Crowdsourcing Conservation: The role of citizen science in securing a future for seagrass

Benjamin L. Jones[1,2]*, Richard K.F Unsworth[1,3], Len J. McKenzie[4], Rudi L. Yoshida[4] & Leanne C. Cullen-Unsworth[1,2]

[1]Project Seagrass, 33 Park Place, Cardiff, CF10 3BA

[2]Sustainable Places Research Institute, Cardiff University, Cardiff, CF10 3BA, UK

[3]Seagrass Ecosystems Research Group, College of Science, Swansea University, Wallace Building, Swansea, SA2 8PP, UK

[4]Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Cairns, Queensland, 4870, Australia

*Corresponding Author: JonesB67@cardiff.ac.uk

Abstract

Seagrass meadows are complex social-ecological systems. Understanding seagrass meadows demands a fresh approach integrating "the human dimension". Citizen science is widely acknowledged for providing significant contributions to science, education, society and policy. Although the take up of citizen science in the marine environment has been slow, the need for such methods to fill vast information gaps is arguably great. Seagrass meadows are easy to access and provide an example of where citizen science is expanding. Technological developments have been pivotal to this, providing new opportunities for citizens to engage with seagrass. The increasing use of online tools has created opportunities to collect and submit as well as help process and analyse data. Citizen science has helped researchers integrate scientific and local knowledge and engage communities to implement conservation measures. Here we use a selection of examples to demonstrate how citizen science can secure a future for seagrass.

Keywords: Citizen science, community engagement, seagrass conservation, seagrass research, seagrass

Introduction

Our oceans, and biodiversity more broadly, are in crisis (Hoag, 2010; Novacek, 2008). Acting to manage many of these complex issues at play requires data and knowledge about these systems. Yet governments generally have limited capacity to generate and manage the scale of data required to respond appropriately to these challenges of environmental management in the 21st century. With growing evidence that marine research is under-resourced compared with that on land, novel solutions to these problems are sorely need (Richardson and Poloczanska, 2008).

Seagrass meadows are marine powerhouses (Lavery et al., 2013), and are a key part of that ocean biodiversity. They provide an example of a data poor habitat of global importance that are undoubtedly in crisis (Orth et al., 2006; Waycott et al., 2009). Seagrasses are flowering marine plants that grow in sheltered shallow coastal areas on sandy or muddy substrates. The meadows they form provide habitat, food and shelter for a diverse range of invertebrates, fish, mammals and birds. As such, these meadows are crucially important for juvenile and larval stages of many commercial, recreational and subsistence fish and shellfish globally (Beck et al., 2001; Heck et al., 2003; Jackson et al., 2001; Lilley and Unsworth, 2014; Short et al., 2011).

In order to protect seagrasses into the future the development of appropriate environmental management strategies at local, regional and global scales must be underpinned by understanding their distribution, what threatens them and their historical loss. Seagrass loss globally is generally the result of poor and reduced water quality, driven by unsustainable coastal development, poor integrated coastal zone management, and physical destruction. In these cases, seagrasses suffer due to lack of acknowledgment of their existence and value (Duarte et al., 2008). Despite a global understanding of the negative effects that these impacts have on seagrass ecosystem services, we know very little about smaller scale impacts (Grech et al., 2012), which are often locally specific and missed in management and practice - for example seaweed farming (Eklof et al., 2006). Obtaining such information at local scales is therefore essential but can be difficult and expensive to collect.

The cost and logistical limitations of working in intertidal and subtidal seagrass environments contribute to this lack of data. In the intertidal, short tidal periods reduce sampling time, and subtidal seagrass meadows require either the use of costly SCUBA teams, sonar equipment or towed video systems. Seagrass monitoring in many regions of the world is absent, and even where it is, monitoring can be infrequent and lack the statistical power needed to sufficiently understand the extent of changes to seagrass condition. As a result, there remains huge gaps in our knowledge of global seagrass distribution and the long-term change in their extent (Waycott et al., 2009). Citizen Science (CS) provides a means to start to fill seagrass data gaps both locally and globally.

The number of and diversity of projects that provide members of the public with an opportunity to assist in research is expanding globally (Cigliano et al., 2015; Pocock et al., 2017), and societies interest in this has risen in the last 10 years (Fig. 1). Primarily, research into ecology, meteorology and astronomy have paved the way due to their characteristic nature. CS is defined as 'a method of integrating public outreach and scientific data collection locally, regionally, and across large geographical scales' (Bhattacharjee, 2005; Bonney et al., 2009a; Bonney et al., 2014; Cooper et al., 2007; Tweddle et al., 2012).

The use of CS as a tool for conservation is emerging as a novel and desirable approach; this is due to associated low budget requirements and potentially rapid data dissemination. Moreover, recent technological advances have enabled collaborative projects to broaden their ambitions

(Pocock et al., 2017). The collection of 'big data' in these projects, involving the collection of data across wide special and temporal scales, was previously unimaginable (Miller-Rushing et al., 2012; Ward et al., 2015). Across the board, one major benefit of using CS data is its inherently large sample size (Greenwood, 2007). With such large sample sizes, CS data has the potential for high statistical power and to derive robust statistical information from. Moreover, data obtained from CS programmes has the potential to yield similar, and sometimes better results than from data collected by trained specialists (Newman et al., 2003; Schmeller et al., 2009).

