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The contributions of citizen science to SDG monitoring and reporting on marine plastics

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Abstract

The accumulation of plastic litter in marine environments is a major environmental challenge along with the difficulties in their measurement because of the massive size of the oceans and vast circulation of plastic litter, which is being addressed as part of the United Nations (UN) Sustainable Development Goals (SDGs). Citizen science, public participation in scientific research and knowledge production, represents a potential source of data for SDG monitoring and reporting of marine plastic litter, yet there has been no evidence of its use to date. Here, we show how Ghana has become the first country to integrate existing citizen science data on marine plastic litter in their official monitoring and reporting of SDG indicator 14.1.1b for the years 2016–2020, which has also helped to bridge local data collection efforts with global monitoring processes and policy agendas by leveraging the SDG framework. The results have been used in Ghana's 2022 Voluntary National Review of the SDGs, and reported on the UN SDG Global Database, as well as helping to inform relevant policies in Ghana. In addition, here, we present a pathway that can be adopted by the relevant government authorities in other countries that have an interest in following a similar citizen science data validation and reporting process for this indicator and potentially others.

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Introduction

The UN Sustainable Development Goals (SDGs) are a set of 17 goals and 169 targets adopted by UN Member States in 2015 to guide the world's development efforts by 2030 (UN 2015a). The key to achieving the SDGs is robust monitoring systems based on timely, accurate and comprehensive data (Dang and Serajuddin 2020; Campbell et al. 2020). To help develop and operationalize such monitoring systems, the UN Statistical Commission (UNSC) established the Inter-agency and Expert Group on SDG Indicators (IAEG-SDGs) in 2015, with representatives of UN Member States including regional and international agencies as observers (UNSTATS 2022). As a result, the IAEG-SDGs have created the global indicator framework, adopted by the UNSC in 2017 (UN 2017). Since then, the indicator framework has been reviewed and refined and currently includes 231 unique indicators that are used to measure progress toward the targets and the goals of the SDG agenda (MacFeely 2019; Mac-Feely and Nastav 2019).

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Countries play a central role in SDG monitoring and reporting processes. This means that global reporting on SDG indicators are expected to be based on data and statistics produced by the National Statistical Systems involving the National Statistical Offices (NSOs), line ministries and other national agencies (UN 2015a). Countries are encouraged to conduct regular reviews of progress toward the SDG agenda at a national and sub-national level (UN 2015a). These reviews, called Voluntary National Reviews (VNRs), should be voluntary and country-led and are considered as the basis for regular reviews by the UN High-Level Political Forum (HLPF), the central platform for the review of the SDG agenda (HLPF 2023). The VNRs help to share experiences, best practices and lessons learned that can support the achievement of the SDG agenda and facilitate partnerships for the SDGs.

Despite these efforts, we are now halfway through the SDG process and large data gaps remain as a persistent barrier to adequate monitoring and achievement of the SDGs (UNSD 2022; Fraisl and Hager et al. 2022a, b). Current SDG monitoring mechanisms rely mainly on traditional data sources such as official surveys, but these have various issues from outdatedness to high implementation costs (Fritz et al. 2019). New data sources, such as mobile data, data from Earth observation and citizen science, are acknowledged as a potential solution to complement these traditional data sources and to address their aforementioned shortcomings (UN Global Pulse and GSMA 2017; Fraisl et al. 2020; Ferreira et al. 2020; Wuebben et al. 2020; König et al. 2020; Head et al. 2020).

Citizen science is the participation of the public in scientific research and in the production of new knowledge—whether led by communities or run by research institutions (Butler et al. 2023; Espinosa and Rangel 2022; Shirk et al. 2012; Eitzel et al. 2017). Citizen science activities can cover a wide range of topics from biodiversity observations to gender-based violence (Manshur et al. 2023; Gotama et al. 2023; Fraisl et al. 2023b). They can also take various forms including projects where participants only contribute data to research led by scientists or there are more bottom-up initiatives where participants are in charge of many aspects of the research from identifying the problem to communicating the results (Franzese and Ripa 2023; Pozzi and Ladio 2023; Zarghani et al. 2023). This diversity of disciplines, approaches and motivations involved in citizen science makes it difficult to agree on a universal definition (Zarghani et al. 2023; Terenzini et al. 2023; Auerbach et al. 2019; Haklay et al. 2021). The complexity becomes even greater, when varying terms to describe citizen science activities are considered, such as citizen-generated data, which is mostly used by the official statistics communities for civil society-led initiatives (Datashift 2017; Lämmerhirt et al. 2018), or crowdsourcing, which refers to harnessing the power of the crowd to build large data sets (Wazny 2017; Howe 2006). Examples of other terms include participatory action research (Effendy et al. 2022; MacDonald 2012), volunteer computing (Nouman Durrani and Shamsi 2014), volunteered geographic information (Anshori et al. 2022; Sieber and Haklay 2015) and community science (Charles et al. 2020). Our use of the term citizen science is inclusive of all the aforementioned practices and leaves space for new approaches to emerge and grow.

The wealth of topics and methodologies covered by citizen science activities also indicates that there is no one-size-fits-all approach for designing and implementing citizen science projects. However, an overview of approaches would be helpful for sharing best practices and building capacity around ethical considerations related to citizen science. Fraisl and Hager et al. (2022a) outlined six stages for designing and implementing citizen science. The authors also highlighted that a meaningful community engagement that ensures inclusiveness and other ethical aspects, such as data quality, data sharing and intellectual property, should be key considerations in all citizen science projects. These considerations are also articulated in the ECSA 10 Principles of Citizen Science, which aims to promote excellence and impact in citizen science (Robinson et al. 2018). For example, one of the 10 Principles refers to the importance of proper acknowledgment of participants in project results and publications, which is an ethical aspect to consider in citizen science activities.

Citizen science has significant potential in addressing data gaps and needs, which is of great importance for science and policy including the monitoring of international frameworks such as the SDGs (Croese et al. 2021; Lin et al. 2023; Cronemberger et al. 2023; Elias et al. 2023). For example, in their systematic review, Fraisl et al (2020) highlighted that citizen science data have the potential to contribute to 33% of the SDG indicators, particularly in the field of environment. They also identified that, out of 81 indicators with potential for benefiting from citizen science data, for only five indicators this potential has actually been realized. These are the indicators related to rural access, protected areas, threatened species and marine plastics. Citizen science data can contribute to SDG monitoring in two main ways: top-down and bottom-up. With top-down contributions, we mean that existing citizen science data, not necessarily collected for SDG monitoring or official reporting purposes, are leveraged and then validated by countries to ensure their quality for official monitoring. With bottom-up contributions, we refer to cases where citizen science practitioners design their initiatives together with government agencies or by considering their requirements for data at the start, so that their data meet the data gaps and quality requirements of government agencies to ensure the uptake of their results.

Citizen science also has benefits beyond addressing data gaps (Fraisl et al. 2023a). For example, it provides an opportunity to bring the public and science closer together (Golumbic et al. 2022). It contributes to transformative actions needed to address societal challenges by raising awareness and mobilizing action, which in turn can support behavioral change (Johnson et al. 2014; Van Brussel and Huyse 2019). Additionally, citizen science approaches and results are used to inform policies at the local, national and global levels, promoting more "democratic" decision-making (Cunha et al. 2017; de Sherbinin et al. 2021). Even though citizen science has a great potential to address many of the scientific and societal challenges, it still has some limitations, as is the case with any scientific method or data source (Walker et al. 2021; Magson et al. 2022; Tan et al. 2022). Examples of such limitations include lack of participant engagement (Measham and Barnett 2008; West and Pateman 2016), biases related to spatial and temporal coverage of data (Daniel and Underhill 2023; Cooper 2014; Cretois et al. 2021) and lack of diversity in participant profiles (Elias et al. 2023; Pandya 2012; Hobbs and White 2012). Depending on the context and the methodology used, there may be other limitations involved.

