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Review Paper

# Incorporating citizen science to advance the Natural Capital approach

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ABSTRACT

There are several frameworks which have been developed to describe the Natural Capital assessment approach. However, some of these frameworks are not fully operational in practice, and there is no unified methodology. Furthermore, calls have been made to increase the public's awareness and understanding of Natural Capital issues. To address some of these limitations it has been suggested to incorporate citizen science methods, an approach which has been increasingly growing in the Natural Capital field. The purpose of this article is to present a framework within the context of UK environmental policy as a case study. It illustrates the practicalities and the potential of using citizen science and other forms of public engagement approaches within a pre-existing Natural Capital accounting framework. This article first reviews current UK Natural Capital assessment approaches, as well as the potential for including citizen science and public engagement approaches. Combining these approaches, the inclusion of citizen science within the Natural Capital assessment framework is explored through the development of a conceptual model. We argue that the inclusion of a citizen science approach, and other forms of public engagement within the Natural Capital assessment can support in gathering a multidimensional perspective on comprehensive Natural Capital assets, and ecosystem service benefits. Knowledge generated could then be implemented to support holistic decision-making for nature-based solutions.

## 1. Introduction

The UK Government describes 'Natural Capital' as a stock of natural assets and includes both the living and non-living aspects of the ecosystem. Examples of assets include water, air, soils, and ecological communities (Defra, 2020). These assets can generate a wide range of direct and indirect goods and services which can support the wellbeing of human societies, i.e., ecosystem service benefits (Natural Capital Committee, 2014). Natural Capital is one of several measurable assets that describe and interpret economic behaviour and the stock that yields a flow of valuable goods or services. Other assets include financial and human capitals (Costanza and Daly, 1992).

Natural Capital is a widely used concept that has been studied and reviewed from different academic standpoints. These include Social-Ecological-Systems (SES; Kremer et al., 2016), ecological economics (Guerry et al., 2015), environmental policy, land management and sustainability (Mace et al., 2015). For this reason, conceptualising Natural Capital has often generated complex debates across different disciplines owing to its multidimensional and dynamic nature (Barbier, 2019). It is, however, beyond the scope of this article to review the many ways these concepts have been previously explored (see for example Islam et al., 2018). Instead, as the review is framed by the UK policy context, Natural Capital is reviewed and portrayed through the lens of the UK Government's Natural Capital definition (Defra, 2020).

Since the 1990s, concerted efforts have been made to develop a comprehensive account of Natural Capital assets and ecosystem service benefits to help sustain resource use, economic prosperity and wellbeing (Barbier, 2019). Owing to its inherently interdisciplinary nature, Natural Capital has been assessed using various evaluation frameworks and related methodological approaches. Examples of existing frameworks include the Ecosystem Service Framework, the Habitat Classification Framework, and the Natural Capital conceptual framework (Kueffer and Daehler, 2009; Matzdorf and Meyer, 2014; Hooper et al., 2019). Similarly, related methodological approaches can range from those more

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conventional economic valuations to those non-monetary approaches (e.g. Cost-Benefit and photographic analysis approaches) (Barbier, 2019). As a result, a diverse range of assessment tools has been developed and implemented. Examples include remote sensing, spatial ecological modelling, and questionnaire surveys (Guerry et al., 2015).

Despite efforts to develop an evaluation framework to encapsulate the Natural Capital assessment approach, there remain five key challenges (Natural Capital Committee, 2020). First, there is a limited amount of data available for certain types of Natural Capital assets (e.g. marine, woodland, and heathland habitats) and related ecosystem service benefits (e.g. soil health, and aquatic environment assets). This includes what types of assets are present, the ecosystem service benefits these assets generate, the pathways from assets to additive benefits, information on management practices as well as the quality, quantity, and spatial configuration of these assets (Hooper et al., 2019; Natural Capital Committee, 2020). Thus, the true Natural Capital value of the associated service benefits is not fully known (Hooper et al., 2019).

Second, it may not be feasible to gather a comprehensive account of Natural Capital assets and continue systematically to monitor progress towards achieving environmental goals (Bright et al., 2019; Natural Capital Committee, 2020). This suggests further monitoring capacity is needed at a large spatial and temporal scale.

Third, some frameworks not fully operational in practice with no unifying methodology through which the Natural Capital assessment approach is applied, and existing frameworks are often being conducted in a 'sectorally siloed approach' (Hooper et al., 2019).

Fourth, there is a need to consider natural assets, ecosystem services and associated data on different spatial–temporal resolutions. This introduces spatial diversity. To date, researchers have adopted and built on an array of pre-existing landscape ecology methods and tools to describe dynamic landscape patterns and processes. Such methods could feed into the Natural Capital approach, i.e., land change modelling, spatiotemporal dynamics, and spatial units model (Frazier and Kedron, 2017).

Finally, there have been calls for increasing citizen's awareness of natural asset issues. There is some evidence that there is a lasting legacy of how engagement in environmentally focused activities (e.g. ecological monitoring) can facilitate a deeper sense of awareness and advocacy for pro-environmental behavioural changes to enhance future environmental, and sustainability impacts (Pillemer et al., 2010; Cooper et al., 2016; Molsher and Townsend, 2016; Seymour et al., 2018; Seymour et al., 2020).

In response to some of these challenges, further action using a multifaceted approach is therefore needed to increase our understanding of existing Natural Capital assets, as well as our capacity to conduct comprehensive large-scale systematic monitoring across various landscape types (Natural Capital Committee, 2020). The incorporation of citizen science and other forms of public engagement to engage communities has been recommended by some as one such approach (Natural Capital Committee, 2020). Therefore, this article explores this gap in knowledge.

Citizen science can be broadly defined as the engagement of citizens in scientific research in partnership with scientists, encompassing a variety of disciplinary fields (Roy et al., 2012; Kullenberg and Kasperowski, 2016). Citizen science is a research approach that has been applied across various fields of research. These include assessments of biodiversity (Roy et al., 2012; Boakes et al., 2016), health (Den Broeder et al., 2018), astronomy (Raddick et al., 2013) and ecosystem services (Schröter et al., 2017). For instance, citizen science can be used to not only collect and analyse large-scale scientific data sets through public participation, but also to explore issues of democratisation of science and public engagement itself (Regalado, 2015; Eitzel et al., 2017).

The use of the citizen science approach to increase our sense of understanding about the state and trends of ecosystem services has grown in interest (Boakes et al., 2016; Natural Capital Committee, 2020). It also holds potential for future ecosystem service research (Schröter et al., 2017). In part this owes to the parallels shared between citizen science and ecosystem research. For example, both bridge links between the natural (e.g. biodiversity) and social sciences (e.g. wellbeing) that help contribute to the conservation and restoration of natural environments (Roy et al., 2012). Similarly, citizen science and ecosystem service research both play a pivotal role in civic participation, linking science and society (Haklay, 2013). Consequently, this would further support the social ambitions of the UK's 25 Year Environment Plan and other policy instruments (e.g. the United Nations Sustainable Development Goals; McKinley et al., 2017).

Furthermore, there is increasing evidence regarding the potential use of citizen science approaches to enhance existing data in ecosystem service research (see Schröter et al., 2017). Nonetheless, while the contribution of the citizens to scientific knowledge does have a degree of influence on policy and decision-making, more could be done to increase existing public engagement (Delaney et al., 2020). Citizen science also has a useful role in helping to shape the ecosystem service agenda and act as mechanisms of the UK's democratic landscape. This could result in a broader community understanding with respect to natural asset issues (Pearse, 2020).