Given that water covers 70% of the earths surface, an international survey of CS programmes, conducted by Roy et al., (2012), identified that marine and coastal environmental projects were proportionally underrepresented (comprising around 15% of projects). These were geared *either* towards highly localised and scientific precision driven programmes *or* mass participation programs designed to raise citizen awareness of a specific issue, with few projects achieving a more balanced 'middle' ground. These middle ground projects enlist more participants than scientific precision driven programmes and have greater scientific accuracy than mass participation projects and are more useful to derive broader conclusions. This represents a unique and novel opportunity for marine and coastal CS to diversify (Berkes, 2007; Roy et al., 2012). Although the range of potential marine and coastal CS projects is not as large as in terrestrial systems (Theobald et al., 2015), projects are increasingly providing opportunities for members of the public to participate in and engage with marine conservation. Data collected through citizen science programmes have been used to better understand the abundance of cetaceans and jellyfish (Embling et al., 2015; Pikesley et al., 2014), the health of coral reef systems (Marshall et al., 2012), how ocean plastics are distributed (Hidalgo-Ruza and Thiel, 2013; Smith and Edgar, 2014) and the spread of invasive species (Delaney et al., 2008). Furthermore, CS, in the context of marine and coastal conservation management, has the potential to strengthen community engagement and influence policy (Conrad and Hilchey, 2011; Danielsen et al., 2013), yet there are still barriers and challenges to translate data into resource management (Done et al., 2017; Schläppy et al., 2017).

In the present paper, we discuss how CS programmes can be useful in addressing the geographically large-scale information gaps that seagrasses are currently facing. Using current programmes to make this case we provide evidence of why CS is a source of optimism in terms of securing a future for seagrass. We highlight the potential of CS tools to fulfil key needs in conservation science that are applicable to seagrass (Duarte, 2002; Whittaker et al., 2005). We provide additional evidence of where CS could be used and highlight a challenge of CS. Lastly, we provide the key considerations for a successful citizen science programme targeting seagrass.

Seagrass Citizen Science

Generally speaking, intertidal seagrass science does not suffer from the same logistical challenges that other marine projects may face such as requirement of boats, the need for volunteers to be at sea, diving qualifications, expansive range of species identification skills, or even the ability to swim (Cigliano et al., 2015). While there are exceptions, seagrass meadows are easily accessible by members of the public at low tide, and have even been used as football pitches in some remote locations. For this reason, the take up of seagrass citizen science (SCS) projects has generally been well received, with successful local, regional, national and global projects in action (Table 1). However, with the exception of Seagrass-Watch and SeagrassSpotter, SCS projects are generally small targeting a range of local or regional issues. For example, the Community Seagrass Initiative (CSI) targets a number of seagrass meadows along the south coast of the UK for which data is lacking. Utilising SCUBA divers (provided with training), CSI map meadows to update ranges on nautical charts so that boaters are more aware of meadows, and enlists members of the public to help analyse Baited Underwater Video Footage collected by kayakers. On the other hand, Port Curtis Seagrass Restoration programme enlists volunteers to help collect seagrass transplants that are then used to improve the ecosystem health of Gladstone Harbour, Australia. Despite the obvious awareness raising potential and the generation of data that these projects provide to support seagrass conservation, the key strengths of these projects have seldom been highlighted or acknowledged. Nor has the recent upward trend in engagement though these projects.

Within seagrass science, no matter how large the sampling effort is, there are trade-offs between monitoring a seagrass meadow continuously, either using a set number of specifically placed transects or via a set approach like boundary walking, versus monitoring a seagrass meadow sporadically (McKenzie et al., 2001). While the first approach gives us very detailed information on what is happening in specific places within a seagrass meadow, over time, it is the ideology of the second approach that is generally adopted by citizen science (CS) programmes. This approach is focused on extrapolating results to a wider scale, whether that is meadow scale or larger. Although the data collected through a single sample provides only a limited amount of information, the key principle here is the use of a simple scientific standard that is replicable thus permitting us to draw broad assumptions across wide spatial and temporal scales.

Examples of current Seagrass Citizen Science programmes

Only two current seagrass citizen science (SCS) programmes (Seagrass-Watch and SeagrassSpotter) cover wide spatial scales, from local to global, and provide examples of SCS projects targeting large numbers of participants in different ways. Through programmes like these one might argue that citizen scientists could potentially provide us with the world's largest seagrass research team. Seagrass-Watch, a participatory science (Haklay, 2013) program developed using design thinking (Bonney et al., 2009b), partners scientists with citizens to accurately monitor the status and trends in seagrass condition. Established in 1998 in Queensland (Australia), Seagrass-Watch has expanded its reach globally, conducting over 5,000 assessments from 396 sites across 19 countries and involving thousands of dedicated (expert amateurs) and occasional participants (www.seagrasswatch.org). Depending on capacity and monitoring intention, assessment frequency can be quarterly (every 3 months), biannual, annual or sporadic. SeagrassSpotter (www.seagrassspotter.org) on the other hand is entry level citizen science. Established in 2016 in the UK, the project uses a smartphone app and website database as its platform and facilitates a participants' ability to spot something interesting and upload geo-tagged photographs. Expanding across Europe in late 2016, since its release the project has accumulated over 700 sightings from 93 locations in 21 countries and engaged nearly 350 users. Once submitted to the digital platform, it provides data from sightings (seagrass or species) to spot checks (seagrass abundance and condition) with additional questions on seagrass phenology, associated fauna, and seagrass change.

