CITIZEN SCIENCE:
THEORY AND PRACTICE

Citizen Science for Enhanced Dengue Vector Surveillance in Solomon Islands: A Methods Paper

METHOD

ubiquity press

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ABSTRACT

Arthropod-borne arboviral diseases—including dengue, Zika, and chikungunya—place a substantial burden on the health of populations, globally. Dengue alone is endemic in more than 100 countries and causes more than 96 million symptomatic cases and approximately 40,000 deaths annually. The recent surge in arboviral disease outbreaks, coupled with the World Health Organization's newly published vector control guidelines, accentuates the imperative to understand the dispersion of disease-carrying mosquitoes across diverse spatial and temporal scales. However, traditional surveillance mechanisms often fall short because of workforce limitations, logistical complexities, jurisdictional boundaries, and budgetary constraints, especially in low- and low-middle-income countries. In this article, we systematically report the design, implementation, and iterative enhancement of a groundbreaking school-based citizen science initiative for augmenting mosquito surveillance in the Solomon Islands. Key reflections encompass the initiative's role in supporting routine government-led disease vector monitoring, sustainability through integration and fostering participant engagement, and the amalgamation of citizen-collected data with government surveillance activities. The article also discusses the impact of the citizen science initiative with regard to the Solomon Islands' pursuit of the Sustainable Development Goals. Our findings underscore the potential of citizen science methods to support and extend public health surveillance activities and to serve as a community-engagement-for-behaviour-change tool in resource-constrained contexts.

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KEYWORDS:
Citizen science; dengue; Aedes; arboviral diseases; infectious diseases; surveillance; entomology

TO CITE THIS ARTICLE:
Craig, A, Panda, N, Palapu, R, Oku, G, Lifoia, C, Tatalu, J, Beebe, N, Kelly, G, Kama, N, Iro'ofa, C and Bugoro, H. 2024. Citizen Science for Enhanced Dengue Vector Surveillance in Solomon Islands: A Methods Paper. *Citizen Science: Theory and Practice,* 9(1): 3, pp. 1–13. DOI: https://doi.org/10.5334/cstp.679

INTRODUCTION

Arthropod-borne arboviral diseases—including dengue, Zika, and chikungunya—place a substantial burden on the global population (Kading et al. 2020). Dengue alone, as the most widespread arboviral disease, is endemic in more than 100 countries and causes more than 96 million symptomatic cases and approximately 40,000 deaths per year (World Health Organization, 2020). The rise in the incidence of dengue and other arboviral diseases is a stark reminder of the profound public health risks posed by *Aedes aegypti* and *A. albopictus* mosquitoes, the primary vectors of the viruses that cause these diseases. Climate and environmental change, the proliferation of global travel and trade, and increasing human mobility have meant that these *Aedes* mosquitoes have emerged in new areas while native species push the boundaries of their ranges, all with implications for environments, economies, and health outcomes (Yu and Cheng 2022).

Recent outbreaks of the aforementioned diseases (Craig et al. 2020; Girard et al. 2020; Kading et al. 2020; Matthews et al. 2022) and recently published World Health Organization (WHO) guidelines for vector control (World Health Organization 2017) underscore the pressing need for a comprehensive understanding of disease-carrying mosquito dispersion across varying spatial and temporal scales. However, traditional surveillance mechanisms are often unable to meet the requirement as they are limited by workforce limitations, logistical challenges, jurisdictional boundaries, and budgetary constraints; this is more often the case in rural and remote areas and low- and low-middle-income countries (Craig et al. 2016).

Eitzel et al. (2017) note that what falls under the guise of citizen science is nuanced and changing. While it is agreed that citizen science refers to the inclusion of members of the public in some aspect of scientific research, the "public" should not be assumed to be homogenous. Citizen science, which may be defined as "scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (Oxford English Dictionary 2016), offers a potential solution to address some of the challenges associated with mosquito surveillance. Braz Sousa et al.'s scoping review of 2022 identified 29 citizen science–based mosquito surveillance programs operating in 16 countries, along with three programs operating across multiple countries. These initiatives engaged the general public (86% of initiatives) and students (14% of initiatives), and employed a diverse range of strategies including app-based reporting, acoustic monitoring, environmental surveying, and adult mosquito, larvae, pupae, or egg collection. The diversity in approaches emphasises the need to tailor citizen science methods to match local capacities and contextual realities (Braz Sousa et al. 2022).

The Solomon Islands is an archipelagic state in the southwest Pacific Ocean just northeast of Australia. Arboviral disease outbreaks (notably dengue) are common in the Solomon Islands, with several significant events affecting the nation in recent years (Cao-Lormeau et al. 2014; Darcy et al. 2001; Mangum et al. 2018; Matthews et al. 2022; Nogareda et al. 2013; Russell et al. 2022). In 2016/17, with 12,329 suspected cases, 877 hospitalisations, and 16 deaths, the Solomon Islands experienced the largest dengue outbreak on record in the Pacific islands (Craig et al. 2018b).