The purpose of this article is to present a framework in the form of a conceptual model within the context of UK environmental policy, as a case study, for incorporating citizen science and other forms of public engagement approaches within a pre-existing Natural Capital accounting framework. Our framework promotes inquiry into understanding the contributions of citizen science on Natural Capital assessments. The model combines theoretical concepts and methodological approaches from all the research fields examined in this review. In doing so, it aims to facilitate a more multidimensional perspective of Natural Capital assets and ecosystem service benefits. It also aims to generate knowledge that could be implemented to support the wider decision-making process in working towards environmental goals. Additionally, through the inclusion of citizen science and other forms of public engagement approaches, we propose that the Natural Capital assessment approach can be employed in collaborative working. This would enhance the UK's ability to conduct large-scale systematic monitoring required for comprehensive Natural Capital accounts (Natural Capital Committee, 2020).

This article has a specific layout. Following this general introduction, we present our conceptual framework, reviewing current UK Natural Capital assessment approaches, as well as the inclusion of citizen science and other forms of public engagement. We also review the core concepts and point out the practical implications of methodological approaches that have been used. Existing research on ecosystem service assessment and citizen science approaches as well as other forms of public engagement used are then highlighted. The article ends by outlining the advantages of our conceptual framework over other conceptual frameworks, the challenges for its implementation, as well as its possible applications in other contexts.

## 2. Towards an interdisciplinary and an inclusive Natural Capital assessment approach

Since the late 1980s, several frameworks have been developed to encapsulate the Natural Capital assessment approach, i.e. the Ecosystem Service Framework and the Habitat Classification Framework (Matzdorf and Meyer, 2014). As Hooper et al (2019) highlight in their review, each have operational limitations. These include a siloed approach to delivery, insufficient guidance, metrics which are habitat context specific, and no standardised approach for classifying services and are not yet fully applicable in practice.

More recently, Hooper et al's (2019) conceptual model broadly describes the current Natural Capital assessment approach undertaken to measure the extent, status and value of Natural Capital assets and services benefits derived from them in the context of UK policy. However, the model, based on existing practices, has been suggested to have no single universal methodology through which the Natural Capital approach is applied (Islam et al., 2018; Bright et al., 2019). Further challenges within existing practices, as outlined in Section 1, include limited data on some key natural assets and ecosystem services, a limited public awareness of and engagement in natural asset issues, as well as spatial variability in existing datasets (Natural Capital Committee, 2020).

To address these limitations identified in the above frameworks and models, we present a framework in the form of a conceptual model (Fig. 1) within the context of UK environmental policy, as a case study. The conceptual model is explained and detailed further in subsections 2.1 to 2.4. Its aim is to illustrate the practicalities and the potential of using citizen science and other forms of public engagement approaches within a pre-existing Natural Capital accounting framework (e.g. both scientific and non-scientific applications) (Pearse, 2020). Our framework therefore promotes inquiry into understanding the contributions of citizen science and other public engagement approaches on Natural Capital assessments.

Our framework is inclusive of a wide range of methodological approaches, multiple data types, and evidence as it works towards creating a more universal and standardised assessment approach to evaluating Natural Capital assets and their associated service benefits (Natural Capital Committee, 2020). This is achieved through bringing together various stakeholders (e.g. policy makers, land managers, economists, ecologists, non-governmental organisations, citizens, and academics) to ensure the Natural Capital asset based metrics developed are applicable in a range of landscape contexts, is interdisciplinary and an example of best practice (Hooper et al., 2019). The framework aims to facilitate a deeper sense of public awareness about the coupled Socio-Ecological-System of interest, supporting the wider decision-making process in working towards environmental goals. It also aims to as well as create a comprehensive set of Natural Capital accounts through the use of a large-scale systematic monitoring and evaluation programme (Schröter et al., 2017). To achieve this, the model builds from Hooper's conceptual model for Natural Capital assessment with the addition of citizen science (Hooper et al., 2019).

Using this evolving conceptual model proposed, the Natural Capital assessment approach can be employed by various actors working collaboratively, enabling a more interdisciplinary and publicly engaged framework. Multiple streams of knowledge from the public participation in scientific research can be combined bringing not only a greater depth to the data collected but also increasing the capacity at which it is collected (Schröter et al., 2017; Hooper et al., 2019; Natural Capital Committee, 2020). This could be achieved through enhancing mixed method approaches and adopting pragmatic research to achieve a comprehensive valuation of Natural Capital components. As such, a more multidimensional perspective of Natural Capital components (e.g. assets and service benefits) across landscape types (landscape and urban ecology) would be gained, adding knowledge that could be implemented to support the wider decision-making process in working towards environmental goals (Defra, 2020; Bright et al., 2019).

The next section will critically evaluate the existing literature at the intersection of the Natural Capital assessment, citizen science and public engagement approaches, as defined in this review. It further describes each of the four stages within our Natural Capital assessment framework. This will be explored through four subsections, presenting each of the stages in our framework, as presented in the conceptual model (Fig. 1): 'System Elements', 'Framework Actors', 'Data Collection and Measurements', and 'Assessment and Appraisal Mechanisms'.

### 2.1. System elements

'System elements' is representative of the three foundation elements used in the Natural Capital assessment approach within the UK policy context (Natural Capital Committee, 2014). This conceptual model presents the pathway of the assessment approach linking the three system elements: (1) 'Natural Capital assets'; (2) the pathways of the 'ecosystem services' from 'Natural Capital assets' to support human wellbeing (e.g. provisioning, regulatory, supporting and cultural ecosystem services); and (3) 'goods' produced from the 'ecosystem service' pathways and provide a valued benefit (monetary and non-monetary) to human wellbeing (Islam et al., 2018).