Although citizen science is an increasingly acknowledged scientific method in many disciplines from astrophysics to public health, it is particularly prevalent in environmental and ecological sciences (George et al. 2021; Zulian et al. 2021; Manshur et al. 2023; Kullenberg and Kasperowski 2016). One area in which citizen science is extensively used in environmental sciences is marine litter (Kawabe et al. 2022; Hermoso et al. 2021; Catarino et al. 2023). Marine litter, particularly plastics, is one of the most pervasive problems facing the world's oceans and seas (Haward 2018). An estimate of 19–23 million metric tons of plastics generated globally in 2016 ended up in aquatic ecosystems (Borrelle et al. 2020; Lau et al. 2020), which poses a growing threat to marine life and ecosystems (Nelms et al. 2017). It also has negative impacts on human health and well-being, adversely affecting livelihoods that depend on industries such as tourism and fishing (Kühn et al. 2015; Newman et al. 2015). Recognizing that urgent action is needed, a resolution was adopted by the United Nations Environment Assembly in 2022 (UNEA-5.2) that aims to end plastic pollution and forge an international and legally binding agreement by 2024 (UNEP 2022). However, the real extent of the marine plastics problem is currently unknown due to the vastness of the oceans and the extensive circulation of plastic litter, including to the most remote areas of the world's marine environment (Eriksen et al. 2014). Hence, research on marine litter and its impact on the environment is challenging and expensive (Woodall et al. 2015).

Many countries around the world are affected by the marine plastic litter problem due to the increasing volumes of plastic waste disposed of in the environment (OECD 2023). In fact, land-based sources account for 80% of the world's marine pollution (UNEP 2016; GESAMP 2019). The municipal solid waste generated annually worldwide is about 2.01 billion tones and about 33% of it is not managed properly (Kaza et al. 2018). At a global level, 93% of waste is dumped in low-income countries and disposed of in a way that is harmful to the environment (Kaza et al. 2018). This waste eventually ends up in marine and freshwater bodies. Among the world regions, the Pacific and East Asia generate 23% of the world's waste, while sub-Saharan Africa is among the fastest growing solid waste-generating regions and by 2050 this will triple (Kaza et al. 2018). In Ghana, with a coastline of 550 km facing the Gulf of Guinea, the coastal zones represent an important natural and economic resource (Van Dyck et al. 2016). However, solid waste management is a problem in Ghana where only 5% of the estimated 1.1 million tons of plastic waste generated annually is collected and recycled (GPAP 2021). To address this problem, a shift in policy and practice is needed to ensure sustainable and efficient management of municipal solid waste including an in-depth understanding of the various categories of marine plastic litter, as well as the amount of litter that enters the sea (Musah et al. 2021). This has led the Ghanaian government to commit to finding a sustainable solution to the plastic waste management problem. For example, Ghana was the first African country to join the Global Plastic Action Partnership in 2019 (Government of Ghana 2020; GPAP 2021). In addition to the growing awareness of the marine plastic litter problem in the country, Ghana has a growing citizen science beach cleanup community (Olen 2022).

The marine litter issue is also recognized at a global level such as in the SDG framework (UN 2015b). SDG 14 *Life Below Water* addresses the issues affecting the seas and oceans including marine litter. Citizen science offers the potential to mitigate the marine litter problem by involving the public as citizen scientists in both data collection and mobilizing action (Hidalgo-Ruz and Thiel 2013; Nelms et al. 2022). Therefore, SDG 14, more specifically, the global methodology for SDG indicator 14.1.1b *Plastic Debris Density*, recommends citizen science as a primary data source for monitoring beach litter (GESAMP 2019; UNEP 2021), and this potential has also been highlighted in recent literature (Oturai et al. 2023; Gacutan et al. 2023; Fraisl et al. 2020; Campbell et al. 2019). However, the value of citizen science in marine litter research goes beyond being a data source (Hidalgo-Ruz and Thiel 2015; Severin et al. 2023) and includes the removal of litter from the environment (Severin et al. 2023) and engaging people in data collection to promote education and raise awareness on the issue (Hermoso et al. 2021; Lucrezi and Cilliers 2023). Examples of citizen science initiatives aiming to collectively achieve

these objectives include Ocean Conservancy's (OC) International Coastal Cleanup, the European Environment Agency's Marine Litter Watch, the National Oceanic and Atmospheric Administration's (NOAA) Marine Debris Monitoring and Assessment Project and Litter Intelligence in New Zealand (Campbell et al. 2019). For example, the ICC alone has been active for more than 35 years and has reached out to 17 million volunteers in 155 countries (Ocean Conservancy 2023a). Despite this potential, the integration of citizen science as a potential new source of input data to the official monitoring of 14.1.1b remains untapped.

The aim of this paper is to present a case study from Ghana that illustrates how existing citizen science data and networks can be leveraged to address the data gap on marine litter at the national level and feed into the global SDG monitoring and reporting process. We also aim to show how these data and networks can help to inform relevant policies and action at a national level with global impact. Finally, we would like to introduce the approach we implemented in Ghana for other countries that may wish to follow a similar reporting process for this indicator. The simplified methodological process can also be used as guidance for integrating citizen science data into other SDG indicators. The potential of citizen science data for SDG monitoring has been the subject of several publications in recent years including our previous work (Campbell et al. 2019; Fritz et al. 2019; Fraisl et al. 2020; Moczek et al. 2021; Walker 2021). In this case study, however, we demonstrate, for the first time, how this potential has been fully realized for Ghana, which was selected as a partner due to (i) the extent of the marine plastic litter problem in the country, (ii) the commitment of the Ghanaian authorities to eliminate the problem, (iii) the established networks of citizen scientists in Ghana dedicated to address the marine litter issue by collecting litter and data on these litter from Ghana's coastlines and (iv) the progressive approach of the Ghanaian government to the use of new data sources including citizen science for SDG monitoring and for official statistics, which are statistics produced by statistical organizations in a country on behalf of the national government to serve as basis for decisions (Eurostat 2017).

Materials and methods

In this section, we present the data validation process as three phases of citizen science data integration into the official monitoring and reporting of SDG indicator 14.1.1b. The approach implemented here is top-down, where we leveraged existing citizen science data through a data validation process. Bottom-up approaches can also be used to work with citizen science data for 14.1.1b monitoring as implemented in New Zealand. The Litter Intelligence Program

by Sustainable Coastlines in New Zealand has designed a citizen science initiative to collect litter data from beaches to generate a litter database for the country (Sustainable Coastlines 2023). Their methodology was based on the UNEP and Intergovernmental Oceanographic Commission guidelines, and they co-developed it with the relevant government agencies including the Ministry for the Environment and Statistics New Zealand. They worked together with the government partners during the design phase of the project to ensure the uptake of their data for official monitoring and reporting purposes of marine litter including the SDGs (New Zealand VNR 2019). This approach is appropriate when there are resources available to launch a new citizen science program and build new networks of citizen scientists in a given context. Our top-down approach presented here is more relevant when there are no resources available to develop a new citizen science initiative, but there are data and citizen scientist networks available, which would allow countries, governments, and UNEP to reuse the existing data to address marine litter data and policy gaps.

Our methodology starts from the point of working with the statistical office in Ghana (the GSS) to the official reporting of indicator 14.1.1b in the UN SDG Global Database. Three interconnected phases were undertaken: (i) understanding the global methodology for indicator 14.1.1b on *plastic debris density;* (ii) finding, compiling and integrating the data, which included leveraging the *Global Earth Challenge Platform* to identify existing marine litter citizen science networks and data in Ghana; and (iii) validating these data, integrating them into the official statistics of the country to inform SDG processes and policy decisions and reporting them to the SDG Global Database. A schematic of this methodology including the three phases is provided in Fig. 1.

