine programs (11 per cent) that have been in operation for less than five years. Finally, programs with a greater number of interactions were more likely to achieve data uptake than those programs with fewer interactions (Figure 6d).

Table 4. Data use by freshwater and estuarine citizen science programs in Australia and applications in catchment decision-making.

Data use category	Elaboration	Percent of programs (<i>n</i> = 45)	Examples of documented cases
Strategy and planning	<ul style="list-style-type: none"> Regional planning Project/program planning Policy development 	8.8% (<i>n</i> = 4)	<p>ACT Waterwatch (incorporating data from four subprograms) integrated citizen science data with government monitoring frameworks within the ACT Government's Environment Division for the Biodiversity, Research and Monitoring Program, the Conservation Effectiveness Monitoring Program and the ACT Integrated Water Monitoring Plan.</p> <p>Data from Waterwatch Manningham City Council used data collected across 20 sites in seven catchments to shape water policy including A Cleaner Yarra River and Port Phillip Bay Action Plan, Manningham Water Cycle Management Plan and Generation 2030.</p> <p>Platypus management plan used volunteer-collected data from the Melbourne Water Waterwatch program through an eDNA approach.</p>
Monitoring and implementation	<ul style="list-style-type: none"> Monitoring and research to test assumptions Monitoring condition change and external influences 	26.6% (<i>n</i> = 12)	<p>Use of data in a targeted monitoring program by Waterwatch South Australia Murray-Darling Basin investigating the effectiveness of Water Sensitive Urban Design (WSUD) infrastructure.</p> <p>Data collected by volunteers from Melbourne Water Waterwatch program on water quality in drought refuges important for the preservation of a vulnerable fish species, triggering emergency watering actions as dissolved oxygen levels in refuges reached critical levels.</p> <p>Waterwatch Goulburn-Broken Region undertook an intensive program of water quality monitoring in the Murray River upstream and downstream of the Barmah Forest to record the potential impact of management activities from the Barmah Forest floodplain.</p> <p>Volunteers measuring estuarine salinity levels and tracking mouth condition to inform estuary closure management.</p> <p>Measurement of environmental flow effects by Melbourne Water Waterwatch program influenced management actions to reduce public health risks following extensive blue-green bloom in a Victorian river.</p> <p>A citizen science project conducted by FrogWatch investigated the relationship between frog species and habitat relationships in urban and peri-urban wetlands used data collected by hundreds of citizen scientists collected over more than ten years.</p>
Reporting and evaluation	<ul style="list-style-type: none"> Resource condition reporting Impact evaluation against targets Annual reporting of management activities 	24.4% (<i>n</i> = 11)	<p>Multiple programs prepare water quality information reports that detail catchment condition across a region commonly through a report card system.</p> <p>User of volunteer data in regional government annual reports.</p> <p>North Central Waterwatch used citizen science data to establish water quality trends to track the success of policy to improve fish numbers and habitat quality.</p> <p>Citizen science data from multiple Waterwatch Victoria subprograms has been used to supplement monitoring information for state of environment reporting such as Argent (2017), Index of Stream Condition (Ladson et al. 1999), Index of Estuary Condition and the Yarra and Bay (2019).</p>

