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Citizen science for assessing ecosystem services: Status, challenges and opportunities

Matthias Schröter [a,b,*], Roland Kraemer [a,b], Martin Mantel [a,b], Nadja Kabisch [a,b,c], Susanne Hecker [a,b], Anett Richter [a,b], Veronika Neumeier [a,b], Aletta Bonn [a,b,d]

[a] Department of Ecosystem Services, UFZ – Helmholtz Centre for Environmental Research, Permoserstr. 15, 04318 Leipzig, Germany
[b] German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Deutscher Platz 5e, 04103 Leipzig, Germany
[c] Department of Geography, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany
[d] Friedrich-Schiller-University Jena, Institute of Ecology, Dornburger Straße 159, 07743 Jena, Germany

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ABSTRACT

Citizen science approaches provide opportunities to support ecosystem service assessments. To evaluate the recent trends, challenges and opportunities of utilizing citizen science in ecosystem service studies we conducted a systematic literature and project review. We reviewed the range of ecosystem services and formats of participation in citizen science in 17 peer-reviewed scientific publications and 102 ongoing or finished citizen science projects, out of over 500 screened publications and over 1400 screened projects. We found that citizen science is predominantly applied in assessing regulating and cultural services. The assessments were often performed by using proxy indicators that only implicitly provide information on ecosystem services. Direct assessments of ecosystem services are still rare. Participation formats mostly comprise contributory citizen science projects that focus on volunteered data collection. However, there is potential to increase citizen involvement in comprehensive ecosystem service assessments, including the development of research questions, design, data analysis and dissemination of findings. Levels of involvement could be enhanced to strengthen strategic knowledge on the environment, scientific literacy and the empowerment of citizens in helping to inform and monitor policies and management efforts related to ecosystem services. We provide an outlook how to better operationalise citizen science approaches to assess ecosystem services.

Contents

* Corresponding author at: Department of Ecosystem Services, UFZ – Helmholtz Centre for Environmental Research, Permoserstr. 15, 04318 Leipzig, Germany.
E-mail address: matthias.schroeter@ufz.de (M. Schröter).

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1. Introduction

The concept of ecosystem services (ES) bridges biodiversity science and society by assessing the benefits people derive from ecosystems for their well-being (Haines-Young and Potschin, 2010). Thereby, the concept integrates across different scientific disciplines of the natural and social sciences (Abson et al., 2014), aligns different sectors and stakeholders to discuss natural resource management (Reed et al., 2013) and attracts both biodiversity conservation and business interests (e.g., Goldman et al., 2008). Still, the integration of the ES concept in policy making and planning is not mainstream (Braat and de Groot, 2012) and related actors have concerns about the understanding and usefulness of the concept (Hansen et al., 2015; Kabisch, 2015).

The need for a better understanding of the state and trends of ES to safeguard and to enhance the benefits derived from them has been translated into global sustainability policies (Geijzendorffer et al., 2017) and the biodiversity strategy of the European Union. In particular, the EU member states are requested to map and assess ecosystems and ES in Target 2, Action 5 (European Commission, 2011). Science has taken up the challenge to develop suitable methods to assess ES, both driven by scientific endeavour (Crossman et al., 2013; Martínez-Harms and Balvanera, 2012; Schröter et al., 2015) and by the request for national and regional assessments (Albert et al., 2016; Maes et al., 2016; Schröter et al., 2016).

Overall, there is yet a bias towards assessing provisioning ES, for which suitable (trade) data and indicators are often available, and towards regulating ES, that can be modelled using mainly biophysical input data (Haase et al., 2014; Karp et al., 2015; Schröter et al., 2015). For assessments of cultural ES, such as the provision of recreational opportunities, aesthetic value of landscapes or cultural heritage (Chan et al., 2012; Daniel et al., 2012; Milcu et al., 2013; Plieninger et al., 2013) data availability is still limited. Specifically, the demand for and use of cultural ES is subject to individual preferences and perceptions of people. Hence, objective data collection and quantification of cultural ES can be difficult (Milcu et al., 2013). Studies that explore cultural ES are often based on assumed use-patterns (Raudsepp-Hearne et al., 2010; Schröter et al., 2014a), refer to perception and use of green spaces without directly linking to ES (Kabisch et al., 2015), or rely on land use and land cover data as proxies (Grêt-Regamey et al., 2015; Kabisch et al., 2014; Larondelle et al., 2014). However, some recent studies employ participatory methods (e.g., van Riper et al., 2017), and provide avenues for co-creating knowledge with affected ES beneficiaries.

In parallel to the interest in ES, citizen science has gained attention as an approach that aims to strengthen bonds between science and society by engaging citizens in research (Haklay, 2013; McKinley et al., 2015; Miller-Rushing et al., 2012). Citizen science is the voluntary, i.e. unpaid involvement of citizens in research activities (Cohn, 2008; Silvertown, 2009). Even though the term citizen science is relatively new (Kullenberg and Kasperowski, 2016), the practice of participatory research and volunteered science has a long tradition in a wide range of disciplines (Haklay, 2013) such as astronomy (Raddick et al. 2013), environmental monitoring (Pocock et al., 2017), natural history (Bonney et al., 2009a,b; Miller-Rushing et al., 2012), archaeology (Smith, 2014) and more recently also in life sciences (Den Broeder et al., 2016). High proportions of biodiversity data are collected by volunteers (Chandler et al., 2017; Schmeller et al., 2009), representing a vital source of information both for scientists and public authorities.

The meaning of the term citizen science varies within the scientific literature. Therefore, citizen science has not one definition or can be described as a replicable methodology. The concept of citizen science has developed from two origins, one in the social sciences and one in the natural sciences (Kullenberg and Kasperowski, 2016) and subsequently touching on issues of democratisation of science, public engagement itself (Irwin, 1995) and collection and analysis of large data sets through public participation (Bonney, 1996). Scholarly communication has mainly discussed the approach within natural sciences in the last 20 years but the discussion broadens with the spread of citizen science. For this article we refer to citizen science projects that mainly contribute to the monitoring of the environment and relate in any way to the assessment of ES.

The level of public participation in citizen science can vary (Shirk et al., 2012), and ranges from short-term data collection to intensive use of leisure time in order to delve deeper into a research topic together with or without scientists (Bonn et al., 2016). Citizens can participate in choosing or defining research questions, gather information and resources, develop explanations, design methods, collect samples and record data, analyse samples or data, interpret data and draw conclusions, disseminate results and discuss results and ask new scientific questions (Shirk et al., 2012). Common forms of citizen science participation comprise (i) contributory projects, led by scientists, involving volunteers mainly in the collection of data or samples, (ii) collaborative projects, that also include joint analysis of data or dissemination of results, (iii) co-created designs, i.e. the joint development of a study or (iv) citizen-led research or so-called collegial approaches where professional researchers are only involved secondarily, e.g. by being consulted for advice or specific analyses (Bonney et al., 2009a; Shirk et al., 2012).