Phase 1: understanding the global methodology

In phase 1, the starting point was to examine the global methodology for SDG indicator 14.1.1b on plastic debris density (UN 2021), which is part of SDG 14 *Life Below Water* that addresses various aspects of ocean health including marine litter. Indicator 14.1.1b follows a progressive monitoring approach, which is divided into three levels. Level 1 is monitoring based on globally available data from Earth Observation, citizen science and modeling. Level 2 is based on national data collection in all countries. Finally, Level 3, which is not part of the official monitoring, is suggested for countries interested in national monitoring of selected issues, e.g., indicators related to plastic ingestion, entanglement, microplastics, etc. The focus of this paper is on national-level reporting for Level 2.

The monitoring methodology of SDG indicator 14.1.1b is based on a global standard outlined in the *Guidelines for*

Fig. 1 The process of integrating citizen science data on marine litter for SDG indicator 14.1.1b reporting in the Ghana case study
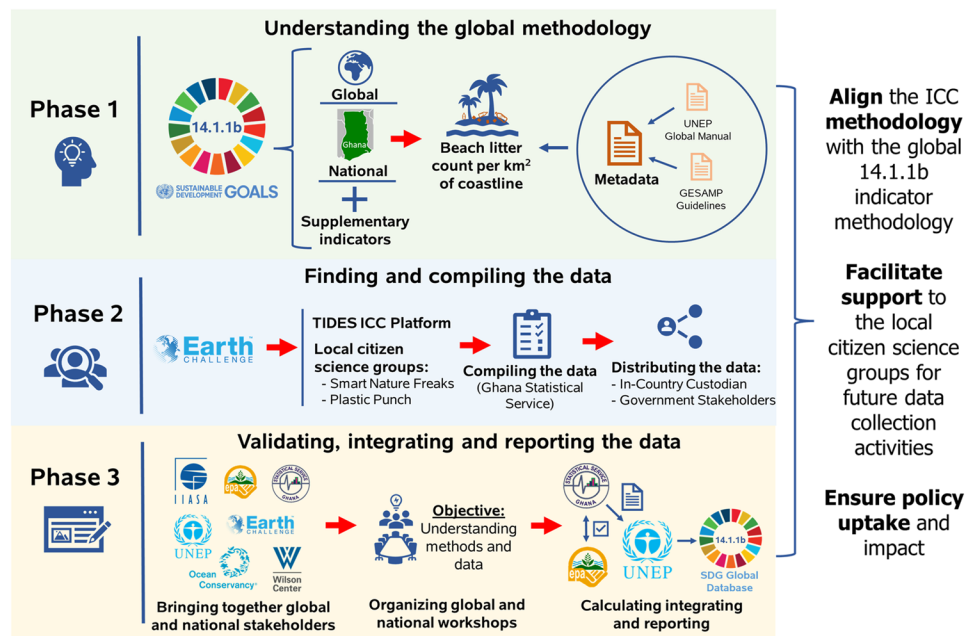
the Monitoring and Assessment of Plastic Litter in the Ocean (GESAMP 2019) and elaborated in more detail by UNEP (2021). The SDG indicator 14.1.1b includes four sub-indicators: (1) beach litter (average count of plastic items per km^2); (2) floating plastics (average count of plastic items per km^2); (3) water column plastics (average count of plastic items per km^2); and (4) seafloor litter (average count of plastic items per km^2). Due to the expense associated with collecting data across the marine environment and the inability to identify small items using available remote sensing data, sub-indicator on beach litter density was chosen for reporting, as it has the highest feasibility for monitoring at present. Moreover, UNEP recommends that all countries where the indicator is relevant should monitor and report on beach litter, as it is an important indicator for characterizing the extent of the marine litter problem. They also recommend that national beach litter data collection efforts can be supported through citizen science and beach cleanup campaigns (UNEP 2021), which are considered to be examples of citizen science, as they engage the public in scientific research and action (Haklay et al. 2021; Fraisl and Hager et al. 2022a). Although the global SDG methodology for 14.1.1b was approved in 2019, there has been no national-level reporting to the SDG Global Database at Level 2, i.e., beach litter, using citizen science prior to this case study.

Phase 2: finding and compiling the data

The next step was to identify existing citizen science data, as well as initiatives and networks active in the field of marine litter in Ghana to compile and aggregate these data for annual reporting of the indicator and for initiating the in-country data validation process. The starting point was the Global Earth Challenge Platform, a citizen science platform led by the Woodrow Wilson International Center for Scholars, the US Department of State, and EarthDay.org. The main aim of the platform is to increase the amount of open and interoperable citizen science data while enabling better decision-making. Within the Global Earth Challenge Platform is the Global Earth Challenge Marine Litter Data Integration Platform, which aims to be a global platform for monitoring marine litter consistently. It is also intended to serve as a long-lasting infrastructure that harmonizes and publishes citizen science data on beach and shoreline litter collected through a diverse range of citizen science initiatives. The developers of the Global Earth Challenge Marine Litter Data Integration Platform have explored a range of citizen science data sets to understand the opportunities for data harmonization and interoperability, with the underlying goal of creating a global baseline data set that is usable for SDG 14.1.1b reporting. The initial baseline was calculated using data from three citizen science initiatives: the National Oceanic and Atmospheric Administration's (NOAA) Marine Debris Monitoring and Assessment Project's Accumulation Data; the European Environment Agency's Marine Litter Watch; and OC's ICC Trash Information and Data for Education and Solutions (TIDES) database (Ocean Conservancy 2022). These were selected because of size, scale (e.g., extending beyond a single country or limited region) and similarity of data collection and classification methodologies. However, even though the methodologies of the above-mentioned initiatives were similar, additional effort was required to make their data interoperable as each

initiative follows different protocols, is led by different teams of researchers and involves various communities spread around the world. For example, the same plastic cup could be counted as part of "cups and plates—foam" in one data set, and as "cups" in another. Hence, a common classification system, which is presented in Supplementary Material (Figure S3), was derived from a cross-walk of taxonomies from the above projects along with recommendations from GESAMP-recommended "Marine Debris Item List" of the Commonwealth Scientific and Industrial Research Organisation (CSIRO 2020). Each data set in this case study was evaluated against this common schema to ensure interoperability. Although aggregating more granular data to generic categories to make the integration possible is often required, the efforts created a global baseline covering the years 2016–2020 using existing citizen science data. In our case study, the Global Earth Challenge Marine Litter Data Integration Platform has helped to guide the data validation process by providing a data set specifically on beach plastics for Ghana. The data set was particularly important as it listed the details of each individual beach cleanup and data collection activity including the organization that conducted these cleanups. This was quite useful to reach out to the Civil Society Organizations (CSOs) as key stakeholders in Ghana that were fundamental for the success of the project, such as Smart Nature Freak Youth Volunteers Foundation (Smart Nature Freaks).

In the case of Ghana, all citizen science data included in the Global Earth Challenge data set came from one citizen science platform, i.e., OC's ICC. ICC has developed a common methodology for using citizen science to collect and classify plastic pollution and all forms of marine litter during cleanup campaigns. This methodology has been implemented by community groups and organizations such as local CSOs to run cleanups. OC then aggregates the data coming from the various campaigns, which are available in their TIDES database (Ocean Conservancy 2022). TIDES is an open database that contains the world's largest ocean trash data set. The data can be viewed at a global or at a very local scale including a local beach. The data can be downloaded, and reports can be produced for any country, state, region or location. Because the ICC is active in 155 countries globally, there is potential for these data to be used for global-level 14.1.1b monitoring, as the citizen scientist networks active in these countries collect litter data using the same ICC methodology, which are then published in TIDES. Access to this aggregated data set in TIDES enabled the Ghana Statistical Service (GSS) and the Environmental Protection Agency (EPA) (as national custodian for the indicator 14.1.1b) to work together to get a better understanding of the data collection methodology developed and implemented by ICC as well as local citizen science groups

contributing data to TIDES, including the Smart Nature Freaks as the official ICC coordinator for Ghana, and Plastic Punch, among others.

