Coding for broader impact: leveraging coding skills for stakeholder communication

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Sharing ecological research with stakeholders has broader impacts for conservation and sustainability outcomes. However, ecologists face major challenges to effective communication with stakeholders, including lack of reciprocal trust, unacknowledged incentives, differing goals, and scientific inaccessibility. These obstacles largely stem from professional training in ecology prioritizing effective communication among peers over the public. Here, we argue that coding skills honed for peer communication can be leveraged to overcome these challenges within a "coding for broader impact" framework that provides tasks to promote effective communication and culminates in individualized stakeholder reports. The reports explicitly incorporate stakeholder knowledge and are coded in conjunction with tasks for peer communication. We illustrate the framework through three case studies in which we shared data and information about backyard biodiversity, agricultural impacts, and tick-borne disease with homeowners, farmers, and land managers. A coding for broader impact framework allows a common analytical tool to become a public communication skill valuable to diverse stakeholder audiences.

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Public communication of ecological research promotes science-based conservation and environmental sustainability goals, appreciation for nature, and funding for basic research. However, communicating ecological research so that stakeholder audiences understand and value scientific narratives can be difficult (Pace *et al*. 2010). Effective communication often does not readily occur between ecologists and stakeholders who require (eg land managers), are affected by (eg property owners), or express interest in (eg the public) ecological research and its technical analyses (eg environmental engineers, epidemiologists, insurance analysts, and environmental risk analysts; Enquist *et al*. 2017). Training in effective stakeholder communication is often unavailable or not prioritized by ecologists because post-graduate training typically focuses on peer-to-peer communication (Kuehne *et al*. 2014). However, broader impacts can be realized if skills honed by ecologists for peer communication are also used for stakeholder communication.

In a nutshell:

- Effective communication between ecologists and their stakeholders may not readily occur due to lack of reciprocal trust, unacknowledged incentives, differing goals, and scientific inaccessibility
- Achieving effective communication becomes easier if ecologists use data visualization and analysis code developed for publications as the basis for individualized stakeholder reports
- This "coding for broader impact" framework is applied across the length of a research project, beginning with initial interactions with stakeholders and data collection and culminating in report generation and distribution
- We discuss three case studies involving different types of stakeholders and ecological questions to demonstrate the wide-ranging application of our framework

Most ecologists today are familiar with coding, at least to some degree. Although ecologists primarily write code to produce data analyses, summaries for publications, and scientific presentations, code can also be repurposed to disseminate information to stakeholders. For example, data journalists use code to communicate complex stories by wrangling data, producing statistics and graphics for general audiences (Gray *et al*. 2012; Coddington 2015). Ecologists likewise can use their coding skills for improving communication both within the scientific community and with affected stakeholders.

We present a "coding for broader impact" framework that helps overcome the major challenges ecologists encounter when attempting to communicate effectively with stakeholders. Our framework outlines steps for stakeholder communication and a programming workflow to produce accessible reports. Stakeholder reports are research summaries written in the context of stakeholder knowledge and goals. We apply the framework in three case studies that vary in terms of the ecological question, the report style, and the target audience. In these case studies, we describe the framework's operationalization in how we interacted with stakeholders, efficiently designed and coded reports, and overcame challenges to effective communication. To facilitate use of the framework, we provide a code repository of the case studies and a report template (https://dbturner.github.io/c4bi).

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Challenges to effective communication between ecologists and stakeholders

Stakeholder communication is often beneficial to ecologists and stakeholders alike, especially when approached with participatory modeling in mind. Participatory modeling involves purposeful interactions that integrate communication with stakeholders into the research and publication process through discussions about how and when knowledge will be shared, the identification of what knowledge is most valuable to stakeholders, and the incorporation of those interests into the methods and results dissemination (Voinov *et al.* 2016). If communication is effective through stakeholder participation, ecologists can receive crucial feedback and knowledge about local systems, develop long-term partnerships, and achieve conservation and sustainability goals (Reed 2008; Velázquez *et al.* 2009). Stakeholders benefit by receiving personalized, accessible, and high-quality information for insight on their system to supplement local knowledge (Sletto and Rodriguez 2013). Despite these benefits, four main challenges often hinder effective communication through stakeholder participation (Walter *et al.* 1997; Roux *et al.* 2006; Burbidge *et al.* 2011).