While dengue has been considered endemic in the Solomon Islands since 2018, health system challenges have conspired to limit capacity to conduct mosquito surveillance over broad temporal and spatial scales (Craig et al. 2018a). In response, a collaboration between the Solomon Islands Ministry of Health and Medical Services, Solomon Islands National University, Solomon Islands Red Cross, and an Australian University was formed in 2019 to test if citizen science was both feasible and useful for enhancing mosquito surveillance in Honiara, the capital of the Solomon Islands. Subsequently, the Solomon Islands Citizen Science for Enhanced Mosquito Surveillance (or simply EMS) project was established.

Here we present the current approach and design of the EMS project. We reflect on the findings of our iterative implementation science–based evaluation of the project, highlighting the challenges faced and actions taken in response.

DESCRIPTION AND CONTEXT

The Solomon Islands is a small, developing island State located in the southwest Pacific Ocean, approximately 1,800 km northeast of Australia (Figure 1). The country's population of 744,407 is dispersed over 992 islands and atolls, with only 10% living in urban areas (i.e., 90% of the population live in rural areas, many of which are difficult to access) (Craig et al. 2018a; Pacific Data Hub 2023). Approximately 80% of the population live in small villages of a hundred or so people and carry out a subsistence lifestyle (Hodge et al. 2015). Regarding development, Solomon Islands is classified as one of the world's "least developed countries" by the Organization for Economic Cooperation and Development (OECD 2023) and is ranked 153 of 189 nations on the United Nations' Human Development Index (UNDP 2022).

The climate in the Solomon Islands is tropical with an average daytime temperature of about 28°C (82°F) and

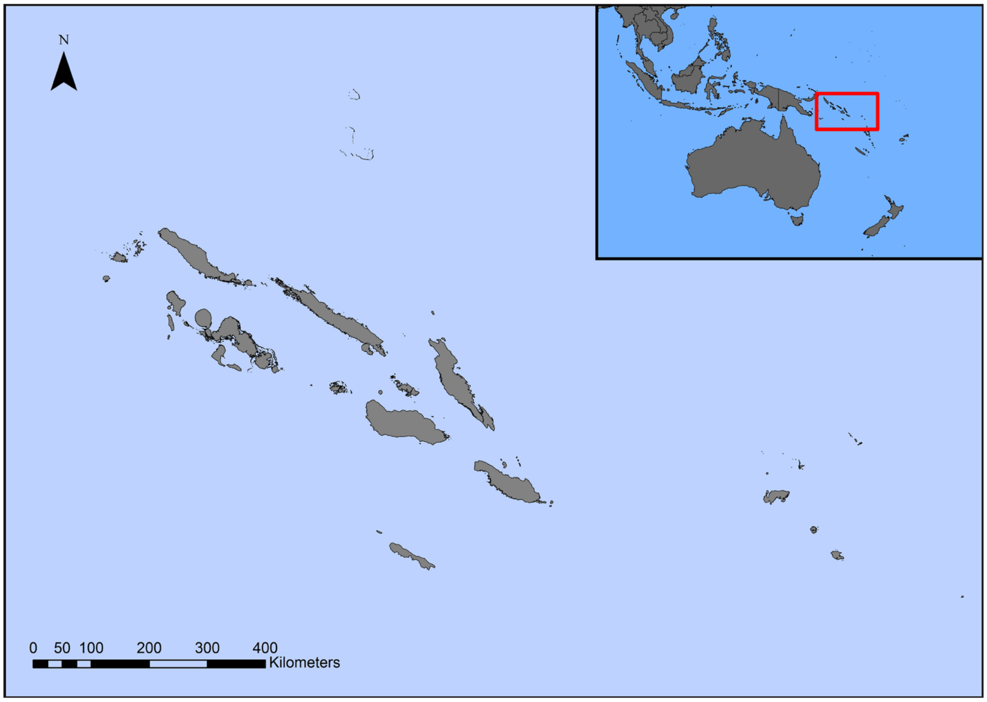

Figure 1 Map and location of Solomon Islands. The map was produced using ArcGIS software and an open-source base layer obtained from diva-gis (www.diva-gis.rog/gdata/).

average annual precipitation of about 2,000 millimetres (79 inches); the wettest period is between November and April (Solomon Islands Ministry of Environment 2023). Honiara, the capital and largest urban settlement in Solomon Islands, is situated on the northwestern coast of Guadalcanal Island.

PILOT STUDY

In 2019, a pilot study was designed to test the feasibility of citizen science as a strategy to enhance the reach of *Aedes* mosquito surveillance (Craig et al. 2021). The study recruited, trained, and equipped 13 general public participants from across Honiara to trap and identify to the genus level (using a magnifying glass and morphological identification key) mosquitoes caught within participants' household settings, and report count data to health authorities. Biogents Sentinel II traps were used as they are considered among the best performing for collecting *Aedes* mosquitos (Akaratovic et al. 2017; Degener et al. 2021). Trap locations were geo-located, and data provided by the citizen scientists were mapped to measure the distribution, density, and change in mosquito populations over time, thereby providing new evidence for arboviral risk assessment.

