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Leveraging conservation action with open-source hardware

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Abstract

Data collection by conservation biologists is undergoing radical change, with researchers collaborating across disciplines to create bespoke, low-cost monitoring equipment from open-source hardware (OSH). Compared to commercial hardware, OSH dramatically reduces participation costs. Four barriers currently hold back its wide adoption: (1) user inexperience inhibits initial uptake; (2) complex and costly manufacturing/distribution procedures impede global dissemination; (3) lack of creator support results in lapsed projects; and (4) lack of user support degrades continued utility in the field. Here, we propose a framework to address these barriers, illustrating how OSH offers a route to rapid expansion of community-driven conservation action.

KEYWORDS
biodiversity monitoring, conservation technology, environmental monitoring, open-source hardware, open-source software

1 | INTRODUCTION

Conservation policy urgently needs accessible, affordable, fit-for-purpose tools to address unprecedented reductions in global biodiversity and rise in illegal wildlife trade (IWT) (The Royal Society, 2018). National governments are now committing to the wild-tech sector, in which open science plays a vital role. For example, the UK government is funding initiatives to tackle IWT using innovative open data standards (UK Government, 2019). In this policy perspective, we identify current barriers to the wide adoption of open-source technology and propose a framework for addressing them.

Over the last 30 years, conservation biology has seen a shift toward data transparency with the growth of open science, including open-access journals, websites hosting open data, software and hardware, and sharing through social media (Hampton et al., 2015). The new openness has generated a profound change in the ways that hardware and software are

developed, leading to conservation biologists collaborating with engineers to create bespoke tools for their specific applications (Berger-Tal & Lahoz-Monfort, 2018; Kwok, 2017). Readily available open-source hardware (OSH) is increasingly used in rapid and cheap development of deployable prototypes (Pearce, 2014). The fields of conservation, ecology, and environmental sciences have seen an increased uptake in OSH over the last 4 years, with over a hundred publications reporting on scientific tools created using open-source microcomputers, such as the Raspberry Pi or Arduino (Ahmad, Nadzri, Rosli, & Amira, 2018; Nazir et al., 2017; Sankupellay et al., 2016; Soro et al., 2018; Tan, Teoh, Fow, & Yen, 2016; wa Maina, Muchiri, & Njoroge, 2016; Whytock & Christie, 2017).

The OSH designation refers to the intellectual property, design principles, and legality of freely available hardware design files, which in their most liberal form can be used to manufacture, distribute, and sell the physically constructed product. Design files consist of circuit-board schematics, circuit-board layout files, and the software source code that together permit construction of a piece of electronic hardware. OSH provides transparency, allowing full public scrutiny of designs to the benefit of their scientific integrity. Open designs create freedom to customize technology for specific applications (Kling, 2018). The unrestricted access of developers to user needs, and users to developer designs, facilitates rapid community prototyping, either by centrally managed revisions based on user feedback or by user modifications on original designs (O'Mahony, 2007). The resulting self-made equipment enables replicable data to be gathered at a lower cost than can be achieved with commercial hardware of equivalent utility (Drack, Hartmann, Bauer & Kaltenbrunner, 2018). These benefits have enabled OSH to colonize niches in technology markets previously unreachable by models based on intellectual property (Hsing, 2018).

Many barriers still lie in the way of implementing OSH for conservation purposes. Conservation practitioners must assemble the technology manually, generally with no support other than build instructions. Organizations formed around OSH find it difficult to obtain financial resources to continue development (Li, Seering, & Wallace, 2018), often resulting in project termination soon after initial funds are spent (Iacona et al., in press). New creators inadvertently reinvent tools when the design files of previously created equipment lapse or become lost. Commercial hardware retains an advantage in this respect with the higher financial outlay paying for product delivery, guarantees, and after-sales care.

Overcoming current barriers to OSH will require (1) establishing procedures for the manufacture and distribution of hardware that facilitate access and dissemination among the conservation community; (2) financial support for product maintenance; (3) nontechnical instructions for implementing OSH; and (4) after-sale support for continued utility in the field. Models now exist to support adoption of open-source software, such as Canonical (https://www.canonical.com/) providing commercial services for consumers of Linux Ubuntu operating systems. Such frameworks are still lacking, however, to support the not-for-profit uptake and implementation of OSH for conservation. Although profitable businesses are being built around OSH, they meet a demand that comes principally from technically savvy users, capable of building their own hardware from published design files (Pearce, 2017). Conservation practitioners largely fall into a different category of user. They often have limited technical electronics know-how, or have limited resources for technical training. These users typically require others to build the hardware for them. They remain hard to target for OSH business models, due to the complexities that go with hand fabricating hardware from an open design. With appropriate support, however, conservation practitioners are best placed to apply OSH to conservation actions.