The first challenge is that ecologists typically lack the necessary incentives to communicate effectively with stakeholders, mainly because the traditional academic reward structure is tied to peer-reviewed publications and grants (McNie 2007; Whitmer *et al.* 2010). Stakeholder communication is often limited to project logistics, yet effective communication requires a reciprocal, transparent, and dynamic relationship (Wall *et al.* 2017). However, for ecologists, deeper stakeholder investment in the project can promote long-term cooperation and enhanced understanding of a local system (Rose *et al.* 2020). Coding for broader impact fits well into a participatory modeling framework because ecologists explicitly incorporate stakeholder knowledge and interests into individualized reports and shared code, thereby increasing stakeholders' incentive to participate (Smetschka and Gaube 2020). To initiate these relationships, we suggest ecologists discuss how and when knowledge will be shared and identify what knowledge is most valued by stakeholders.

The second challenge is a lack of trust between stakeholders and ecologists, for three main reasons (Lutter *et al.* 2018). First, ecologists and stakeholders often work at different timescales, and ecologists may take longer to disseminate results than is expected by their stakeholders (Morales and Martin 2018). Second, high turnover in early-career researchers (ie undergraduates, graduate students, postdoctoral students) may prevent long-lasting partnerships (Duchelle *et al.* 2009). Finally, negative experiences with scientists and conservation efforts, such as scientific knowledge extraction from and exploitation of lands belonging to marginalized communities, erode trust in researchers (Tuhiwai Smith 2012; Schell *et al.* 2020). To build trust, the coding for broader impact framework includes an early commitment to mutually beneficial research operations, adherence to a clear timeline for the dissemination of research output, and sustained interactions.

The third challenge to successful communication is goal misalignment (Matzek *et al.* 2014). For stakeholders, basic research often fails to generate useful knowledge, and location-specific research questions may be too narrow for acceptance within peer-reviewed publications (Walter *et al.* 1997). When contacting potential stakeholders, we recommend ecologists outline their project goals and solicit feedback on stakeholders' questions that can be answered concurrently during planned data collection. Coding for broader impact incorporates stakeholder inquiries into the project scope to ensure that reports include relevant information for stakeholders.

The final challenge is that research results are often presented in scientific jargon that renders them inaccessible to stakeholders (Cook *et al.* 2013; Bertuol-Garcia *et al.* 2018). Coding for broader impact includes making report graphics and text without discipline-specific vocabulary by learning and applying the terms stakeholders use to describe their system (Shanley and López 2009). Beyond summarizing results, code for analysis and visualization is often not written to be shared broadly and therefore may be inaccessible to peers and stakeholders alike due to wide variation in coding practices. If stakeholder goals require sharing coded analyses, accessibility is further reduced when code is written inconsistently, without informative comments, or without following tidy or clean coding principles (Wickham 2020). If ecologists expend the effort to make their research accessible, they may receive valuable feedback from stakeholders to inform future work.

The coding for broader impact framework

The goal of the coding for broader impact framework is to apply code written for ecological research to stakeholder communication. We provide an R code repository in support of the framework, but our framework can be applied using any coding language with document rendering capability (eg Python). The framework consists of four steps, and each step is composed of tasks to overcome challenges to effective communication (Figure 1).

