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Addressing data gaps in marine litter distribution: Citizen science observation of plastics in coastal ecosystems by high-school students

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The Citizen Observation of Local Litter in coastal ECosysTems (COLLECT) project (2021-2022) is a citizen science initiative, supported by the Partnership for Observation of the Global Ocean (POGO), which aimed to acquire distribution and abundance data of coastal plastic litter in seven countries: in Africa (Benin, Cabo Verde, Côte d'Ivoire, Ghana, Morocco, Nigeria) and Asia (Malaysia). In this paper, we describe the workflow used to establish and run this project, as well as the methodologies to acquire data. The COLLECT project consisted of training local students (15 - 18 years old) from ten second cycle institutions ("high schools") on sampling and analyzing macro-, meso- and microplastics in beach sediments, using a quantitative assessment protocol. We further describe in detail the methodologies applied in assessing the impact of participating in the activities from a social sciences perspective. All documents and materials resulting from this project will be open access and available according to the FAIR Principles (Findable, Accessible, Interoperable, and Reusable). The results and outcomes from COLLECT will contribute to expanding knowledge and establishing baseline information on coastal plastic pollution, with citizen science being an enabler of

open science, allowing data to be freely available to the public, academics and policymakers. Expected results from the use of the COLLECT protocol globally will further contribute to the identification of hotspots of coastal plastic litter, and bring awareness to local communities on the potential consequences of plastic pollution. The COLLECT project actively contributes with data suitable to survey plastic litter to the United Nations' Sustainable Development Goals (UN SDGs), in particular to SDG 14, on the sustainable use of the ocean.

KEYWORDS

citizen science, plastic pollution, marine litter, microplastics, beach sampling, ocean literacy, well-being, pro-environmental behavior

1 Introduction

The accumulation of plastic litter in coastal environments has become an issue of high priority for policymakers around the globe due to its potentially hazardous effects on biota, impact on ecosystem services (e.g., fisheries), local economies (e.g., tourism) and human health. Because the presence of plastic litter in the environment is mostly negatively perceived by the public (Catarino et al., 2021a), various community initiatives on manual plastic "clean-ups" have become popular (Garcia-Soto et al., 2021), but these initiatives very often do not follow standardized methodologies for plastic litter collection and reporting. However, the willingness of the public to clean beaches or other coastal environments offers an opportunity to deepen this engagement with the research community and to develop standardized sampling methodologies to quantify debris, assess origin and fate of plastic items, and resolve spatial-temporal trends of litter accumulation, all of which are key to informing regulators and to developing effective mitigation measures (TReNDS, 2021; Fanini et al., 2022). In many regions, including Africa, this need is noticeable, as the levels of plastic debris reaching coastal areas are still poorly known (Bergmann et al., 2017; Maes and Preston-Whyte, 2023). To address the data gaps in marine plastic litter distribution worldwide, citizen science programs are instrumental in complementing shoreline assessments, and are effective in increasing public awareness of plastic pollution (Kawabe et al., 2022; Severin et al., 2023). For example, the United Nations (UN) has established a Sustainable Development Goal (SDG) indicator (SDG 14.1.1.b) on plastic debris density, and monitoring parameters (Level2: Beach Litter) should include beach litter and microplastics data collected by citizen scientists in surveys, to assist countries in establishing baseline levels (United Nations, 2022a).

Citizen science initiatives for the observation of plastic litter can actively involve the public in the scientific research process, bringing significant benefits for both the citizens and the researchers (GESAMP, 2019; Garcia-Soto et al., 2021; Kawabe et al., 2022; Severin et al., 2023). The development of clear sampling methodologies, which include quality control and quality assurance, transparency of data management, and sharing principles, contribute to the acquisition of high-quality data and the establishment of interoperability standards in citizen science outputs (de Rijck et al., 2020). Citizen science enables sampling over larger geographical areas (Rambonnet et al., 2019) and the data acquired can thus fill in gaps on litter levels and distribution in the environment, often limited due to resource constraints (time, staff, etc.). The environmental litter data acquired by citizen science participants, either school children and/or adults, is often of equivalent quality to that collected by trained professionals (van der Velde et al., 2017). Consequently, citizen science initiatives have the potential to contribute significantly to obtaining information on litter distribution and accumulation in the environment (GESAMP, 2019).

The participation of citizens in scientific projects can lead to an increased awareness of environmental issues. The scientific advantages of citizen science environment related projects, as well as the educational benefits, indicate that these initiatives contribute to the success of assessing information on litter accumulation while promoting civic collaboration and engagement (SAPEA, 2019). Participants can obtain topic-specific knowledge and an overview of scientific methodologies (Cronje et al., 2011; Aristeidou and Herodotou, 2020; Peter et al., 2021). Beyond impacting knowledge and awareness, citizen science initiatives can also stimulate pro-environmental attitudes and enhance connectedness to nature (Peter et al., 2019; Kelly et al., 2022), which can ultimately lead to sustainable action towards environmental issues (Ashley et al., 2019; Martin et al., 2020). Moreover, participating in citizen science activities can have a positive effect on well-being, particularly in terms of eudaimonic well-being, in which the activity is perceived as meaningful and in line with the participant's values (Wyles et al., 2017). Within citizen science initiatives related to plastic pollution, the evaluation of these benefits is increasing (Hartley et al., 2015; Locritani et al., 2019; Wichmann et al., 2022), but still remains limited (Kawabe et al., 2022; Severin et al., 2023), despite the increasing concern from the public on plastic pollution related issues (Catarino et al., 2021a).

1.1 The COLLECT Project

The Citizen Observation of Local Litter in coastal ECosysTems (COLLECT) project (2021-2022) is a citizen science initiative which aimed to acquire distribution and abundance data of coastal plastic litter in seven countries, in Africa (Benin, Cabo Verde, Côte d'Ivoire,

Ghana, Morocco, Nigeria) and Asia (Malaysia). The COLLECT project consisted of training local students (15 - 18 years old) from second cycle institutions on sampling and analyzing macro-, meso- and microplastics (see size definitions in Methods) in beach sediments, using a quantitative assessment. The project further aimed to measure the impact of the citizen science intervention in ocean literacy, pro environmental behavior, and wellbeing of the participating students. The methodologies used in COLLECT followed best practices of citizen science projects on plastic litter quantification in aquatic environments (Rambonnet et al., 2019; Barnardo et al., 2020; de Rijck et al., 2020). The project ran under the auspices of the Partnership for Observation of the Global Ocean (POGO), a well-established network of oceanographic research institutions that work together to promote and implement global ocean observations through innovation, capacity development, outreach, and advocacy (Miloslavich et al., 2019; POGO, 2021). To reach out to a broad audience, COLLECT follows the 'FAIR Guiding Principles for scientific data management and stewardship' (Wilkinson et al., 2016), to guarantee the Findability, Accessibility, Interoperability, and Reuse (FAIR) (GFISCO, 2022) of all the digital assets produced within the project. The COLLECT project contributes to the United Nations' Sustainable Development Goals (SDGs) by focusing on the sustainable use of the ocean (United Nations, 2022b).