Building on the idea of a large research or monitoring team, SCS programs offer more than traditional, government led monitoring efforts. Much like some of the plants they investigate, SCS programs themselves are perennial; carefully designed and planned to ensure that they endure despite (in many cases) a limited renewal of participants. Provided instruments are in place to ensure new participants can suitably conduct the exercise using globally standardised methods (Scientific led program incorporating CS – e.g., Seagrass-Watch), or so that the exercise does not require training (Entry level CS – e.g., SeagrassSpotter), CS programs can be resilient to variations in the financial challenges that other monitoring or research programs face (Couvet et al., 2008).

Tools for securing a future for seagrass

The ideal way to assess changes to seagrass condition and distribution globally would be to use data from large multi-site monitoring programmes. However, due to the lack of publicly available information, previous attempts have relied solely on published literature to gather information or data so that assumptions can be made (Duarte, 2002; Orth et al., 2006; Short et al., 2007; Waycott et al., 2009). To answer the array of different questions needed for seagrass conservation, new approaches are needed. However, new approaches must also look to the past in the way that scientists and society act and engage with the environment. A little over 30 years ago a scientist could visit a seagrass meadow, merely describe it and publish literature based solely on observations. In this respect, simple observations from citizen science (CS) could provide the key indicators essential for identifying seagrass change over wide spatial and temporal scales for both science and policy.

As part of the European Union (EU) Water Framework Directive (WFD), seagrasses are used as an indicator to identify the ecological status of coastal areas (Wilkes et al., 2017). Here, coastal ecological status can be identified by comparing specific plant characteristics, mainly shoot density, percentage cover or depth limits, to a reference level which generally reflects that of perceived low anthropogenic influence (Foden and Brazier, 2007; Marbà et al., 2013). Generally, WFD monitoring requires a monitoring team, usually made up of consultants with no specific "seagrass training" and is also costly. Evidence, in which ecological indicators of land-use change have been quantified using data from CS programmes (Devictor et al., 2008), suggests that the seagrass characteristics measured as part of WFD (percentage cover and shoot density) could be easily identified using citizen scientists. While some SCS programmes successfully incorporate such indicators (e.g *Sarasota County Seagrass Survey*), they do so only at regional or national level and no continental wide applications of specific SCS programmes exist.

In addition to their potential role in identifying key ecological indicators that are useful to managers, SCS programmes already have the potential to collect information pertaining to a range of viewpoints (Table 2). For example, one of the biggest remaining gaps in our knowledge of seagrass ecosystems are associated faunal communities. This is an area where we believe SCS programmes can assist with knowledge development, learning from targeted programmes like the "Great Eggcase Hunt", which has helped inform new descriptions and revised keys to the skate and catshark eggcases in the British Isles (Gordon et al., 2016), and observational UK SeaSearch SCUBA campaigns. Additional to this, tools already exist for more detailed development through website's like zooniverse.org. The *Community Seagrass Initiative* leads by example in this case, utilising the website to allow citizens to identify fish recorded using Baited Remote Underwater Video systems. There exists significant potential for even entry level SCS programmes to span biological, ecological and socio-ecological levels. With continually advancing technology, issues such as seagrass resilience or wide scale investigations of plant phenology can be identified using a phone app (identification of seeds and flowers – *a great marine flower search*?). Moreover, advancements in cloud software such as Google Forms provide the potential to widen the scope of socio-ecological surveys that could identify how fishers use seagrass meadows across both spatial and temporal scales.

Reconnecting with nature

While seagrass projects generally don't suffer from the same challenges that broader marine projects have, a fundamental pitfall is perceived lack of charismatic appeal. And while there exists much potential for seagrass citizen science (SCS) to grow, the question of how to get people to engage with seagrass science remains.

Nearly half of the world's population lives within 200 kilometres of a coastline (Matti et al., 2016). This number is set to double by 2025, and by 2050, three-quarters of the world's population will be urban (Morgenroth et al., 2016). As this populations continue to grow, society may progressively disconnect from nature. This lack of contact with nature increases collective insignificance for participation in conservation (Miller, 2005). However, contact with nature, and the marine environment specifically, may be crucial in stimulating an appreciation of the need to protect the marine environment (Nichols, 2014).

Learning from large-scale studies of terrestrial plants, one SCS programme (*SeagrassSpotter*) explicitly deals with this issue, using a phone application for monitoring and identifying seagrass. Reliance on mobile devices is now rapidly increasing within all age groups of societies (Robinson et al., 2015). Using CS programmes could therefore be a promising way for reconnecting people to nature (Miller, 2005, 2006). Indeed, while some programmes may require specific skills like scuba diving (*Community Seagrass Initiative*), *SeagrassSpotter* can be conducted by anybody. Similarly, *SeagrassSpotter* requires a limited contribution (e.g one photo during a two-week holiday at the beach) while others are time-demanding (*SeagrassWatch, SeaSearch, Community Eelgrass Mapping Initiative*) or costly (*Sailing for Seagrass*). It is this range in sampling protocol, where citizens may contribute as much as they want (from a curious singer user to experienced naturalist) that fills the gap between the members of society who feel connected with nature and those who don't, yet both contribute to the same goal.