From a scientific perspective, the study was successful with participants engaged and able to identify mosquitoes with a high degree of accuracy (a 94% agreement between participants' and an entomologist's assessment) (Craig et al. 2021). From an implementation science viewpoint, we identified both opportunities and challenges. We found that the opportunity to contribute to a project of social benefit, the chance to learn new skills, and the frequency of engagement with project staff were prime motivators for citizen scientists' participation and continued engagement in the pilot. Conversely, we found that the choice of an overly complex and cumbersome trap that required electricity to operate, lack of buy-in from all household members, insufficient personal finances (to buy electricity and phone credit required to run the trap and report data by short message service), and inconvenience were barriers to sustained participation. An unexpected benefit was a self-reported change in the mosquito bite prevention behaviour of the participants and their advocacy to friends, family, and their community for environmental change to address exposure risks. A detailed account of this pilot study is reported elsewhere (Craig et al. 2021).

Given the pilot study's success, there was motivation to continue the EMS project, albeit in a refined model considering lessons learned. Although motivation was high, the emergence of COVID-19 and ensuing disruptions stalled progress and no action was taken for the two years following the end of the study.

IMPLEMENTATION OF THE SOLOMON ISLANDS CITIZEN SCIENCE MOSQUITO SURVEILLANCE PROJECT

In early 2022, the partners reconvened to discuss opportunities to re-invigorate the initiative. Subsequently, and with the financial and technical support of the Pacific Mosquito Surveillance Strengthening for Impact (PacMOSSI) program (www.pacmossi.org), the collaboration was extended to include the Ministry of Education and a school-based citizen science *Aedes* mosquito surveillance and education project was developed.

METHODOLOGY

PROJECT COORDINATION

The EMS project had both health surveillance and health promotion goals (Figure 2).

Objective 1. To enhance *Aedes* mosquito surveillance capacity in the Solomon Islands.

Objective 2. To engage the public meaningfully to communicate information about arboviral disease transmission risk and influence the public's risk-related behaviour.

Figure 2 Objectives of the Solomon Islands School-based Citizen Science for Enhanced Mosquito Surveillance project.

The coordination group met periodically to conceptualise and design the project, to extend invitations to schools to gain participants, and to monitor and refine the implementation model.

To build sustainability and scalability of the project, responsibility for its implementation was embedded as an assessable component of the Solomon Islands National University (SINU) post-graduate diploma of public health students' capstone course. The capstone course is undertaken as a one-month field placement towards the end of students' coursework. It is designed to provide scholars with the opportunity to gain field experience, apply their newfound knowledge, and make them "work ready" upon graduation. The scheme has close ties with the National Vector-Borne Disease Control Program (www.solomons.gov.sb/ministry-of-health-medical-services/) and is used to build the human resource capacity of the program, particularly in rural and remote areas.

At the commencement of their capstone, SINU scholars were oriented to the Solomon Islands EMS project, trained how to engage with and effectively provide educational content to high school–aged children, and supported to make teaching resources (Supplemental File 1). Scholars were assigned a school at which to implement the project. Scholars worked individually or in small groups, depending on where they were placed.

SCHOOL SELECTION

High schools were used as mosquito surveillance sites. Schools were purposefully and pragmatically selected considering the proximity to SINU scholars' capstone placement locations, the number of schools within the location, and current (or recent) evidence of arboviral disease transmission within the vicinity.

Schools that were approached were given information about the project and what would be expected. Schools that did not respond (positively or negatively) to the invitation were contacted one more time. If no response was received, no further invitations were sent. Figure 3a shows the location of schools that have been engaged to date (as of July 2023).

SCHOOL STUDENT ENGAGEMENT, TRAINING, AND TRAP DEVELOPMENT

The SINU scholars actively engaged with schools that responded positively to the invitations to participate in the program. The SINU scholars organised a time to visit the school and deliver a ~2-hour workshop to grade-10