The goal of the current work is to present and discuss the workflow (Figure 1) of the establishment of the COLLECT project, along with its challenges and mitigation measures. We describe in detail the methodologies applied in sampling plastic litter and processing data (Figure 2), and in assessing the impact of participating in the activities from a social sciences perspective. We further discuss the expected results and outcomes of the project, and offer recommendations for similar projects in citizen science observation of environmental litter.

2 Methods

2.1 Study areas and sampling seasons

To address the paucity of data on plastic litter distribution in Africa, the COLLECT (Citizen Observation of Local Litter in coastal

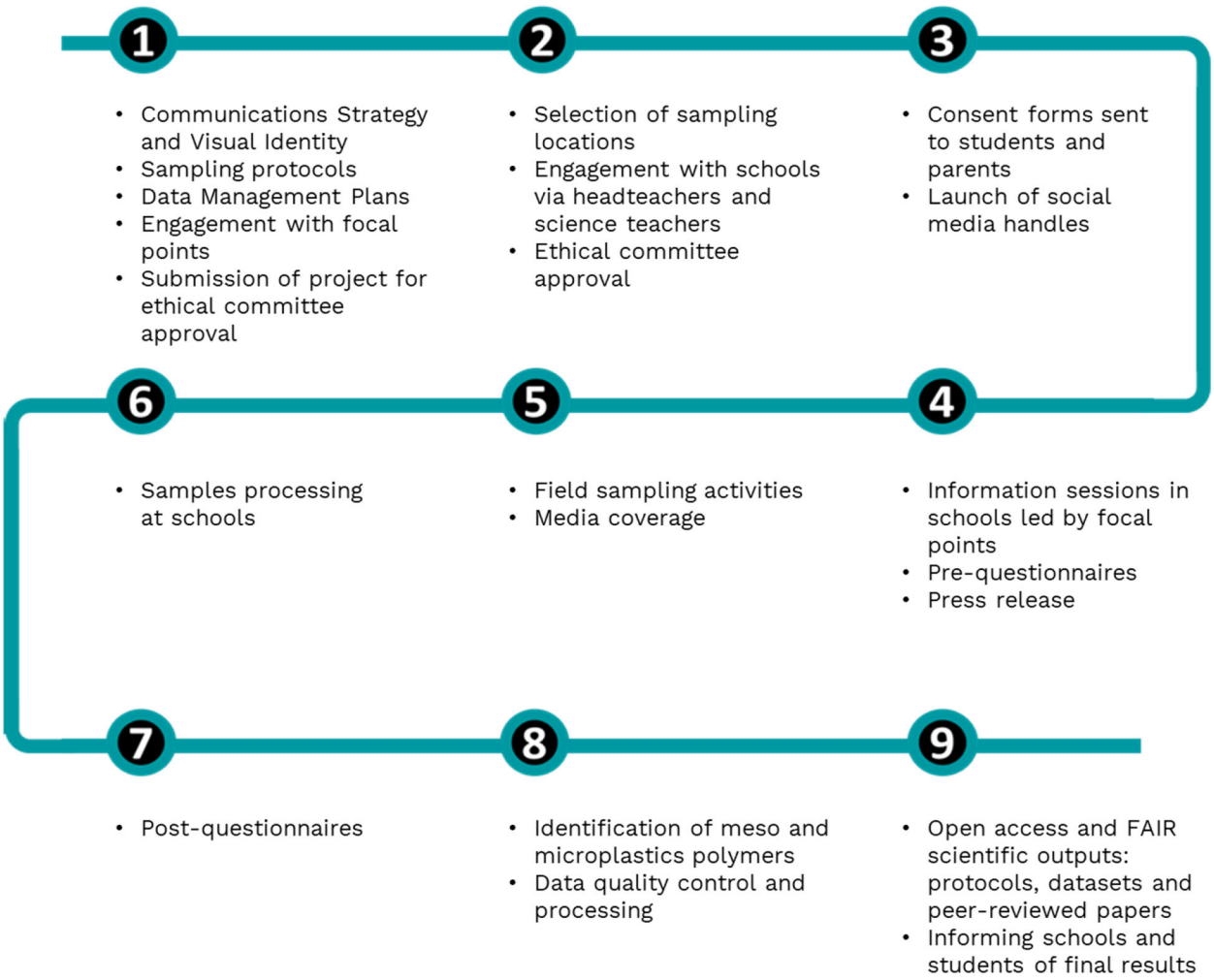

FIGURE 1
Workflow of COLLECT (Citizen Observation of Local Litter in coastal ECosysTems, 2021-2022), a citizen science project to acquire distribution and abundance data of coastal plastic litter in seven countries, in Africa (Benin, Cabo Verde, Côte d'Ivoire, Ghana, Morocco, Nigeria) and Asia (Malaysia), as well as to evaluate the educational, behavioral, and well-being impact of the citizen science intervention in the participating students.

FIGURE 2
The COLLECT sampling procedures for plastic litter observations in the field **(A–D)** and sampling processing in schools **(E, F)**: **(A)** briefing before sampling activities, **(B)** 50 m transect parallel to the water line, with 6 sampling spots, **(C)** sampling area (1 m radius circle) containing macroplastics, **(D)** sampling sand for meso- and microplastics (10 x 10 x 5 cm), **(E)** meso- and microplastics samples processing in the classroom with the assistance of teachers and trained Science, technology, engineering, and mathematics (STEM) professionals, **(F)** meso- and microplastics isolated using density separation techniques (NaCl, supersaturated solution), and data recording.