However, even if one is to provide opportunities, the true success of a SCS programme ultimately relies on the curiosity of volunteers to learn about and observe a relatively secret and unknown part of their marine environment. Further to this, the fulfilment an activity provides influences how attached a participant becomes to an area (Evans et al., 2005; Horwitz et al., 2001; Miller, 2005). The benefits seagrass provide are crucial to this (Nichols, 2014). The terms familiar species and ordinary nature are frequently used in conservation biology and generally refer to the environment surrounding the area in which a person lives. However, the marine environment is seldom included in this. It is thus the challenge of CS to make seagrass a familiar or ordinary species.

Key Considerations for a Successful Seagrass Citizen Science Programme

Based on our understanding of seagrass citizen science (SCS), the challenges facings seagrass more broadly and the points made within this paper, we have identified 5 key elements leading to a successful SCS programme.

1. Scale

To find solutions to the problems facing seagrass meadows globally we need improved, and more up to date, information on their geographical distribution and condition. By definition, this requires large spatial and temporal datasets. Currently only around 1/5 of the worlds estimated seagrass distribution has been mapped. Therefore, a key requirement of SCS programmes is the collection of comparable data across scales. Of course, the quality of such information is dependent on trade-offs made between the limited amount of precision provided by a certain sample, and the number of samples. While citizen science (CS) programmes can be beneficial, the bias and precision that come hand in hand with such sampling must be considered before analysis (Schmeller et al., 2009), and also in sampling design (McKenzie et al., 2000). However, the use of technological innovation provides opportunities for improved quality assurance and quality control measures through photographic georeferenced records of samples (McKenzie et al., 2001).

2. Programme flexibility

Anthropogenic, geographic, environmental and biological factors will mean that SCS information collected on factors such as the distribution of an individual species, the condition of a meadow, or an assessment of threats associated to seagrasses will require different methods and equipment dependent upon locality and user.

SCS programmes need to be of sufficient flexibility to provide information on a range of aspects important for seagrass conservation at a range of scales dependent upon both the user's needs and the local circumstances. By being flexible an SCS programme can maximise opportunities for its uptake.

By ensuring flexibility and hence maximising opportunities for programme uptake SCS programmes can be used to provide a means to fill knowledge gaps in our understanding of seagrass conservation. For example, one the biggest remaining gaps in our knowledge of seagrass ecosystems are associated faunal communities. This is an area that we believe SCS programmes can assist with knowledge development.

3. Quality control

The capacity for any programme to meet the large-scale challenges faced in biodiversity conservation is not simply a matter of scale and numbers. Even significantly large datasets can suffer from bias, induced mainly from sampling design (Lepczyk, 2005). In this respect, a common pitfall for both terrestrial and marine programmes is in the identification of species; characteristic to programmes that involve counting the number individuals or species. Programmes of this kind, moulded by the collection of presence or absence data, depend solely on the ability of the observer to detect and identify individuals. While the identification of some species is difficult, for SCS programmes, these challenges can somewhat be avoided with the use of simple ID guides and species training, whether distributed as part of the project (e.g. *Seagrass-Watch*), or as an add-on (e.g. *Community Seagrass Initiative*). Similarly, with a much smaller range of species than other groups of plants or animals, local programmes can be extremely user friendly and involve people from all age groups of societies.

4. Co-creation

Co-creation is a term commonly used to describe the bringing together of both designers and end users to jointly produce a mutually valued product. These values can be translated into seagrass conservation though co-research (Cigliano et al., 2015). Feedback and citizen understanding is recognized as an essential element when improving the communication and/or development of biodiversity strategies (Evans et al., 2007; Fischer and Young, 2007; Miller, 2006). In the public eye seagrass meadows suffer significantly, with their profile and appreciation low when compared to other marine habitats like coral reefs or mangroves. This is often due to the benefits that seagrasses provide to humanity being poorly understood. "*Thinking outside the box*" in respect to the scientific element of large-scale projects, SCS needs to move from achieving scientific impact towards integrating public impact for value-led global conservation strategies (Jepson and Canney, 2003). By involving local communities in well informed conservation efforts, and providing opportunities for feedback and discussion, community views and values can be used to target conservation efforts.

5. Communication

SCS programmes need to communicate data and key findings back to the citizen scientists who collected the data so that their commitment to the programme grows. This may assist with growing social capital (Pretty and Smith, 2004). Data also needs to be publically available so that stakeholder's key to the conservation process can utilise the data when applicable to environmental management and conservation. This publically available data needs to be presented alongside clear explanation of associated methods, analysis and quality control procedures (Reichman et al., 2011). The Seagrass-Watch programme provides some example of this, where data analysis is presented clearly to stakeholders via their website, additionally providing names of volunteers, precise location of sampling and the best tide height to visit, and the programme method guide is easily accessible via download.

Conclusions

In conclusion, we believe that current seagrass citizen science (SCS) programmes provide a significant opportunity to assist with filling the many knowledge gaps in our understanding of seagrass ecology, particularly their spatial extent and condition. Citizen science is not the panacea needed to secure a future for seagrass, however these SCS programmes provide the characteristics that are needed to collect scientifically valid and robust data about seagrass globally. Given the success of certain programmes for inputting data into management and monitoring (McKenzie et al., 2012) there exists significant potential for citizen science to contribute to seagrass conservation more frequently and more extensively, particularly when linked to data accessibility and communication.