Step 1: interact with stakeholder

At the outset, ecologists should establish initial contact with the stakeholder to discuss the research objectives and learn about stakeholder objectives and vocabulary before any substantive ecological research is performed. The first task is to provide a written description of research goals and methods. For efficiency, the content made for this initial stakeholder document can be adapted from a research proposal, incorporated into the report, repurposed for scientific publications, and used for social and news media. The second task is to learn stakeholder goals and "acceptable" research methods (for example, whether sampling will be prohibited in certain areas or at certain times). Interactions with

Step	Interact with stakeholder	Collect data	Code reports	Distribute reports
Tasks	1.1 Provide a document on research goals and methods 1.2 Learn stakeholder goals and permitted methods 1.3 Learn stakeholder vocabulary and system knowledge	2.1 Sample site 2.2 Demonstrate and photograph data collection methods	3.1 Clean and process data 3.2 Explore data 3.3 Choose graphics 3.4 Design aesthetics for stakeholder appeal 3.5 Code report template 3.6 Iterate code to produce reports	4.1 Deliver reports to stakeholders 4.2 Obtain feedback 4.3 Iterate reports to address feedback and redistribute
Challenges Addressed	*Lack of Trust*: Commitment to clear timeline and useful project outcomes begins with reciprocal communication. *Goal misalignment*: Ecologists and stakeholders identify mutual benefits to find new objectives. *Accessibility:* Both parties develop a shared vocabulary.	*Lack of Incentive*: Researchers collect data for both parties' questions while engaging stakeholders for potential future sampling. *Lack of Trust:* Experiential learning can boost research transparency.	*Lack of Incentive*: Research findings are communicated timely to stakeholders and in publications. *Goal Misalignment*: Ecologists distribute relevant results to stakeholders and generate insights. *Accessibility*: Report figures and vocabulary are familiar to stakeholders.	*Lack of Incentive*: Ecologists share knowledge with stakeholders to satisfy applied and conservation needs. *Lack of Trust*: Stakeholders receive reports to fulfill initial agreements. *Accessibility*: Ecologists clarify research results.

Figure 1. Lack of trust, goal misalignment, accessibility, and lack of incentive impede ecological researchers from communicating effectively with stakeholders. The coding for broader impact framework addresses these challenges in four steps, in which an ecologist interacts with stakeholders, collects data, codes reports according to six tasks (illustrated in further detail in Figure 2), and distributes customized stakeholder reports.

stakeholders can identify scientific misinformation that can be addressed in the report (such as the estimated costs associated with threatened or invasive species). The final task is for the ecologists to learn stakeholder vocabulary and system knowledge for use in the reports and refining the research approach. Overall, the tasks of this first step align goals by identifying mutual benefits while developing a shared vocabulary to describe the system and increase accessibility.

Step 2: collect data

The two tasks in this step are sampling the site and disclosing data collection methods to stakeholders. If stakeholders are present during sampling, they may be curious about sampling methods. Demonstrating methods to stakeholders may also be necessary to maintain sampling integrity, such as imparting locations of data loggers or passive sampling equipment on properties.

Step 3: code reports

Ecologists are incentivized to code for broader impact when the effort to code reports is low. To minimize effort, we suggest coding reports in parallel with exploratory data analysis (Wickham and Grolemund 2017). The reports should summarize stakeholder-specific results in the context of the entire project. For example, if stakeholders are homeowners, the reports can provide results for a single home relative to all residential properties sampled. Effective reports include accessible figures and are written with vocabulary understood by the stakeholder and without negative connotations. This step is associated with six tasks; see "Coding stakeholder reports" section below.

Step 4: distribute reports

Reports are delivered to stakeholders in digital and/or printed format. When possible, we recommend digital reports be used because they are easily updated and redistributed based on feedback; when stakeholders lack technological access, however, printed reports should be provided. Delivering the report fulfills a promise made to the stakeholder and builds greater trust. The second task is to obtain stakeholder feedback on report content by inviting questions and comments, possibly through a survey link at the end of the report document. The final task is to repeat Steps 3 and 4 if indicated by feedback or if additional data collection is undertaken. The ecologist iterates code for new reports (Step 3), distributes the updated version, obtains feedback on the new content (Step 4), and repeats this process until stakeholder goals are achieved.