ECosysTems) project recruited participants in six countries, namely Benin, Cabo Verde, Côte d'Ivoire, Ghana, Morocco, Nigeria (Figure 3). The project included a Southeast Asian country, Malaysia, to demonstrate that the project could be expanded to other geographic areas, and that plastic litter samples could be collected and processed by school children globally, following the same procedures. In each country, one or two representatives from POGO member institutes in the region (focal points), organized the local activities, such as recruiting and training students and teachers, and leading the field sampling. Local focal points selected the sampling areas based on the following criteria: proximity to the research institute and the participating schools, sandy beaches

FIGURE 3
Sampling locations (red) of the project COLLECT in Benin (Abomey Calavi area), Cabo Verde (Calhau and São Vincente), Côte d'Ivoire (Port Bouet), Ghana (Accra area), Malaysia (Pantai Ombak Damai and Pantai Pasir Panjang), Morocco (Sidi Kacem and Sidi Kankouch beaches), and Nigeria (Ibeno Beach in Calabar area, and Lagos). Map by the Flanders Marine Institute (2020), World Countries Geodatabase.

located preferably at least 5 km away from an estuary or any other inland water bodies, accessibility by transportation vehicles, and with minimum impediments to ensure the health and safety of the participants (Figures 2, 3). Sampling events took place in rainy (or wet) versus dry seasons, or Autumn versus early Spring [October – December and January – April respectively], depending on the participating countries. Where needed, each focal point requested the necessary permission from local authorities for the field activities to take place.

2.2 Participants recruitment and training

The goal of COLLECT was to engage with ten second cycle schools and to recruit and train local students, preferably between the ages of 15 and 18, in beach litter sampling methodologies. Focal points managed recruiting tasks and communicated directly with participating schools, introducing the project and methodologies to the students and teachers, i.e., the citizen scientists. They also engaged with local media to promote the project, and managed all the local logistical arrangements. Each headteacher received an official letter from POGO, introducing the project and the planned activities (Supplementary Information, Letters of Consent), and inviting a maximum of 50 students per school to participate. Due to the COVID restrictions in place, and to minimize risks, participants were assigned to one of two smaller groups (≤ 25), each of which carried out a dedicated field activity in each season. In cases where the students were underage (< 18 y.o.), parents were required to provide consent for their child's participation in the COLLECT activities (Supplementary information, Informed Consent Letter(s) to Parents). All students 16 y.o. or older had to provide additional personal consent forms to participate in all project related activities (Supplementary Information, Informed Consent Letter(s) to Students, 16 y.o. or older; for the ethical committee approval, see below section *Evaluation of the educational, behavioral, and well-being impact on students*). In addition, consent from parents and schools was required to take photo or video recordings of students and to use it for educational and outreach purposes (Supplementary Information, Informed Consent Letter(s) to Parents). Templates for invitation letters and consent forms are available in the supplementary information, in the working languages (English, French, Portuguese) of the project.

Prior to the field activities, there was an educational in-person workshop in each school, led by the local focal points and their teams, and supported by the collaborating science and head teachers, to discuss the topic of plastic pollution, and to inform and train the students on the sampling procedures (Figure 4). The workshop was an opportunity for students to interact directly with local scientific researchers and institutions. To ensure message consistency, focal points delivered the same presentation, scripted in the local language (Supplementary Information, Information session). During each field campaign, and prior to the sampling activity, the students participated in a briefing led by focal points, to receive instructions and training on how to sample and/or collect information on plastic litter items and where each student received a simplified graphical illustration of the sampling procedure (Catarino et al., 2021c).

2.3 Survey and processing methods for plastic litter quantification

The goal of the COLLECT project was to sample macro- (> 25 mm), meso- (5 - 25 mm) (MSFD Technical Subgroup on Marine Litter, 2013; GESAMP, 2019) and microplastics (< 5 mm, sampled up to 1 mm) (Bosker et al., 2017b; Kiessling et al., 2021) in sandy beaches following quantitative procedures. To do so, we developed an extended and technical standard operating procedure (SOP) (Catarino et al., 2021d), with detailed instructions on materials and methods, and on sampling acquisition and processing, together with detailed recording sheets, and a section with health and safety recommendations (Cheshire et al., 2009; OSPAR, 2010; MSFD Technical Subgroup on Marine Litter, 2013; Bosker et al., 2017a; Bosker et al., 2017b; Barnardo et al., 2020). Both the extended SOP (Catarino et al., 2021d), including required materials, and the recording datasheets (Catarino et al., 2021e) were translated into the local school languages from English, i.e. French and Portuguese. All equipment was provided to the schools and students participating in the field activities [see detailed and technical SOP https://dx.doi.org/10.48470/38, (Catarino et al., 2021d)]. For sampling and processing activities, students were divided into groups (up to 5 groups per field campaign) of 5 – 6 students, and their work was mentored either by a teacher, researcher (e.g. focal point) or trained technical staff from the focal point institution. Sampling was done along a 50 m transect displayed at the high tide line, parallel to the water line, in six sampling spots displayed every 10 m. In each sampling spot, participants defined a 1 m radius circle (sampling spot area of 3.14 m^2). Students recorded and classified all the macroplastic items visible on the sand surface (Figure 2) according to the Guideline for Monitoring Marine Litter on the Beaches (OSPAR, 2010), which provides not only the name of the items in various languages (including English, French, Portuguese and Spanish), as well as images of the litter items, to assist in their identification and classification. In each circle, participants sampled the top 5 cm of sand of a 10 x 10 cm randomly displayed quadrat (Figure 2). Sand was first sieved using a 25 mm mesh, and all macroplastics of smaller dimensions were collected. The sand was sieved once more using a 5 mm meshed sieve, and all mesoplastics and sieved sand were collected in separate zip bags until further processing. The sampling procedures were repeated in all sampling spots, along each group's transect [see detailed and technical SOP https://dx.doi.org/10.48470/38, (Catarino et al., 2021d)].