As a community of scientists, we must recognise that the conservation of seagrass (and the wider ecosystem) is not independent from human activities, and while charismatic species such as turtles and dugong add value and incentives, seagrass is no longer exclusively a subject of traditional academic science. The protection of coupled socio-ecological systems like seagrass meadows, which provide communities with livelihoods and food security (Cullen-Unsworth and Unsworth, 2013; Cullen-Unsworth et al., 2014; Unsworth et al., 2014), has received increased credence as of late, yet the value of seagrasses to communities is still poorly acknowledged. Citizen science provides us with the opportunity to promote seagrass as a 'familiar' species, and go further than simply monitoring condition to potentially understanding the true values that people see in their marine environment.

References

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J., Orth, R.J., Sheridan, P.F., Weinstein, M.R., 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51, 633-641.

Berkes, F., 2007. Community-based conservation in a globalized world. Proc Natl Acad Sci U S A 104, 15188-15193.

Bhattacharjee, Y., 2005. Ornithology. Citizen scientists supplement work of Cornell researchers. Science 308, 1402-1403.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., Wilderman, C.C., 2009a. Public participation in scientific research: Defining the field and assessing its potential for informal science education. A CAISE Inquiry Group report. Center for Advancement of Informal Science Education (CAISE), Washington, DC.
Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., Shirk, J., 2009b. Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. Bioscience 59, 977-984.
Bonney, R., Shirk, J.L., Phillips, T.B., Wiggins, A., Ballard, H.L., Miller-Rushing, A.J., Parrish, J.K., 2014. Citizen science. Next steps for citizen science. Science 343, 1436-1437.
Cigliano, J.A., Meyer, R., Ballard, H.L., Freitag, A., Phillips, T.B., Wasser, A., 2015. Making marine and coastal citizen science matter. Ocean & Coastal Management 115, 77-87.
Conrad, C.C., Hilchey, K.G., 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. Environ Monit Assess 176, 273-291.
Cooper, C.B., Dickinson, J., Phillips, T., Bonney, R., 2007. Citizen science as a tool for conservation in residential ecosystems. Ecology and Society 12, 11.
Couvet, D., Jiguet, F., Julliard, R., Levrel, H., Teyssedre, A., 2008. Enhancing citizen contributions to biodiversity science and public policy. Interdisciplinary Science Reviews 33, 95-103.
Cullen-Unsworth, L., Unsworth, R., 2013. Seagrass Meadows, Ecosystem Services, and Sustainability. Environment 55, 14-27.
Cullen-Unsworth, L.C., Nordlund, L.M., Paddock, J., Baker, S., McKenzie, L.J., Unsworth, R.K.F., 2014. Seagrass meadows globally as a coupled social-ecological system: Implications for human wellbeing. Marine Pollution Bulletin 83, 387-397.
Danielsen, F., Pirhofer-Walz, K., Adrian, T.P., Kapijimpanga, D.R., Burgess, N.D., Jensen, P.M., Bonney, R., Funder, M., Landa, A., Levermann, N., Madsen, J., 2013. Linking public participation in scientific research to the indicators and needs of international environmental agreements. Conservation Letters 7, 12-24.
Delaney, D.G., Sperling, C.D., Adams, C.S., Leung, B., 2008. Marine invasive species: validation of citizen science and implications for national monitoring networks. Biological Invasions 10, 117-128.
Devictor, V., Julliard, R., Clavel, J., Jiguet, F., Lee, A., Couvet, D., 2008. Functional biotic homogenization of bird communities in disturbed landscapes. Global Ecology and Biogeography 17, 252-261.
Done, T., Roelfsema, C., Harvey, A., Schuller, L., Hill, J., Schlappy, M.L., Lea, A., Bauer-Civiello, A., Loder, J., 2017. Reliability and utility of citizen science reef monitoring data collected by Reef Check Australia, 2002-2015. Mar Pollut Bull 117, 148-155.
Duarte, C.M., 2002. The future of seagrass meadows. Environmental Conservation 29, 192-206.
Duarte, C.M., Dennison, W.C., Orth, R.J.W., Carruthers, T.J.B., 2008. The Charisma of Coastal Ecosystems: Addressing the Imbalance. Estuaries and Coasts 31, 233-238.
Eklof, J.S., Henriksson, R., Kautsky, N., 2006. Effects of tropical open-water seaweed farming on seagrass ecosystem structure and function. Marine Ecology Progress Series 325, 73-84.
Embling, C.B., Walters, A.E.M., Dolman, S.J., 2015. How much effort is enough? The power of citizen science to monitor trends in coastal cetacean species. Global Ecology and Conservation 3, 867-877.