It is important to highlight that the protocols from other citizen science projects can also potentially be used in other countries or contexts to monitor this indicator. In Ghana, we worked with the OC's ICC and the local citizen science networks that use the ICC methodology, because that is the only project that had data available for Ghana and that made these data openly available through TIDES for calculation and reporting on 14.1.1b. Hence, as part of Phase 2, we recommend countries, who would like to replicate our approach, to explore what data are available in their own contexts that can potentially be used to monitor 14.1.1b.

Phase 3: validating, integrating and reporting the data

In the final phase, key stakeholders were brought together by the project coordinator, the International Institute for Applied Systems Analysis. This included the GSS and EPA as the country leads; UNEP as the custodian agency responsible for global monitoring and reporting of various environmental SDG indicators including 14.1.1b; Earth Challenge and OC as data compilers; and Smart Nature Freaks and Plastic Punch as the local citizen science community representatives and CSOs in Ghana. This was followed by the GSS establishing a broader national partnership by streamlining internal coordination between different stakeholders to ensure that the data collected could be used for SDG reporting. The partnership included representatives from relevant ministries, universities and CSOs to explore citizen science methodologies and to incorporate the results into Ghana's Integrated Coastal and Marine Management Policy. Table S1 in Supplementary Material shows the projects partners, platforms used and the actors directly and indirectly involved in the project, as well as the particular roles of these partners, actors and platforms. Several workshops were organized by the International Institute for Applied Systems Analysis and UNEP at a global level, and two by the GSS and EPA at a national level, to understand the citizen science data and methodologies used and to discuss their integration into the official statistics. This included the workshops *Understanding the Contributions of Citizen Science to Plastic Pollution Monitoring through the SDG Framework* organized by UNEP, the International Institute for Applied Systems Analysis and the OC, and the *Ghana Citizen Science, Marine Litter Policy Roundtable* organized by the GSS and EPA, among others. The half-day virtual *Policy Roundtable* aimed to harmonize efforts around marine policy across government agencies as well as building familiarity with citizen science methodologies by involving relevant ministries and departments including: the

GSS, EPA, the Ministry of Planning, the Ministry of Environment Science Technology and Innovations, the Ministry of Sanitation and Water Resources, the Ministry of Fisheries and Aquaculture Development and the National Development Planning Commission. Thematic experts from UNDP and the University of Legon were also invited to share their perspectives on integrating citizen science data to marine policy monitoring (Table S1). Some of these workshops were dedicated to detailed discussions of the ICC methodology presented by OC and how this methodology has been implemented on the ground by the volunteer groups and communities in Ghana presented by Smart Nature Freaks and Plastic Punch. These workshops were designed to (i) ensure broader stakeholder engagement to address data gaps on marine litter; (ii) understand if the existing citizen science data were of high enough quality to be incorporated into official SDG monitoring and reporting, and for marine litter-related policy decisions in Ghana considering the ICC methodology, how this methodology has been implemented on the ground by the local citizen science groups and global 14.1.1b methodology; and (iii) identify the areas of improvement for future data collection efforts and how to support the ICC to improve the alignment of their methodology with the global 14.1.1b methodology. These workshops were successful as the broader stakeholder engagement was achieved both at a global and local level. For example, the involvement of UNEP at a global scale and local citizen science networks at a local scale helped ensure common goals across diverse stakeholders. Active involvement of citizen science networks operating in the country helped to understand how the data collection methodology was executed on the ground, which was helpful to assess data quality. Involvement of OC, UNEP and Ghanaian government representatives helped to improve the methodology used by the volunteers for 14.1.1b monitoring for future data collection activities, which resulted in changes being made to the data collection methodologies and tools of OC (the OC data sheets and CleanSwell app) (Ocean Conservancy 2023b). One important learning from these consultations was the 3-phase methodology of integrating citizen science data into official monitoring and reporting of 14.1.1b presented here, which demonstrated how the data validation process adopted can be implemented in other countries and contexts. Although aligning all the stakeholders around common goals required time and space due to different motivations, interests and concerns involved, the project has helped to build trust in citizen science data and approaches and between stakeholders. Once everyone was able to understand the concerns, motivations and interests of one another, it was much easier to ask questions, understand problems, find solutions and reach consensus.

The validation of the data set was led by a subgroup of statisticians and thematic experts from the EPA and GSS. Following this process of validating the quality and fitness-for-purpose of citizen science data, the indicator was calculated for 2016–2020 by the GSS with support from UNEP and the ICC.

It is important to note that the global indicator methodology 14.1.1b recommends the average count of plastic items per square kilometer (km^2). However, existing ICC data did not initially capture the km^2 covered, so an assumed 1 m width was used to calculate area. This means that the calculation was made with the assumption that each volunteer covered a 1 m width. The ICC data methodology has always tracked the linear distance that volunteers cover as a group even though volunteers may not follow strict survey lines in practice, as over ICC experience shows that the most accurate distance to report is simply the greatest distance linearly that individuals in the group covered. Therefore, the calculation was made with the assumption that, in a typical beach cleanup, individual volunteers walk a certain linear distance, and most are only looking diligently in their immediate path, which is assumed to be roughly their wingspan. While it was acknowledged that this is an imperfect approximation method, it enabled the reuse of this historic data to demonstrate the policy relevance of the data set. Due to the harmonization efforts of this case study, changes are being made to the data collection tools (the OC data sheets and CleanSwell app) so that in future data collection activities, the width of the cleanup area will be recorded in the same way that length is recorded (with a marked start and end point).

The 1 m width was used for calculating area, as this is based on the global 14.1.1b methodology developed by the custodian agency UNEP (UNEP 2021). The methodology states that a standard transect should be used for monitoring beach litter. For example, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) uses 1 m in their handbooks (CSIRO 2020; NOAA 2021). The same CSIRO handbook was used and pilot tested in the context of 14.1.1b by UNEP during the methodology development process of indicator 14.1.1b. Based on their relevant policy needs, the GSS and the EPA agreed to use 1 m width as the sampled width for their purpose of creating the proxy indicator for 14.1.1b using the historic data available. Although each SDG indicator is guided by a global methodology recommended by their custodian agencies, for national-level use, each country can adjust this methodology depending on their needs. The SDG methodology suggests using 1 m width for 14.1.1b, which was also used in Ghana. If another country wants to refine the global methodology based on national data and policy needs, this is feasible, as long as they standardize this method and apply it consistently. For global-level SDG reporting, they should follow the SDG methodology. The Government of Ghana stipulated that once available, they will utilize the newly included width approximation in the data collection tools for their future use of the ICC data sets to report on indicator 14.1.1b. Additionally, the

ICC data cover the collection of both plastic and non-plastic items, while the SDG indicator focuses only on plastics, which was addressed by focusing on individual counts of plastic items. Table S2 of Supplementary Material is a checklist that shows the step-by-step data validation process of leveraging existing citizen science data for 14.1.1b reporting.