All litter samples were transferred to the schools and air dried for 1 week or longer, before sample processing. Macroplastics collected from the circle surface and from the quadrat sand sample, and mesoplastics collected from the quadrat, were weighed and their length measured (to the nearest mm) wherever possible. The sand sample collected in the field was sieved using a 1 mm meshed sieve, with the aid of water (Catarino et al., 2021d). Collected particles were extracted from the remaining sediment and other materials using a simplified density separation method (supersaturated NaCl solution made using cooking salt) (Cutroneo et al., 2021). All microplastics were handpicked using metal spoons or tweezers, weighed (total weight of particles to the nearest g), and observed using a didactic microscope (purchased locally). The smaller macro-, the meso- and the microplastics were described and classified according to shape and

FIGURE 4
Images of the COLLECT activities at school during information sessions (most photos from first two rows) and during field activities (bottom two rows), in: **(A, I)** Benin (both during field activities); **(B, J)** Cabo Verde; **(C, K)** Côte d'Ivoir; **(D, L)** Ghana; **(E, M)** Malaysia (both during field activities); **(F, N)** Morocco; **(G, O)** Calabar, Nigeria; **(H, P)** Lagos, Nigeria. Please refer to the main text and the Supplementary Information for further details on the information session's format and content, including the banner design.

color following the classification of the MSFD Technical Subgroup on Marine Litter (MSFD Technical Subgroup on Marine Litter, 2013). All items were displayed on a white surface and photographed (together with a ruler for scale reference). All meso- and microplastics were carefully wrapped in aluminum foil and stored until further analysis by collaborating researchers, while macroplastics were disposed according to local litter recycling and waste disposal guidelines (Catarino et al., 2021d).

2.4 Intercalibration exercise for polymer identification of microplastics

Within the POGO network of member institutions, we have identified collaborating partner research groups with access to equipment to assess the polymer types of meso- and microplastics, such as Raman and Fourier transform infrared (FTIR) spectroscopy. To guarantee intercomparability of polymer identification methodologies applied by each research group, a series of standard particles was distributed amongst partners to perform a calibration exercise (blind identification test); the particles size ranged between 5 and 1 mm (CARAT, Belgium), and the polymer types were based on frequently sampled plastic items on beaches (Suaria et al., 2020; Everaert et al., 2022), namely polystyrene (PS), polyvinyl chloride (PVC), polypropylene (PP), nylon, polyethylene (PE) and polyethylene terephthalate (PET). Up to 100 randomly selected sub-samples of meso- and microplastics were then shipped to the collaborating institutes and analyzed for polymer identification.

2.5 Data validation, quality assurance and control and data reliability

To ensure the reliability of the data procedures, the SOP and datasheets were trialed in Ghana prior to the project by one of the project principal investigators and a team of professional and technical staff. Even though the participation of school students in citizen science plastic litter sampling campaigns is of comparable efficiency to researchers and trained teachers (Hidalgo-Ruz and Thiel, 2015; van der Velde et al., 2017), during this project we ensured that all steps of data acquisition and processing done by the students were supervised by trained technical staff and researchers, to have robust

and reliable data (Hidalgo-Ruz and Thiel, 2015). Because the sampling did not target microplastics smaller than 1 mm, there were limited opportunities for sample contamination, as particles that could have been released from the use of plastic materials (e.g., zip lock bags used for sand and particles storage) and airborne fibers would most likely be smaller than 1 mm (Everaert et al., 2022), a size range outside the scope of this project (Bosker et al., 2017b). Using supersaturated sodium chloride solutions (density = 1.2 g/cm^3) for microplastic extraction from field samples is not the most efficient salt to separate denser particles (e.g. PVC > 1.16 g/cm^3, or PET > 1.37 g/cm^3), when compared, for instance, to sodium polytungstate, zinc chloride or sodium iodide (MSFD Technical Subgroup on Marine Litter, 2013; Cutroneo et al., 2021). However, complex density separation techniques performed in a laboratory setting use salts that are either expensive and inaccessible to citizen science projects, or that may have associated health and safety risks (MSFD Technical Subgroup on Marine Litter, 2013; Cutroneo et al., 2021). Supersaturated solutions of NaCl are an accessible and safe alternative for any school activity, and their preparation requires only inexpensive and commercially available cooking salt (MSFD Technical Subgroup on Marine Litter, 2013; Cutroneo et al., 2021). All data recorded in paper format [see field and classroom datasheets in the COLLECT DMP, https://dx.doi.org/10.48470/40, (Catarino et al., 2021d)] were curated before insertion in digital table format (Microsoft Excel). Handwritten information was double checked by at least two independent users and all data were verified for consistency (Kiessling et al., 2019). The photos of plastic litter (from macro- to microplastics) were checked to confirm the suitability and reliability of the data inserted in the datasheets (Kiessling et al., 2019).

2.6 Evaluation of the educational, behavioral, and well-being impact of COLLECT on students

The social sciences component of the COLLECT project aimed to evaluate the educational, behavioral, and well-being impact of the citizen science intervention, by means of a pre- and post-assessment questionnaire (Severin et al., 2021). Students answered the same 15-minute questionnaire in their school language [available here: https://doi.org/10.17605/OSF.IO/VB8TX] prior to the training and again after the conclusion of their participation in the school activities (30 days on average). COLLECT's social sciences component, including experimental design, questionnaires and data analysis plan, was preregistered in the Open Science Framework (OSF, see https://doi.org/10.17605/OSF.IO/VB8TX) registry prior to data collection (Severin et al., 2021), had its own data management plan (DMP) submitted to the DMPonline platform (dmponline.be, Belgium) [see section *Data management and analysis*], and was approved by the ethical committee of the Faculty of Psychology and Educational Sciences of Ghent University (ref: 2021/65). Parents and educators provided written informed consent for the students to participate in this study (see Supplementary Material for consent form templates). The questionnaire was prepared in English and translated to French and Portuguese, with each translation reviewed by at least a second native speaker. Schools conducted the questionnaire either on paper (African schools) or online (Malaysian school), using the Limesurvey platform (Limesurvey GmbH; www.limesurvey.org).