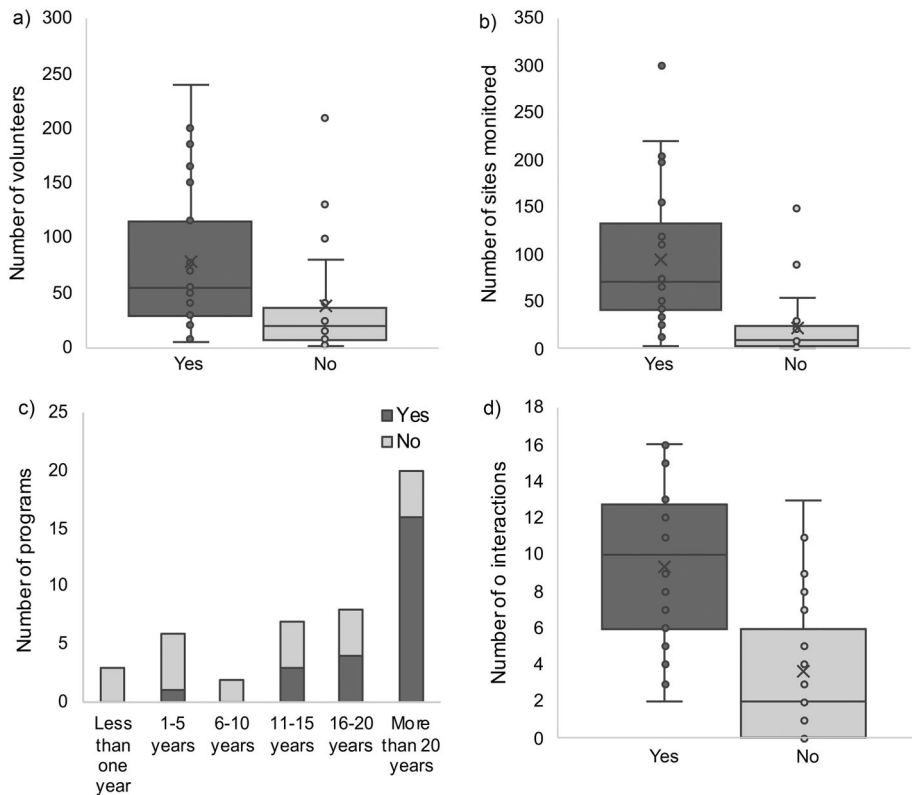


Figure 6. The relationship between the uptake of program data in decision-making (i.e. yes versus no) and (a) number of volunteers per program, (b) number of sites monitored per program, (c) longevity of monitoring and (d) number of organisational interactions.

Barriers to uptake

Of the 29 coordinators who reported the presence of barriers to data uptake, the most common comment was about the presence of funding and financial constraints and difficulties connecting and coordinating with decision-makers, followed by a lack of interest by decision-makers in volunteer-collected data (78 per cent) (Figure 7). Data quality aspects of the programs that may limit uptake, such as accuracy, frequency of sampling and management procedures were lower level concerns. Many coordinators (46 per cent) claimed that their data are viewed 'somewhat receptively' by decision-makers, eight (17 per cent) indicated that decision-makers were 'very receptive' towards their data, and 37 per cent responded with 'neutral' or 'somewhat sceptical'. However, one coordinator cited an example of funding restrictions for their monitoring program due to a perceived lack of value of volunteer-collected data by the funding body.

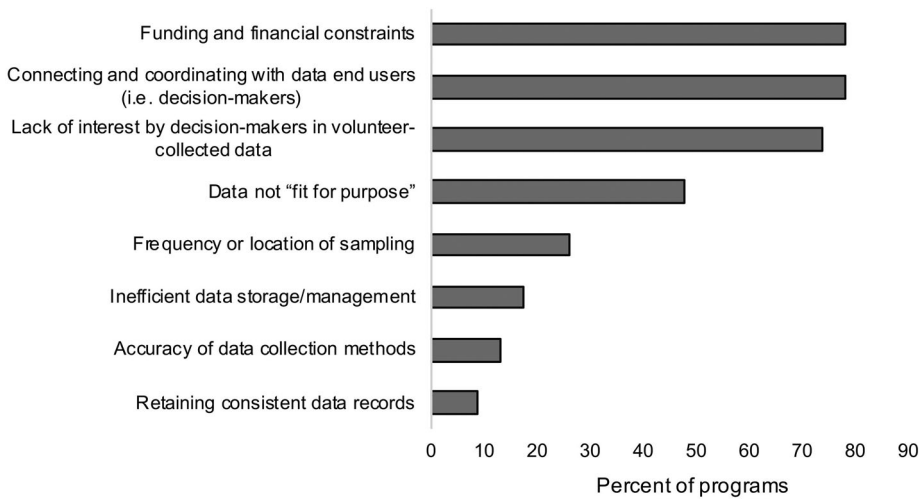


Figure 7. Barriers to data uptake as reported by program coordinators ($n = 29$).

Volunteer impact and influence on program operations and participation in decision-making

All programs involved volunteers in data collection, with site selection and data management a feature for more than half of programs (Figure 8). Participation in other aspects of the research process was less common. Approximately 18 per cent of programs involved volunteers in developing research questions and 26 per cent participated in data analysis. Only three coordinators reported that volunteers in their program were involved in all steps of the research process from developing research questions, collecting data to analysing and dissemination of monitoring results.

The active involvement of volunteers in program operation and catchment decision-making was reported by coordinators in two open-ended questions; they offered the following examples:

- volunteers’ local knowledge was important in the selection of safe, accessible and/or scientifically relevant monitoring sites (23 of 47 programs);

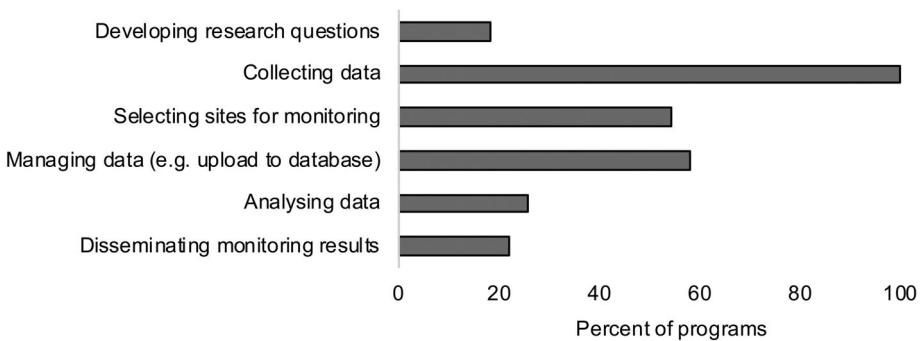


Figure 8. Extent of volunteer participation in the research/monitoring process.