Recent technological advances led to growth in popularity of citizen science by facilitating participation (Bonney et al., 2014; Newman et al., 2012; Silvertown, 2009). The internet helps projects to reach broad audiences by increasing visibility and allowing interested participants to find topics or projects. Further, the development of social media, mobile devices (incl. sensors), powerful (online) networks and computational facilities multiplies the capacity for data collection, storage, integration, analysis and dissemination (Pimm et al., 2015). Disseminating and applying new technologies such as intuitive mapping applications also allows for engaging previously not involved communities including indigenous people often hosting valuable traditional or local ecological knowledge (Drew, 2005; Liebenberg et al., 2017; Pimm et al., 2015). Beside technological advances, there is a rising awareness in the scientific community that citizen science can serve as a valuable tool to enhance the research design, to ease data acquisition and processing, to support science-policy-society communication and knowledge exchange and thus increase its social and policy impact (Bonney et al., 2014; McKinley et al., 2015; Newman et al., 2012). The wider involvement of lay, local and traditional knowledge is also hoped to fill knowledge gaps that otherwise cannot be efficiently addressed (e.g. Low et al., 2009). At the same time, citizen science can foster scientific literacy and learning (Bela et al., 2016).

Despite the long-term experience with citizen science in ecosystem and biodiversity research (McKinley et al., 2015; Miller-Rushing et al., 2012; Theobald et al., 2015), the concept of ES, i.e. the provision of ecosystem benefits to humans, has been less addressed by citizen science approaches. For instance, a recent review using a meta-analysis to describe the conceptual structure of contemporary citizen science revealed a near absence of ES in citizen science studies (Kullenberg and Kasperowski, 2016). This is rather surprising since both approaches are essentially addressing citizens, as contributors to science on the one hand and as beneficiaries of services on the other. The ES concept can thereby serve as an entry point for engaging citizens more strongly in assessing ES, in particular those that have direct relation to people's everyday life (e.g. opportunities for recreation, water quality of lakes) or those that can be meaningfully assessed only through beneficiaries or 'the eye of the beholder' (such as sense of place, aesthetics, aspects of social cohesion).

The aim of this paper is to analyse the state of the art of employing citizen science approaches for ES assessments. For the purpose of this review we define ES assessments as all forms of measurement of ES, including quantification and valuation (Seppelt et al., 2012). Specifically, we address the questions where and how citizen science has been applied for ES assessments. Therefore, we first conducted a systematic quantitative review of peer-reviewed literature. Second, to capture also frequently non-published studies within citizen science (cf. Theobald et al., 2015) or studies that may have not credited volunteers sufficiently (Cooper et al., 2014), we reviewed posters and associated project websites presented at recent international citizen science conferences in combination with screening most common web portals of citizen science projects. Finally, we discuss opportunities and challenges of using citizen science for assessing ES.

2. Methods

2.1. Literature review and analysis of peer-reviewed articles

We performed a systematic, structured quantitative literature review of peer-reviewed articles that were published in international scientific journals. The literature search was conducted in May 2016 on Scopus©, following a systematic and replicable procedure. The primary search terms were entered using the categories 'title, abstract, and keywords' according to four categories (see Appendix A for details on search terms). Group one of the search terms refers to specific ES using CICES, the Common International Classification of ES (Haines-Young and Potschin, 2013) as basis. The second group relates to more general terms that are often used in combination with ES, such as aesthetics or medicine, and thus were only included when they appeared together with the phrase "ecosystem services". This systematic approach focussed specifically on ES and deliberately excluded studies from related fields that do not use common terms related to ES, e.g. studies on agricultural production. The restriction on the terms was an expression of our focus on studies that specifically work with the framework of ES. The third group refers to terms that are often synonymously used to citizen science (cf. See et al., 2016), e.g. "volunteered information". The fourth group relates to the form of assessments (including quantification, measurement or valuation). The search of published literature was restricted to peer-reviewed original research articles published in English and included all years available in the Scopus database. Thus, we excluded review articles, conference papers, books and editorials from our search.

The Scopus search revealed a total of 541 articles. After the initial search, articles were screened and excluded when the content of the title or abstract did not match our main research aims. Studies were included when they met the following criteria: (i) the study assessed (e.g. quantified, valued, mapped) at least one ES rather than developing or discussing a framework or synthesis; (ii) the study related clearly to ES and not only to an environmental threat such as air pollution, to an ecosystem disservice, e.g. negative effects of certain species, or to species distribution without a clear link to ES. We defined ES as resulting from abiotic and biotic interactions in ecosystems, which excluded abiotic phenomena (wind, ice) as ES. (iii) The study had to employ a citizen science approach, i.e. citizens are actively involved in the research process and are not the object of research themselves.

Consequently, our criteria deliberately excluded studies employing focus group discussions and questionnaires elucidating information about participants. While these studies often apply participatory research approaches, the citizens involved may contribute only passively by responding to questionnaires or interviews or by participating in workshops that assess their knowledge or opinion rather than being effectively involved in data collection or even research design or analysis. For example, Horn and Johansen (2013) sent questionnaires to wild bird feeders for surveying their socioeconomic background, motivation and attitudes, and here participants were rather the objects of investigation than active contributors. The focus of our study interest was the active voluntary involvement of citizens in research activities.

For the same reason, we also excluded studies that used already existing crowd-sourced or citizen-generated data that had no clear pre-defined citizen science project embedment in the sense of an active involvement of citizens in a systematic research approach. These were either studies that mined the content of social media and file sharing platforms (e.g., flickr, Facebook or YouTube) or of crowdsourcing projects (e.g. OpenStreetMap, openstreetmap.org) as input data. For instance, Araujo et al. (2017) applied photographic identification of pictures of whale sharks (*Rhincodon typus*) uploaded to flickr and Facebook to gather input data for species distribution modelling, or Dorn et al. (2014) used data provided by OpenStreetMap to assess the retention potential of riparian zones.

Furthermore, we excluded studies focusing on recording biodiversity or environmental parameters without directly relating to ES. For instance, Strohbach et al. (2013) analysed the influence of small urban greening projects on bird diversity. In this study, volunteer bird observers conducted bird counts at several locations within the Boston city area including mapping various amounts of small green spaces. Another example is a study employing video recordings of divers for marine fish species richness (Bulleri and Benedetti-Cecchi, 2014). Others analysed the potential of citizen-supported methods (e.g. smartphone sensors) for the measurement of environmental parameters (e.g., air temperature, Overeem et al., 2013) without clearly linking to the beneficial effects of ecosystems, such as potential local climate regulation through urban green space. Further, the study of Robertson et al. (2015) assessed a recreational service (ice-skating) relying rather on men-made infrastructures and abiotic factors (climate) rather than on biotic components of an ecosystem, i.e. the study is in a strict sense not assessing an ES.

Participatory GIS studies are a growing field also within ES science (Brown and Fagerholm, 2015; Brown et al., 2012). As the focus of these studies is most often on surveys of citizens rather than on citizens surveying environmental phenomena, we only included those participatory GIS studies that also mentioned the term citizen science (see also Haklay, 2013).

Eventually, 17 articles met our search criteria and were included for further analysis using a standardized data extraction sheet based on predefined review questions for the systematic review. The review questions covered general information (publication data, case study location, scale, assessment method) and detailed questions concerning the type of ES assessed and the level of participation in the citizen science approach. We also screened the articles for reporting on opportunities and challenges in applying citizen science for ES assessments. We distinguished five types of approaches to assess ES and grouped studies accordingly. These groups were surveys, experiments, environmental monitoring, service-providing unit assessments and participatory GIS schemes. Survey studies apply questionnaires used by citizens (to survey other citizens). Experiments are specifically designed to involve citizens in data collection and analysis of cause-and-effect relationships for the assessment of ES. Environmental monitoring schemes relate to provisioning or regulating ES in which citizens predominantly contribute to data collection. Here, monitoring refers to systematic, assessment of an environmental parameter measured by citizens with focus on indicators for ES. Studies grouped into "service-providing unit assessment" measure the abundance of a species population providing an ES (cf. Luck et al., 2009). Participatory GIS approaches apply spatially explicit surveys often of a specific focus group, mostly experts such as rangers, but are in principle open to the public (Sieber, 2006).