Evans, C., Abrams, E., Reitsma, R., Roux, K., Salmonsen, L., Marra, P.P., 2005. The Neighborhood Nestwatch program: Participant outcomes of a citizen-science ecological research project. Conservation Biology 19, 589-594.
Evans, J.M., Wilkie, A.C., Burkhardt, J., Haynes, R.P., 2007. Rethinking exotic plants: using citizen observations in a restoration proposal for Kings Bay, Florida. Ecological Restoration 25, 199–210.
Fischer, A., Young, J.C., 2007. Understanding mental constructs of biodiversity: Implications for biodiversity management and conservation. Biological Conservation 136, 271-282.
Foden, J., Brazier, D.P., 2007. Angiosperms (seagrass) within the EU water framework directive: a UK perspective. Mar Pollut Bull 55, 181-195.
Gordon, C.A., Hood, A.R., Ellis, J.R., 2016. Descriptions and revised key to the eggcases of the skates (Rajiformes: Rajidae) and catsharks (Carcharhiniformes: Scyliorhinidae) of the British Isles. Zootaxa 4150, 255-280.
Grech, A., Chartrand-Miller, K., Erftemeijer, P., Fonseca, M., McKenzie, L., Rasheed, M., Taylor, H., Coles, R., 2012. A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. Environmental Research Letters 7, 024006.
Greenwood, J.J.D., 2007. Citizens, science and bird conservation. Journal of Ornithology 148, S77-S124.
Haklay, M., 2013. Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation, in: Sui, D., Elwood, S., Goodchild, M. (Eds.), Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice. Springer Netherlands, Dordrecht, pp. 105-122.
Heck, K.L., Hays, G., Orth, R.J., 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. Marine Ecology-Progress Series 253, 123-136.
Hidalgo-Ruza, V., Thiel, M., 2013. Distribution and abundance of small plastic debris on beaches in the SE Pacific (Chile): a study supported by a citizen science project. Marine Environmental Research 87-88, 12-18.
Hoag, H., 2010. Confronting the biodiversity crisis. Nature Reports Climate Change, 51-54.
Horwitz, P., Lindsay, M., O'Connor, M., 2001. Biodiversity, endemism, sense of place, and public health: Inter-relationships for Australian inland aquatic systems. Ecosystem Health 7, 253-265.
Jackson, E.L., Rowden, A.A., Attrill, M.J., Bossey, S.J., Jones, M.B., 2001. The importance of seagrass beds as a habitat for fishery species. Oceanography and Marine Biology, Vol 39 39, 269-303.
Jepson, P., Canney, S., 2003. Values-led conservation. Global Ecology and Biogeography 12, 271–274.
Lavery, P.S., Mateo, M.-Á., Serrano, O., Rozaimi, M., 2013. Variability in the Carbon Storage of Seagrass Habitats and Its Implications for Global Estimates of Blue Carbon Ecosystem Service. PLoS ONE 8, e73748.
Lepczyk, C.A., 2005. Integrating published data and citizen science to describe bird diversity across a landscape. Journal of Applied Ecology 42, 672-677.
Lilley, R.J., Unsworth, R.K.F., 2014. Atlantic Cod (Gadus morhua) benefits from the availability of seagrass (Zostera marina) nursery habitat. Global Ecology and Conservation 2, 367-377.
Marbà, N., Krause-Jensen, D., Alcoverro, T., Birk, S., Pedersen, A., Neto, J., Orfanidis, S., Garmendia, J., Muxika, I., Borja, A., Dencheva, K., Duarte, C., 2013. Diversity of European seagrass indicators: patterns within and across regions. Hydrobiologia 704, 265-278.

Marshall, N.J., Kleine, D.A., Dean, A.J., 2012. CoralWatch: education, monitoring, and sustainability through citizen science. Frontiers in Ecology and the Environment 10, 332-334.
Matti, K., Hans de, M., Gianluigi, S., Daniel, V., Philip, J.W., Olli, V., 2016. Over the hills and further away from coast: global geospatial patterns of human and environment over the 20th–21st centuries. Environmental Research Letters 11, 034010.
McKenzie, L., Collier, C.J., Waycott, M., Unsworth, R.K.F., Yoshida, R.L., Smith, N., 2012. Monitoring inshore seagrasses of the GBR and responses to water quality. *Proceedings of the 12th International Coral Reef Symposium* 15B: 4.
McKenzie, L.J., Campbell, S.J., Roder, C.A., 2001. Seagrass-Watch: Manual for Mapping & Monitoring Seagrass Resources by Community (citizen) volunteers. Queensland Fisheries Service, Department of Primary Industries, Cairns, p. 100pp.
McKenzie, L.J., Lee Long, W.J., Coles, R.G., Roder, C.A., 2000. Seagrass-Watch: Community based monitoring of seagrass resources. Biologia Marina Mediterranea 7, 393-396.
Miller, J.R., 2005. Biodiversity conservation and the extinction of experience. Trends in Ecology & Evolution 20, 430–434.
Miller, J.R., 2006. Restoration, reconciliation, and reconnecting with nature nearby. Biological Conservation 127, 356–361.
Miller-Rushing, A., Primack, R., Bonney, R., 2012. The history of public participation in ecological research. Front. Ecol. Environ. 10, 285-290.
Morgenroth, J., Nielsen, A.B., Konijnendijk van den Bosch, C.C., Östberg, J., Harðarson, S.B., Wiström, B., 2016. URBAN TREE DIVERSITY FOR SUSTAINABLE CITIES [POLICY BRIEF].
Newman, C., Buesching, C.D., Macdonald, D.W., 2003. Validating mammal monitoring methods and assessing the performance of volunteers in wildlife conservation: ‘‘Sed quis custodiet ipsos custodies ?’’. Biological Conservation 113, 189–197.
Nichols, W.J., 2014. Blue Mind: the Surprising Science that Shows How Being Near, in, on, or Under Water Can Make You Happier, Healthier, More Connected, and Better at What You Do. . Little, Brown and Company, New York, NY.
Novacek, M.J., 2008. Engaging the public in biodiversity issues. Proceedings of the National Academy of Sciences 105, 11571-11578.
Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K.L., Randall Hughes, A., Kendrick, G.A., Judson Kenworthy, W., Olyarnik, S., Short, F.T., Michelle, W., Williams, S.L., 2006. A global crisis for seagrass ecosystems. Bioscience 56, 987-996.
Pikesley, S.K., Godley, B.J., Ranger, S., Richardson, P.B., Witt, M.J., 2014. Cnidaria in UK coastal waters: description of spatio-temporal patterns and inter-annual variability. Journal of the Marine Biological Association of the United Kingdom 94, 1401-1408.
Pocock, M.J.O., Tweddle, J.C., Savage, J., Robinson, L.D., Roy, H.E., 2017. The diversity and evolution of ecological and environmental citizen science. PLOS ONE 12, e0172579.
Pretty, J., Smith, D., 2004. Social capital in biodiversity conservation and management. Conservation Biology 18, 631-638.
Reichman, O.J., Jones, M.B., Schildhauer, M.P., 2011. Challenges and Opportunities of Open Data in Ecology. Science 331, 703-705.
Richardson, A.J., Poloczanska, E.S., 2008. Under-Resourced, Under Threat. Science 320, 1294-1295.
Robinson, S., Marsden, G., Jones, M., 2015. Chapter 1 - Introduction, There's Not an App for That. Morgan Kaufmann, Boston, pp. 1-29.