To some stakeholders, it is inconsequential how the reports were generated and indeed whether code was even used in their generation; but for ecologists, using code to produce reports reduces the time barrier for making impactful interactions with stakeholders. Nonetheless, several stakeholders' goals will necessitate the inclusion of the technical information within an accessible report, and the code and data to generate the reports should be shared. Report source code can be provided in a code repository for stakeholder use, and if the ecologist follows a standard coding style (eg Wickham 2020), the code will already be reproducible and formatted to communicate effectively to stakeholders familiar with code. We recommend including a link to an open-source repository in every report to be inclusive across stakeholders.

Coding stakeholder reports

For Step 3 of the framework, we include six tasks (Tasks 3.1–3.6) implemented in a programming workflow in R to produce stakeholder reports based on tasks associated with drafting a manuscript for submission to and consideration

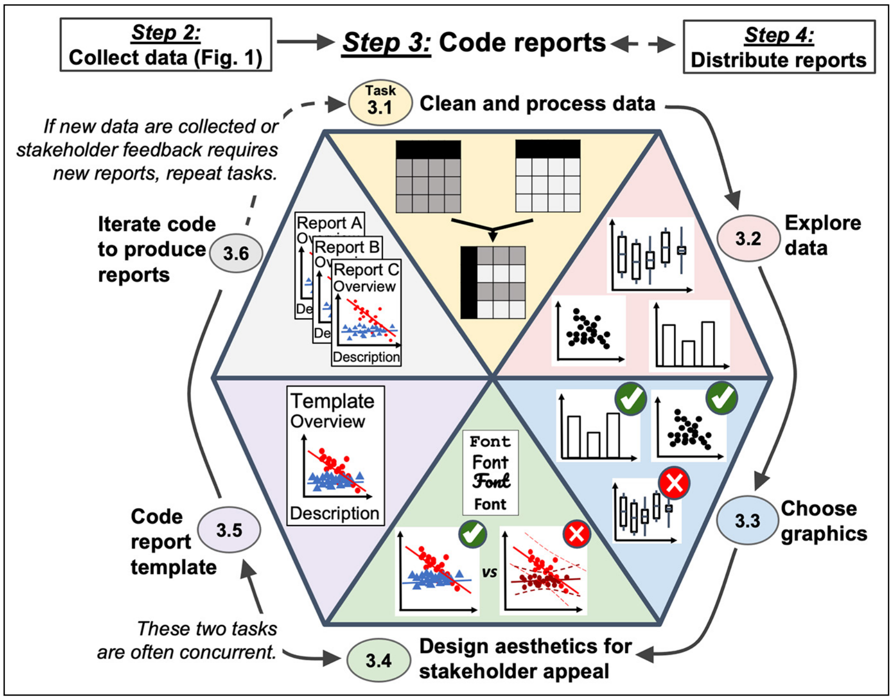

Figure 2. In Step 3 of the coding for broader impact framework, reports are coded in six tasks in which data are cleaned and explored, stakeholder-friendly graphics and aesthetics are developed, and templates are iterated to produce customized reports for every stakeholder. These tasks are repeated when new data are collected (as in ecological forecasting) or when stakeholder feedback on the content of existing reports requires generation of new reports.

by a peer-reviewed scholarly journal (Figures 2 and 3). Table 1 provides practices for effective stakeholder communication, including report language, plot aesthetics, and coding style.

Task 3.1: clean and process data

Cleaned and processed data are structured such that each variable is a unique column, each observation is a unique row, and each value is its own cell (Wickham and Grolemund 2017). Although this structure is efficient and understandable, data structure ultimately depends on coder preference. Code for cleaning and processing data imports raw data, cleans it by checking for outliers, missing values, and other errors, and wrangles it into variables that can be used for analysis. Variable and category names should be written with meaningful vocabulary. In our report programming workflows, we used a separate R script to tidy the data before writing the exploratory data analysis script.