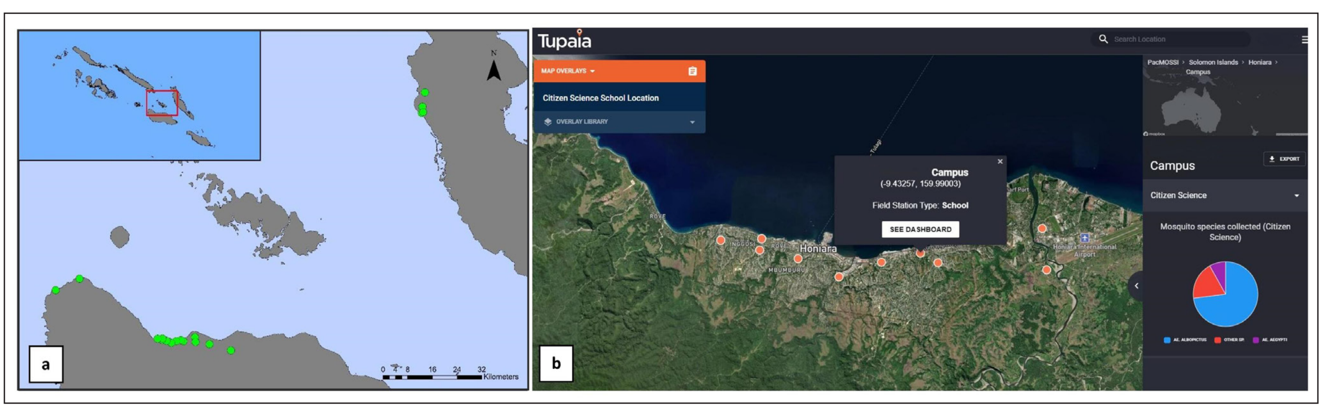

Figure 3 (a) Location of schools participating in the Solomon Islands Citizen Science for Enhanced Aedes Mosquito Surveillance project [green circles]. The map was produced using ArcGIS using an open-source base layer obtained from diva-gis (www.diva-gis.rog/gdata/). **(b)** Example of a map produced from data collected by the project. This map was produced by Beyond Essential Systems (BSE). BSE have given permission to reproduce the map.

students (aged ~16 years). The workshops involved two parts: (i) a short interactive presentation that provided information about mosquitoes, arboviral diseases, arboviral disease transmission risks, public health surveillance methods for arboviral disease vectors, citizen science, and the project; and (ii) a practical component during which high school students built a simple gravid mosquito egg collection trap (ovitraps) out of readily available material (Figure 4). Scholars brought printed materials and, where appropriate, a laptop to aid their presentation.

Ovitraps were constructed by cutting the top off a wide-based (for stability) plastic container (such as a soft drink bottle) that could comfortably hold ~300 ml of water. As female mosquitoes prefer to lay eggs in dark places (Day 2016), clear or light-coloured containers were blackened by placing them in a larger dark container (such as a plant pot), wrapping them with dark paper, or painting them. A strip of red cotton fabric 22 cm long and 3.5 cm wide was placed inside the container so that it hung down the inside to the bottom. The cloth was secured to the container's rim by a strong paperclip. The cloth strip serves as a medium to which mosquito eggs laid by visiting female mosquitos bind. Traps were filled with ~225 mls of rainwater (collected from a rainwater tank) and a single lucerne chicken food pellet was added. The pellet served as a mosquito-attracting lure. Each trap was labelled with a unique trap identification number (a trap ID). The scholars brought the materials required to make the traps with them when they visited the schools.

Figure 4 provides a photo of the equipment used, and Table 1 an equipment list and alternatives that may be considered.

After construction of the ovitraps, the SINU scholar/s led the high school students on a walk around the school's campus to identify suitable locations to set up the traps. Suitable locations were those that were outdoors, at low risk of being disturbed, in a shaded place close to the ground and amongst foliage but with a clear line of sight, and within 5 m of a building occupied by humans. Multiple traps were set on each school campus. Traps were placed >30 m apart to reduce inter-trap interference. Each trap's geolocation was recorded using the Global Positioning System (GPS) function built into modern smart mobiles.

Each trap's identification code, geo-coordinates, and set date and time was recorded in a purpose-built data collection phone application, as was information about the environment in which the trap was set.

COLLECTING, PACKAGING, AND RETURNING EGGS

Five days after setting the traps, the SINU scholar returned to the school and, together with students, harvested eggs laid in the ovitraps. The process of egg harvesting involved the careful removal and part-drying of the red cloth fabric hung inside the trap (the ovistrip), and packaging of the part-dried strip in an airtight zip-lock bag. The associated trap's ID code was written on the bag. Mosquito eggs that are properly prepared remain viable for a few months, allowing flexibility as to when they are processed and analysed.

The zip-lock bags containing the ovistrips were transported to an insectary at SINU for processing, rearing, and analysis. The time and date the bags were received at the insectary, along with the information provided on the enclosed data forms, were recorded.

MOSQUITO REARING AND IDENTIFICATION

At the SINU insectary, the ovistrips were carefully removed from the returning zip-lock bag, placed into a clear container,

Figure 4 (a) Equipment provided to citizen scientists and used to make a basic mosquito egg trap (an ovitrap). **(b)** A constructed ovitrap set in the field.