- volunteers have prompted investigation by raising concerns about local environmental issues, including logging coupes, septic leaks, pollution and excessive sediment impacts (5 of 47 programs);
- the presence of volunteers on advisory committees, working groups and leading community engagement initiatives (7 of 47 programs);
- instances of volunteers contacting environmental regulatory agencies, local council or water management authorities about their concerns (8 of 47 programs);
- one case involving a volunteer lobbying government for more funding for the monitoring program to continue and be able to disseminate results to the rest of the community.

Discussion

This broad review of citizen science projects conducting research and monitoring in Australia's waterways finds a diversity of projects operating nationwide. Despite this, evidence suggests a contraction in the size and scale of activities over the past decade. This claim is substantiated by analysis of program data records which revealed a steady decline in monitoring effort in Victoria since 2008. While the same analysis found monitoring effort in ACT to be increasing, the claim of a nationwide contraction is furthermore supported by previous reports on the extent of community-based monitoring activities that highlighted strong rates of volunteer participation in monitoring a large number of sites across Australia (Thomson 2007). This finding contrasts with studies in the United States and Canada where similar activities have increased in recent years (Carlson and Cohen 2018; Jalbert, Kinchy, and Perry 2014; Stepenuck and Genskow 2017). The decline in program extent in Victoria appears to coincide with changes to federal funding, which has put pressure on the delivery of regionally-administered community-based programs (Robins and Kanowski 2011). This is a particular challenge for water-based citizen science projects whose activities are usually centred on the long-term collection of water condition data, which conflicts with governments having a short-term focus for community-based programs.

While programs differed considerably in their size and scope, a number of consistent characteristics were found in a majority of programs. First, many are affiliated with government environmental agencies and catchment committees with an expanded network of interactions and partnership with other organisations, including schools, universities, and local councils, among others. Second, volunteers are primarily involved in the long-term collection of water condition data, particularly physicochemical and biological indicators in lakes, rivers, wetlands and some artificial waterbodies, such as storm water drains and irrigation channels. Third, many programs display considerable longevity with over half of programs collecting data in waterways for more than 15 years. Finally, over two-thirds of the programs surveyed had goals of informing catchment management and policy in addition to the educative priorities that have long formed their primary remit. We uncovered few programs that emanated from universities, aimed to advance ecological research or that were entirely educational. Instead, the predominant model of freshwater and estuarine citizen science has not deviated substantially from the foundational principles and practices in early initiatives.

Perhaps the most significant development in freshwater and estuarine citizen science in Australia has been the increased attention towards integrating volunteer data within

catchment decision-making. Despite this, less than half of programs with data-related priorities have experienced uptake of their data. Where it existed, data use for reporting and evaluation of resource condition and the investigation of management efforts was the most common form. Programs have developed 'report cards' detailing baseline water quality or catchment condition (e.g. Bunn et al. 2010). Report cards provide a valuable communication tool about the status of water quality for future decision-making, but it is often unclear how they are subsequently used to inform 'on-the-ground' management practices or shape policy (Stem et al. 2005). More tangible links with decision-making were revealed in instances where programs triggered action, such as emergency watering of drought refuges, and local investigations of management efforts and external environmental influences. Engaging monitoring groups in place-based projects with clear aims and outcomes builds on the strong volunteer interest in the management decisions that affect local areas (Newman et al. 2017). It was far less common for programs to contribute data for strategy planning and policy development. Some examples showed volunteer data being integrated within government monitoring frameworks and being used to shape various environmental policies and underpin species management plans. In these cases, volunteer data were mostly used as a supplementary, rather than standalone, data source at a regional to state scale. The lower levels of data uptake for strategy planning and policy development could be related to recent evidence that suggested volunteer data is viewed less receptively for policy decisions than for natural resource management decisions, due to the perceived risks associated with relying on volunteer data for large-scale or long-term policy decisions (Stepenuck and Genskow 2018).

Data uptake was found to be most common in larger projects, which have monitored water environments for a longer period of time and have developed a broad network of interactions and partnerships with other organisations. Larger, long-term projects may have more resources, extensive datasets and time to develop productive connections that improve their capacity to make positive impacts on decision-making. We did not consider other factors known to be important in delivering positive impacts on decision-making, such as program objectives, level of financial support, data quality assurance plans and level of volunteer participation in the research process (Stepenuck and Genskow 2018). We suggest continued investigation into the factors that enable citizen science contributions to catchment decision-making as a critical avenue of future research. Such investigations are likely to benefit from in-depth studies using qualitative methods that engage with a wider breadth of actors in citizen science networks.

Our study provides evidence that volunteers participate actively in water management issues by, for example, raising environmental concerns with local agencies, participating on advisory committees and lobbying government for additional funding. These examples of civic engagement were reported by coordinators, and opportunities to elicit information and experiences directly from volunteers should be pursued in future research. Further, this study is unable to provide clarity on the mechanisms related to this civic engagement and whether they are directly caused by participation in citizen science. Nevertheless, these emerging indicators are important to furthering discussion about the extent to which citizen science promotes active engagement in environmental decision-making and strengthens relationships, which remains a key question for public participation advocates. This is particularly crucial since water policy in Australia specifies community engagement in water management and policy processes as a key priority (e.g. ACT Government 2014; DEPI 2013).