Here, we introduce a provisional framework for developing and sustaining the life cycle of not-for-profit OSH for conservationists. The framework addresses current technical barriers to manufacture and presents simple guidelines for distribution, user accessibility, creator support, and user support. It comprises a set of defined product-development processes that guide a collaborative team through the life cycle of an open-source product, from construction and after-sales support, to the reinvestment strategy that sustains the creators and community. We demonstrate an application of the framework with a real-world case study of an OSH product in the form of an acoustic monitoring device (Hill et al., 2018). The case study serves to illustrate how the framework unlocks useful technology for local communities, researchers funded by government research councils, and individuals funded by non-government organizations (NGOs). In recent years, similar frameworks, such as Crowd Supply, have been shown to increase the adoption of proprietary products by consumers (Ilin, Platis, & Hammouda, 2018) and even to improve competitive advantage through crowdsourced tools (Nagle, 2018). We argue for wide adoption of flexible approaches of this sort by conservation NGOs and universities in particular. A framework can facilitate rapid uptake of OSH for conservation activities supported by these organizations, thereby fostering the proliferation of local-scale projects that lead to global-scale action (Arlettaz et al., 2010; Pocock et al., 2018).

2 | A FRAMEWORK TO SUPPORT OSH FOR CONSERVATION

The framework has six phases, each with formulated guidelines: (1) hardware, (2) manufacture, (3) release, (4) distribution, (5) support, and (6) sustainability (Figure 1). The framework is formed around a management team consisting
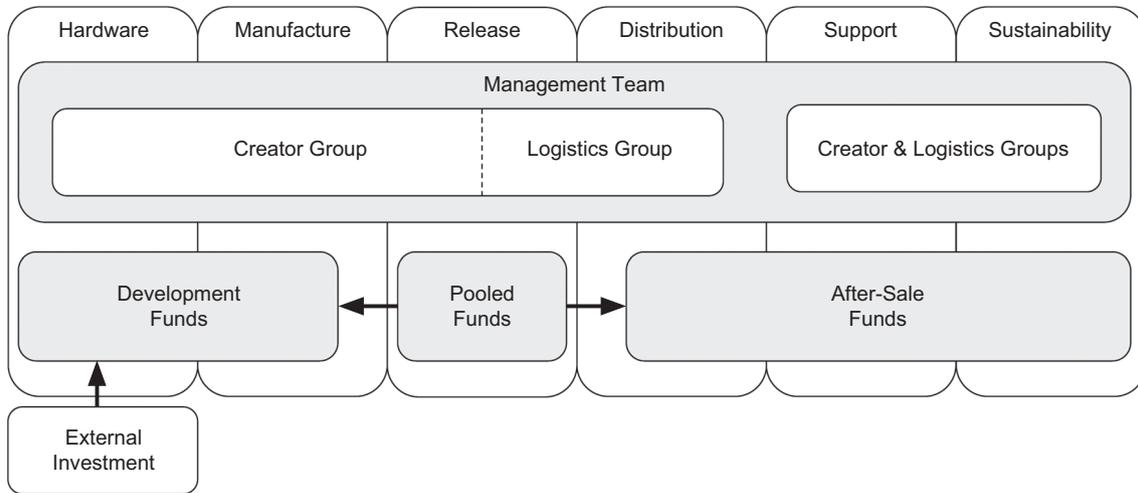
FIGURE 1 An overview of the framework for developing, funding, supporting, and sustaining open-source hardware (OSH) for conservation. The framework differs from a traditional business model for a commercial product in having open-source licenses, relying on word-of-mouth in lieu of an advertising budget, allowing group-purchase only, explicitly excluding housing for electronic components and guarantees on product performance, and outsourcing after-sales care to web forums

of a creator group (engineering team), which leads the technical developments of the technology, and a logistics group (funder/NGO/university), which leads logistical and financial operations. This unified entity requires an open and collaborative relationship between the two groups, with clear lines of responsibility (detailed in Table 1).

