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Ecology and conservation researchers should adopt open source technologies

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1 Introduction

In light of globally declining biodiversity (Butchart et al., 2010; IPBES, 2019) and threats to both rare and common species (Gaston and Fuller, 2008; Dirzo et al., 2014), there are calls to utilize modern technologies for monitoring and conservation (Pimm et al., 2015; Lahoz-Monfort et al., 2019; Wich and Piel, 2021; Schulz et al., 2023). Technologies are deployed to improve data collection and analysis in both terrestrial and aquatic environments (Lahoz-Monfort and Magrath, 2021). These advancements can enable more efficient data collection compared to traditional survey methods (Witt et al., 2020) and aid crowdsourced data collection and processing (Dorward et al., 2017; Fraisl et al., 2022). There are emerging communities of practice, such as Conservation X Labs[1] or WILDLABS[2] which report on the state of conservation technology (Speaker et al., 2022) and provide guidelines on socially responsible use (Sandbrook et al., 2021).

The advancement of conservation technologies coincides with the increased adoption of open science practices. As defined in the Recommendation on Open Science ratified by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2021), open science entails inclusive, equitable, and sustainable approaches to scientific practices and outputs. Ecological research has increasingly adopted these practices (Hill et al., 2019), notably through more open and FAIR data (Hampton et al., 2015; Wilkinson et al., 2016). There also exists open source software used in biodiversity research, such as the R programming language (R Core Team, 2023) and analytical packages built on it.

However, unlike software and data, the hardware used for ecological research is still typically closed source (i.e. proprietary), and its designs (and accompanying software source code) are legally restricted, preventing others from studying, reproducing, or modifying them.

1 https://conservationx.com/.

2 https://wildlabs.net/.

Apart from just increasing effort and cost when adapting existing equipment to new contexts, closed source hardware also reinforces global inequalities. As reviewed by Arancio (2023a), the manufacturing and dissemination of scientific equipment is often monopolized by entities in the Global North. This creates barriers for researchers in the Global South including, but not limited to, prohibitive costs, lack of availability, and technical support. They lead to epistemic injustice, where research questions are constrained by the physical tools researchers are allowed to access or modify. Additionally, the vendor lock-in and forced obsolescence of closed source hardware mean that users are legally barred from maintaining them. This creates e-waste, which has been described as a form of environmental crime (Bisschop et al., 2022).

One solution to these problems is open source hardware. It is defined as hardware whose design is "made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design"[3]. In our view, while open source hardware is beginning to be adopted for ecology research (Hill et al., 2019; Lahoz-Monfort and Magrath, 2021), its potential is still largely untapped.

We are researchers with experience in both ecology and open source hardware communities. In this opinion article, we argue for wider recognition and adoption of open source hardware in biodiversity research. Among other benefits, we provide examples demonstrating how open source hardware can: reduce upfront and maintenance costs; enable adapting to novel contexts; and improve research quality and transparency. We end with suggestions for individuals and institutions on adopting open source hardware in research.

2 Reducing upfront and maintenance costs

By its nature, closed source hardware allow their manufacturers to command a high price through monopolies. In contrast, anyone can manufacture and sell hardware based on an open source design, so the cost of purchase can be close to the actual manufacturing cost. One study suggests that open source hardware can create cost savings of up to 87% compared to closed source functional equivalents (Pearce, 2020).

SnapperGPS[4] is one example of such low-cost open source hardware for ecology research. It is a location data logger specifically designed for wildlife tracking (Beuchert et al., 2023). In contrast with proprietary equivalents costing thousands of USD, the component cost of a SnapperGPS receiver is under USD 30, making it accessible to research groups with lower budgets. The project also has a discussion forum[5] where the community can ask questions, discuss issues, provide technical support, and share experiences.

Because users have complete access to the hardware design files, they can also maintain and repair their equipment independently, rather than having to rely on the original manufacturer who has an incentive to sell new units instead of repairing existing ones. Any knowledge about repair and maintenance can also be freely shared with the community further helping other users, without expensive support contracts or infringing on intellectual property restrictions. This is exemplified by the Appropedia Foundation[6], an online community where sustainability researchers share designs and provide mutual help on the repair and maintenance of open source hardware (Pearce, 2012).

3 Adapting to novel contexts

Off-the-shelf proprietary technology is unlikely to fit every application well. Ecologists, in particular, may need specific hardware properties to accommodate unique environments or species. However, modifying devices to meet research needs is difficult with closed source hardware, because its designs are not shared and modifications are not permitted. In the case of open source hardware, however, modifications can be added to an existing design and even be published as a new version that can then be freely manufactured and used by future researchers.

OpenFlexure[7] exemplifies this advantage. It is an open source, low-cost, lab-grade microscope, originally developed for microscopy in biomedical research (Collins et al., 2020). Its design has since been adapted to many other contexts. For example, researchers trialling OpenFlexure for orchid bee identification in Panamanian rainforests found the device was not suited for their use case, which does not require high magnification but does need robustness under field conditions. In response, the researchers adapted OpenFlexure into a dissection microscope that is easy to use and repair in the field. At the time of writing, the first version of this design has been completed, and feedback from field trials is being incorporated into the next version (Stirling and Quitmeyer, 2023).

4 Improving the quality and transparency of research

Closed source hardware is opaque, preventing researchers from fully understanding how the equipment operates. This makes identifying systematic errors difficult, especially if the manufacturer has a monopoly on the technology so that users have no alternatives for comparison.