2.2. Review of citizen science conference posters and web portals

Citizen science studies often do not publish in scientific journals (Theobald et al., 2015) or when published, often do not give sufficient credit to involved volunteers or do not use appropriate wording related to citizen science (Cooper et al., 2014). Hence, our review of peer-reviewed articles might provide an incomplete picture of activities of the citizen science community that could still be of use for assessing ES. To address this issue, we extended our review to citizen science project websites derived from posters that were presented at three recent international citizen science conferences. We further scanned web portals hosting or listing (linking to) citizen science projects. Since there is no unified platform or overview for citizen science projects on a global scale, we approached conference material and web portals as most formalized communication channels in the citizen science community. Recently, several networks and associations have emerged to professionalise and formalise citizen science. These include among others the American Citizen Science Association (CSA, http://citizenscience.org/association/), the Australian Citizen Science Association (ACSA, http://csna.gaiaresources.com.au/) and the European Citizen Science

Table 1
Review questions for analysis of peer-reviewed literature.

Criterion (question)
General information • What is the study region (city, region, country) and the spatial scale of the study? • What is the time scale of the study?
Methodology • Which ecosystem service was assessed? • Which form of citizen science participation (after Shirk et al., 2012) has been applied?
Assessment of citizen science approach • Which opportunities of involving citizen science approaches have been reported or discussed? • Which challenges of involving citizen science approaches have been reported or discussed?

Table 2
Summary of reviewed conference posters and projects listed in citizen science web portals.

Name of conference or web portal	URL	Total number of posters and listed projects (as by Nov 30 th 2016)	Number of projects included in review
ACSA conference	http://csna.gaiaresources.com.au/past-events/2015-australian-citizen-science-conference-report/	74	5
Biocollect (Atlas of Living Australia)/SciStarter*	http://www.ala.org.au/biocollect/	447	51
Buerger schaffen Wissen (GEWISS) (Germany)	http://www.buergerschaffenwissen.de/projekte-finden	66	4
Citizen-Science.at (Austria/Europe)	http://www.citizen-science.at/	30	0
CitSci.org (U.S./global)	citsci.org/cwis438/Browse/Project/Project_List.php?WebSiteID=7	349	20
CSA conference	citizenscience.org/association/conferences/citsci2015/	145	6
ECSA conference	http://www.ecsa2016.eu/	99	3
Open Air Laboratories (OPAL) Surveys (UK)	http://www.opalexplorenature.org/surveys	11	2
Sparkling Science (Austria)	http://www.sparklingscience.at/en/projects/ueberblick.html	215	1
Zooniverse (global)	http://www.zooniverse.org/projects	48	10
Total		1,484	102

* Biocollect/ALA often pointed to SciStarter.com as source platform (in 14 cases). Thus it was also scanned for project information and additional relevant projects. However, the Scistarter database did not deliver additional new projects.

Table 3
Results of the review of peer-reviewed articles assessing ecosystem services with citizen science approaches.

Ecosystem service assessed (P-Provisioning, R-Regulating, C-Cultural)	Approach of assessment	Study reference	Study location/ Spatial scale	Time scale	No. of participants	Study description	Acronym
P- Honey production	Experiment	Sponsler and Johnson (2015)	Ohio, U.S.A.	2012–2013	32 and 18	The influence of landscape composition and beekeepers experience on bee colony success assessed	Sp
P- Fish harvest	Environmental Monitoring scheme	Fairclough et al. (2014)	West coast of Australia	2007/2008-ongoing	>350 / year	Recreational fishers send fish skeletons of three fish species from their catch, needed for stock assessments	Fa
P- Drinking water	Environmental Monitoring scheme	Little et al. (2016)	Rocky View County. Alberta, Canada	2007–2012 (partly 2013)	39 (wells)	Monthly water level measurements in privately owned wells using a water level sounder	Li
R- Water quality regulation	Environmental Monitoring scheme	Lottig et al. (2014)	3.251 lakes in the upper midwest of U.S.A.	1972–2012	not indicated	Water transparency measurements with Secchi-disks	Lot
R- Pollination	Experiment	Birkin and Goulson (2015)	80 sites across the U.K.	2014(growing season)	173	Participants germinate seeds of *Vica faba* L. and grow 4 plants with 3 treatments and record flower visitors	Bi
R- Pollination	Service-providingunit assessment	Pauw and Louw (2012)	46 gardens in Cape Town, South Africa	2002–2003	46	Presence/absence of four pollinating hummingbird species (*Nectarinia famosa, Cinnyris chalybea, Anthobaphes violacea, Promerops cafer*) in urban gardens	Pa
R- Pest control	Service-providingunit assessment	Roy et al. (2012)	Belgium and U.K.	1990–2010	~67000 (BE) / 90000 (U.K.)	*Coccinellidae* recording scheme (in Britain since 1971,in Belgium since 1999) surveying eight endemic and one invasive species.	Ro
R- Pest control	Service-providingunit assessment	Weed and Schwarzländer (2014)	38 observation sites within the state of Idaho (U.S.A.)	2007–2011	30	Effect of stem miner insects (weevil *Mecinus janthiniformis*) on invasive plant species (*Linaria dalmatica*) estimated at 38 sites (6 three minute counts and 10 sampling plots at each site)	We
R- Carbon storage	Environmental Monitoring scheme	Butt et al. (2013)	Wytham Woods, Oxford, southern England, U.K.	2008–2012	260	Volunteers measured tree breast-height diameter and tree height with dendrometer bands	Bu
R- Bio-remediation	Experiment	Kaartinen et al. (2013)	82 cattle farms across Finland	2011(growing season)	79	Dung decomposition experiment with five different treatments: exclusion of dor beetles (Geotropes) and/or earthworms (Oligochaeta)	Ka
C- Multiple cultural ES	Service-providingunit assessment	Bruce et al. (2014)	Jervis Bay, New South Wales, Australia	2007–2011	not indicated	Migration patterns and behavior of humpback whales in Jervis Bay, Australia were assessed by trained volunteers and Crew of whale-watching boats	Bru
C- Multiple cultural ES	Service-providingunit assessment	Bramanti et al. (2011)	western Italian coastline	Spring 2008-June 2009	616questionnaires	locations, and ecological conditions of red corals (*Corallium rubrum*) were reported by SCUBA-Divers	Lor
C- Multiple cultural ES	Service-providingunit assessment	Sequeira et al. (2014)	Adelaideand the Mount Lofty Ranges region of South Australia	28.11.2012	not indicated	Koala (*Phascolarctos cinereus*) assessment during fixed time period using a standardized sampling scheme (presence/absence, location, validation photo)	Se
C- Multiple cultural ES	Service-providingunit assessment	Williams et al. (2015)	Inhambane Province, Mozambique.	2008–2011	918	Sightings of three sea turtle species (*Caretta caretta, Chelonia mydas, Eretmochelys imbricata*) by recreational SCUBA divers	Wi
C- Multiple cultural ES	Participatory GIS	Newton et al. (2012, 2013)	Frome catchment, county of Dorset, southern UK (480 km^2)	2010	~200	The non-marked value of cultural, aesthetic and recreational ES was elicited from local stakeholders using a web-mapping tool.	Ne
Multiple ES (water quality, soil retention, habitat provisioning, recreation)	Survey	Nicosia et al. (2014)	Barnegat Bay watershed, New Jersey, U.S.A. (~1,500 km^2)	2010–2011	33	Survey on willingness to pay (WTP) for four ES related to water among 1000 randomly selected residents	Ni
Multiple ES	Participatory GIS	Brown (2013), Brown et al. (2014)	3 California forest sites: Sierra National Forest, Sequoia National Forest, Inyo National Forest, U.S.A.	Feb.-Apr. 2012	84	Public participation GIS was used to identify locations for 14 ES in three National forests in California.	BrO

Association (ECSA, https://ecsa.citizen-science.net/). In 2015 and 2016, each of these associations held an international conference of which we systematically reviewed the presented posters. The posters were obtained either via photographs taken at the conferences or via the book of abstracts. Each copy of the poster was individually reviewed for any indication of citizen science being related to ES. Following this selection, we scanned the project websites for detailed information following the review questions on general information on the project and the methodology used (ES assessed, citizen science approach applied) (Table 1).