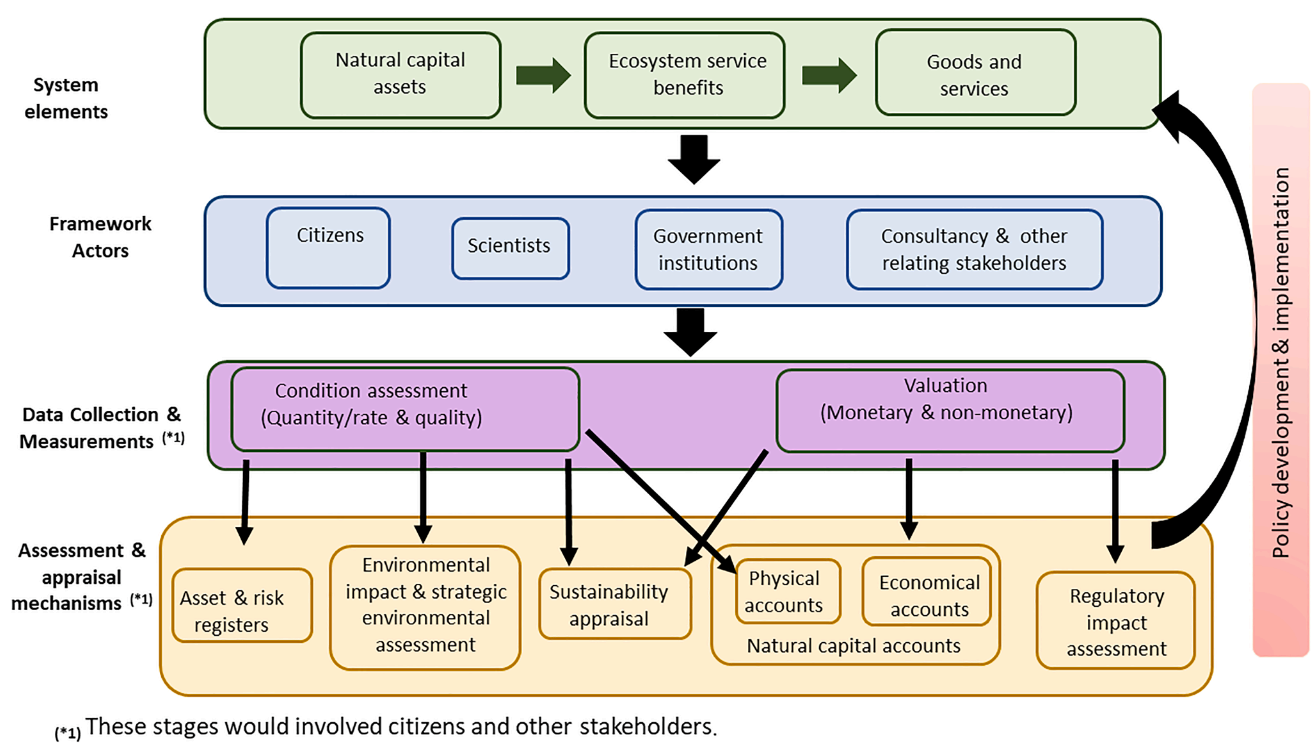


**Fig. 1.** Towards an interdisciplinary Natural Capital assessment approach, inclusive of citizen science. The framework builds on from Hooper et al. (2019)'s Natural Capital assessment approach logic model.

Natural assets includes both the living and non-living aspects of the ecosystem. Examples of assets include water, air, soils, and ecological communities (Defra, 2020). These assets can generate a wide range of direct and indirect goods and services which can support the wellbeing of human societies, i.e., ecosystem services (Natural Capital Committee, 2014).

Ecosystem services can be described as a service generated and they have been grouped into categories which are used to describe the types of services generated (Guerry et al., 2015; Bright et al., 2019). For instance, Hinterberger et al (1997) suggested that there are three types of ecosystem services: non-renewable resource-based services, renewable resource-based services, and an ecosystem's assimilative capacity to sustain itself. However, more recently others have highlighted the importance of those more intangible services (Costanza, 2008). As such, four major categories of ecosystem services have been more broadly identified and measured, as illustrated in the UK's Natural Capital assessment approach (Defra, 2020). These are supporting, provisioning, regulating, and cultural ecosystem services (Costanza et al., 2008; Islam et al., 2018). These four categories of ecosystem services are outlined below.

Supporting ecosystem services are the fundamental ecosystem processes necessary to produce all other ecosystem services and deliver societal benefits. Examples include photosynthesis, evolution, biomass production, production of atmospheric oxygen, soil formation, nutrient cycling, water cycling, maintenance of genetic diversity, and provisioning of habitats for species (Islam et al., 2018).

Regulating ecosystem services are the ecosystem processes and conditions which help to modulate natural phenomena. Examples of these include climate regulation, biological control, pollination, carbon sequestration and wastewater treatment (Islam et al., 2018).

Cultural ecosystem services also generate a wide range of benefits each describing the many ways in which people find meaningful relationships with nature and their links (direct and indirect) with human wellbeing (Seymour, 2016). They have also been described as the beneficial contributions of nature to a good quality of life for all people (Diaz et al., 2018). 'Goods' and service benefits generated include wellbeing, spiritual enrichment, as well as aesthetic, artistic and educational values (Satz et al., 2013). These benefits can be generated from a host of nature-based activities in all forms of habitats (urban and rural), from outdoor recreation and tourism to environmental volunteering and wildlife monitoring (Gould et al., 2019).

Finally, provisioning ecosystem services are the material 'Goods' and energy outputs generated by ecosystems. These include water, food, raw materials, medicinal resources, and biofuels (Islam et al., 2018).

### 2.2. Framework actors

'Framework actors' is an added feature in this conceptual model building on the Natural Capital assessment framework in Hooper et al (2019). Our reason for including 'Framework Actors' in our conceptual model was to illustrate the inclusion of citizen science and public engagement approaches within the UK Natural Capital assessment approach in addition to other framework actors involved. The term identifies the actors involved, their roles, and collaborative working practices within the framework (see Table 1 for details). The four actors involved are: (1) citizens who engage in scientific research and decision-making processes who work in partnership with multiple stakeholders; (2) scientists who engage in and conduct scientific research (e.g. those in both public and private research-focused institutions as well as within academia); (3) government institutions referring to all government agencies, departments, and public bodies in the context of Natural Capital research; and (4) consultancy and other relevant stakeholders relevant to Natural Capital research (e.g. local authorities, community groups, landowners, and NGOs). In our model, 'Framework Actors' are viewed through a UK perceptive, as a case example. Similarly, we focus on the role of citizens for the purpose of our article aim, with further

**Table 1**
Summarised description of Framework Actors, their roles and collaborative working practices within the framework.

| Framework Actor | Description of roles, and collaborative working practices within the framework |
|---|---|
| Citizens | • Citizens who engage in scientific research and decision-making processes and who work in partnership with multiple stakeholders. This refers to all levels of public participation in citizen science, where possible: contributory projects, collaborative projects, co-created projects, and citizen-led research. For example, citizens can participate in multiple research activities, from defining research questions and designing methods to interpreting data and disseminating findings.<br>• Citizens work in collaboration with scientists, government institutions, consultancies, and other relevant stakeholders. This would help to foster knowledge and support within citizen science programmes, to increase existing knowledge in the fields of natural capital assets, ecosystem services and service benefits (e.g. the impacts of human related activities), as well as feed information gathered into the wider decision-making process (e.g. policy evaluation). |
| Scientists | • Scientists engage in and conduct scientific research (e.g. those in both public and private research-focused institutions as well as within academia). They support, work in partnership with and/or lead scientific research involving a citizen science research approach (e.g. contributory and co-created projects). This involves providing research training, recruiting citizens to participate in projects, to assist or lead in developing methodological designs, as well as to provide expertise on data collect and analyse where needed.<br>• Scientists work in collaboration with citizen scientists, consultancies, and other relevant stakeholders. This collaboration would provide support to government institutions in monitoring large-scale systematic monitoring needed to develop comprehensive Natural Capital accounts, as well as developing Natural Capital asset-based metrics to be developed that are applicable across various landscape types. |
| Government institutions | • Government institutions in our model refers to all government agencies, departments, and public bodies in the context of Natural Capital research. They create and monitor the ongoing progress of working towards developing a comprehensive account of all Natural Capital assets to help measure overall progress towards achieving the environmental goals (e.g. the UK Government's 25 Year Environment Plan).<br>• Government institutions work in collaboration with citizen science programmes, scientists, consultancies, and other relevant stakeholders. This would provide guidance and support for other collaborators on developing Natural Capital asset-based metrics as well as relating methodological designs. |
| Consultancy & other relevant stakeholders | • Consultancy and other relevant stakeholders relevant to Natural Capital research (e.g. local authorities, community groups, landowners, and NGOs). They can provide advice, local knowledge, and can be involved in Natural Capital research involving a citizen science approach. This would include acting as gatekeepers to access those hard-to-reach local community groups, to provide advice and localised knowledge, as well as to have direct involvement or to support the delivery of Natural Capital research using a citizen science research approach.<br>• Consultancy and other relevant stakeholders can work in collaboration with citizen science |

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**Table 1** (*continued*)

| Framework Actor | Description of roles, and collaborative working practices within the framework |
|---|---|
| | programmes, scientists, consultancies, and other relevant stakeholders. This collaboration would provide support to government institutions and scientists in large-scale systematic monitoring needed to develop comprehensive Natural Capital accounts, as well as developing Natural Capital asset-based metrics to be developed that are applicable across various landscape types. |

descriptions on the roles of other framework actors found in other literature (e.g. Mace et al., 2015; Bright et al., 2019).