The end users are the communities requiring the conservation hardware, such as local conservation activists, research scientists, educators, and wildlife enthusiasts. The framework provides a provisional set of management guidelines for OSH development, and a scalable method for the community to acquire and use the created technology. The framework generates a pool of crowdsourced funds out of unit sales margins obtained in the bulk manufacturing of hardware. Funds can be reinvested back into the hardware project to sustain its lifespan. In addition to providing support for creators and users, the framework minimizes the investment in human and financial capacity needed to initiate, manufacture, and distribute OSH. It makes use of new websites for crowdfunding and for turn-key electronics manufacturing to provide tailored and cheap solutions for nontechnical conservation organizations. A framework can be viewed as successful if it is able to harness a large community of individuals to acquire low-cost single units from a high volume manufacturing process, while also creating extra funds to continue support. Success will depend on simple hardware construction to reduce overheads when manufacturing at bulk, and the timely orchestration of a large group of buyers to crowdfund industrial manufacture of the hardware (Kohler & Chesbrough, 2019).

The initial "hardware" phase is the design stage, which commences after the creator group has proven the feasibility of using a particular technology for a desired conservation task. The proven hardware needs to be adapted to an open-source design, and initial investment is required to fund this development. To open source a technology means to apply an open license to it. Various licenses are commonly used to define how OSH design files can be adapted, shared, or commercialized by the user community (Table 2). Each license has its own benefits, depending on the goal. For example, the most open license, CC0, may be useful for community ownership of the design, thus allowing it to be shared, adapted, and commercialized without the need to attribute changes to the original creator(s). Any of the OSH licenses can be used in the framework. Oberloier and Pearce (2017) detail formal procedures for designers of OSH.

The "manufacture" phase involves physical fabrication and testing of the subsequent OSH design. Manufacturing often involves complex fabrication processes, including sourcing parts, assembly of printed circuit boards (PCBs), programming the PCBs, and developing housing for the product suitable for field deployment. Keeping this sequence as simple as possible minimizes manufacturing costs. Web services chosen for PCB manufacture should be trialed by testing the build quality of small batches of the developed hardware units before release. Tests should involve checking the quality of assembled PCBs, assessing the fit-for-purpose functionality of the final product and providing solutions to assembly problems found during manufacture. Issues found at this stage need to be resolved before continuing to the next phase. Spare devices built during this process can be used as trial devices or backup units to support after-sales assurance issues.

The "release" phase consists of the publication, promotion, sales, and large-batch manufacture of the hardware units. Technology design files are first uploaded to a publically

TABLE 1 Distribution of responsibilities for the management team, between the creator group, which focuses on hardware issues, and the logistics group, which focuses on assurance issues

	Responsibility
Creator group	Conception of idea
	Circuit design
	Hardware development
	Software development—website, firmware, supporting software and algorithm design
	Prototyping
	Bench testing
	Field testing
	Choosing appropriate manufacturers
	Testing small-batch build quality of chosen manufacturer
	Sourcing components for crowd funding order
	Testing alternative components if original components become obsolete
	Website maintenance
	Technical community support via website forum
Logistics group	Initiating crowd funded campaign
	Taking payment from crowdfunding organisation
	Co-organising distribution of units
	Assurance-related community support via crowd funders website
	Holding pool of funds
	Distributing pool of funds to support technology development
Shared responsibilities	Social media presence

accessible open-source hosting website to allow community access. The guiding principle of this phase is to minimize the cost per unit for users while also generating a pool of funds. Large-scale industrial manufacturing processes reduce unit material cost and assembly time; however, they require an initial sum of money to bulk order before making any

sales. To this end, minimum quantity batch manufacturing can be crowdsourced to reduce risk and produce an economy of scale (Wheat, Wang, Byrnes, & Ranganathan, 2013). A crowdfunding platform is required to collect user's funds during funding campaigns. Campaigns should run at regular intervals and each should end when a maximum order quantity is reached, or a time period is elapsed. The crowdfunding campaign should be publicized on social media and conservation forums, so as to gain traction and reduce the risk of failing to meet the monetary target.

The "distribution" phase consists of the global dissemination of the manufactured units. Depending on the crowdfunding organization used, the logistics group may need to take on the role of global distributor, or employ a dedicated distribution house to ship and track deliveries.

The "support" phase provides technical and logistical assistance to the community of users. Users may require support with diverse issues, including devices getting lost in transit, out-of-box malfunctions, and difficulties with operating the device. A mechanism should be established for users to send their end-of-life devices back to the creator group, for re-use or disposal according to Waste Electric and Electronic Equipment (WEEE) Regulations.