Additionally, we reviewed projects enlisted in seven well-established German- and English-language citizen science project web portals on whether they applied citizen science methods to assess ES following our review questions (Table 1). These portals represent to the best of our knowledge the most comprehensive and accessible collections of citizen science projects. To avoid double counting we excluded projects from the poster or portal list once they produced a scientific article captured by our review. If we found an identical project on a poster and in a portal, we listed the project only once under the respective portal. In total, 1,484 projects were reviewed, of which 102 were included into detailed review based on the same criteria we applied for selecting peer-reviewed articles (Table 2). For this, we had to rely on a sufficient project description on the websites allowing us to infer a clear relation to ES assessments.

3. Results

3.1. Overview of peer-reviewed articles

The resulting 17 reviewed studies have been published relatively recently, from 2011 to 2016, with the majority of studies from the U.S. (five studies), the U.K. (four studies) and Australia (three studies) (Table 3). Spatial coverage of studies ranged from single sites spread across a city or country, to covering entire watersheds, provinces or states. Time scales varied considerably ranging from a 1-day observation of a particular species to a 40-years water monitoring programme, while most studies employed a time frame of one growing season up to two to five years. Further characteristics of the peer-reviewed studies are presented in more detail in the following sections, including the type of ES assessed, the form of participation and the approach to assess the ES (Table 3).

3.2. Variety of ES assessed

We found a wide variety of ES that has been assessed with citizen science approaches (Table 3 and 4). Among peer-reviewed articles, two studies assessed multiple services in the same area (Brown, 2013; Nicosia et al., 2014). Three studies assessed one provisioning service (ground water replenishment, fish harvest, honey production). Seven studies addressed regulating services, including water quality regulation, climate regulating through carbon storage, bio-remediation, pollination and pest control. Five studies related to multiple cultural services focussing on observation and distribution modelling of iconic species (whales, turtles, koalas, corals) although they did not explicitly assess or quantify the provision or use of ES. Nonetheless, the assessment of the distribution of red corals (Bramanti et al., 2011) relates to the potential of an ecosystem to provide options for recreational purposes as well as to the existence value of symbolic species. Similarly, the assessment of migration patterns of humpback whales (Bruce et al., 2014) links to physical and experiential experiences and to determining the existence value of a symbolic species. Likewise, the Great Koala Count (Sequeira et al., 2014) shows aspects of experiential, scientific and educational uses of a charismatic species. The presence of these species provides the basis for several cultural ES including physical experience, aesthetic appreciation and existence value (Table 3).

Through our review of posters and portals we found 102 projects, many of them focussing on links to multiple cultural ES (studies did not explicitly mention an ES category) (Table 4). Of these, 64 projects target the observation of iconic species, mostly mammals and birds across diverse ecosystems, from marine to mountain species, ranging from local to global scale and from short-term, mostly recurring campaigns (BioBlitz) to long-term surveys. In 17 projects assessment of cultural services was coupled with the recording of regulating services (14 cases, 6 of which reef projects) and provisioning services (3 cases, all fishery projects). In contrast, only 20 projects were dealing solely with the assessment of regulating ES (mostly water quality regulation, followed by tree carbon storage and pollination). No study was exclusively assessing provisioning services. One project combined the assessment of regulating and provisioning services by linking water quality assessment to the provision of drinking water (see Appendix B for full list of reviewed projects).

3.3. Different forms of participation in citizen science projects

Reviewing the different levels of participation (after Shirk et al., 2012), we found all levels of participation in citizen science except citizen-led approaches in the scientific articles (Table 4). All studies involved citizens in data collection, and nearly half of them (8 of 17) required knowledge and advanced skills from volunteers such as species identification, assessment of ecosystem condition according to a protocol, or more in-depth procedures during the completion of an experiment protocol (e.g., Birkin and Goulson,

Table 4
Summary of reviewed studies (articles) and projects by assessed ES type and level of involvement of citizens (for acronyms of articles s. Table 3; for details of screened projects refer to Appendix B).

ES type (CICES section level)	Level of involvement	No. of peer-reviewed articles (acronym)	No. of projects	Sum
Provisioning	Contributory	1 (Fa)	–	1
(P)	Collaborative	2 (Li, Sp)	–	2
	Co-created	–	–	0
Regulating	Contributory	5 (Bi, Bu, Pa, Ro, We)	17	22
(R)	Collaborative	1 (Ka)	3	4
	Co-created	–	–	0
Cultural	Contributory	5 (Bru, Lor, Ne, Se, Wi)	64	69
(C)	Collaborative	–	–	0
	Co-created	–	–	0
Multiple	Contributory	2 (BrO, Lot)	16	18
(P + R+C)	Collaborative	–	–	0
	Co-created	1 (Ni)	2	3
Total		17	102	119

2015; Kaartinen et al., 2013). Thereby, most of the studies can be classified as contributory (13 of 17), i.e. they were designed by scientists while citizens primarily contributed data or samples. Some studies also showed aspects of collaborative design, as citizens were engaged also in more advanced analyses of samples (Kaartinen et al., 2013; Sponsler and Johnson, 2015) or also active dissemination of findings (Little et al., 2016). Only one study could be classified as a co-created project employing deeper citizen involvement including study design, data analysis and interpretation (Nicosia et al., 2014). In this study, 9th grade high school students assessed the willingness to pay for ES supplied within a watershed in New Jersey (U.S.). Advised by scientists, students designed the study, analysed data, interpreted results and wrote a scientific paper as a final dissemination of the results.

Among reviewed projects found on posters and portals, the vast majority (95%) involved citizens on the contributory level. All of the projects related solely to cultural ES where citizens are asked to observe (and identify) iconic species but are, according to the project description, not involved further in study design or interpretation of the sightings. In general, all of the online-only type of projects where volunteers participate via remote desktop screens (the usual format at the Zooniverse portal) feature low levels of involvement, e.g. by identifying species on images. We found three collaborative projects that dealt with regulating services and stronger involvement of citizens mainly through outreach work or advanced data analysis, e.g. of water samples or pollen. Two projects were co-created. The main distinction of these projects compared to others is the engagement of citizens in project design and evaluation by strong mutual exchange with the coordinating professionals. An example is the project "Tauchen für den Naturschutz" (diving for conservation) in Germany led by a major NGO for conservation that was initiated by a regional agency and an NGO and strongly collaborates with divers to monitor vegetation and water quality of lakes.