Evidence has shown that the role citizens have provided a valuable step change in our ability to collect data and monitor Natural Capital assets, ecosystem services, as well as goods and services in addition to the actors mentioned above (Pocock et al., 2018). As studies show, there is a history of recording by citizens using citizen science approaches both in the UK and across the world (Meyer et al., 2016; Thornhill et al., 2018). The inclusion of citizen science approaches within the Natural Capital assessment approach has been driven by the pressures of policy instruments across local, national, and international scales with data forming part of the frameworks assessing policy outcomes, enhancing our ability to respond to threats at all scales from local to global, i.e., the UK's 25 Year Environment Plan, and the Convention on Biological Diversity (Defra, 2018; Secretariat of the Convention on Biological Diversity, 2020; Ryan et al., 2018). Similarly, there is some evidence that citizen science data has been used by governments and various stakeholders, both globally and in the UK (Chandler et al., 2017). To assess the effects of other policy decisions and investments on the environment, society, and the economy, i.e., Millennium Ecosystem Assessment 2005 and United Nation's Sustainable Development Goals 2015 (see Chandler et al., 2017; Latombe et al., 2017; Pocock et al., 2018).

However, in our model the role of citizens within the Natural Capital assessment framework goes beyond data collection and analysis of large-scale datasets for scientific research (Shirk et al., 2012). The role of citizens also includes their involvement in decision-making processes. Here the role of citizens has both a scientific and non-scientific application (Pearse, 2020). This notion goes beyond the idea that citizens can enhance their own knowledge and also contribute to scientific knowledge which could, to a degree, have an influence on policy and decision-making (Hauck et al., 2016). This is because citizen involvement in conservation and natural resource management initiatives (e.g. Natural Capital assessment processes) often do so in many different contexts stemming from traditions as varied as participatory engagement and citizen science (Shirk et al., 2012). Within these initiatives, both traditions engage citizens in activities (e.g. environmental monitoring and other public engagement approaches) that help contribute to addressing complex social-ecological issues (Roy et al., 2012; Pearse, 2020).

A further reason for citizens' role in decision-making processes within the Natural Capital assessment process, owes to the importance of engaging those stakeholders due to be affected by policy issues (Pearse, 2020). By stakeholder, we refer to "any group or individual who can affect or is affected by the ecosystem's services" including citizens (e.g. beneficiaries, those negatively affected, landowners, and decision makers) (Hauck et al., 2016). As others point out, stakeholder involvement is not only regarded as an essential element in environmental management and decision making, but is also considered critical in the context of ecosystem services (e.g. Harrington et al., 2010; Hauck et al., 2013). This is because not only does the inclusion of stakeholder knowledge provide important information for decision making that reflects a range of interests (e.g. technical, theoretical, and social or practical), but it also adds legitimacy to decision making (Pearse, 2020). In attempts to include stakeholders, including citizens, within the UK policy and decision-making process we are seeing more forms of public engagement approaches (e.g. including citizen science) enabling stakeholders to participate in reflective and informed discussions relating to policy issues and decision making. This includes ecosystem services (Delaney et al., 2020; Pearse, 2020).

Public engagement is a diverse term often used interchangeably with public participation and consultation, covering a spectrum of activities (Mohensi, 2020). More broadly, public engagement can be defined as "a two-way process, involving interaction and listening, with the goal of generating mutual benefit" between researchers and the public (National Co-ordinating Centre for Public Engagement, 2021). This includes any attempt to contact members of the public to inform decision making (Marino et al., 2019). It is rooted in democratic principles (e.g., the theory of deliberative democracy) where evidence informed discussions are central to the public decision-making process, adopting both consensus decision-making and majority rule approaches (Chambers, 2003; Delaney et al., 2020). In our model, various types of public engagement approaches feature in both 'Data Collection and Measurements' as well as 'Assessment and Appraisal Mechanism' components. Further details about these approaches are summarised in Sections 2.3 and 2.4.

Finally, the level of participation in scientific research and decision-making processes can vary widely, owing to both a project design and the motivation of participating citizens for engagement (Ponciano and Brasileiro, 2014; Boakes et al., 2016; Seymour and Haklay, 2017). For example, citizens can participate in multiple research activities, from defining research questions and designing methods to interpreting data and disseminating findings (Shirk et al., 2012). More broadly, there are four stages or parts of the citizen science and public engagement project process that participants can get involved in as part of their role (Shirk et al., 2012; Regalado, 2015): (1) contributory projects, where citizens collect data or samples are part of a project led by scientists; (2) collaborative projects, where citizens and scientists jointly interpret and disseminate project findings based on data collected; (3) co-created designs, where citizens and scientists jointly develop a project across all of its stages; and (4) citizen-led research, where citizens take the lead across all project stages with scientists taking on a secondary supporting role. Further typologies and definitions of public participation in scientific research and decision-making processes have been previously explored (e.g. Haklay, 2013; Eitzel et al., 2017; Delaney et al., 2020; Pearse, 2020), but it is beyond the scope of the present article to detail these. Instead, we focus on all forms of participation which relate to ecosystem services.

### 2.3. Data collection and measurements

'Data Collection and Measurements' is an adapted feature in this conceptual model building on the Natural Capital assessment framework in Hooper et al (2019). This adapted feature has been added to illustrate the supporting data pathways in the UK Natural Capital assessment process, as a case example. Here, 'Data Collection' refers to the various data types (e.g. species biodiversity, and aesthetic quality of habitat types) collected to define the characteristics of Natural Capital assets as well as provide evidence regarding their links to ecosystem services and goods produced (Mace et al., 2015; Defra, 2020). Such data collected are often implemented through various methodological approaches including ecological field surveys, wellbeing indices, questionnaire surveys, participatory engagement approaches (e.g. participatory GIS), as well as a host of spatial mapping techniques (Islam et al., 2018). These data can then be used to undertake 'Measurements'.

'Measurements', as identified by Hooper et al (2019), describes the two main approaches in which Natural Capital system elements are assessed, using data collected (Hooper et al., 2019). First, condition assessment refers to the quantity, quality and spatial configuration of natural assets and ecosystem services being assessed. For example, the condition, structure, and function of water bodies (in natural, managed, and urban landscapes) can be identified by assessing their biological, chemical, and ecological quality status (Huston and McBride, 2002). Second, 'valuation' refers to the methodologies used to measure the 'value' generated by ecosystem services as well as their relating goods and benefits used to support human wellbeing (Mace et al., 2015). Examples include conventional economic valuation approaches (e.g. Willingness To Pay and gross national income) as well as non-monetary valuation approaches (e.g. voting mechanisms and stakeholder analysis) (Guerry et al., 2015; Barbier, 2019). For instance, the cultivation of food *via* provisioning ecosystem service activities (e.g. farming or urban allotments) has a monetary market value. Conversely, an increase in a person's subjective wellbeing linked to cultural ecosystem service activities (e.g. visiting a green space or engaging in food growing activities) typically has a non-monetary value. Though there are exceptions, i.e., expenditure by tourists (Gliozzo et al., 2016; Seymour et al., 2020). Both approaches used to assess Natural Capital system elements are then used during the 'Assessment and appraisal mechanism' stage.