Task 3.2: explore data

Code is written to summarize, plot, and identify patterns to highlight in the report, as in standard exploratory data analysis (Wickham and Grolemund 2017). The questions asked are determined by the project and stakeholder goals (Step 1). Performance of this task is most efficient when stakeholder goals align with project goals, because code produced for the reports can be used in publications. When stakeholder and project goals differ, exploring stakeholder questions can enhance understanding of the system. Our exploratory data analysis scripts are often not shared with stakeholders because they contain chunks of code that produce many different summary graphics produced without context and use data that are not in the final reports.

Task 3.3: choose graphics

Select code chunks from the exploratory data analysis script that produce graphics to be included in the report. Ideally, figures and tables that require little statistical knowledge to interpret should be included in reports (such as bar charts, pie charts, and scatter plots) rather than more technical representations (like box-and-whisker plots and ordinations). Data should be summarized using easy-to-understand metrics; for example, biodiversity data are easier to understand as abundance and richness on a bar chart, whereas evenness and phylogenetic and functional diversity metrics can be confusing if the stakeholder is not familiar with them. If model statistics are required, choose commonly used forms, such as moving-average trendlines, univariate regressions, and *t* tests. Making reports accessible means that variables and summaries presented in reports may not be included in published manuscripts. However, because the data are already tidy and explored, it would be relatively easy to conduct additional analyses later.

Task 3.4: design aesthetics for stakeholder appeal

Coding aesthetics includes writing the report text, choosing fonts and color schemes, editing photos, determining figure formats, and developing other content for the report. For effective communication, text should be neutral in tone and familiar to the stakeholder audience. Reports should also not contain extensive, uninterrupted sections of prose. Figure designs and color schemes should follow existing resources for data visualization (Table 1; eg Chang 2018). In our workflow, we design report aesthetics by editing the graphics R code chunks within an R Markdown report template. R code chunks in templates render figures and tables, whereas interweaved markdown code renders prose, titles, pictures, and ultimately the report's layout.

Task 3.5: code report template

The template is created from the graphics code and aesthetics code. The same template is used to produce all individualized stakeholder reports for a project. This task may be performed concurrently with Task 3.4 because coding aesthetics often occurs when writing the report template. The template for a stakeholder report varies across projects, but designing reports to mirror peer-reviewed publications is intuitive and efficient. We suggest templates contain (1) an overview (introduction and methods condensed together), (2) results, and (3) a "further information" section. The overview informs the stakeholder about who conducted the research, why the project was completed, and what sampling was performed (including photos of researchers engaged in data collection, if available). The overview can be based on the project document provided to the stakeholder during the initial interaction (Step 1). The results section summarizes, compares, and provides interpretation of stakeholder-specific data in the context of the project and stakeholder goals. The "further information" section includes study conclusions, management recommendations, reference information for additional reading, contact information, and a request for feedback. The template code makes personalized text, images, and results for each report given to each stakeholder. Titles and headings contain stakeholder-specific text (eg stakeholder name) and summaries addressing stakeholder goals (eg bar chart comparing the stakeholder's site to other sampling sites). Other stakeholders' names should be anonymized.