3.4. Types of approaches to assess ES

Based on the review results we grouped the citizen science studies according to their approach for assessing ES, namely surveys, experiments, environmental monitoring, service-providing unit assessments and participatory GIS schemes (Table 3). We categorized Nicosia et al. (2014) as a survey study that was applying questionnaires in order to estimate willingness to pay for ES among watershed residents. We assigned three studies to the second category of experiments. In these studies citizens deliberately changed parameters to test for an effect according to a protocol. Environmental monitoring schemes related to provisioning or regulating ES in which citizens predominantly contribute to data collection. This group contains the studies that involve recreational fishers in collecting data on fish species (Fairclough et al., 2014) or assessing groundwater supply (Little et al., 2016), carbon storage (Butt et al., 2013) and lake water quality (Lottig et al., 2014).

The fourth group of studies, service-providing unit assessment, relates biodiversity assessments (such as habitat suitability models, species observations) to the provision of ES. The assessed service-providing units include particular iconic, charismatic and symbolic species or those that provide pollination or pest control. However, the service-providing unit assessment delivers often rather an indicator or proxy for a service (presence or abundance of relevant species) than a direct measure of the service itself (e.g. number of visited flowers). Even though these kinds of studies mainly represent biodiversity monitoring they make links to beneficial effects of these populations for humans. We assigned seven of the 17 studies to this category including the monitoring of service-providing species such as pollinating hummingbird species, pest controlling ladybird *Coccinellidae* species or stem miner insects. Others relate the observation of species such as whales, koalas, turtles or red corals to multiple cultural services. In these studies, there is often an implicit link to ES, and hence such studies develop suitable indicators for ES.

	Type of opportunity/challenge	Related study (for acronyms cf. Table 3)
OPPORTUNITIES	Bigger data amount, better spatial/temporal coverage	Bi, Ka, Fa, Li, Lot, Bru, Lor, Ro, Se, Wi, Ne
	Good quality of data, low sampling errors	Bu, Ne
	Cost advantage	Bi, Ka, Fa, Se, Wi, Ne
	Sustainability education/stewardship	Ni, Fa, Li, Lor
	Public involvement/place-based value elucidation	Ni, Bro, Ne
	Establishing collaborations/strengthening community	Ni, Ne
	Generate locally relevant data for decision-making	Ni, Ne
CHALLENGES	Complicated protocol/observer bias	Ni, Bi, Sp, Bu, Bru, Lor, Wi, Ne
	Restricted standardized design	Ka, Ne
	Spatial bias (sampling effort, sparse, patchy)	Ni, Bi, Li, Bru, Se, Bro, Ne
	Interest bias in mobilisation	Bro, Ne
	Presence only, no absence data	Ro, Ne
	Overall sample effort not recorded	Wi
	Initial costs	Fa

Fig. 1. Opportunities and challenges of the citizen science approach discussed in the 17 reviewed studies (15 studies mention opportunities and challenges; order and acronyms of studies according to Table 3).

Participatory GIS schemes included two studies. Since we deliberately excluded the term '(public) participatory GIS' from our review, we do not cover this type of research exhaustively. Thus, more participatory GIS studies exist that address ES but these have not been framed under citizen science in this focussed study context (e.g., Brown and Fagerholm, 2015; Raymond et al., 2009).

For poster and portal projects we assigned two categories of ES assessment (cf. Appendix B). The category monitoring scheme applied to 28 projects in which citizens predominantly measured parameters; e.g. of water quality or reef vitality, thus, relating predominantly to regulating and occasionally to cultural services. The remaining 74 reviewed projects fall into the category of service-providing unit assessment, comprising all biodiversity recording projects, of which 65 deal with iconic species and their related cultural ES. Two projects, both based in Germany, map and assess the perception and value of cultural landscapes or single prominent places in landscapes as service providing units principally serving as cultural heritages rather than providers of regulating or provisioning services.

3.5. Reported opportunities and challenges of citizen science approaches in assessing ES

The 17 reviewed scientific articles mentioned a range of opportunities and challenges in applying citizen science for ES assessments (Fig. 1). These include the facilitation to collect larger amounts of data over broader temporal and spatial ranges, the most often mentioned benefit (11 of 17 studies), followed by cost advantages through citizen science projects (six mentions), i.e. low or no staff cost which enables large scale monitoring over certain (longer) time periods. This links back to the first benefit of enabling large scale data collection across space and time (e.g., Birkin and Goulson, 2015; Bruce et al., 2014; Sequeira et al., 2014). Another important benefit of using citizen science for ES assessment is that projects may serve educational objectives and promoting the value of nature to a bigger audience and different target groups (Fairclough et al., 2014; Kaartinen et al., 2013). The outreach value of large citizen science projects may then also be used as justification and argumentation for the allocation of money into local or regional public or nongovernmental organisation funds or to support conservation programmes and strategies (Williams et al., 2015).

Mentioned challenges were complicated protocols that give rise to observer biases (8 of 17 studies) and spatial biases (7 of 17 studies). Main concerns are the adequacy of training of volunteers and problems in reliably applying the scientific study design leading to potential sources of errors (Williams et al., 2015). These errors could lead to an overestimation of abundance and diversity (Roy et al., 2012), incomplete observation protocols (Bramanti et al., 2011) and a partly non-reliability of taxa identification due to lacking skills of participants (Birkin and Goulson, 2015; Newton et al., 2013).

However, across all reviewed studies we found an overall sparse reporting and discussion of experienced opportunities and challenges. Most studies discussed only two to three aspects of evaluating citizen science, and two did not discuss shortcomings at all. In contrast, two studies (Newton et al., 2013; Nicosia et al., 2014) conducted a comprehensive discussion and reflection on the experiences with involving citizens in their projects.

4. Discussion

4.1. Types of ES assessed by citizen science approaches

Our review revealed a low number of published studies in peer-reviewed journals applying citizen science for ES assessments. We found that all three main categories of ES (provisioning, regulating and cultural) were addressed, with a focus on cultural services. The low number of citizen science projects dealing with provisioning services could be explained by relatively good availability of statistical data (for traded goods) for this group of services (Karp et al., 2015), so that for many studies citizen science might not be an attractive or indeed most useful approach. An exception are provisioning services that are directly harvested by consumers and thus not traded afterwards, e.g., non-timber forest products such as berries, mushrooms or fire wood, honey, game or fish for private consumption (Fairclough et al., 2014; Sponsler and Johnson, 2015). Here, citizen science approaches could help to gather data and better understand in particular these kinds of provisioning ES, that may also classify as cultural services in some settings. Several regulating services were assessed by experiments and collecting field data in monitoring schemes (Birkin and Goulson, 2015; Butt et al., 2013; Kaartinen et al., 2013). Benefits of using citizen science here are the expansion of spatial and temporal coverage of data collection, especially when field data collection can help to improve or validate ES models, e.g. for water quality regulation assessments (Alender, 2016; Lottig et al., 2014). In particular for regulating ES, the involvement of volunteers has potential to improve the quality of maps, which are often modelled and lack ground-truth data or validation (Martínez-Harms et al., 2016; Seppelt et al., 2011).

A considerable number of studies and projects had a link to multiple cultural ES through the repeated or one-time assessment of iconic or emblematic species being appealing and of specific interest for the public. The direct relation of volunteers to species and ecosystems that are of recreational, aesthetic or mere existence value offers ways to motivate and involve citizens in assessing these ES (Clary and Snyder, 1999; West and Pateman, 2016). Many of these cultural ES assessments, however, focus mainly on the ecological basis for providing a service, i.e. the presence or ecological status of an ecosystem or certain species (e.g. for coral reefs). There was less focus on the actual service provision (e.g. aesthetic appreciation, recreational use), or (monetary) valuation of services (e.g. for coral reef diving or willingness-to-pay for the continued existence of coral reefs).