Roy, H.E., Pocock, M.J.O., Preston, C.D., Roy, D.B., Savage, J., Tweddle, J.C., Robinson, L.D., 2012. Understanding Citizen Science and Environmental Monitoring. Final Report on Behalf of UK-EOF. NERC Centre for Ecology & Hydrology and Natural History Museum.
Schläppy, M.-L., Loder, J., Salmond, J., Lea, A., Dean, A.J., Roelfsema, C.M., 2017. Making Waves: Marine Citizen Science for Impact. Frontiers in Marine Science 4.
Schmeller, D.S., Henry, P.Y., Julliard, R., Gruber, B., Clobert, J., Dziock, F., Lengyel, S., Nowicki, P., Déri, E., Budrys, E., Kull, T., Tali, K., Bauch, B., Settele, J., Van Swaay, C., Kobler, A., Babij, V., Papastergiadou, E., Henle, K., 2009. Advantages of volunteer-based biodiversity monitoring in Europe. Conservation Biology 23, 307–316.
Short, F., Carruthers, T., Dennison, W., Waycott, M., 2007. Global seagrass distribution and diversity: A bioregional model. Journal of Experimental Marine Biology and Ecology 350, 3-20.
Short, F.T., Polidoro, B., Livingstone, S.R., Carpenter, K.E., Bandeira, S., Bujang, J.S., Calumpong, H.P., Carruthers, T.J.B., Coles, R.G., Dennison, W.C., Erftemeijer, P.L.A., Fortes, M.D., Freeman, A.S., Jagtap, T.G., Kamal, A.M., Kendrick, G.A., Kenworthy, W.J., La Nafie, Y.A., Nasution, I.M., Orth, R.J., Prathep, A., Sanciangco, J.C., van Tussenbroek, B., Vergara, S.G., Waycott, M., Zieman, J.C., 2011. Extinction risk assessment of the world's seagrass species. Biological Conservation 144, 1961-1971.
Smith, S.D.A., Edgar, R.J., 2014. Documenting the density of subtidal marine debris across multiple marine and coastal habitats. PLoS One 9, e94593.
Theobald, E.J., Ettinger, A.K., Burgess, H.K., DeBey, L.B., Schmidt, N.R., Froehlich, H.E., Wagner, C., Hille-Ris-Lambers, J., Tewksbury, J., Harsch, M.A., Parrish, J.K., 2015. Global change and local solutions: tapping the unrealized potential of citizen science for biodiversity research. Biological Conservation 181, 236-244.
Tweddle, J.C., Robinson, L.D., Pocock, M.J.O., Roy, H.E., 2012. Guide to citizen Science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK. Natural History Museum and NERC Centre for Ecology & Hydrology for UK-EOF Available online: http://www.ukeof.org.uk/.
Unsworth, R.K.F., Hinder, S.L., Bodger, O.G., Cullen-Unsworth, L.C., 2014. Food supply depends on seagrass meadows in the coral triangle. Environmental Research Letters 9, 094005.
Ward, E.J., Marshall, K.N., Ross, T., Sedgley, A., Hass, T., Pearson, S.F., Joyce, G., Hamel, N.J., Hodum, P.J., Faucett, R., 2015. Using citizen-science data to identify local hotspots of seabird occurrence. PeerJ 3, e704.
Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T., Williams, S.L., 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences of the United States of America 106, 12377-12381.
Whittaker, R.J., Araújo, M.B., Jepson, P., Ladle, R.J., Watson, J.E.M., Willis, K.J., 2005. Conservation biogeography: assessment and prospect. Diversity and Distributions 11, 3–23.
Wilkes, R., Bennion, M., McQuaid, N., Beer, C., McCullough-Annett, G., Colhoun, K., Inger, R., Morrison, L., 2017. Intertidal seagrass in Ireland: Pressures, WFD status and an assessment of trace element contamination in intertidal habitats using Zostera noltei. Ecological Indicators 82, 117-130.

Table 1. Seagrass projects that are either based on, or use citizen science. Projects listed with their type and spatial range.