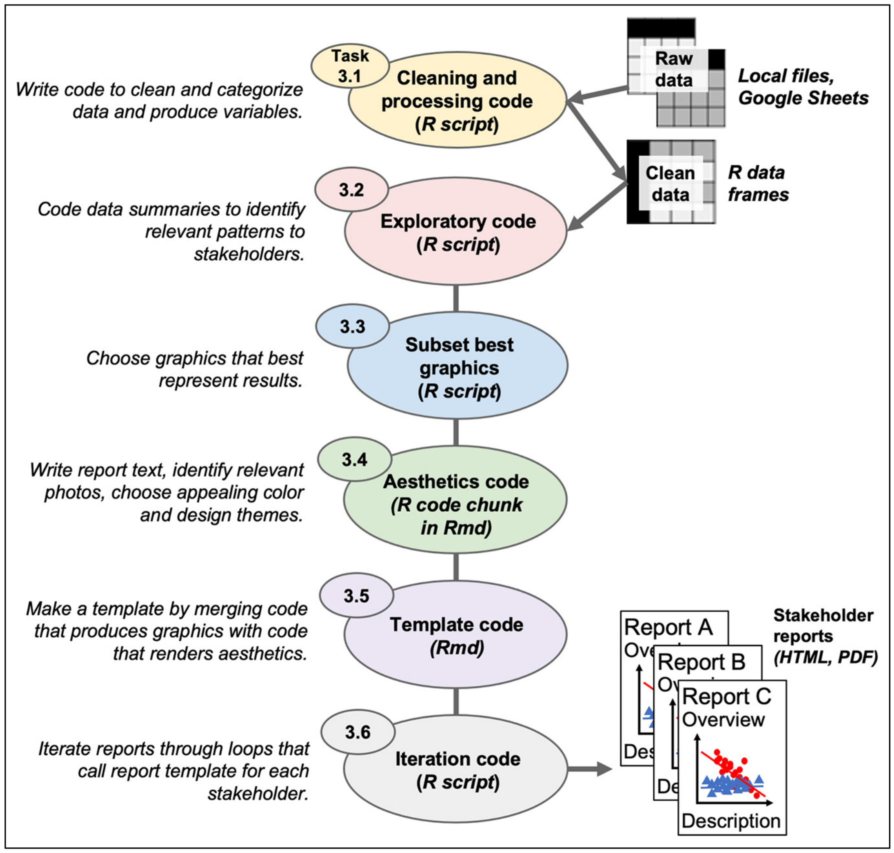

Figure 3. The scripting workflow we developed in our coding for broader impact case studies (WebPanel 1) used a mix of R and R Markdown (Rmd) scripts. Colors correspond to the six tasks for Step 3 (code reports), as depicted in Figure 2. See our code repository for a template that uses this programming workflow and example scripts, data files, and case study reports (https://dbturner.github.io/c4bi).

Task 3.6: iterate code to produce reports

The template code (Task 3.5) is iterated to render a unique final report for each stakeholder. We iterate with a separate R script that calls the report template code for each stakeholder, reads through their data, and renders individualized reports in a chosen file format. HTML and PDF file formats are suitable for both emailing and printing stakeholder reports. Reports can be produced on institutional letterhead. If a report requires periodic updating with additional rounds of data (as in iterative ecological forecasting; Dietze 2017), or if feedback from stakeholders warrants a report revision or an entirely new report focused on a different set of stakeholder goals, Steps 3 and 4 must be repeated (Figures 1 and 2).

Case studies

To highlight the coding for broader impact framework, we provide three case studies that represent projects involving different stakeholder groups and ecological research goals. In the first case study, we surveyed residential garden biodiversity on the Caribbean island of Curaçao and provided a hardcopy report to each homeowner summarizing the species found in their garden. In the second, we surveyed arthropod diversity on farms in southeastern Pennsylvania and provided a set of digital reports to farmers on how their management practices impacted beneficial arthropods. In the third, we examined tick-borne diseases and host diversity in temperate forest patches and provided land managers with digital reports summarizing the diversity of ticks, pathogens, and wildlife on their properties. Ecologists interested in coding for broader impact can find a report template and reproduce the case-study stakeholder reports using our code repository (https://dbturner.github.io/c4bi). Additional details about each case study are presented in WebPanel 1.