4.2. Overlap of ES assessments with biodiversity assessments

The comparatively high share of articles and projects in our study that performed an assessment of ES closely connected to biodiversity observation reflects the relatively strong tradition of citizen science in biodiversity assessments and natural history (Miller-Rushing et al., 2012; Silvertown, 2009; Theobald et al., 2015). The overlap between ES and biodiversity assessments appeared when service-providing units (Luck et al., 2009) were assessed or regularly monitored, i.e. populations of certain species whose presence or functioning within an ecosystem provides a service to people. Biodiversity can serve both as a regulator of ecosystem functions, as a direct ES (Mace et al., 2012; Reyers et al., 2012) or as an indicator for an ES, and as such citizen science projects surveying biodiversity can provide strong overlap to ES assessments. One group of examples is related to species that contribute directly to regulating services. In these cases not the service itself is assessed (e.g. the actual amount of pest insects reduced, or the actual amount of plants being pollinated), but rather the presence of a population is used to infer the provision of a service. Examples are the studies on ladybirds (pest control, Roy et al., 2012), stem miner insects (pest control, Weed and Schwarzländer, 2014), and hummingbirds (pollination, Pauw and Louw, 2012). A second group of examples which illustrated the strong overlap between biodiversity and ES assessment is the case of characteristic species of particular cultural interest. These species have been classified as charismatic, symbolic, iconic, emblematic or flagship species in the literature (Bowen-Jones and Entwistle, 2002; Simberloff, 1998). It has been acknowledged in ES classifications (de Groot et al., 2002; Haines-Young and Potschin, 2013) that these species can provide different ES such as recreation or aesthetic enjoyment for instance symbolic-emblematic species, spiritual enjoyment of sacred species or the existence value of certain species (which is independent of actively using them).

Furthermore, the presence of a species could be used as an indicator for ES provision through the physical use of a land or seascape (e.g., watching wild animals, Willemen et al., 2015). Many studies found in our review are typical examples of such iconic or emblematic species (koala, turtles, humpback whales, red corals) that are directly enjoyed by beneficiaries, such as tourists or recreational divers. An open question is, however, where to draw a line, i.e. which species is particularly important or has a particularly high emblematic, iconic value, and contributes to specific cultural ES (Ducarme et al., 2013; Home et al., 2009). Future ES studies should elaborate this aspect and build upon a number of respective biodiversity studies (Brambilla et al., 2013; Prokop and Fančovičová, 2013). Only recently the presence of such species is considered as an integral part of ES assessments (Sutherland et al., 2016; Willemen et al., 2015).

4.3. Opportunities and challenges of using citizen science in ES research

4.3.1. Opportunities

The application of citizen science in ES studies may link to other fields of research, particularly in ecology (Bonney et al., 2014; Dickinson et al., 2010; Silvertown, 2009) and biodiversity monitoring (Chandler et al., 2017). The most prevailing opportunity of using citizen science for ES assessments as discussed in the reviewed journal articles is the large amount of surveillance data leading to an extended spatial, temporal or, in case of species observation, taxonomic coverage, as well as related cost advantages (Fig. 1). This finding is in line with the most commonly acknowledged benefits of citizen science (Chandler et al., 2017; McKinley et al., 2015; Theobald et al., 2015). For the assessment of regulating and provisioning ES, citizen science could provide large scale data to enrich and validate e.g. earth observation or statistical models (Cord et al., 2017; Hochachka et al., 2012). Accurate and fit-for-purpose study design can produce reliable data for ES assessment, e.g. for water quality or soil studies, that require measurements at a certain location (Buytaert et al., 2014). New technical solutions and advances such as sensor development (e.g. in earth observation, camera traps), forms of communication via social media and accessible (interlinked) databases on environmental or biodiversity data (e.g. GEOSS, GBIF) offer new ways for participation and ES assessment, e.g. linking biodiversity or ES maps with social, environmental or health data (Cord et al., 2015; Pimm et al., 2015; Vercayie and Herremans, 2015). The widespread equipment of people with smart mobile devices and apps allows for enhanced data collection, capturing key metadata at once, for individual in-field instruction and guidance of volunteers or for involvement of previously non-involved people (Adriaens et al., 2015; Pimm et al., 2015).

Further benefits, such as environmental literacy, awareness raising or establishing collaborations were rather underrepresented in discussions of the peer-reviewed articles captured by our review (Fig. 1). Integrating knowledge and information domains from outside academia or indigenous local knowledge provides options to gain multifaceted information about the coupled socio-ecological system of interest which in turn provides opportunities to better inform policy makers (Colin and Crona, 2017; Haklay, 2015; Hollow et al., 2015). Motivations of citizens to participate in citizen science projects monitoring biodiversity and the environment are closely linked to personal benefits of enjoyment and well-being (Clary and Snyder, 1999; Hobbs and White, 2012).

4.3.2. Challenges

Citizen science also implies considerable challenges. First, citizen science approaches are not generally suitable or useful for all types of ES assessments, particularly when other high quality data are sufficiently available. Volunteers need to be capable and motivated to meaningfully contribute to scientific objectives with reasonable efforts by both sides, project managers and volunteers (McKinley et al., 2015). This implies a thorough project design and implementation, which balances needs of scientists and citizens (Bonney et al., 2009b; Shirk et al., 2012). Additional challenges for project design arise when broad-scale citizen science data needs to be handled by finding appropriate computing systems, statistical tools and sufficiently trained staff (Hochachka et al., 2012; Kosmala et al., 2016). Furthermore, suitability and success of applying citizen science depends on the type of natural resource to be assessed, e.g. there might be a higher feasibility for projects dealing with charismatic species or popular topics such as whales or coral reefs (Chase and Levine, 2016).

Overall, the limited application of citizen science for ES assessments becomes apparent as most of the examined studies rely on the measurement of simple proxies, which are only indirectly related to ES (e.g. species counts or basic environmental parameters like tree diameters or water turbidity). Furthermore, in most cases the level of engagement of citizens is limited to data collection. In many cases, this level of involvement may suffice and suit the citizen science participants, and the high prevalence of data collection projects may be seen as an expressed preference, too.

Data quality is a commonly raised concern, while this depends highly on training, expertise and level of involvement of volunteers (Dickinson et al., 2010; Kosmala et al., 2016). The most often reported difficulty in the surveyed studies regarded complex protocols, observer biases and sampling effort (Fig. 1). Highly standardized or complex protocols for data collection may lead to limited understanding of the applied methods by volunteer participants and eventually to reduced motivations (Bonney et al., 2009b), while appropriate training and feedback mechanisms can ensure sound as well as enjoyable data collection (Dickinson et al., 2010). In terms of spatial, temporal or taxonomic observer biases, professional scientists and non-experts can be similarly prone at same levels of study design (Bird et al., 2014; Kosmala et al., 2016; Robertson et al., 2010). To overcome this challenge, projects should apply a minimum sampling standard to control for biases during data collection or give detailed information on sampling effort in order to allow for statistical control of collected data (Bird et al., 2014; Hochachka et al., 2012; Robertson et al., 2010). In the case of ES assessments, observer biases need to be specifically addressed since citizen scientists are often beneficiaries of ES at the same time, for instance in the case of recreational hiking. Here, citizen scientists can act as observers of other beneficiaries using ES or as observers of an ES itself (self-reporting).