EQUIPMENT	PURPOSE	ALTERNATIVE MATERIALS THAT MAY BE USED
Envelope	In which all equipment was packaged.	
Red cotton fabric 22 cm long and 3.5 cm wide marked with an "A"	To serve as a medium on which female container-laying mosquitoes may lay eggs (an ovistrip).	A paddle-pop stick or rough durable piece of paper.
Sheet of absorbent paper marked with a "B"	To soak up excess water on the ovistrip after removal from the trap. To wrap oviposit strip in protection while being transported.	Absorbent cloth.
Lucerne chicken food pellet	To add to water in trap and serve as a mosquito lure.	A very small amount of dry grass.
A zip-lock bag	To package collected eggs ready for transport.	
Data collection sheet	To record information about the trap and its set/collection date.	
Instructions sheet	To provide simple diagrammatic guidance for the construction and position of an ovitrap.	Verbal instruction and demonstration. Web-based instruction. Video-based instruction.

Table 1 Equipment provided to citizen scientists engaged in the project, the purpose of each, and feasible alternatives.

and flooded with ~200 ml of rainwater. A larval food pellet was added, and a polyethylene netting fixed across the opening to prevent other mosquitoes from laying eggs (ovipositing) in the water. Eggs were hatched and reared to pupae (Figure 5) before being transferred by pipette to a separate container filled with ~200 ml rainwater. The container was covered with a netting barrier to prevent emerged adult mosquitoes from escaping. Using an adult mosquito aspirator, emerged adults were transferred to a killing tube where cotton wool soaked in chloroform was used to terminate the mosquitoes.

Using a dissecting microscope (x4 magnification), reared mosquitoes were identified using standard morphology methods and an adult mosquito identification key (Anish and Sreelakshmi 2013; Rueda 2004) to the species level. Figure 6 shows students processing the specimens.

This rearing and identification process was performed by the SINU scholars under the supervision of a medical entomologist. Data on the date that eggs were flooded, when larvae were transferred, and when emerged adult mosquitoes were terminated was recorded.

DATA MANAGEMENT

A purpose-built data collection, storage, and visualization tool was developed using Beyond Essential System's integrated Tupaia software and Meditrack mobile application (https://www.bes.au/products/tupaia/). The customized Meditrack application operates on both Android and iOS-based mobile devices, enabling convenient form-based digital data entry and upload to a cloud-based database. In instances of no or unstable internet connectivity, data entered using the application was stored on the device until a connection could be restored.

The tool allowed the project coordinators to tailor user-specific functionality and data access rights, thereby streamlining the interface and limiting unnecessary access to information. For example, SINU scholars were granted permission to enter data related to the specific schools they worked with, and view data collected from across all schools, while teachers' access was limited to information relevant to their school. The adaptable data collection system architecture allowed for easy modifications and enhanced flexibility.

The process of data entry into the Meditrack application occurred at multiple stages. First, when setting the trap, the unique ID, geolocation, environmental, and set time data were recorded. Second, on receipt of the zip-lock bag at the insectary, data about collection dates and times were added. Third, as the mosquitoes were reared, key process data were added. And finally, data on mosquitoes, to the species level, were added to the record. Each trap's unique ID served as the record link throughout this process, connecting all the data fields.

DATA ANALYSIS

To assess the population presence and estimate the abundance of *Aedes* mosquitoes, the study employed entomological indices as per the recommendations of the Solomon Islands Ministry of Health and Medical Services. Specifically, the positive ovitrap index (POI), mean eggs per trap (MET), and mean mosquitos per trap by species (MMT_S) were calculated. The POI value provided insights into the distribution of mosquitoes, while the POI, MET and MMT values offered indicators of mosquito population abundance. To gain understanding of *Aedes* mosquito distribution across communities, a descriptive analysis incorporating temporal and spatial data was conducted.

The formula used to calculate the abovementioned indicators are as follows.

$$POI = \frac{\text{Number of positive traps}}{\text{Number of successfully deployed traps}} * 100$$

$$MET = \frac{\text{Number of eggs}}{\text{Number of positive traps}}$$

$$MET\_S = \frac{\text{Number of} \times \text{species mosquitoes}}{\text{Number of positive traps}}$$

REPORTING OF RESULTS

The data resulting from the analysis was utilized to create informative maps, visually depicting the distribution and estimated density of mosquito species (Figure 3b). These maps were shared with the Vector-Borne Disease Control Program of the Solomon Islands Ministry of Health and Medical Services, enhancing arboviral risk assessment efforts. Additionally, the maps were presented to the participating schools, thereby closing the feedback loop with the community stakeholders

By showcasing the scientific significance of systematic data collection and rigorous analysis, these maps served as a valuable tool for fostering community engagement.

RESULTS

The project was implemented twice (in August 2022 and December 2022/January 2023), with 18 schools, 340 high school students, and 16 SINU scholars engaged. On average, 18.9 students were involved and 4.8 traps were set at each school. Schools include both government and church-run single-sex and co-educational institutions. Ten of the schools were in Honiara, seven in or near Auki (the capital of Malaita Province) and one in a remote location in Guadalcanal Province. The timing of implementation was based on convenience and did not align with high mosquito prevalence.