This problematic "black box" effect of closed source devices is exemplified by CTDs, an oceanographic instrument that measures salinity, temperature, and depth. These three variables are essential for almost all marine scientific studies. Commonly-used closed source CTDs are not only expensive (at least several thousand

3 Open Source Hardware Definition: https://www.oshwa.org/definition/.

4 https://snappergps.info.

5 https://github.com/orgs/SnapperGPS/discussions.

6 https://www.appropedia.org.

7 https://openflexure.org/.

USD), but also require costly maintenance services. In recent years, the OpenCTD was developed as an open source CTD for coastal oceanographic research (Thaler et al., 2024), along with openly published calibration procedures[8]. Notably, in addition to making this technology more accessible, the OpenCTD team identified a systemic problem of handheld proprietary CTDs being out of calibration but remaining in field use (Thaler, pers comms). This error remained undetected for years until a comparison could be made with OpenCTD devices, and underscores the crucial role for open source hardware to improve research quality and transparency.

5 Discussion

Open source hardware and software enshrine the freedoms to study, reproduce, modify, and distribute them without restrictions. They enable equitable access to technology, allowing context-relevant and cost-effective adaptations with the potential to improve research quality and transparency. The examples we used to illustrate these benefits are part of a growing movement, which seeks to adopt open source hardware in ecology and conservation research (Berger-Tal and Lahoz-Monfort, 2018; Hill et al., 2019; Lahoz-Monfort and Magrath, 2021; Zeuss et al., 2024). We end this opinion article with suggestions for publishing open source hardware in a reproducible way and reforming institutional policies to encourage its development.

5.1 Publishing open source hardware

In recent years, best practices have emerged to ease the publication and reproducibility of open source hardware in scientific research. For example, the Open Know-How specification (Internet of Production Alliance, 2022) defines structured metadata to accompany hardware designs, such as requiring a bill of materials (BOM) or listing key contact persons. This metadata is stored in a YAML-formatted file, and is published with design files in a public repository (e.g. platforms such as GitLab or GitHub) similar to current best practice for software. Crucially, Open Know-How specifies that hardware designs should be published with open source licenses, the most popular of which are the three CERN Open Hardware licenses[9].

Once hardware designs are published, detailed information about their fabrication and use can be published in peer-reviewed journals such as the Journal of Open Hardware[10] or HardwareX[11]. A variety of hardware with biodiversity applications has been published this way, from a camera trap for benthic marine organisms (Humbert et al., 2023) to a strain gauge for measuring wind damage to trees (Nickl et al., 2022). In support of these academic journals is the DIN SPEC 3105 standard (DIN e.v, 2020), which defines guidelines for effective peer review of hardware documentation and reproducibility.

5.2 Reforming institutional policy to encourage open source hardware

Research institutions and funding bodies should support open source hardware as a key pillar of open science, as recognized in the UNESCO Recommendation on Open Science (UNESCO, 2021). Actionable policy guidance has been developed for universities (Arancio, 2023b), including embedding open source hardware in open science training; creating career pathways for developing open source hardware; and developing mechanisms to monitor adoption.

A common misconception is that open source hardware cannot be commercially viable. But in actuality, open source hardware allows commercialization and multiple profitable open hardware business models have already been demonstrated (Pearce, 2017). Successful examples from biology research include IORodeo[12] (a producer of laboratory analytical equipment), NinjaPCR[13] (a seller of digital real-time polymerase chain reaction (PCR) machines), or the Arribada initiative[14] (a consultancy for biodiversity research and developer of hardware kits for biologging and satellite tracking). In light of these successes, university technology transfer offices (TTOs) should update their policies to support open source hardware (Arancio, 2023b), including using its development as a way to achieve sustainable development goals (Faez et al., 2023).

6 Conclusion

The urgency of the biodiversity crisis is connected to technological waste and global inequalities (Bisschop et al., 2022; Kubiszewski et al., 2023; Arancio, 2023a). As biodiversity researchers, we have an ethical imperative to adopt open source hardware as part of the solution. In addition, with growing popular interest in biodiversity conservation (de Oliveira Caetano et al., 2023), the use of open source hardware (and software) would signal transparency and accountability that strengthens public trust in science. In this opinion piece, we highlighted the progress that open source hardware can enable for ecology research.

Lastly, we note that biodiversity researchers are not the only ones who would benefit from open source hardware. Anyone considering open source hardware for their research could engage with global practitioner communities, including the Gathering for

8 https://github.com/OceanographyforEveryone/OpenCTD/blob/main/Documentation/Manual/OpenCTDCalibrationDataManagement.pdf.

9 https://cern-ohl.web.cern.ch/.

10 https://openhardware.metajnl.com/.

11 https://www.hardware-x.com/.

12 https://iorodeo.com/.

13 https://qninja.hisa.dev/.

14 https://arribada.org/.

Open Science Hardware[15], Open Science Hardware Foundation[16], Internet of Production Alliance[17], or the Open Source Hardware Association[18]. They collectively sustain ongoing discourse on the development and use of open source hardware, and reflect a growing recognition for its role in scientific research.

Author contributions

P-YH: Conceptualization, Investigation, Resources, Writing – original draft, Writing – review & editing. BJ: Conceptualization, Resources, Writing – original draft, Writing – review & editing. AM: Writing – original draft, Writing – review & editing.

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Conflict of interest

AM was a member of the SnapperGPS project; BJ is the Community Coordinator and P-YH was a member of the Community Council at the Gathering for Open Science Hardware. The opinions in this article are based on their experiences working in these communities. That said, this paper was composed in the absence of any other relationships, financial or otherwise, that could be construed as a conflict of interest.

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15 https://openhardware.science/.

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17 https://www.internetofproduction.org/.

18 https://www.oshwa.org/.

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