Enhancing linkages between citizen science and decision-making

The goals, characteristics and strong associations with NRM organisations shared by many freshwater and estuarine citizen science projects highlight their potential for productive linkages with water management and policy. While this study has provided evidence to suggest some programs are making positive impacts, the extent of data uptake remains limited relative to the duration of community-based water monitoring and citizen science activities in Australia. This has been recognised as an issue for similar programs in other parts of the world and suggests that significant barriers limit data uptake for programs in Australia (Chapman and Hodges 2016). Respondents in this study identified difficulties connecting and coordinating with data end users and funding and resource constraints as the two main barriers to data uptake. Moreover, a lack of interest in volunteer-collected data was rated a significant barrier, suggesting continued hesitation in the use of citizen science in decision-making processes. This result is supported by over a third of coordinators indicating decision-makers were neutral or somewhat sceptical of citizen science data. The presence of strategies to assure high data quality in a majority of programs, and coordinators considering data accuracy as a relatively low-level concern, both suggest that social and institutional factors impeding the uptake of citizen science are just as relevant as scientific or technical barriers.

Based on these findings and building on insights in the citizen science literature, we propose three recommendations to enhance linkages between freshwater and estuarine citizen science and catchment decision-making: (1) increasing long-term institutional support; (2) improving coordination and embracing new possibilities for collaboration, and (3) demonstrating and communicating program achievements.

First, the strong rates of participation in community-based monitoring and citizen science activities demonstrate a willingness by communities to act as stewards for their local areas but their efforts require adequate resourcing and supportive institutional cultures. Community-based programs in Australia have historically been challenged to undertake their work in the face of short-term funding arrangements, with an expectation to expend additional efforts to acquire further sources of funding (Ross, Buchy, and Proctor 2002). Program stability is therefore critical for project success and the satisfaction and empowerment of participants. As citizen science becomes increasingly accepted and institutionalised, the challenge will be how to maximise its contributions to decision-making while maintaining the diverse and distinctive benefits afforded to participants who often contribute large amounts of time and resources.

In Europe and the United States, the emergence of policies and strategies to facilitate citizen science contributions are examples of significant developments in the effort to build more supportive institutions (Shanley et al. 2019). For example, the USA's *Crowdsourcing and Citizen Science Act 2016* (15 USC 3724) is recent legislation that provides clarity to decision-makers about whether an agency can use citizen science for its work (Guerrini et al. 2018). Similar developments are nascent in Australia and will be necessary steps if citizen science is to reach its full potential for policy. Some positive signs in this area include a recent citizen science funding initiative established by the Australian government's Inspiring Australia Science Engagement Programme (Ministers for the Department of Industry, Innovation and Science 2017). While the projects emerging from these new initiatives are encouraging, government departments should also maintain

commitment to pre-existing freshwater and estuarine citizen science programs since they already comprise high stocks of human and social capital.

Second, our findings indicate that more effective coordination is needed between existing citizen science projects and decision-makers. Similar issues have been highlighted by other researchers who have consistently recommended communication between programs and decision-makers at early stages of project development to ensure data are collected within, rather than apart from, the decision-making frameworks (Aceves-Bueno, Adeleye, and Bradley 2015; Chapman and Hodges 2016). This recommendation acknowledges the limitations of a 'linear or technocratic model of communication' and recognises that contemporary decision-making is a complex, multidimensional and social process (Young et al. 2014, 387). Improving coordination between citizen science projects and decision-makers requires clear articulation of the roles and responsibilities of all participants, sensitivity to stakeholder interests and motivations, the development of a shared vision with realistic expectations (McKinley et al. 2016; Tulloch et al. 2013; Weston and Conrad 2015). Further, this requires willingness on the part of policy makers to work collaboratively with new and existing citizen science projects (Conrad and Daoust 2008).

Furthermore, we echo calls for programs to improve collaboration by experimenting with new forms of participation (e.g. Hecker et al. 2018). This study found that few programs enlisted volunteers in all phases of the research process, from devising research questions, to collecting data and interpreting and disseminating results. One possibility to increase volunteer engagement is to undertake activities under the principles of 'co-created' citizen science (Shirk et al. 2012). Co-creation brings together scientists, decision-makers and community in a 'bottom-up', collaborative arrangement throughout the entire research or monitoring process, which can improve the social relevance of research efforts, strengthen relationships between stakeholders and may lead to stronger policy (Chapman and Hodges 2016; Hecker et al. 2018). Despite having potential for greater depth of engagement, particularly for small, local catchment groups (Wilderman and Monismith 2016), practitioners should be aware that well-conceived and well-designed co-created citizen science can be time consuming, require significant levels of trust and can be difficult to implement if engaging with large numbers of participants (Chapman and Hodges 2016).