The effort that an ecologist must expend to produce stakeholder reports varies. For us, our case studies required only basic experience from students who were trained to code. Undergraduate and early graduate students (authors DBT, PMP, VAR) designed and coded the three case studies. All students passed a course in which the "R for Data Science" open-source textbook was taught (Wickham and Grolemund 2017). The agroecology reports (case study 2) were coded and distributed by a senior undergraduate with only classroom R

Table 1. Effective communication practices "dos and don'ts" when coding stakeholder reports

Report item	More effective	Less effective	Task(s)
Summary plots	Less technical plots (eg bar charts, pie charts, scatter plots)	More technical plots (eg boxplots, histograms)	3.2, 3.3
Individualized results	Comparing individual stakeholder results to the mean of all stakeholders or groups of stakeholders	Only presenting results from the average across the entire study, without highlighting the individual's results	3.1–3.3
Variables to visualize	Less technical variables (eg mean abundance, mean species richness)	More technical variables (eg ordinations, hierarchical model results) unless the stakeholder is already familiar	3.1–3.3
Word choice	Neutral, common words (eg "landscaped", "maintained", "developed")	Charged, esoteric words (eg "disturbance", "impacted", "anthropogenic")	3.4, 3.5
Formatting text	Bold or italicize words to highlight important findings and concepts	No special text formatting	3.4, 3.5
Text-to-figure ratio	Minimum amount of text with graphics and photos to supplement and replace text	High text-to-figure ratio that dilutes messages from results	3.4, 3.5
Report title	Specific and informative title that includes stakeholder's name or location title (eg Alex's Apple Orchard Arthropod Biodiversity Report)	General title or one using project identification numbers (eg Your Report, Farm Report A)	3.4, 3.5
Contact	Contact information, project website, and invitation for feedback and questions	No information or feedback solicitation	3.4, 3.5
Respecting stakeholder privacy	Anonymizing all participant names; group participants to maintain individual privacy	Using any participant names beyond the report's focal stakeholder	3.1, 3.3–3.5
Professionalism	Generating reports on institutional letterhead; adding titles and affiliations of authors	Lacking affiliations in report	3.4, 3.5
Graphing aesthetics	Highlighting major differences by changing both colors and shapes in plots; provide legends and labels often to maximize clarity	Plotting without contrasting colors, shapes, and/or legends to highlight differences	3.4
Coding style	Commenting code without acronyms or jargon for broad interpretability	Sharing raw code with no comments	3.4–3.6
Code archive	Archive data files within the same repository as the code and write paths (hyperlinks) to files within that remote repository	Data files not archived, or they are in a separate repository as the code; file paths reference a local computer or broken hyperlink	3.4–3.6

Notes: numbers in the "Task(s)" column refer to the six relevant task(s) listed in Step 3 (code reports).

experience (DBT), and an ecology professor (JEB) provided feedback on both rounds of the drafts. The first and second rounds of the agroecology reports took 3 weeks (part time) and 1 week (part time) to complete, respectively. The invasive species reports (case study 1) took 6 weeks (part time) for the same student (DBT) when he was a first-year graduate student to produce a draft. A professor (MRH) with 20 years of coding experience then spent 2 days (full time) refining this code and constructing the physical reports. The disease ecology reports (case study 3) were completed in less than 2 weeks (part time) by two graduate students (PMP, VAR), both of whom had less than 2 years of R coding experience. The other authors provided feedback on the disease ecology drafts. Our experience coding for broader impact demonstrates how the timeframe to code reports is substantially shorter than publishing academic papers when students are involved. Collaborating with students is key to distributing the time and effort required to share knowledge with stakeholders, and training to code also allows students to participate in broader impact work. For students who choose not to pursue a research-oriented career path after graduation, training in coding and effective stakeholder communication are marketable skills that can be applied beyond academic work.