"Sustainability" encompasses the reinvestment strategy to facilitate continued functioning of the technology into the future. It involves addressing how pooled funds can be generated and used to continue future development and promote future purchases. To create pooled funds, a margin should be added to each unit sold that generates enough funds from the minimum quantity order to sustain the team until the next group purchase campaign ends. The crowdfunding campaign should set its goal to this minimum batch order. Costs incurred by the logistics group to manage logistical operations, such as employing a part-time member of staff and purchasing packaging for shipping, should be reimbursed from this generated fund. The creator and logistics groups should take a percentage of funds to support their tasks after each group funding campaign. The remaining pool of funds can be held by the logistics group and made accessible to the creator group as needed to pay for further support, bug fixes, and further enhancement or development.

TABLE 2 Comparison of the available Creative Commons OSH licenses

Creative Commons licenses	Adaptations can be shared	Commercial use
CC0 (No attribution)	Yes	Yes
Attribution (BY)	Yes	Yes
ShareAlike (CC BY-SA)	Yes, but must share alike	Yes
NonCommercial (CC BY-NC)	Yes	No
NonCommercial-NoDerivatives (CC BY-NC-ND)	No	No
NoDerivatives (BY-ND)	No	Yes
NonCommercial-ShareAlike (CC BY-NC-SA)	Yes, but must share alike	No

3 | CASE STUDY

The framework was developed and formalized for the open-source manufacture and distribution of an acoustic monitoring device called AudioMoth, created by Open Acoustic Devices (OAD) (https://www.openacousticdevices.info). Within the management team, the creator group comprised OAD, and the logistics group comprised a small conservation NGO called the Arribada Initiative (https://blog.arribada.org).

The AudioMoth case study used the "Creative Commons Attribution 4.0 International (CC BY)" open-source license (Table 2). This attribution allowed full participation by the community in all aspects of design, attributing all changes to the original creators. The license allowed other manufacturers to construct and re-sell the platform independently (e.g., LabMaker: https://www.labmaker.org/). This brought mixed benefits: it raised awareness and distribution of devices, while also reducing the funds available for sustaining the devices, although in this case only by about one-tenth.

Hardware was designed to fit a single fixed part, consisting of one single-sided PCB that could be purchased from a single manufacturer. The creator group developed the hardware as part of their research budget from UK Research Council grants. Development of the product was funded by grants totaling ~USD$13,000 per/year over 3 years for two PhD students, excluding stipends and course fees.

The chosen manufacturer was CircuitHub (https://www.circuithub.com/). This online web service specializes in assembly of open-source PCBs. It enables design files to be uploaded, shared, manufactured, and delivered to order, with transparent batch size, lead time, and pricing. It first built small test batches of prototype PCBs, which were used to evaluate the single-board construction and address any build issues. Test boards had a 20-day lead time and cost USD$60 per unit for a batch of 50.

The finalized AudioMoth design files were published on the open-source hosting websites GitHub and CircuitHub. This made them freely available to adapt and share. CircuitHub's online quotation tool was used to calculate the unit selling price on a manufactured batch of 200 units. A further 20% was added to this unit price, which was calculated to generate enough funds to support global distribution, after-sales support, and future enhancements. Cost-free promotion of AudioMoth was achieved through the WILDLABS forum (https://www.wildlabs.net), social media, and the OAD subscription page. Trial devices were distributed to potential users to proliferate the spread of information throughout the conservation community and to generate feedback to the creator group on AudioMoth utility.

The crowdfunding organization GroupGets (https://groupgets.com/) coordinated the group purchase campaign for each batch order from CircuitHub. GroupGets linked back to OAD's subscription page to help the creators gauge the level of online interest. To fulfill a cost-effective manufacturing run, each campaign had to gain a minimum of 200 backers.

GroupGets handled postage to users based in the United States. For orders bound elsewhere, GroupGets batch posted the ordered units to the UK headquarters of the logistics group. This minimized individual customs declarations, freeing up sufficient funds from the price margin for the logistics group to distribute units to the rest of the world. The logistics group handled all non-U.S. distribution until the rising level of demand necessitated a dedicated distribution house. Weengs (https://www.weengs.co.uk/) were then selected to receive devices directly from GroupGets and manage the major distribution channels to the UK and EU.