In total, 86 ovitraps were set with 80 running successfully (some were disturbed and hence were not successful). From these, 916 mosquitoes were reared to adulthood and examined. *A. albopictus* mosquitoes (the secondary vector for dengue and other arboviral diseases) were identified at all school sites across the Solomon Islands, including in villages where mosquito surveillance has never been conducted or had not been conducted for many years. *A. aegypti* (the primary vector for arboviral diseases) were found at seven school sites, all in Honiara. Culicine mosquitoes were collected at all sites at which traps ran successfully.

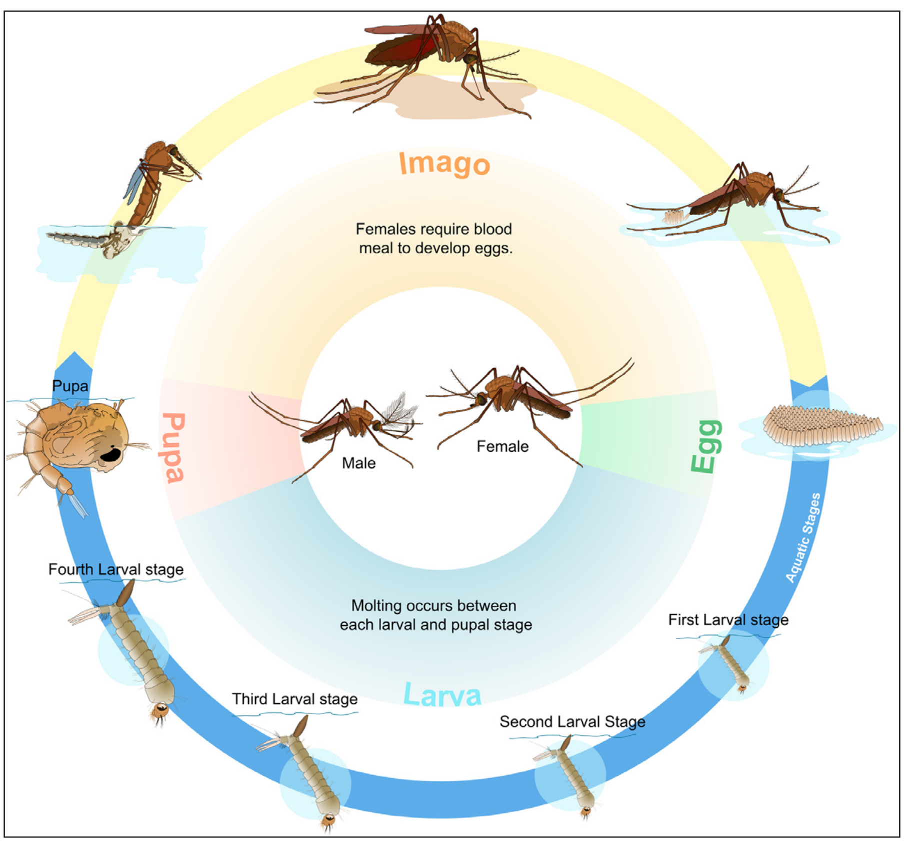

Figure 5 Mosquito life cycle. Image reproduced under a Creative Commons CC0 Licence.

Figure 6 Solomon Islands National University scholars rearing mosquito eggs collected by citizen scientists. Image: Hugo Bugoro, Solomon Islands National University. The image was reproduced with the photographer's approval, and those in the photo consented to the use of their image.

While no formal evaluation was conducted, anecdotal evidence and feedback from SINU scholars, high school teachers, and students has been positive, with the opportunity to participate in a "real" science activity of personal relevance a benefit commonly expressed.

DISCUSSION

This paper elucidates the rationale and progressive evolution of the EMS project for augmented mosquito surveillance, designed not only to bolster the monitoring of arthropod arboviral disease vectors but also to serve as a means of community engagement. In the subsequent section, we discuss pivotal discoveries gleaned from the initiative and frame these within a broader context of implementing citizen science within resource-constrained environments.

SIMPLICITY IS KEY TO SUCCESS

A key lesson from our project was that in resource-limited contexts, the design of a citizen science initiative must prioritize simplicity to ensure stability, scalability, and long-term sustainability while considering the contextual constraints likely to be encountered.

For example, during the initial phase of our project, we utilized a Biogent Sentinel II trap, which offered superior performance but posed challenges when used in household settings by civil society members. Its dependence on electricity for operation and its relatively large size resulted in limited acceptance, with instances of traps being stored away and left unused. Additionally, the trap's design focused on capturing adult mosquitoes, requiring careful handling and time-consuming specimen retrieval and packaging. The considerable cost of these traps also presented a significant investment for health authorities. In response, we adapted our project by transitioning to a simpler trap—the ovitrap—which can be easily constructed using readily available materials. While ovitraps have their own limitations and challenges, such as the need for time, space, and skilled personnel for rearing and analysis of collected egg samples, they offered a cost-effective and context-appropriate alternative.