The questionnaire was divided into three main topics: knowledge and awareness of marine litter, attitudes and behaviors towards marine litter and the environment in general, and nature connectedness and well-being. Questions regarding knowledge and awareness of marine litter were based on previous studies evaluating the impact of citizen science interventions on children or adolescents and perceptions of marine litter (Hartley et al., 2015; Wyles et al., 2017; Hartley et al., 2018; Locritani et al., 2019). Specifically, participants were evaluated on problem awareness, concern, and perceived causes and impacts of marine litter, with the use of Likert agreement scales. Perceived prevalence of plastic on the coastline was assessed with multiple-choice questions such as "what percentage of litter on the beach and in the sea do you think is plastic?" or "what do you think was the most common type of litter found on the coastline near you in 2020?". An additional question on the objective knowledge of degradation time of plastic was included. The second topic of the questionnaire measured litter-reducing behaviors with items adapted from Hartley et al. (2015) and Locritani et al. (2019). Pro-environmental behavioral intentions were assessed by participants rating how often they think they will participate in beach clean-ups in the future (Wyles et al., 2017), as well as how often they will engage in more generic pro-environmental behaviors (e.g., "recycle"; "re-use plastic bags"). Participants' attitudes towards beach litter removal were measured with items taken from Lucrezi and Digun-Aweto, 2020, e.g., "it is a responsibility of the local community to remove litter from the beach". An additional item was also included: "only those who originally pollute the beach are responsible for removing litter from the beach". General pro-environmental attitudes were measured with the revised version of the New Ecological Paradigm (NEP) scale (Dunlap et al., 2000) that is adapted for children and adolescents (Manoli et al., 2007). This 10-item scale assesses the extent to which one endorses the rights of nature, the possibility of an eco-crisis, and rejects human exemptionalism. The third and final topic of the questionnaire consisted of measuring the participants' sense of connection with nature, with the use of the Nature Connection Index (NCI) (Richardson et al., 2019), which has been validated for both children and adults. Participants' well-being was assessed with the Short Warwick Edinburgh Mental Well-Being Scale (SWEMWBS), developed by the Universities of Warwick, Edinburgh, and Leeds in conjunction with NHS Health Scotland (Stewart-Brown et al., 2009). The seven-item scale measures various aspects of well-being, such as social connection and sense of agency. A question on how happy participants felt was also added to evaluate well-being, with a ten-point scale going from *extremely unhappy* to *extremely happy*. Finally, the post-questionnaire included additional questions on how satisfied participants were with the COLLECT project, how worthwhile and meaningful it was to them, and which adjectives best described their experience of the project.

It is important to note that the items and scales were carefully chosen according to their established validity and reliability regarding the socio-demographics of our sample (i.e., being of young age and residing in African or Asian countries). For example, the NEP scale has been applied within an African context (Petegem and Blieck, 2006; Ogunbode, 2013), and the SWEMWBS has been validated in

various cultural settings (Stewart-Brown et al., 2009). In addition, the items taken from Hartley et al., 2015; Locritani et al., 2019 were designed to be appropriate for children and adolescents. To ensure further validity of the survey questions, the survey was piloted with the students from Calabar, Nigeria, who could additionally indicate when they did not understand the question.

2.7 Data management and analysis

The COLLECT project had two data management plans (DMPs), one focused on plastic litter sampling and processing procedures (Catarino et al., 2021e) and another one focused on the component of social sciences (Severin et al., 2021). Each DMP, a document specifying how research data will be handled both during and after a research project, was submitted to the platform DMPonline (www.dmponline.be, Belgium). The DMPs identified the collection and origin of new data, types of data to be acquired, file formats and expected volume, metadata standards and the controlled vocabularies to be used, where data would be archived, and backup procedures. The DMP concerning the social sciences also contained information concerning General Data Protection Regulation (GDPR) under European Union (EU) law (https://eur-lex.europa.eu/eli/reg/2016/679/oj), which protects individuals with regard to the processing of personal data and on the free movement (i.e., transfer to third parties) of such data. Ethical aspects and additional security measures for data protection (e.g., a Data Protection Impact Assessment) were also included.

All materials and data generated during the COLLECT project comply with the FAIR (Findability, Accessibility, Interoperability, and Reuse) principles of digital assets (Wilkinson et al., 2016). Materials and data will be archived using the Marine Data Archive (MDA, www.mda.vliz.be, VLIZ, Belgium), and searchable *via* a Digital Object Identifier (DOI, www.doi.org) The Integrated Marine Information System (IMIS, www.vliz.be/en/imis, VLIZ, Belgium). The macroplastics litter was classified following the OSPAR guidelines for monitoring marine litter on beaches (OSPAR, 2010). The meso- and microplastics items were classified according to the type, shape and color reported by the Marine Strategy Framework Directive (MSFD) technical Subgroup on marine Litter (MSFD Technical Subgroup on Marine Litter, 2013). All the data generated will be made open access and unrestricted after completion of the project. This means that data will be freely available at no charge to third parties, submitting it to the The European Marine Observation and Data Network (EMODnet) central beach litter database, operated by EMODnet Chemistry (www.emodnet-chemistry.eu). A link to the data portal will be included in the metadata record in IMIS.

During the design phase of the project, international data and metadata standards were consulted to comply with dataset requirements for the targeted data portal, ensuring interoperability and facilitating exchange and re-use of the data. Common controlled vocabularies, such as the OSPAR guidelines and BODC Vocabularies (British Oceanographic Data Centre, www.bodc.ac.uk/resources/vocabularies), and file format (Excel spreadsheet file), were used for consistency and interoperability, enabling records to be interpreted by computers. The data quality control procedure was initiated locally by the focal points and overseen by the data management collaborators based at VLIZ (Belgium). The latter ensure the quality and completeness of the data, before datasets are made available through international repositories. After the initial quality checks and formatting of the data according to the requirements from EMODnet, the EMODnet Beach Litter Format Validator will be used to check correctness and approval of the generated files. Quality control procedures will be described in the metadata of the dataset (Fraisl et al., 2022).

Analysis of the sampled plastic litter data will be done using the free software R (R Core Team, 2022). We will assess differences in the diversity and abundance of macroplastic items observed in each season and collection site. We will further investigate the size frequency distribution of meso- and microplastics and diversity of these particles according to shape, color and polymer types at each collection site. Absence of litter observations was considered as data observations, if sampling was performed, and will be expressed as 0 items per sampling unit.

The analysis of the social sciences data will be carried out with the use of the software IBM SPSS Statistics (Version 28). We will evaluate changes in knowledge and awareness of marine litter, attitudes and behaviors towards marine litter and the environment in general, and well-being, using a within-subject design with pre- and post-assessment. Potential differences amongst countries, ages, and genders will be explored (Severin et al., 2021).