It is also important to highlight that the volunteer groups in Ghana, which may be the case for other similar initiatives in different parts of the world, collect data opportunistically, which means they collect litter and data in areas that are easily accessible or where the need has arisen. This may lead to the concentration of data collection activities in areas that are in easier reach or with the most pollution, which may bias the results. Therefore, a proper sampling approach is important to obtain an unbiased estimate of beach litter in the case of 14.1.1b for future data collection activities. This means that the government partners, along with stakeholders including the citizen science groups, will need to design a methodology for

an improved sampling protocol. Therefore, the discussions in the workshops mentioned above included identifying hotspot areas and planning for the future, i.e., the EPA will follow a systematic approach for sampling site identification together with the citizen science groups considering aspects such as accessibility and safety of participants to conduct cleanups in these places in future years.

The input data for the calculation of the indicator (number of plastic items per km^2 of beach) are provided in Table 1, which was computed as:

$$\text{Indicator} \, 14.1.1b = \frac{(1,000,000 \times \text{number of plastics found})}{\text{total area cleaned (m}^2)}.$$

Note that the figures from 2018 are still being validated and are not reported in the SDG Global Database and here. A study on microplastics in 2018 reported over 72 million pieces of litter collected from beaches in Ghana (Ocean Conservancy 2022). This study has substantially influenced the

Table 1 Raw data grouped by year from each survey, including the number of volunteers who attended, length and width of beach cleaned, total items and total plastic items collected

Year	Beach cleanup ID	No. of volunteers	Total length (m)	Total width (m)	Total items (any type)	Total plastic items	Proxy indicator	Standard deviation
2020	3	1615	12,200	1	1,882,390	1,856,043	152,134,672	87,427,732
1	149,829	220	450	1	132,276	132,264	293,920,000	–
2	159,695	837	6440	1	1,313,410	1,296,871	201,377,484	–
3	159,696	558	5310	1	436,704	426,908	80,396,987	–
2019	11	7864	38,800	1	7,041,811	6,974,692	179,760,103	232,632,351
1	112,855	2547	12,600	1	2,311,434	2,288,195	181,602,778	–
2	112,856	435	2400	1	63,156	62,300	25,958,333	–
3	112,857	351	2200	1	57,373	55,505	25,229,545	–
4	112,858	188	1700	1	87,692	84,326	49,603,529	–
5	112,860	327	2000	1	96,719	95,245	47,622,500	–
6	112,862	1301	8300	1	412,089	401,882	48,419,518	–
7	112,864	98	1000	1	34,684	33,986	33,986,000	–
8	112,865	1246	4300	1	1,902,301	1,889,269	439,364,884	–
9	112,866	53	1000	1	13,238	13,055	13,055,000	–
10	112,867	1095	2300	1	1,841,029	1,828,846	795,150,435	–
11	150,904	223	1000	1	222,096	222,083	222,083,000	–
2017	7	1873	27,800	1	1,649,009	1,581,128	56,875,108	28,752,653
1	26,481	852	9600	1	703,445	682,927	71,138,229	–
2	26,483	281	4100	1	300,254	286,611	69,905,122	–
3	26,484	193	2600	1	285,765	271,100	104,269,231	–
4	26,486	208	3700	1	127,650	115,916	31,328,649	–
5	26,487	162	3100	1	124,441	120,814	38,972,258	–
6	26,490	76	2100	1	52,921	51,189	24,375,714	–
7	26,491	101	2600	1	54,533	52,571	20,219,615	–
2016	2	1757	30,700	1	1,076,136	1,030,884	33,579,283	17,860,438
1	13,201	1755	28,700	1	1,075,714	1,030,513	35,906,376	–
2	14,270	2	2000	1	422	371	185,500	–

computation of the indicator and would, therefore, affect the integrity of any time series analysis. For this reason, EPA and GSS decided to exclude the 2018 data until the in-country team can better understand the details of this study. Note that the number of collections, number of volunteers and area traversed, all determine the volume of litter collected. For example, the volume of plastics items differs greatly between 2017 and 2019, in which a similar number of collections were conducted, but with the cleanups in 2019 involving over four times more volunteers than in 2017.

Figure 2 includes maps that show where Ghana is located in West Africa (2a) and the cleanup sites showing the locations of data collection activities for the years 2016, 2017, 2019 and 2020 (2b). The cleanup sites are clustered into three areas (outlined in Fig. 2b): (1) Western Ghana around the port city of Takoradi, (2) the capital city Accra and its neighboring port town Tema and (3) Keta Lagoon Protected Area, an area of natural beauty popular with tourists, although prone to coastal flooding.

Once the indicator was calculated, an official communique from the GSS was sent to the EPA for approval, followed by the reporting of the calculations to the SDG Global Database by UNEP.

Finally, all three phases were implemented keeping the policy uptake in mind. Ghana is currently implementing various aspects of its National Plastics Management Policy and is in the process of formulating an Integrated Coastal and Marine Management Policy to ensure the sustainable management of its oceans and marine resources. One of the focus areas of these policies is pollution including marine litter and its effects on the environment. The results of this case study will help inform the situational analysis for the policy formulation processes, monitoring and evaluation of implementation strategies and management approaches.

Results

Marine plastic litter in Ghana

Table 2 shows the officially reported values for indicator 14.1.1b on *plastic debris density* that were derived from citizen science data as a direct result of this case study in Ghana. These values are now listed in the SDG Global Database as of 15 September 2021 (UN 2021), which is one of four annual SDG reporting dates to the UN by the custodian agencies, as well as Ghana's latest Voluntary National Review (VNR) (UN Ghana 2022). This reporting outcome represents the final step of a process to demonstrate how existing citizen science data on marine litter can be incorporated into the formal SDG monitoring and assessment processes for indicator 14.1.1b (Supplementary Material—Table S2). As discussed previously, 2018 values

were excluded due to a microplastics study that took place in 2018 and the challenges of comparison related to data from that year.

Due to the historic nature of the data set, sites were selected based on the resources and priorities of the citizen science groups who organized the cleanups before the involvement of the Government of Ghana and the partners in this case study. These sites spanned three regions: the turtle conservation sites in Takoradi, Western Region, the protected coastal area of the Volta Region and the Greater Accra metropolitan areas of Accra and the port of Tema. While it was acknowledged that this is not an exhaustive listing of affected coastal sites, the reviewing team in Ghana deemed that spanning two regions was sufficient to calculate a proxy indicator. The Government of Ghana expressed interest in implementing the methodology for inland waterways, namely Lake Volta, and would also take a more active role in the strategic selection of collection sites going forward as part of the integration of citizen science methodologies into Ghana's Integrated Coastal and Marine Management Policy.

Figure 3 shows the top 10 items of plastic litter as a percentage of their total between 2016 and 2020. Plastic pieces are the most frequent items found, and the majority of identifiable items are single use plastics, such as grocery bags, plastic cups and plastic plates; tackling this problem requires national and international policies to bring about change, e.g., the proposed global treaty on plastic pollution (Stokstad 2022), especially if SDG target 14.1 on reducing marine pollution is to be met. The complete list containing the number of plastics by category for each year is provided in Table 3, which also clearly shows the impact of the COVID-19 pandemic, as the year 2020 was the first time that gloves and masks (personal protective equipment) were found during beach cleanups.

A process to integrate citizen science data into SDG indicator reporting

Prior to the case study presented here, there were no values reported for indicator 14.1.1b for Ghana. Although this is one of the main outcomes of this study, the advances made to the process of integrating citizen science data into SDG indicator 14.1.1b monitoring and what this may mean for other indicators, other countries and globally is its farther-reaching accomplishment (Olen 2022). This involved investigating and ultimately validating data from citizen science for indicator 14.1.1b in Ghana, as outlined in the methodology, summarized in Fig. 1 and in Table S2 of the Supplementary Material as a checklist.