Discussion

Coding for broader impact represents an opportunity for ecologists to overcome persistent challenges to effective ecologist–stakeholder communication by incorporating the skills gained in technical training with the elements of participatory modeling that integrate stakeholder engagement with research design (Voinov *et al.* 2016; Smetschka and Gaube 2020). By following our framework, ecologists are incentivized to incorporate stakeholder knowledge and interests into their scientific questions and meet mutually beneficial goals while minimizing the time and labor required to make individualized research reports. Likewise, stakeholders are incentivized through increased investment in the research design process, building trust when a useful report is delivered and ultimately improving knowledge that fulfills their needs. The framework stresses that challenges to effective ecologist–stakeholder communication are not overcome by coding reports alone. Early, sustained, and transparent interactions with stakeholders promote impactful research (Lutter *et al.* 2018).

In addition to facilitating effective communication with stakeholders, our coding for broader impact framework intersects with three trends in ecology: formal training in coding, open-science initiatives like research compendia, and applied ecological forecasting. While calls for formal training in ecological coding have increased over the past two decades (Mislan *et al*. 2016; Hampton *et al*. 2017), current training focuses on coding visualizations and analyses for peer communication. In our case studies, we demonstrated how students can become key participants and leaders in timely stakeholder communication. Our experiences indicate the need for emphasis in ecology toward a coding education that includes tools to communicate with stakeholders that are relevant to decision making, policy, and management. We suggest that coding for broader impact be incorporated into coding courses during lessons on exploratory data analyses, visualization, and document generation. These early introductions to code as a tool to communicate outside the scientific community can teach students how to learn from stakeholder knowledge, identify mutual goals with diverse audiences, and present their findings with accessible and relevant vocabulary.

Open-science initiatives call for data transparency and accessibility across scientific disciplines by using repository sites like Dryad and GitHub (Marwick *et al*. 2018). Research compendia can be posted to these sites as packages containing data files, code for analyses, and insights from scientific publications in a format that enables readers to access and reproduce each step in the code (Gentleman and Temple Lang 2007). Including code written for stakeholder reports and code written for scientific publications in research compendia increases innovation within the ecological community for more effective practices while coding for broader impact. Our case studies present only a few options for how ecological data can be conveyed to stakeholders. If many ecologists share code for broader impact, the ecological community can evaluate each option's strengths and weaknesses to advance conservation and sustainability initiatives.

As the world responds to human-induced environmental change through invasive species management, climate-change mitigation, and habitat restoration, ecological forecasting presents a tractable tool for decision making, especially when coupled with participatory modeling and effective stakeholder communication (Clark *et al*. 2001; Dietze 2017; Gaydos *et al*. 2019). Stakeholders managing land and resources require updated predictions about their system based on the most recent data, and recent methodological developments provide tools to continuously iterate ecological forecasting as new data become available (White *et al*. 2019). With our framework, individualized stakeholder reports can be used in ecological forecasting initiatives to provide updated insights to stakeholders. For example, agricultural agencies often rely on ecological modelers to forecast scenarios on the control of invasive pests based on resource allocation (eg Petrasova *et al*. 2020). Once an allocation scheme is chosen for a growing season, ecologists could then produce reports for farmers on the predicted impact of the pest given the magnitude of control performed by the agency. Ecological forecasters can communicate with stakeholders through products more appropriate for continuous integration, like R Shiny applications that can be frequently updated and allow for stakeholder interactivity (eg Pascal *et al*. 2020).

As coding continues to gain popularity, ecologists increasingly need methods, models, and examples to facilitate its use beyond academic environments. We hope our framework serves as a catalyst for conversations about the potential and limitations of coding scientific communication using the tools already available to ecologists. With the adoption of coding for broader impact in informal and formal scientific training, ecologists can forge new partnerships and strengthen existing relationships with stakeholders to conduct the ecological research necessary to address imminent conservation and sustainability issues.

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Data Availability Statement

Novel code and data are currently located in a repository (https://github.com/dbturner/c4bi); an associated website for user interface with the repository can be found at https://dbturner.github.io/c4bi. The code in the repository is archived permanently on Zenodo (doi.org/10.5281/zenodo.5090882).

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