The 'Data Collection and Measurements' stage is undertaken by 'Framework Actors', including citizens, with their individual roles, methodological approaches used, and collaborative working practices individually shaped by project goals and objectives (Sauermann et al., 2020). Much evidence is already emerging to support citizen involvement in the Natural Capital Assessment approach in the UK and across the world (for further details see Schröter et al., 2017). This includes activities in data collection and more in-depth procedures, across various levels of participation (e.g. contributory, collaborative, and codesign), excluding citizen-led approaches (Shirk et al., 2012; Schröter et al., 2017). However, such citizen involvement in assessing Natural Capital's 'System Elements' is widely varied. For instance, more studies have been found on regulating and cultural services, than those supporting and provisional owing to a host of factors, i.e., availability of data, abstract nature of ecosystem services, inaccessibility of those more remote areas and inadequate indicators (Schröter et al., 2017). It is, however, beyond the scope of this article to review the wide variety of 'System Elements' that have been assessed using citizen science and public engagement approaches previously explored (see Schröter et al., 2017). Instead, we have summarised evidential examples outlining citizen sciences' increasing contributions to each of the three 'System Elements' from a UK perspective in Table 2 below.

Finally, 'Measurements' also features those values generated by citizen science activities and other forms of public engagement approaches. These include understanding how people learn through environmental science learning, what benefits they gain as well as how these relate to pro-environmental behaviours (Ballard et al., 2017). This is a further adapted feature in this conceptual model building on the Natural Capital assessment framework in Hooper et al (2019). We have included these 'Measurements' owing to their usefulness to other features of the interdisciplinary Natural Capital assessment approach, i.e., assessment, appraisal, and future policy development (Ballard et al., 2017).

### 2.4. Assessment and appraisal mechanisms

'Assessment and appraisal mechanisms' occur towards the end of the Natural Capital assessment process. This stage can be defined as those systematic evidence-based procedures through which the information gathered on Natural Capital accounts can be incorporated into the wider decision-making process, i.e., policy evaluation, development and future implementation (Hooper et al., 2019). Information gathered can include the characteristics (e.g. extent, status, and value) and future trends of Natural Capital assets and ecosystem service benefits derived during earlier stages of the Natural Capital Assessment approach (e.g. 'Data Collection and Measurements') by multiple 'Framework Actors' (Mace et al., 2015; Hooper et al., 2019). This information can then serve as a useful baseline against which impacts of management, policy, and development options can be evaluated in the context of defined objectives for environmental exploitation, protection, maintenance, and

**Table 2**
Summarised evidential examples outlining citizen sciences' increasing involvement to each of the three 'System Elements'.

| System Elements | Description of data collection and measurements used | Examples of citizen involvement in data collection and measurements used | References illustrating citizen involvement |
|---|---|---|---|
| Natural Capital Assets | • Natural Capital Asset can be measured using methodological approaches from various disciplines including ecology (all landscape types), social science, computer science, and health science fields in the context of Natural Capital. These approaches measure the quality, quantity, and spatial configuration of such assets as well as the whether the assets are at risk of deteriorating in status. Example data collection methods include remote sensing, ecological monitoring, and questionnaire surveys undertaken by citizen scientists, researchers, and other stakeholders.<br>• Natural Capital Asset data collected can be used to conduct a condition assessment. This will evaluate the quantity, quality and spatial configuration of natural assets and ecosystem services using various mixed methods. | • Data collection and monitor Natural Capital assets and ecosystem services.<br>Examples: Water quality sampling, biodiversity (presence and absence identification), and monitoring community garden crop yields. | Pocock et al., 2015; Gliozzo et al., 2016; Boakes et al., 2016; Schröter et al., 2017; Thornhill et al., 2018; Mahajan et al., 2020; Edmondson et al., 2019; Dunkley, 2020; Pinho et al., 2021; Koffler et al., 2021; |
| Ecosystem Service benefits | • 'Ecosystem Service Benefits' builds on from the data collected about Natural Capital Assets.<br>• 'Ecosystem Service Benefits' measures the services generated from 'Natural Capital Assets' to support human wellbeing. These services can be measured using methodological approaches from various disciplines including ecology (all landscape types), social science, and health science fields in the context of Natural Capital. These approaches would | • Data collection and monitor Natural Capital assets and ecosystem services.<br>Examples: Monitoring the changing populations of UK pollinators, identifying aesthetic and wellbeing impacts of UK national parks, and damage to leaves of the horse-chestnut tree across Great Britain. | Pocock and Evans, 2014; Gliozzo et al., 2016; Boakes et al., 2016; Fish et al., 2016; Saarikoski et al., 2019; August et al., 2019; Carvel et al., 2020; |

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**Table 2** (*continued*)

| System Elements | Description of data collection and measurements used | Examples of citizen involvement in data collection and measurements used | References illustrating citizen involvement |
|---|---|---|---|
| | evaluate the type of services derived from the 'Natural Capital Assets' identified and the processes which have led to the services' outcomes. Example data collection and analytical methods include ecological modelling, spatial modelling, participatory system mapping, and semi-structured interviews undertaken by citizen scientists, researchers and other stakeholders. <br>• 'Ecosystem Service Benefit' data collected can be used to conduct a condition assessment. This will evaluate the quantity, quality and spatial configuration of ecosystem services using various mixed methods. <br>• It can also be used to evaluate the value generated by ecosystem services as well as their relating goods and benefits used to support human wellbeing (see below). | | |
| Goods and Services | • 'Goods and Services' builds on from 'Ecosystem Service Benefit' data collected and measures the valued benefits produced from 'Ecosystem Service benefit' to support human wellbeing. <br>• 'Goods and Services' can be measured both in monetary and non-monetary terms. The approach uses various 'Valuation' approaches from economic valuation, participatory research, and social science fields in the context of Natural Capital. These approaches. Example methods include Cost-Benefit Analysis, Willingness To Pay, | • Indirectly involving citizens, by measuring a project's ability to raise awareness and enhance the citizens' scientific knowledge. <br>Examples: Pro-environmental behaviours, and informal science opportunities (e.g., museum-led learning) as well as engagement and stewardship in research <br>• Valuing 'Goods and Services' through forms of engagement and dialogue instruments. <br>Examples: Deliberative multicriteria | Stagl et al., 2003; Bateman et al., 2013; Gliozzo et al., 2016; Seymour and Haklay, 2017; Ballard et al., 2017; Phillips et al., 2018; Haklay et al., 2018; Seymour et al., 2018; Ballard et al., 2019; Edmonson et al., 2019; Saarikoski et al., 2019; Peter et al., 2021; |
| | photographic analysis and participatory GIS approaches undertaken by citizen scientists, researchers and other stakeholders. <br>• It can also include measuring enhanced scientific literacy and pro-environmental behaviours associated with being involved in citizen science, deliberative and participatory forms of engagement. | evaluation method, participatory GIS, Willingness To Pay, and participatory multi-criteria decision aid. | |

restoration (Hooper et al., 2019). Further, all information generated, would feed into policy development and implementation (e.g. process and impact evaluation), its ongoing evaluation, and its future implementation (Hooper et al., 2019).

It is noteworthy that there is no single universal methodology through which these assessment and appraisal mechanisms are applied, with a variety being currently being implemented (Barbier, 2019). The five main assessment and appraisal mechanisms generally used in the UK are: (1) asset and risk registers referring to an inventory of the natural assets, their quality, quantity and spatial entity as well as whether the assets are at risk of deteriorating in status based on data collected; (2) Environmental Impact and Strategic Environmental Assessments (EIA, SEA) of specific programmes, plans and projects to consider and address their potential impacts on the environment; (3) Sustainability Appraisal, a tool used to appraise planning policy documents to promote sustainable development; (4) Natural Capital accounting elements of Natural Capital research assessing stocks and flows, in monetary and nonmonetary terms; and (5) regulatory impact assessments used to evaluate the economic, social, and environmental implications of new legislation or other policy changes (Hooper et al., 2019). It is noteworthy that not all these evidence-based procedures are framework specific to UK Natural Capital accounting.