The creator group maintained a website supporting users of AudioMoth. This was updated on a weekly basis, taking approximately 2 person-hours/week. The website hosted usage instructions, open-source design files, and a support forum. The forum enabled users to discuss ongoing projects, report technical issues, and suggest modifications to the open-source design files. Over time, it became partially self-sustaining as the community of users gained expertise in the technology. The creator group was still required to provide solutions to more technical issues.

The case study supported six rounds of group-purchase campaigns over 18 months from October 2017 to March 2019. These campaigns generated a pool of funds to finance U.S. distribution, hardware improvements, ongoing user support for all purchased devices, and community-based events including workshops for users. The sixth group-funding campaign introduced the first hardware modification to the design files. A lesson learned during this change was the importance of maintaining backwards compatible firmware across hardware versions.

The six campaigns resulted in 5,242 unit sales in total, with 34% purchased by universities, 23% by conservation organizations, 11% by businesses/consultants, 1% by government agencies, and 30% by unspecified individuals. All devices sold for USD$49.99 per unit, creating a net revenue of USD$262,048 and a pool of funds after device manufacture and distribution of USD$58,188 (discounting the initial external investment). Pooled funds were managed by the logistics group throughout the study. The remaining pool will continue to be reinvested back into the framework to pay for ongoing maintenance of the website, to support the community of users, and to further improve the hardware (Table 3).

4 | LEVERAGING FRONTLINE ACTION

The case study demonstrates the capability of the framework for sustaining the lifecycle of an open-source conservation tool, while also stimulating global deployment of
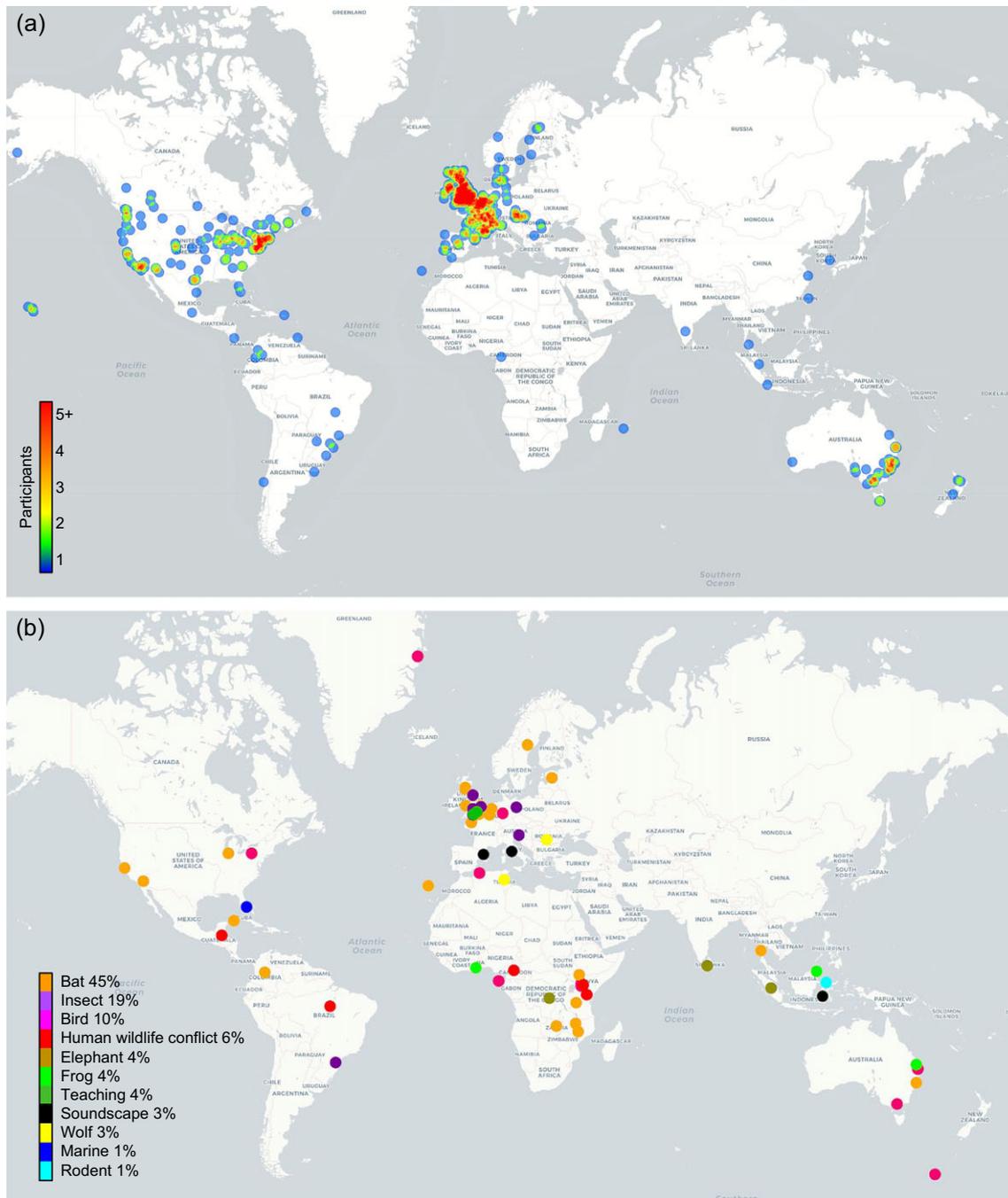
FIGURE 2 The global impact of the framework to support OSH. (a) Heat map of all OSH purchase locations; (b) deployment locations and field applications of a 14% sample of purchasers