Finally, demonstrating and communicating program achievements should be integrated into program development to justify funding, attract additional resources, promote the development of new partnerships and reinforce the value of existing ones. This should also involve communicating how data were collected and the quality assurance and control procedures that promote confidence in the data. Furthermore, research suggests volunteer motivation is enhanced when they see that their efforts are valued by researchers, NRM bodies and private industry (Alender 2016), thereby increasing the stability of the program into the future. Instances of data uptake reported in this study are not likely to be a comprehensive list due to an underreporting by coordinators and a lack of documentation of all data contributions. It is also possible that when data are used for catchment decision-making, program coordinators and volunteers may not be aware of this use (Carlson and Cohen 2018). Therefore, the communication of data contributions, and program achievements more broadly, is critical and requires a two-way knowledge exchange between programs (including volunteers) and decision-makers (Jacoby et al. 1997).

Conclusion

With support for citizen science increasing in Australia, the present study responds to calls for increased understanding about the position and influence of citizen science in catchment and water resource management (Conrad and Hilchey 2011; Stepenuck and Green 2015). We find that freshwater and estuarine citizen science in Australia is primarily a community capacity-building initiative with widespread potential for integration in government monitoring and community engagement policy frameworks. Our evidence shows citizen science data has been used for catchment decision-making, particularly for short term investigations and reporting on resource condition. Yet, program coordinators reported significant barriers that limit increased data uptake, which were largely social and organisational in nature rather than scientific and technical. We recommend that to improve the standing of citizen science in the context of water resource management, practitioners will benefit from focusing on the processes underpinning environmental decision-making, including coordinating activities to meet the data requirements of decision-makers, embracing new modes of collaboration i.e. co-creation, maintaining and furthering the development of partnerships with supportive organisations and institutions and demonstrating and communicating program achievements. By shedding light on the characteristics and contributions of programs monitoring water environments, we highlight the possibilities of citizen science as a meaningful and effective participatory approach to lessen the chasm between environmental management and the public.

Note

1. Waterwatch is the main focus in this historical account due to a lack of documentation of other past and current freshwater citizen science programs in Australia.

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References

- Aceves-Bueno, E., A. S. Adeleye, and D. A. Bradley. 2015. "Citizen Science as an Approach for Overcoming Insufficient Monitoring and Inadequate Stakeholder Buy-in in Adaptive Management: Criteria and Evidence." *Ecosystems* 18 (3): 493–506. doi:10.1007/s10021-015-9842-4.
- ACT Government. 2014. *ACT Water Strategy 2014-44: Striking the Balance*. Canberra: Environment and Planning Directorate, ACT Government.
- Alender, B. 2016. "Understanding Volunteer Motivations to Participate in Citizen Science Projects: A Deeper Look at Water Quality Monitoring." *Journal of Science Communication* 15 (3): 1–19.
- Argent, R. M. 2017. *Australia State of the Environment 2016: Inland Water*. Independent report to the Australian Government Minister for the Environment and Energy. Canberra: Australian Government Department of the Environment and Energy.
- Ballard, H. L., L. D. Robinson, A. N. Young, G. B. Pauly, L. M. Higgins, R. F. Johnson, and J. C. Tweddle. 2017. "Contributions to Conservation Outcomes by Natural History Museum-led Citizen Science: Examining Evidence and Next Steps." *Biological Conservation* 208: 87–97. doi:10.1016/j.biocon.2016.08.040.
- Bonney, R., C. B. Cooper, J. Dickinson, S. Kelling, T. Phillips, K. V. Rosenberg, and J. Shirk. 2009. "Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy." *BioScience* 59 (11): 977–984. doi:10.1525/bio.2009.59.11.9.
- Bonney, R., T. B. Phillips, H. L. Ballard, and J. W. Enck. 2016. "Can Citizen Science Enhance Public Understanding of Science?" *Public Understanding of Science* 25 (1): 2–16. doi:10.1525/bio.2009.59.11.9.
- Buckland-Nicks, A., H. Castleden, and C. Conrad. 2016. "Aligning Community-based Water Monitoring Program Designs with Goals for Enhanced Environmental Management." *Journal of Science Communication* 15 (3): 1–23.
- Bunn, S. E., E. G. Abal, M. J. Smith, S. C. Choy, C. S. Fellows, B. D. Harch, M. J. Kennard, and F. Sheldon. 2010. "Integration of Science and Monitoring of River Ecosystem Health to Guide Investments in Catchment Protection and Rehabilitation." *Freshwater Biology* 55: 223–240. doi:10.1111/j.1365-2427.2009.02375.x.
- Buytaert, W., Z. Zulkafli, S. Grainger, L. Acosta, T. C. Alemie, and J. A. Bastiaensen. 2014. "Citizen Science in Hydrology and Water Resources: Opportunities for Knowledge Generation, Ecosystem Service Management, and Sustainable Development." *Frontiers in Earth Science* 2: 1–21. doi:10.3389/feart.2014.00026.
- Carlson, T., and A. Cohen. 2018. "Linking Community-based Monitoring to Water Policy: Perceptions of Citizen Scientists." *Journal of Environmental Management* 219: 168–177. doi:10.1016/j.jenvman.2018.04.077.
- Carr, A. 2002. *Grass Roots and Green Tape: Principles and Practices of Environmental Stewardship*. Sydney: Federation Press.
- Carr, A. 2004. "Why Do We All Need Community Science?" *Society and Natural Resources* 17 (9): 841–849.
- Carr, G. 2015. "Stakeholder and Public Participation in River Basin Management: An Introduction." *Wiley Interdisciplinary Reviews: Water* 2 (4): 393–405. doi:10.1002/wat2.1086.
- Chapman, C., and C. Hodges. 2016. "Can Citizen Science Seriously Contribute to Policy Development?" In *Analyzing the Role of Citizen Science in Modern Research*, edited by L. Ceccaroni and J. Piera, 246–261. Hershey, PA: IGI Global.
- Conrad, C. T., and T. Daoust. 2008. "Community-based Monitoring Frameworks: Increasing the Effectiveness of Environmental Stewardship." *Environmental Management* 41 (3): 358–366. doi:10.1007/s00267-007-9042-x.
- Conrad, C. C., and K. G. Hilchey. 2011. "A Review of Citizen Science and Community-based Environmental Monitoring: Issues and Opportunities." *Environmental Monitoring and Assessment* 176: 273–291. doi:10.1007/s10661-010-1582-5.
- Cooper, C. B., J. Dickinson, T. Phillips, and R. Bonney. 2007. "Citizen Science as a Tool for Conservation in Residential Ecosystems." *Ecology and Society* 12 (2).