Similar to the 'Data Collection and Measurement' stage of our Natural Capital Assessment framework, our model includes citizens within the 'Assessment and Appraisal Mechanisms' stage. Our purpose for its inclusion here is to enhance scientific knowledge and decision-making processes associated with ecosystem services, thereby supporting, or are being included within existing 'Assessment and Appraisal Mechanisms'. This is achieved through various forms of engagement and dialogue instruments, which can be used to support and included within the five key assessment and appraisal mechanism identified above (Langemeyer et al., 2018; Delaney et al., 2020; Pearse, 2020). Descriptions of these forms of engagement and dialogue instruments as well as examples of how they could be used to support key 'Assessment and Appraisal Mechanisms' used in the UK are summarised in Table 3.

Early evidence suggests such deliberative and participatory forms of engagement are and could be seen as having a useful role in helping to shape the UK ecosystem service agenda (Delaney et al., 2020). This is because they could be seen to act as mechanisms of the democratic landscape resulting in a broader community understanding with respect to natural asset issues (Mavrommati et al., 2017; Pearse, 2020). For instance, Delaney et al (2020) used a citizens' jury approach to identify management priorities for a section of the North Sea, the Dogger Bank. Similarly, the deliberative multicriteria evaluation (DMCE) method for

**Table 3**
Summarised evidential examples outlining citizen sciences' increasing involvement to each of the 'Assessment and Appraisal Mechanisms'.

| Assessment and Appraisal Mechanisms | Description of data collection and measurements used to support assessment and appraisal mechanisms | Examples of citizen involvement in data collection and measurements used to support assessment and appraisal mechanisms | References illustrating citizen involvement |
|---|---|---|---|
| Asset and risk registers | Data collected and associated measurements regarding the condition and valuation of natural assets, relating goods and benefits that will feed into an inventory of the natural assets (including their risk status). | • Data collection and monitor Natural Capital assets and ecosystem services.<br>Examples:Water quality sampling, biodiversity (presence and absence identification), and monitoring community garden crop yields. | Pocock and Evans, 2014; Pocock et al., 2015; Boakes et al., 2016; Fish et al., 2016; Gliozzo et al., 2016; Schröter et al., 2017; Thornhill et al., 2018; Saarikoski et al., 2019; Edmondson et al., 2019; Dunkley, 2020; Mahajan et al., 2020; August et al., 2019; Carvel et al., 2020; Pinho et al., 2021; Koffler et al., 2021; |
| Environmental Impact and Strategic Environmental assessments (EIA, SEA) | Data collected and associated measurements regarding the condition and valuation of natural assets, relating goods and benefits that will feed into these assessments. | • Data collection and monitor Natural Capital assets and ecosystem services.<br>Examples: Water quality sampling, biodiversity (presence and absence identification), and monitoring community garden crop yields. | As above. |
| Sustainability appraisal | Data collected and associated measurements regarding the condition and valuation of natural assets, relating goods and benefits that will feed into these appraisals. This could also include deliberative and participatory forms of engagement with members of public and other stakeholders as part of the appraisal process (e.g. the citizens' jury, deliberative multi-criteria evaluation method and participatory multi-criteria decision aid). | • Indirectly involving citizens, by measuring a project's ability to raise awareness and enhance the citizens' scientific knowledge.<br>Examples:Pro-environmental behaviours, and informal science opportunities (e.g. museum-led learning) as well as engagement and stewardship in research<br>• Valuing 'Goods and Services' through forms of engagement and dialogue instruments.<br>Examples: Deliberative multicriteria evaluation method, participatory GIS, Willingness To Pay, and participatory multi-criteria decision aid.<br>• Decision making through forms of engagement and dialogue instruments.<br>Examples:Citizens' jury, deliberative multicriteria evaluation method, and participatory multi-criteria decision aid. | Stagl, 2006; Bateman et al., 2013; Gliozzo et al., 2016; Seymour and Haklay, 2017; Ballard et al., 2017; Haklay et al., 2018; Seymour et al., 2018; Phillips et al., 2018; Ballard et al., 2019; Edmondson et al., 2019; Saarikoski et al., 2019; Delaney et al., 2020; Peter et al., 2021; |
| Natural Capital accounts | Data collected and associated measurements regarding the condition and valuation of natural assets, relating goods and benefits that will feed into these accounts. This could also include deliberative and participatory forms of engagement with members of public and other stakeholders as part of the appraisal process (e.g. the citizens' jury, deliberative multi-criteria evaluation method and participatory multi-criteria decision aid). | • Indirectly involving citizens, by measuring a project's ability to raise awareness and enhance the citizens' scientific knowledge.<br>Examples: Pro-environmental behaviours, and informal science opportunities (e.g. museum-led learning) as well as engagement and stewardship in research.<br>• Valuing 'Goods and Services' through forms of engagement and dialogue instruments.<br>Examples: Deliberative multicriteria evaluation method, participatory GIS, Willingness To Pay, and participatory multi-criteria decision aid.<br>• Decision making through forms of engagement and dialogue instruments.<br>Examples:Citizens' jury, deliberative multicriteria evaluation method, and participatory | As above. |

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Table 3 (*continued*)

| Assessment and Appraisal Mechanisms | Description of data collection and measurements used to support assessment and appraisal mechanisms | Examples of citizen involvement in data collection and measurements used to support assessment and appraisal mechanisms | References illustrating citizen involvement |
|---|---|---|---|
| | | multi-criteria decision aid. | |
| Regulatory impact assessment | Data collected and associated measurements regarding the condition and valuation of natural assets, relating goods and benefits that will feed into these assessments. This could also include deliberative and participatory forms of engagement with members of public and other stakeholders as part of the appraisal process (e.g. the citizens' jury, deliberative multi-criteria evaluation method and participatory multi-criteria decision aid). | • Indirectly involving citizens, by measuring a project's ability to raise awareness and enhance the citizens' scientific knowledge.<br>Examples:Pro-environmental behaviours, and informal science opportunities (e.g. museum-led learning) as well as engagement and stewardship in research.<br>• Valuing 'Goods and Services' through forms of engagement and dialogue instruments.<br>Examples: Deliberative multicriteria evaluation method, participatory GIS, Willingness To Pay, and participatory multi-criteria decision aid.<br>• Decision making through forms of engagement and dialogue instruments.<br>Examples: Citizens' jury, deliberative multicriteria evaluation method, and participatory multi-criteria decision aid. | As above. |

decision making about UK energy policy (Stagl, 2006). However, although emerging evidence is already available, much remains unknown about the potential of other forms of engagement approaches within a pre-existing Natural Capital assessment framework (Pearse, 2020). Therefore, a robust research effort guided by a focus on key unanswered questions is needed but is beyond the scope of this article.

## 3. Opportunities and challenges for including citizens in the Natural Capital assessment framework

### 3.1. Opportunities

The most prevailing opportunity of including citizen science and public engagement approaches within the Natural Capital assessment, is its ability to collect and analyse large-scale datasets at different spatial–temporal resolutions (e.g. species presence, land change modelling, and taxonomic coverage) (Bonney et al., 2009; Theobald et al., 2015; Frazier and Kedron, 2017). For instance, the assessment of regulating and provisioning ecosystem services have provided large-scale data to address many grand challenges, including within human food systems, water quality regulation, climate regulation through carbon storage, pollination, and pest control (Hulbert et al., 2017; Ryan et al., 2018). Examples include monitoring the changing populations of UK pollinators (e.g. the UK Pollinator Monitoring Scheme; Carvell et al., 2016), and identifying pollution levels in European freshwater rivers (e.g. Freshwater Watch; August et al., 2019). This finding is in line with the most acknowledged benefits of these approaches (Bonney et al., 2009; Meyer et al., 2016; Schröter et al., 2017). As such, these approaches could therefore assist calls to gather a comprehensive account of Natural Capital assets and continue systematically to monitor progress towards achieving environmental goals (Bright et al., 2019; Natural Capital Committee, 2020). This includes what types of assets are present, the ecosystem service benefits these assets generate, the pathways from assets to additive ecosystem service benefits, information on management practices as well as the quality, quantity, and spatial configuration of those natural assets where there is a limited amount of data (Hooper et al., 2019; Natural Capital Committee, 2020). Thus, the true Natural Capital value of the associated service benefits would become increasingly known (Hooper et al., 2019).