Project	Project type	Responsible Organisation	Reach	Description of Citizen Science element	Ref
Seagrass-Watch	Scientific Lead program incorporating contributory and collaborative Citizen Science & Citizen Engagement	Seagrass-Watch, Australia	Global	Utilises groups of trained volunteers to collect monitoring data.	www.seagrasswatch.org
SeagrassSpotter	Contributory Citizen Science & Citizen Engagement	Project Seagrass	Global	Uses a phone app and website where users upload georeferenced seagrass pictures and answer basic questions pertaining to health and threats.	www.seagrassspotter.org
Community Seagrass Initiative	Contributory Citizen Science & Citizen Engagement	National Marine Aquarium, Plymouth, UK	Local	Primarily utilises groups of trained volunteers to collect seagrass monitoring data using SCUBA.	www.csi-seagrass.co.uk
Sailing for Seagrass	Contributory Citizen Science & Citizen Engagement	Healthy Waterways and Earthwatch Australia	Regional	Utilises groups of trained volunteers to collect seagrass monitoring data, seagrass samples and fish surveys while on board a research vessel.	hlw.org.au/initiatives/science/sailing-for-seagrass
Community Eelgrass Mapping Initiative	Citizen Science	Seagrass Conservation Working Group, BC, Canada	Regional	Utilises groups of trained volunteers to collect monitoring data.	www.seagrassconservation.org/conservation
Sarasota County Seagrass Survey	Contributory Citizen Science & Citizen	Sarasota County, US	Regional	Utilises a large group of volunteers for assistance with annual monitoring survey.	www.scginternet.scgov.net/Watersheds/Pages/Seagrass.aspx

	Engagement				
Port Curtis Seagrass Restoration	Citizen Engagement	Central Queensland University (Australia)	Local	Utilises a group of volunteers for assistance with transplant collection.	www.facebook.com/PortCurtisSeagrass
SeaSearch	Citizen Science	Parks Victoria (Australia)	Regional	Utilises groups of trained volunteers to collect monitoring data.	www.parkweb.vic.gov.au/get-involved/volunteer/sea-search

Table 2. Applications of seagrass citizen science programmes.

Viewpoint	**Focus Level**	**Characteristics**
Phenology and Resilience	Biological	• Identification of flower occurrence • Sediment seed counts
Seagrass Disease	Biological	• Occurrence of wasting disease
Seagrass Distribution and Abundance	Ecological	• Presence of seagrass locally, regionally, nationally or globally • Site specific species abundance
Seagrass community species	Ecological	• Presence of fish within seagrass • Presence of invertebrates within seagrass • Identification of large marine fauna within seagrass
Threats to seagrass	Socio-ecological	• Identification of current threats, e.g. mooring surveys
Historic Seagrass Loss	Socio-ecological	• Identification of historical seagrass change
Fisheries use	Socio-ecological	• Identification of fisheries use of seagrass meadows
Responses to land-use changes	Socio-ecological	• How seagrass meadows may have changed over time

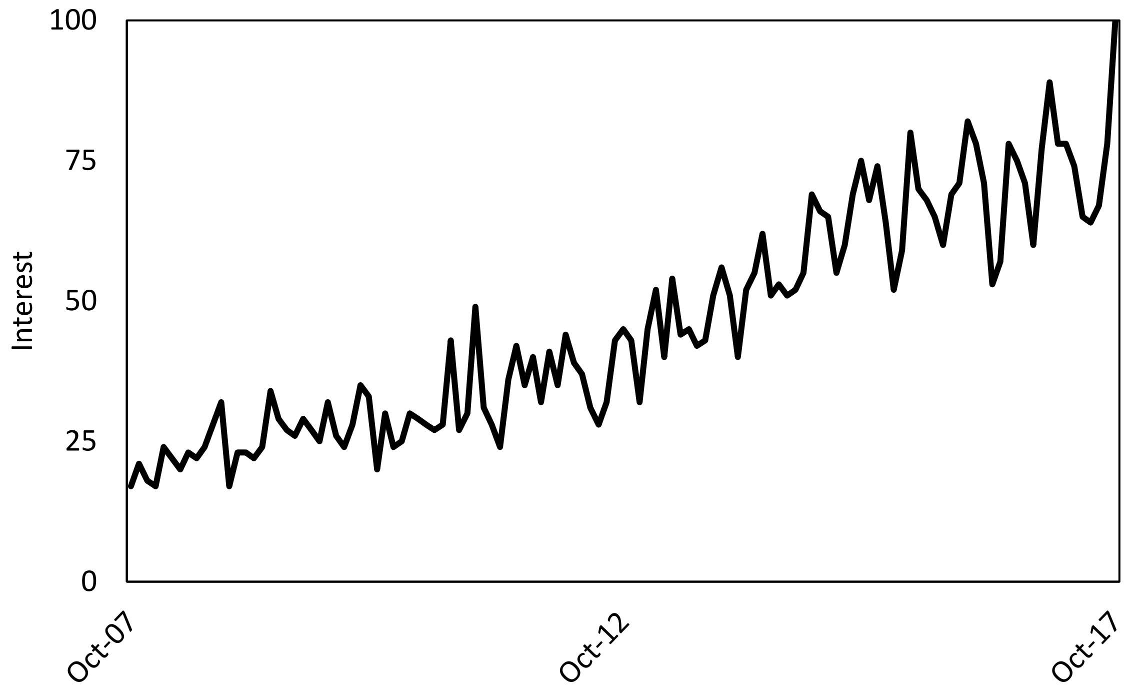

Fig. 1. Searches on the Google search engine for “citizen science” from 1st October 2007 to 1st October 2017. Data has been normalised (y-axis), where 100 = the day with most searches for citizen science as a proportion of all Google searches, and 75 = 75% the proportion of searches for citizen science as a proportion of all Google searches compared to the day with the most searches.