- Curtis, A., H. Ross, G. R. Marshall, C. Baldwin, J. Cavaye, C. Freeman, A. Carr, and G. J. Syme. 2014. "The Great Experiment with Devolved NRM Governance: Lessons from Community Engagement in Australia and New Zealand since the 1980s." *Australasian Journal of Environmental Management* 21 (2): 175–199. doi:10.1080/14486563.2014.935747.
- Dean, A., K. Fielding, F. Newton, and H. Ross. 2016. *Community Engagement in the Water Sector: An Outcome-focused Review of Different Engagement Approaches*. Melbourne: Cooperative Research Centre for Water Sensitive Cities.
- DEPI (Department of Environment and Primary Industries). 2013. *An Overview of the Victorian Waterway Management Strategy*. Melbourne: Department of Environmental and Primary Industries, Victorian Government.
- Deutsch, W. G., and S. Ruiz-Cordova. 2015. "Trends, Challenges, and Responses of a 20-Year, Volunteer Water Monitoring Program in Alabama." *Ecology and Society* 20 (3): 14. doi:10.5751/ES-07578-200314.
- Dickinson, J. L., J. Shirk, D. Bonter, R. Bonney, R. L. Crain, J. Martin, T. Phillips, and K. Purcell. 2012. "The Current State of Citizen Science as a Tool for Ecological Research and Public Engagement." *Frontiers in Ecology and the Environment* 10 (6): 291–297. doi:10.1890/110236.
- Finlayson, C. M., and D. S. Mitchell. 1999. "Australian Wetlands: The Monitoring Challenge." *Wetlands Ecology and Management* 7: 105–112.
- Fore, L. S., K. Paulsen, and K. O'Laughlin. 2001. "Assessing the Performance of Volunteers in Monitoring Streams." *Freshwater Biology* 46 (1): 109–123. doi:10.1046/j.1365-2427.2001.00640.x.
- Gooch, M. 2004. "Volunteering in Catchment Management Groups: Empowering the Volunteer." *Australian Geographer* 35 (2): 193–208.
- Guerrini, C. J., M. A. Majumder, M. J. Lewellyn, and A. L. McGuire. 2018. "Citizen Science, Public Policy." *Science* 361: 134–136.
- Hardie, R., S. Tilleard, and A. Wealands. 2009. *Waterwatch Victoria: A Strategic Review of Future Directions*. Melbourne: Alluvium for Department of Sustainability and Environment.
- Haywood, B. K. 2016. "Beyond Data Points and Research Contributions: The Personal Meaning and Value Associated with Public Participation in Scientific Research." *International Journal of Science Education, Part B* 6 (3): 239–262. doi:10.1080/21548455.2015.1043659.
- Hecker, S., R. Bonney, M. Haklay, F. Hlker, H. Hofer, C. Goebel, M. Gold, et al. 2018. "Innovation in Citizen Science – Perspectives on Science-policy Advances." *Citizen Science: Theory and Practice* 3 (1): 1–14. doi:10.5334/cstp.114.
- Hyder, K., B. Townhill, L. G. Anderson, J. Delany, and J. K. Pinnegar. 2015. "Can Citizen Science Contribute to the Evidence-base That Underpins Marine Policy?" *Marine Policy* 59: 112–120. doi:10.1016/j.marpol.2015.04.022.
- Irwin, A. 1995. *Citizen Science: A Study of People, Expertise and Sustainable Development*. London: Routledge.
- Jacoby, C., C. Manning, S. Fritz, and L. Rose. 1997. "Three Recent Initiatives for Monitoring of Australian Coasts by the Community." *Ocean and Coastal Management* 36: 205–226. doi:10.1016/S0964-5691(97)00002-1.
- Jalbert, K., A. J. Kinchy, and S. L. Perry. 2014. "Civil Society Research and Marcellus Shale Natural Gas Development: Results of a Survey of Volunteer Water Monitoring Organizations." *Journal of Environmental Studies and Sciences* 4 (1): 78–86. doi:10.1007/s13412-013-0155-7.
- Kinchy, A. J., K. Jalbert, and J. Lyons. 2014. "What Is Volunteer Water Monitoring Good For? Fracking and the Plural Logics of Participatory Science." In *Fields of Knowledge: Science, Politics and Publics in the Neoliberal Age*, edited by S. Frickel and D. J. Hess, 259–289. Bingley: Emerald Group.
- Ladson, A. R., L. J. White, J. A. Doolan, B. L. Finlayson, B. T. Hart, P. S. Lake, and J. W. Tilleard. 1999. "Development and Testing of an Index of Stream Condition for Waterway Management in Australia." *Freshwater Biology* 41: 453–468. doi:10.1046/j.1365-2427.1999.00442.x.
- Limesurvey GmbH. *Limesurvey: An Open Source Survey Tool*. Hamburg: LimeSurvey GmbH. <http://www.limesurvey.org>.
- McKinley, D. C., A. J. Miller-Rushing, H. L. Ballard, R. Bonney, H. Brown, S. C. Cook-Patton, D. M. Evans, et al. 2016. "Citizen Science Can Improve Conservation Science, Natural Resource