Another opportunity includes the increasing accessibility of advancing technology (e.g., smart mobile phone apps) and available data resources (e.g. citizen science platforms and databases) combined with increased forms of communication (e.g. social media) which enhances citizens' ability to collect data for research projects. For instance, this would include linking biodiversity or ecosystem service spatial analysis with other social or health-related data (Bonney et al., 2009; Colin and Crona, 2017; Schröter et al., 2017). It also offers new ways for citizens to participate in scientific research and decision-making processes (Theobald et al., 2015).

A further benefit of using citizen science and public engagement approaches is their potential to help foster the production of partnerships between citizens, scientists, policy makers, other stakeholders (e.g. businesses and charitable organisations). This would provide several outcome benefits for the Natural Capital Assessment approach including increased public trust and empowerment, provide opportunities for guidance and support, as well as decreased objection to decisions (Langemeyer et al., 2018; Dryzek et al., 2019; Delaney et al., 2020). This is partially indebted to the methods' ability to be used as effective dialogue-based instruments incorporating citizen viewpoints into policy making processes and tend to vary in their approach depending on the objectives and issues being addressed (Farrell et al., 2019). It would also help to maximise the exposure and impact of their research, as well as strengthen ongoing and future methodological designs (e.g. recruitment and retention) (Boakes et al., 2016; Seymour and Haklay, 2017).

These approaches also have a useful role in helping to shape the ecosystem service agenda as well as act as mechanisms of the UK's democratic landscape (Pearse, 2020). This is because not only does the inclusion of stakeholder knowledge provide important information for decision making that reflects a range of interests (e.g. technical, theoretical, and social or practical), but it also adds legitimacy to decision making (Pearse, 2020). It could also result in a broader community awareness and understanding with respect to natural asset issues as well as enhance scientific literacy (Mavrommati et al., 2017; Natural Capital Committee, 2020; Pearse, 2020). As such, this further supports the social ambitions of the UK's 25 Year Environment Plan and other policy instruments (e.g. the United Nations Sustainable Development Goals; McKinley et al., 2017). This is because of its ability to provide practical experiences in scientific inquiry to enrich people's academic and professional skills base (e.g. problem solving and self-confidence), facilitate a deeper sense of awareness of environmental issues, and improve the accessibility of science regardless of personal, geographical, or socio-economic background (Ballard et al., 2017). Examples include engaging students in research on urban habitat for pollinators and collecting wildlife observations through the iSpot mobile app (Herodotou, 2018), and the Natural History Museum-led Citizen Science initiatives (Ballard et al., 2019).

Additionally, there is some evidence that there is a lasting legacy of how public engagement in environmental management issues can facilitate a deeper sense of awareness and advocacy for pro-environmental behavioural changes to enhance future environmental, and sustainability impacts (Pillemer et al., 2010; Cooper et al., 2016; Molsher and Townsend, 2016; Seymour et al., 2018; Seymour et al., 2020). For example, Chao et al (2021) identified that those who engaged in citizen science bird surveys in Taoyuan, China, increase their degree of pro-environmental behaviours. Similarly, Cooper et al (2016) found wildlife recreationists were more likely than non-recreationists to engage in conservation behaviours. Such behaviours included donating to support local conservation efforts, enhancing wildlife habitat on public lands, advocating for wildlife recreation, and participating in local environmental groups. This is particularly important if we are to understand the value of nature for people and the environment (Barbier, 2019). It is also important to understand how people learn through environmental science, what benefits they gain as well as how these relate to pro-environmental behaviours. Such knowledge may also be useful for the assessment, appraisal, policy development, and implementation features of the interdisciplinary Natural Capital assessment approach (Ballard et al., 2017).

Finally, owing to our models' inherently interdisciplinary and pragmatic nature, Natural Capital is assessed using various evaluation and related methodological approaches. Whilst we are seeing more studies within the Natural Capital field using methods across various dimensions (e.g. quantitative, qualitative or mixed methods), our model goes further to include multiple streams of knowledge from the citizen participation in scientific research. In doing so, this brings not only a greater depth to data collected but also increase the capacity at which it is collected (Schröter et al., 2017; Hooper et al., 2019; Natural Capital Committee, 2020). As such, a more multidimensional perspective of Natural Capital components (e.g. assets and service benefits) across landscape types (landscape and urban ecology) would be gained, adding knowledge that could be implemented to support the wider decision-making process in working towards environmental goals (Bright et al., 2019; Defra, 2020). Furthermore, whilst adopting a pragmatic outlook can bring its own challenges (e.g. issues combining qualitative and quantitative methods), several researchers have proposed methodological frameworks to address these concerns (Onwuegbuzie and Johnson, 2006; Tashakkori and Teddlie, 2006).

### 3.2. Challenges

The inclusion of citizen science and public engagement approaches in the Natural Capital Assessment process is, however, not without challenges. Data quality is a commonly raised concern within any citizen science and public engagement research project, including ecosystem services research (Dickinson et al., 2010; Schröter et al., 2017). Further criticism relates to temporal and spatial biases in data as well as variability sampling efforts (Boakes et al., 2016). Such data quality concerns can often be dependent on volunteers' training, expertise, and level of engagement in the project (Kosmala et al., 2016). However, some researchers have identified ways these issues can be addressed through project design and its implementation (Dickinson et al., 2010). This includes selecting an approach compatible with the volunteer users' skills and knowledge, as well as the adoption of highly standardised protocols or a minimum sampling standard during data collection (Dickinson et al., 2010; Kim et al., 2011; Seymour, 2019). Similarly, others have highlighted the valuable insights biases can provide into volunteers' recording behaviour which could be used to design projects (e.g. sampling protocols and recruitment strategies) to enhance the fit between volunteers' interests, observation behaviours, and the requirements of scientific projects (Boakes et al., 2016; Seymour and Haklay, 2017).

Another challenge relates to the usability of information and communications technology (ICT), as well as accessibility of data resources and suboptimal tools (e.g. low-quality sensors) available for citizens to use (Hecker et al., 2018; Skarlatidou et al., 2019). Whilst low-cost technological advances for both gathering and analysing data are increasingly growing (e.g. Petäjä et al., 2021), the use of suboptimal ICT can have negative impacts on projects, such as hidden costs (Hecker et al., 2018). In response, some have called for improvements to current project designs and funding schemes to be made available moving forward (Willemen et al., 2015; Skarlatidou et al., 2019). One notable example is the recent technological developments of identification systems-based artificial intelligence (AI). This includes sensors that may be able to undertake automatic species identification where possible and future monitoring of regulating ecosystem services (e.g. pollination) from pictures or sounds increasingly accurate, rapid and reliable (e.g. the obsidentify app; see Fontaine et al., 2021). It is noteworthy that not all species can be identified using these technological developments. As such, it is not known whether these technological developments question the need for amateur involvement in biodiversity observations, highlighting the need to use such technology in a way that truly benefits both scientists and amateurs (Høye et al., 2021).