A key enabling factor for the success of the case study was the interest by the EPA and the GSS in using citizen science data for their national SDG reporting. They then
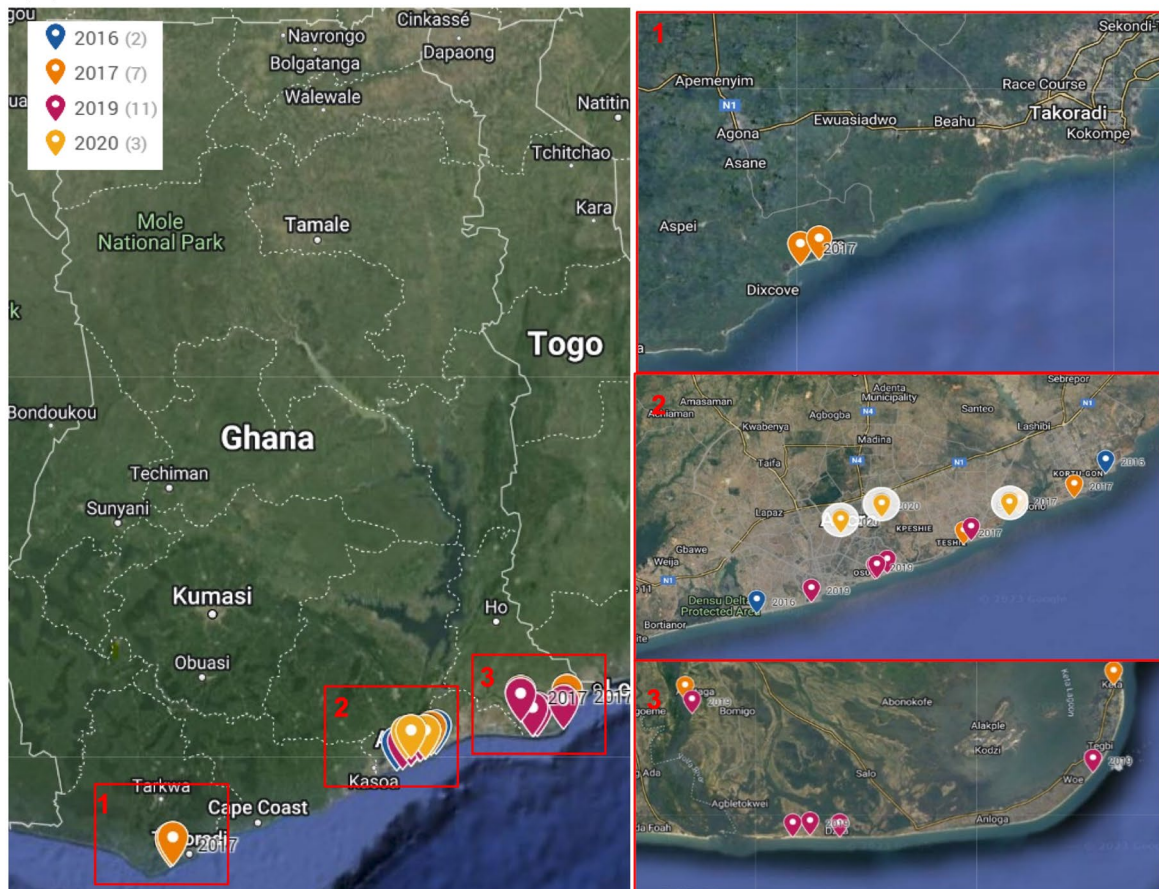
Fig. 2 **a** A map showing where Ghana is located in West Africa. Source: MapChart.net. **b** A map of coastal cleanup sites showing the locations of data collection activities between 2016 and 2020 by year and by cleanup site cluster. Source: Google; Coastal cleanup sites

Table 2 The officially reported values for indicator 14.1.1b *Number of plastic items per square kilometer of beach*, reported by Ghana

	2016	2017	2018	2019	2020
14.1.1b Ghana validated beach litter data	33,579,283	56,875,108	Not reported	179,760,103	152,134,672
Number of CSOs contributing to the data	2	1	Not reported	2	3
Number of beach cleanups	2	7	Not reported	11	3

Fig. 3 The top 10 items found on beaches in Ghana over the period 2016–2020 excluding data from 2018
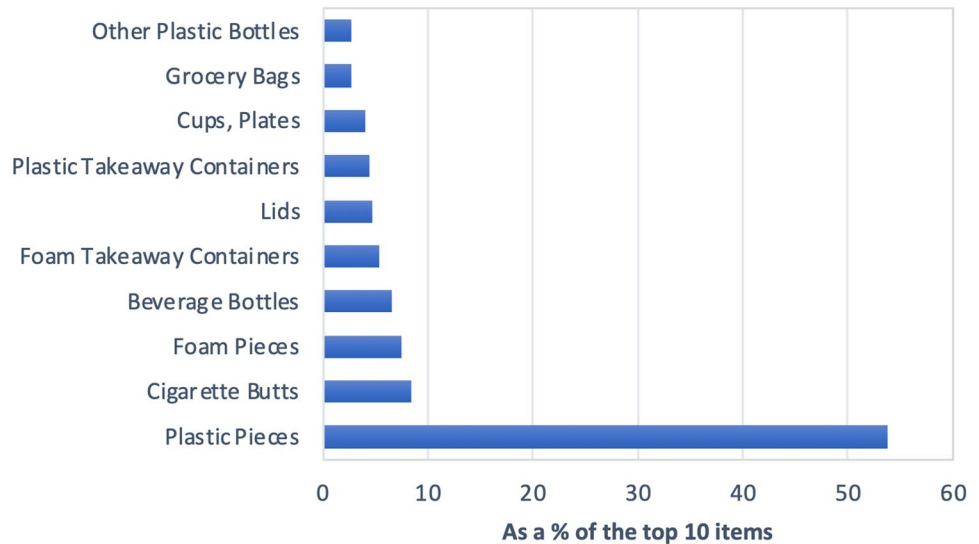
agreed to go through a data validation process consisting of two remote half-day workshops involving statisticians and key stakeholders from the project team, CSOs conducting the cleanups (Smart Nature Freaks and Plastic Punch), and UNEP. As a result of this validation process, the values estimated for 2016 and 2017 for Ghana by UNEP and initially reported in the SDG Global Database were updated with the results validated by Ghana as part of this case study. It is important to highlight that UNEP initially reported on this indicator as a proxy with regional and global estimates using the ICC data, which were not validated by countries. Following our work in Ghana, the data validated by the country, which excluded non-plastics as the 14.1.1b methodology recommends, were used for the reporting instead. New values were also reported for 2019 and 2020 for Ghana. The data validation strategy involved looking at several dimensions: the number of beach litter collections per year; the dispersion of the locations of the collections; the classification into plastics and non-plastics and identification of any outlier values. Regarding the number of collections, initially 2020 recorded only one beach cleanup, likely due to the COVID-19 pandemic restricting access to the beaches and prohibiting gatherings for much of the second and third quarter of the year. It was decided that Ghana would only report on years with more than 1 beach cleanup event, as one event could not be considered as representative of the

country. Following engagement with the CSOs, two further collections were identified and added for 2020, meaning that the data compiled met the eligibility requirements of Ghana for reporting. This demonstrated that other CSOs carrying out citizen science activities in the country may also need to be engaged to ensure completeness of the data. For the future, Ghana will determine the number and locations of data collection activities based on the specific policy question that is addressed and the environmental, social and economic constraints at hand, as highlighted in the global methodology for 14.1.1b. Secondly, in Ghana, there are four regions with coastal areas, and the locations of data collections were considered to verify whether they span at least two different locations, preferably in different regions. Thirdly, the categories of litter collected and reported on include both plastic and non-plastic items. To isolate only items relevant to indicator 14.1.1b, an initial classification of plastics was provided by UNEP. The in-country team then reviewed each category to assess whether such items contained plastic in local production and use (e.g., in some countries fishing lines contain plastic) and adjusted the classification accordingly. The agreed classification of plastic categories is provided in Table 4. Finally, each year's collections were checked for outlying values. This whole process along with actions that may require context-dependent decisions is presented in the form of a checklist in Table S2 of the Supplementary