Another finding in the review of the citizen science studies is the strong spatial imbalance (cf. also Theobald et al., 2015). 12 of the 17 studies were conducted in the U.S., U.K or Australia. This shows that at least for the case of projects dealing with ES assessments and publishing their results in peer-reviewed journals, there is yet a concentration in these three countries. Moreover, this spatial imbalance applies also for projects we found through the poster and online portal review (cf. Appendix B).

4.4. Fostering connections between ES and citizen science

To date relatively few scientific articles have used citizen science approaches to assess ES – when considering the common terms associated with the ES concept and citizen science. A first reason might be lack of awareness of the need to assess ES and subsequent motivation and commitment to ES projects. In addition to the articles matching our study criteria we found several citizen science projects during our reviewing process that addressed environmental pollution (like air, soil and water pollution) or disservices (occurrence of invasive species). These are apparent environmental problems that affect people directly and might motivate them more to get involved and help to solve them (Alender, 2016; West and Pateman, 2016). A better communication of the relevance of ES and benefits to communities may therefore strengthen interest and participations. However, it may indeed at times be easier to assess proxies, such as emblematic species than ES. Environmental citizen science projects found that the altruistic, environment-related value to serve wildlife is in general the most important motivation (Geoghegan et al., 2016) followed by personal benefits linked to e.g. health and well-being (Hobbs and White, 2012). Hence there is potential to involve citizen scientists in projects that specifically assess cultural ES, as these may on the one hand be directly important to affected citizens and on the other hand depend on individual perception and value. Citizen involvement can provide valuable new insights through social data and the development of new methods for quantifying cultural ES (Cord et al., 2015; van Zanten et al., 2016). This might be particularly fruitful in cities where many people directly benefit from urban ES (Cooper et al., 2007) and where the density of potentially available participants is higher.

A second reason for the currently relatively low number of citizen science studies on ES assessments might be the abstract nature of many ES. While ES originated as an eye-opener and simple metaphor for societal dependence on functioning ecosystems (Norgaard, 2010; Raymond et al., 2013) their actual measurement is less straightforward as they often appear to be abstract, mental-conceptual phenomena. This makes ES hard to communicate (Metz and Weigel, 2010) even to regional and urban planners and decision makers (Hansen et al., 2015). The inherent complexity and abstract nature of the ES approach might be an obstacle for the involvement and motivation of citizens to participate in ES research, which poses needs for training of participants. Besides, many ES assessments might actually require complex scientific approaches (Birkin and Goulson, 2015), that need more knowledge and training than counting individuals of a species in the context of a biodiversity monitoring. To achieve both a better communication of the ES approach and a more in-depth involvement of citizens in ES research we recommend to develop robust and easily measurable ES indicators accompanied by education and training efforts. This would also contribute to an improved familiarity of society with ES. Yet another factor might be the relatively young field of ES, as compared to biodiversity science. ES science is continuing to grow and has involved more disciplines over the years (Chaudhary et al., 2015) and will probably develop to stronger embrace citizen science approaches.

There are several conceptual aspects that align the ES concept and the citizen science approach. First, one could argue that ecosystems already set the appealing foundation to get involved in volunteering and scientific projects. As such, certain citizen science activities could actually be themselves used as an indicator for cultural ES (Fish et al., 2016). This includes for instance intellectual and experiential interaction with species and ecosystems by people while performing a biodiversity monitoring project. Species and ecosystems are hence objects for scientific research and educational purposes while performing citizen science projects. Second, both the ES concept and the citizen science approach have the goal to link biodiversity science and society and thereby to raise awareness on environmental problems (Costanza et al., 2014). Both have a normative aim. ES can be seen as a boundary object that links different actors with different interests in how ecosystems should be used sustainably (Schröter et al., 2014b). A goal of citizen science, in the same vein, is to more strongly link society and science and to build bridges (Bonn et al., 2016; Bonney et al., 2009b; Haklay, 2015). Hence, citizen science can serve as a catalyst to enhance understanding of ES research.

However, beside all possible conceptual and intrinsic obstacles to link citizen science and ecosystem services, our review at first revealed a low visibility of appropriate projects in peer-reviewed scientific literature. This issue has been raised by previous reviews in the context of biodiversity and climate research (Cooper et al., 2014; Theobald et al., 2015). Hence, we draw similar conclusions and call for better project designs, funding schemes, eased publication opportunities, but also higher confidence among project managers and participants in order to increase scientific publishing in the context of citizen science. At the same time, publishing scientists need to give sufficient credit whenever they make use of citizen-generated data.

5. Conclusion

We explored the characteristics of citizen science applied in ES assessment and demonstrated the diversity of ES assessed via the application of citizen science approaches. The majority of projects and studies assessed cultural services related to iconic or charismatic species, including recreational opportunities and intellectual interactions of people with these species such as aesthetic appreciation or existence values. However, most projects focussed on biodiversity and few provided direct links to ES assessments. A stronger focus on the assessment of the benefits and values derived from the existence of attractive species as proxy for ES could open opportunities for the ES community. In this endeavour, ES assessments can benefit from long-term experience with citizen science in biodiversity monitoring or natural history.

Projects explicitly targeting ES assessments focused on the assessment or monitoring of regulating services mostly by involving citizens for collecting environmental samples and conducting in-situ analyses. In the peer-reviewed articles and in projects, provisioning services played only a minor role, which could be attributed to the high availability of statistical data to assess this service group or to the deliberate restriction of our review to studies that explicitly refer to the ES framework and the respective terminology (potentially excluding studies from, e.g. agricultural or forestry sciences).

The review has revealed that in most cases the level of involving citizens is limited to sample collection and analyses, meaning that project or study design, data analysis and interpretation, and result dissemination is conducted by the scientists. In particular for cultural ES assessments there seems a substantial and yet untapped opportunity to more strongly involve citizens. Moreover, also for data driven and spatially explicit ES assessments or models, citizen science approaches can be a valuable complement to gather data to improve or validate ES models. Together with new technological developments for sensors and mobile technologies that facilitate accurate and standardised data collection citizen science might evolve to a powerful tool for ES assessments. Overall, joint working through citizen science approaches can raise awareness and acceptance of the ES concept in society.

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Appendix A. Applied search terms and operators in the Scopus database for the systematic literature review

Search term categories	Search terms
Ecosystem services related (specific)	"ecosyst* servic*" OR food OR nutrit* OR fish OR water OR drinking OR irrigation OR material* OR fibre OR timber OR "raw materia*" OR wood* OR energ* OR biomass OR fuel* OR "water purif*" OR "water waste treatment" OR "wastewater treatment" OR "water nutrient*" OR "water qualit*" OR "water regulat*" OR "water flow*" OR "water quantit*" OR "flood prevent*" OR "flood attenuat*" OR "drought mitigat*" OR "drought prevent*" OR "storm protect*" OR "water retention" OR "air qualit*" OR "fine dust*" OR "air pollut*" OR "dry deposition*" OR "soil qualit*" OR "soil format*" OR "soil fertil*" OR "nutrient cycl*" OR "soil nutrient*" OR weathering OR recycl* OR "microb* proces*" OR "decompos*" OR "soil retent*" OR erosion* OR sedimentat* OR "soil conservat*" OR climate* OR carbon* OR sequestr* OR gas OR pollinat* OR "life cycle maintenance" OR nurser* OR "biological control*" OR pest*
	OR
Ecosystem services related (general terms only in combination with ES)	((gene* OR medic* OR ornament* OR "recreat*" OR "touris*" OR amenit* OR "cognitive development*" OR bequest OR "well-being" OR entertain* OR scienc* OR scientif* OR educatio* OR heritag* OR cultur* OR inspiratio* OR art* OR aesthet* OR symbolic OR sacred OR spirit* OR religi*) AND ("ecosyst* servic*" OR "ecosystem-serv*" OR es OR ess)
	AND
Citizen science	("citizen scienc*" OR "crowd sourc*" OR "volunteer* information*" OR "volunteer* geogr* information*" OR vgi)
	AND
Focus on assessments	(assess* OR quantif* OR valuat* OR valuing* OR measur* OR apprais* OR survey* OR study* OR count* OR monitor* OR mapping))