Furthermore, the adoption of citizen science and public engagement approaches may not always be suitable or useful for ecosystem service assessments (Schröter et al., 2017; Fish et al., 2016; Gould et al., 2019; Johnson et al., 2019). Reasons for this include the availability of other high-quality data, the complexity of ecosystem service assessments required, the need for more appropriate indicators, the paucity of methods for connecting cultural ecosystem services to human wellbeing, as well as inability to collect data beyond indirect proxies related to ecosystem services (e.g. species counts) (Gliozzo et al., 2016; Boakes et al., 2016; Ryan et al., 2018; Huelsman and Epstein, 2018; Bubalo et al., 2019; Manes et al., 2016; Halliwell, 2019; Haywood et al., 2021). Moreover, supporting, cultural, and regulating ecosystem services are valued indirectly as they are processes which give rise to other goods and service benefits, i.e., improving water quality, or costs associated with direct human wellbeing (Gittleman et al., 2012; Russo et al., 2017; Thornhill et al., 2018; Callaghan et al., 2019). For this reason, they are often not fully captured in commercial markets or adequately quantified in terms that are comparable with economic services and manufactured capital (Winthrop, 2014; Small et al., 2017; Bright et al., 2019). In response, some studies have attempted to show how to integrate supporting ecosystem services information in multidimensional assessments (e.g. Thornhill et al., 2018; Manea et al., 2019). Additionally, others suggest the use of alternative approaches, such as non-economic assessments and preference-based valuation has grown in recent years. These include surveying perceptions, deliberative focus group discussions and narrative short stories (Mahajan et al., 2020; Toomey et al., 2020). However, each of these approaches comes with their own set of criticisms and disadvantages, reinforcing the opinion that mixed methods are the most effective way to capture in-depth information (Church et al., 2014).

Finally, a further challenge relates to managing ethical issues effectively, such as exploitation of citizen scientists, conflicts of interest, data sharing and intellectual property (Dickinson et al., 2010; Boakes et al., 2016; Seymour and Haklay, 2017). To overcome this challenge, some suggest the need to promote ethical research throughout the course of scientific investigation (Resnik et al., 2015). This includes managing expectations with citizens from the outset, clarifying roles and responsibilities, discuss issues around data ownership as well as ensure transparency in the communication of project findings (Dickinson et al., 2010; Resnik et al., 2015).

## 4. Gaps and further applications of citizen science approaches: Ecosystem service research and beyond

As noted in Section 2.3, citizen involvement in assessing Natural Capital's 'System Elements' is widely varied, and currently presents some evidence gaps (Manes et al., 2016; Pocock et al., 2018; Ritson et al., 2019; Sampson et al., 2019). For example, relatively more studies can be found on regulating and cultural services, than those supporting and provisional services, albeit with studies of these steadily growing (Schröter et al., 2017; Bright et al., 2019). Furthermore, few citizen science studies exist presenting the use of monetary economic valuation methods to assess ecosystem services in landscape and urban sustainable management, particular in response to different land management practices (Saarikoski et al., 2019). Whilst some of these evidence gaps owes to a host of factors, such as method suitability (see Section 3.2), addressing some of these challenges may offer a unique opportunity for scientists and other stakeholders alike to use these approaches to act as promoters for an understanding of how to conserve the societal benefits gained from nature (Russo et al., 2017; Wanjala et al., 2018). Similarly, it is anticipated that the inclusion of citizen science and public engagement approaches might evolve into powerful standardised tools for future Natural Capital assessments as advanced technologies evolve, data resources become increasingly more accessible, and collaborations across 'Framework Actors' increase (Schröter et al., 2017; Pocock et al., 2018; Sauermann et al., 2020). In this way, the true Natural Capital value of the ecosystem service benefits may become increasingly known as will their underlying characteristics (Hooper et al., 2019).

Furthermore, this article is framed by the UK policy context, with Natural Capital being portrayed through the lens of the UK Governments Natural Capital definition which makes for a particularly timely case study (Natural Capital Committee, 2020). However, progress on incorporating citizen science to advance the Natural Capital approach to environmental valuation is taking place globally and continuously evolving, including through efforts to monitor global biodiversity and to increase the availability of this data, such as in Asia and Africa (e.g. eBird, Pocock et al., 2018). Future revisions of our model would perhaps benefit from the integrated application of the wider natural capital approaches more globally, to provide a more holistic framework for the complete assessment.

Beyond its inclusion in the Natural Capital assessment approach, the application of citizen science and public engagement approaches appear in a broad range of research fields and outlets (e.g. health and astronomy), presenting various opportunities and challenges (see Dickinson et al., 2010; Sauermann et al., 2020). Although implemented across all areas of research, these approaches have gained most prominence as a tool to address environmental, and land management issues, i.e., preserving biodiversity, conserving natural resources, and enhancing social-ecological resilience (Chandler et al., 2017; Pocock et al., 2018; Seymour et al., 2020). This owes to citizen sciences' significant innovative potential in science, society, and policy to address many grand challenges, as noted in Section 3.1 (Turrini et al., 2018). Nonetheless, given the innovative potential of these approaches some argue over its ability to support growing sustainability transitions needed to address some of humanity's' biggest issues (Pocock et al., 2018; Sauermann et al., 2020). The extent of these challenges spanning a range of disciplines is evident in the UN 2015 Sustainability Development Goals, and includes climate change, public health, and environmental conservation (McKinley et al., 2017; Sauermann et al., 2020). However, it is not without some challenges. Notably the need for increasing aspects of citizen participation (e.g. diversity of citizens and intensity of participation), as well as addressing the social and technical nature of sustainability issues through further interdisciplinary collaborations (see Sauermann et al., 2020).

## 5. Conclusion

The purpose of this article is to present a framework in the form of a conceptual model within the context of UK environmental policy as a case study, building on Hooper et al's (2019) existing Natural Capital assessment approach conceptual model. It is based on an interdisciplinary outlook at the intersection of the Natural Capital assessment approach and the inclusion of public engagement, addressing the limitations identified in existing models. Some of the limitations include no unifying methodology through which Natural Capital accounting is applied, and a lack of implementation in practice. In addition, Natural Capital research is often conducted in a 'sectorally siloed approach' (Hooper et al., 2019).

Our framework promotes inquiry into understanding the contributions of citizen science on Natural Capital assessments. To achieve this, we review the core concepts and point out the practical implications of methodological approaches that have been used to bring a greater depth of interdisciplinary understanding. In attempting this, a balance between both rigorous scientific analysis as well as collaborative participatory research will be required through the adoption of a pragmatic outlook. We also explore existing research on ecosystem service assessment and citizen science approaches as well as other forms of public engagement used.

Finally, the central discussion explored the practicalities and potential of using citizen science approaches and other forms of public engagement within the Natural Capital assessment approach. To improve the Natural Capital assessment approach, existing uses of citizen science as a data collection and measurement approach was explored. The paper also acknowledges current gaps and limitations of applying existing citizen science approaches to the different types of ecosystem service assessments (as characterised by Islam et al (2018)). Most of these relate to research at the intersection of ecosystem services and citizen science projects which have been increasingly growing in the Natural Capital field. It has also been highlighted that the use of citizen science approaches and other forms of public engagement within the Natural Capital assessment approach brings its own challenges to the already complex research base in relation to its methodological design.

In summary, our conceptual model illustrates that an interdisciplinary and citizen science approach can facilitate a more multidimensional perspective of Natural Capital components (e.g. assets and service benefits). It therefore adds knowledge that could be implemented to support the wider decision-making process in working towards environmental goals. Additionally, through the inclusion of a citizen science and other forms of public engagement, the Natural Capital assessment approach can be employed by various framework actors working collaboratively (policy makers, environmental practitioners, NGOs, researchers and citizens). It also has the ability to conduct large-scale systematic monitoring needed to develop comprehensive Natural Capital accounts (Natural Capital Committee, 2020).

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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