Through the pilot study, we realized that placing the burden on the already time-constrained Ministry of Health and Medical Services workforce was unsustainable. Consequently, we decided to leverage established community groups, focusing on engaging classes of school students as citizen scientists. This approach, combined with the adoption of a simpler and cost-effective sampling method (as described above), enabled us to leverage others while also achieving economies of scale for time investments made. Furthermore, we integrated the responsibility for project implementation as a requirement for SINU scholars' capstone projects, thereby creating opportunities for authentic learning, reducing the workload on Ministry of Health and Medical Service staff, and creating opportunities to expand the initiative to new locations. With roll-out embedded within SINU's curriculum, we have found implementation to be sustainable without need for additional funding.

ENSURING RELEVANCE FOR END USERS

During the pilot study, it became evident that citizen participants felt empowered and motivated to take proactive measures to reduce their own and their family's exposure to *Aedes* mosquitoes. For instance, observing increased catch numbers, one participant reported organizing clean-ups of vector breeding sites around their homes. Additionally, in one inspiring instance, citizens advocated for behavioural and environmental changes within their community to reduce habitats conducive to mosquito breeding. By framing the citizen science project as a part of school-based learning, and creating opportunities for citizen participation in a practical scientific endeavour directly relevant to their own lives, we hope to extend engagement and behaviour-change outcomes. We expect that the approach will also instil a sense of personal responsibility for health security and, as students engage in the project and learn about arboviral disease transmission and control, they will become agents of change within their families and communities, leading to heightened disease prevention efforts and improved public health outcomes. Further studies to verify any change in participants' knowledge, attitude, and practice are planned.

MAINTAINING STAKEHOLDER PARTICIPATION

Our initiative demonstrated that by engaging a diverse range of stakeholders, we not only discovered new opportunities but also devised innovative solutions to challenges. Sustaining participation in such projects is an ongoing endeavour that necessitates continuous investment in building and maintaining trusting relationships with all involved parties. Crucially, we recognised the importance of ensuring that each stakeholder derived value from their engagement. For instance, anecdotal accounts suggest that the national health authority benefited from the initiative by acquiring additional data at no extra cost, while schoolteachers found value in incorporating a practical activity into their science curriculum. Furthermore, SINU students report their education was enriched through participation in the project.

Our observations align with the findings of researchers Souza et al. (2019), who emphasised that for citizen science initiatives, investing in stakeholders is paramount to achieving sustainability. They add that actively involving stakeholders in the planning and framing of the initiative holds equal significance to the data collected, ensuring a collaborative and mutually beneficial endeavour.

FINANCIAL SUSTAINABILITY

In low-resourced settings, where achievement of health service delivery goals is highly resource-sensitive, any new initiative must add demonstrable benefits to justify the expenditure of resources that could otherwise be allocated to established programs, facilities, equipment, staff, medicines, and other essential commodities (Cullen and Hassall 2017). Although the EMS project is relatively inexpensive to implement, it still incurs costs, and securing continuous funding remains one of the main challenges. Thus far, the project has been supported by grants from the WHO's "for research on diseases of poverty" program and PacMOSSI. However, these funding sources are time-limited and cannot be relied upon for long-term sustainability.

In this context, it becomes critical to demonstrate the value of the project in terms of its outcomes and impact, as well as its cost-benefit. Proving the efficacy and positive outcomes of the initiative is paramount in garnering support from potential funding sources, both local and international. Moreover, while funding remains uncertain, establishing and leveraging local partnerships for implementation is imperative. An excellent example of this approach can be observed in the Solomon Islands, where the citizen science project has been successfully integrated into the core curriculum of SINU scholars, ensuring a continuous pipeline of engaged participants.

It is important to avoid viewing voluntary participation in science solely to cut costs (Cronemberger et al. 2023). Instead, it should be regarded as a genuine strategy to extend scientific research through liberating the human resources available in civil society and fostering understanding of science through active engagement. By emphasising the intrinsic value of participation, we aim to encourage an authentic commitment from citizens, ultimately bolstering the impact and sustainability of our citizen science initiative.

MONITORING AND EVALUATION

As we've already mentioned, establishing the value of citizen science initiatives in low-resource settings is vital to garner political and financial support. Although demonstrating tangible results in the short term may be unrealistic, it is imperative to incorporate monitoring and evaluation (M&E) mechanisms from the very outset. The evidence gathered from M&E processes can substantiate the benefits and effectiveness of the citizen science project, strengthening the case for continued support and investment. Additionally, the insights obtained can motivate project collaborators and citizen participants by highlighting their contributions and demonstrating the value of their engagement.

To optimize M&E efforts, an implementation science perspective addressing three primary aims should be considered. M&E should seek to understand and explain the factors that influence successful (and not so successful) implementation of the initiative; M&E should assess actual implementation practice,; and M&E should generate evidence-based guidance to refine the implementation process, enabling greater effectiveness and efficiency (Nilsen 2015).