Appendix B: Overview of the reviewed citizen science projects found on conference posters and web portals

Platform	Typology	Project Name	CICES section level	Involvement of citizens in scientific process after Shirk et al. (2012) (NA in this column, if not provided)
ACSA	SPU	The Gang-gang Cockatoo Survey	Cultural	Contributory
ACSA	SPU	The Powerful Owl Project	Cultural	Contributory
ALA	SPU	Carnaby's Black-Cockatoo Recovery Project	Cultural	Contributory
ALA	SPU	Caspian Tern Research	Cultural	Contributory
ALA	SPU	Counting Weddell Seals in Antarctica	Cultural	Contributory
ALA	SPU	Dolphin Watch	Cultural	Contributory
ALA	SPU	eShark	Cultural	Contributory
ALA	SPU	Eyre Peninsula Goannas	Cultural	Contributory
ALA	SPU	Australian white ibis community survey	Cultural	Contributory
ALA	SPU	Bell Miner Colony Project	Cultural	Contributory
ALA	SPU	Kangaroo Island Dolphin Watch	Cultural	Contributory
ALA	SPU	Killer Whale Tracker	Cultural	Contributory
ALA	SPU	Annual Koala Counts/Quests (BioBlitzes)	Cultural	Contributory
ALA	SPU	KoalaTracker	Cultural	Contributory
ALA	SPU	Living Links: Valuing Biodiversity in South-East Melbourne	Cultural and regulating	Co-created
ALA	SPU	Pollinators.info Bumble Bee Photo Group	Regulating	Contributory
ALA	SPU	Wild Pollinator Count	Regulating	Contributory
ALA	SPU	International Sea Turtle Observation Registry (iSTOR)	Cultural	Contributory

(*continued*)

Platform	Typology	Project Name	CICES section level	Involvement of citizens in scientific process after Shirk et al. (2012) (NA in this column, if not provided)
ALA	SPU	Global Whale Tracking with Happywhale	Cultural	Contributory
ALA	SPU	Mapping Application for Penguin Populations and Projected Dynamics (MAPPPD)	Cultural	Contributory
ALA	SPU	Glossy Black-Cockatoo Project	Cultural	Contributory
ALA	SPU	Goanna Watch	Cultural	Contributory
ALA	SPU	Manta Matcher	Cultural	Contributory
ALA	SPU	Monitoring Coastal Raptor Nests in Redland City	Cultural	Contributory
ALA	SPU	Operation Rainbow Roost	Cultural	Contributory
ALA	SPU	Orange-bellied Parrot Recovery	Cultural	Contributory
ALA	SPU	OspreyWatch	Cultural	Contributory
ALA	SPU	PHOWN, Photos of Weaver Nests	Cultural	Contributory
ALA	SPU	PltypusSPOT	Cultural	Contributory
ALA	SPU	PlatypusWatch	Cultural	Contributory
ALA	SPU	Project Manta - The Manta Rays of Eastern Australia	Cultural	Contributory
ALA	SPU	Queensland Glider Network	Cultural	Contributory
ALA	SPU	Quoll Seekers Network Project	Cultural	Contributory
ALA	SPU	Report a Platypus project	Cultural	Contributory
ALA	SPU	SA Murray-Darling NRM Bat Survey	Cultural	Contributory
ALA	SPU	Searching for the yellow-bellied sea snake	Cultural	Contributory
ALA	SPU	SharkBase	Cultural	Contributory
ALA	SPU	Sulphur-crested Cockatoo population survey	Cultural	Contributory
ALA	SPU	Superb Parrot Monitoring project	Cultural	Contributory
ALA	SPU	Tiger Nation	Cultural	Contributory
ALA	SPU	Turtle Monitoring	Cultural	Contributory
ALA	SPU	TurtlSAT	Cultural	Contributory
ALA	SPU	Wildlife Sightings in the City of Logan	Cultural	Contributory
ALA	SPU	WomSAT	Cultural	Contributory
CitSci	SPU	Bird Conservancy of the Rockies Bird Watching Projects	Cultural	Contributory
CitSci	SPU	Tamarisk Coalition	Cultural and regulating	Contributory
CitSci	SPU	Seven Gill Shark Monitoring	Cultural	Contributory
CitSci	SPU	Colonial Waterbird Monitoring Project	Cultural	Contributory
CitSci	SPU	Mt Tam Turtle Observers	Cultural	Contributory
CitSci	SPU	ADF&G Wing Collection Program	Cultural	Contributory
CitSci	SPU	Monarch Citizen Science Project	Cultural	Contributory
CitSci	SPU	The Kestrel Project	Cultural	Contributory
CitSci	SPU	Front Range Pika Project	Cultural	Contributory
CitSci	SPU	Nature in the City Biodiversity Project	Cultural	Contributory
CitSci	SPU	Cascades Pika Watch	Cultural	Contributory
CitSci	SPU	PikaNet	Cultural	Contributory
CSA	SPU	Bumblebee Conservation	Regulating	Contributory
CSA	SPU	Vancouver Island white-tailed ptarmigan	Cultural	Contributory
CSA	SPU	Oakquest	Cultural and regulating	Contributory
ECSA	SPU	CIGESMED for Divers	Cultural	Contributory
GEWISS	SPU	Bienenstand.at & C.S.I. Pollen	Regulating	Collaborative
GEWISS	SPU	KLEKs	Cultural	Contributory
GEWISS	SPU	Landschaft im Wandel	Cultural	Contributory
OPAL	SPU	Polli:Nation Survey	Regulating	Contributory
OPAL	SPU	Biodiversity Survey	Cultural and regulating	Contributory
Zooniverse	SPU	Arizona Batwatch	Cultural and regulating	Contributory
Zooniverse	SPU	Camera Catalogue	Cultural	Contributory
Zooniverse	SPU	Snapshots at Sea	Cultural	Contributory

(*continued on next page*)

(*continued*)

Platform	Typology	Project Name	CICES section level	Involvement of citizens in scientific process after Shirk et al. (2012) (NA in this column, if not provided)
Zooniverse	SPU	Whales as individuals	Cultural	Contributory
Zooniverse	SPU	Chimp & See	Cultural	Contributory
Zooniverse	SPU	Penguin Watch	Cultural	Contributory
Zooniverse	SPU	Condor Watch	Cultural	Contributory
Zooniverse	SPU	Snapshot Serengeti	Cultural	Contributory
Zooniverse	SPU	Bat detective	Cultural	Contributory

SPU = service-providing unit assessment, ACSA - Australian Citizen Science Association, ALA - Web Portal of Atlas of Living Australia, CitSci - www.citsci.org, CSA - American Citizen Science Association, ECSA - European Citizen Science Conference, GEWISS - Web Portal of Bürger schaffen Wissen (Germany), OPAL - Open Air Laboratories, Zooniverse - www.zooniverse.org.

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