- Management, and Environmental Protection.” *Biological Conservation* 208 (19): 15–28. doi:10.1016/j.biocon.2016.05.015.
- Ministers for the Department of Industry, Innovation and Science. 2017. “\$4.4 m to Mobilise Australia’s Citizen Scientists.” Canberra: Media Release, Minister of Sinodinos, 25 May, viewed 14 January 2020.
- Nascimento, S., J. M. Rubio Iglesias, R. Owen, S. Schade, and L. Shanley. 2018. “Citizen Science for Policy Formulation and Implementation.” In *Citizen Science: Innovation in Open Science, Society and Policy*, edited by S. Hecker, M. Haklay, A. Bowser, Z. Makuch, J. Vogel, and A. Bonn, 219–240. London: UCL Press.
- Nederhof, A. J. 1985. “Methods of Coping with Social Desirability Bias: A Review.” *European Journal of Social Psychology* 15 (3): 263–280.
- Newman, G., M. Chandler, M. Clyde, B. McCreavy, M. Haklay, H. Ballard, S. Gray, et al. 2017. “Leveraging the Power of Place in Citizen Science for Effective Conservation Decision Making.” *Biological Conservation* 208: 55–64. doi:10.1016/j.biocon.2016.07.019.
- Newman, G., A. Wiggins, A. Crall, E. Graham, S. Newman, and K. Crowston. 2012. “The Future of Citizen Science: Emerging Technologies and Shifting Paradigms.” *Frontiers in Ecology and the Environment* 10 (6): 298–304. doi:10.1890/110294.
- Nicholson, E., J. Ryan, and D. Hodgkins. 2002. “Community Data: Where Does the Value Lie? Assessing Confidence Limits of Community Collected Water Quality Data.” *Water Science and Technology* 45 (11): 193–200.
- Pecl, G. T., C. Gillies, C. D. Sbrocchi, and P. Roetman. 2015. *Building Australia through Citizen Science*. Canberra: Office of the Chief Scientist, Australian Government.
- Pfeffer, M., and L. Wagenet. 2007. “Volunteer Environmental Monitoring, Knowledge Creation and Citizen-scientist Interaction.” In *The Sage Handbook of Environment and Society*, edited by J. Pretty, A. Ball, T. Benton, J. Guivant, D. R. Lee, D. Orr, M. Pfeffer, and H. Ward, 235–249. London: Sage.
- Pocock, M. J. O., J. C. Tweddle, J. Savage, L. D. Robinson, and H. E. Roy. 2017. “The Diversity and Evolution of Ecological and Environmental Citizen Science.” *PLOS One* 12 (4), doi:10.1371/journal.pone.0172579.
- Reed, M. S. 2008. “Stakeholder Participation for Environmental Management: A Literature Review.” *Biological Conservation* 141 (10): 2417–2431. doi:10.1016/j.biocon.2008.07.014.
- Robins, L., and P. Kanowski. 2011. “‘Crying for Our Country’: Eight Ways in Which ‘Caring for our Country’ Has Undermined Australia’s Regional Model for Natural Resource Management.” *Australasian Journal of Environmental Management* 18 (2): 88–108. doi:10.1080/14486563.2011.566158.
- Ross, H., M. Buchy, and W. Proctor. 2002. “Laying Down the Ladder: A Typology of Public Participation in Australian Natural Resource Management.” *Australian Journal of Environmental Management* 35 (2): 216–224. doi:10.1080/14486563.2002.10648561.
- Shanley, L. A., A. Parker, S. Schade, and A. Bonn. 2019. “Policy Perspectives on Citizen Science and Crowdsourcing.” *Citizen Science: Theory and Practice* 4 (1): 1–5. <https://doi.org/10.5334/cstp.293>.
- Shirk, J. L., H. L. Ballard, C. C. Wilderman, T. Phillips, A. Wiggins, R. Jordan, E. McCallie, et al. 2012. “Public Participation in Scientific Research: A Framework for Deliberate Design.” *Ecology and Society* 17 (2): 29. doi:10.5751/ES-04705-170229.
- Stem, C., R. Margoluis, N. Salafsky, and M. Brown. 2005. “Monitoring and Evaluation in Conservation: A Review of Trends and Approaches.” *Conservation Biology* 19 (2): 295–309.
- Stepenuck, K. F., and K. D. Genskow. 2017. “Characterizing the Breadth and Depth of Volunteer Water Monitoring Programs in the United States.” *Environmental Management* 61 (1): 46–57. doi:10.1007/s00267-017-0956-7.
- Stepenuck, K. F., and K. D. Genskow. 2018. “Traits of Volunteer Water Monitoring Programs that Influence Natural Resource Management and Policy Impacts.” *Society and Natural Resources*, 1–6. doi:10.1080/08941920.2018.1511022.