Table 3 Number of plastic items collected by category in Ghana

Plastics	2016	2017	2019	2020	Total
Cigarette butts	31,426	71,426	531,376	221,001	855,229
Food wrappers (candy, chips, etc.)	24,753	80,208	43,611	32,506	181,078
Take out/away containers (plastic)	103,734	200,132	117,999	34,487	456,352
Take out/away containers (foam)	207,351	298,336	13,618	24,171	543,476
Bottle caps (plastic)	27,161	82,133	87,513	17,127	213,934
Lids (plastic)	132,643	223,469	100,872	26,813	483,797
Straws, stirrers	13,412	16,001	122,805	37,540	189,758
Forks, knives, spoons	36,213	29,160	16,929	5499	87,801
Beverage bottles (plastic)	76,761	97,326	320,361	170,987	665,435
Grocery bags (plastic)	136,412	100,739	27,402	11,582	276,135
Other plastic bags	41,424	91,445	40,371	21,817	195,057
Cups, plates (plastic)	21,738	34,971	329,209	24,830	410,748
Cups, plates (foam)	16,089	22,162	14,913	6909	60,073
Fishing line (1 yard/meter = 1 piece)	629	832	2082	2348	5891
6-Pack holders	809	993	2717	1006	5525
Other plastic/foam packaging	10,441	11,639	8232	2612	32,924
Other plastic bottles (oil, bleach, etc.)	90,246	120,146	40,725	21,455	272,572
Strapping bands	609	534	1273	498	2914
Tobacco packaging/wrap	914	663	4209	1333	7119
Beverages sachets	N/A	N/A	N/A	2314	2314
Balloons	422	626	234	51	1333
Cigar tips	71	634	162	81	948
Cigarette lighters	641	1193	5664	1268	8766
Construction materials	498	726	465	656	2345
Fireworks	63	66	702	80	911
Tires	15,246	15,242	1829	898	33,215
E-cigarettes	N/A	N/A	N/A	0	0
Other tobacco (packaging, lighter, etc.)	N/A	N/A	N/A	3	3
Condoms	691	739	5922	2320	9672
Diapers	24,222	41,322	34,275	11,144	110,963
Tampons/tampon applicators	2	7	3	0	12
Gloves and masks (PPE)	N/A	N/A	N/A	56,412	56,412
Foam pieces	6012	6017	534,389	213,266	759,684
Plastic pieces	10,251	32,241	4,564,830	903,029	5,510,351
Total	1,030,884	1,581,128	6,974,692	1,856,043	11,442,747

Material to provide guidance for other countries or stakeholders interested in replicating our approach.

Additionally, the citizen science country-level data validation strategy that was developed as part of the case study for indicator 14.1.1b can be replicated by and/or adapted to other countries, SDGs and indicators. Figure 4 summarizes the experiences in the Ghana case study based on Fig. 1 as a generalized methodological tool for government agencies in other countries that want to use existing citizen science data to report on indicator 14.1.1b and other indicators.

Aligning global and local methodologies

Another result from the case study was the better alignment of the ICC methodology for collecting beach litter and data with the global 14.1.1b indicator methodology. Previously, the ICC methodology requested volunteers to provide high-level information about their data collection activities, such as the number of volunteers taking part, the total weight of debris removed and the distance covered. OC then received, organized, archived and shared these data on their TIDES database, which also fed into the Global Earth Challenge Platform. The ICC methodology and the data card used for recording marine litter have changed several times in the

Table 4 Classification of ICC protocol beach litter items into plastic and non-plastic items

Plastics	Non-plastics
Cigarette butts	Bottle caps (metal)
Food wrappers (candy, chips, etc.)	Beverage cans
Take out/away containers (plastic)	Paper bags
Take out/away containers (foam)	Cups, plates (paper)
Bottle caps (plastic)	Fishing buoys, pots and traps
Lids (plastic)	Fishing net and pieces
Straws, stirrers	Rope (1 yard/meter = 1 piece)
Forks, knives, spoons	Fishing gear (Clean Swell)
Beverage bottles (plastic)	Other packaging (Clean Swell)
Grocery bags (plastic)	Appliances (refrigerators, washers, etc.)
Other plastic bags	Toys
Cups, plates (plastic)	Other trash (Clean Swell)
Cups, plates (foam)	Syringes
Fishing line (1 yard/meter = 1 piece)	Personal hygiene (Clean Swell)
6-Pack holders	Glass pieces
Other plastic/foam packaging	Beverage bottles (glass)
Other plastic bottles (oil, bleach, etc.)	
Strapping bands	
Tobacco packaging/wrap	
Beverages sachets	
Balloons	
Cigar tips	
Cigarette lighters	
Construction materials	
Fireworks	
Tires	
E-cigarettes	
Other tobacco (packaging, lighter, etc.)	
Condoms	
Diapers	
Tampons/tampon applicators	
Gloves and masks (PPE)	
Foam pieces	
Plastic pieces	

Fig. 4 Process for integrating existing citizen science data into the official reporting of SDG indicators
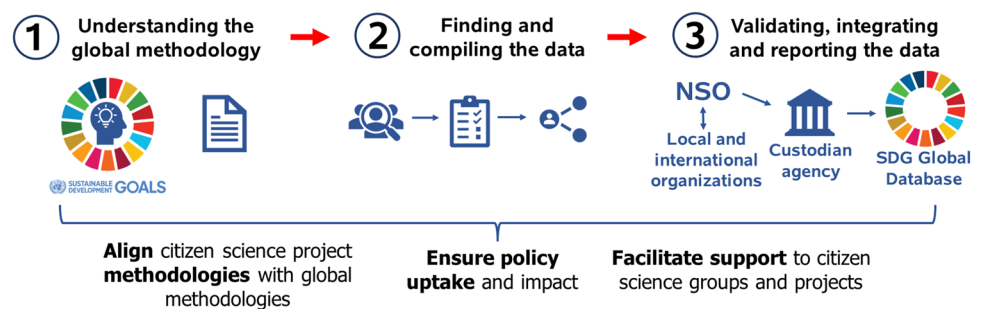
past, as new science and priorities for marine litter have evolved. Before the case study, the ICC methodology did not include the "per square kilometer calculation", which is required to match the global methodology for this SDG indicator. The most recent ICC data card, implemented in 2021, was modified to ensure that the ICC data can directly contribute to the monitoring of indicator 14.1.1b and feed into marine litter-related policies, both at a national and

global level. This included the addition of "area covered" information to the ICC data card to calculate beach litter density as one component of 14.1.1b. In addition, updates to the Clean Swell mobile app are ongoing so that this information will be captured automatically. The updated ICC data card for volunteers and team leaders of citizen science groups, as well as screenshots from the Clean Swell app are provided in Figures S1 and S2 in the Supplementary Material.

Discussion

We have demonstrated that using citizen science in SDG monitoring and reporting of indicator 14.1.1b, where existing data are leveraged and then validated by countries in a top-down approach, is feasible as it allows countries to understand existing data for reuse to address their data gaps and potential policy needs. This also allows meaningful engagement with stakeholders for monitoring sustainable development and helps to achieve trusted partnerships, as indicated in the 2030 Agenda for Sustainable Development (UN 2015a). Additionally, this is beneficial for ensuring cost-effective monitoring systems in comparison to official monitoring programs, as there are already citizen science projects, networks and local volunteer teams that collect these data such as the ICC and Smart Nature Freaks (Fritz et al. 2019; Fraisl and Hager et al. 2022a, b). This reuse of existing data becomes even more important when considering the funding required to measure and monitor the SDGs (Global Partnership for Sustainable Development Data 2016).