2.8 Communications plan

The COLLECT communications plan focused on the development of tools to support the collaborating schools, reach out to local communities, and to provide visibility for the project activities and progress (Seeyave et al., 2017). It consisted of creating a visual identity, establishing social media profiles on appropriate public platforms, engaging with local media outlets, producing educational materials, and compiling media clippings to assess impact (Table 1). The COLLECT visual identity, created in collaboration with a consultancy company (Science Crunchers, Portugal), comprises the project logo and the branding guidelines for visuals, colors and fonts applied across all project materials. Through application of the guidelines, communication activities (e.g., presentations, banners, documentation, etc.) were consistent in all participating countries. A webpage (pogo-ocean.org/innovation-in-ocean-observing/activities/collect-citizen-observation-of-local-litter-in-coastal-ecosystems) lists the main information about the project (e.g., goals, strategy, outcomes, team, collaborators, contacts) and social media presence on various platforms (Twitter, Instagram, Facebook) ensures dissemination of the project goal and activities to a broad audience. The project educational materials, namely a simplified illustrated sampling protocol (Catarino et al., 2021c) and its video companion (YouTube, shorturl.at/gyGHP) (Catarino et al., 2021b),developed in collaboration with the same consultancy as the visual identity, were based on the extended technical sampling protocol and produced or translated into the working languages (i.e., English, French, Portuguese and for the illustrated versions additionally in Spanish). The COLLECT communication plan included a component focused on national/local advertisement/engagement *via* traditional media (radio,

TABLE 1 Communication activities related to the project COLLECT, with information on platforms and products created during the project, target audiences and metrics (when available).

Platform/Product	Handle/Website/Reference	Target Audience	Metrics
Visual Identity including logo	COLLECT brandbook (internal use)	General public, academics, schools and citizen scientists, other stakeholders	NA
2-Pager simplified illustrated standard operating procedure (SOP)	Catarino et al., 2021b	Schools: teachers and students, i.e., citizen scientists	NA
Animated (video) simplified illustrated standard operating procedure (SOP)	YouTube Playlist: https://youtube.com/playlist?list=PL3Mh9bBxde-Xbv668RRV51xovJlgaKy9e (Catarino et al., 2021b)	Schools: teachers and students, i.e., citizen scientists	Total views (22/11/2022): 165
Webpage	Link: pogo-ocean.org/innovation-in-ocean-observing/activities/collect-citizen-observation-of-local-litter-in-coastal-ecosystems	General public, academics, schools and citizen scientists, other stakeholders	Total views (24/10/2022): 879, of which 394 were unique views
Social Media platforms: Twitter, Instagram and Facebook	Twitter: @COLLECT_Ocean Facebook page: Collect - Citizen Observation of Local Litter in Coastal ECosysTems Instagram @collect_ocean (See also content and mentions on @cemacs_usm [Instagram], and @Zebrazuli and @EdemMahu [Twitter])	General public, academics, schools and citizen scientists, other stakeholders	Total combined users (20/11/2022): 443
Press release	Available on webpage (see link above)	Press and media platforms	NA
POGO newsletters	Link: pogo-ocean.org/pogo-newsletter, see Supplementary Information for complete list	POGO members, academics, other stakeholders	(12/12/2022) Three articles
TV reports, newspapers, radio shows, videos, news agencies posts, blog posts, etc.	See Supplementary Information for complete list	General public and press	NA
Cotton facemask (for COVID-19 prevention) with project logo	NA	Schools: teachers and students, i.e., citizen scientists	> 400 masks
Conferences	See Supplementary Information for complete list	Academic and other stakeholders	Nine presentations (posters and oral presentations)
Webinars and information sessions	Information sessions done in each school, see Supplementary Information for further information; webinar done by IMAR, Cabo Verde, on 03/06/2022	Schools: teachers and students, i.e., citizen scientists; press	NA

For further information (including Twitter and Webpage analytics), please see the Supplementary Information.
NA, not applicable.

newspaper and television). All media clippings were compiled to assess media impact and demonstrate outreach (see Supplementary Information). The results of the project are being shared with participating schools, teachers and students *via* webinars organized by the local focal points, and *via* a poster or booklet to be distributed to the headteachers.

3 Results and discussion

The present initiative, COLLECT, aimed to respond to the need for assessment of a significant source of pollution (i.e., plastic litter) in relatively uncharted regions by employing a citizen science approach with scientifically sound and standardized methodology; and, concurrently, evaluate the impact the participation in such an activity can have on a citizen's well-being and environmental awareness. COLLECT was designed for the participation of secondary school students in surveying macro-, meso- and microplastics on beaches. Over 400 students participated in the COLLECT activities and had a mean age of 15 y.o. (± 2.2 SD) (based on the number of answered questionnaires, M. I. Severin 2022, VLIZ, personal communication), from 11 schools (see full list in Supplementary Information). Students and teachers followed standardized methodologies for data acquisition, covering a wider geographical range for sampling in comparison to conventional observational and monitoring efforts (Fraisl et al., 2022; Severin et al., 2023). The school recruitment was largely dependent on ongoing collaborations between institutes and science teachers and/or on the stakeholders' network of focal points, who directly contacted the headteacher or a science teacher of one to two local schools to join the project. The extended and technical standard operating procedure (SOP) (Catarino et al., 2021d)and sampling sheets (Catarino et al., 2021e) used in the beach litter collecting campaigns followed the most recent guidelines and recommendations for plastics sampling and data handling (Cheshire et al., 2009; OSPAR, 2010; MSFD Technical Subgroup on Marine Litter, 2013; Bosker et al., 2017b; Barnardo et al., 2020; Fraisl et al., 2022). The technical SOP has been simplified into an illustrated 2-pager to provide accessible guidelines for the citizen scientists (students and schools' staff) (Catarino et al., 2021c), accompanied by animated and subtitled videos (YouTube, shorturl.at/gyGHP) (Catarino et al., 2021b), all in the four working languages of

the project. The simplification of the workflow and guidelines on the technical SOP facilitated the understanding and increased the engagement of COLLECT participants (Dittmann et al., 2022). COLLECT educational resources (illustrated SOP and animated videos) were developed to be easily followed, with step-by-step instructions for visual census, collection, and processing of plastic litter in various size categories. These, as well as the other outputs of the project (e.g., publications and data) will be open access (Suber, 2012) and compliant to FAIR data guidelines (Wilkinson et al., 2016; Catarino et al., 2021e; Fraisl et al., 2022). It is expected that this approach will allow the project strategy to be widely implemented and followed by youths (Dittmann et al., 2022; Fraisl et al., 2022). Data acquired by citizen scientists is instrumental in obtaining an initial 'snap-shot' of the distribution and abundance of marine litter (Hidalgo-Ruz and Thiel, 2015; GESAMP, 2019; Dittmann et al., 2022; Fraisl et al., 2022) and to evaluate the effectiveness of mitigation actions and local environmental policies, such as recycling initiatives (Lippiatt et al., 2013; Harris et al., 2021). We expect that COLLECT will contribute to establishing baseline information on coastal plastic debris and that results will contribute to the identification of hotspots of plastic coastal litter.