- Stepenuck, K. F., and L. T. Green. 2015. "Individual- and Community-level Impacts of Volunteer Environmental Monitoring: A Synthesis of Peer-reviewed Literature." *Ecology and Society* 20 (3), doi:10.5751/ES-07329-200319.
- Storey, R. G., A. Wright-Stow, E. Kin, R. J. Davies-Colley, and R. Stott. 2016. "Volunteer Stream Monitoring: Do the Data Quality and Monitoring Experience Support Increased Community Involvement in Freshwater Decision Making?" *Ecology and Society* 21 (4). doi:10.5751/ES-08934-210432.
- Thomsen, D. C. 2008. "Community-based Research: Facilitating Sustainability Learning." *Australasian Journal of Environmental Management* 15 (4): 222–230. doi:10.1080/14486563.2008.9725206.
- Thomson, D. 2007. "Waterwatch – An Integrated Capacity Building Initiative." Proceedings of the 5th Australian Stream Management Conference. Australian Rivers: Making a Difference. Charles Sturt University, Thurgooona, New South Wales.
- Tulloch, A. I. T., H. P. Possingham, L. N. Joseph, J. Szabo, and T. G. Martin. 2013. "Realising the Full Potential of Citizen Science Monitoring Programs." *Biological Conservation* 165: 128–138. doi:10.1016/j.biocon.2013.05.025.
- Turrini, T., D. Drler, A. Richter, F. Heigl, and A. Bonn. 2018. "The Threefold Potential of Environmental Citizen Science – Generating Knowledge, Creating Learning Opportunities and Enabling Civic Participation." *Biological Conservation* 225: 176–186. doi:10.1016/j.biocon.2018.03.024.
- Waterwatch Victoria. 2000. *Waterwatch Victoria: Moving Into the Mainstream 2000+*. Victoria: Waterwatch Victoria.
- Weston, S., and C. Conrad. 2015. "Community-based Water Monitoring in Nova Scotia: Solutions for Sustainable Watershed Management." *Environment and Natural Resources Research* 5 (2): 1–13. doi:10.5539/enrr.v5n2p1.
- Wilderman, C. C., and J. Monismith. 2016. "Monitoring Marcellus: A Case Study of a Collaborative Volunteer Monitoring Project to Document the Impact of Unconventional Shale Gas Extraction on Small Streams." *Citizen Science: Theory and Practice* 1 (1): 1–17. doi:10.5334/cstp.20.
- Wilson, P. D. 2002. "Community-based Research: Science Conducted as if People Really Matter." In *A Clash of Paradigms: Community and Research-based Conservation*, edited by D. Lunney, C. Dickman, and S. Burgin, 74–87. Mosman: Royal Zoological Society of New South Wales.
- Yarra and Bay. (2019) Port Phillip Bay, Western Port and Gippsland Lake Report Cards. (accessed 22 March 2019). <https://yarraandbay.vic.gov.au/report-card>.
- Young, J. C., K. A. Waylen, S. Sarkki, S. Albon, I. Bainbridge, E. Balian, J. Davidson, et al. 2014. "Improving the Science-policy Dialogue to Meet the Challenges of Biodiversity Conservation: Having Conversations Rather Than Talking at One-another." *Biodiversity and Conservation* 23 (2): 387–404. doi:10.1007/s10531-013-0607-0.