This case study has made an important impact on addressing the marine litter issue in Ghana more generally. For example, the results will support the formulation of Ghana's Integrated Coastal and Marine Management Policy, currently under development. Additionally, throughout the data validation process, a greater level of awareness of the relevance of citizen science data for the SDGs has been raised among all the stakeholders. The government partners became familiar with citizen science methodologies and data, as well as the landscape of citizen science activities related to marine litter in Ghana. CSOs that organize beach cleanups and data collection activities in Ghana obtained a better understanding of the potential and impact of the data they produce for official statistics and policy making, which can motivate them to further improve data quality. The case study has also had global impact because Ghana has become the first country to report on 14.1.1b *plastic debris density* and the first country to use citizen science data for that purpose. The process outlined in Fig. 1 and Table S2 of the Supplementary Material can be replicated by any country seeking to use an already-established baseline citizen science data set

in national SDG reporting efforts. These findings can also be used as a model for incorporating already existing citizen science data into other SDG indicators, particularly across the environmental SDGs, 41% of which lack data according to UNEP (2023) and where many citizen science projects operate (Schade et al. 2017). The results of the case study can therefore provide a concrete pathway that can be adapted to other SDG indicators, where the data are lacking.

In terms of other known examples of citizen science integration in official statistics in the field of marine litter, this case study complements an existing proof of concept for using citizen science for official monitoring and reporting of marine litter in New Zealand. The collaboration between the Litter Intelligence Program and the New Zealand authorities was a result of the early and ongoing consultations between citizen science groups and government authorities. As a result, data from this citizen science initiative have been formally used in government reports from 2019 onward, but they have not yet been officially used for reporting on indicator 14.1.1b (Howitt 2019). Close collaboration at an early phase of a citizen science initiative at the national level represents one important pathway for enabling the uptake of citizen science data in formal monitoring schemes and policy processes. However, the approach taken in Ghana represents a different pathway, where already existing citizen science data were integrated into official statistics, particularly for SDG monitoring in the country. In the case of New Zealand, a national-level citizen science project with local data worked closely with government authorities to address the marine litter issue at a national scale. In the Ghana case study, a representative data set, focusing on the global level, was brought to the national-level monitoring and assessment scheme. This shows that a bottom-up approach, e.g., the case of New Zealand, can help ensure buy-in at a country level if citizen science practitioners can design their initiatives so that they meet the data gaps and quality requirements of government agencies at the start to ensure the uptake of their results. On the other hand, top-down approaches, as implemented in Ghana, can help leverage already existing data and networks at a global level.

Some of the challenges identified in the use of citizen science data for SDG reporting include lack of awareness of citizen science, lack of capacity and resources to run citizen science initiatives, the lack of an enabling environment in terms of policies that enable the use of citizen science data and/or a lack of political will to use new sources of data (Fritz et al. 2019). Ghana was selected as a partner in this case study due to their progressive approach to the use of new sources of data for official statistics. For example, Ghana updated its Statistical Service Act in 2019, which mandates the GSS to coordinate statistical information across the whole government system, develop and raise awareness of codes of ethics and practices to produce data

and include new sources of data as a valid input for production of official statistics (Republic of Ghana 2019). Hence, effective legal arrangements at a national level can prepare the groundwork for new data sources, including those from citizen science, to be used as official statistics and for SDG monitoring and reporting.

Subsequent efforts should focus on bringing more citizen science data providers into the network and linking platforms to better enable data discovery, sharing and access such as through the UNEP-coordinated *Global Partnership on Plastic Pollution and Marine Litter (GPML) Digital Platform.* Because the GPML Digital Platform seeks to offer a coordinated, authoritative point of entry for information across the marine litter and plastic pollution life cycle, providing access to citizen science data through the GPML Digital Platform elevates the value of citizen science data through enabling enhanced access by a range of stakeholders including UN member states. For example, such a platform could enable a national authority, such as an NSO, to use a centralized platform like the GPML Digital Platform to retrieve data from a range of sources, including citizen science information, review and validate the data (including by sharing with local experts) and easily submit the data to a formal reporting entity through already established processes. Better technical support for data sharing and validation would help not only in reporting 14.1.1.b, but also create a stronger pathway for getting a range of citizen science data used in formal reporting processes.

However, there are caveats associated with the use of citizen science data as with any other source of information. Limitations of this particular case study included potential spatial and temporal biases in the data. In terms of spatial bias, many volunteers collect data opportunistically, which may lead to oversampling of some locations and undersampling of others. In terms of temporal bias, because citizen science data collection activities are usually not at a regular frequency and can randomly happen any time, the results may be very different depending on different variables at the time of data collection. Additionally, a group of volunteers or an individual may collect litter and data at a location that was cleaned before by another group of volunteers or an individual, which is not represented in the same data set. This means the actual litter at that location may be greater than what is being found and reported in a data set. As a follow-up initiative, the GSS and EPA are working together with the local volunteer groups to discuss how they can be supported moving forward to ensure sustainable, more representative and high-quality data collection efforts that can also achieve policy, environmental and societal impact.

Finally, it is important to highlight that citizen science programs are not necessarily created as a service to SDG monitoring processes (Fraisl et al. 2020). Most importantly, participants should not be considered as free labor for

governments or for UN agencies to close their data gaps, but instead their motivation in participation should be a key consideration (Fraisl and Hager et al. 2022a). Otherwise, exploitation may occur, because citizen scientists potentially provide research support without particular expectations such as financial compensation (Riesch and Potter 2014). Therefore, it is important to ensure that the participants receive a share of the benefits from the research. These benefits can be in the form of ownership of intellectual property, authorship or formal recognition through a certificate or payment (Resnik et al. 2015). Project owners should make sure that citizens are comfortable and happy with the tasks they are expected to carry out and are well informed about how their contributions will benefit them, their communities and the research activity to which they contribute.

Conclusions

In our case study, we highlighted one citizen science initiative, ICC, and one country, Ghana, toward connecting existing marine plastic litter citizen science data with 14.1.1b monitoring and reporting. There are many other relevant citizen science initiatives and the data they generate can also be useful for tracking progress toward this indicator in many parts of the world. As the custodian agency for 14.1.1b, UNEP provided guidelines for the countries on how to measure this indicator including utilizing citizen science data, such as the UNEP Global Manual (UNEP 2021) and GESAMP Guidelines (GESAMP 2019). Additionally, some countries have also produced or are producing guidelines at a national level to test the feasibility of reusing already existing data that come from non-official sources, such as citizen science data. For example, the Office of National Statistics (ONS) in the UK has developed guidelines for using non-official statistics for reporting against the SDGs (UK ONS 2022). Similarly, the UN Statistics Division has recently established an Expert Group on data generated by citizens that aims to produce guidelines for the use of citizen science data for SDG reporting and official monitoring processes more generically (UN Economic and Social Council 2023; UN Statistical Commission 2023). Such guidelines are helpful, but our process offers a more concrete process for 14.1.1b and for existing citizen science data that can be replicated or adapted to other countries and contexts.

With less than 7 years left to achieve the SDGs, it is imperative that we recognize the potential offered by citizen science initiatives, not only to help close data gaps, but more importantly to support inclusive data ecosystems, decision-making and action. We need to continue raising awareness and understanding of citizen science data and methodologies through successful demonstrations such as the one outlined here. In this way, we can foster the development of

more trusted citizen science data partnerships and achieve evidence-based inclusive policies and collective action at a global scale for the SDGs and sustainable development more broadly.

Data availability The original contributions presented in the study are included in the article and the Supplementary Material. Further inquiries can be directed to the corresponding author.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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