Targeted tasks to engage with project participants and broader audiences were deliberately established throughout COLLECT. Face-to-face interactions between focal points and participants (e.g., information sessions in the classroom, briefings in the field and/or during sample processing at schools) reinforced the bond between the citizen scientists and local researchers, and guaranteed that the students were well informed about the activity to be executed, the project objectives, the importance of investigating plastic pollution and to set the foundation for an engaging and trustworthy collaboration (Rüfenacht et al., 2021; Dittmann et al., 2022; Fraisl et al., 2022). The focal points of the project were crucial in supervising and guaranteeing the quality of the sampling campaigns, in enabling the dataflow between the schools and the researchers, in providing contextualized information to the students and in being an open channel between all researchers participating in the project and the citizen scientists. To engage with external stakeholders (i.e., not associated with COLLECT) such as policymakers and non-governmental organizations (NGOs), the COLLECT initiative has submitted a commitment for the United Nations (UN) aiming to accelerate and contribute to the implementation of the Sustainable Development Goal (SDG) 14, on life below water (sdgs.un.org/partnerships/collect-citizen-observation-local-litter-coastal-ecosystems). To reach out to the scientific community, the project has been presented in various international meetings and conferences (see list in supplementary information), a fundamental dissemination step (Rüfenacht et al., 2021). As COLLECT is reaching its final implementation phase (September 2022 – February 2023), the engagement with the scientific community will be concluded by publishing the workflow and data analysis results in peer reviewed and open access publications (Rüfenacht et al., 2021; Fraisl et al., 2022). All results will be communicated back to schools and students *via* online seminars (when possible), posters or booklets.

COLLECT covered the geographic area of West and North Africa, which is under-represented in terms of both citizen science initiatives (Kawabe et al., 2022; Severin et al., 2023) and marine litter data availability (Bergmann et al., 2017), as well as South-East Asia. Most citizen science publications concerning plastic litter initiatives have focused on activities in Europe and North America, while Africa was the continent with the least reported projects (Kawabe et al., 2022; Severin et al., 2023). In this project, we aim to contribute to an increased data availability in these regions, concerning plastic litter. In addition, to broaden its outreach, COLLECT materials and videos were tetralingual (i.e., available in English, French, Portuguese and Spanish). All data, collected by the children in their local language, had furthermore to be translated back to English to be readily available to the international scientific community. Our recommendation is that international projects and funding bodies consider and account for the required effort and costs of the translation of materials and of acquired data. These are no easy tasks, and require particular attention from the scientific community and citizen science experts when extending projects to broader geographical areas and scales. COLLECT, alongside initiatives such as the WIOMSA's (Western Indian Ocean Marine Science Association) Marine Litter Monitoring Project (Western Indian Ocean Marine Science Association 2021) (Barnardo et al., 2020), contribute towards data acquisition on plastic litter on African sandy beaches, while training citizen scientists and promoting Ocean Literacy. The application of the same sampling procedures on Malaysian beaches indicates that the COLLECT methodology can be followed and applied by citizen scientists from around the globe, creating opportunities to acquire quality open access data, which can be used to assess the fate and geographical distribution of litter (Kiessling et al., 2019) and to indicate if mitigation measures have been successful (Haarr et al., 2020). Therefore, engaging with citizens in acquiring data from under-represented geographic areas contributes to the obtention of new datasets, a key step in prioritizing and tackling environmental issues (Pandya, 2012; Pandya and Dibner, 2019; Pateman et al., 2021).

We expect that participating in COLLECT will lead to an increased knowledge and awareness of marine litter, accompanied by a higher tendency to undertake actions in reducing marine litter. Additionally, we expect to find a positive "spillover effect", which is the notion that engaging in one pro-environmental behavior might support further engagement in other pro-environmental behaviors (Thøgersen and Ölander, 2003). We thus speculate that the students will have a greater willingness to adopt generic pro-environmental behaviors and stronger pro-environmental attitudes, as well as higher nature connectedness. These overall outcomes could positively impact ocean literacy(Paredes-Coral et al., 2022), a concept that has been identified as a main driver towards achieving a sustainable future (Kelly et al., 2022). Finally, we will assess if taking part in COLLECT will boost the students' eudaimonic and hedonic well-being, an aspect often overlooked when assessing the impact of citizen science initiatives (Wyles et al., 2017; Severin et al., 2023).

Evaluating the impact of participating in COLLECT on the students enables the inclusion of a human and social dimension within the project, which is an essential component to ensure successful conservation projects (Catalano et al., 2019; Kelly et al., 2022). The COLLECT project is in line with the "people and nature" approach within conservation science as it promotes the understanding of the perceptions and attitudes that local communities hold towards the marine environment and the issue of plastic pollution (Mace, 2014). This approach advocates the synthesis of social and biological sciences to optimize the dynamic

interactions between humans and nature (Sanborn and Jung, 2021). Exploring this human dimension was accompanied by certain challenges, particularly in terms of considering the influence of culture on the measured outcomes of the survey, as pro-environmental attitudes are shown to be partly determined by culture (Vikan et al., 2007). Another challenge, that is often presented when using self-reported data, was to limit social desirability bias, which is the tendency for respondents to provide answers that are more socially desirable. To reduce this bias, we assured participants that their answers would remain confidential and be reported anonymously, we asked participants to answer the survey as honestly as possible, and we did not reveal the exact aim of the survey to the participants (Larson, 2019).

COLLECT relies on public engagement, making its communications plan a critical piece for deepening its impact (Rüfenacht et al., 2021; Fraisl et al., 2022). In this project we identified key audiences, such as the participating schools and students (i.e., COLLECT's citizen scientists), local and international civil communities, and a broad audience of various stakeholders, including researchers, and we targeted specific tasks towards these publics (Table 1). The project visual identity, which included the development of a logo and a color scheme, was an important asset in establishing COLLECT's international recognition and consistency in all communication tools (Rüfenacht et al., 2021; Fraisl et al., 2022). Until November 2022, COLLECT was identified a total of 22 times in news outlets, such as newspaper articles, newsletters, radio and TV shows (Table 1, Media Clippings information available in Supplementary Information). COLLECT has gathered until November 2022 a combined total of over 400 followers in social media (Twitter, Instagram and Facebook), with over 160 views on the YouTube channel, and the COLLECT webpage has reached a total of nearly 880 views (Table 1, See also Supplementary Information, Media and Social Media). Engaging with the press and social media are key steps to reaching out to the broader community and to key stakeholders such as policymakers, to contribute to evidence-based policies (Rüfenacht et al., 2021).