conservation technology. The framework has to date enabled 687 separate projects to purchase OSH. Purchasers are globally distributed (Figure 2a), with clusters around the financial hubs of advanced economies, particularly in Europe (63%), North America (23%), and Australia (8%). Purchases made elsewhere include Central and South America (4%), Asia (2%), and Africa (<1%).

Fourteen percent of the framework's end-users posted on social media about conservation work using AudioMoths,

with conservation action occurring largely away from purchase locations. For example, Africa was the source country for only two sales, but the deployment location for 23% of purchases. Devices were used for a wide range of applications, including terrestrial monitoring of individual species, general ecosystem soundscape analysis, monitoring of human–wildlife conflicts, experimental marine surveys, and university-level education (Figure 2b). Also by lowering the cost of participating in applied acoustic monitoring research,

TABLE 3 Breakdown of revenue and expenditure throughout the 18-month AudioMoth case study using the framework to support OSH

Payments in/out	Amount (USD)
Sale of 5,242 units	$262,047.58
Manufacturing costs	−$141,404.28
Group purchase fees	−$36,871.01
Postage fees	−$11,228.25
Community activity costs	−$8,076.19
Additional hardware improvements	−$6,279.67
Total pool of funds	$58,188.18

the application of the framework to AudioMoth facilitated public engagement, including citizen science projects for a national bat survey (https://www.bats.org.uk/our-work/national-bat-monitoring-programme), biodiversity mapping surveys (https://www.soundscapes2landscapes.org, https://www.wesa.fm/post/pitt-researchers-are-eavesdropping-birds-name-science, https://www.cetalingua.com/citizen-science/), and engagement by the general public in wildlife monitoring (https://www.nocmig.com/audiomoth). It also led to the development of new methods to address previously untestable research questions (Piña-Covarrubias et al., 2018).

Those participating in group purchases of AudioMoths actively shared modifications and enhancements, including designs for housing the devices, on independent forum pages as well as on the OAD online community forum (https://www.openacousticdevices.info/support/) where changes could be validated by the creator group. Although the framework functions well for AudioMoth, more complicated OSH products may need additional manufacturing stages. Incorporating a framework to support OSH into NGO policy still requires substantial work, including further case studies of different conservation monitoring equipment. Without a framework of the type we propose, however, existing OSH will continue to have short life spans, and remain out of reach for the majority of conservation biologists.

Creating legacy value for OSH and proprietary projects used for conservation should be the first principle of action for conservation organizations and universities. Online community platforms for conservation technology such as WILDLABS could take a lead in policy adoption, creating an official platform for recording long-term OSH findings for the community to share and learn from. It is important to push access to OSH toward communities outside of the pockets of wealth and high opportunity that the framework may initially serve. Future developments should investigate benefits and costs of completely transitioning the framework to the conservation community, ways of making it more accessible to those communities typically underserved by citizen science, and methods of community-led support for conservation tools.

AUTHOR CONTRIBUTIONS

Andrew P. Hill, Peter Prince, Alex Rogers, C. Patrick Doncaster, and Jake L. Snaddon contributed to the design of AudioMoth acoustic sensors, with Alex Rogers, Andrew P. Hill, and Peter Prince leading hardware and software development; Alasdair Davies led the logistics group and AudioMoth distribution service; and all authors contributed to writing of the paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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