INTEGRATION WITH ESTABLISHED SURVEILLANCE PRACTICES

The issue of integrating the data obtained through this novel approach with routine Ministry of Health vector-borne disease mosquito surveillance systems has been a persistent challenge. Presently, the initiative functions as a vertical project, operating somewhat independently from core surveillance systems. To fully harness the potential of citizen science data and maximise its impact, seamless integration with established monitoring frameworks is imperative.

A promising opportunity to address this challenge lies in aligning data collection protocols and harmonising data collection fields between the citizen science initiative and existing surveillance systems. By adopting standardised data collection procedures and utilising a common information management system, we hope to streamline data integration, making it easier to use citizen science–collected data as part of comprehensive analyses, and enhancing the overall effectiveness of disease vector monitoring efforts in the Solomon Islands. Given the flexibility of the citizen science model, we anticipate that it offers opportunities to strengthen surveillance interventions at sub-national levels where routine data collection is not feasible due to logistical challenges and workforce limitations.

CONTRIBUTION TO THE SDGs

The Solomon Islands EMS project's actions and results align, directly or indirectly, with Sustainable Development Goals (SDGs) 3, 4, and 15.

Sustainable Development Goal 3 focuses on promoting health and wellbeing for all. The citizen science project contributes to target 3.3 and 3b of SDG 3 by enhancing capacity for essential surveillance data collection required for monitoring, detecting, and responding to arthropod-borne arboviral diseases. It strengthens capacity for early warning and risk reduction locally and globally by enhancing national ability to detect and respond to emergent health threats quickly.

Sustainable Development Goal 4 emphasises the importance of quality education. While the impact of the project needs to be validated through further research, it has the potential to contribute to target 4.7 of SDG 4 by offering novel opportunities for knowledge and skill development, promoting sustainable development, and fostering lifestyles in harmony with nature. Through the provision of education-based opportunities, individuals may develop valuable knowledge about their arboviral disease risk and how to manage transmission threats leading to bottom-up action that improves health security.

Sustainable Development Goal 15 centres on protecting and restoring terrestrial ecosystems and promoting their sustainable use. The citizen science project contributes to target 15.8 of the SDG by collecting data on the presence and distribution of *Aedes* mosquitoes. These data play a pivotal role in informing policy and interventions to monitor and prevent the introduction, spread, and impact of invasive alien mosquito species on ecosystems, including human-inhabited environments.

LIMITATIONS

Our study is not without limitations. First, our results are based on the experience and reflections of the project team and may have benefited from broader consultation. Second, we report anecdotal evidence that the project provided a positive learning experience for students; this evidence could be strengthened through participant interviews-based evaluation research. Third, the project continues to expand, and as experience grows, so will the lessons learned.

CONCLUSIONS

In this methods paper, we report the evolution and current approach taken to implement the Solomon Islands EMS program. We provide a step-by-step overview of the methods used and discuss the rationale for the methodological choices made based on discoveries gleaned during implementation; we frame the discussion within a broader context of implementing citizen science initiatives within resource-constrained environments. Our results show the potential for a citizen science approach to help address human resource limitations for surveillance in a resource-constrained setting. We highlight that significant investment is required to establish and maintain stakeholder relationships and integrate citizen-derived data streams into routine surveillance practice.

DATA ACCESSIBILITY STATEMENT

All data are included in the manuscript.

SUPPLEMENTARY FILE

The supplementary file for this article can be found as follows:

- **Supplemental File 1.** Video resource developed to support the training of citizen scientist participants. DOI: https://doi.org/10.5334/cstp.679.S1

ACKNOWLEDGEMENTS

We acknowledge the contribution of the high school teachers and students who contributed to the project.

FUNDING INFORMATION

The pilot phase of the EMS program received funding from WHO/TDR (Reference 884822–0). The Australian Government–supported PacMOSSI project continues to provide technical support for the implementation of the initiative.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

AC and HB conceived the study; AC, JT, NP, NB, NK, HB managed the initiative; NP, RP, GO, CL, NK, CI collected data; GK developed the data collection tool; AC, NB, GK, CI, IR, HB drafted the manuscript. All reviewed and approved the final version.

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TO CITE THIS ARTICLE:
Craig, A, Panda, N, Palapu, R, Oku, G, Lifoia, C, Tatalu, J, Beebe, N, Kelly, G, Kama, N, Iro'ofa, C and Bugoro, H. 2024. Citizen Science for Enhanced Dengue Vector Surveillance in Solomon Islands: A Methods Paper. *Citizen Science: Theory and Practice,* 9(1): 3, pp. 1–13. DOI: https://doi.org/10.5334/cstp.679

Submitted: 13 September 2023 **Accepted:** 23 January 2024 **Published:** 12 February 2024