The implementation of COLLECT faced other challenges, which required dedicated mitigation measures. The project started in 2021, during the global pandemic of coronavirus (COVID-19) (Hannah Ritchie et al., 2020) and to have a reduced number of participants in each event, including during transportation, the number of sampling campaigns was increased. The pandemic led to numerous delays due to school closures or other local restrictions in place, but focal points arranged for flexible dates with schools, to accommodate for field campaigns running outside stricter restriction periods. General compliance guidelines with local rules were provided to the participants and COLLECT-branded cotton masks were offered to participating schools' staff and students. The project further benefited from the swift development of online meeting and conference platforms, which enabled frequent meetings between partners and focal points, and the presentation of COLLECT at top rated international conferences (e.g., SETAC annual meetings in Europe and a biannual meeting in Africa), overcoming potential mobility issues and costs. Developing documentation and acquiring data in various languages brought additional challenges to the project, such as increasing costs and time needed to run tasks, namely in converting all data acquired in paper format to digital, while translating data information from French, Portuguese and Spanish to English. To develop materials in four different languages, the project benefited from having multilingual collaborators, used translation services to create educational materials and followed the OSPAR guidelines for monitoring beach litter, which included a translation of the macro-litter classification (OSPAR, 2010). Data was acquired mostly in paper format (handwritten), except for a few online surveys (Malaysia), as in most schools, students are not allowed to use mobile phones or may not have access to mobile devices in the field. Copies of the datasheets and surveys were compiled by the focal points and sent to the organizers *via* post/courier or scanned digital copies, and data was compiled manually in Microsoft Excel. Even though this procedure was time consuming, this task was coupled with a data quality check, as per best practices guidelines (Kiessling et al., 2019; Dittmann et al., 2022; Fraisl et al., 2022), enabling expert supervision before data archiving and submission to EMODnet.

4 Conclusions and perspectives

The Citizen Observation of Local Litter in coastal ECosysTems (COLLECT) project followed standardized methodologies for data acquisition and reporting. This project offers an opportunity to balance out data gaps in critical geographical areas, such as the west and north coasts of Africa, and to inform evidence-based environmental policies (Maes and Preston-Whyte, 2023). The COLLECT methodology can be followed globally by youth, adults, citizen groups (e.g., schools, youth groups and other associations, NGOs) and others to observe and collect plastic litter data in sandy beaches, which after appropriate quality checks made by experts, can be open and accessible to the scientific community and other key stakeholders. Furthermore, all digital assets resulting from COLLECT, such as procedures, datasets and scientific publications, will be open access and compliant with FAIR guidelines, thus, increasing and promoting information accessibility and reproducibility within the scientific community. We foresee that COLLECT will contribute to the global effort of enabling access to key information in areas with data gaps, and to actively monitor the UN SDG14 (Fraisl et al., 2020). For example, the current report on the SDG14 indicator compiled by Ghanaian authorities includes citizen science data from plastic litter surveys (TReNDS, 2021), critical to establish baselines levels of plastic litter in the environment and monitor progress of mitigation measures.

Working together with schools was critical to enhance recruitment of citizens for the project and assure retention of participants. It also further enabled and facilitated the connection between participants and researchers, as most participating teachers had a science background and promptly assisted in mediating the knowledge transfer. Because citizen science initiatives related to plastic pollution can have an impact on the environmental perception and well-being of school children, we combined multidisciplinary expertise to evaluate the outcomes of COLLECT *via* social science assessments, which we strongly advise similar projects to consider. COLLECT promoted both multilingualism and multiculturalism, as these can foster social innovation (Heinisch, 2021), as well as access to science (and ocean) literacy to a broader community (Márquez and Porras, 2020). Future funding of citizen science projects should particularly support projects that welcome diverse communities, to promote a truly open access to information (UNESCO, 2021), to achieve an impactful ocean literacy framework and to globally reach the UN SDG14 on the conservation and sustainable use of the oceans, seas and marine resources (UNESCO, 2018).

Data availability statement

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

Ethics statement

The studies involving human participants were reviewed and approved by Ethical committee of the Faculty of Psychology and Educational Sciences of Ghent University (ref: 2021/65). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

All the authors contributed to the final version of the manuscript and approved the submitted article. AC: Conceptualization, methodology, investigation, data curation, validation, writing - original draft, resources, project administration and funding acquisition, supervision; writing - review & editing. EM: Conceptualization; methodology, investigation, data curation, validation, resources, project administration and funding acquisition, supervision, writing - review & editing. MS: Conceptualization, methodology, investigation, data curation, validation, writing - original draft, writing - review & editing. LA: Investigation, data curation, resources, project administration, writing - review & editing. PA: Investigation, data curation, writing - review & editing, FA: Investigation, data curation, resources, project administration, writing - review & editing. FB: Conceptualization, investigation, data curation, resources, project administration, supervision, writing - review & editing. MB: Investigation, data curation, resources, project administration, writing - review & editing. AJ-R: Investigation, data curation, resources, project administration, writing - review & editing. MM: Investigation, data curation, resources, project administration, writing - review & editing. JM: Conceptualization, resources, funding acquisition, writing - review & editing. IM: Investigation, data curation, resources, project administration, writing - review & editing. JN: Data curation, validation, writing - review & editing. PN: Investigation, data curation, resources, project administration, writing - review & editing. NA: Investigation, data curation, resources, project administration, writing - review & editing. PM-C: Investigation, data curation, resources, project administration, writing - review & editing. YS: Data curation, validation, resources, writing - review & editing. ZS: Investigation, data curation, resources, project administration, writing - review & editing. SW: Investigation, data curation, resources, project administration, writing - review & editing. SZ: Investigation, data curation, resources, project administration, writing - review & editing. GE: Conceptualization, investigation, methodology, resources, project administration and funding acquisition, supervision, writing - review & editing. LK: Conceptualization, investigation, methodology, resources, project administration and funding acquisition, supervision, writing - review & editing. AS-H: Conceptualization, investigation, methodology, resources, project administration and funding acquisition, supervision, writing - review & editing. SS: Conceptualization, investigation, methodology, resources, project administration and funding acquisition, supervision, writing - review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1126895/full#supplementary-material

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